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Hydrologic Engineering Center

Delaware River Basin Flood Analysis Model

Reservoir Operations and Streamflow Routing Component

February 2010

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Joan Klipsch, CEIWR-HEC-WMS
Marilyn Hurst, CEIWR-HEC-WRS
Matthew Fleming, CEIWR-HEC-HHT

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609 Second Street
Davis, CA 95616-4687

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14. ABSTRACT
The Delaware River Basin Commission (DRBC) engaged the Hydrologic Engineering Center (HEC), along with the U.S. Geological Survey (USGS), and the National Weather Service (NWS), in the development of a flood analysis model for the Delaware River Basin. The flood analysis model was developed to evaluate the existing reservoirs for flood mitigation and provide data to evaluate the effects of various reservoir operating alternatives on flooding locations downstream of the reservoirs. HEC in coordination with DRBC, USGS and NWS created the HEC-ResSim model of the Delaware River Basin. The purpose of this report is to describe the reservoir modeling and flow routing, focusing primarily on the aspects or features the modelers will need to be aware of as further alternatives are developed.

15. SUBJECT TERMS
HEC-ResSim, reservoir, operations, streamflow, routing, Delaware River Basin Commission, DRBC, Delaware River, Delaware River Basin, USACE, HEC, CENAP, watershed, projects, computation points, junctions, basins, reaches, reservoir network, data collection, alternatives, simulations, Delaware River Flood Analysis Model, flood, river system, flood damage reduction, conservation storage

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Prepared for:
Delaware River Basin Commission
25 State Police Drive
PO Box 7360
West Trenton, NJ 08628-0360

Prepared by:
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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Abbreviations

acre-ft – acre-feet (a unit of measurement for storage in a reservoirs)

cfs – cubic feet per second (a unit of measurement for flow)

elev – elevation

ft – feet (a unit of measurement for elevation, stage, or distance)

CEIWR-HEC - U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center

CENAP – U.S. Army Corps of Engineers, Philadelphia District

DEL-FAM - Delaware River Flood Analysis Model

DRBC – Delaware River Basin Commission

EAP Emergency Action Plan

EB Del R - East Branch Delaware River

EPA - Environmental Protection Agency

FEMA - Federal Emergency Management Agency

FERC - Federal Energy Regulatory Commission

GIS – Geographical Information System

HEC – Hydrologic Engineering Center

HEC-HMS – Hydrologic Modeling System

HEC-ResSim – Reservoir System Simulation

MCOG – Merrill Creek Owners Group

NRCS - Natural Resrouces Conservation Service

NWS – National Weather Service

NWS-RFC – National Weather Service, River Forecast Center

NYC - New York City

NYCDEP – New York City Department of Environmental Protection

O&M – Operations and Maintenance

OASIS - Operational Analysis and Simulation of Integrated Systems

PPL – or PPL Corporation, originally Pennsylvania Power & Light Co.

PRMS - Precipitation-Runoff Modeling System

SI - International System of Units (metric)

USACE – U.S. Army Corps of Engineers

USGS – U.S. Geological Survey

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Executive Summary

Following three recent major flood events in the Delaware River Basin, the Delaware River Basin Commission (DRBC) initiated a study to develop flood damage reduction strategies. As part of this study, a flood analysis model of the Delaware River Basin was needed. An interagency team of experienced hydrology and reservoir simulation modelers from the United States Geologic Survey (USGS), the United States Army Corps of Engineers (USACE), and the National Weather Service (NWS) were assembled to develop the Delaware River Basin Flood Analysis Model.

The USACE Hydrologic Engineering Center (HEC) was tasked to develop the HEC-ResSim (Reservoir System Simulation) component of the Delaware River Flood Analysis Model for the simulation of reservoir operations under flood conditions and routing of flood flows through the river system. HEC-ResSim (USACE, 2007) is a modeling software program used to assist in planning studies for evaluating existing and proposed reservoirs, reservoir operations, and to assist in sizing the flood risk management and conservation storage requirements for each project. In this application, an HEC-ResSim model was developed as a tool to assess the influence of major reservoirs on flood flows and flood crests in the Delaware River Basin. HEC coordinated with the DRBC, USGS, and NWS to create the HEC-ResSim component of the Flood Analysis Model of the Delaware River Basin.

Model development began with creation of an HEC-ResSim watershed which is defined through the development of a stream alignment that serves as the framework or skeleton upon which the model schematic is created. Geo-referenced map files (provided by USGS and DRBC) were used to establish the stream alignment and model schematic. Such files included rivers and streams, lakes and reservoirs, watershed boundaries with sub-basin delineations, stream gage locations, and state boundaries.

The next step in model development was the establishment of a reservoir network. The network includes all the reservoirs, reaches and junctions needed for the model and is where all the physical and operational data are entered and stored in the model. Physical reservoir data about the reservoirs were obtained from reservoir operators, reservoir operating plans, DRBC's water code in place at the time of the events (D-77-20 CP Rev 7), and the DRBC's OASIS (Operational Analysis and Simulation of Integrated Systems) model (storage-area-elevation curves, capacities, etc.). The junctions were defined primarily by the locations of headwaters, NWS Flood Forecast Points and confluences of major rivers and tributaries. Where available, primarily at gages co-located with NWS Flood Forecast points, the USGS provide rating curves that are used to convert flow to river stage. Initial river routing parameters were obtained from the NWS. Routing parameters define how the flow travels through a reach.

The final step in model development was the formation of simulations and alternatives. Storm event observed data, start time, end time and duration and any scenarios for that event are stored as a simulation. Alternatives specify the initial conditions, operations rule sets, and time-series data (inflows) that are needed to run the model. Alternatives are run and analyzed within a simulation. The USGS provided time-series data (both observed and simulated by Precipitation-Runoff Modeling System (PRMS)) for use as inflows to the HEC-ResSim model. USACE, Philadelphia District (CENAP), provided observed time series data for the USACE reservoirs and other locations on the river.

Chapters 2, 3, 4, and 5 describe how the HEC-ResSim model was developed for the Delaware River Basin above Trenton. Trenton is the downstream-most flood damage area significantly impacted by upstream reservoir operations but not subject to tidal influence. These chapters discuss the information that was available and how it was used. Chapter 5 also presents model results at the reservoirs and at key NWS Flood Forecast points and demonstrates the ability of the model to simulate the 2004, 2005, and 2006 observed storm events. Chapter 6 summarizes how the ResSim model was built, description of the alternatives and their usage, and provides recommendations for enhancements to the final model. Chapter 7 contains a list of references that were used in the development of the model and this report.

Chapter 1

Introduction

1.1 Background

In September 2004, April 2005 and June 2006, the Delaware River Basin received excessive amounts of precipitation, resulting in major flooding along the Delaware River and its tributaries. Other than floods related to ice jams, the main stem had not experienced such pervasive flooding since August of 1955, from back-to-back Hurricanes Connie and Diane[1]. The Delaware River Basin Commission (DRBC) was tasked by the Governors of its four member states to develop an Interstate Flood Mitigation Task Force to develop flood damage reduction strategies. One recommendation was to develop a Flood Analysis Model to gain a better understanding of the flood mitigation potential of existing reservoirs within the basin. The DRBC was able to implement this recommendation with funding[2] provided by the four basin states along with in-kind contributions from the United States Geological Survey (USGS), the United States Army Corps of Engineers (USACE) and the National Weather Service (NWS). The USGS, USACE and NWS formed the interagency team of experts that developed the Flood Analysis Model.

1.2 Scope of Model

The Flood Analysis Model was developed as a tool to evaluate the effects of hydrology and reservoir operations on flooding throughout the basin. It will be used to inform, but will not set, policy decisions. Two public domain software packages were used to develop the Flood Analysis Model: the USGS's Precipitation Runoff Modeling System (PRMS) and the USACE's HEC-ResSim (Reservoir System Simulation) program. The intent of using PRMS was to develop a rainfall-runoff model of the basin to generate inflows (runoff and snowmelt) to the HEC-ResSim model in order to evaluate the effects that land use decisions might have on resulting streamflows. The purpose of developing an HEC-ResSim reservoir operations model was to evaluate the potential flood mitigation opportunities from existing reservoirs, in particular, the ability of the reservoirs to reduce flood crests. As part of model development, both models have been used to simulate the three storm events identified above and integrated through a graphical user interface intended for use by experienced PRMS and HEC-ResSim modelers.

[1] Information about recent flooding events and associated damages in the Delaware River Basin can be found on the DRBC website at http://www.state.nj.us/drbc/Flood_Website/floodinf.htm.

[2] The Governor of Delaware contributed $50,000; the Governors of New Jersey, New York and Pennsylvania contributed $150,000 each; the USGS contributed $155,000 as match and in-kind services; the USACE contributed $100,000; and the National Weather Service contributed $30,000 in in-kind services.

In addition to the PRMS inflow file, an alternate inflow file was developed based on observed data from streamflow gages. The additional inflow file was developed because the rainfall-runoff model, while generally capturing the nature of the storm events, did not predict the peak flood flows with the desired accuracy to evaluate the effects of the reservoirs on flood crests. By using the alternate inflow file, the effects of reservoir operations can be isolated from uncertainties associated with the inflows generated by the rainfall-runoff model. In the absence of a rainfall-runoff model, a HEC-ResSim model would typically be developed using observed data from streamflow gages.

The Delaware River Basin was modeled as three separate watersheds: the non-tidal portion of the basin above Trenton, New Jersey; the non-tidal portion of the Schuylkill River basin; and the non-tidal portion of the Christina-Brandywine basin. The reservoirs in one watershed do not affect river elevations or flood flows in the other basins. This report summarizes the development of the HEC-ResSim component of the Flood Analysis Model for the non-tidal portion of the basin above Trenton. The report does not present the results of simulations used to test the potential flood mitigation opportunities using existing reservoirs. The documentation of the PRMS model development and the user interface that integrates both models can be found at www.usgs.gov. Development of the HEC-ResSim models of the Schuylkill and Christina-Brandywine basin will be documented as an addendum to this report.

1.3 Study Area

The Delaware River is the longest un-dammed river east of the Mississippi River, extending 330 miles from the Catskill Mountains of New York State to the mouth of the Delaware Bay where it flows into the Atlantic Ocean. The natural drainage area of the Delaware River Basin crosses many man-made boundaries in addition to the four state lines: 25 congressional districts, two Federal Emergency Management Agency (FEMA) regions, two Environmental Protection Agency (EPA) regions, five U.S. Geological Survey (USGS) offices, four Natural Resources Conservation Service (NRCS) state offices, two National Weather Service (NWS) local forecast offices, 42 counties, and 838 municipalities. The Delaware River Basin Commission has regulatory authority[3] and responsibilities for planning and coordinating management of the Basin's water resources, both water quality and quantity.

The headwaters of the Delaware River form in New York State, Pennsylvania, New Jersey, and Delaware. The river is fed by 216 substantial tributaries, the largest of which are the Schuylkill and Lehigh rivers in Pennsylvania. The watershed drains four-tenths of one percent of the total continental U.S. land area. In all, the basin contains 13,539 square miles, draining parts of Pennsylvania (6,422 square miles, 50.3 percent of the basin's total land area); New Jersey (2,969 square miles, 23.3 percent); New York (2,362 square miles, 18.5 percent); and Delaware (1,004 square miles, 7.9 percent).

Approximately five percent of the nation's population (15 million people) relies on the waters of the Delaware River Basin for drinking and industrial use. The Catskill Mountain Region in the upper basin provides New York City (NYC) with a high quality source of water from three basin

[3] The Commission's authority is limited by the enabling Compact of 1961 and 1954 Supreme Court Decree.

reservoirs, Cannonsville, Pepacton, and Neversink. Nearly half of its municipal water supply comes from these reservoirs. Within the basin, the river supplies drinking water to much of the Philadelphia metropolitan area and major portions of New Jersey, both within and outside of the basin.

From the Delaware River's headwaters in New York to the Delaware Estuary and Bay, the river also serves as an ecological and recreational resource. Over the past half century, as a result of the maintenance of minimum flow targets in Montague and Trenton, New Jersey, cold-water fisheries have been established in the tailwater reaches of the East Branch Delaware, West Branch Delaware, Neversink River and the upper main stem Delaware River. Most of the main stem upstream of Trenton, New Jersey has been designated by Congress as part of the federal Wild and Scenic Rivers system.

Figure 1.1 (page 4) depicts the watershed and major reservoirs of the Delaware River Basin and denotes the three model sub-basins. The reservoirs include five projects of the Corps that were designed to maintain dedicated flood storage capacity. Other major reservoirs not specifically designed for flood damage reduction, include water supply, hydropower, and recreational reservoirs. The USACE' projects include Jadwin, Prompton, Beltzville, Blue Marsh and Francis E. Walter Reservoirs. The New York City water supply and flow augmentation reservoirs include Cannonsville, Pepacton and Neversink. The hydroelectric power generation reservoirs are Toronto, Swinging Bridge, and Rio in the Mongaup System and Lake Wallenpaupack in the Lackawaxen Basin. Other major multipurpose reservoirs include Marsh Creek, Lake Nockamixon, and Merrill Creek. The reservoirs included in the Delaware above Trenton model include Cannonsville, Pepacton, Neversink, Prompton, Jadwin, Lake Wallenpaupack, the Mongaup System (Toronto, Swinging Bridge, Rio), Francis E Walter, Beltzville, Merrill Creek and Nockamixon. Blue Marsh and Marsh Creek are contained in the Schuylkill and Christina-Brandywine watersheds, respectively.

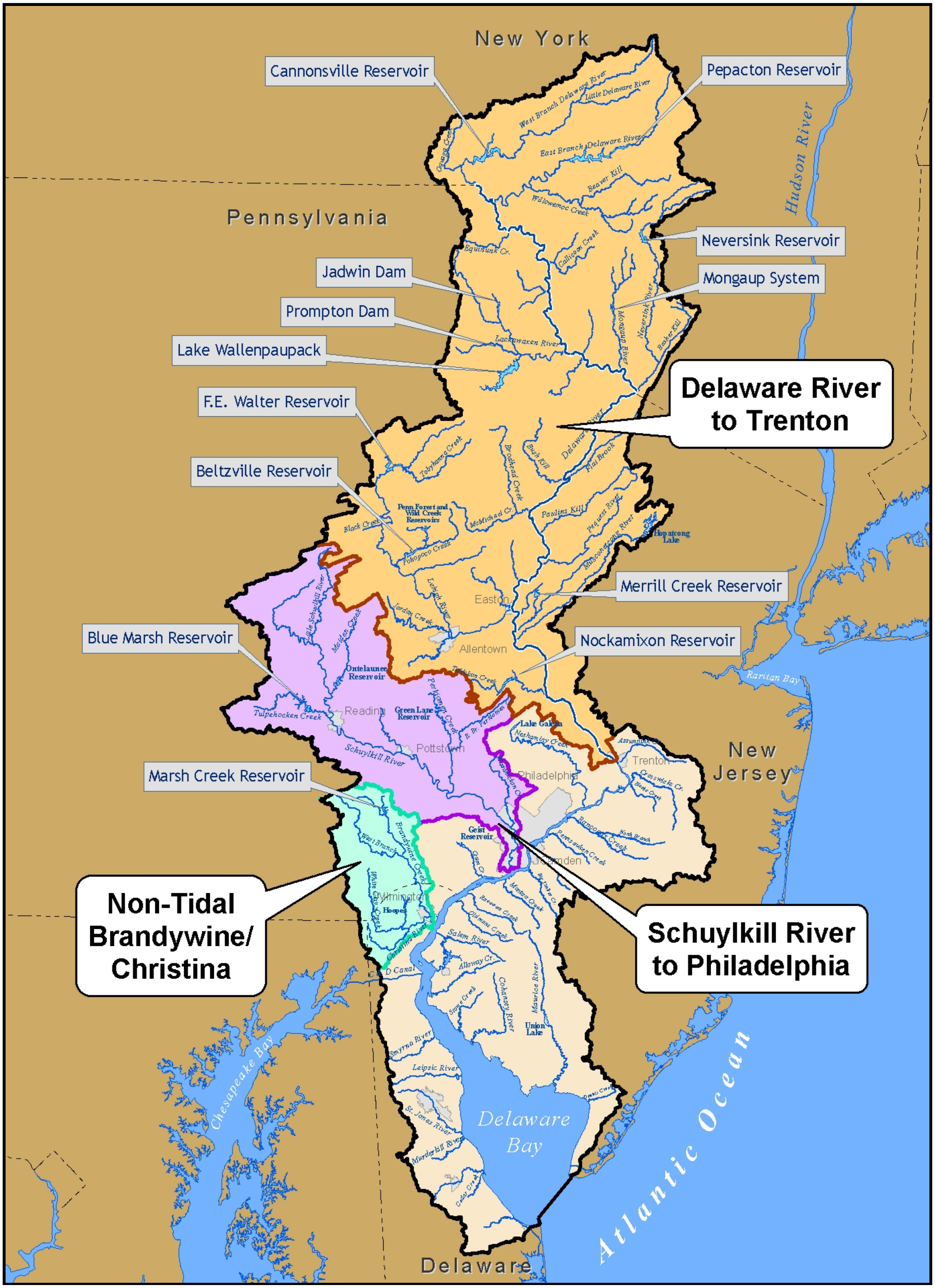


Figure 1.1 Map of Delaware River Basin showing major reservoirs (DRBC, 2007**)**

Chapter 2

Watershed Setup

The foundation of an HEC-ResSim model, the watershed, is created in the Watershed Setup module. Within this module, the stream alignment is defined and the projects (e.g., reservoirs) and computation points (e.g., locations of interest) are placed on it.

Prior to developing the HEC-ResSim watershed model for the Delaware River Basin, the projects and computation points were identified. The projects included thirteen reservoirs of the 22 reservoirs in the basin. These thirteen reservoirs were identified by the DRBC as their first priority reservoirs to be represented in this flood operations model. The computations points included NWS Flood Forecast locations and streamflow gages managed and maintained by the USGS. USACE, USGS, NWS and DRBC worked together to establish a consistent naming convention to facilitate communication and data transfer between the HEC-ResSim model, the PRMS model and the Delaware River Flood Analysis Model graphical user interface (DEL-FAM). The naming convention covered locations, model elements, model components, and various types of input data. Graphical Information System (GIS) layers were also collected and comprise the background maps used in developing the stream alignment and for locating the reservoirs and computations points.

2.1 Watershed Creation and Layout

The HEC-ResSim watershed for this study is named: *Delaware_River*. Background maps were added the watershed and include: the watershed boundary (complete and within each state), the state boundaries (New York, Pennsylvania, New Jersey, and Delaware), the rivers and streams, the reservoir locations, the streamflow gage locations, and the NWS Flood Forecast locations. Figure 2.1 shows the HEC-ResSim map display of the watershed where the state and watershed boundaries have been selected.

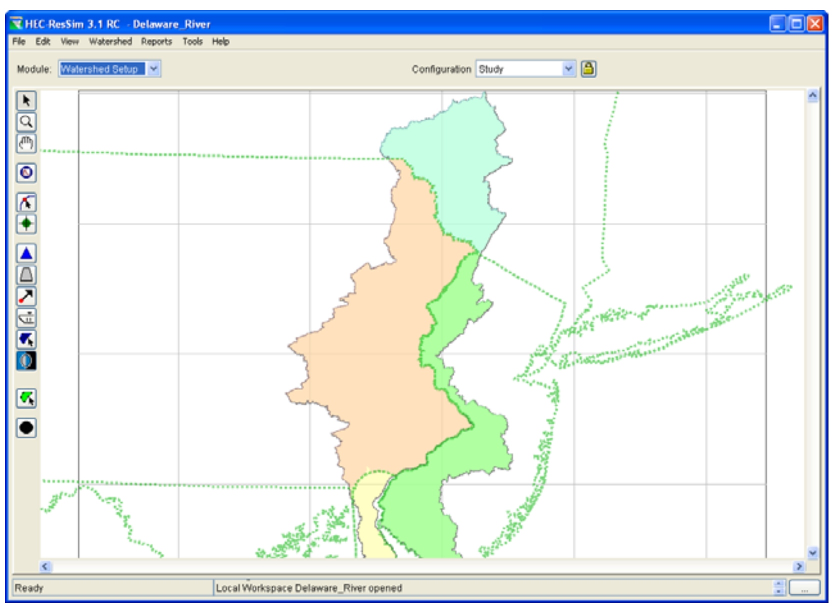


Figure 2.1 Watershed Setup - Delaware River Watershed

Figure 2.2 shows a list of all of the map layers that are included in the watershed and that are available for selection.

2.2 Stream Alignment

The Stream Alignment was developed by importing data from several of the stream shapefiles. Figure 2.3 shows the resulting stream alignment. The orange lines in this map are the streams of the stream alignment. The green dots represent stream nodes which are used to specify stream stationing and the lighter green "halos" represent the stream junctions or confluences.

A complete listing of the rivers and streams that are included in the Stream Alignment is presented in Table 2.1. For a variety of reasons, not all streams in the stream alignment could be imported from the available map layer and had to be hand drawn. The names of those streams that were added by-hand are followed by a * in Table 2.1.

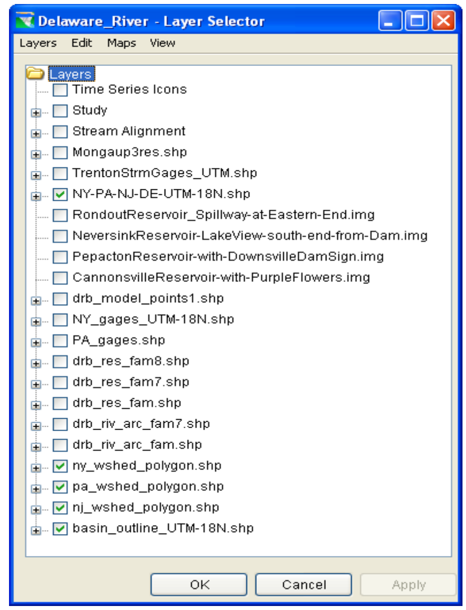


Figure 2.2 Map Layers for Delaware River Watershed

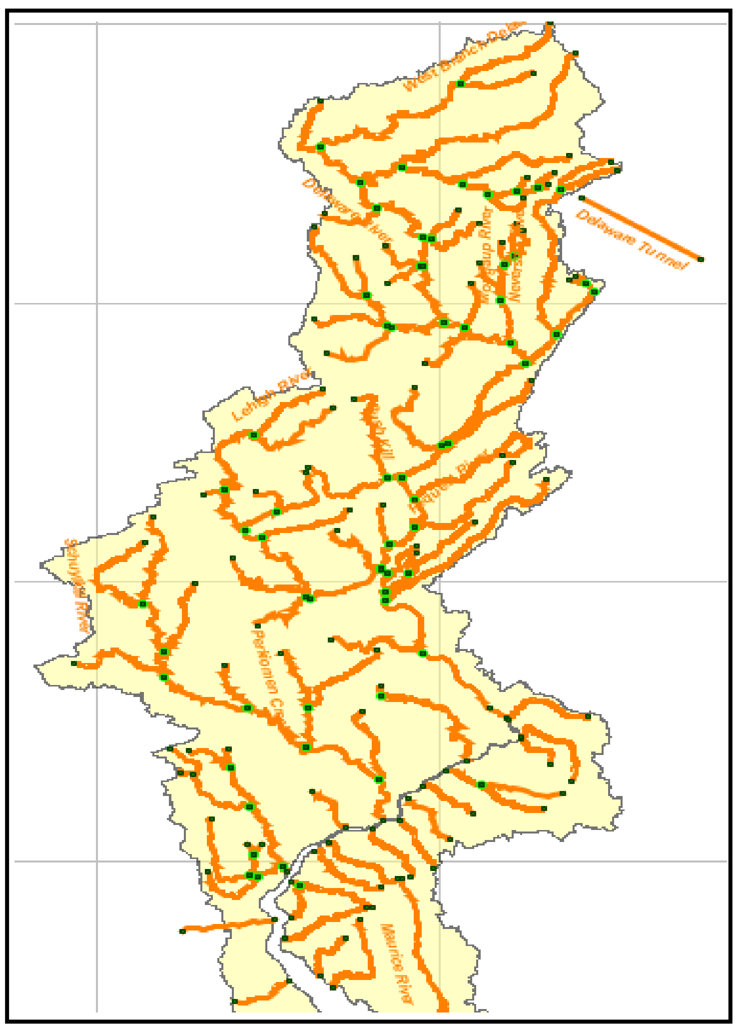


Figure 2.3 Delaware River Watershed Stream Alignment

Table 2.1 List of Streams

Stream Name	Stream Name	Stream Name
Alloway Creek	Fir Brook	Paulins Kill
Aquashicola Creek	Flat Brook	Pennsauken Creek
Assunpink Creek	Gumaer Brook	Pequest River
Basher Kill*	Halfway Brook	Perkiomen Creek
Beaver Kill	Jordan Creek	Pohatcong Creek
Big Timber Creek	Lackawaxen River	Pohopoco Creek
Birch Run	Lehigh River	Primrose Brook
Black Creek	Leipsic River	Raccoon Creek
Black Lake Creek*	Lewes & Rehoboth Canal	Rancocas Creek
Blacks Creek	Little Beaver Kill	Red Clay Creek
Brandywine Creek	Little Delaware River	Salem Canal
Broadkill River	Little Lehigh Creek*	Salem River
Brodhead Creek	Little Schuylkill River	Schuylkill River
Bush Kill*	Lopatcong Creek	Shohola Creek*
Bushkill Creek*	Maiden Creek	South Brook
C & D Canal	Manatawny Creek	St. Jones River
Calkins Creek	Mantua Creek	Stowe Creek
Callicoon Creek	Marsh Creek	Tobyhanna Creek*
Cape May Canal	Martins Creek	Tohickon Creek
Cedar Creek	Maurice River	Tributary to Red Clay Creek*
Christina River	McMichael Creek	Tulpehocken Creek
Cohansey River	Merrill Creek	Wallenpaupack Creek*
Cooper River*	Middle Mongaup River	Wangum Creek
Crosswicks Creek	Mispillion River	West Branch Brandywine Creek
Crum Creek*	Mongaup Creek	West Branch Delaware River
Delaware River	Mongaup River	West Branch Lackawaxen River
Delaware Tunnel*	Murderkill River	West Branch Mongaup River
Dennis Creek	Musconetcong River	West Branch Neversink River
Dyberry Creek	Neshaminy Creek	White Clay Creek
East Branch Brandywine Creek	Neversink River	Wild Creek
East Branch Callicoon Creek	North Branch Calkins Creek*	Willowemoc Creek
East Branch Delaware River	North Branch Callicoon Creek*	Wissahickon Creek
East Branch Mongaup River	North Branch Neshaminy Creek*	
East Branch Neversink River	North Branch Rancocas Creek*	
East Branch Perkiomen Creek	Oldmans Creek	
Equinunk Creek*	Oquaga Creek	

2.3 Watershed Configurations

A watershed configuration is a collection of projects (i.e., reservoirs and diversions) and computation points. These projects and computation points are created by using the appropriate drawing tools from the HEC-ResSim drawing toolbar to place the project or point in the appropriate location along the stream alignment. Only one configuration, named *Existing* was needed for the *Delaware_River* model.

2.3.1 Projects

In HEC-ResSim, watershed projects include reservoirs and diversions. There are thirteen reservoirs and three diversions currently being modeled in the HEC-ResSim Delaware River above Trenton model. These projects, listed in Table 2.2 are included in the *Existing* configuration and their locations are shown in Figure 2.4. Separate listings of reservoirs and diversions are available from the Reports menu in the Watershed Setup module.

Table 2.2 List of Projects (Reservoirs and Diversions)

Project Name	Description	Project Type	Stream Name	Corps Project
Beltzville	The Beltzville Lake Project is an integral part of the Lehigh River Flood Control Program …	Reservoir	Pohopoco Creek	Yes
Cannonsville	Placed in service in 1964. Largest drainage basin of all of the NYC reservoirs (455 sq. mi). …	Reservoir	West Branch Delaware River	No
F.E. Walter	The Francis E. Walter Reservoir Project is an integral part of the Lehigh River Flood Control …	Reservoir	Lehigh River	Yes
Jadwin	The Jadwin Reservoir project is part of an integrated reservoir flood control system …	Reservoir	Dyberry Creek	Yes
Lake Wallenpaupack	A reservoir in Pennsylvania, USA. It was built in 1927 by the Pennsylvania Power & Light Co. …	Reservoir	Wallenpaupack Creek	No
Merrill Creek	Merrill Creek Reservoir is a 650-acre reservoir surrounded by a 290-acre Environmental …	Reservoir	Merrill Creek	No
Neversink	Finished in 1953, began sending water in 1954 and reached capacity in 1955 …	Reservoir	Neversink River	No
Nockamixon	Creation of the lake was first proposed by the Secretary of the Department of Forests …	Reservoir	Tohickon Creek	No
Pepacton	Also known as Downsville Reservoir or the Downsville Dam. Finished in 1954 …	Reservoir	East Branch Delaware River	No
Prompton	The Prompton Reservoir project is part of an integrated reservoir flood control system …	Reservoir	West Branch Lackawaxen River	Yes
Rio	Part of the Mongaup System (which also includes Toronto and Swinging Bridge …	Reservoir	Mongaup River	No
Swinging Bridge	Part of the Mongaup System (which also includes Toronto and Rio Reservoirs) …	Reservoir	Mongaup River	No
Toronto	Part of the Mongaup System (which also includes Swinging Bridge and Rio Reservoirs) …	Reservoir	Black Lake Creek	No
to NYC	The "recipient" of diverted water from Cannonsville, Pepacton, and Neversink …	Reservoir	Delaware Tunnel	No
Can_Tunnel	Diverted Outlet from Cannonsville to NYC (via Delaware Tunnel) …	Diversion	West Branch Delaware River	No
Nev_Tunnel	Diverted Outlet from Neversink to NYC (via Delaware Tunnel) …	Diversion	Neversink River	No
Pep_Tunnel	Diverted Outlet from Pepacton to NYC (via Delaware Tunnel) …	Diversion	East Branch Delaware River	No

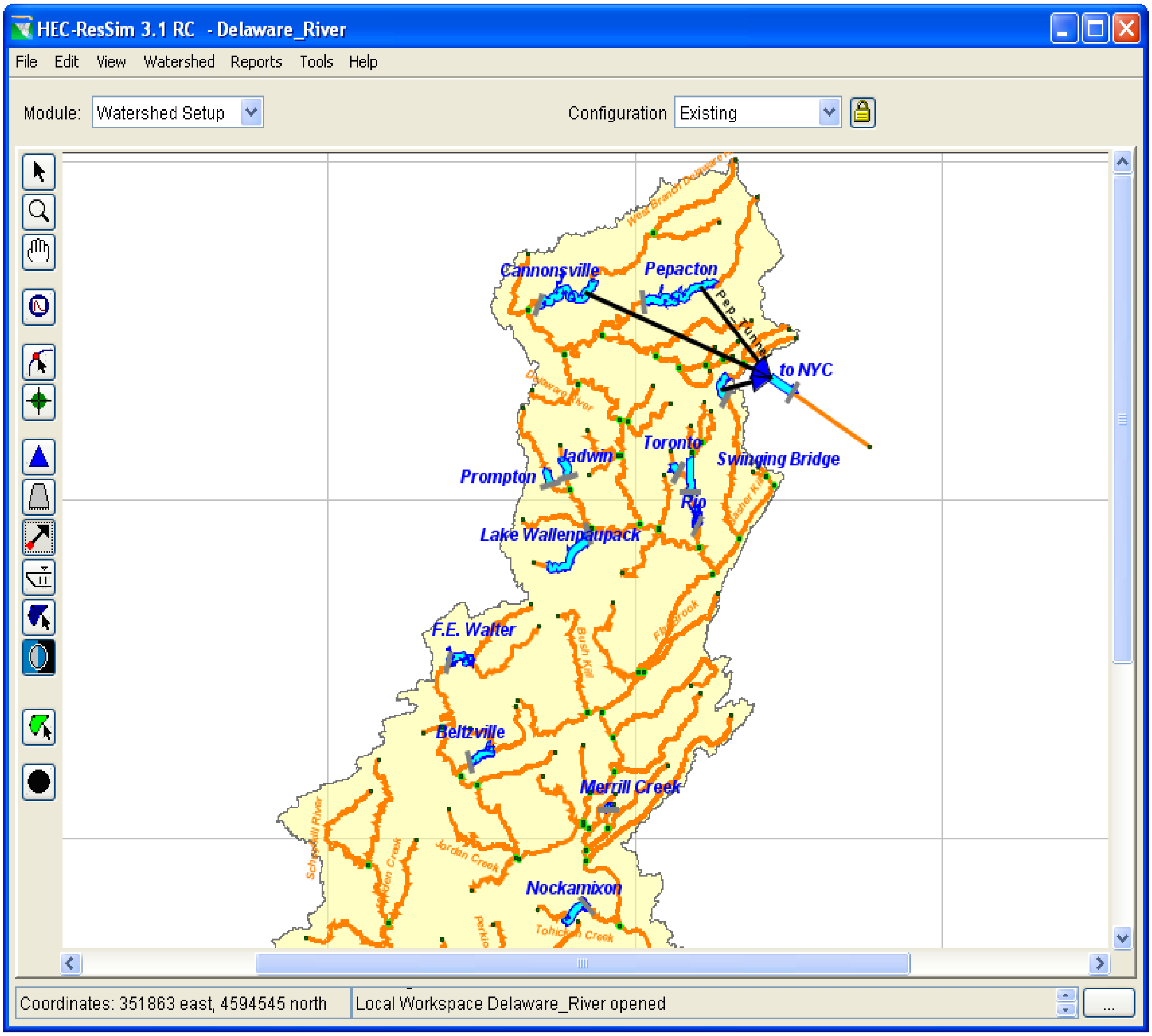


Figure 2.4 Project Locations (Thirteen Reservoirs and Three Diversions)

2.3.2 Computation Points

Computation points (i.e., modeling locations) include reservoir inflow and outflow points, operational locations, confluences, forecast locations (NWS), and USGS gage locations.

Figure 2.5 and Figure 2.6 show the locations of the computation points (black dots) for the *Delaware_River* watershed.

Figure 2.5 shows the region above Montague, and Figure 2.6 shows the region between Montague and Trenton.

Table 2.3 is an *alphabetical listing* of the computation points. In addition to the computation point names and partial descriptions, also included is the project the computation point belong to (if applicable) as well as the stream stations where the computation point resides on the stream alignment.

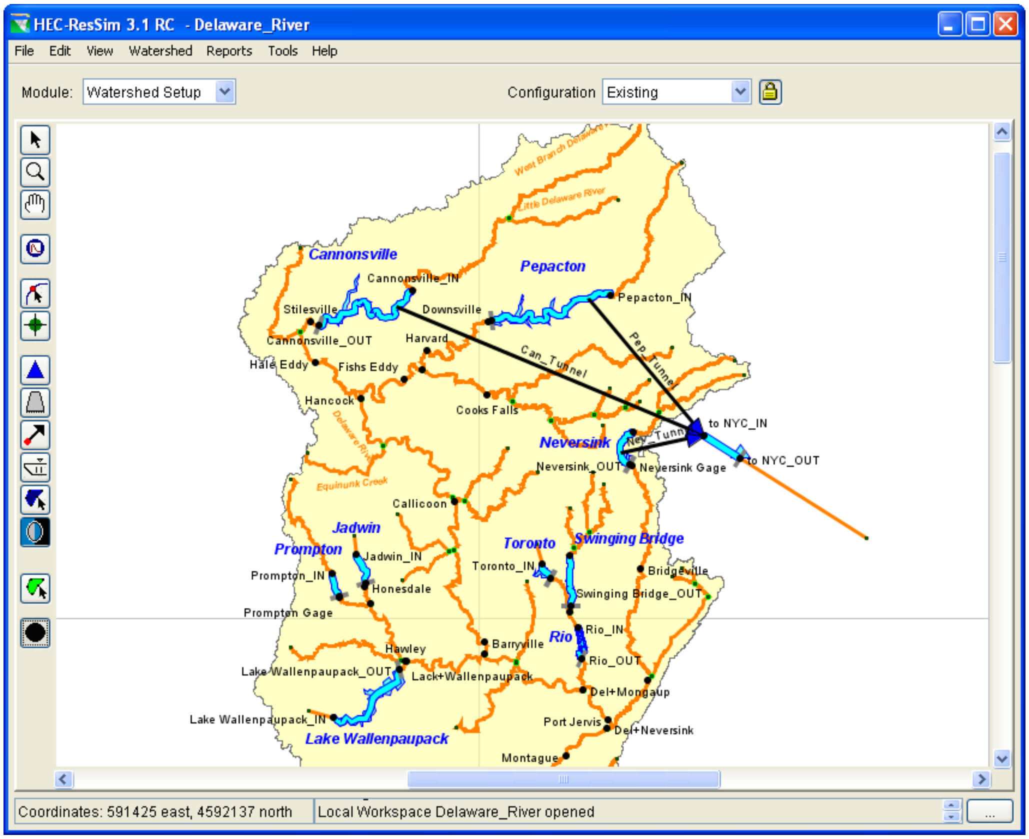


Figure 2.5 Locations of Computation Points above Montague

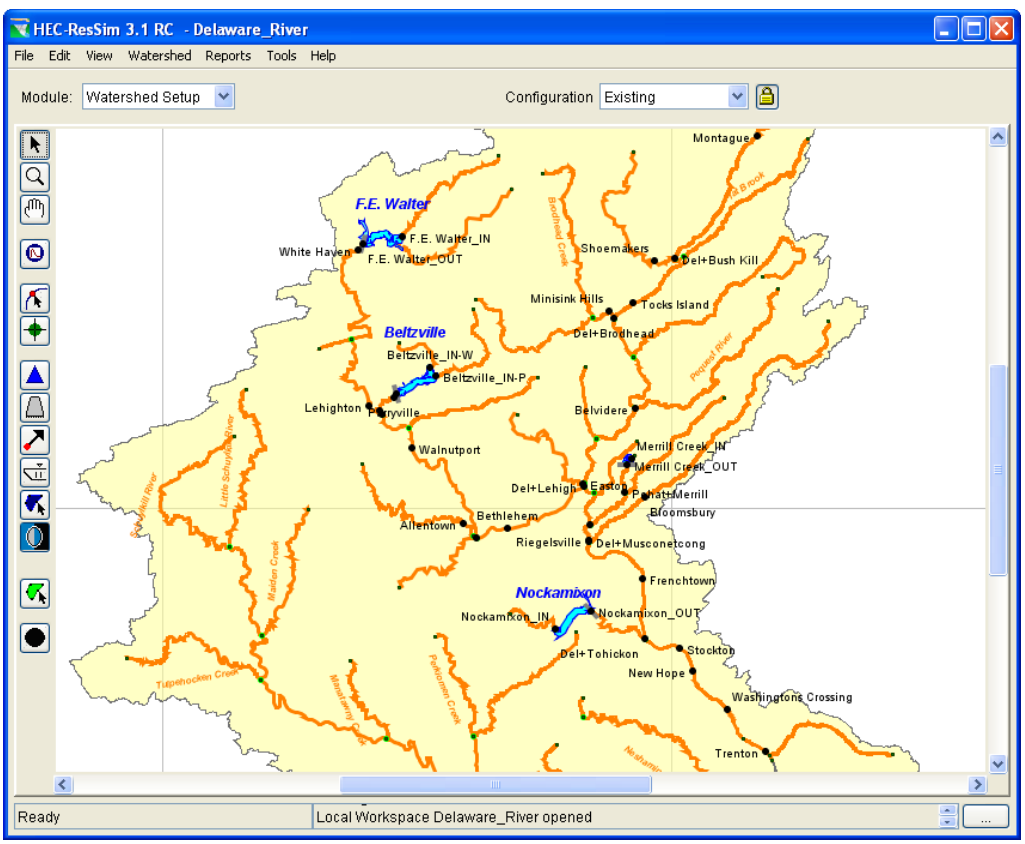


Figure 2.6 Locations of Computation Points between Montague & Trenton

Table 2.3 List of Computation Points

Name	Description	Stream Name	Project Name	Stream Station
Allentown	USGS Gage No. 01452000. Jordan Creek at Allentown, PA	Jordan Creek		5,389.3
Barryville	USGS Gage No. 01428500. Delaware River above Lackawaxen River near Barryville, NY	Delaware River		165,595.5
Beltzville_IN-P	Inflow for Reservoir Beltzville from Pohopoco Creek	Pohopoco Creek	Beltzville	18,469.4
Beltzville_IN-W	Inflow for Reservoir Beltzville from Wild Creek	Wild Creek	Beltzville	3,149.8
Beltzville_OUT	Outflow for Reservoir Beltzville (ref: USGS gage 01449790)	Pohopoco Creek	Beltzville	8,724.4
Belvidere	USGS Gage No. 01446500. Delaware River at Belvidere, NJ	Delaware River		72,573.9
Bethlehem	USGS Gage No. 01453000. Lehigh River at Bethlehem, PA	Lehigh River		18,832.0
Bloomsbury	USGS Gage 01457000 Musconetcong River near Bloomsbury, NJ	Musconetcong River		16,172.8
Bridgeville	USGS Gage No. 01436690. Neversink River at Bridgeville, NY	Neversink River		43,363.4
Callicoon	USGS Gage No. 01427510. Delaware River at Callicoon, NY	Delaware River		192,250.9
Cannonsville_IN	Inflow for Reservoir Cannonsville. For comparison with Observed flow, use Walton gage (01423000).	West Branch Delaware River	Cannonsville	57,306.9
Cannonsville_OUT	Outflow for Reservoir Cannonsville	West Branch Delaware River	Cannonsville	28,602.3
Cooks Falls	USGS Gage No. 01420500. Beaver Kill at Cooks Falls, NY	Beaver Kill		16,530.5
Del+Brodhead	Confluence of Delaware River & Brodhead Creek	Delaware River		89,819.0
Del+Bush Kill	Confluence of Delaware River & Bush Kill	Delaware River		105,744.1
Del+Lackawaxen	Confluence of Delaware River & Lackawaxen River	Delaware River		163,920.3
Del+Lehigh	Confluence of Delaware River & Lehigh River	Delaware River		56,612.3
Del+Mongaup	Confluence of Delaware River & Mongaup River	Delaware River		144,695.5
Del+Musconetcong	Confluence of Delaware River & Musconetcong River	Delaware River		46,597.8
Del+Neversink	Confluence of Delaware River & Neversink River	Delaware River		135,887.5
Del+Pohatcong	Confluence of Delaware River & Pohatcong Creek	Delaware River		49,650.9
Del+Tohickon	Confluence of Delaware River & Tohickon Creek	Delaware River		26,558.5

Name	Description	Stream Name	Project Name	Stream Station
Del_EB+Beaver Kill	Confluence of East Branch Delaware River and Beaver Kill	East Branch Delaware River		25,814.0
Downsville	USGS Gage No. 01417000. East Branch Delaware River at Downsville, NY. Should be comparable to PEPACTON Reservoir OUTFLOW.	East Branch Delaware River		54,264.8
Easton	Delaware River at Phillipsburg-Easton Bridge, NJ	Delaware River		57,043.3
F.E. Walter_IN	Inflow for Reservoir F.E. Walter	Lehigh River	F.E. Walter	137,933.6
F.E. Walter_OUT	Outflow for Reservoir F.E. Walter (ref: USGS gage 01447780)	Lehigh River	F.E. Walter	125,283.9
Fishs Eddy	USGS Gage No. 01421000. East Branch Delaware River at Fishs Eddy, NY	East Branch Delaware River		19,027.7
Frenchtown	USGS Gage No. 01458500. Delaware River at Frenchtown, NJ	Delaware River		34,958.0
Godeffroy	USGS Gage No. 01437500. Neversink River at Godeffroy, NY	Neversink River		14,501.2
Hale Eddy	USGS Gage No. 01426500. West Branch Delaware River at Hale Eddy, NY. Downstream of the confluence of Oquaga Creek and West Branch Delaware River	West Branch Delaware River		15,354.2
Hancock	Confluence of the East and West Branches of the Delaware River	Delaware River		223,397.5
Harvard	USGS Gage No. 01417500. East Branch Delaware River at Harvard, NY	East Branch Delaware River		30,679.1
Hawley	USGS Gage No. 01431500. Lackawaxen River at Hawley, PA	Lackawaxen River		25,818.7
Honesdale	USGS Gage No. 01429500. Dyberry Creek near Honesdale, PA. Should be comparable to JADWIN Reservoir OUTFLOW.	Dyberry Creek		4,071.2
Jadwin_IN	Inflow for Reservoir Jadwin	Dyberry Creek	Jadwin	11,463.8
Jadwin_OUT	Outflow for Reservoir Jadwin. (ref: USGS gage 01429400)	Dyberry Creek	Jadwin	4,774.3
Lack+Wallenpaupack	Confluence of Lackawaxen River & Wallenpaupack River	Lackawaxen River		25,542.8
Lack_WB+Dyberry	Confluence of WB Lackawaxen River & Dyberry Creek	Lackawaxen River		42,734.7
Lake Wallenpaupack_IN	Inflow for Reservoir Lake Wallenpaupack	Wallenpaupack Creek	Lake Wallenpaupack	23,048.2
Lake Wallenpaupack_OUT	Outflow for Reservoir Lake Wallenpaupack (ref: USGS gage 01431700)	Wallenpaupack Creek	Lake Wallenpaupack	2,398.1
Lehigh+Jordan	Confluence of Lehigh River & Jordan Creek	Lehigh River		26,004.3
Lehigh+Pohopoco	Confluence of Lehigh River & Pohopoco Creek	Lehigh River		65,104.3

Name	Description	Stream Name	Project Name	Stream Station
Lehighton	USGS Gage No. 01449000. Lehigh River at Lehighton, PA	Lehigh River		68,346.2
Merrill Creek_IN	Inflow for Reservoir Merrill Creek	Merrill Creek	Merrill Creek	8,172.8
Merrill Creek_OUT	Outflow for Reservoir Merrill Creek	Merrill Creek	Merrill Creek	6,268.5
Minisink Hills	USGS Gage No. 01442500. Brodhead Creek at Minisink Hills, PA	Brodhead Creek		1,641.3
Mongaup+Black Lake Cr	Confluence of Mongaup River & Black Lake Creek	Mongaup River		19,609.9
Montague	USGS Gage No. 01438500. Delaware River at Montague, NJ	Delaware River		127,936.6
Neversink Gage	USGS Gage No. 01436000. Neversink River at Neversink, NY. Should be comparable to NEVERSINK Reservoir OUTFLOW.	Neversink River		69,126.8
Neversink_IN	Inflow for Reservoir Neversink	Neversink River	Neversink	78,004.2
Neversink_OUT	Outflow for Reservoir Neversink	Neversink River	Neversink	69,693.2
New Hope	Delaware River at New Hope Bridge, PA	Delaware River		17,164.7
Nockamixon_IN	Inflow for Reservoir Nockamixon	Tohickon Creek	Nockamixon	28,433.3
Nockamixon_OUT	Outflow for Reservoir Nockamixon	Tohickon Creek	Nockamixon	18,014.2
Parryville	USGS Gage No. 01449800. Pohopoco Creek Below Beltzville Dam near Parryville, PA	Pohopoco Creek		7,791.6
Pepacton_IN	Inflow for Reservoir Pepacton. For comparison with observed flow, use Margaretville gage (01413500).	East Branch Delaware River	Pepacton	84,641.2
Pepacton_OUT	Outflow for Reservoir Pepacton	East Branch Delaware River	Pepacton	55,123.2
Pohat+Merrill	Confluence of Pohatcong Creek & Merrill River	Pohatcong Creek		12,477.1
Pohopoco Mouth	Pohopoco Creek Near Parryville, PA, site of the original Parryville Gage (UGSG #01450000 - discontinued in 1970)	Pohopoco Creek		1,049.8
Port Jervis	USGS Gage No. 01434000. Delaware River at Port Jervis, NY.	Delaware River		137,461.1
Prompton Gage	USGS Gage No. 01429000. West Branch Lackawaxen River at Prompton, PA. Should be comparable to PROMPTON Reservoir OUTFLOW.	West Branch Lackawaxen River		7,387.3
Prompton_IN	Inflow for Reservoir Prompton	West Branch Lackawaxen River	Prompton	12,390.7
Prompton_OUT	Outflow for Reservoir Prompton (ref: USGS gage 01428900)	West Branch Lackawaxen River	Prompton	7,726.7
Riegelsville	USGS Gage No. 01457500. Delaware River at Riegelsville, NJ	Delaware River		46,720.9

Name	Description	Stream Name	Project Name	Stream Station
Rio_IN	Inflow for Reservoir Rio	Mongaup River	Rio	15,357.8
Rio_OUT	Outflow for Reservoir Rio	Mongaup River	Rio	7,504.4
Shoemakers	USGS Gage No. 01439500. Bush Kill at Shoemakers, PA	Bush Kill		5,634.7
Stilesville	USGS Gage No. 01425000. West Branch Delaware River at Stilesville, NY. Should be comparable to CANNONSVILLE Reservoir OUTFLOW.	West Branch Delaware River		26,747.1
Stockton	Delaware River at Stockton Bridge, NJ	Delaware River		21,011.4
Swinging Bridge_IN	Inflow for Reservoir Swinging Bridge	Mongaup River	Swinging Bridge	30,983.7
Swinging Bridge_OUT	Outflow for Reservoir Swinging Bridge	Mongaup River	Swinging Bridge	20,883.7
Tocks Island	USGS Gage No. 01440200. Delaware River at Tocks Island, NJ. a.k.a. Delaware River near Delaware Water Gap, PA	Delaware River		93,252.9
Toronto_IN	Inflow for Reservoir Toronto	Black Lake Creek	Toronto	12,411.8
Toronto_OUT	Outflow for Reservoir Toronto	Black Lake Creek	Toronto	8,763.3
Trenton	USGS Gage No. 01463500. Delaware River at Trenton, NJ	Delaware River		1,340.3
Walnutport	USGS Gage No. 01451000. Lehigh River at Walnutport, PA	Lehigh River		53,727.3
Washingtons Crossing	Delaware River at Washington's Crossing Bridge, NJ	Delaware River		9,583.6
White Haven	USGS Gage No. 01447800. Lehigh River below F.E. Walter Reservoir near White Haven, PA	Lehigh River		123,237.6
to NYC_IN	Inflow Jct for Reservoir "to NYC" - a "dummy" reservoir to receive NYC diversions	Delaware Tunnel	to NYC	37,480.9
to NYC_OUT	Outflow Jct for Reservoir "to NYC" - a "dummy" reservoir to receive NYC diversions	Delaware Tunnel	to NYC	29,258.5

2.4 Summary

To summarize, the following model development steps that occurred in the **Watershed Setup** module:

- The **Stream Alignment** was created (imported from rivers and streams shapefiles) and edited (to add or extend streams). The Stream Alignment serves as the framework for placing reservoirs, diversions and computations points (i.e., modeling locations).
- The *Existing* **Configuration** was created to include all reservoir and diversion projects.
- **Reservoirs** were created and added to the configuration.

- **Diversions** were created (from the three NYC Reservoirs) and added to the configuration.
- **Computation Points** were created to represent NWS Flood Forecast locations, USGS gage locations, and other points of interest.

USACE, USGS, NWS and DRBC worked together to establish the **Naming Conventions** for consistency among modeling software programs (PRMS, HEC-ResSim, and the GUI) being used for this study.

Computation points (black dots) in the **Watershed Setup** module become **Junctions** (red circles) in the **Reservoir Network** module. In the Watershed Setup module, the computation points are not connected with one another. The connections or Routing Reaches are defined in the Reservoir Network module.

Similarly, **Diversions** from Reservoirs in the **Watershed Setup** module become **Diverted Outlets** in the **Reservoir Network** module.

Chapter 3

Data Collection

Data for the reservoir and streamflow routing component of the Delaware River Flood Analysis model was gathered from three primary sources: the Delaware River Basin Commission (DRBC), the Philadelphia District (CENAP), and the US Geologic Survey (USGS). Other data sources included: the National Weather Service (NWS), the New York City Department of Environmental Protection (NYCDEP), Pennsylvania Power and Light (PPL), Merrill Creek Owners Group (MCOG), and the current superintendant of the hydropower reservoirs in the Mongaup system.

Two categories of data were collected: time-series data representing stream flows, reservoir release, river stages, and pool elevations; and model data defining the physical capacities and operational limits of the rivers and reservoirs in the basin.

3.1 Time Series Data

3.1.1 USGS Gage Data

The USGS provided most of the time-series data used in the model. The data covered the three flood events studied (September 2004, March-April 2005, and June-July 2006) and includes:

- daily and hourly flow records for all the streamflow gages in the basin
- hourly stage records for a subset of the stream gages
- hourly pool elevation records for the CENAP reservoirs
- daily and hourly inflows computed by the USGS's PRMS model for all headwater and inflow locations throughout the model.
- elevation datum for the streamflow or reservoir pool elevation gages is specific for each gage and was not used in the model

3.1.2 CENAP Gage Data

The CENAP partners with the USGS to maintain many of the gages in the basin needed for operation of the CENAP reservoirs. CENAP maintains a database of these gage records for its own use. The CENAP database also includes records of observed and computed reservoir elevation, storage, inflow, and releases. The data provided by CENAP spans the three flood events studied (September 2004, March-April 2005, and June-July 2006) and includes:

- daily and hourly flow and stage records for most of the streamflow gages in the basin
- hourly pool elevation, storage, and computed inflow records for the CENAP reservoirs
- hourly reservoir releases from the CENAP reservoirs

3.1.3 DRBC Data

As a regulating and monitoring authority in the basin, the DRBC also maintains a database of time-series data covering most of the reservoirs and stream gages in the basin. Data provided by the DRBC originated with the operators of the reservoirs and is identified as such. This data includes:

- daily and hourly elevation and release records for the NYCDEP reservoirs, Cannonsville, Pepacton and Neversink
- hourly elevation and release records for the PPL reservoir, Lake Wallenpaupack
- hourly release records for Rio Reservoir, a part of the Mongaup system of hydropower reservoirs.
- hourly elevation and release records for Merrill Creek Reservoir, owned and operated by MCOG
- monthly elevation and release records for Nockamixon Dam and Reservoir, owned and operated by the Pennsylvania Department of Natural Resources

3.2 Model Data

CENAP provided electronic and hard copies of the Water Control Manuals for the four USACE reservoirs in the Delaware River Basin above Trenton: Prompton, Jadwin, F.E. Walter, and Beltzville. The water control manuals contained most of the physical and operational data used to describe these reservoirs in the model. Other data was also provided by CENAP in Excel® spreadsheets and by email.

The DRBC provided the physical and operational data for all other reservoirs modeled in the basin. This data was provided through a mixture of media including: hard copies of various documents that described the reservoirs, an electronic copy of the DRBC's OASIS (Operational Analysis and Simulation of Integrated Systems) model that they use to study water supply issues in the basin, and email correspondence with reservoir operators to fill in the gaps. OASIS is a software product developed by HydroLogics, Inc. for modeling the operations of water resources systems. OASIS uses a linear programming solver to optimize the reservoir releases to best meet the operating rules that have been represented as either goals or constraints.

NWS provided the routing parameters used in their real-time forecasting model of the Delaware River Basin as well as a complete description of the Variable Lag and K routing method.

Tables listing all the physical and some of the operational data used in the model can be found in Appendix B of this report.

Chapter 4

Reservoir Network

The reservoir network is the basis of a reservoir model developed using HEC-ResSim. The network developed for this project is named: *Delaware above Trenton*. This network includes all the physical and operational data needed for the various alternatives developed for the *Delaware_River* watershed. From this point forward in the report, the network, *Delaware above Trenton,* and its associated alternatives will be referred to as "the model". The alternatives will be described in Chapter 5, Alternatives and Simulations.

The modeling elements that make up a reservoir network include: reservoirs, reaches, junctions, diversions, reservoir systems, and state variables. Each of these elements consists of one or more sub-elements. The following sections will describe each element type beginning with the simplest elements, the junctions, and working up to the most complex, the reservoirs and reservoir systems.

The Delaware River Basin above Trenton consists of the following major subbasins:

- The Upper Basin contains all three of the New York City water supply reservoirs and includes the West and East Branches of the Delaware River and the Neversink River. Cannonsville and Pepacton Reservoirs are located on the West and East Branches, respectively. The Neversink Reservoir is on the Neversink River and it releases flows into the Delaware below two other major subbasins (Lackawaxen and Mongaup). It was included with the Upper Basin so that all three New York City water supply reservoirs and the unique aspects of their operations could be evaluated together.
- The Lackawaxen River Basin which includes Prompton and Jadwin, two USACE flood damage reduction reservoirs, and Lake Wallenpaupack, a PPL Corporation hydropower reservoir.
- The Mongaup River Basin includes three hydropower reservoirs: Swinging Bridge, Toronto and Rio Reservoirs. Although the Mongaup River basin contains five reservoirs, only the three largest were represented in the model in order to enable the DRBC to evaluate their possible flood damage reduction benefits.
- The Lehigh River Basin contains F.E. Walter and Beltzville Reservoirs, both USACE flood damage reduction reservoirs.
- The Mainstem Delaware River Basin receives flow from all the other basins as well as several smaller tributaries, two of which include Merrill Creek and Nockamixon Reservoirs which are located on two of the smaller tributaries, Merrill Creek and Tohickon Creek.

The following sections will describe each element type beginning with the simplest elements, the junctions, and ending with the most complex, the reservoirs and reservoir systems. To facilitate understanding of the different model elements and how they relate to one another, the discussion of each element type will be grouped by major subbasin of the watershed.

4.1 Junctions

The junction elements serve four functions: 1) they link model elements together, 2) they are the means by which flow (headwater or incremental) enters the network, 3) they combine flow – the outflow of a junction is the sum of the inflows to the junction, and 4) when provided with an optional rating curve, they calculate stage using the computed junction outflow.

Once a reservoir network is assembled, the connection between network elements is taken for granted, however a good model design includes junctions at key locations to identify and manage inflow data effectively across various alternatives. Depending on the objectives of the model, rating curves may be important to the operation of the reservoirs for downstream controls, such as in the Lackawaxen River Basin where the downstream control for the Jadwin and Prompton Reservoirs is based on stage, or may simply be used to produce additional output (e.g., at National Weather Service Flood Forecast points).

As inflow locations, junctions can fall into two categories: *boundary* junctions and *interior* junctions. Boundary junctions have no reaches or reservoirs above them in the network and typically identify a single upstream gage or inflow representing the total headwater inflow. Interior junctions combine inflow routed from upstream with incremental local flow before passing the total flow on to the downstream element.

To support the various inflow alternatives that were requested for this model, the Local Inflow list at each junction includes all relevant gages for tributaries that enter the upstream reach or the immediately downstream reservoir, as well as an entry for any ungaged incremental local flow that was computed for the reach or reservoir. In the *FC-GageQ* alternative, the gaged local inflows are assigned to the time-series holding the observed gage data and the computed locals are either attached to zero flow time-series or to a derived ungaged local flow time-series. In the *FC-PRMS* alternative, the computed local is attached to the PRMS computed inflow and local inflows identified as gaged flows are attached to a zero flow time-series. An example is presented in the explanation for Figure 4.1.

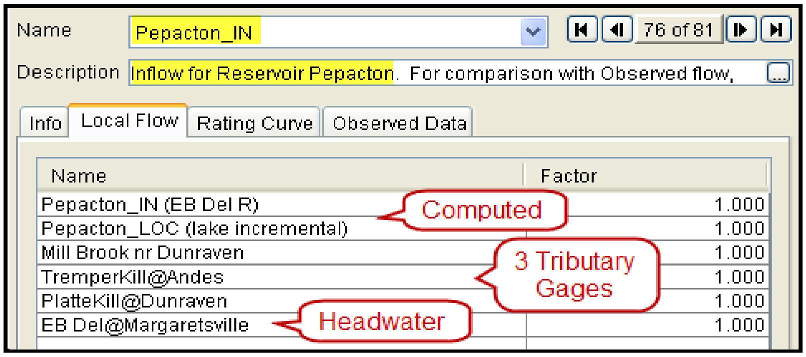


Figure 4.1 Pepacton Reservoir Inflow Junction – Local Flow List

A list of the junctions in the Upper Basin and a summary of their significance in the model are provided in Table 4.1.

Table 4.1 Upper Basin Junctions

Junction Name	Stream Name	Boundary or Interior Junction	Incremental Inflow (Yes/No)	Gage Location (Yes/No)	Rating Curve (Yes/No)
Cannonsville_IN	West Branch Delaware	B	Yes*	Yes	No
Cannonsville_OUT	West Branch Delaware	I	No	No	No
Stilesville	West Branch Delaware	I	No	Yes	No
Hale Eddy	West Branch Delaware	I	Yes*	Yes	Yes†
Pepacton_IN	East Branch Delaware	B	Yes*	Yes	No
Pepacton_OUT	East Branch Delaware	I	No	No	No
Downsville	East Branch Delaware	I	No	Yes	No
Harvard	East Branch Delaware	I	Yes	Yes	Yes†
Cooks Falls	Beaver Kill	B	No	Yes	Yes
Del_EB+Beaver Kill	East Branch Delaware	I	Yes	No	No
Fishs Eddy	East Branch Delaware	I	Yes	Yes	Yes†
Hancock	Confluence EB&WB Del.	I	Yes	No	No
Callicoon	Delaware River	I	Yes	Yes	Yes
Neversink_IN	Neversink River	B	Yes*	Yes	No
Neversink_OUT	Neversink River	I	No	No	No
Neversink Gage	Neversink River	I	No	Yes	No
Bridgeville	Neversink River	I	Yes	Yes	Yes
Godeffroy	Neversink River	I	Yes	Yes	No
toNYC_IN		B	No	No	No

* The local inflow list to some junctions includes an entry for one or more gaged flows in addition to an entry for computed or derived incremental local flow and/or total headwater flow.

† The rating curve for the junctions marked with this symbol has had an extra point added to the rating curve provided by the USGS. The extra point was added by extrapolating a straight line through the last two values and determining stage for a flow larger than the largest computed unregulated flow.

Figure 4.1 shows the **Local Flow** list for Pepacton_IN, one of the three boundary junctions located at the inflow to the reservoirs in the Upper Basin. Since this junction represents the total inflow to Pepacton Reservoir, in addition to the headwater gage, several gages listed are for other tributaries to the pool. Also listed are Pepacton_IN (EB Del R) and Pepacton_LOC (lake incremental). In the *FC-GageQ* alternative, observed data is assigned to the gaged tributaries in the list, the derived inflows that represent the ungaged areas are assigned to *Pepacton_IN*, and a zero time-series is assigned to *Pepacton_LOC (lake incremental).* In the *FC-PRMS* alternative, all inflows above the reservoir are assigned to *Pepacton_IN*, flow simulated to represent contributions from areas around the reservoir are assigned to *Pepacton_LOC (lake incremental),* and zero flow time-series are assigned to gage entries.

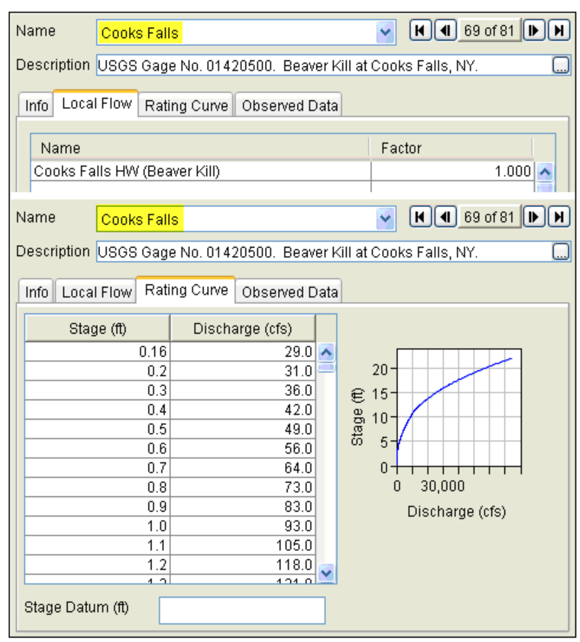


Figure 4.2 Cooks Falls Junction – Inflows & Rating Curve

The Cooks Falls Junction, illustrated in Figure 4.2, is also a boundary junction, but it represents a gage on Beaver Kill, an unregulated tributary to the East Branch Delaware River. As one of the significant gages in the basin, a rating curve was provided – a portion of which is also illustrated in Figure 4.2.

Like Cooks Falls, several other junctions in the Upper Basin represent gage locations, so, where available, each includes a rating curve. Unlike Cooks Falls, these are interior junctions so the "Local Flows" identified at these junctions are incremental local inflows that are added to the flow routed from the upstream reach(es).

Images of the data entry screens for most of the interior junctions were not included in this report. However, Figure 4.3 shows the local flow list for Callicoon Junction to illustrate the inflow factor feature. The Callicoon Junction identifies two incremental local flows. Both entries represent the incremental local flow entering the network at this junction. In the *FC-PRMS* alternative, the computed local inflow was assigned to the Callicoon Local (PRMS) and a zero time-series was assigned to Callicoon Local (0.95 Callicoon); whereas for the *FC-GageQ* alternative, the derived local inflow was assigned to Callicoon Local (0.95 Callicoon) and a zero time-series was assigned to Callicoon Local (PRMS). The use of the inflow factor of 0.95 indicates that 95% of the inflow time-series mapped to the Callicoon Local was used by the model. That inflow was derived as follows:

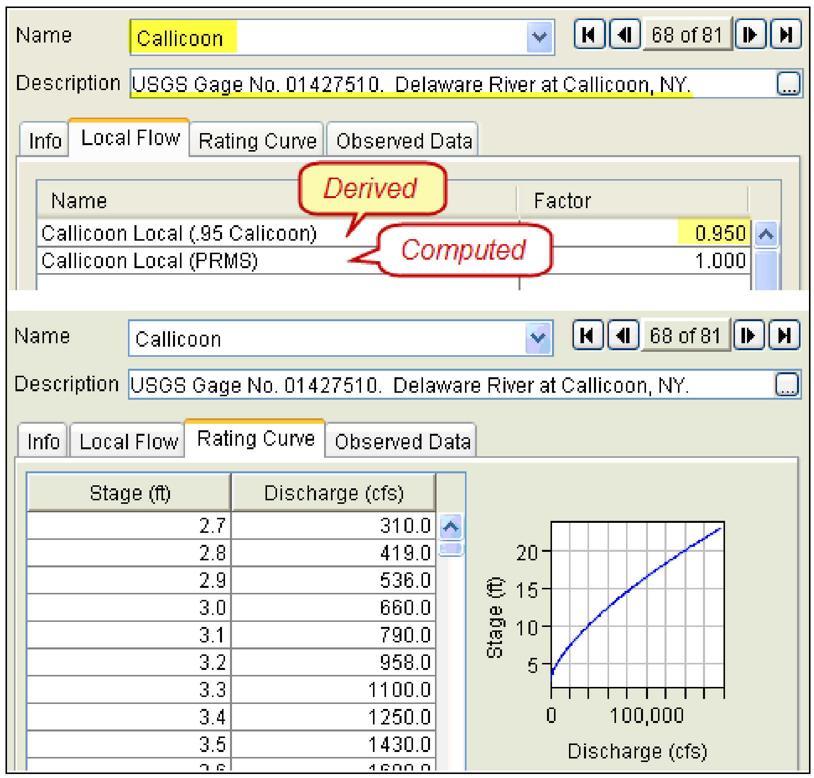


Figure 4.3 Callicoon Junction, Rating Curve

The gaged flows at Hale Eddy and Fishs Eddy were routed to the confluence of the West and East Branches of the Delaware River, combined, and then routed to Callicoon. The total routed flow was then subtracted from the Callicoon gaged flow to produce the incremental local at Callicoon.

In the calibration of the routing, it was determined that a small fraction of the derived local computed at Callicoon should be brought into the model at the confluence and then routed to Callicoon. The factor of 0.95 represents the portion of the derived Callicoon local that is brought in at Callicoon. A similar entry exists at the upstream confluence but a factor of 0.05 is used there.

The junctions in the other basins of the model are summarized in the following tables.

Table 4.2 Lackawaxen River Basin Junctions

Junction Name	Stream Name	Boundary or Interior Junction	Incremental Inflow (Yes/No)	Gage Location (Yes/No)	Rating Curve (Yes/No)
Prompton_IN	West Branch Lackawaxen	B	Yes*	No	No
Prompton_OUT	West Branch Lackawaxen	I	No	No	No
Prompton Gage	West Branch Lackawaxen	I	No	Yes	No
Jadwin_IN	Dyberry Creek	B	Yes*	No	No
Jadwin_OUT	Dyberry Creek	I	No	No	No
Honesdale	Dyberry Creek	I	No	Yes	No
Lack_WB+Dyberry	Confluence Lack+Dyberry	I	Yes	No	No
Hawley	Lackawaxen	I	Yes	Yes	Yes
Wallenpaupack_IN	Wallenpaupack Creek	B	Yes	No	No
Wallenpaupack_OUT	Wallenpaupack Creek	I	No	No	No
Lack+Wallenpaupack	Confluence Lack.+Wall.	I	Yes	No	No
* The local inflow list to some junctions includes an entry for one or more gaged flows in addition to an entry for computed or derived incremental local flow and/or total headwater flow.					

Table 4.3 Mongaup River Basin Junctions

Junction Name	Stream Name	Boundary or Interior Junction	Incremental Inflow (Yes/No)	Gage Location (Yes/No)	Rating Curve (Yes/No)
Swinging Bridge_IN	Mongaup River	B	Yes*	No	No
Swinging Bridge_OUT	Mongaup River	I	No	No	No
Toronto_IN	Black Lake Creek	B	Yes	No	No
Toronto_OUT	Black Lake Creek	I	No	No	No
Mongap+Black Lake Cr	Confluence Mong+BLC	I	Yes	No	No
Rio_IN	Mongaup River	I	Yes	No	No
Rio_OUT	Mongaup River	I	No	No	No
* The local inflow list to some junctions includes an entry for one or more gaged flows in addition to an entry for computed or derived incremental local flow and/or total headwater flow.					

Table 4.4 Lehigh River Basin Junctions

Junction Name	Stream Name	Boundary or Interior Junction	Incremental Inflow (Yes/No)	Gage Location (Yes/No)	Rating Curve (Yes/No)
F.E. Walter_IN	Lehigh River	B	Yes*	No	No
F.E. Walter_OUT	Lehigh River	I	Yes*	No	No
White Haven	Lehigh River	I	No	Yes	Yes†
Lehighton	Lehigh River	I	Yes*	Yes	Yes†
Beltzville_IN-P	Pohopoco Creek	B	Yes*	No	No
Beltzville_IN-W	Wild Creek	B	Yes	No	No
Beltzville_OUT	Pohopoco Creek	I	No	No	No
Parryville	Pohopoco Creek	I	No	Yes	Yes†
Pohopoco Mouth	Pohopoco Creek	I	Yes	Yes	No
Lehigh+Pohopoco	Confl. Lehigh+Pohopoco	I	Yes	No	No
Walnutport	Lehigh River	I	Yes	Yes	Yes
Allentown	Jordan Creek	I	Yes	Yes	Yes
Lehigh+Jordan	Confluence Lehigh+Jordan	I	Yes	No	No
Bethlehem	Lehigh River	I	Yes	Yes	Yes
* The local inflow list to some junctions includes an entry for one or more gaged flows in addition to an entry for computed or derived incremental local flow and/or total headwater flow.					
† The rating curve for the junctions marked with this symbol has had an extra point added to the rating curve provided by the USGS. The extra point was added by extrapolating a straight line through the last two values and determining stage for a flow larger than the largest computed unregulated flow.					

Table 4.5 Mainstem Delaware River Basin Junctions

Junction Name	Stream Name	Boundary or Interior Junction	Incremental Inflow (Yes/No)	Gage Location (Yes/No)	Rating Curve (Yes/No)
Barryville	Delaware River	I	Yes*	Yes	Yes
Del+Lackawaxen	Confluence Del+Lack	I	Yes*	No	No
Del+Mongaup	Confluence Del+Mongaup	I	No	Yes	No
Port Jervis	Delaware River	I	Yes	Yes	Yes
Montague	Delaware River	I	Yes	Yes	Yes†
Shoemakers	Bush Kill	B	Yes*	Yes	Yes
Del+Bush Kill	Confluence Del+Bush Kill	I	Yes	No	No
Tocks Island	Delaware River	I	Yes	Yes	Yes
Minisink Hills	Brodhead Creek	B	Yes	Yes	Yes
Del+Brodhead	Confluence Del+Brodhead	I	Yes	No	No
Belvidere	Delaware River	I	Yes	Yes	Yes
Easton	Delaware River	I	Yes	No	No
Delaware+Lehigh	Confluence Del+Lehigh	I	Yes	No	No
Merrill Creek_IN	Merrill Creek	B	Yes	No	No
Merrill Creek_OUT	Merrill Creek	I	No	No	No
Pohat+Merrill	Confl. Pohatcong+Merrill	I	Yes	No	No
Del+Pohatcong	Confl. Del.+Pohatcong Cr	I	Yes	No	No
BloomsBury	Musconetcong River	B	Yes	Yes	No
Riegelsville	Delaware River	I	Yes	Yes	Yes
Del+Musconetcong	Confl. Del.+Musconetcong	I	Yes	No	No
Frenchtown	Delaware River	I	Yes	Yes	No
Nockamixon_IN	Tohickon Creek	B	Yes	No	No
Nockamixon_OUT	Tohickon Creek	I	No	No	No
Del+Tohickon	Confluence Del+Tohickon	I	Yes	No	No
Stockton	Delaware River	I	Yes	No	No
New Hope	Delaware River	I	Yes	No	No
Washingtons Crossing	Delaware River	I	Yes	No	No
Trenton	Delaware River	I	Yes	Yes	Yes

* The local inflow list to some junctions includes an entry for one or more gaged flows in addition to an entry for computed or derived incremental local flow and/or total headwater flow.

† The rating curve for the junctions marked with this symbol has had an extra point added to the rating curve provided by the USGS. The extra point was added by extrapolating a straight line through the last two values and determining stage for a flow larger than the largest computed unregulated flow.

4.2 Reaches

The reaches route water from one junction to another in the network. Routing is performed in HEC-ResSim using one of a handful of hydrologic routing methods. In this model, only three of the available methods were used: Null (direct translation – no lag or attenuation), Variable Lag & K, and Muskingum. Null routing was used for very short reaches that have no appreciable impact on the flow that can be represented in a one-hour timestep.

The Variable Lag & K method is a routing method used extensively by the NWS in their hydrologic forecasting models. Since calibration of routing parameters can be significantly labor intensive and because the NWS already had developed Lag & K routing parameters calibrated for much of the Delaware River Basin, at the onset of this project, HEC chose to add the Lag & K routing method to HEC-ResSim rather than redevelop routing parameters for the entire basin in another method. However, due to differences in model configurations and assumptions, the routing in all the reaches of the basin had to be revisited and in many cases recalibrated. Some of the reasons for this are:

1) the NWS's Lag & K routing parameters were developed based on the assumption of a six-hour timestep while the HEC-ResSim model is computed on a one-hour timestep;
2) the discretization of the routing reaches in the model do not exactly match those used in the NWS's model;
3) the NWS parameters were intended to manage the full range of flows (from low to high) while the HEC-ResSim model parameters were developed to route major flood flows; and
4) the initial implementation of the Lag & K method in HEC-ResSim inadequately manages an inherent weakness in the method that occurs when the variable lag parameter values decrease with increasing inflow values.

For those reaches that could not be easily re-calibrated with the Variable Lag & K method, the Muskingum method was used. This method provided a fairly simple means of approximating the lag and attenuation of the flood wave for several reaches of the model. It should be noted that the parameters derived for these reaches were for flood flows and will not likely translate well to low flow situations. Routing information for each reach is provided below and in Appendix B.

Three Upper Basin reaches were selected as examples for the following routing discussion and represent three routing methods: Downsville to Harvard (Muskingum), Stilesville to Hale Eddy (original Lag & K data), and Hancock to Callicoon (constant Lag). All other reaches in this and the other basins are summarized in Tables 4.6 through 4.10.

The Downsville to Harvard reach, illustrated in Figure 4.4 provides an example of the Muskingum routing method. The Muskingum routing method was chosen because the Variable Lag & K parameters were developed for a six-hour time-step did not account for attenuation in the reach which, though small, was needed to produce a better match to the observed flood flows.

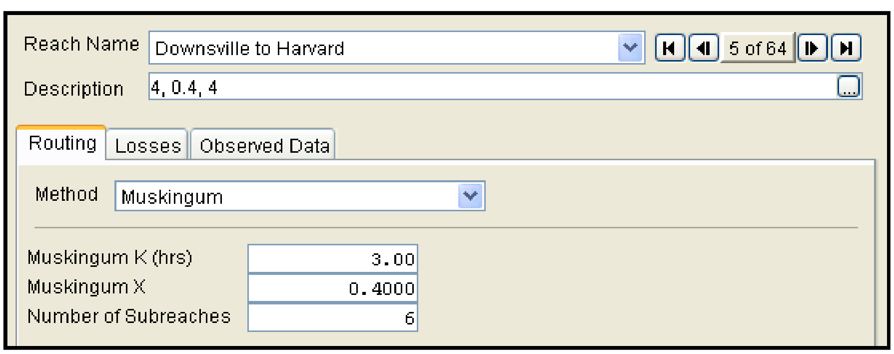


Figure 4.4 Downsville to Harvard Reach, Muskingum Routing

For the Stilesville to Hale Eddy reach, the original Lag & K parameters provided by NWS were used since the variable K data as developed by the NWS were able to adequately represent the lag and attenuation in this reach for the three major flood events. Figure 4.5 shows the variable K parameters used.

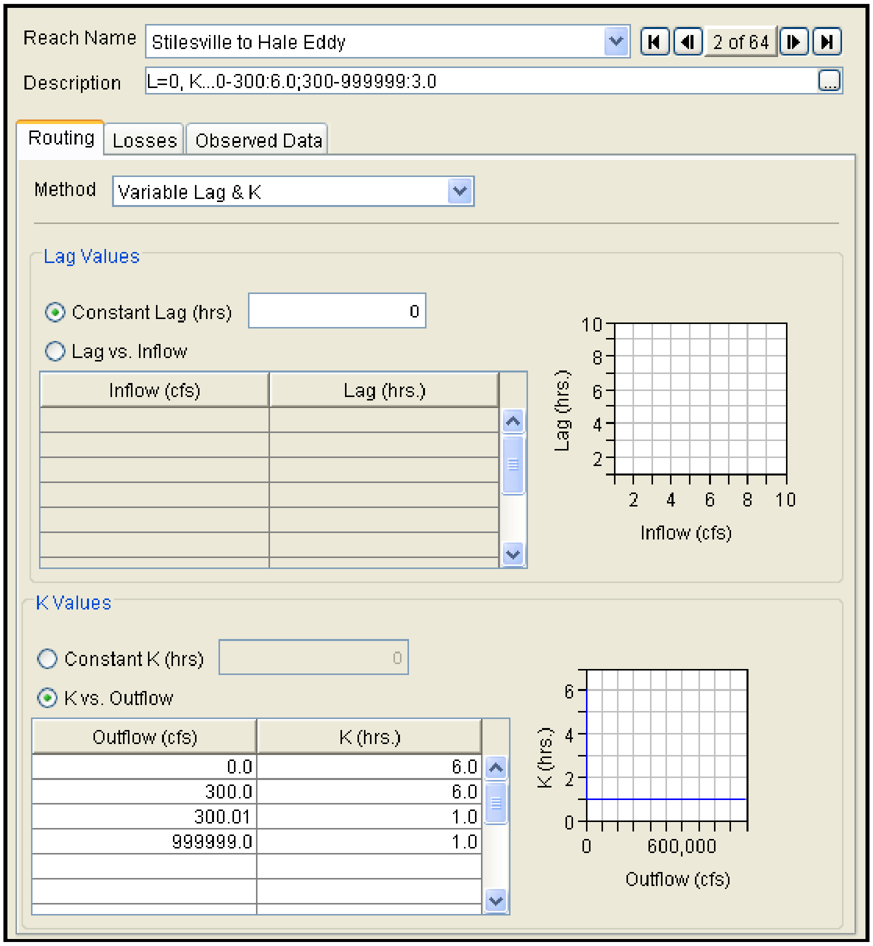


Figure 4.5 Stilesville to Hale Eddy, Lag & K Routing – Variable K

The recalibration of the routing for the Hancock to Callicoon reach, illustrated by Figure 4.6, was required due to all four of the reasons listed (see page 23).

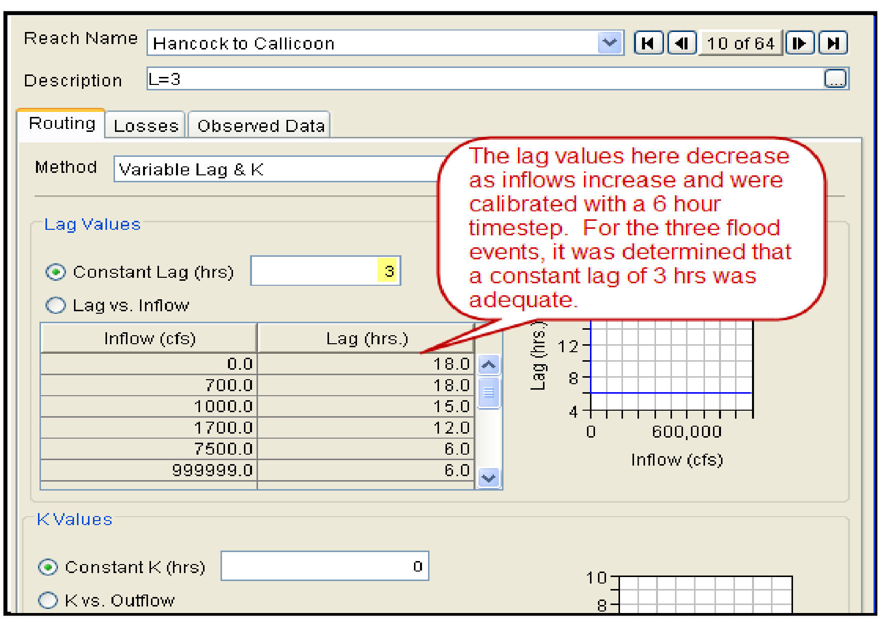


Figure 4.6 Hancock to Callicoon, Lag & K Routing – Constant Lag

1) As is true for all the Lag & K parameter data supplied by the NWS, the parameters were calibrated in a model using a six hour timestep.
2) For this reach, the parameters provided were for a reach that routes the combined Hale Eddy + Fishs Eddy flow to Callicoon. In the NWS model, neither Hale Eddy nor Fishs Eddy was routed to a confluence point before being combined and routed to Callicoon.
3) The Variable Lag parameters covered a broad range of flows which were not as effective in reproducing the observed extreme flood flows of the three events modeled. And,
4) When used in HEC-ResSim, this NWS set of Variable Lag parameters could produce a hydrograph that, under certain flow conditions, had a significant volume loss. Since the volume loss is caused by a weakness in the routing method and since the variability of the lag is not needed for the extreme flood flows modeled, a representative constant Lag was determined and used.

The following tables provide a summary of the reaches in each of the basins in the model.

Table 4.6 Upper Basin Reaches

Reach Name	Routing Method	Parameters
Cannonsville_OUT to Stilesville	Null	
Stilesville to Hale Eddy	Lag & K	L=0, K=0-300:6.0;300-999999:3.0
Hale Eddy to Hancock	Null	
Pepacton_OUT to Downsville	Null	
Downsville to Harvard	Muskingum	K=4, X=0.4, subreaches= 4
Harvard to Del_EB+Beaver Kill	Null	
Cooks Falls to Del_EB+Beaver Kill	Lag & K	Lag=3
Del_EB+Beaver Kill to Fishs Eddy	Null	
Fishs Eddy to Hancock	Null	
Hancock to Callicoon	Lag & K	Lag=3
Neversink_OUT to Neversink Gage	Null	
Neversink Gage to Bridgeville	Lag & K	Lag=3
Bridgeville to Godeffroy	Muskingum	K=6, X=0.1, subreaches= 2
Godeffroy to Del+Neversink	Lag & K	Lag=1

Table 4.7 Lackawaxen River Basin Reaches

Reach Name	Routing Method	Parameters
Jadwin_OUT to Honesdale	Null	
Honesdale to Lack_WB+Dyberry	Null	
Prompton_OUT to Prompton Gage	Null	
Prompton Gage to Lack_WB+Dyberry	Null	
Lack_WB+Dyberry to Hawley	Lag & K	Lag=6
Hawley to Lack+Wallenpaupack	Null	
Lake Wallenpaupack_OUT to Lack+Wallenpaupack	Null	
Lack+Wallenpaupack to Del+Lack	Lag & K	Lag=3

Table 4.8 Mongaup River Basin Reaches

Reach Name	Routing Method	Parameters
Toronto_OUT to Mongaup+Black Lake Cr	Muskingum	K=1, X=0.1, subreaches=1
Swinging Bridge_OUT to Mongaup+Black Lake Cr	Null	
Mongaup+Black Lake Creek to Rio_IN	Muskingum	K=1, X=0.1, subreaches=1
Rio_OUT to Del+Mongaup	Null	

Table 4.9 Lehigh River Basin Reaches

Reach Name	Routing Method	Parameters
F.E. Walter_OUT to White Haven	Null	
White Haven to Lehighton	Lag & K	Lag=6
Lehighton to Lehigh+Pohopoco	Null	
Beltzville_OUT to Parryville	Null	
Parryville to Pohopoco Mouth	Null	
Pohopoco Mouth to Lehigh+Pohopoco	Null	
Lehigh + Pohopoco to Walnutport	Lag & K	Lag=3
Walnutport to Lehigh + Jordan	Lag & K	Lag=5
Allentown to Lehigh+Jordan	Null	
Lehigh + Jordan to Bethlehem	Lag & K	Lag=1

Table 4.10 Mainstem Delaware River Basin Reaches

Reach Name	Routing Method	Parameters
Callicoon to Barryville	Lag & K	Lag=3
Barryville to Delaware + Lackawaxen	Null	
Del+Lackawaxen to Del+Mongaup	Lag & K	Lag=2
Del+Mongaup to Port Jervis	Null	
Port Jervis to Del+Neversink	Null	
Del+Neversink to Montague	Lag & K	Lag=3
Montague to Del+Bush Kill	Muskingum	K=5, X=0.1, subreaches=1
Shoemaker to Del+Bush Kill	Null	
Del+Bush Kill to Tocks Island	Muskingum	K=3, X= 0.1, subreaches=1
Tocks Island to Del+Brodhead	Null	
Minisink Hills to Del+Brodhead	Null	
Del+Brodhead to Belvidere	Muskingum	K=4, X=0.1, subreaches=1
Belvidere to Easton	Muskingum	K=3, X=0.1, subreaches=1
Easton to Del+Lehigh	Null	
Del+Lehigh to Del+Pohatcong	Muskingum	K=1, X=0.1, subreaches=1
Merrill Creek_Out to Pohat+Merrill	Lag & K	K=1
Pohat+Merrill to Del+Pohatcong	Muskingum	K=2, X=0.1, subreaches=1
Del+Pohatcong to Riegelsville	Null	
Riegelsville to Del+Musconetcong	Null	
Bloomsbury to Del+Musconetcong	Muskingum	K=2, X=0.1, subreaches=1
Del+Musconetcong to Frenchtown	Muskingum	K=2, X=0.1, subreaches=1
Frenchtown to Del+Tohickon	Muskingum	K=1, X=0.1, subreaches=1
Nockamixon_Out to Del+Tohickon	Muskingum	K=2, X=0.1, subreaches=1
Del+Tohickon to Stockton	Null	
Stockton to New Hope	Muskingum	K=2, X=0.1, subreaches=1
New Hope to Washingtons Crossing	Null	
Washingtons Crossing to Trenton	Muskingum	K=3, X=0.1, subreaches=1

4.3 Reservoirs

The reservoir is the most complex element in HEC-ResSim. The physical data of a reservoir are represented by a pool and one or more dams. Both the pool and the dam are complex sub-elements of the reservoir. The pool contains the reservoir's elevation-storage-area relationship and can optionally include evaporation and seepage losses. The dam represents both an uncontrolled outlet and an outlet group – the top of dam elevation and length specifies the minimum parameters for an uncontrolled spillway and the dam may contain one or more controlled or uncontrolled outlets.

Reservoir elements also hold the operational data for a reservoir. The operational data represents the goals and constraints that guide the release decision process. The operation data is grouped as a unit called an operation set. A reservoir can hold multiple operation sets, but only one operation set per reservoir may be used in an alternative. The operation set is made up of a set of operating zones, each of which contains a prioritized set of rules. Rules describe a minimum or maximum constraint on the reservoir releases.

Since the model of the Delaware River Basin was developed to analyze the operation of the system during flood events, some of the physical and operational data options were not used because they would not significantly impact the flows or stages during a flood event. The physical pool options not used were: evaporation, seepage, and leakage. Operationally, the most significant constraints not directly represented were low flow augmentation, drought operation, and hydropower demands. Although there are several reservoirs in the basin that are operated primarily for low flow augmentation and hydropower, the operation to meet these demands is not a factor when those reservoirs are reacting to a large inflow (flood) event.

4.3.1 Upper Basin Reservoirs

The three reservoirs in the Upper Basin are owned and operated by New York City (NYC). These reservoirs, Cannonsville, Pepacton, and Neversink provide drinking water to New York City through an interbasin transfer to Rondout Reservoir. Simulation of Rondout Reservoir was not within the scope of this study. In the model, the diversion of water from these reservoirs is represented with a diverted outlet from each reservoir and several operating rules to control the quantity and timing of the out-of-basin diversion flows. The three diverted outlets, Can_Tunnel, Pep_Tunnel, and Nev_Tunnel, are drawn as arrows in the schematic shown in Figure 4.7 and they connect downstream to the inflow junction of a reservoir named toNYC. The toNYC reservoir was added merely as a "receiver" for the diversions and is not an operational part of the model.

The figures in Section 4.3.1.1, detail the definition of Cannonsville Reservoir. Since all three reservoirs (Cannonsville, Pepacton, Neversink) are similar, only figures needed to illustrate some property or operation unique to that reservoir will be presented.

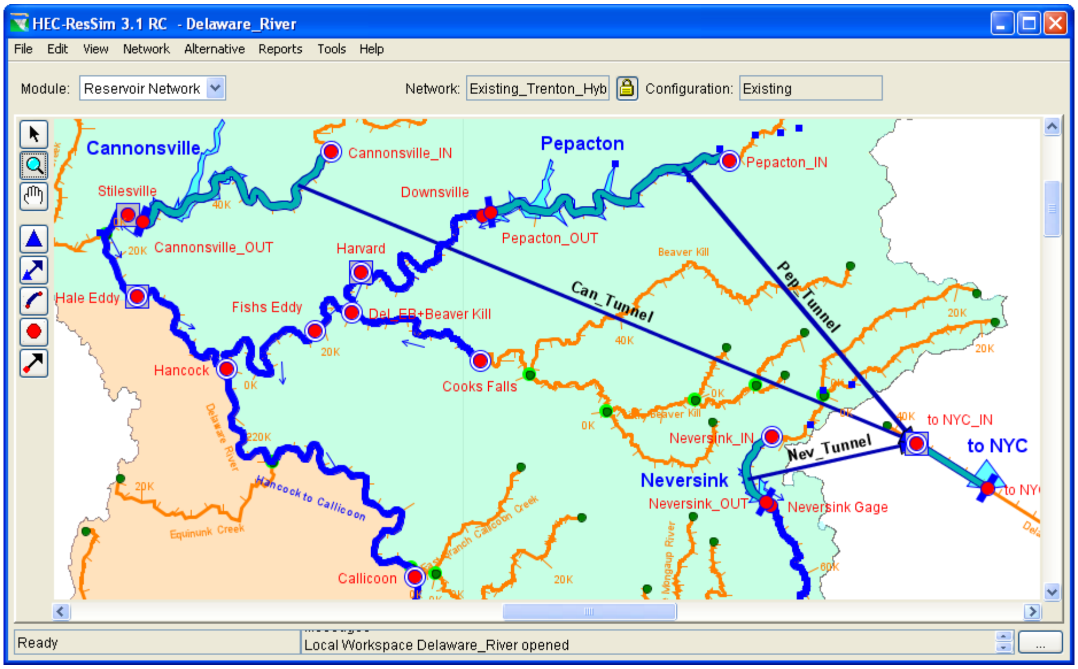


Figure 4.7 Upper Basin Reservoirs

4.3.1.1 Cannonsville

The reservoir editor in HEC-ResSim is shown in Figure 4.8. In this figure, the Physical tab is active, it contains two panels. The left panel holds the reservoir element tree, which illustrates the hierarchy of physical elements that make up the reservoir. The right panel is an edit pane –

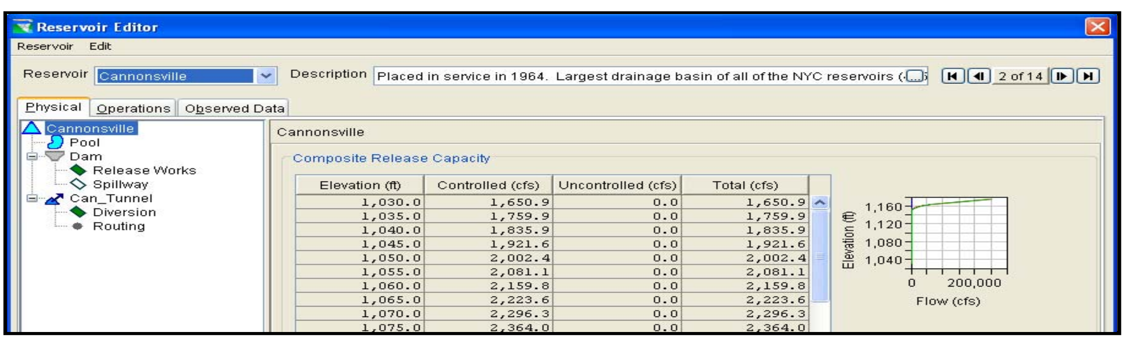


Figure 4.8 Cannonsville – Physical Element Tree and Composite Outlet Capacity Table

when an element is selected in the tree, the edit pane displays the data entry fields and available options for defining that element. At the reservoir and group levels of the hierarchy, the edit pane shows a composite release capacity table for all outlets below that level.

Most of the physical data used to define the three NYC reservoirs was from a spreadsheet containing the data for the 2.1 Version of the OASIS model of the Delaware River Basin. The OASIS model spreadsheet provided the elevation-storage-area table, and the outlet capacity tables for the release works, spillway, and diversion tunnel. Figure 4.9 shows the edit pane for the Cannonsville pool. The edit pane is where the elevation-storage-area relationship is specified.

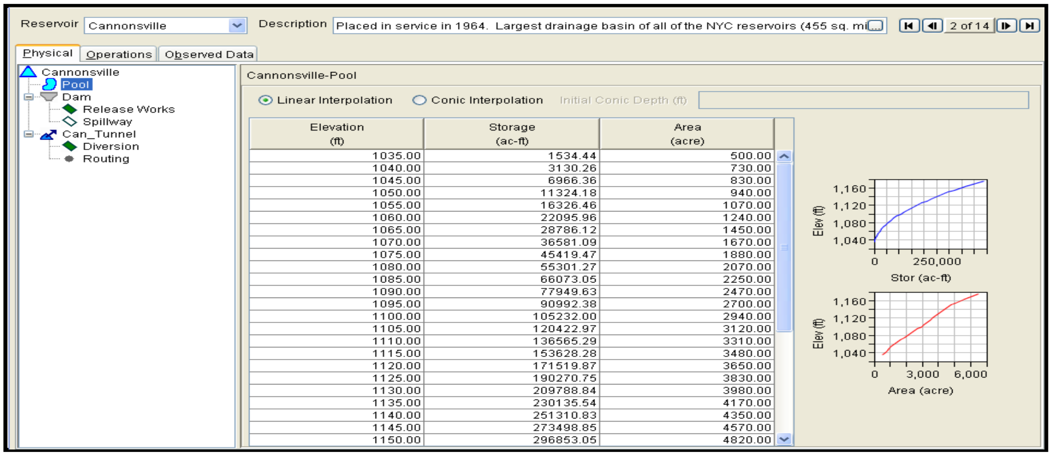


Figure 4.9 Cannonsville – Pool Definition

Figure 4.10 shows the edit pane for the Cannonsville Reservoir's dam definition. The dam data is used by HEC-ResSim to describe a default uncontrolled spillway. Since HEC-ResSim does not perform dam-break scenarios, should the reservoir pool elevation exceed the top of dam elevation, the dam will act as an uncontrolled spillway and allow water to flow over it. The capacity of this default spillway is computed with a standard weir equation using the dam elevation, length, and a coefficient of 3.0 (1.65 in SI units): Q= weir coef * length * height$^{(3/2)}$.

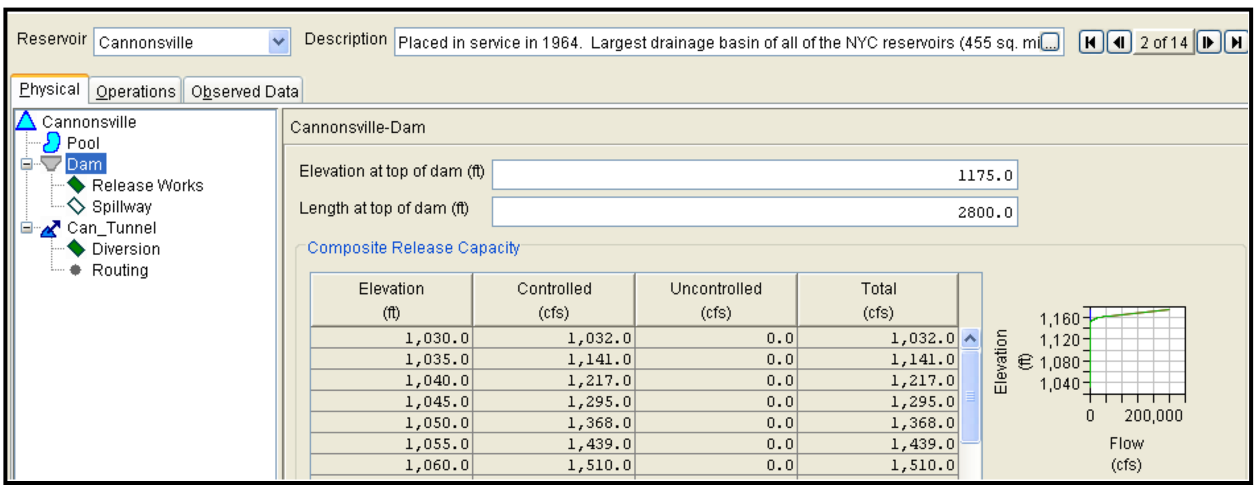


Figure 4.10 Cannonsville – Dam Definition

The outlets that release water into the river downstream of the dam were added to the dam element. These outlets are Release Works and Spillway. The Release Works is a controlled outlet that represents the composite capacity of the controlled outlets at Cannonsville. The Spillway is an uncontrolled overflow weir. Figure 4.11 shows the edit pane for the Release Works and Figure 4.12 shows the edit pane for the uncontrolled Spillway. The capacity tables for these outlets were obtained from the OASIS model spreadsheet.

The image in Figure 4.13 (as well as many other similar figures in this chapter) was obtained through the use of Microsoft Bing® Maps. It shows the spillway at Cannonsville. The importance of this figure is that it shows water going over the spillway on a dry, sunny day. The image has no date, but by the somewhat random nature of the satellite photos available through

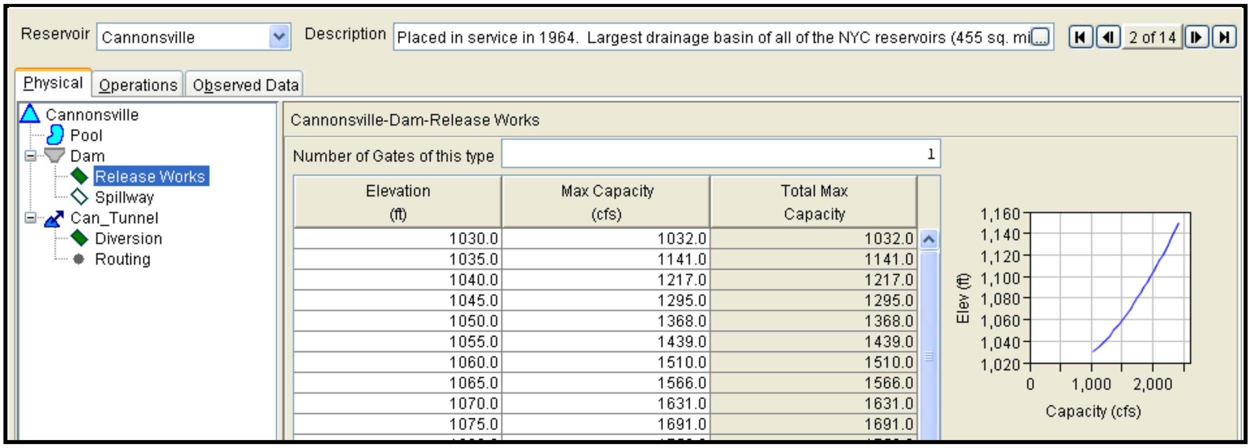


Figure 4.11 Cannonsville – Release Works

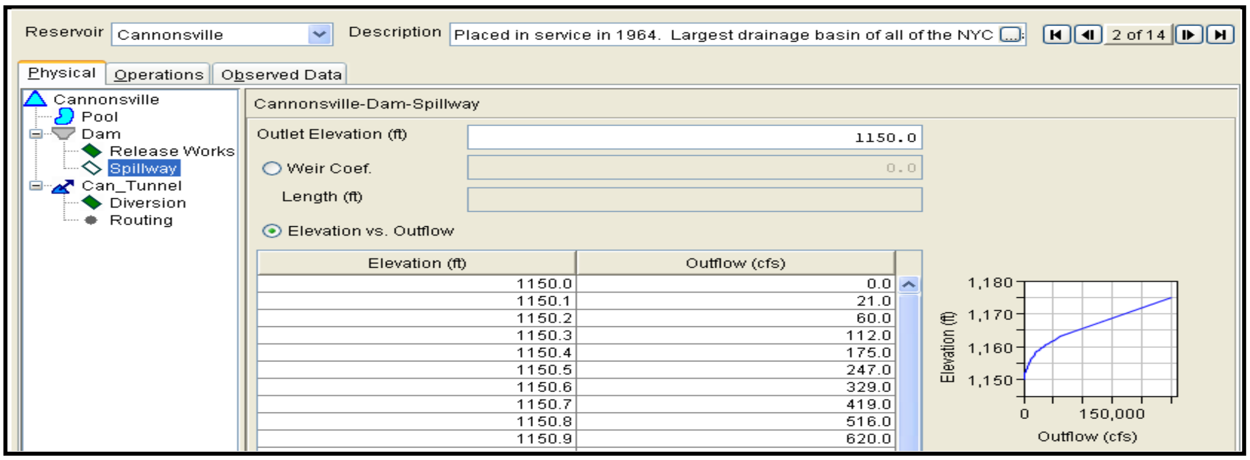


Figure 4.12 Cannonsville – Spillway

Figure 4.13 Cannonsville Spillway Photo

Bing® Maps, it is reasonable to assume water over the spillway is a fairly common occurrence at Cannonsville Reservoir.

As previously mentioned, the diversions from the NYC reservoirs are represented through the use of HEC-ResSim's diverted outlet element. When a diversion from a reservoir is drawn on the network schematic, a diverted outlet "group" is added to the reservoir element tree (Figure 4.14). This outlet group is created containing a controlled outlet. If the diversion connects to a junction at its outlet, then a Routing node is also included in the group.

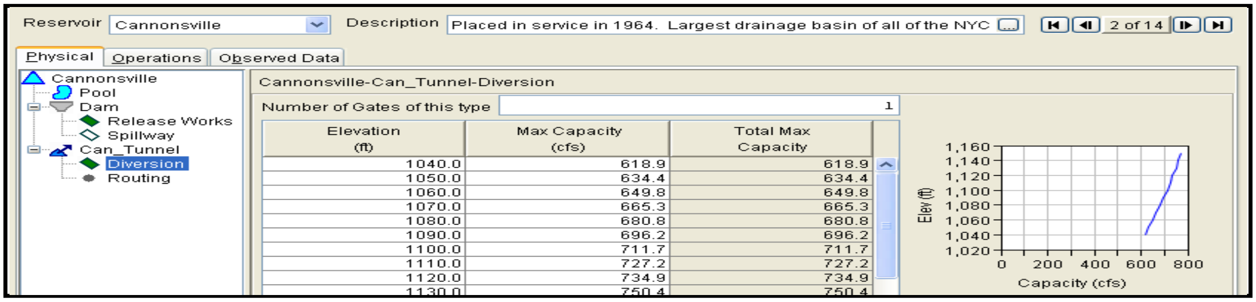


Figure 4.14 Cannonsville's Diverted Outlet – Can_Tunnel

The diverted outlet group at Cannonsville was given the name Can_Tunnel and the outlet inside it was simply called Diversion. This naming convention was replicated at Pepacton and Neversink Reservoirs. The diversion tunnel capacity tables from the OASIS model were applied to the Diversion outlet at each reservoir. The Null routing method was chosen for the reservoir diversion since the rate of transport of the diverted water is not relevant to the flood model.

Figure 4.15 shows the Operations tab of the HEC-ResSim Reservoir Editor for Cannonsville Reservoir. In the Operations tab, one or more operation sets can be defined to describe different reservoir operating plans. Each tab of the Operations Editor has a specific function in the description of an operation set, however the operational constraints for most reservoirs can be described on the first two tabs; Zone-Rules and Rel. Alloc. (Release Allocation).

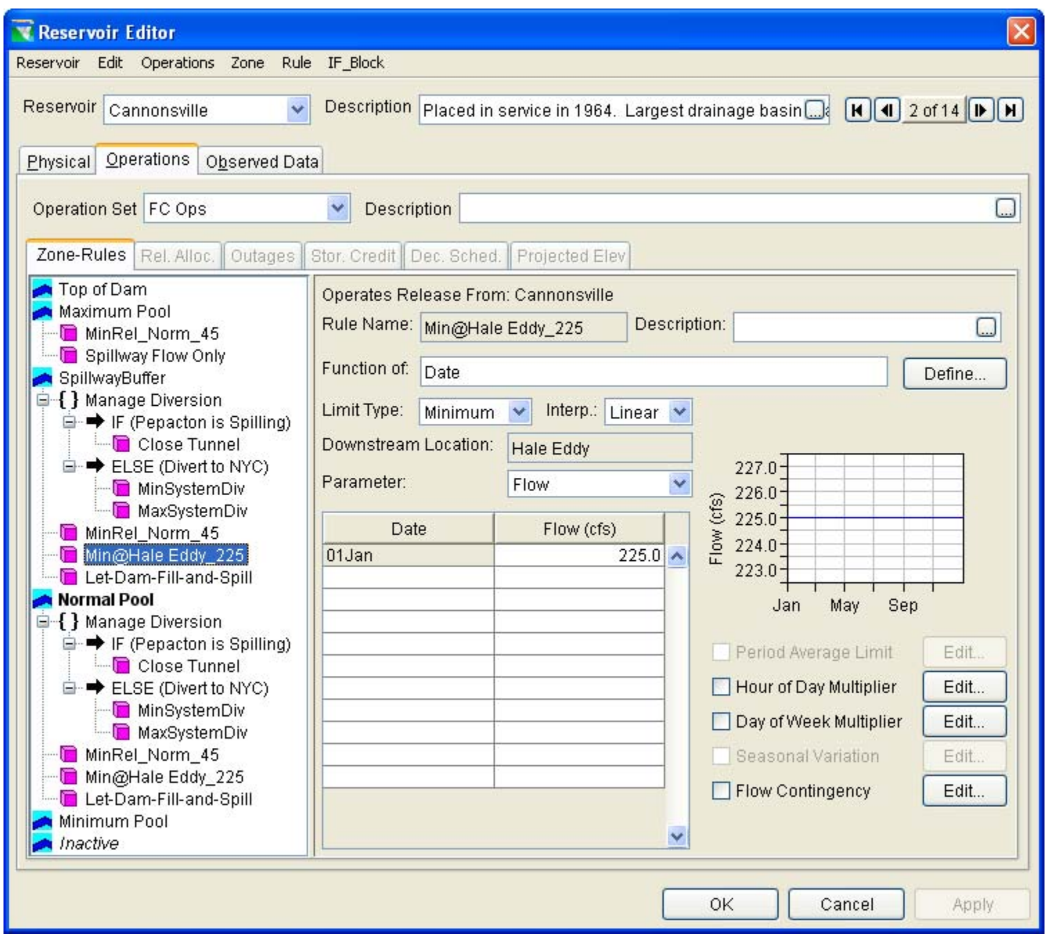


Figure 4.15 Cannonsville Operations Editor – *FC Ops*

Operation sets are a set of zones and rules that describe the constraints on reservoir releases. Each zone can have a prioritized list of rules that are followed if the reservoir pool elevation is within that zone. Additional constraints can be applied to the rule list with *If-Blocks*. Other operational constraints can be defined by activating and specifying the data for any of the other tabs of the Operations editor.

The operation set displayed in Figure 4.15 is called *FC Ops*. There are two operation sets defined for each of the NYC reservoirs – *FC Ops* and *FC Ops-SpecDiv*. The *FC Ops* operation sets were developed to represent the standard flood operations at each reservoir. Included in this operation set is a subset of rules that attempt to define the operational constraints on the diversions as they were operated during the three flood events studied. In *FC Ops-SpecDiv* the primary operation of the reservoir is same as in *FC Ops*, but the rules constraining the diversion has been changed to exactly replicate the observed diversion record for the three flood events studied in order to avoid introducing errors related to not reproducing the observed diversion.

Development of each operation set began with the definition of the operating zones of the reservoirs. Operational information for the NYC reservoirs was drawn from the OASIS model. The OASIS model identified dead storage and max storage – using the elevation-storage relationship for each reservoir, these storage values were converted to elevation and used to represent the *Inactive* and *Top of Dam* zones, respectively. Similarly, the OASIS Upper and Lower Rule storages were converted to elevations and used to represent the top of the *Buffer* and *Conservation* zones. And, for modeling purposes, the extent of the storage and/or spillway capacity table was used to define the top of the *Maximum Pool* zone.

FC Ops – Normal Flood Operations

Since the primary purpose of the NYC reservoirs is to divert water to New York City, a group of diversion rules were developed in an attempt to mimic the observed operation of the diversions as well as to approximate the operations described in the OASIS model. The primary rules developed for the diversions are *MinSystemDiv* and *MaxSystemDiv*. These are downstream control rules for the control point, to NYC_IN, and are used in all three reservoirs so that they can share the responsibility to meet the water supply demand. In addition, a minimum release function rule for the diversion was added at Pepacton and Neversink to influence the allocation of the demand between the three reservoirs. The values of these local minimum requirements were estimated based on a review of the available observed data for the three events. The more complex operation of the diversions for water supply, as detailed in the OASIS model, were not attempted as they define operations during extended low flow and low storage periods and were not needed to assess flood operations.

The operation of the diversions during a flood event was determined to be different from normal operation. Based on analysis of the observed data provide for the three flood events, the diversions were suspended during each event. In most reservoir systems with interbasin water supply diversions, the diversions are seldom used to divert flood waters from one basin into another basin to avoid possibly causing flooding in the receiving basin. The rule used to represent this behavior in the model is Close Tunnel. At both Cannonsville and Pepacton the rule is contained within an If-block. The purpose of the If-block is to check if the other reservoir is spilling, if so then to stop diverting. This cross correlation between Cannonsville's and Pepacton's state of spill and the closing of the diversions was observed in the event data and used to approximate the real operational criteria. The state of Rondout Reservoir, which receives the diversion as well as the state of the NYC water supply reservoirs in the Hudson River Basin are actually used to control the diversions. Since simulation of Rondout and the Hudson River Reservoirs was outside the scope of the watershed – the approximation was accepted as adequate.

Along with several other reservoirs in the Delaware River Basin, the NYC reservoirs share the responsibility for maintaining acceptable environmental flows in the Delaware River and its tributaries. The OASIS model identified a minimum at-site release requirement for each NYC reservoir as well as minimum flow targets for Montague and Trenton. These downstream constraints were initially added to each of the NYC reservoirs but were later removed from the model since minimum flow requirements have no impact on flooding. Other downstream flow objectives were found for each of the NYC reservoirs: Cannonsville has a flow objective for Hale Eddy; Pepacton has Fishs Eddy; and Neversink has Bridgeville. The objectives were added to the model to provide a basis for normal releases in the model before onset of a high flow event.

As single-purpose water supply reservoirs, the NYC reservoirs have no dedicated flood control storage. The target pool elevation for these reservoirs is at the crest of the uncontrolled spillways and these reservoirs spill regularly during normal and wet periods. The operations described in the OASIS model indicate that when the pool at any of the NYC projects exceeds spillway crest, the controlled gates should be utilized up to capacity to draw the reservoir pool back down to target as quickly as possible. However, observed data indicate that during the three flood events the release works were set at the minimum flow rate and thus the spillway passed the event through the reservoir. This operation was represented with a rule named *Let-Dam-Fill-and-Spill*. This rule is a maximum release rule of zero and is applied to the dam, effectively limiting all controlled outlets in the dam (diverted outlets are not considered part of the "dam"). The *Let-Dam-Fill-and-Spill* rule was placed as the lowest priority rule in the *SpillwayBuffer* and *Conservation* zones to allow higher priority rules to set the minimum release but to not allow guide curve operation to increase the minimum release. The *SpillwayBuffer* zone is not a standard operating zone of the NYC reservoirs. It was added to separate storage above the spillway crest into two parts: 1) the lower portion, the spillway buffer, to represent the region of the reservoir where the spillway is spilling, but normal conservation operations continue and 2) the upper portion to represent the region where diversion operations are suspended. A companion rule to the *Let-Dam-Fill-or-Spill* rule is the *Spillway Flow Only* rule, used in the *Maximum Pool* zone, which is also a maximum release rule of zero but is applied to the reservoir to limit flow from the outlet works and halt diversions when no higher priority rule is used to set the diversions.

The operations for all simulated reservoirs in the watershed represented are illustrated in Figure 4.14 through Figure 4.37 and summarized in Table 4.11 through Table 4.26. As needed, additional description is provided.

FC Ops-SpecDiv – Normal Flood Operations, Specified Diversions

As explained above, the operation set *FC Ops-SpecDiv* is based on the *FC Ops* operation set. The primary difference is how the diversion operations are handled. In *FC Ops-SpecDiv*, specified release rules defined as a function of an external time-series were used to operate the diversion. The external time-series contains the observed data for the diversion for the three events.

Table 4.11 Cannonsville Operations Summary, *FC Ops*

Name	Description	Reference
Cannonsville	**FC Ops**	***OASIS Model 2.1***
TOP OF DAM	**1175 ft**	
MAXIMUM POOL	**1163 ft**	No diversion flow
MinRel_Norm_45	Minimum Conservation Release = 45 cfs	***OASIS Model***
Spillway Flow Only	Maximum reservoir release set to zero. This rule caps all higher priority min rules and forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1151.4 ft** **1150 ft**, Spillway Crest	Allow diversion flow
Manage Diversion If Pepacton is spilling **Close Tunnel** Else	 If Pepacton pool > spillway buffer Set max diversion flow to zero Else Normal Diversion Rules (below)	Derived from observed events.
MinSystemDiv	min system diversion rate to 1100 cfs (700 mgd)	***OASIS Model***
MaxSystemDiv	max system diversion rate to 1238 cfs (800 mgd)	***OASIS Model***
MinRel_Norm_45	Minimum Conservation Release = 45 cfs	***OASIS Model***
Min@HaleEddy_225	Min flow at Hale Eddy = 225 cfs	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule limits all higher priority min rules and forces flood flows over the spillway.	
MINIMUM POOL	**1056.28 ft**	Minimum Pool
INACTIVE	**1040 ft**	

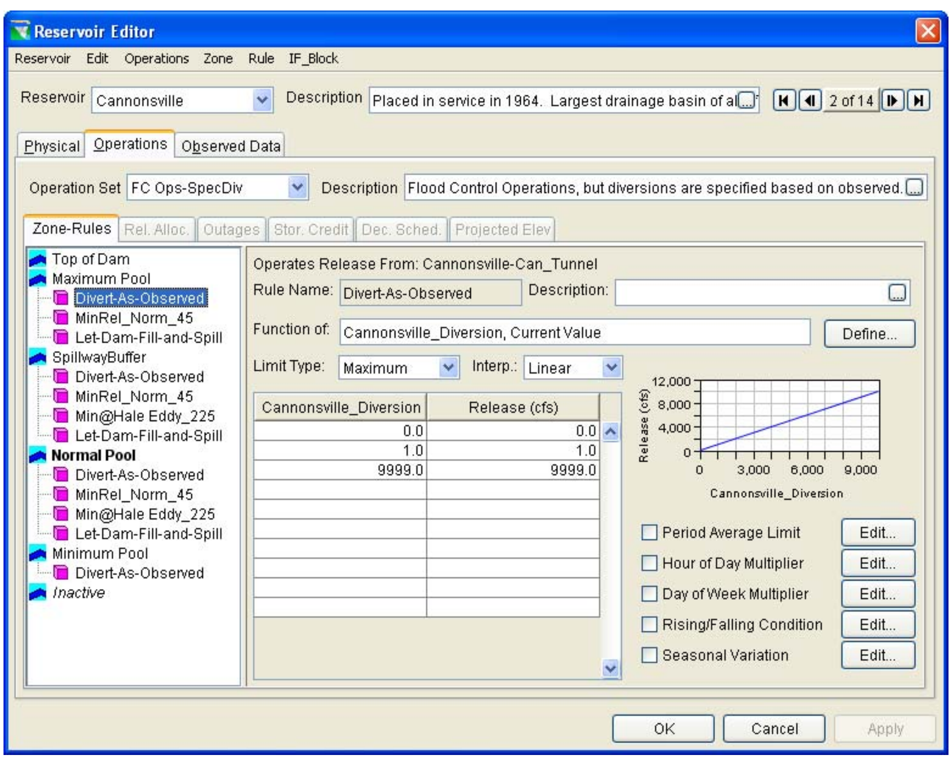


Figure 4.16 Cannonsville Operations Editor – *FC Ops-SpecDiv*

Table 4.12 Cannonsville Operations Summary, *FC Ops-SpecDiv*

Name	Description	Reference
Cannonsville	**FC Ops–SpecDiv** (Specified Diversions) Diversions are set to observed releases	***OASIS Model 2.1***
TOP OF DAM	**1175 ft**	
MAXIMUM POOL	**1163 ft**	
Divert-as-Observed	Function of external time series – used to set diversion flows equal to observed. This rule replaces the other rules in *FC Ops* that were used to attempt to mimic diversion operations	
MinRel_Norm_45	Minimum Conservation Release = 45 cfs	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule limits all higher priority min rules and forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1151.4 ft** **1150 ft**, Spillway Crest	Allow diversion flow
Divert-as-Observed		
MinRel_Norm_45	Minimum Conservation Release = 45 cfs	***OASIS Model***
Min@HaleEddy_225	Min flow at Hale Eddy = 225 cfs	***OASIS Model***
Let-Dam-Fill-or-Spill	Release set to zero	
MINIMUM POOL	**1056.28 ft**	Minimum Pool
Divert-as-Observed		
INACTIVE	**1040 ft**	

4.3.1.2 Pepacton

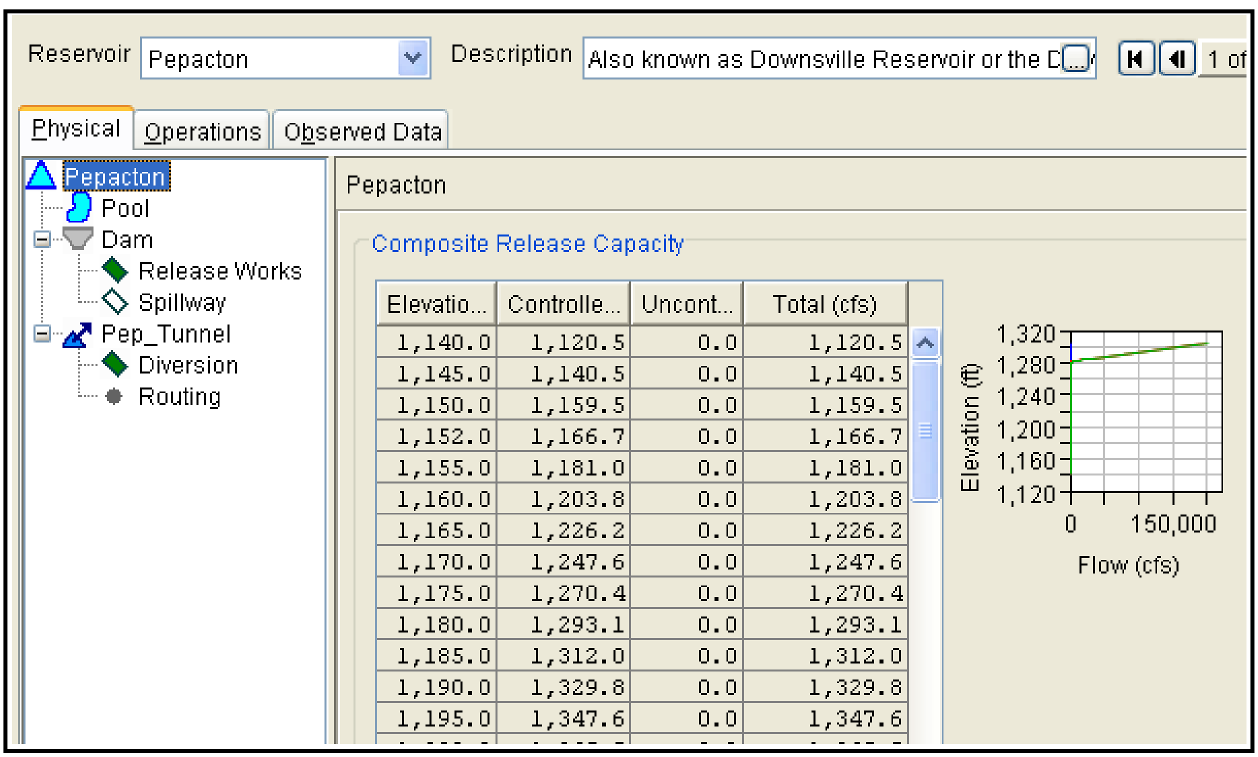
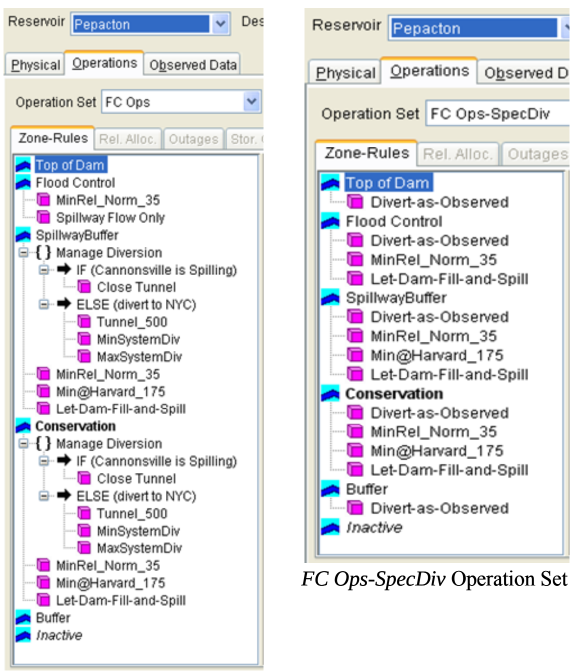


Figure 4.17 Pepacton Physical Element Tree and Composite Release Capacity



FC Ops Operation Set

FC Ops-SpecDiv Operation Set

Figure 4.18 Pepacton Operations

The operations at Pepacton were described with the operations at Cannonsville. Table 4.13 and Table 4.14 summarize these operations.

Table 4.13 Pepacton Operations Summary, *FC Ops*

Name	Description	Reference
Pepacton	**FC Ops**	***OASIS Model 2.1***
TOP OF DAM	**1304 ft**	
MAXIMUM POOL	**1290 ft**	No diversion flow
MinRel_Norm_35	Minimum Conservation Release	***OASIS Model***
Spillway Flow Only	Maximum reservoir release set to zero. This rule forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1280.65 ft** **1280 ft**, Spillway Crest	Allow diversion flow
Manage Diversion If Cannonsville is spilling Close Tunnel Else	 If Cannonsville pool > spillway buffer Set max diversion flow to zero Else Normal Diversion Rules (below)	Derived from observed events.
Tunnel_500	min diversion rate to 500 cfs (325 mgd)	Estimated from observed data
MinSystemDiv	min system diversion rate to 1100cfs (700mgd)	***OASIS Model***
MaxSystemDiv	max system diversion rate to 1238cfs (800mgd)	***OASIS Model***
MinRel_Norm_35	Minimum Conservation Release = 35 cfs	***OASIS Model***
Min@Harvard_175	Min flow at Harvard = 175 cfs	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule forces flood flows over the spillway.	
MINIMUM POOL	**1165.87 ft**	Minimum Pool
INACTIVE	**1152 ft**	

Table 4.14 Pepacton Operations Summary. *FC Ops–SpecDiv*

Name	Description	Reference
Pepacton	**FC Ops–SpecDiv** (Specified Diversions) Diversions are set to observed releases	***OASIS Model 2.1***
TOP OF DAM	**1304 ft**	
MAXIMUM POOL	**1290 ft**	
Divert-as-Observed	Function of external time series – used to set diversion flows equal to observed. This rule replaces the other rules in *FC Ops* that were used to attempt to mimic diversion operations	
MinRel_Norm_35	Minimum Conservation Release = 35cfs	***OASIS Model***
Spillway Flow Only	Maximum reservoir release set to zero. This and forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1280.65 ft** **1280 ft**, Spillway Crest	
Divert-as-Observed		
MinRel_Norm_35		
Min@Harvard_175	Min flow at Harvard = 175 cfs	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule forces flood flows over the spillway.	
MINIMUM POOL	**1165.87 ft**	Minimum Pool
Divert-as-Observed		
INACTIVE	**1152 ft**	

4.3.1.3 Neversink

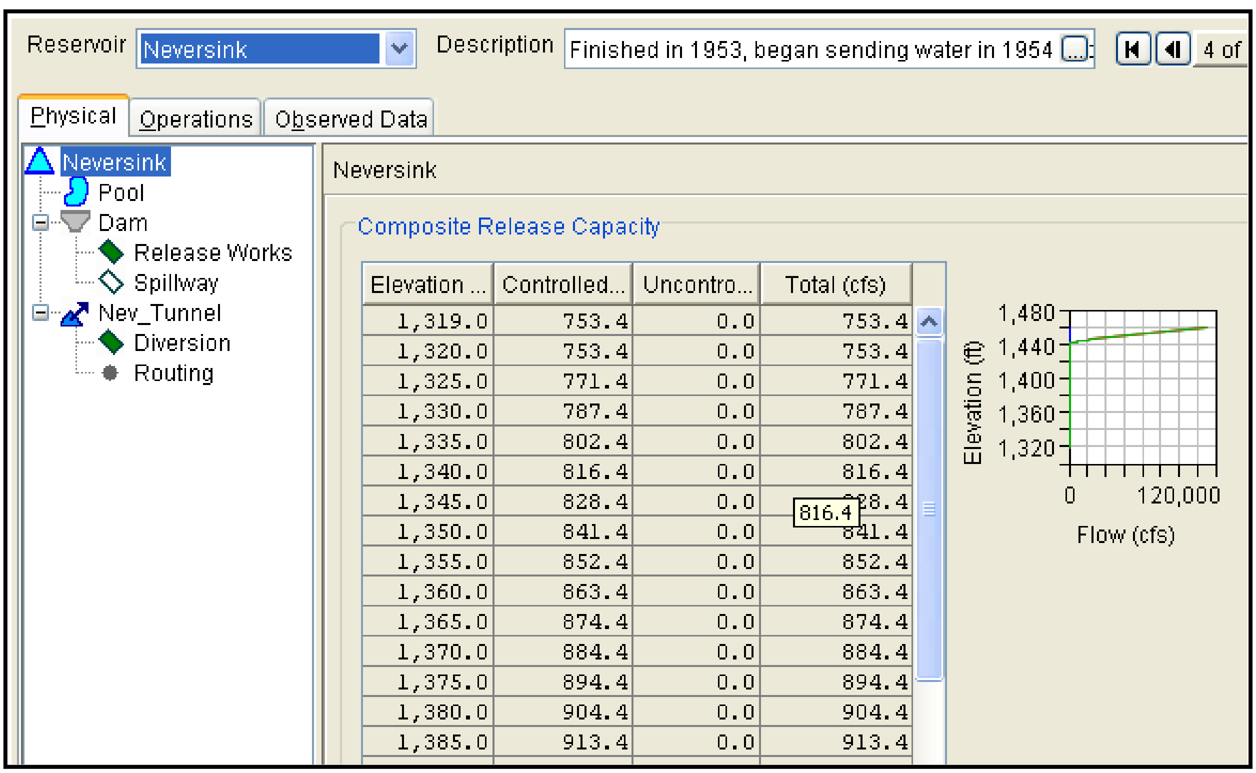
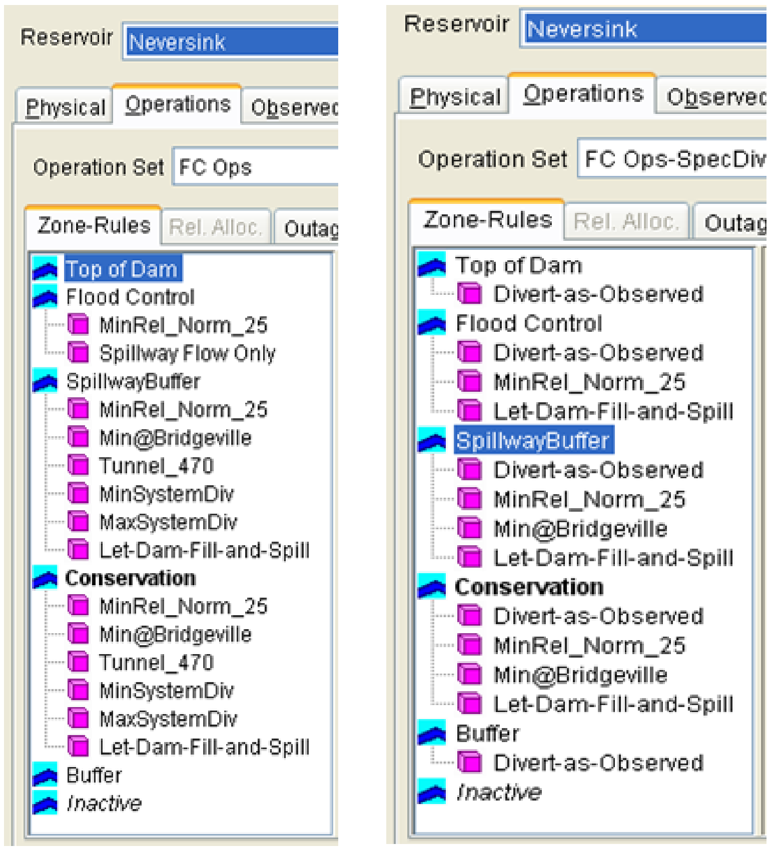


Figure 4.19 Neversink Physical Element Tree and Composite Release Capacity



FC Ops Operation Set   *FC Ops-SpecDiv* Operation Set

Figure 4.20 Neversink Operations

The operations at Neversink were described with the operations at Cannonsville. Table 4.15 and Table 4.16 summarize these operations. An important difference at Neversink is that in the *FC Ops* operation set, no If-block was used to correlate the suspension of the diversion to conditions at the other reservoirs in the system. In the model, the suspension was triggered by pool elevation and is represented by the *Spillway Flow Only* rule the *Maximum Pool* zone.

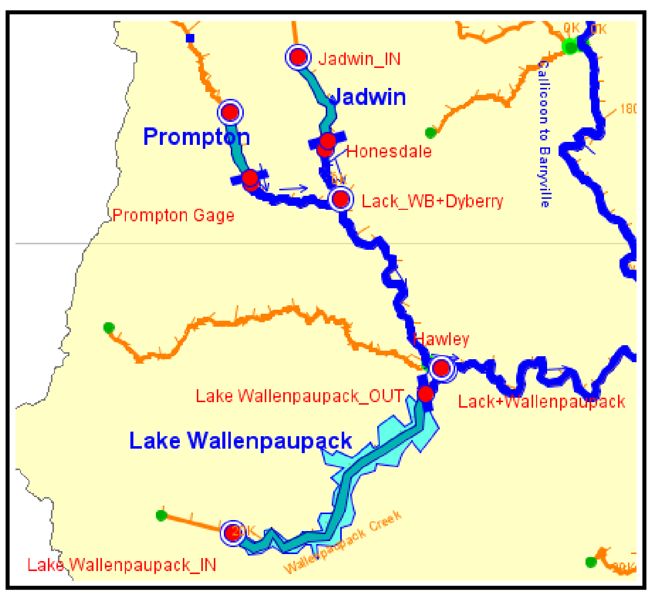


Figure 4.21 Lackawaxen River Basin Reservoirs

4.3.2 Lackawaxen River Basin Reservoirs

There are three reservoirs in the Lackawaxen River Basin - two are USACE flood damage reduction reservoirs and the third is a hydropower reservoir owned and operated by PPL Generation, LLC. This portion of the model schematic is illustrated in Figure 4.21

Table 4.15 Neversink Operations Summary, *FC Ops*

Name	Description	Reference
Neversink	**FC Ops**	***OASIS Model 2.1***
TOP OF DAM	**1460 ft**	
MAXIMUM POOL	**1450 ft**	No diversion flow
MinRel_Norm_25	Minimum Conservation Release = 25cfs	***OASIS Model***
Spillway Flow Only	Maximum reservoir release set to zero. This rule caps all higher priority min rules and forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1440.2 ft** **1440 ft**, Spillway Crest	Allow diversion flow
MinRel_Norm_25	Minimum Conservation Release = 25cfs	***OASIS Model***
Min@Bridgeville	Min flow at Bridgeville = 115cfs	***OASIS Model***
Tunnel_470	min diversion = 470cfs (303mgd)	
MinSystemDiv	min system diversion =1100 cfs (700mgd)	***OASIS Model***
MaxSystemDiv	max system diversion =1238 cfs (800mgd)	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule caps all higher priority min rules through the dam and forces flood flows over the spillway.	
MINIMUM POOL	**1332.71 ft**	Minimum Pool
INACTIVE	**1319. 04 ft**	

Table 4.16 Neversink Operations Summary, *FC Ops–SpecDiv*

Name	Description	Reference
Neversink	**FC Ops–SpecDiv** (Specified Diversions) Diversions are set to observed releases	***OASIS Model 2.1***
TOP OF DAM	**1460 ft**	
Divert-as-Observed	Function of external time series – used to set diversion flows equal to observed. This rule replaces the other rules in *FC Ops* that were used to attempt to mimic diversion operations	
MAXIMUM POOL	**1450 ft**	Maximum Pool
Divert-as-Observed		
MinRel_Norm_25	Minimum Conservation Release = 25 cfs	***OASIS Model***
Let-Dam-Fill-and-Spill	Maximum dam release set to zero. This rule limits all higher priority min rules and forces flood flows over the spillway.	
SPILLWAY BUFFER and NORMAL POOL	**1440.2 ft** **1440 ft**, Spillway Crest	
Divert as Observed		
MinRel_Norm_25	Minimum Conservation Release = 25 cfs	
Min@Bridgeville	Min flow at Bridgeville = 115cfs	***OASIS Model***
Let-Dam-Fill-and-Spill		
MINIMUM POOL	**1332.71 ft**	Minimum Pool
Divert as Observed		
INACTIVE	**1319. 04 ft**	

The Corps reservoirs, Prompton and Jadwin, utilize ungated outlets to control excess inflows. The maximum capacities of the primary outlets at these reservoirs were designed to equal channel capacity of the rivers immediately below the reservoirs. When inflows exceed this outlet capacity, the reservoirs will begin to fill. In addition to the primary outlets, each reservoir has an emergency spillway that will spill if and when the pool exceeds spillway crest.

4.3.2.1 Prompton

The main intake at Prompton was designed to allow the reservoir to maintain a recreation pool and a low level outlet was included to maintain a minimum flow in the downstream channel under low inflow conditions.

Figure 4.22 shows the physical element tree for the reservoir as well as the operations set and its zones.

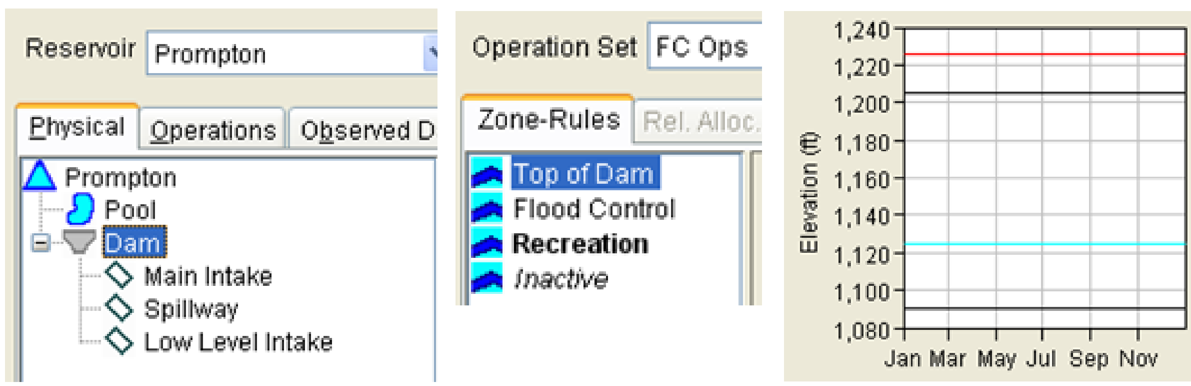


Figure 4.22 Prompton's Pool and Dam Elements and its "operating" zones

Table 4.17 summarizes the operation set for Prompton Reservoir. The summary is exceptionally brief since, without controllable outlets, there are no rules to constrain releases.

Table 4.17 Prompton Operations Summary, *FC Ops*

Name	Description	Reference
Prompton	**FC Ops** Prompton has no gated outlets and therefore, no rules to control releases. Releases are controlled by the capacities of the ungated outlets.	***Water Control Manual, Prompton Reservoir, September 1968, revised September 1997***
TOP OF DAM	**1226 ft**	
FLOOD CONTROL	**1205 ft** – spillway crest	
RECREATION	**1125 ft** – main intake crest	
INACTIVE	**1090 ft** – bottom of pool	

4.3.2.2 Jadwin

The main intake at Jadwin is located at the invert of the natural channel and passes normal channel flow. No pool is maintained behind the dam and the reservoir, illustrated in Figure 4.23, is referred to as a dry dam.

The Water Control Manual document files that were provided by the Corps of Engineers, Philadelphia District included a note that states that the pool gage at Jadwin Reservoir begins reporting pool elevations hourly when the pool reaches elevation 990.0 feet. During periods of no storage, this gage reports a daily elevation of the water in the gage's stilling well, but this does not represent storage in the reservoir.

Figure 4.23 Jadwin Reservoir, a dry dam

Figure 4.24 shows the physical element tree for the Jadwin Reservoir as well as its operations set and zones. Table 4.18 is the operations summary. Like Prompton's, this summary is exceptionally brief since, without controllable outlets, there are no rules to constrain releases.

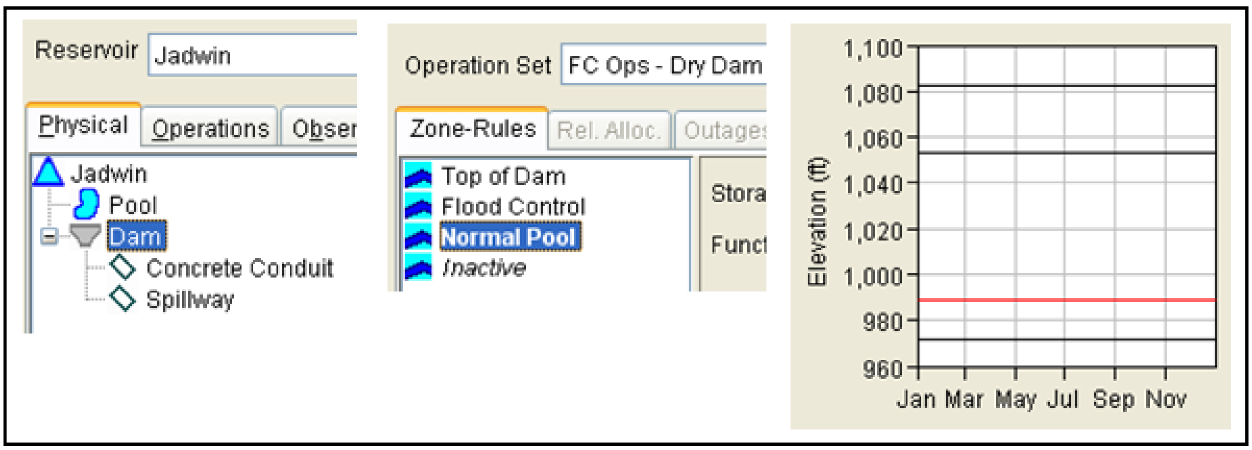


Figure 4.24 Jadwin's Pool and Dam Elements and its "operating" zones

Table 4.18 Jadwin Operations Summary, *FC Ops – Dry Dam*

Name	Description	Reference
Jadwin	**FC Ops - Dry Dam** As a "dry dam", Jadwin has no gated outlets and therefore, no rules to control releases. Releases are controlled by the capacities of the ungated outlets.	*Water Control Manual, Prompton Reservoir, September 1968, revised September 1997*
TOP OF DAM	**1082 ft**	
FLOOD CONTROL	**1053 ft**, spillway crest	
NORMAL POOL	**989 ft**	
INACTIVE	**972 ft** – note: bottom of pool = 980 ft	

4.3.2.3 Lake Wallenpaupack

Lake Wallenpaupack, the PPL project, is operated primarily for hydropower although operating documents indicate that it also operates to meet recreation and flood control objectives, as well as providing flow augmentation to the Lackawaxen and Delaware Rivers during declared drought emergency periods (Emergency Action Plan, DRBC Resolution 2002-33). The dam is located on Wallenpaupack Creek and its gated spillway discharges directly into the creek. The Wallenpaupack powerhouse is located on the Lackawaxen River, approximately three miles downstream of the confluence of Wallenpaupack Creek and the Lackawaxen River. The pipeline was constructed to deliver water from the reservoir to the powerhouse.

Under normal operating conditions, all releases from Lake Wallenpaupack are made through the pipeline and powerhouse and the spillway gates are closed leaving the lower reach of Wallenpaupack Creek dry. Only under very high water conditions are the gates opened to allow the reservoir to spill into the creek. The decision to open the spillway gates at Lake Wallenpaupack involves a number of individuals and a complex set of conditions. The flood operations described in the model are an attempt to represent the most important factors that would precipitate a spill and the expected magnitude of the spill. The operation set, summarized in Table 4.19 does not cover all the conditions described in the Lake Wallenpaupack Emergency Action Plan, but does provide an adequate representation of the operation of the reservoir during the three modeled events.

4.3.3 Mongaup Basin Reservoirs

The three reservoirs modeled in this basin are Toronto, Swinging Bridge, and Rio. The Mongaup Basin section of the model schematic is illustrated in Figure 4.25.

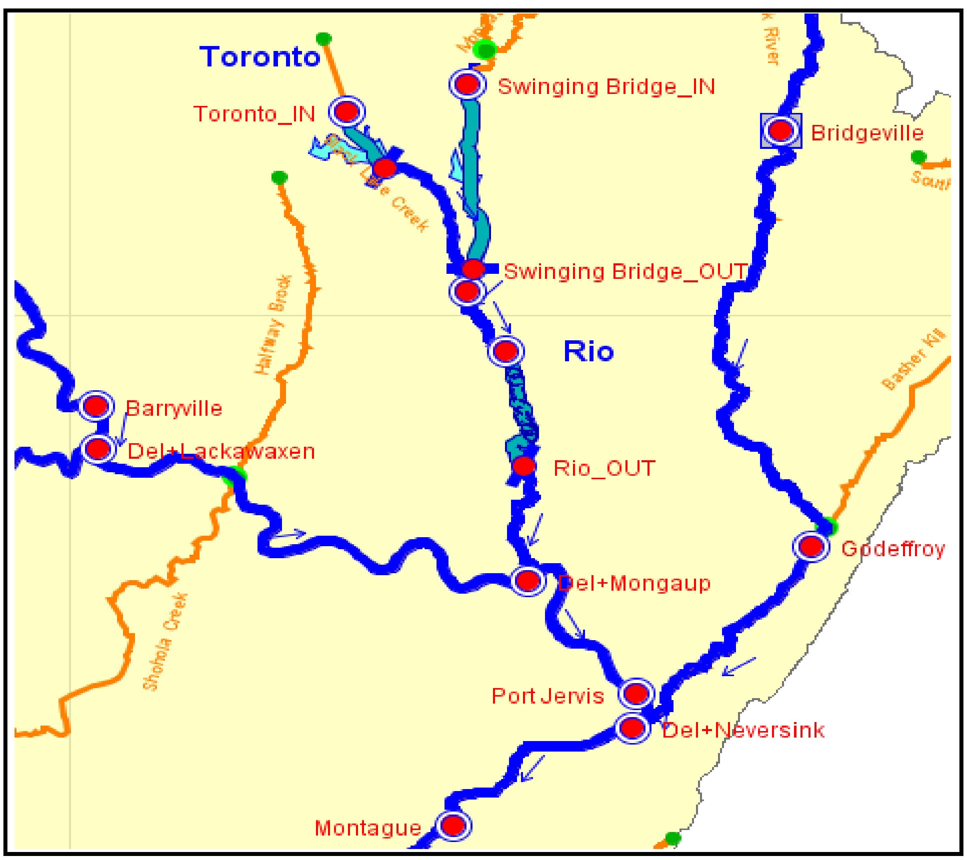


Figure 4.25 Mongaup Basin Schematic

Table 4.19 Lake Wallenpaupack Operations Summary, *FC Ops*

Name	Description	Reference
Lake Wallenpaupack	**FC Ops** Release Allocation – sequential: Pipeline Spillway	***Lake Wallenpaupack Emergency Action Plan, Dec2007 Revision***
TOP OF DAM	**1200 ft**	***DRBC Resolution No. 2002-33***
Max 6200_Spillway	Maximum Spillway Release of 6200 cfs. Spillway + Powerhouse = 8000 cfs	8000 cfs =Wallenpaupack Creek channel capacity
MAJOR FLOOD	**1193 ft**	
Maintain Peak Release	Decreasing rate of change rule of zero – on the spillway. This will not allow spillway releases to decrease.	
IROC_Spillway	Increasing rate of change rule of 1000 cfs/hr	***EAP, Dec07 pg G-14***
ManageSpillway_MajorFC	This if-block is used to limit the spillway release as long as possible…	
MaxSpill : pool>1192 ft **Max 6200_Spillway**	Maximum Spillway Release of 6200 cfs Spillway + Powerhouse = 8000	
MediumSpill: pool > 1190 ft **Max 4200_Spillway**	Maximum Spillway Release of 4200 cfs Spillway + Powerhouse = 6000	
MustSpill: pool > 1189 ft **Max 2200_Spillway**	Maximum Spillway Release of 2200 cfs Spillway + Powerhouse = 4000	
Run Pipeline Full	Minimum pipeline release of 1999 cfs – this is greater than phys-max-cap to force power plant flow to full capacity. When the reservoir is above target pool, the primary operation is to max out the powerhouse before considering spilling.	
FLOOD CONTROL	**1189 ft**	
DROC_Spillway	A decreasing rate of change rule of 2000 cfs – to limit how fast the spillway can be closed – a safety concern.	
IROC_Spillway	Increasing rate of change rule of 1000 cfs/hr	***EAP, Dec07 pg G-14***
Lower Flood Pool If pool > 1185 ft **Keep Spillway Closed**	Since the bottom of the flood pool varies seasonally, this if-block is used to keep the spillway closed if the pool is below 1185.4.	***EAP, Dec07 pg G-15***
***Control Spillway on Recession*:** If inflow falling **MaintainPeakRelease**	This if-block will maintain the peak spillway flow if the pool is approaching Major Flood, but the inflow is falling.	
Manage Spillway_Normal	This if block uses the ***projected*** pool elevation to limit the spillway release as long as possible. Although the original structure of this if-block was based on the ***Figure 1, EAP, Dec07 pg G-28,*** the computed results did not match the observed operation – so the decision structure was modified to attempt to better match observed.	
Max Spill: ***proj*** pool > 1193 ft **Max 6200_Spillway**	Maximum Spillway Release of 6200 cfs	
MustSpillMore: ***proj*** pool>1189 ft **Max 4200_Spillway**	Maximum Spillway Release of 4200 cfs	
Don't Spill: pool <=1189 ft **Keep Spillway Closed**	Maximum Spillway Release of 0 cfs	
Manage Pipeline **RunPipelineFull**	This if block used to force the power house to flow full if pool > 1 ft over guide curve	
CONSERVATION	Seasonally varies: **1180 ft-1187 ft**	
Keep Spillway Closed	Maximum Spillway Release of 0 cfs	
INACTIVE	**1160 ft**	

Two other reservoirs exist in the Mongaup basin. Cliff Lake is located downstream of Toronto on Black Lake Creek and Mongaup Falls is located upstream of Rio. These reservoirs were not included in the model because they do not significantly impact the routing of flood water through the system. Figure 4.26 shows a map of the five reservoirs obtained from Google Maps®.

The reservoirs in the Mongaup Basin are operated primarily for hydropower benefits, although some flow augmentation during declared drought emergency periods may be called for by the

River Master[4]. These reservoirs have changed ownership within the last five years and access to operational data has been limited both for the DRBC and the current owners.

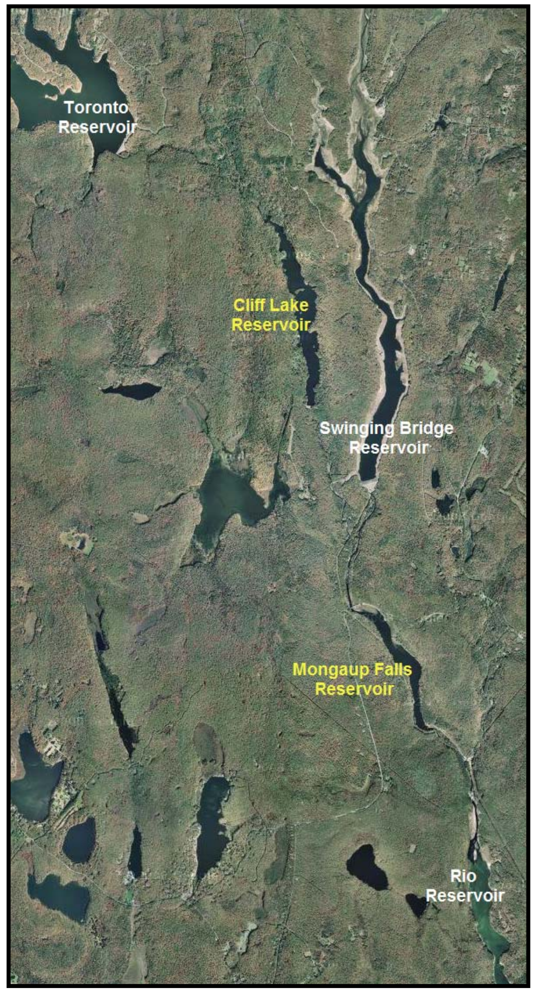


Figure 4.26 Mongaup Basin Reservoirs

Although flood damage reduction is not one of the project purposes for the Mongaup reservoirs, all three reservoirs have overflow spillways with flashboards installed along the crest. The flashboards allow these reservoirs to maintain a higher pool than the spillway alone could provide and two of the three reservoirs operate with a normal pool at to or near the top of the flashboards. To represent the operation of the flashboards, the model includes a scripted state variable to determine if the flashboards are UP or DOWN and an If-block to define outlet capacity based on the flashboard state.

4.3.3.1 Toronto

Toronto Reservoir was built to work in tandem with Cliff Lake to supply water to Swinging Bridge from Black Lake Creek by means of a diversion from Cliff Lake. The capacity of the Cliff Lake diversion is small, thus it cannot divert a significant quantity of flood water to Swinging Bridge. Because they have little impact on flood flows, Cliff Lake and its diversion are not represented in the model and flow from Toronto Reservoir enters the Mongaup River at the confluence above Rio.

Figure 4.27 shows the physical element tree for the Toronto Reservoir as well as its operation set and zones. Table 4.20 is the operations summary for Toronto.

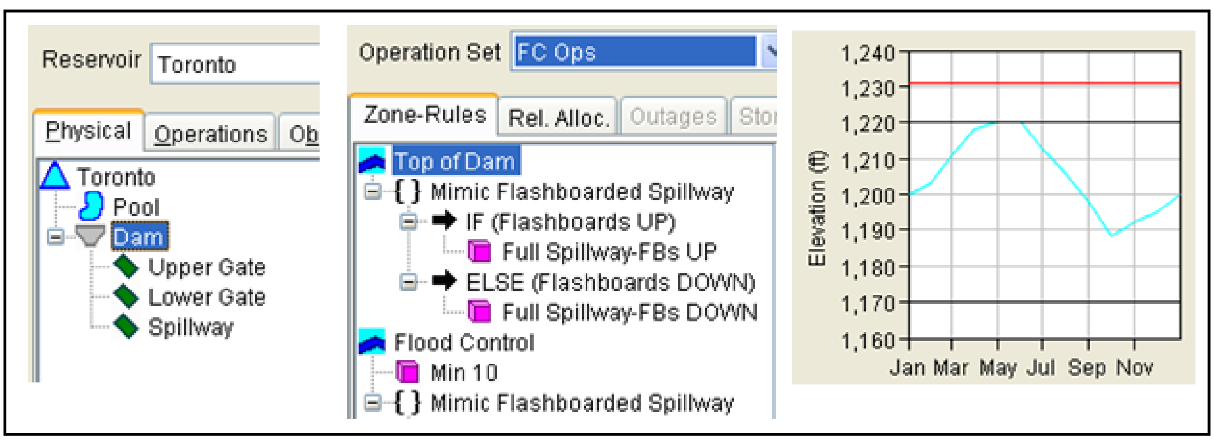


Figure 4.27 Toronto's Pool and Dam Elements and its "operating" zones

[4] A description of the office and duties of the Delaware River Master can be found at: http://www.state.nj.us/drbc/river_master.htm

Table 4.20 Toronto Operations Summary, *FC Ops*

Name	Description	Reference
Toronto	**FC Ops** Release Allocation, sequential: Lower Gate Upper Gate Spillway	*Mongaup River Hydroelectric System Operating Plan, Draft – May 2007* and *Conversation with Mr. Joe Kimazewski, the current superintendant.*
TOP OF DAM	**1231 ft**	
Mimic Flashboarded Spillway Flashboards UP: **Full Spillway-FBs UP** Flashboards DOWN: **Full Spillway-FBs DOWN**	Using a state variable to determine flashboard state, Max Spillway flow limited - max flow fn of top of flashboards Full Spillway flow – no flashboards	Toronto has a small flashboarded spillway. Spillway crest=1215 ft. Top of Flashboards=1220 ft. Flashboards are designed to fall when pool exceeds 1222.5 ft. An if-block, a state variable, and a few rules are used to mimic the flashboarded spillway operation.
FLOOD CONTROL	**1220 ft -** top of flashboards	
Min 10	Minimum 10cfs release	***Draft Operating Plan***
Mimic Flashboarded Spillway	Same as above…Note: when pool is below spillway crest, flashboards will not fall. However, if they have already fallen, the pool will draw down to the reset elevation.	
CONSERVATION	**Seasonally varying: 1188-1220 ft**	
Min 10	Minimum 10cfs release	***Draft Operating Plan***
Mimic Flashboarded Spillway	Same as above	
INACTIVE	**1170 ft**	

4.3.3.2 Swinging Bridge

Two sources were used to develop the operation set for Swinging Bridge Reservoir as well as the other two reservoirs modeled in the Mongaup Basin. The first source is the "Mongaup River Hydroelectric System Operating Plan, Draft – May 2007"**.** This document provided some insight into the definition of the operating zones, but it specified only drought operation and a minimum flow requirement. It contained no information on flood operation. The second source was a Mr. Joe Kimazewski, the current superintendant of the Mongaup reservoirs[5]**.** Mr. Kimazewski provided a description of normal flood operations at Swinging Bridge: when the pool exceeds seasonally varying target, the hydropower plant is run at full capacity and the gated spillway is used to pass the remaining inflow. If inflow exceeds the release capacity of the plant plus the gated spillway, the pool will continues to rise. When the pool exceeds the trigger point of the flashboards, the spillway will gradually fall and releases will eventually stabilize to inflow until inflow starts to recede.

The 2005 flood event caused serious damage to one of the two penstocks at Swinging Bridge, resulting in this penstock being permanently closed, thus greatly reducing the normal release capacity of the reservoir and powerhouse. This event also caused the flashboarded spillways at both Swinging Bridge and Rio to fail (not operate as designed). According to the current operators, the remaining flashboards at both reservoirs were removed after the 2005 event and

[5] The conversation with Joe Kimazewski was summarized in an email to the DRBC, dated 1 Jun 2009.

were not replaced until repairs at Swinging Bridge were completed some time in 2007. Figure 4.28 shows the dam at Swinging Bridge Reservoir as well as the spillway. Careful review of this image, obtained from Microsoft Bing® Maps and copyrighted in 2009, shows that the flashboarded section of the spillway had not been rebuilt at the time of the photo.

Figure 4.28 Swinging Bridge Reservoir

To represent the missing flashboards in the third event, a time-series of initial condition of the flashboard state was developed. This time-series identified the flashboards as "UP" at the start of the 2004 and 2005 events, but as "DOWN" at the start of the 2006 event. The scripted state variable was used to disable the ability to reset within the span of the event simulations.
Due to the loss of Penstock 1, a scheduled outage was added to the Swinging Bridge operation set in the model. This outage reduces the release capacity of the Power Conduit by 32% and begins on 4 April 2005, just as the event is receding. This date is estimated since no records were available indicating when the sinkhole in Penstock 1 was found and the penstock "closed".

Figure 4.29 shows the physical element tree for Swinging Bridge Reservoir, a portion of its operation set, and a plot of the operation zones. Table 4.21 summarizes the operations set developed for Swinging Bridge.

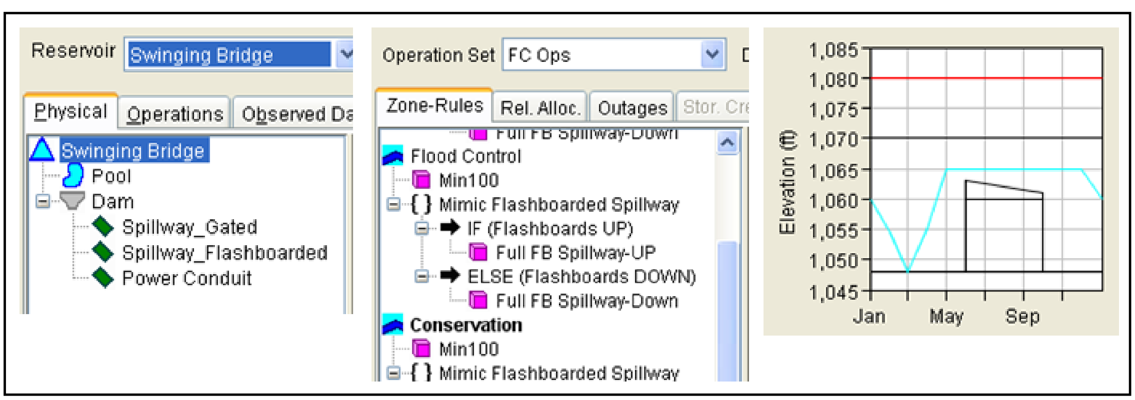


Figure 4.29 Swinging Bridge's Pool and Dam Elements and its "operating" zones

Table 4.21 Swinging Bridge Operations Summary, *FC Ops*

Name	Description	Reference
Swinging Bridge	**FC Ops** Release Allocation, sequential: Power Conduit Spillway-Gated Spillway-Flashboarded **OUTAGE:** **Power Conduit -** Penstock 1 was permanently disabled after April 2005 Event. Max Cap now about 1075 ft. With a 0.68 factor in scheduled outage, Max Cap = 1068 ft	***Mongaup River Hydroelectric System Operating Plan, Draft – May 2007;*** and ***Conversation with Joe Kimazewski, the current superintendant***
TOP OF DAM	**1080 ft**	
Mimic Flashboarded Spillway Flashboards Up – **Full FB Spillway-UP** Flashboards Down – **Full FB Spillway-Down**	Using a state variable to determine flashboard state, Max Spillway flow limited - max flow fn of top of flashboards Full Spillway flow – no flashboards	This reservoir has a spillway with a gated section and a flashboarded section. Spillway crest=1065. Top of Flashboards=1070. Flashboards are designed to fall when pool exceeds (1073 ft). An if-block, a state variable, and a few rules are used to mimic the flashboarded spillway operation.
FLOOD CONTROL	**1070 ft** – top of flashboards	
Min100	Minimum release of 100cfs	***Draft Operating Plan***
Mimic Flashboarded Spillway	Same as above…Note: when pool is below spillway crest, flashboards will not fall. However, if they have already fallen, the pool will draw down to the reset elevation.	
CONSERVATION	**Seasonally varying: 1048-1065 ft**	
Min100	Minimum release of 100cfs	***Draft Operating Plan***
Mimic Flashboarded Spillway	Same as above…	
LEVEL 2	**1048 ft** except summer varies **1063-1061 ft**	Levels 2 and 1 are defined for summer operation of hydropower versus recreation and are meaningful only to low flow operation – no minimum flow is required from these zones
Mimic Flashboarded Spillway	Same as above	
LEVEL 1	**1048 ft** except summer **1060 ft**	
Mimic Flashboarded Spillway	Same as above	
INACTIVE	**1048 ft**	

4.3.3.3 Rio

Rio is the downstream-most reservoir in the Mongaup River Basin. As such, Rio receives the releases from its upstream partners. In the 2005 event, the flashboards failed to fall at Swinging Bridge and Rio. The model indicates that they could have fallen. As with Swinging Bridge, the flashboards were removed after the 2005 event, so a similar time-series was developed to set the flashboard state initial condition for each event appropriately. The only observed records available for the Mongaup system were daily outflows for Rio. Hourly flow information was not available.

Figure 4.30 shows the physical element tree for Rio, a portion of its operation set, and a plot of the operating zones. Table 4.22 summarizes Rio's *FC Ops* operation set.

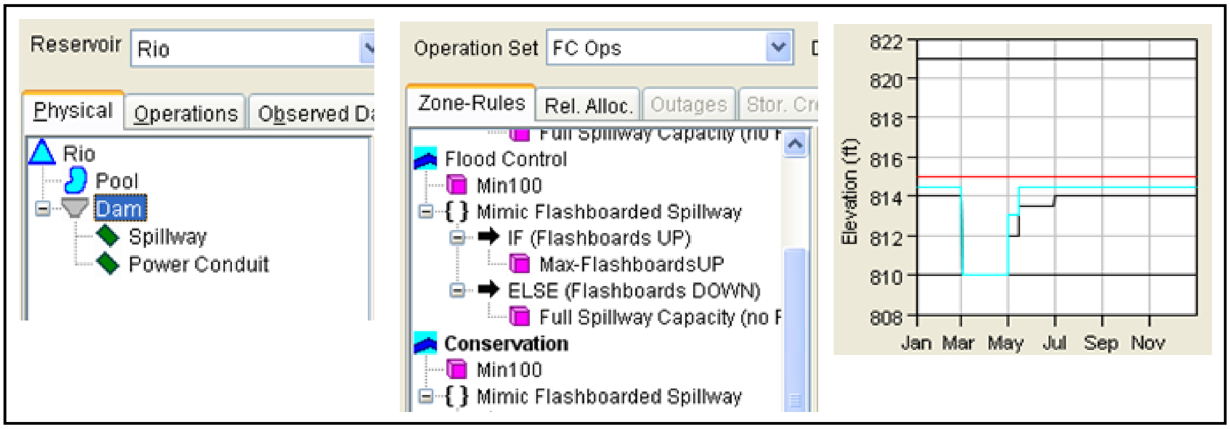


Figure 4.30 Rio's Pool and Dam Elements and its operating zones & rules

Table 4.22 Rio Operations Summary, *FC Ops*

Name	Description	Reference
Rio	**FC Ops**	***Mongaup River Hydroelectric System Operating Plan, Draft – May 2007*** and ***Conversation with Joe Kimazewski, the current superintendant.***
TOP OF DAM	**821 ft**	
Mimic Flashboarded Spillway Boards Up – **Full Spillway-FBs UP** Boards Down – **Full Spillway-FBs DOWN**	Using a state variable to determine flashboard state, Max Spillway flow limited - max flow fn of top of flashboards Full Spillway flow – no flashboards	This reservoir has a flashboarded spillway Spillway crest=810 ft. Top of Flashboards=815 ft. Flashboards are designed to fall when pool exceeds (818 ft). An if-block, a state variable, and a few rules are used to mimic the flashboarded spillway operation.
FLOOD CONTROL	**815 ft** – top of flashboards	
Min 100	Minimum 100cfs release	*Draft Operating Plan*
Mimic Flashboarded Spillway	Same as above…Note: when pool is below spillway crest, flashboards will not fall. However, if they have already fallen, the pool will draw down to the reset elevation.	
CONSERVATION	**Seasonally varying: 810-814.5 ft**	
Min 100	Minimum 100cfs release	*Draft Operating Plan*
Mimic Flashboarded Spillway	Same as above	
MINIMUM	**Seasonally varying: 810-814 ft**	
Mimic Flashboarded Spillway	Same as above	
INACTIVE	**810 ft** - spillway crest	

4.3.4 Lehigh River Basin Reservoirs

The two reservoirs in the Lehigh River Basin (Figure 4.31) are owned and operated by the US Army Corps of Engineers. These are multipurpose reservoirs whose primary authorized purpose is flood damage reduction. Secondary purposes include recreation, water quality control and drought emergency water supply and low flow augmentation.

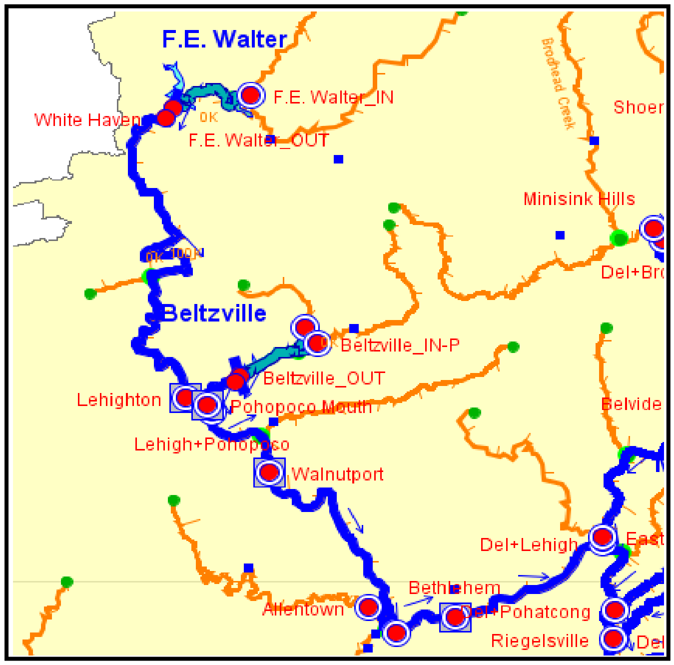


Figure 4.31 Lehigh Basin Reservoirs

4.3.4.1 F.E. Walter

The operations for F.E. Walter are reasonably straightforward and well defined in its Water Control Manual. For flood damage reduction, it operates to not exceed a peak stage at Lehighton, Walnutport and Bethlehem, all on the Lehigh River. F.E. Walter also operates for a local channel capacity constraint so as to not flood its immediate downstream neighbors.

Deviations from F.E. Walter's summer pool are often requested and approved to enhance recreation and to increase water quality storage. To represent this in the model, the target pool for F.E. Walter for each of the three events was entered into a time-series record and used to define the guide curve in the F.E. Walter *FC Ops-Dev* operation set. As a result, the plot of the zones in Figure 4.32 looks unusual.

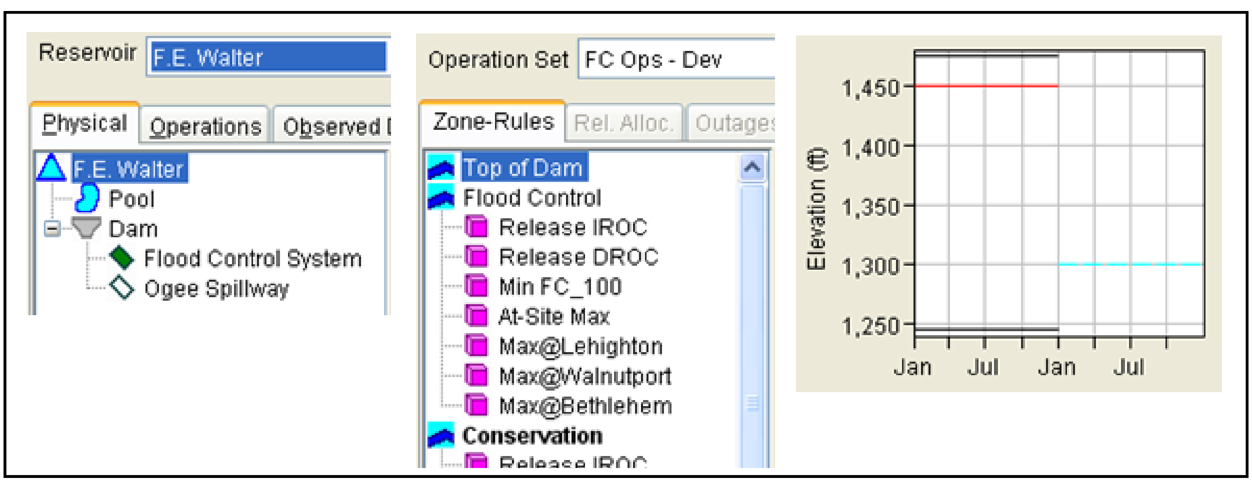


Figure 4.32 F.E. Walter's Pool and Dam Elements and its "operating zones" and rules

4.3.4.2 Beltzville

Like F.E. Walter, Beltzville's operations for flood damage reduction are straightforward and well defined in its Water Control Manual; in addition to a local channel capacity constraint, it operates in parallel with F.E. Walter to reduce peak flood flows so as not to exceed peak flood stage at Walnutport and Bethlehem.

Table 4.23 F.E. Walter Operations Summary, *FC Ops-BTB* and *FC Ops-Dev*

Name	Description	Reference
F.E. Walter	**FC Ops – BTB** (by the book) **FC Ops – Dev** (deviation)	***Water Control Manual, CENAP 1994; 1/22/09 Email from Christine Lewis-Coker, CENAP.***
TOP OF DAM	**1474 ft**	
FLOOD CONTROL	**1450 ft**, Spillway Crest	
Release IROC **Release DROC**	Increasing and decreasing rate of change constraints apply. Value of 500 cfs/hr is based primarily on observed data.	***WCM page 7-11***, supported by conversations and follow-up material from Christine Lewis-Coker, CENAP
Min FC_100	100 cfs minimum release when "impounding for Flood Emergency"	***WCM pg 7-13***
At-Site Max	10,000 cfs maximum allowed release from the reservoir	***WCM***
Max@Lehighton	Operates for 9.7 ft Flood Control Initiation stage at Lehighton	***WCM,*** Rating curve at Lehighton provides flow limit
Max@Walnutport	Operates for 6.3 ft Flood Control Initiation stage at Walnutport	***WCM,*** Rating curve at Walnutport provides flow limit
Max@Bethlehem	Operates for 9.9 ft Flood Control Initiation stage at Bethlehem	***WCM,*** Rating curve at Bethlehem provides flow limit
CONSERVATION	**1300 ft (FC Ops – BTB)** **Defined with an external time-series (FC Ops – Dev)**	***WCM*** ***1/22/09 Email from Christine Lewis-Coker, CENAP*** **-details conservation pool deviations in effect during the three events.**
Same as above except… MaxFC_100 rule replaced with:		
Min WQ_50	Water Quality min – 50cfs	***WCM pg 7-6, 2003 revision.***
INACTIVE	**1250 ft**, invert of inlet channel to FC Gates	

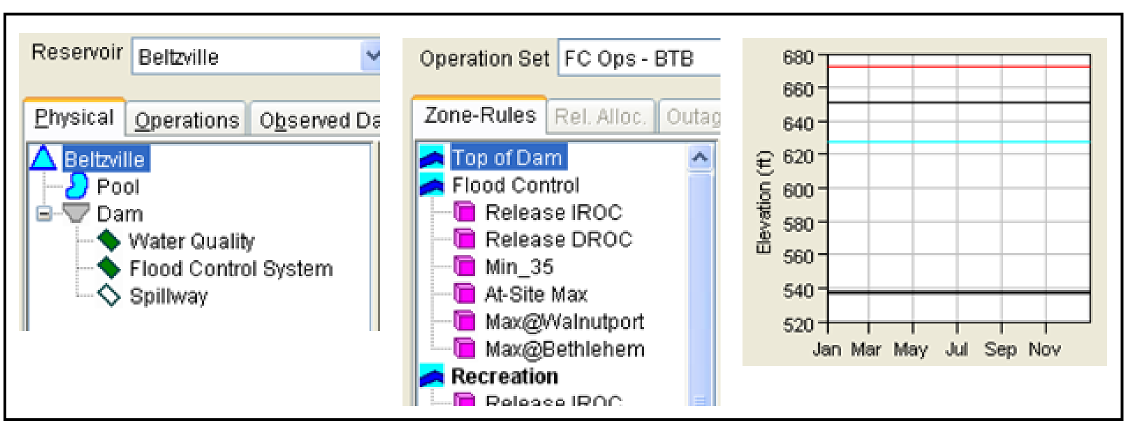


Figure 4.33 Beltzville's Pool and Dam Elements and its "operating zones" and rules

Table 4.24 Beltzville Operations Summary, *FC Ops-BTB*

Name	Description	Reference
Beltzville	**FC Ops – BTB** (by the book)	***Water Control Manual, CENAP 1994***
TOP OF DAM	**672 ft**	
FLOOD CONTROL	**651 ft**, Spillway Crest	
Release IROC **Release DROC**	Increasing and decreasing rate of change constraints apply. Value of 500 cfs/hr is based primarily on observed data.	***WCM page 7-11***, supported by conversations and follow-up material from Christine Lewis-Coker, CENAP
Min_35	Minimum required release	***WCM***
At-Site Max	Maximum allowed release from the reservoir	***WCM***
Max@Walnutport	Operates for 6.3 ft Flood Control Initiation stage at Walnutport	***WCM,*** Rating curve at Walnutport provides flow limit
Max@Bethlehem	Operates for 9.9 ft Flood Control Initiation stage at Bethlehem	***WCM,*** Rating curve at Bethlehem provides flow limit
RECREATION	**628 ft**	
Same rule set as above		
INACTIVE	**537 ft**	

4.3.5 Mainstem Delaware River Basin Reservoirs

The two Mainstem Delaware reservoirs (Figure 4.34) modeled are Merrill Creek and Nockamixon. Each is located on a tributary of the Delaware River and is operationally different from the other reservoirs represented in the model.

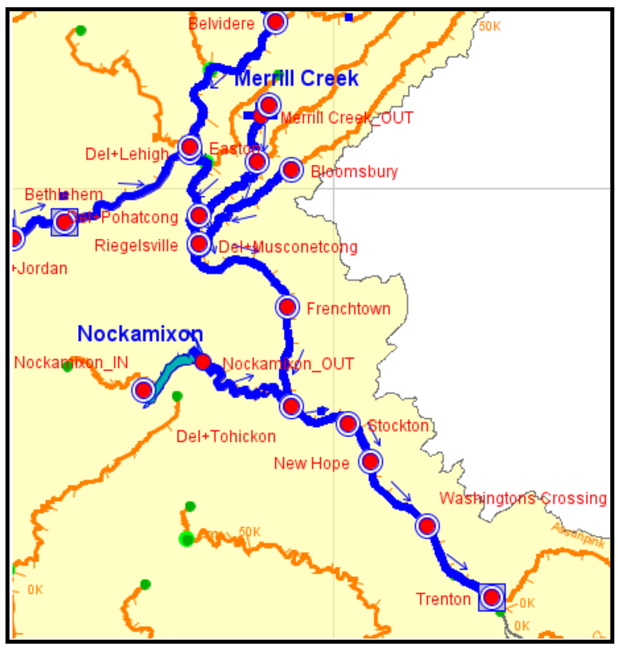


Figure 4.34 Mainstem Delaware Reservoirs

4.3.5.1 Merrill Creek

Merrill Creek Reservoir was constructed to serve as an off-stream storage project for flow augmentation under low flow conditions. It is filled by a pumped diversion from the main stem Delaware River when the river flow is considered normal. The diversion is not used during flood events. The natural basin that drains into Merrill Creek is small, so even in a large event, Merrill Creek can store its natural flood waters and not increase flows in the lower system beyond its flood control maximum release of 20 cfs. Records indicate that when Merrill Creek is releasing for flow augmentation, releases are often in excess of 100 cfs, so the flood control limit of 20 cfs was not considered to be a local channel capacity constraint.

Figure 4.35 shows Merrill Creek's physical element tree, a portion of its operation set, and a plot of the operation zones. Table 4.18 summarizes the *FC Ops* operation set developed for Merrill Creek.

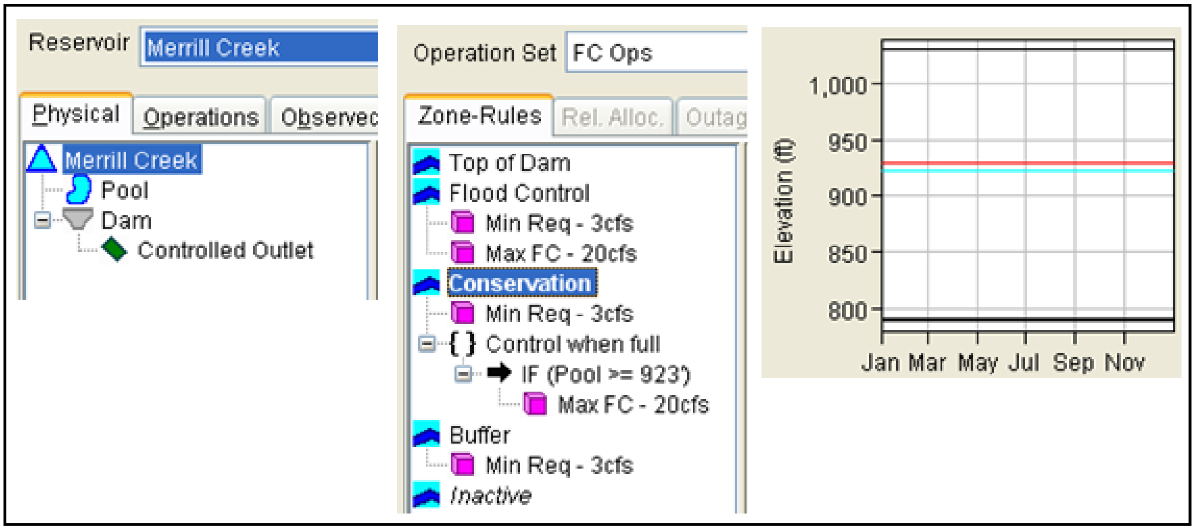


Figure 4.35 Merrill Creek's Pool and Dam Elements and its "operating" zones and rules

Table 4.25 Merrill Creek Operations Summary, *FC Ops*

Name	Description	Reference
Merrill Creek	**FC Ops**	***DRBC Docket D-77-110 CP, Docket 77-110-CP Amendment 1; 1993 MCOG Plan of Operations; OASIS Model 2.1***
TOP OF DAM	**1030 ft** Estimated pool invert ~ 770 ft. Dam height = 260 ft. Thus, top of dam=1030 ft	Estimate based on data in ***URS Memorandum –RE: Reservoir Volume-Elevation Curve***
FLOOD CONTROL	**929 ft**, Spillway crest	
Min Req – 3cfs	Minimum release of 3cfs	***DRBC Docket D-77-110 CP; Plan of Operations***
Max FC – 20cfs	Maximum release of 20cfs	***DRBC Docket D-77-110 CP; Plan of Operations***
CONSERVATION	**923 ft**	
Min Req – 3 cfs	Minimum release of 3cfs	
Limit Release when Full If pool >= 923 ft **Max FC – 20 cfs**	This if-block and rule were added to stabilize operation when pool is at guide curve.	
INACTIVE	**790 ft**	

4.3.5.2 Nockamixon

The dam at Nockamixon State Park is designed to provide storage for recreation, flood damage reduction, and future water supply. The dam controls the runoff from a drainage area of 73.3 square miles and will reduce peak discharges of floods downstream from the site (Nockamixon O&M Manual). An image of the Nockamixon dam is shown in Figure 4.36.

Nockamixon's normal and flood damage reduction operations are straightforward: other than meeting a minimum flow requirement, the pool stores inflow until it reaches spillway crest, then the spillway manages the releases from the project.

Figure 4.36 Nockamixon Dam

To meet minimum and water supply requirements, the intake tower utilizes a set of four electronically operated sluice gates to deliver water into the diversion tunnel. At the downstream end of the diversion tunnel is an outlet structure that utilizes a number of different sized valves to control the release into the river. One of the valves, a 10 inch cone valve is locked in the open position. This valve is sized to provide the minimum release requirement from the project under all conditions. If the reservoir pool is below spillway crest, water supply releases can be made by operating one or more of the other valves in the outlet structure.

Figure 4.37 shows Nockamixon's physical element tree, the zone and rules tree for its *FC Ops* operation set, and a plot of the operating zones. Table 4.26 summarizes the operation set developed for Nockamixon.

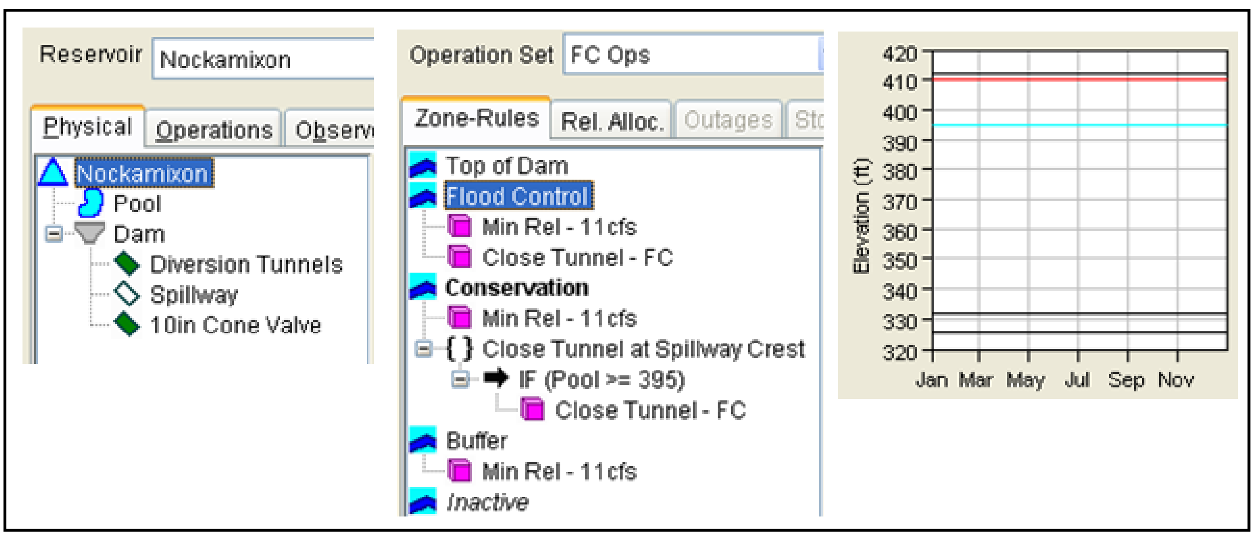


Figure 4.37 Nockamixon's Pool and Dam Elements and its "operating" zones and rules

Table 4.26 Nockamixon Operations Summary, *FC Ops*

Name	Description	Reference
Nockamixon	**FC Ops** Release Allocation, sequential: Cone Valve Diversion Tunnel Spillway (uncontrolled)	***Nockamixon O&M Manual; OASIS model 2.1; Letter dated 22May1979 from Pennsylvania Dept of Environmental Resources***
TOP OF DAM	**412 ft**	
FLOOD CONTROL	**409.9 ft**	**No source. Value is the last value in the elev-storage data found in documentation and the OASIS model**
Min Rel – 11cfs	Min release, all the time, 11cfs – cone valve capacity	***PA Letter***, Cone Valve remains open at all times
Close Tunnel - FC	Max controlled release =0 used to direct flood flows to spillway. No flood control is provided for the downstream system (other than that controlled by the spillway capacity.) Therefore, all outlets other than the cone valve, are closed when the reservoir is spilling.	***O&M Manual*** , Chapter 3, Section 7 "Flood Emergency Operation Procedures"
CONSERVATION	**395 ft**, Spillway Crest	***O&M Manual***
Min Rel – 11cfs		
Close Tunnel at Spillway Crest: If (pool>=395) **Close Tunnel - FC**	used to curtail tunnel flows if pool is sitting at guide curve	
BUFFER	**331.5 ft**	
Min Rel – 11cfs		
INACTIVE	**325.5 ft**	

Chapter 5

Alternatives and Simulations

In HEC-ResSim, an Alternative is a construct that represents the combination of a reservoir network, the selection of an active operation set for each reservoir in the network, and the specification of the starting (or lookback) conditions and inflow time-series data for the network. A Simulation is a time window over which to compute and analyze one or more alternatives.

5.1 Alternatives

Two alternatives were created for the Delaware River Flood Analysis Model: *FC-PRMS* and *FC-GageQ*. The *FC-PRMS* alternative was the original alternative specified in the scope of work for the project. The United States Geological Survey (USGS) developed a PRMS (Precipitation Runoff Modeling System) model of the Delaware River Basin above Trenton to simulate the runoff and generate inflow time-series data for the HEC-ResSim model. The objective of the *FC-PRMS* alternative was to produce inflow for HEC-ResSim that could be used to adequately represent the flows that would be experienced in the basin under a selected set of hydrologic conditions. Reservoir operations and flow routing in the major tributaries and main stem Delaware River are simulated by HEC-ResSim. Due to uncertainties in rainfall-runoff modeling, the *FC-PRMS* alternative did not satisfactorily reproduce the peak flows or total volumes that occurred during the three major flood events of 2004, 2005 and 2006. The *FC-GageQ* alternative, using gaged and gage-based inflows, was developed to reduce the uncertainty and error contributed by the rainfall-runoff modeling, resulting in HEC-ResSim model output that more closely reproduces the peak flows and the total volumes that occurred during the three events.

The difference between the two alternatives is in the selection of the inflow time-series data. The source of the inflow data for the *FC-PRMS* alternative is the output from the PRMS rainfall-runoff model developed by the USGS. The source of the inflow data for the *FC-GageQ* alternative is the gage data provided by the USGS and the USACE Philadelphia District. Wherever flow from a headwater was directly measured by a gage, the gage record was used as the inflow time-series to the model at that junction. Where inflow was not measured, primarily at the reservoirs, an inflow record was derived either by calculation (inflow = outflow – change in storage, known as reverse pool routing) or by using the measured flow from a nearby subbasin and factoring that flow for the relative basin size to which it was applied. For the interior junctions, where total river flows were measured at two successive gages, the intervening local flows were calculated by routing the upstream gage flows to the downstream gage and subtracting the two flow records. In the absence of a rainfall-runoff model developed to supply inflows (such as a PRMS or an HEC-HMS (Hydrologic Modeling System) model), this is how inflows for an HEC-ResSim model would normally be developed.

Both alternatives use the same starting conditions and, for the most part, the same selection of operation sets; however, the NYC reservoirs use a different operation set (*FC Ops-SpecDiv*) is used for the NYC reservoirs in the *FC-GageQ* alternative than in the *FC-PRMS* alternative (*FC Ops*). The *FC Ops-SpecDiv* operation set uses the observed diversions for the NYC reservoirs. By using the observed diversions, errors associated with not correctly reproducing the diversion values are eliminated. The *FC Ops* operations set uses a function of storage in two of the three NYC reservoirs to generate the diversions and does not turn off the diversions at the same time that they happened during these three events.

5.2 Simulations

Three simulations were created for the model, one for each of the three recent flood events: September 2004, March-April 2005, and June-July 2006. In each simulation, both alternatives were computed and results analyzed. In the following sections, selected results are presented for all the reservoirs and most of the major flood forecast locations in the model to demonstrate the ability of the model to represent the reservoir operations and flow routing that occurred during the three flood events.

5.2.1 Upper Basin

The locations in the Upper Basin presented include the three NYC reservoirs: Cannonsville, Pepacton, and Neversink, as well as the downstream flood forecast locations: Hale Eddy, Harvard, and Bridgeville.

The observed data for the Upper Basin reservoirs was provided by the New York City Department of Environmental Protection (NYCDEP). Due to a computer malfunction, the hourly observed data for the three NYC reservoirs was lost for the 2004 event, so daily data was used to approximate the hourly record. In addition, the hourly record for the 2005 and 2006 events contains anomalies which are displayed in various figures in the following sections.

The outflow gage of each reservoir is maintained by the USGS. The observed data at these gages provided a complete and stable record of releases into the river for all three events. These gages were used to validate the operation of the reservoirs under the three modeled high flow events. Observed data at these outflow gages are included in the plots of results for Stilesville and Downsville, the outflow gage for Cannonsville and Pepacton, respectively; see

5.2.1.1 Cannonsville

Figure 5.1 through Figure 5.3 shows the standard HEC-ResSim reservoir plot for Cannonsville Reservoir for each of the three events. The upper plot region shows the computed reservoir pool elevation and operating zones for each alternative as well as the observed pool elevation. The lower plot region shows the computed pool inflow and outflow for each alternative as well as the observed pool outflow. It should be noted that pool outflow for the reservoirs in the upper basin is not equivalent to the flow that is released into the downstream system. The upper basin reservoirs have diverted outlets that may be diverting some of the total reservoir outflow out of the basin rather than to the dam's tailwater.

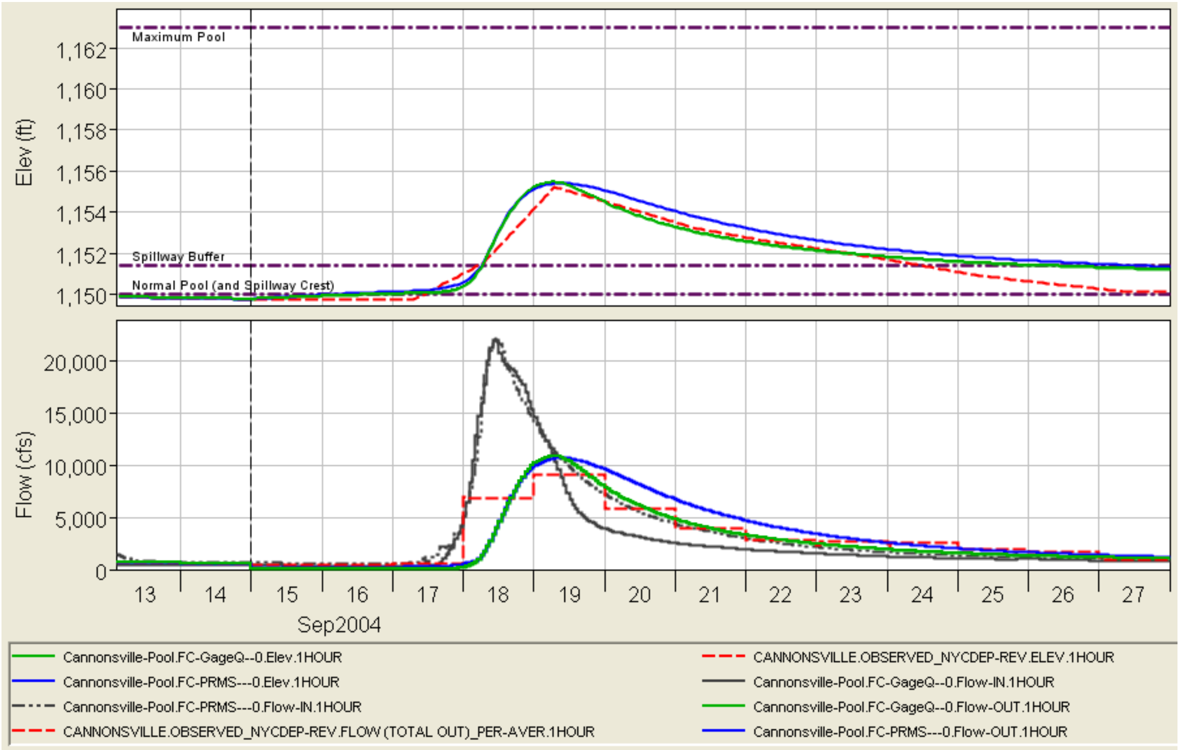


Figure 5.1 Cannonsville Reservoir Plot – 2004 Event

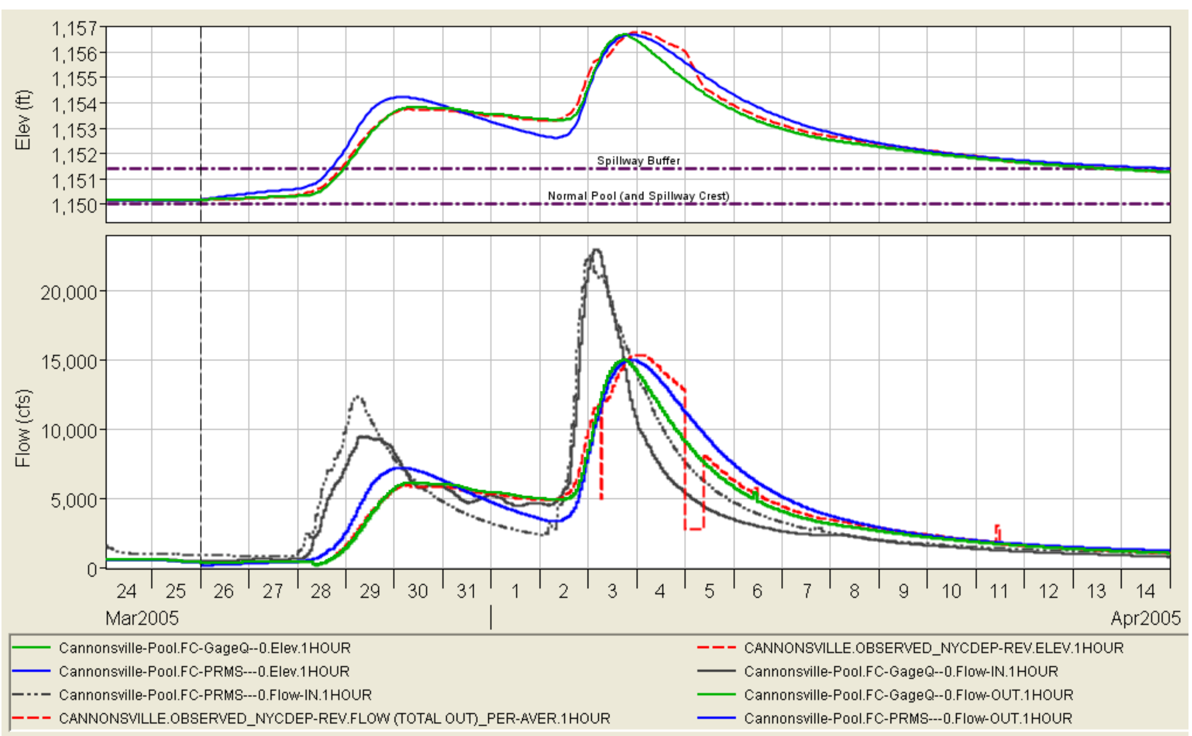


Figure 5.2 Cannonsville Reservoir Plot – 2005 Event

Since the *FC-GageQ* alternative is based on observed and derived-from-observed data, the *FC-GageQ* results compare well to the observed record. The *FC-PRMS* results at this location also compare well to the observed data. For example, in Figure 5.1 and Figure 5.2 the magnitude and timing of the peak inflow match well with the observed data for both alternatives.

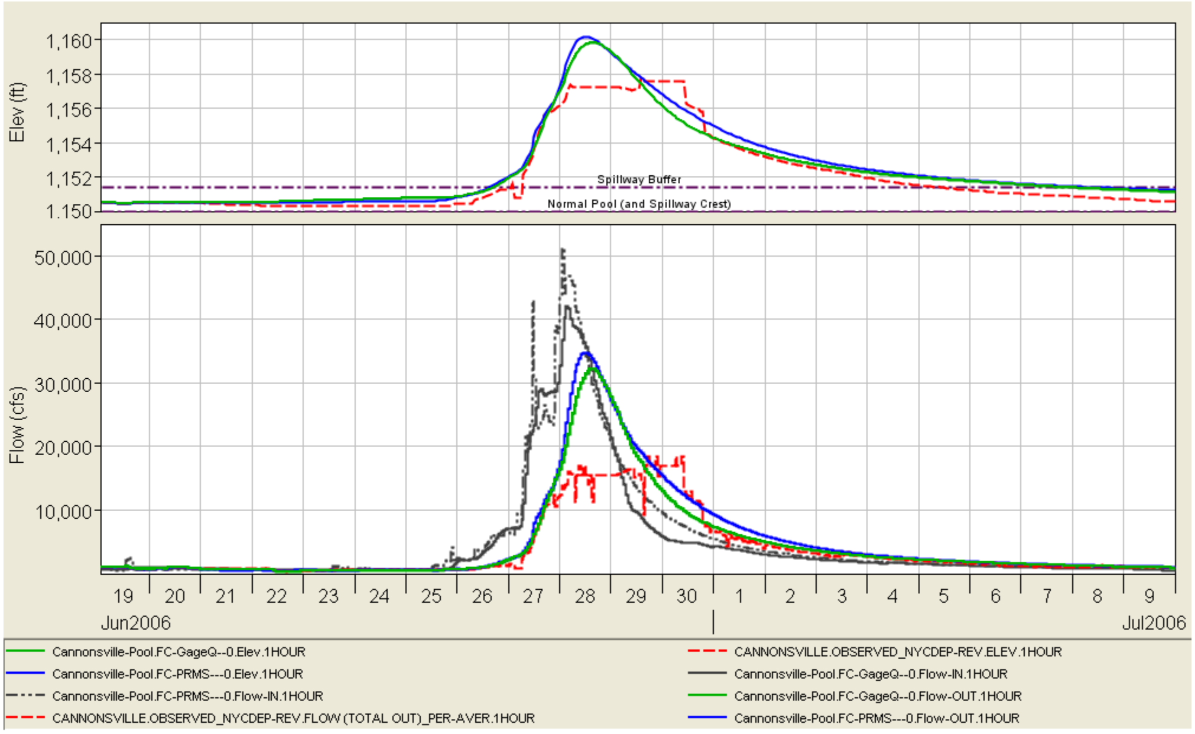


Figure 5.3 Cannonsville Reservoir Plot – 2006 Event

In Figure 5.3, the computed pool elevation and outflow for the two alternatives does not match as well to the observed for the 2006 event as they did for the other two events. To verify the operation of Cannonsville for this event, the USGS gage record at Stilesville, Cannonsville's outflow gage was used. Figure 5.6 through 5.6 show the Stilesville Junction plots for the 2004, 2005, and 2006 events. These plots show that the two alternatives compare well to the gage record.

5.2.1.2 Stilesville

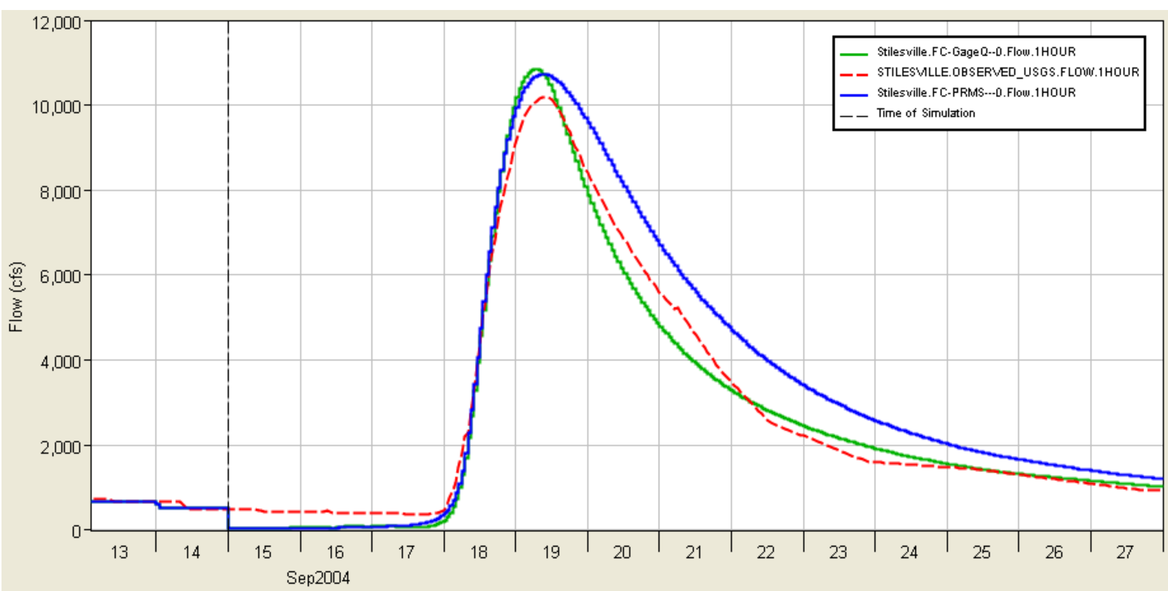


Figure 5.4 Stilesville Junction Plot – 2004 Event

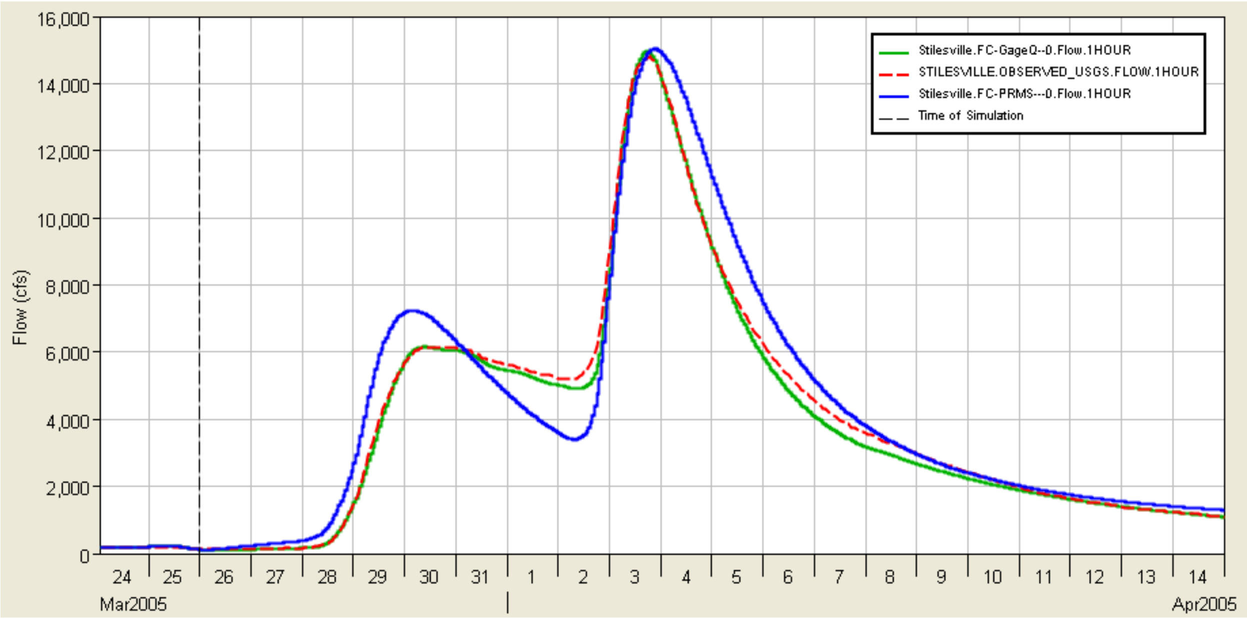


Figure 5.5 Stilesville Junction Plot – 2005 Event

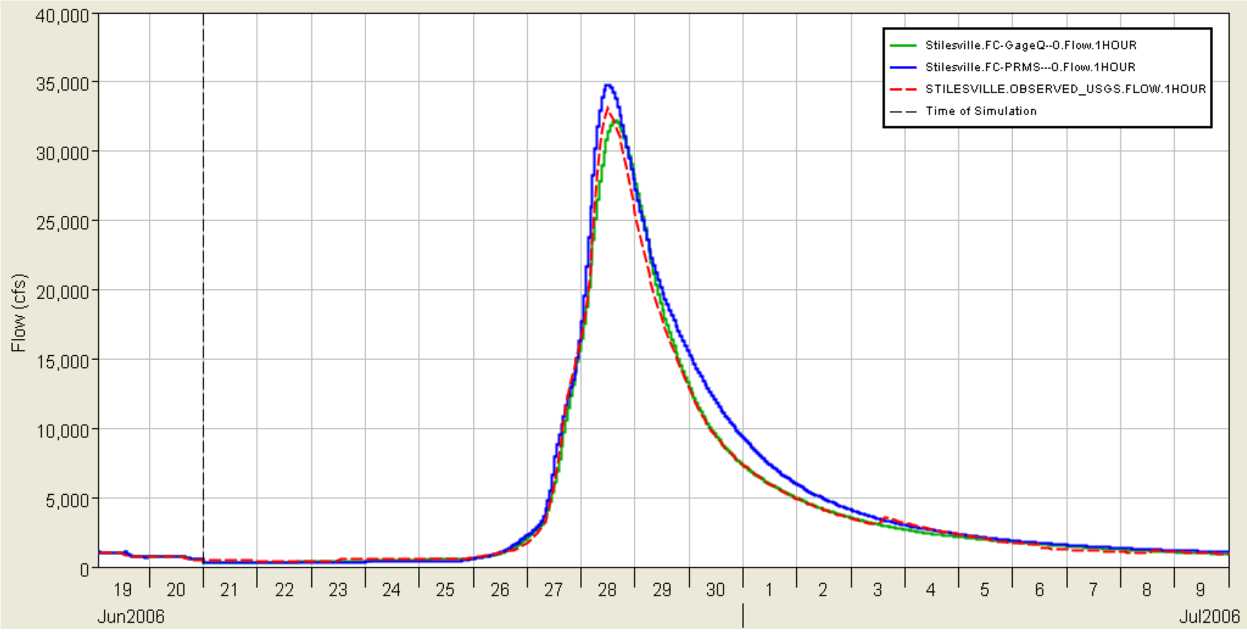


Figure 5.6 Stilesville Junction Plot – 2006 Event

5.2.1.3 Hale Eddy

Hale Eddy is the first NWS forecast location downstream of Cannonsville. An unregulated tributary, Oquaga Creek, enters the West Branch of the Delaware River above Hale Eddy. Plots showing cumulative local flow and outflow from Hale Eddy are shown in Figure 5.7 through Figure 5.9 for the three events. These plots show the impact of high flows out of Cannonsville combined with high local flows in the river.

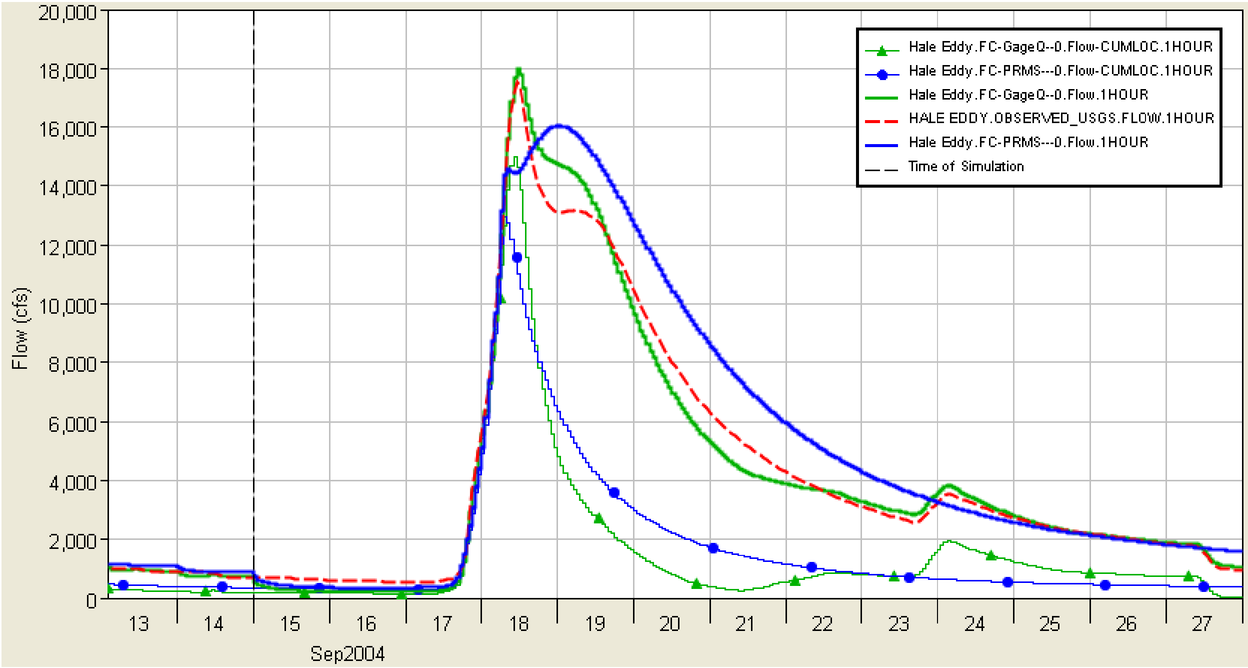


Figure 5.7 Hale Eddy Junction Plot – total and cumulative local flow – 2004 Event

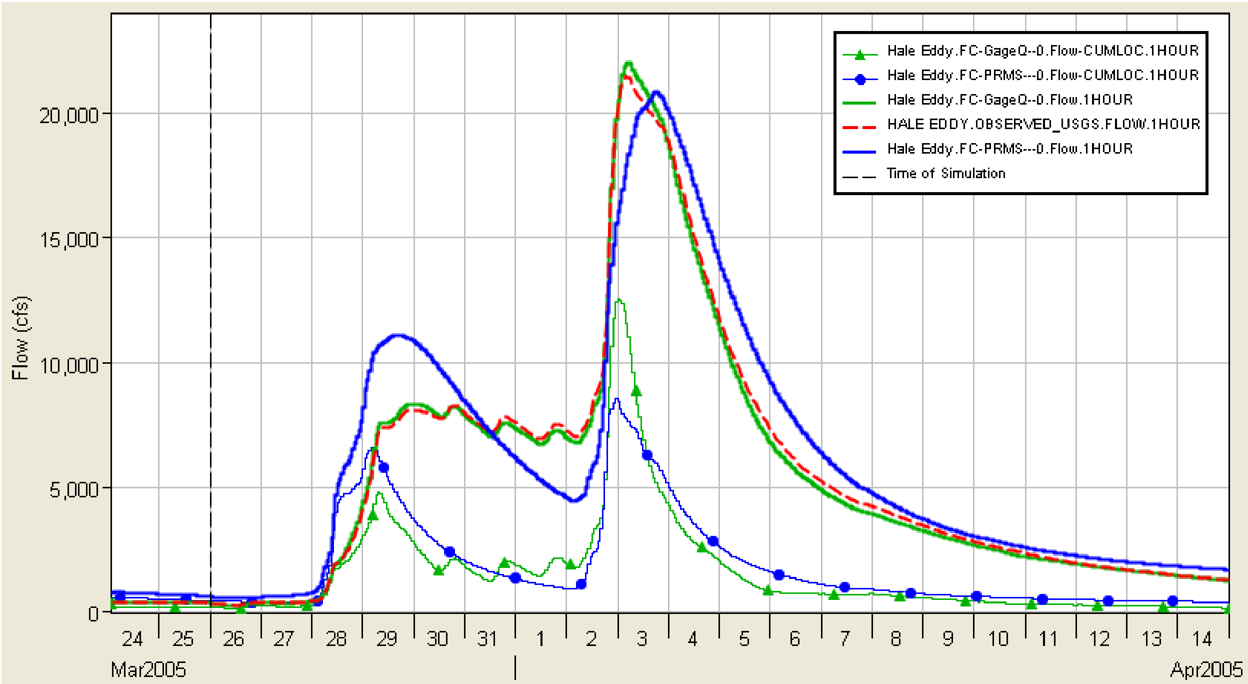


Figure 5.8 Hale Eddy Junction Plot – total and cumulative local flow – 2005 Event

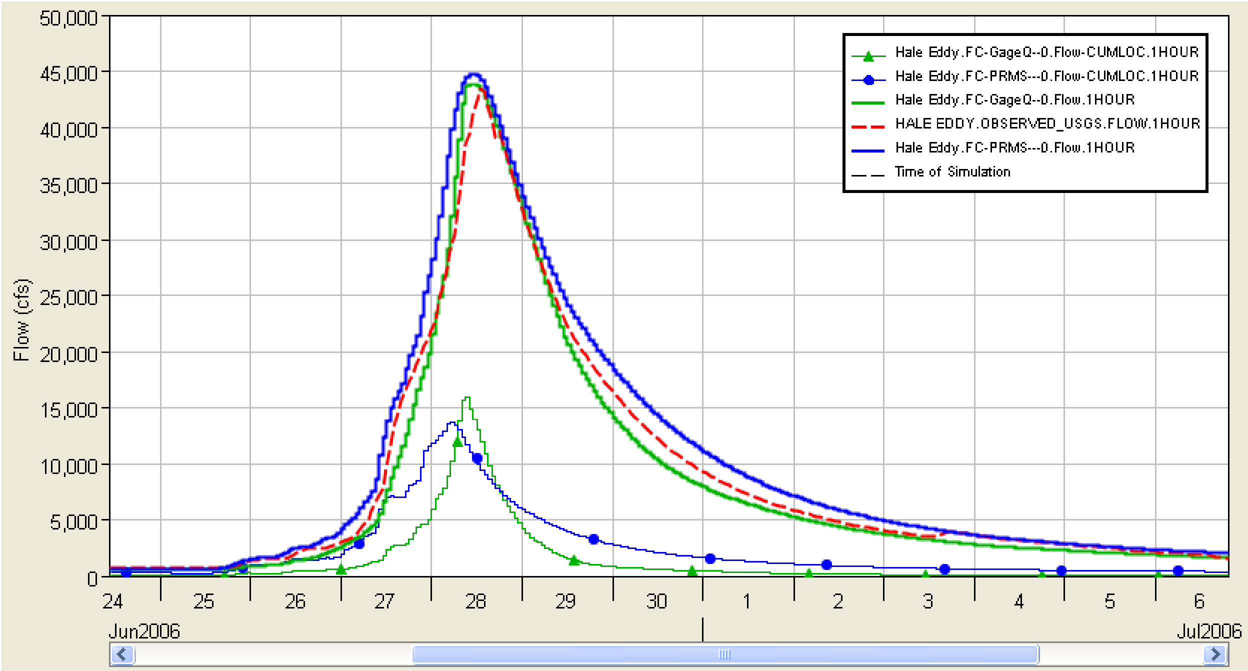


Figure 5.9 Hale Eddy Junction Plot – total and cumulative local flow – 2006 Event

5.2.1.4 Pepacton

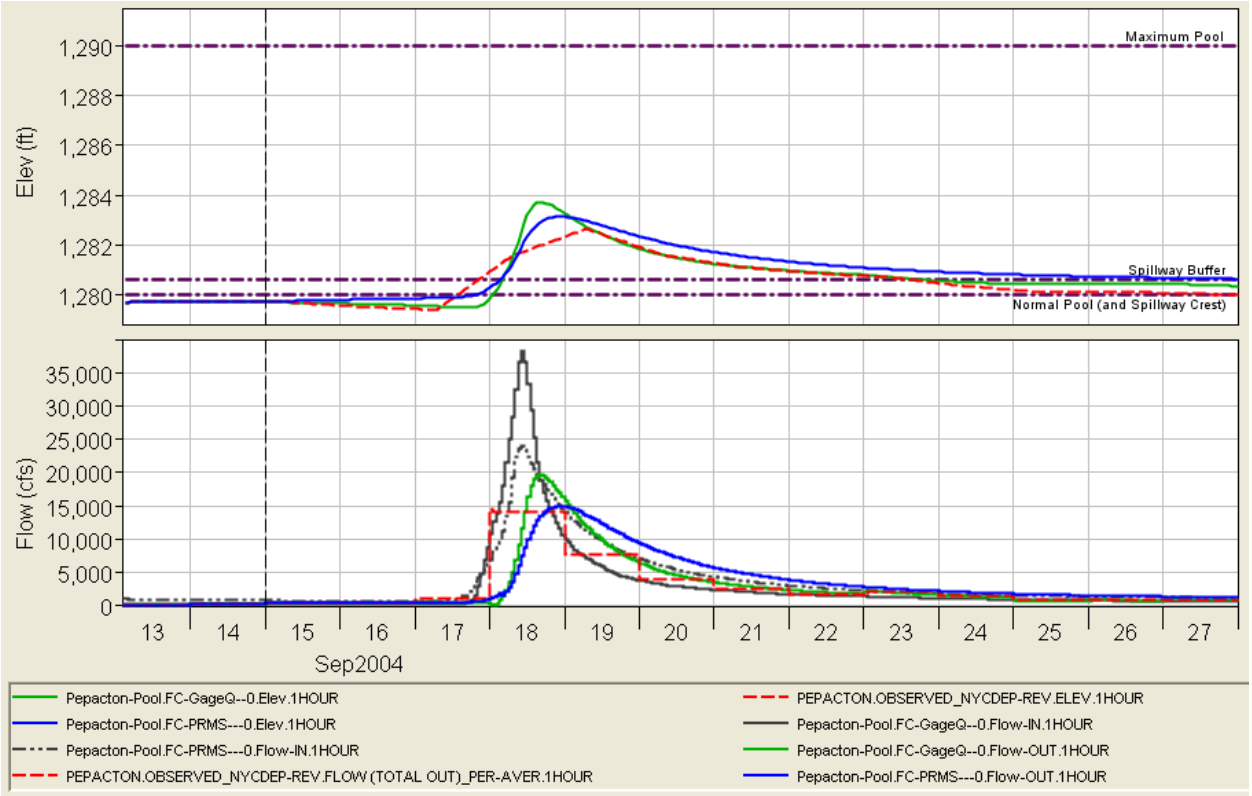


Figure 5.10 Pepacton Reservoir Plot – 2004 Event

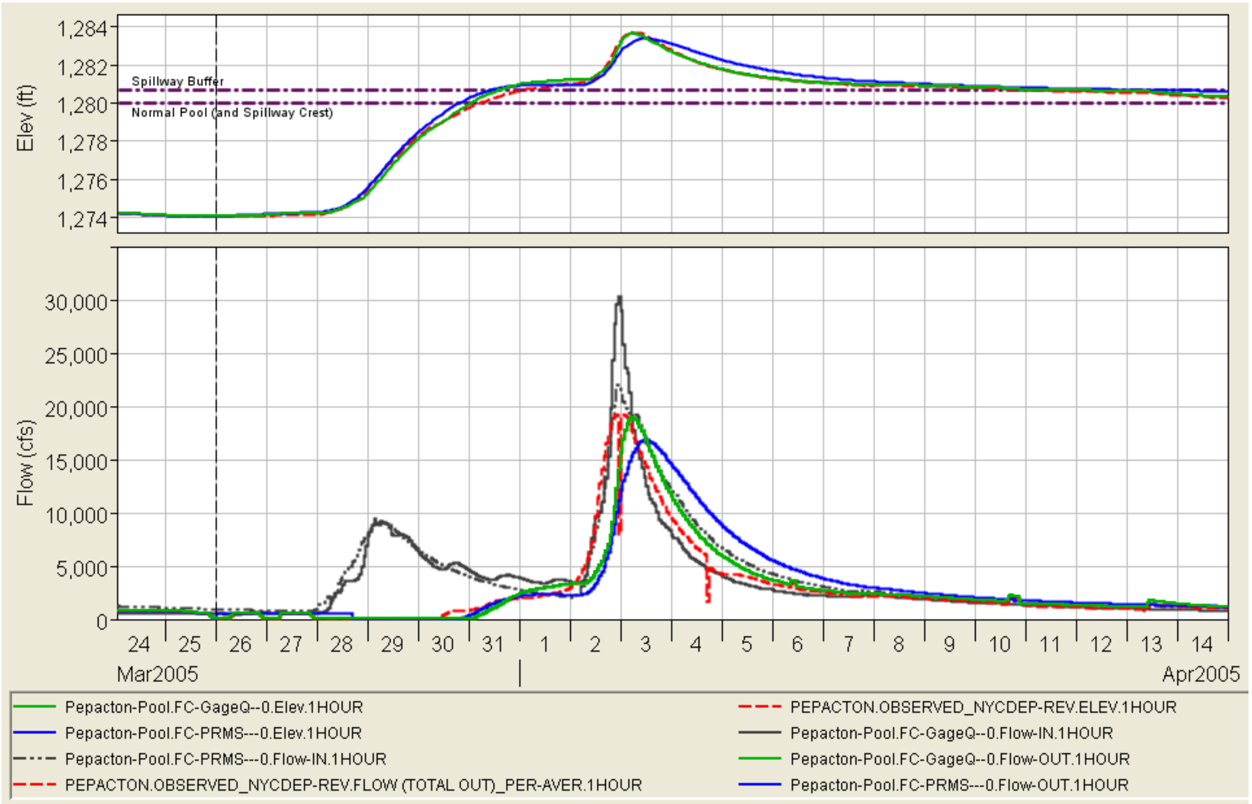


Figure 5.11 Pepacton Reservoir Plot – 2005 Event

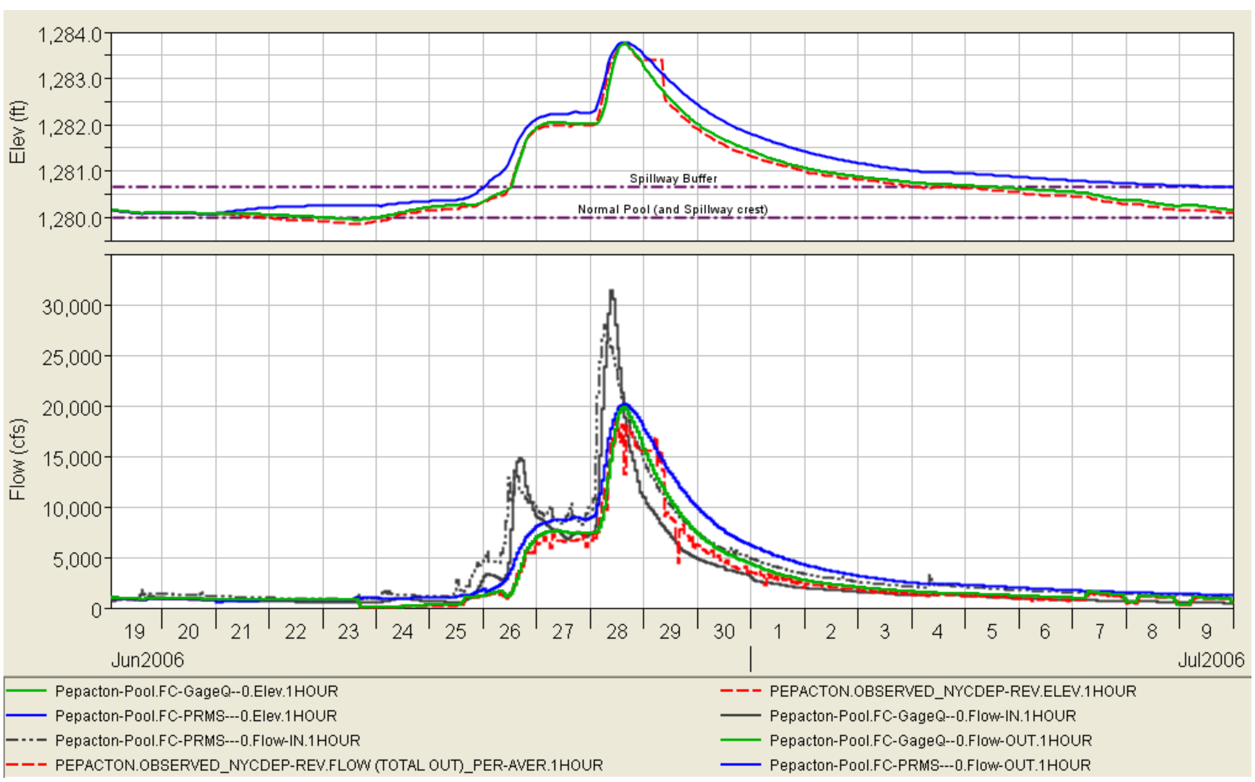


Figure 5.12 Pepacton Reservoir Plot – 2006 Event

5.2.1.5 Downsville

In the *FC-GageQ* alternative, the observed diversion flow from Pepacton was used in the simulation. With the diversion flow established, the sum of the controlled release and uncontrolled spillway flow closely matches the gaged outflow, as can be seen in the plots (Figure 5.13 through Figure 5.15).

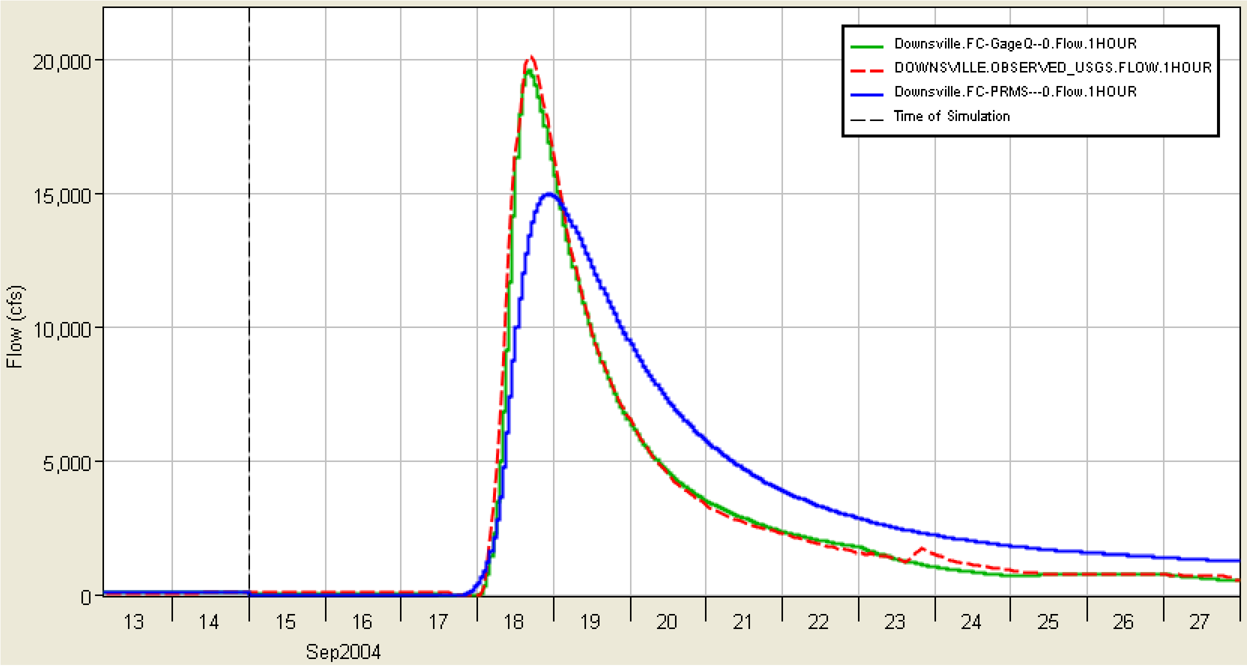


Figure 5.13 Downsville Operations Plot – 2004 Event

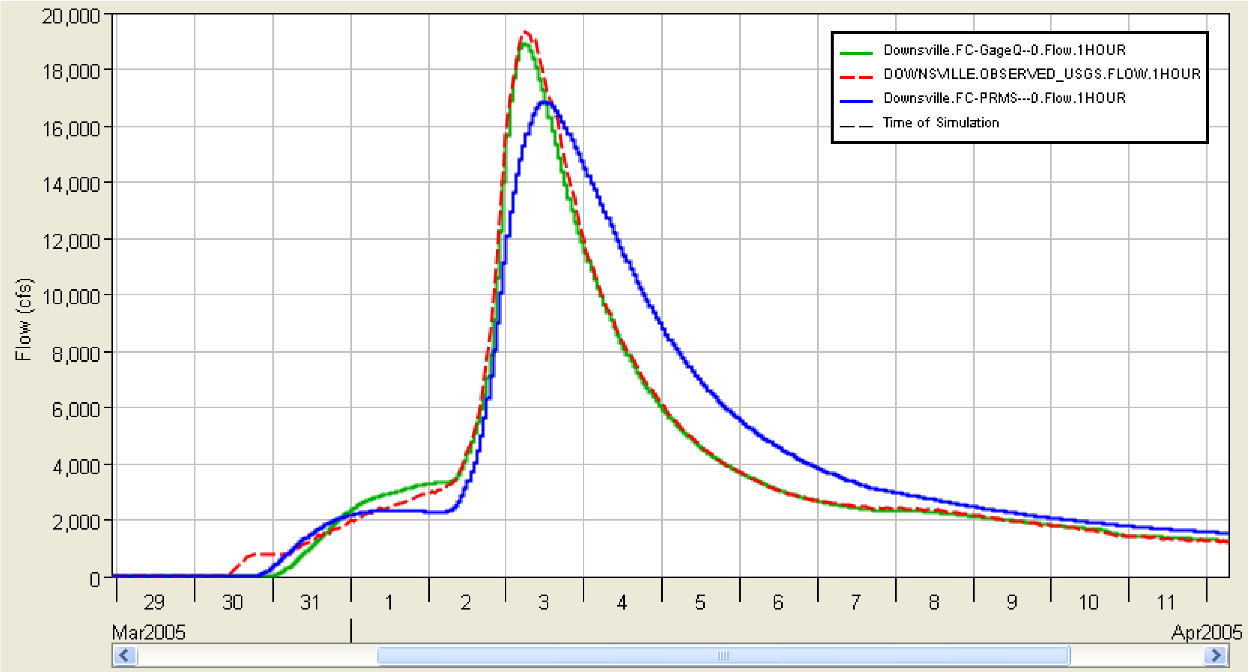


Figure 5.14 Downsville Operations Plot – 2005 Event

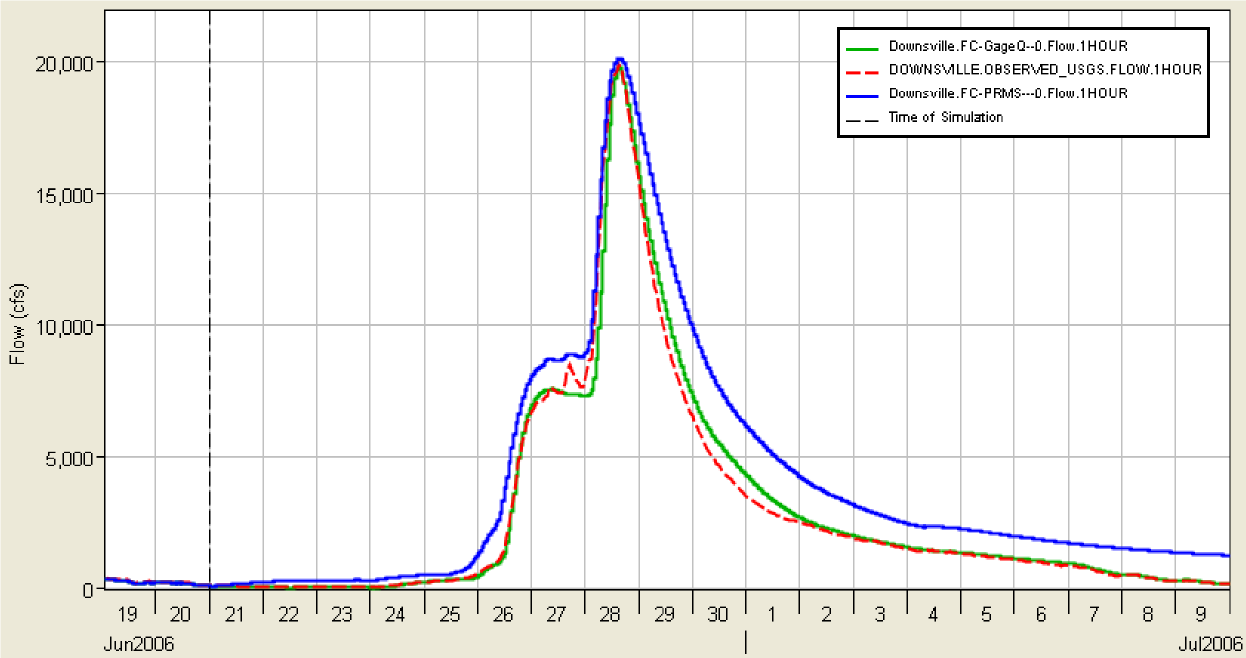


Figure 5.15 Downsville Operations Plot – 2006 Event

5.2.1.6 Harvard

Harvard is the first NWS forecast location downstream of the Pepacton Reservoir. Figure 5.16 through Figure 5.18 shows the computed total and cumulative local flow at Harvard for the three events.

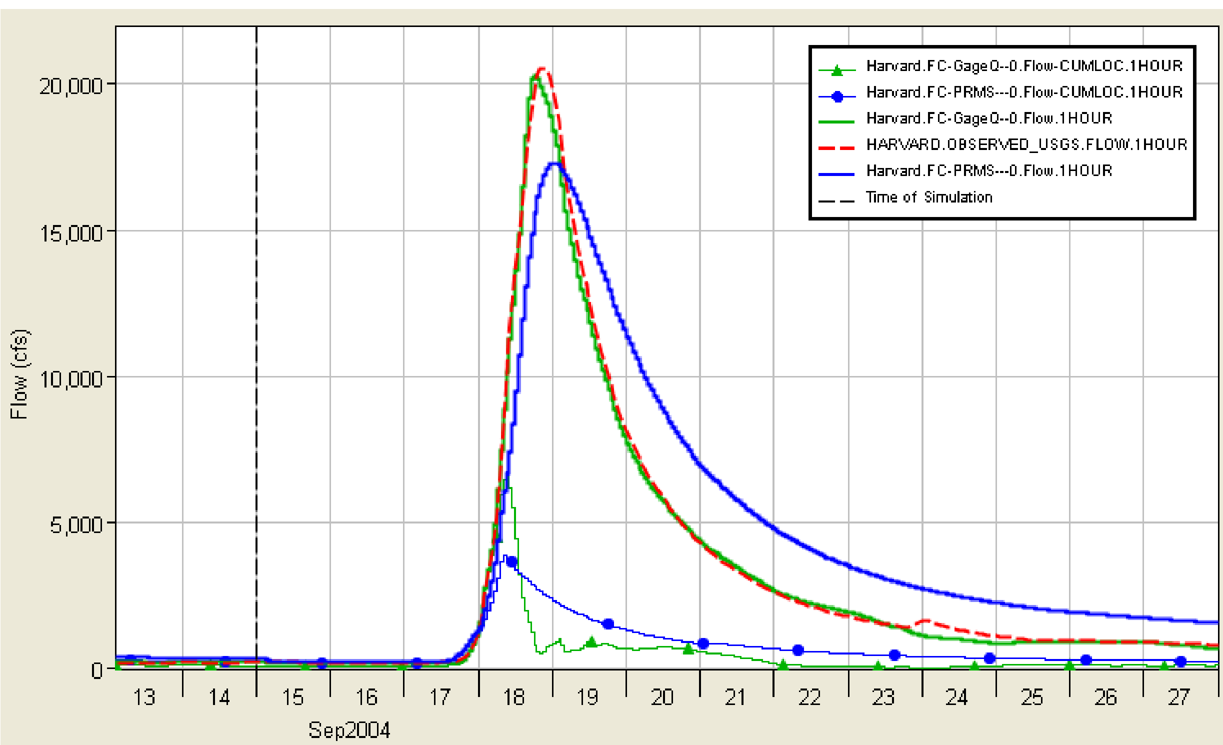


Figure 5.16 Harvard Total and Cumulative Local Flow – 2004 Event

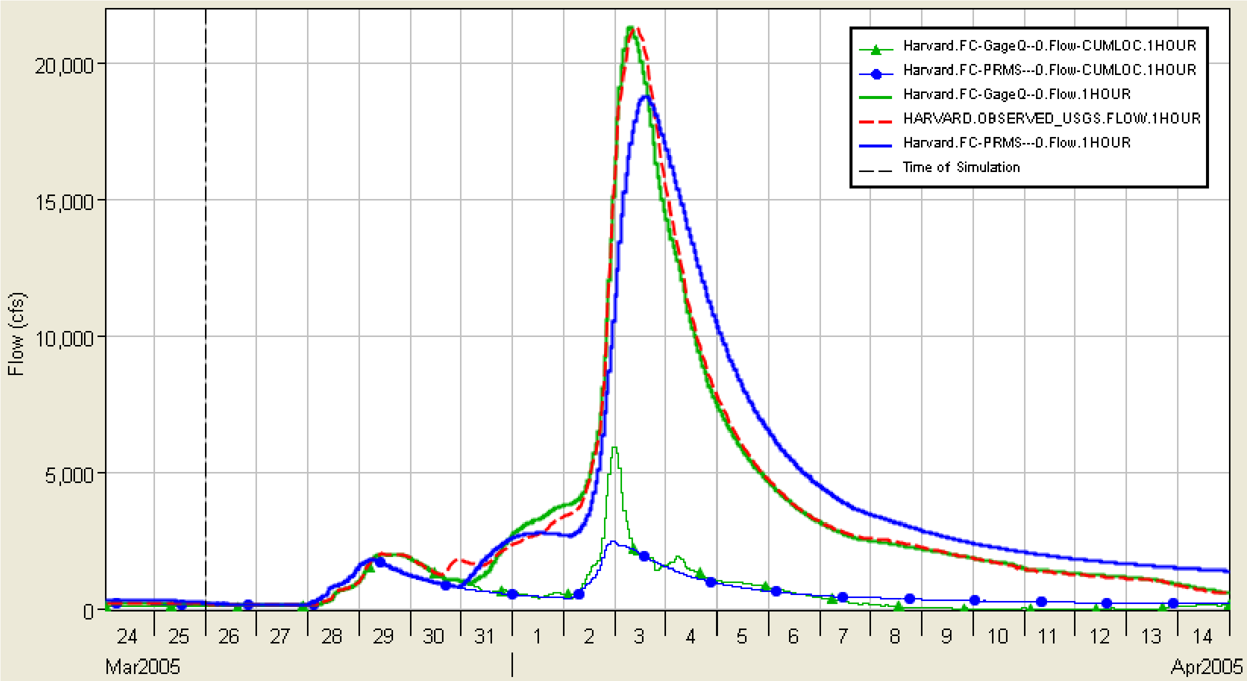


Figure 5.17 Harvard Total and Cumulative Local Flow – 2005 Event

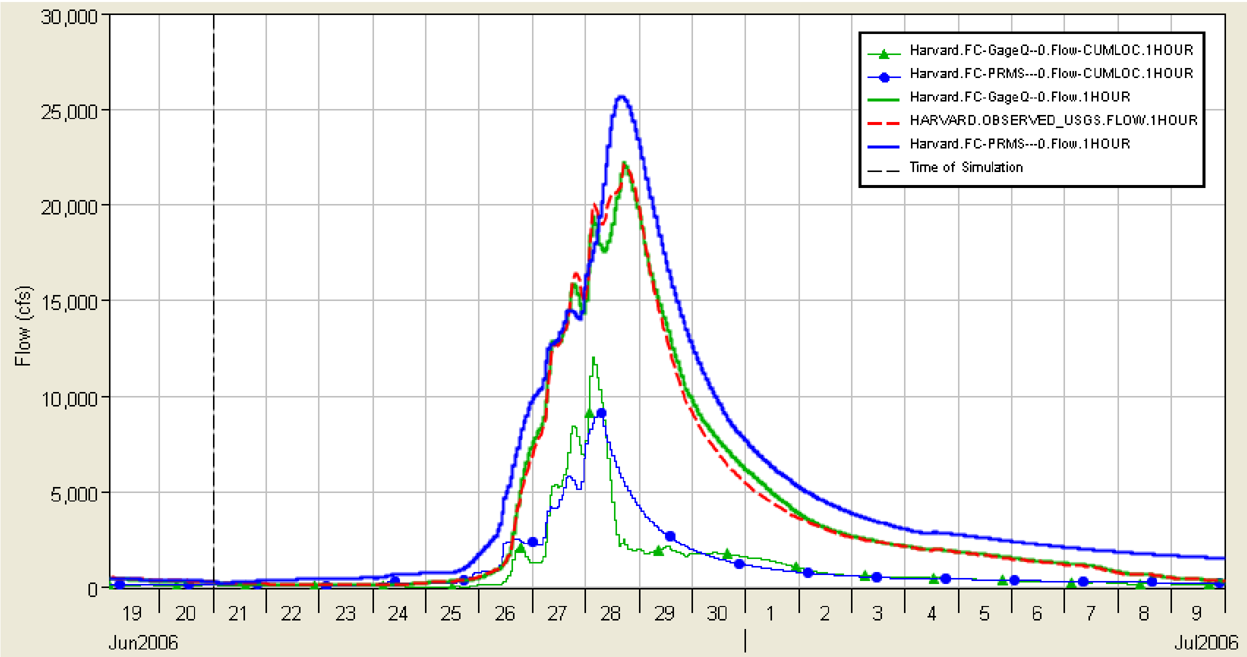


Figure 5.18 Harvard Total and Cumulative Local Flow – 2006 Event

5.2.1.7 Barryville

Barryville is the last gage location on the Delaware River before the confluence with the Lackawaxen River. The high peak in the cumulative local flow and the broad peak of the outflow illustrated in Figure 5.19 indicates that the peak releases from the upstream reservoirs were delayed and the combination of spill with local flow did not substantially increase the peak flow at Barryville.

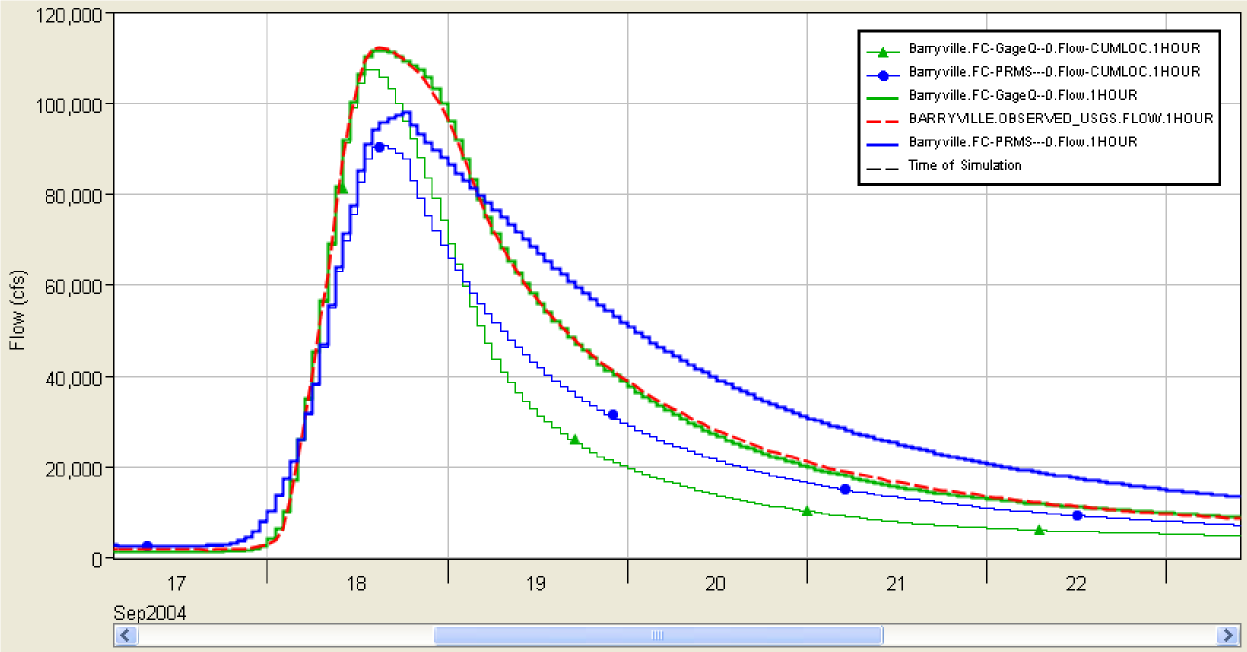


Figure 5.19 Barryville Total and Cumulative Local Flow – 2004 Event

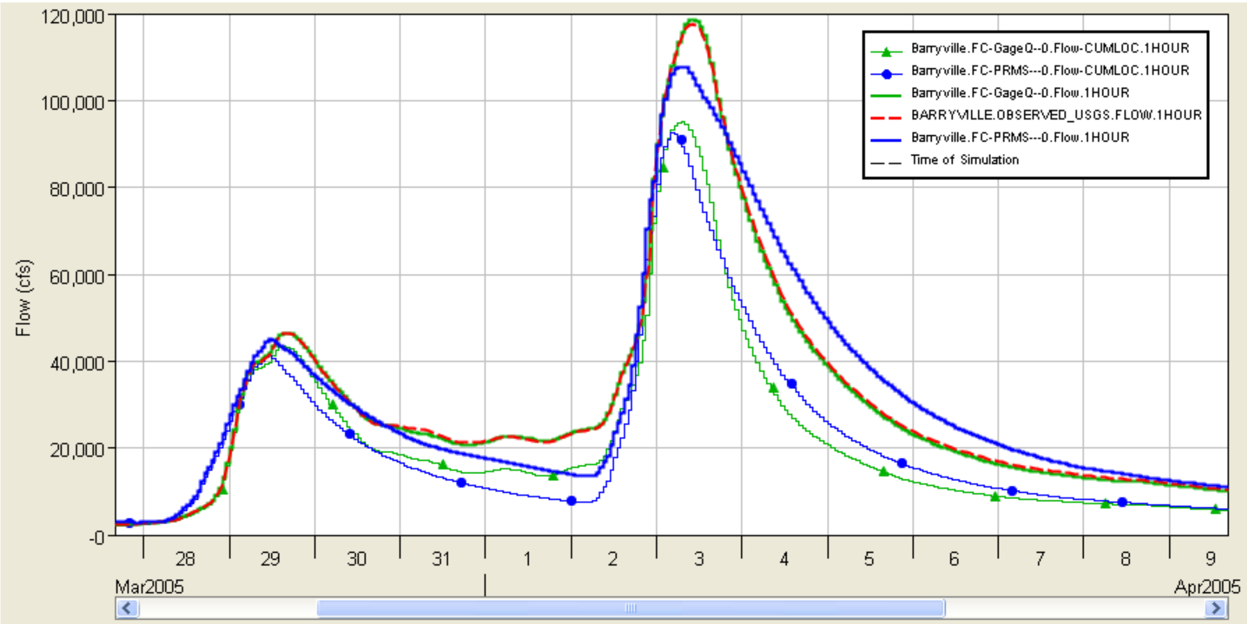


Figure 5.20 Barryville Total and Cumulative Local Flow – 2005 Event

Figure 5.21 shows a gap in the observed record during the peak of the 2006 event. Gaps like this can be seen in a number of other figures in this chapter and usually represent a failure of some kind in the gage measuring, recording, or reporting equipment.

5.2.1.8 Neversink

In the Delaware River Basin, New York City typically meets most of its water supply demands from Neversink and Pepacton Reservoirs, using Cannonsville to meet downstream flow

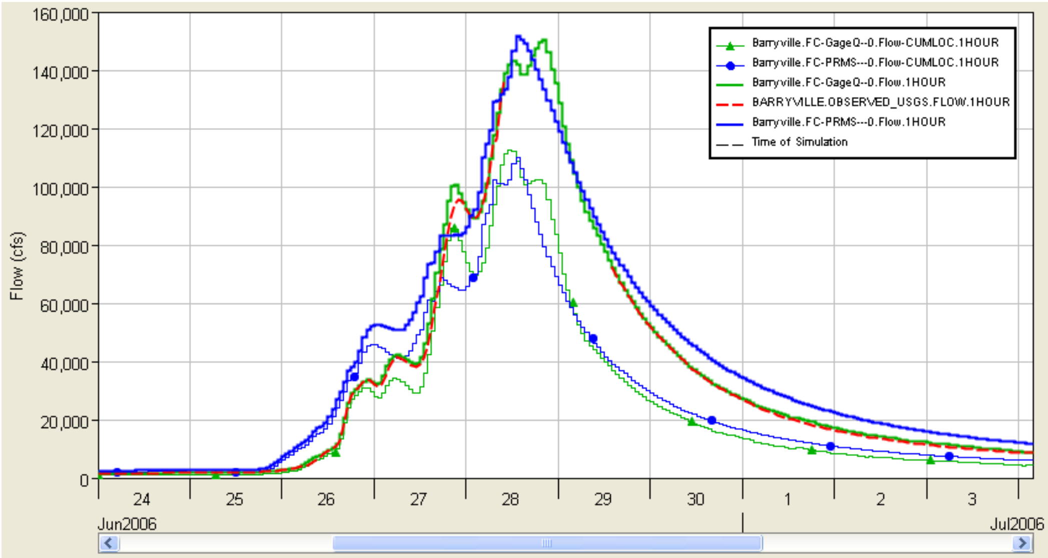


Figure 5.21 Barryville Total and Cumulative Local Flow – 2006 Event

objectives at Montague on the Delaware River. Defining the operation of the diversion was challenging given the preferential uses of the reservoirs.

As described in Chapter 3, the diversion operations are the primary operational difference between the *FC-GageQ* and *FC-PRMS* alternatives. The results of this difference are most apparent at Neversink Reservoir. In each of the three events, the *FC-PRMS* alternative produces a drawdown of the Neversink pool in advance of the event. This drawdown is primarily caused by the estimated diversion operations used in the *FC-PRMS* alternative and can be seen in Figure 5.22 through Figure 5.24. Following the Neversink Reservoir plots, Figure 5.25 through Figure 5.27, show plots of the Neversink diversion, were added to illustrate the difference in the operation of the diversion between the two alternatives.

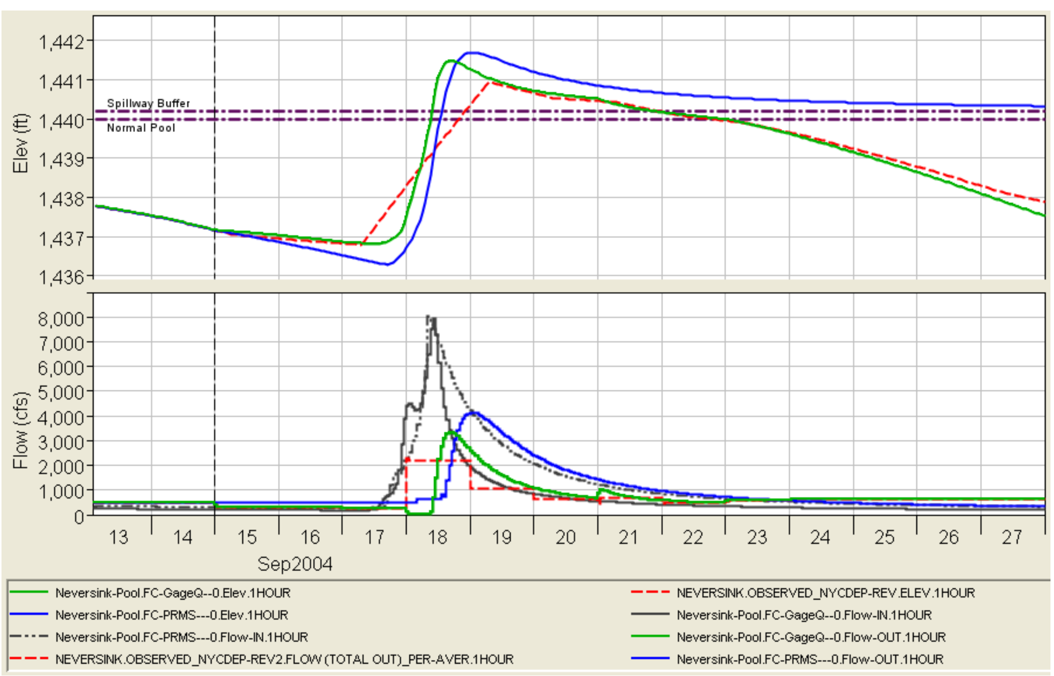


Figure 5.22 Neversink Reservoir Plot – 2004 Event

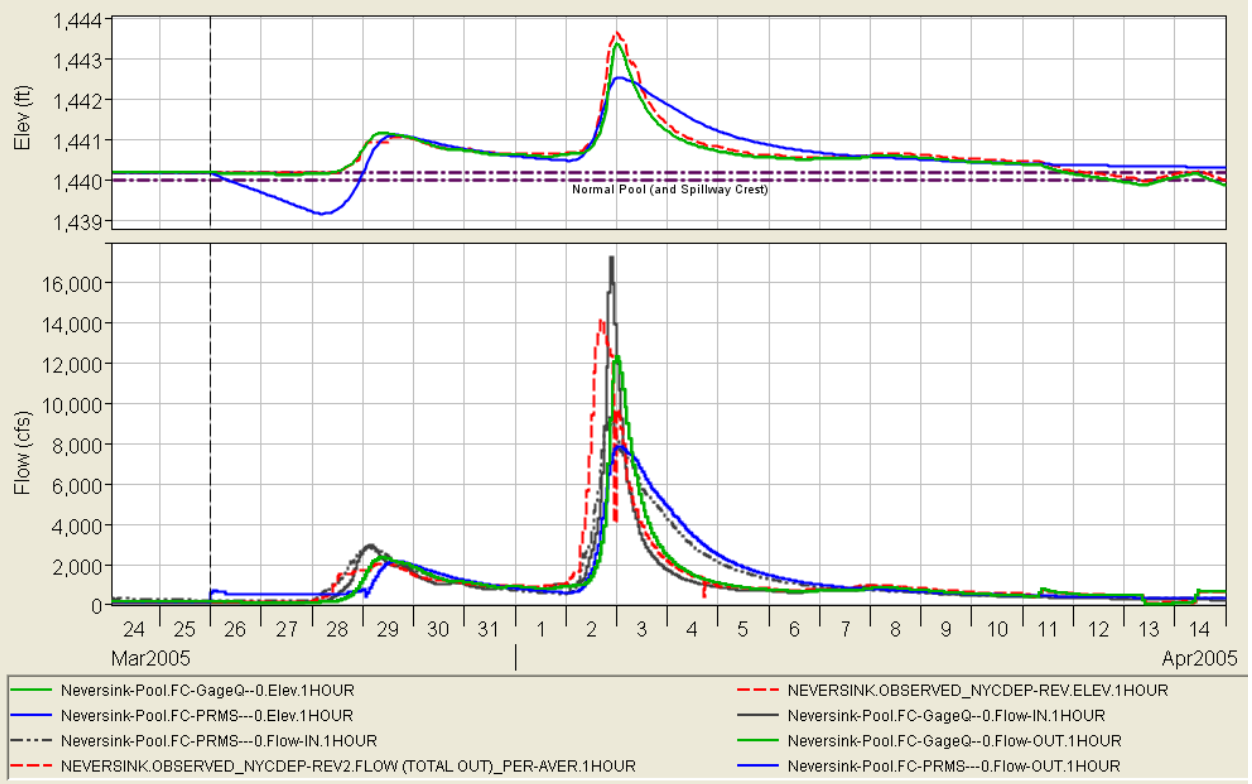


Figure 5.23 Neversink Reservoir Plot – 2005 Event

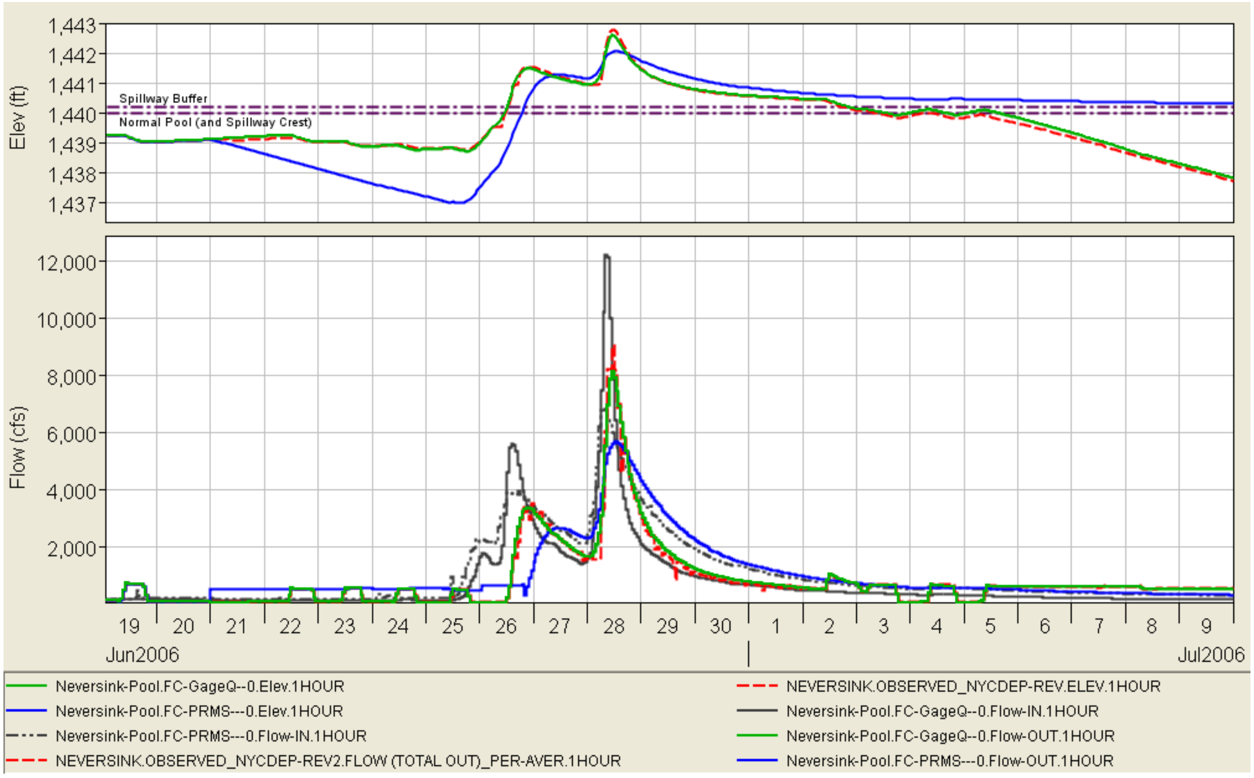


Figure 5.24 Neversink Reservoir Plot – 2006 Event

5.2.1.9 Neversink Diversion to NYC

The diversion flows from Neversink Reservoir are shown in Figure 5.25 through 5.27. In each figure, the *FC-PRMS* alternative, using the estimated diversion operations, produces a substantially larger diversion release than the *FC-GageQ* alternative, which diverts only as much as the observed record specifies.

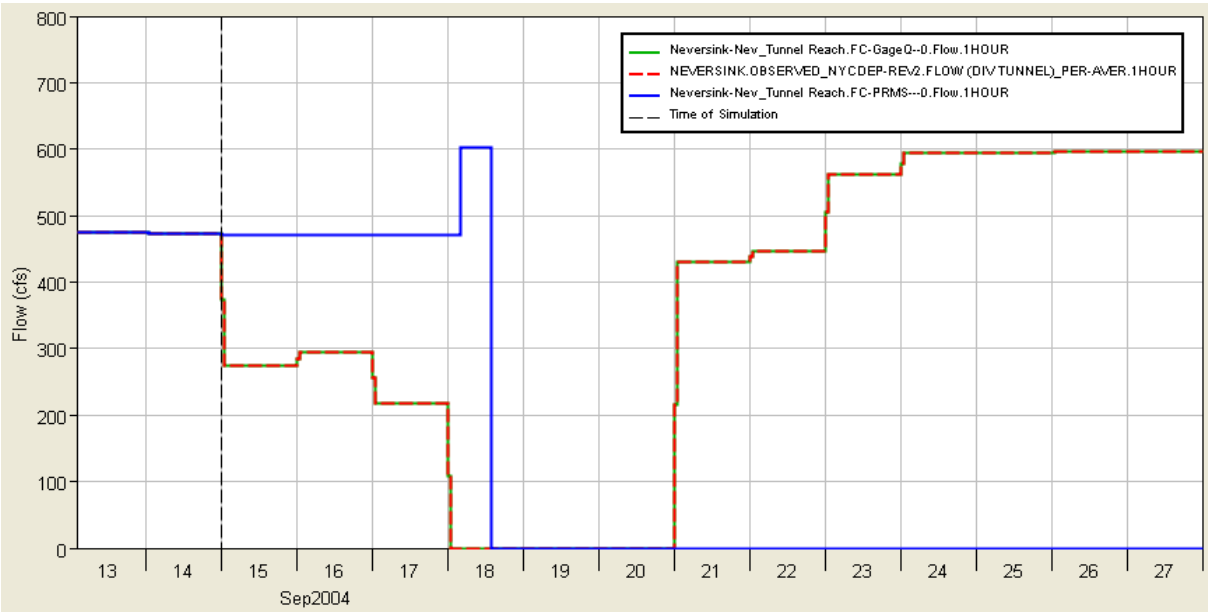


Figure 5.25 Neversink Diversion Plot – 2004 Event

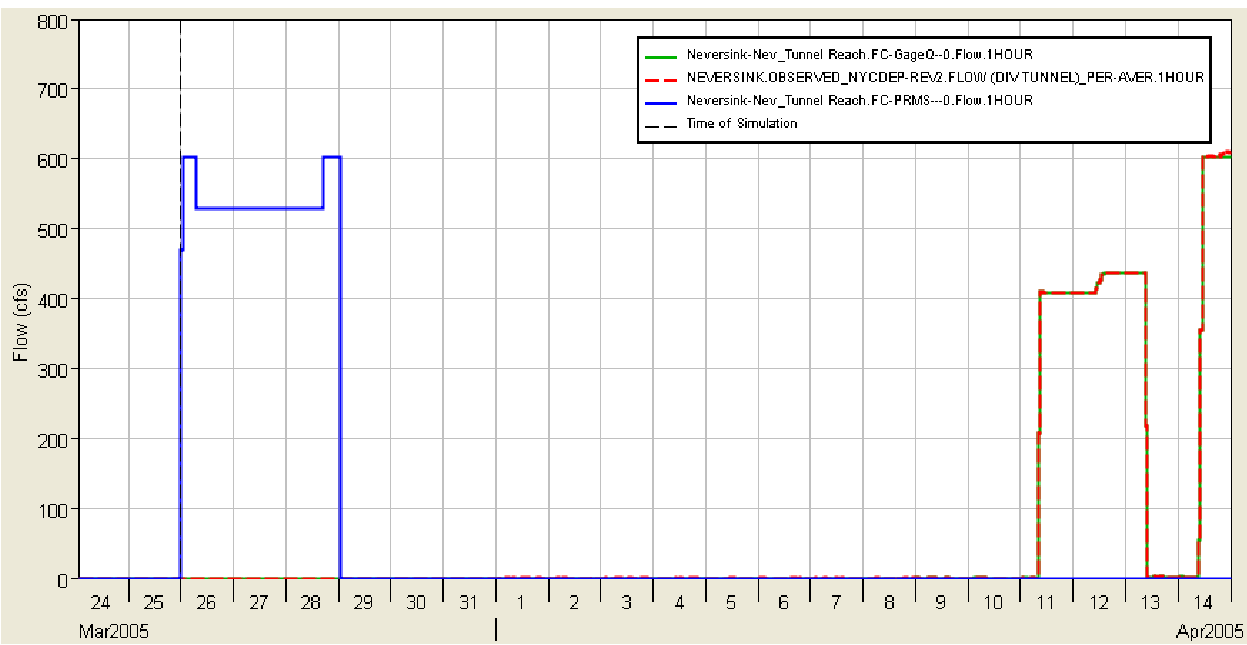


Figure 5.26 Neversink Diversion Plot – 2005 Event

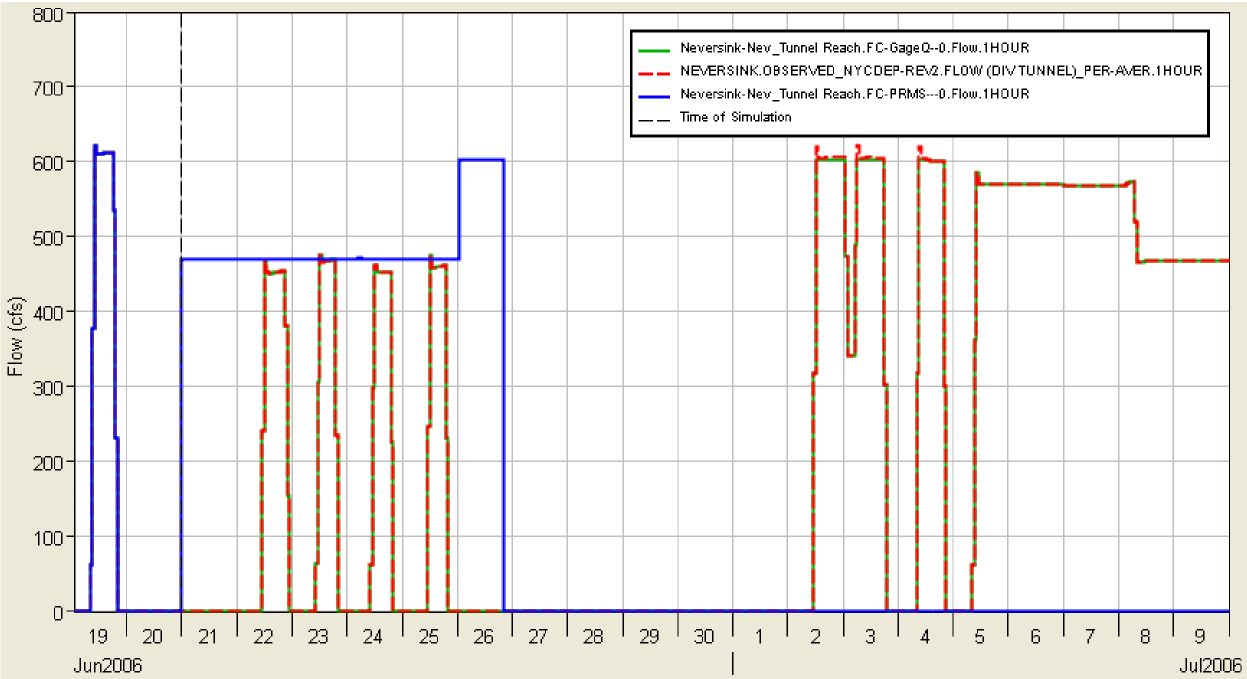


Figure 5.27 Neversink Diversion Plot – 2006 Event

5.2.1.10 Bridgeville

Bridgeville is the first NWS forecast location downstream of Neversink Reservoir. Figure 5.28 through 5.30 show model results at this location. In the 2004 event, the peak of the releases lagged behind the substantial peak of the local inflow producing a double peak at Bridgeville. In the 2005 and 2006 events, the peak of the local coincided with the arrival of the peak release.

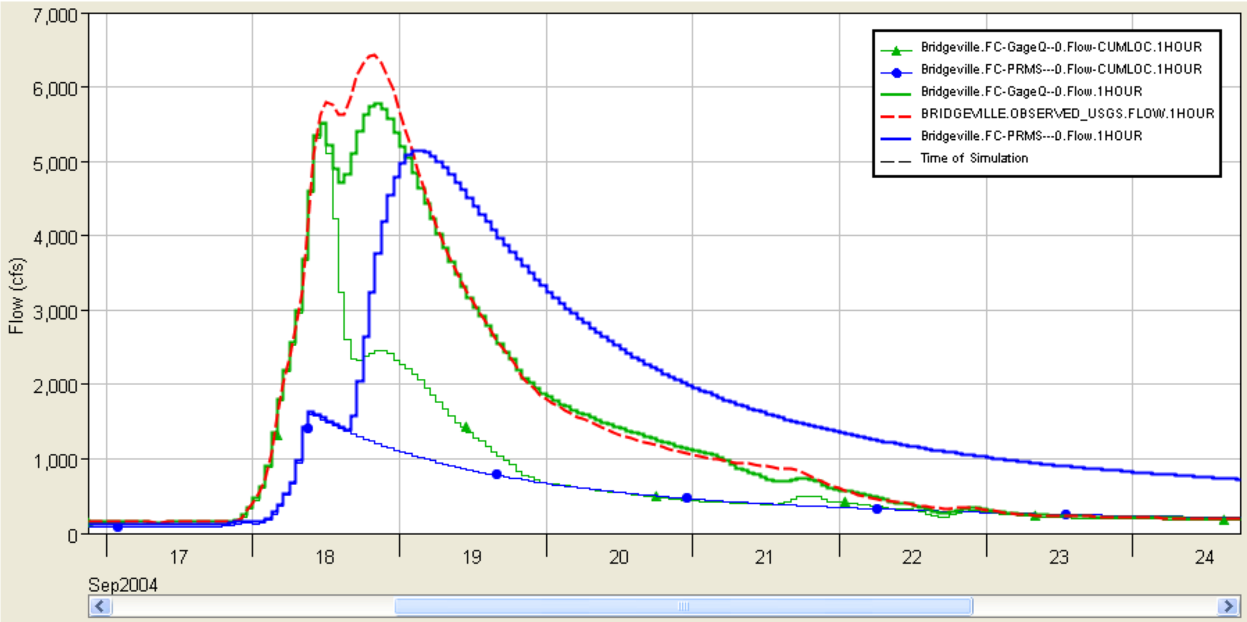


Figure 5.28 Bridgeville Junction Plot – total and cumulative local flow – 2004 Event

The simulated flows of the *FC-GageQ* alternative for the 2005 and 2006 events match the observed record reasonably well. The *FC-GageQ* results for 2004 do not match as well. The shape and timing of the hydrograph is good, but the magnitudes of the peaks are significantly different. Review of the results upstream at Neversink Reservoir and downstream at Montague showed that results at these locations matched the observed record well, so no model adjustments were made for Bridgeville.

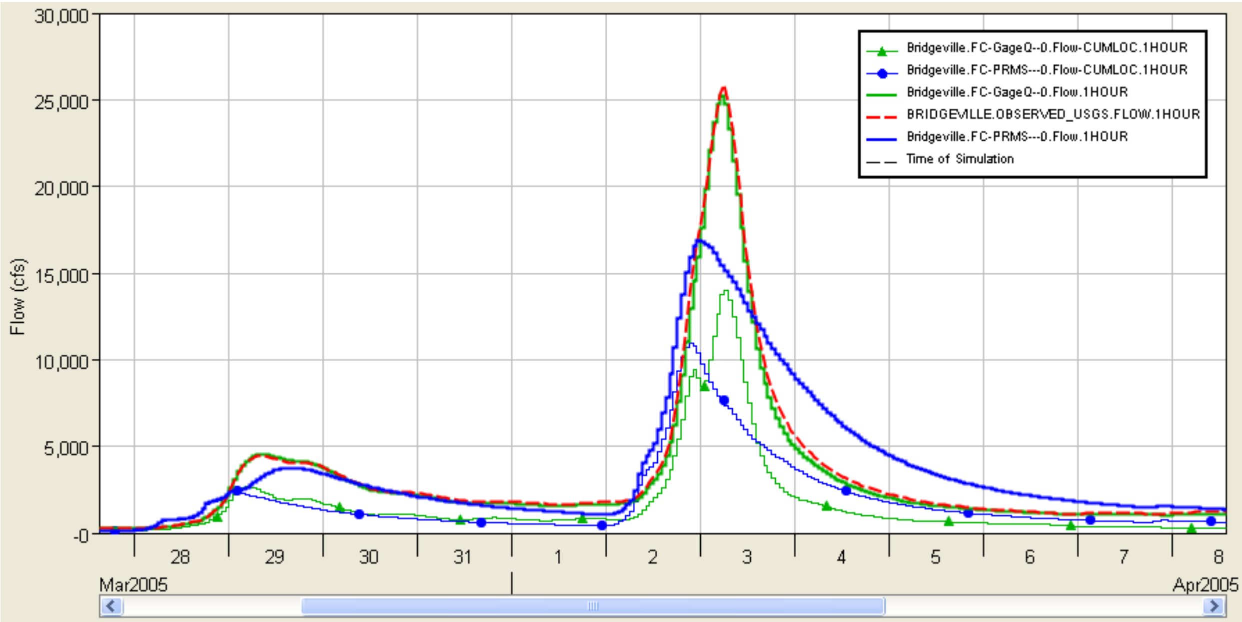


Figure 5.29 Bridgeville Junction Plot – total and cumulative local flow – 2005 Event

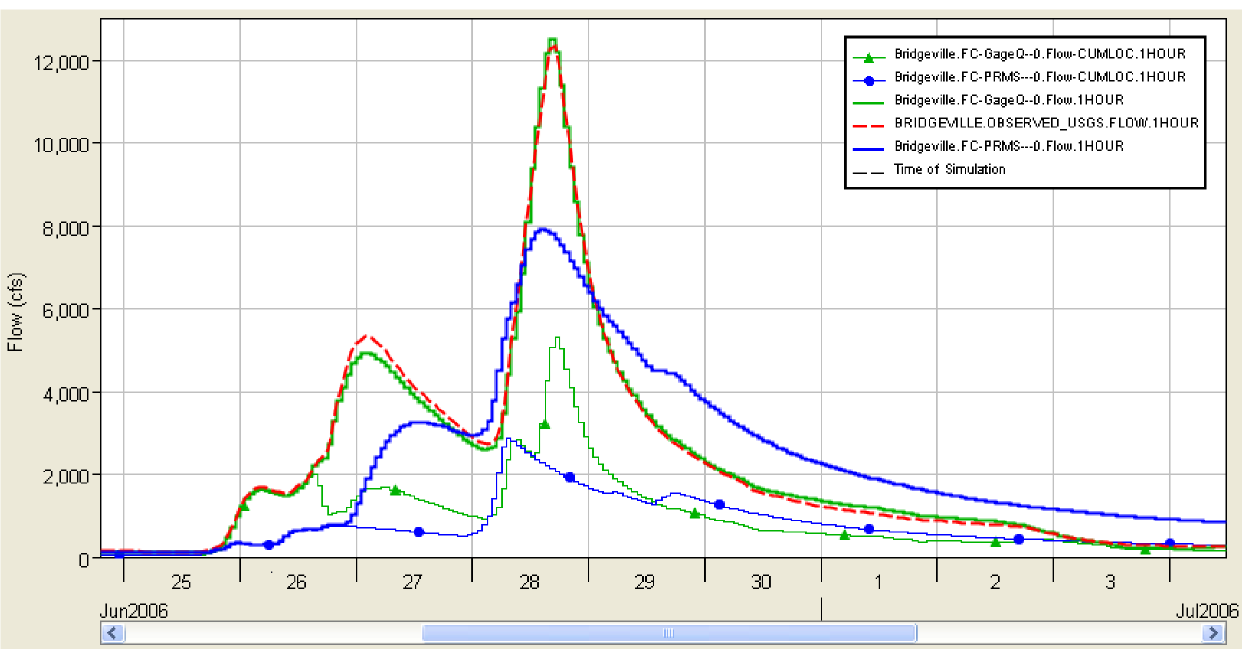


Figure 5.30 Bridgeville Junction Plot – total and cumulative local flow – 2006 Event

5.2.2 Lackawaxen River Basin

The Lackawaxen Basin contains three reservoirs that provide flood control to the basin, two US Army Corps of Engineers flood damage reduction reservoirs and a PPL hydropower reservoir. The USACE reservoirs, Prompton and Jadwin, were designed with primary outlet works that have a maximum uncontrolled release capacity equal to the local channel capacity. The spillway operations of the PPL project, Lake Wallenpaupack, are designed to not exceed channel capacity even during the largest probable inflow events.

5.2.2.1 Prompton

The main intake at Prompton was designed to maintain a recreation pool at 1,124 feet. A smaller, lower level intake was also included to maintain a minimum channel flow during dry conditions. The sill of the emergency spillway is at 1,205 feet, well above the highest level reached during these three events. Model results for the three events are show in Figures 5.31 through 5.33. Although results for the *FC-GageQ* alternative match the basic shape and timing of the observed elevation and outflow hydrographs, the results miss the recorded peak release and pool elevation for all three events. As is true for most reservoirs, this is likely due to the accuracy of the reservoir storage and outlet capacity data. Due to sedimentation processes in the reservoir pool, the storage-elevation relationship used in the model may not accurately reflect the shape of the reservoir during one or more of these events. Also, the outlet capacity data used in the model represents the design capacities and may not reflect the as-built or as-modified condition of the structures.

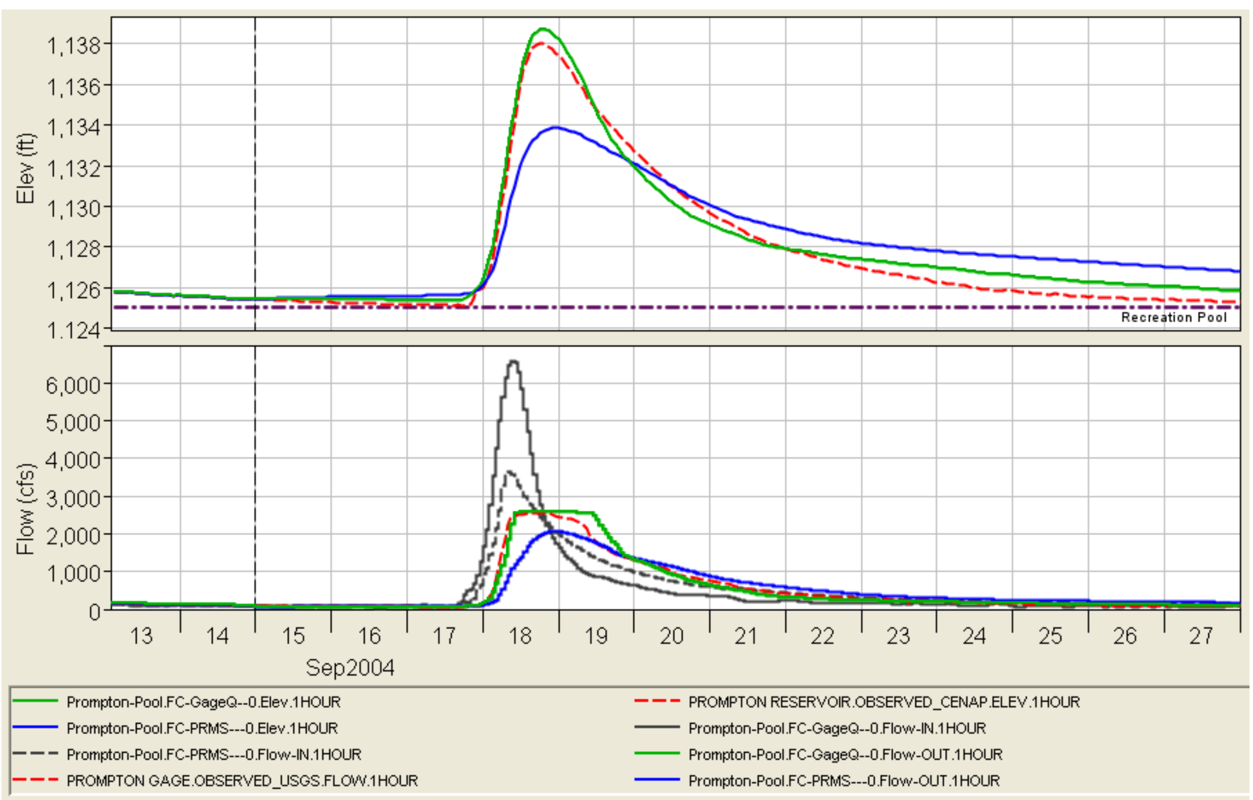


Figure 5.31 Prompton Reservoir Plot – 2004 Event

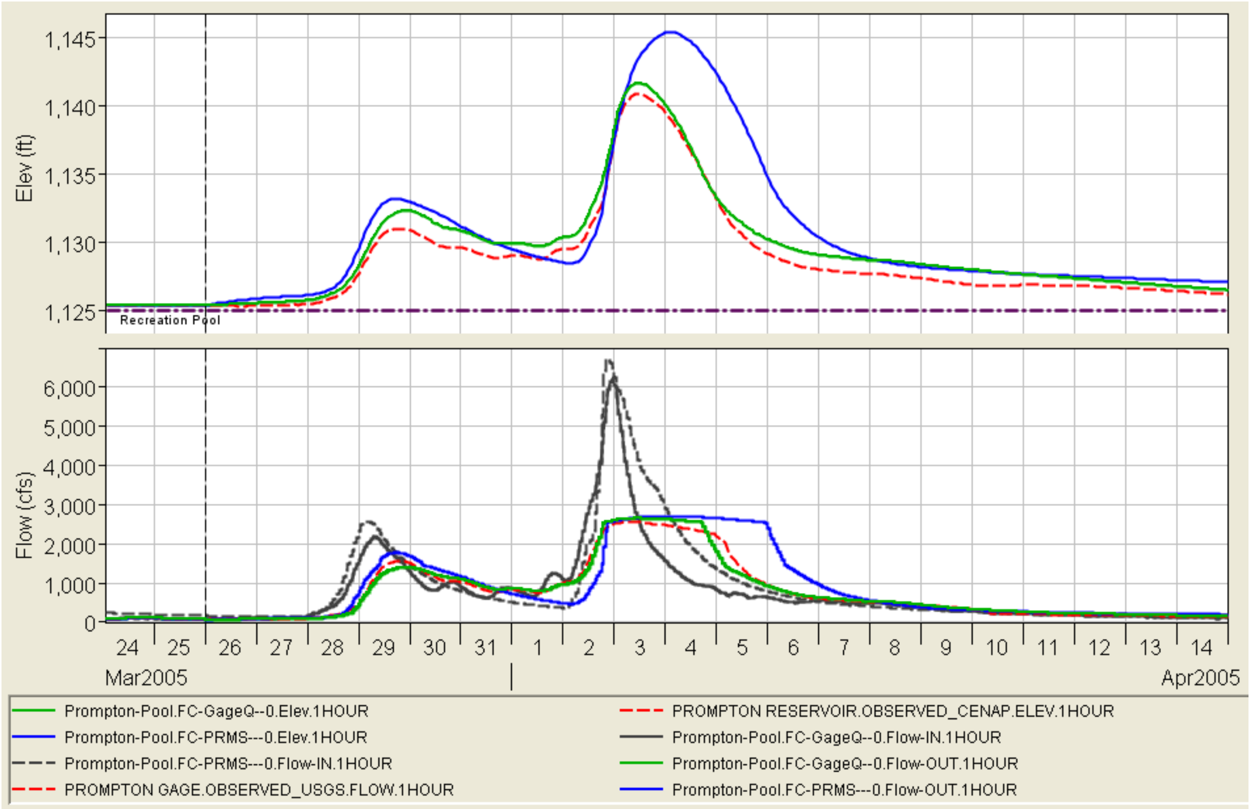


Figure 5.32 Prompton Reservoir Plot – 2005 Event

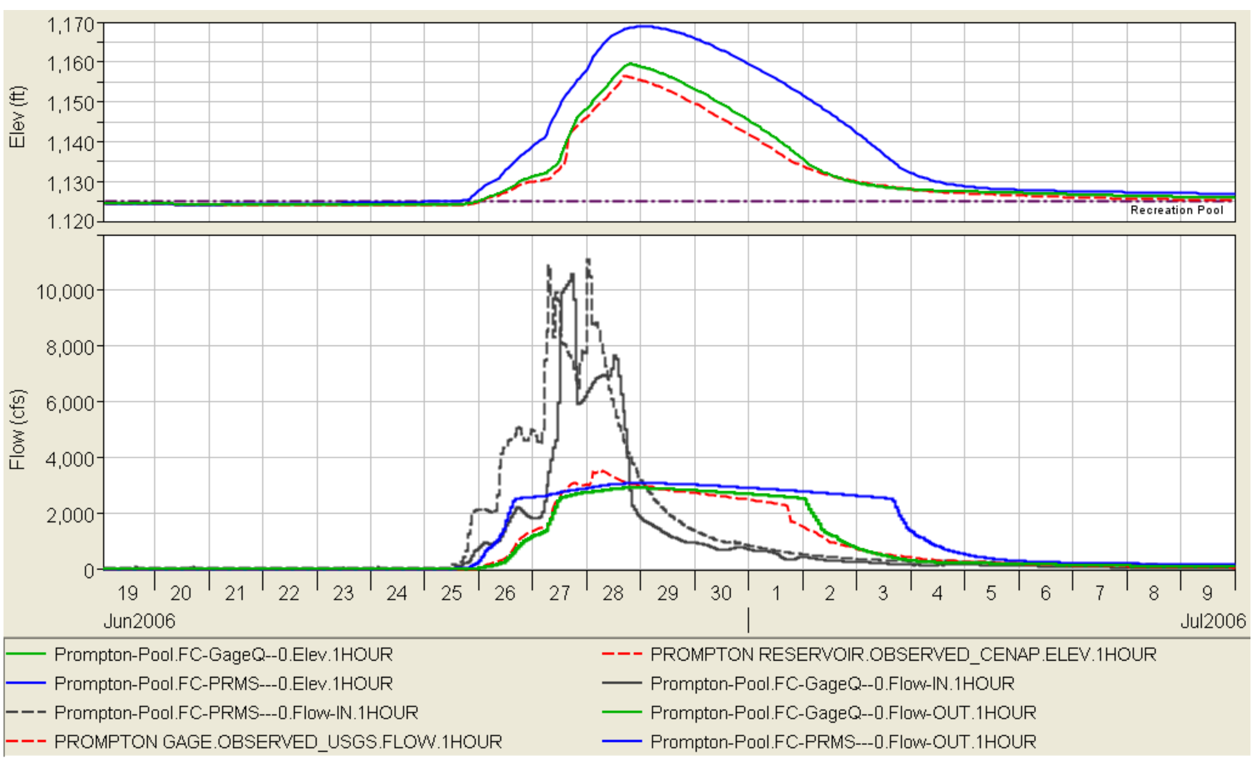


Figure 5.33 Prompton Reservoir Plot – 2006 Event

5.2.2.2 Jadwin

As a flood control reservoir, Jadwin is what is often referred to as a dry dam. The outlet works were designed to pass normal stream flows up to the downstream channel capacity. Thus, under normal conditions, no pool is maintained behind Jadwin dam. However, once inflows exceed outlet capacity, the pool will begin to fill. After the inflow event recedes, the outlet will continue to flow at capacity until the pool has emptied.

The natural channel invert is 973 feet at the intake to the outlet tunnel and normal channel depth ranges between 974 and 990 feet. The pool gage at Jadwin is located near the upstream face of the dam and does not measure depths in the natural stream channel. When the dam is dry, the gage records a value of approximate 989.2 feet as shown in Figures 5.34 through 5.36. 990 feet is the minimum measurement the gage recognizes as the point at which actual storage occurs in the reservoir.

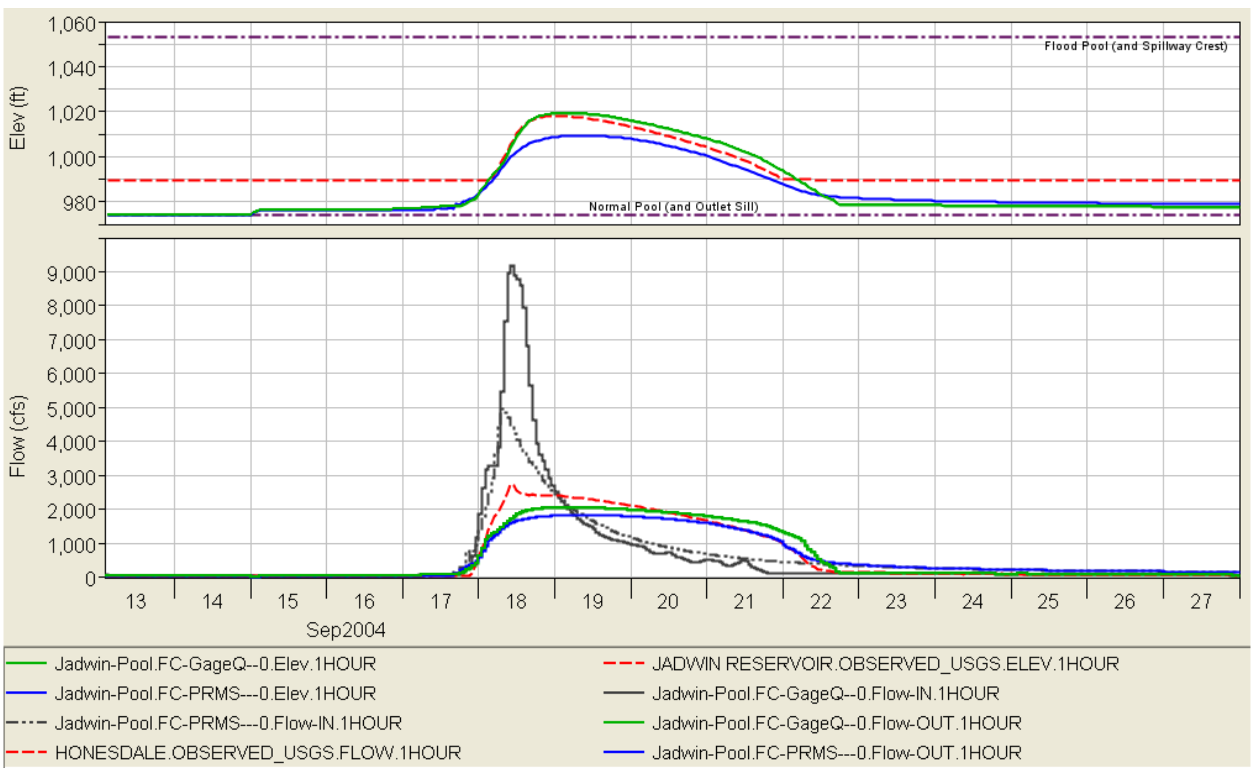


Figure 5.34 Jadwin Reservoir Plot – 2004 Event

All three events modeled were large enough to produce a pool behind Jadwin dam. The 2004 event raised the pool by over forty feet in about thirty-six hours, reaching a maximum pool elevation of about 1,019 feet. Similar behavior was exhibited during the 2005 event with a maximum pool height of about 1,020 feet. 2006 was the largest of the three events at Jadwin, both in terms of peak inflow and duration. This event caused the pool to rise to approximately 1,040 feet, still thirteen feet below the spillway crest of 1,053 feet.

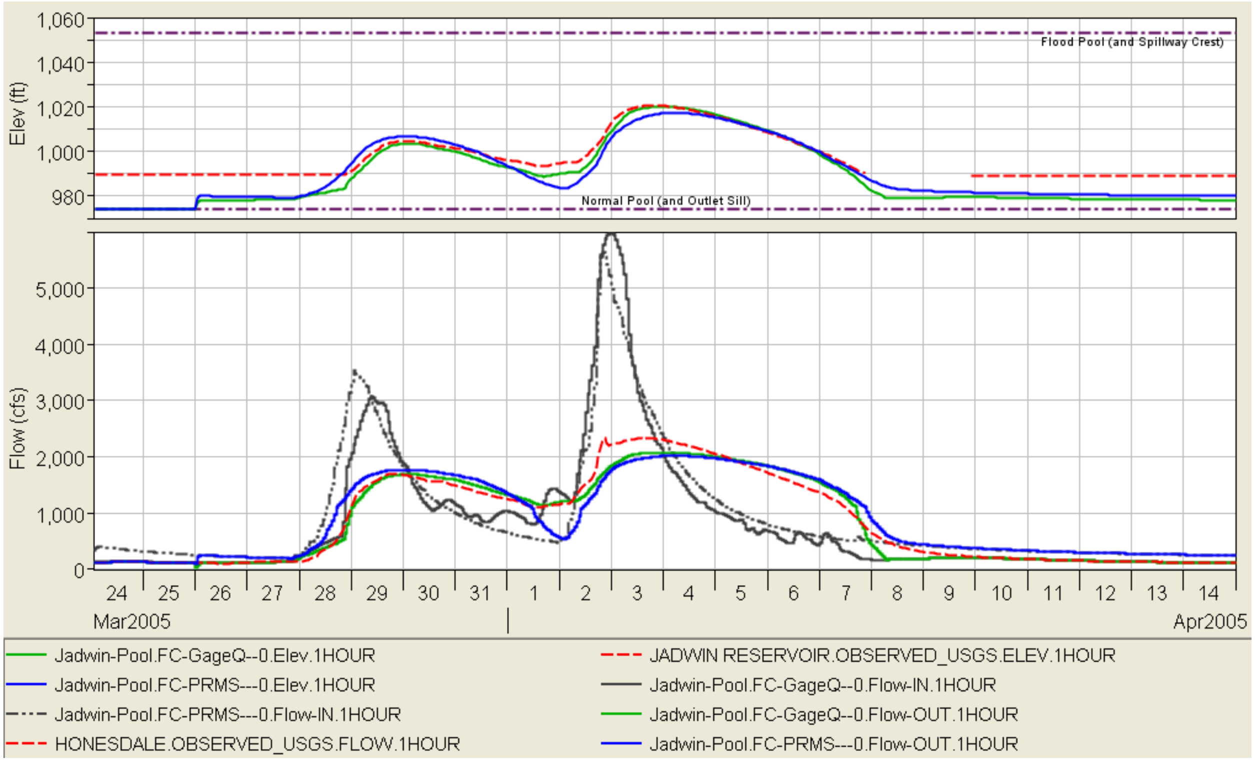


Figure 5.35 Jadwin Reservoir Plot – 2005 Event

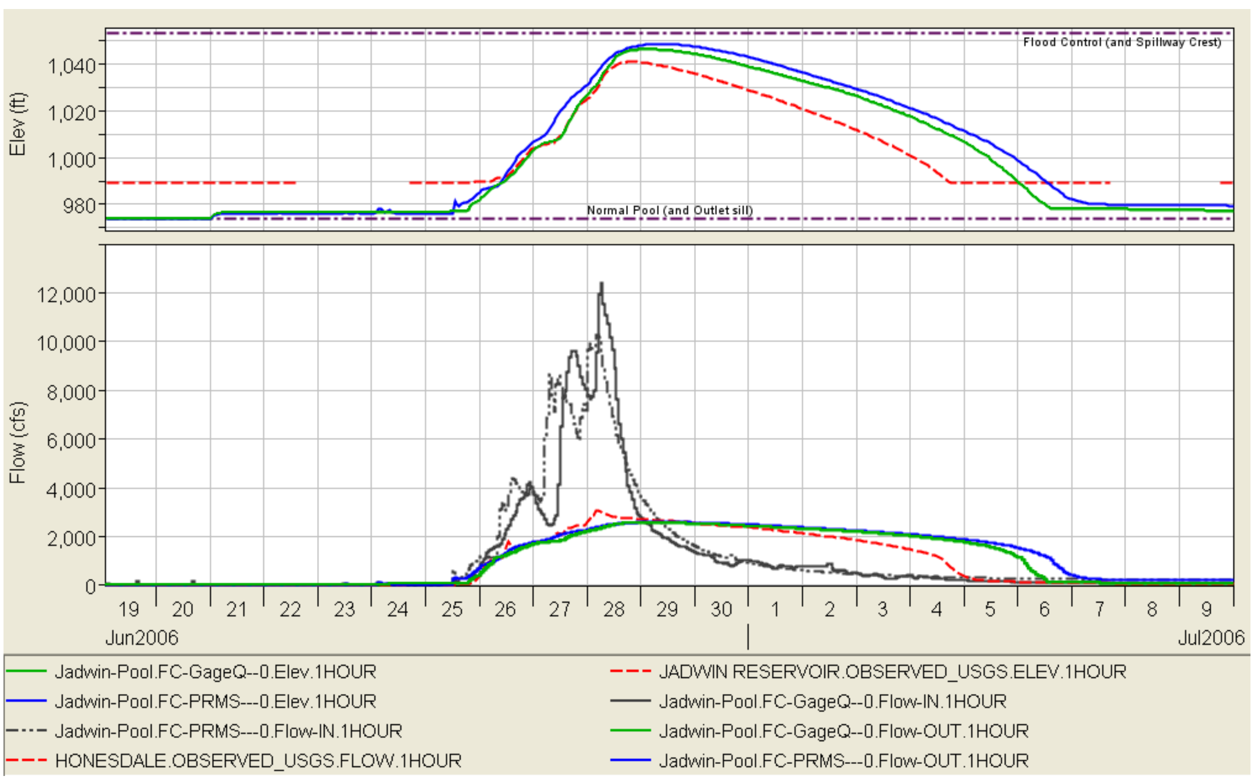


Figure 5.36 Jadwin Reservoir Plot – 2006 Event

5.2.2.3 Hawley

Hawley is a USGS stream gage location just upstream of the confluence of the Lackawaxen River with Wallenpaupack Creek and reflects releases from both Prompton and Jadwin. Although this location is not directly impacted by releases from Lake Wallenpaupack, this gage can be used by the operators at Lake Wallenpaupack to determine required releases. The plots in Figure 5.37 through Figure 5.39 show computed and observed flow and stage at Hawley for the three events. The results for the *FC-GageQ* match the observed record well, however the peak flows in the 2004 and 2006 events are not quite captured. This is due to the limitations of the model to mimic the recorded peak releases from Prompton and Jadwin Reservoirs.

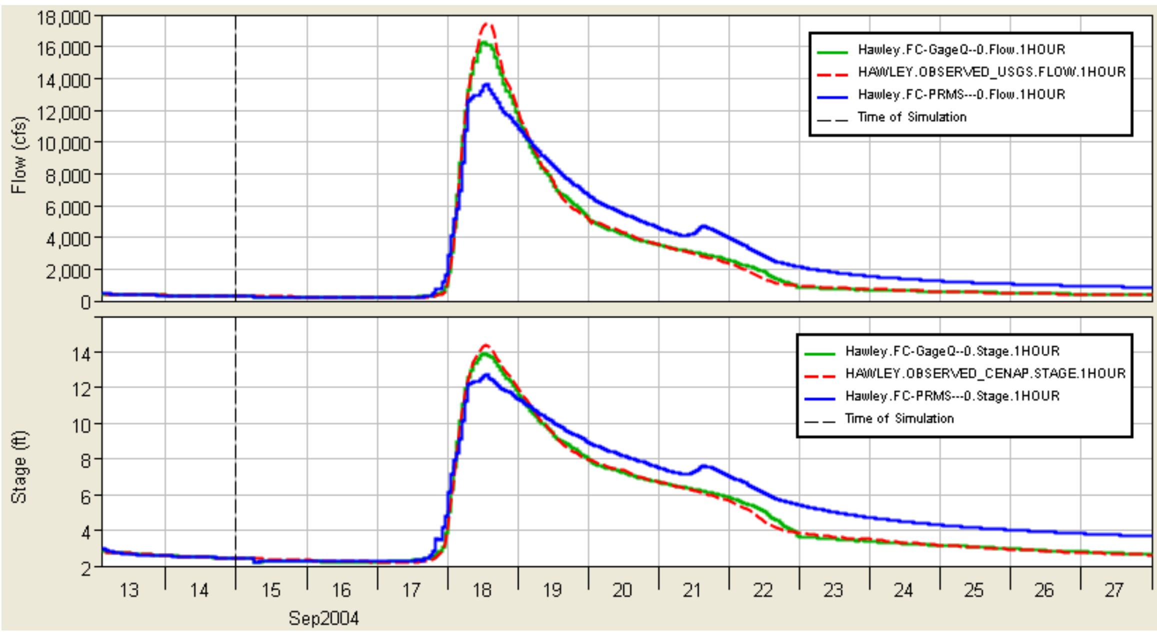


Figure 5.37 Hawley Flow and Stage – 2004 Event

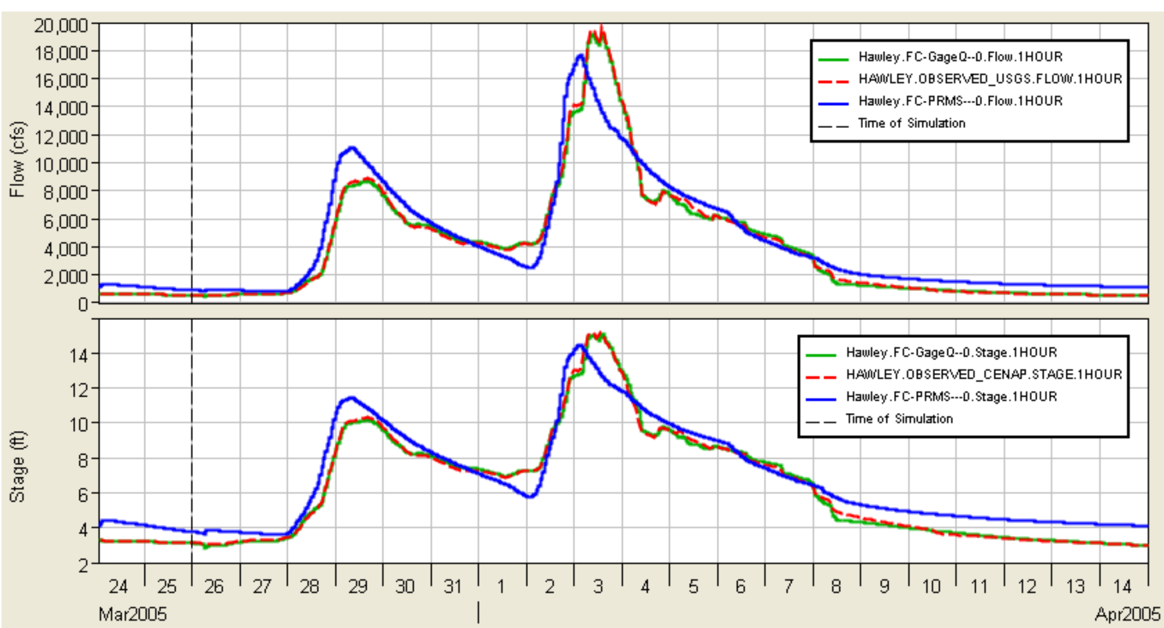


Figure 5.38 Hawley Flow and Stage – 2005 Event

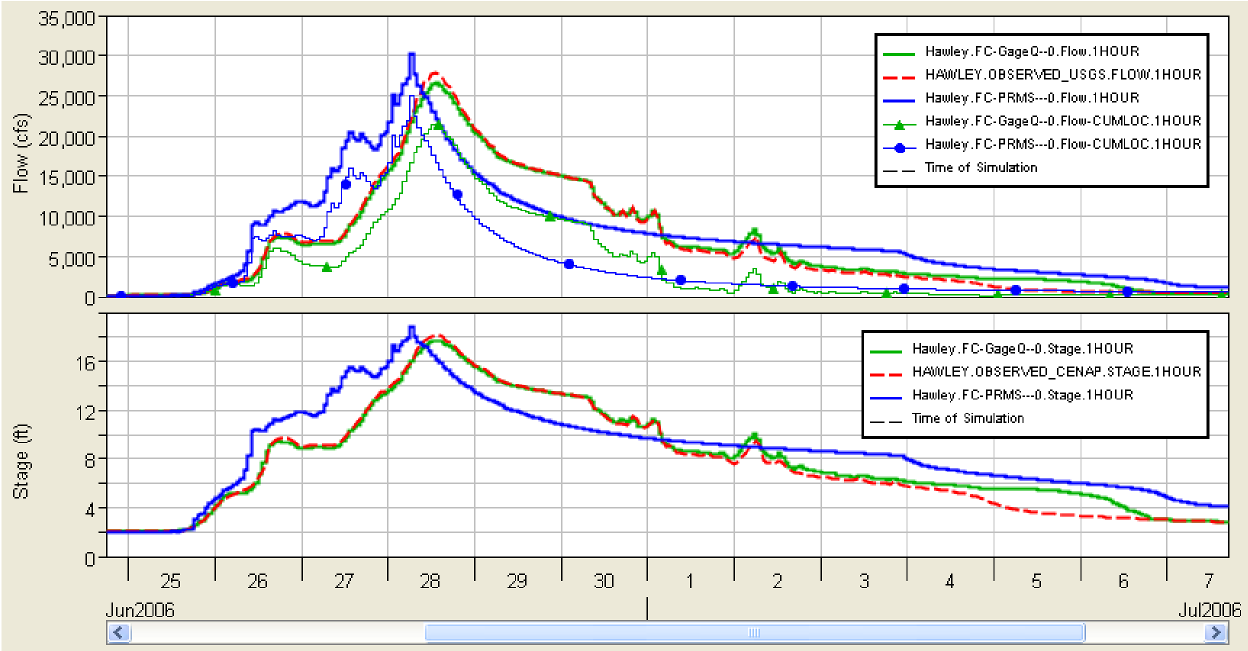


Figure 5.39 Hawley Flow and Stage – 2006 Event

5.2.2.4 Lake Wallenpaupack

The model results at Lake Wallenpaupack differ from observed for at least three reasons. The first reason is the quality and completeness of the observed data. Two sources of data were provided for Lake Wallenpaupack: 1) Pennsylvania Power and Light (PPL) – the owner/operator of the reservoir and 2) the Federal Energy Regulatory Commission (FERC). The PPL data covered all three events and included pool elevation and flow. However, review of the data identified that the observed flow record represented powerhouse flow only and did not include spillway flow. The FERC data covered only part of the 2005 and 2006 events, but included separate records for the powerhouse and the spillway, as well as a combined total. Another difference between the two sources of observed data was in the pool elevation data. The pool elevations in the two records were similar but the FERC record showed somewhat higher pool elevations.

A second reason for the differences between model results and the observed data is in the inflow estimates. The observed data from FERC included a record labeled "estimated 4 hour average inflow" for the 2005 and 2006 events. This data was used to validate the derived inflows based on gage flow in a nearby basin adjusted for basin size.

The third reason for the differences is the operation scheme defined in the model. As noted in Chapter 3, PPL flood operations are complex and involve real-time decisions made by consensus of the various managers of the reservoir's systems. The flood operations in the model represent normal flood operations as described in the manual and uses the most important factors that would result in a decision to release from the spillway.

Since the primary purpose of Lake Wallenpaupack is to generate hydropower, normal flood operations of the reservoir focus on conserving water in the pool (not spilling). A real-time runoff and reservoir model is used by the operators to forecast inflow and pool elevation. As the pool rises during an event, the first action is to release from the powerhouse at full capacity. If the pool continues to rise, the forecasted pool elevation from PPL's real-time model is used by the managers to determine if the spillway should be used and, if so, to what extent. A number of conditions are involved in the determination to open the spillway gates, some of which can not be represented in the HEC-ResSim model – including the forecasted information supplied to the operators by the PPL model. A simplified set of conditions was defined in the model to approximate the PPL operators' decision-making procedure.

Although the model does not fully mimic the observed operation during the three events, some key behaviors are replicated. For example, the 2004 event did not produce a high enough pool to compel the operators to make spillway releases and the model reflected this. Both the 2005 and 2006 events caused the operators to use the spillway and the model reflected those spill decisions. The spill produced by the model was of lesser magnitude but of longer duration for both events. Model results for Lake Wallenpaupack are illustrated in Figure 5.40 through Figure 5.42.

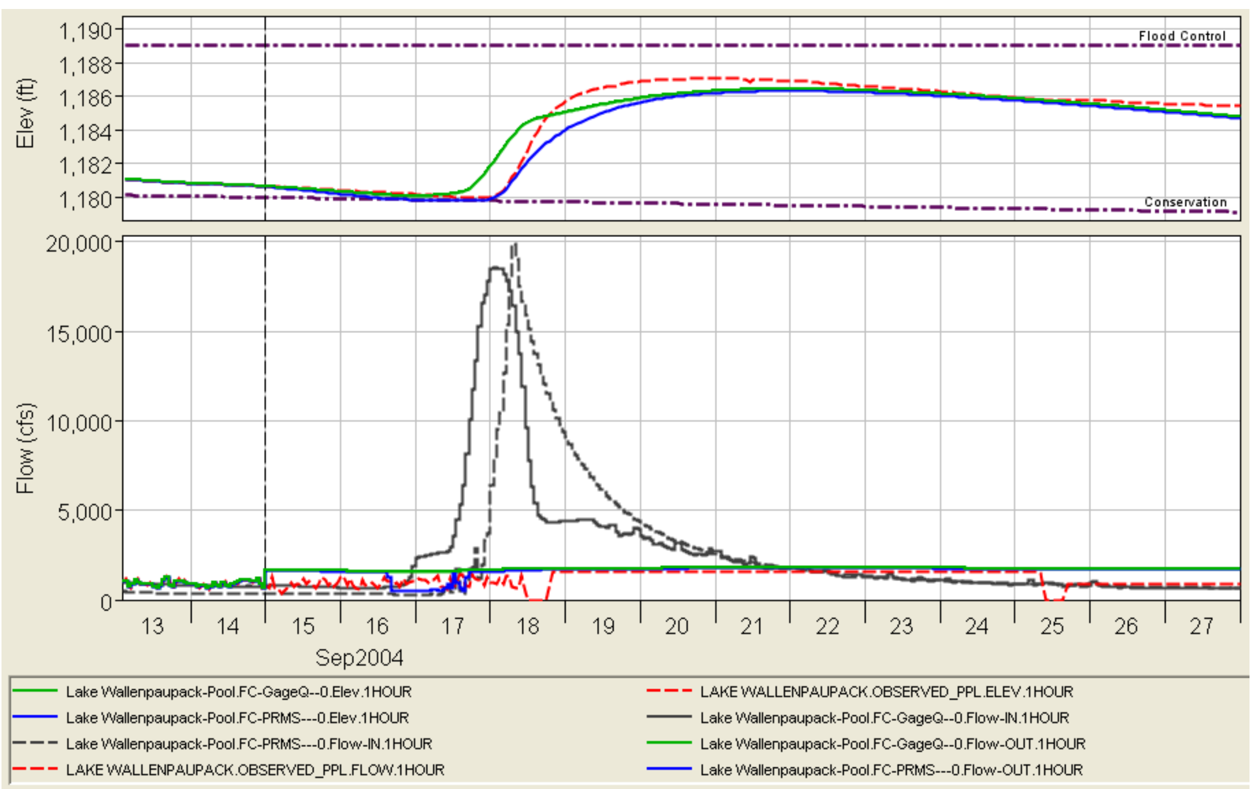


Figure 5.40 Lake Wallenpaupack Reservoir Plot – 2004 Event

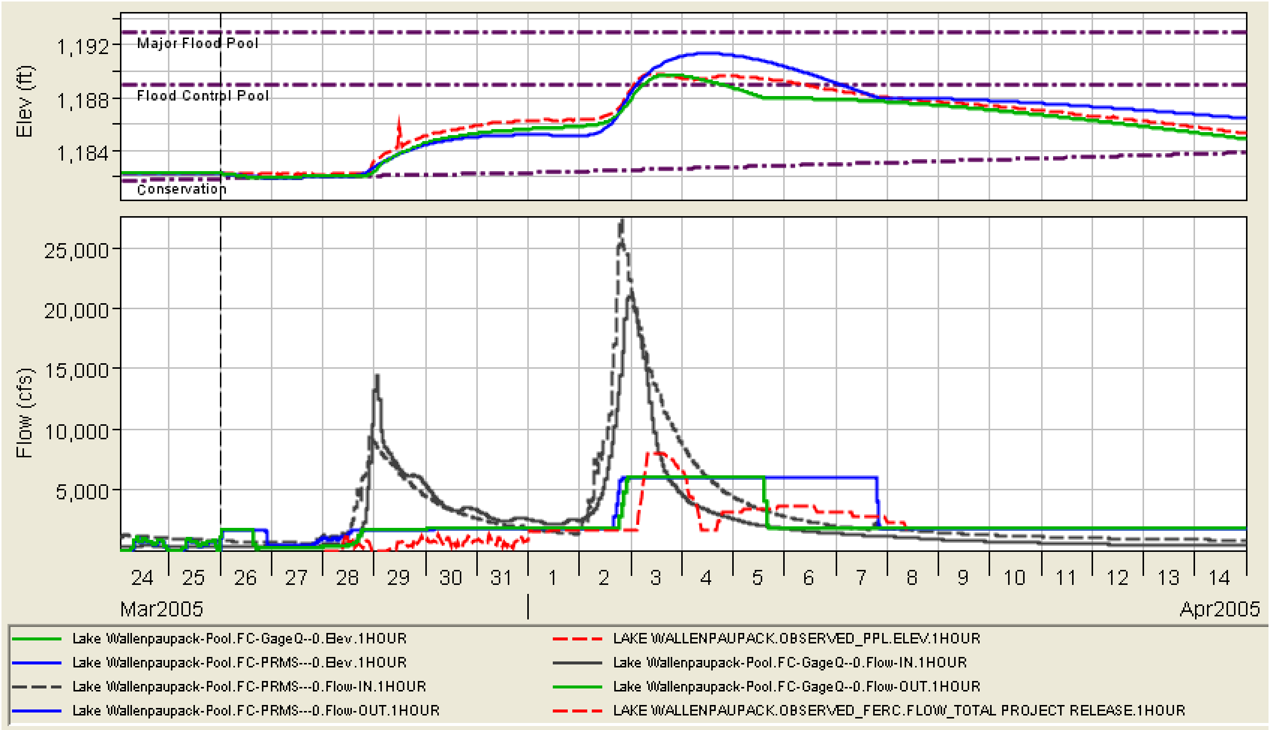


Figure 5.41 Lake Wallenpaupack Reservoir Plot – 2005 Event

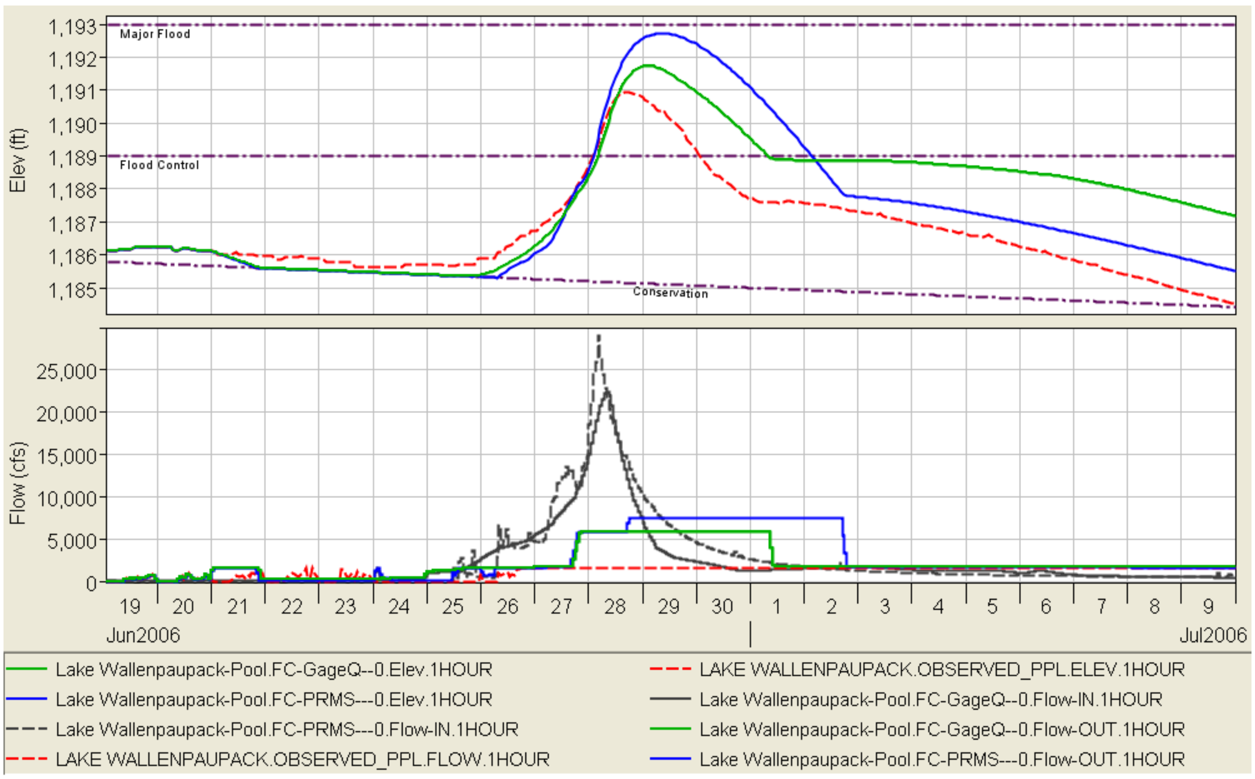


Figure 5.42 Lake Wallenpaupack Reservoir Plot – 2006 Event

5.2.3 Mongaup River Basin

The reservoirs modeled in the Mongaup system of five hydropower reservoirs include: Toronto, Swinging Bridge, and Rio. Little observed data was available to validate this portion of the model. The available data included the hourly record for the Mongaup Valley gage located upstream of Swinging Bridge, some daily average release information for Rio, and the gage record for the Port Jervis gage located on the Delaware River just downstream of the confluence with the Mongaup River.

Other operational information was obtained during a telephone conversation with the current superintendant of operations of the Mongaup system. Unfortunately, neither the superintendant of operations nor his staff were involved in the operation of these reservoirs during the modeled events because the system was sold and none of the staff that was in place at the time remained, only anecdotal information was available.

5.2.3.1 Toronto

Toronto Reservoir does not have a hydropower generation facility; storage is its primary purpose. Under normal conditions, Toronto operates in tandem with Cliff Lake to maintain a stable conservation pool at Swinging Bridge by means of a tunnel from Cliff Lake. Under high flow conditions, the tunnel capacity is too small to impact flood operation, so Cliff Lake and its tunnel were not represented in this model. Figure 5.43 through Figure 5.45 show model results for Toronto Reservoir.

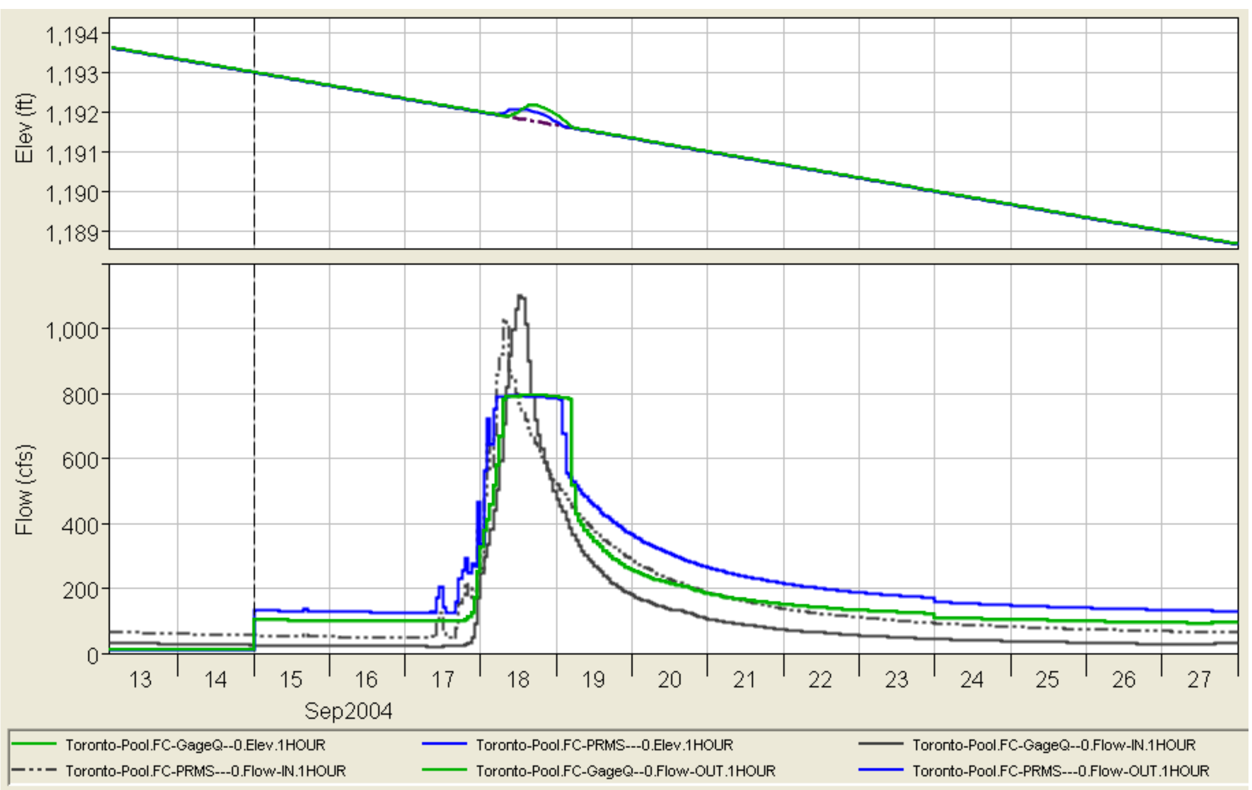


Figure 5.43 Toronto Reservoir Plot – 2004 Event

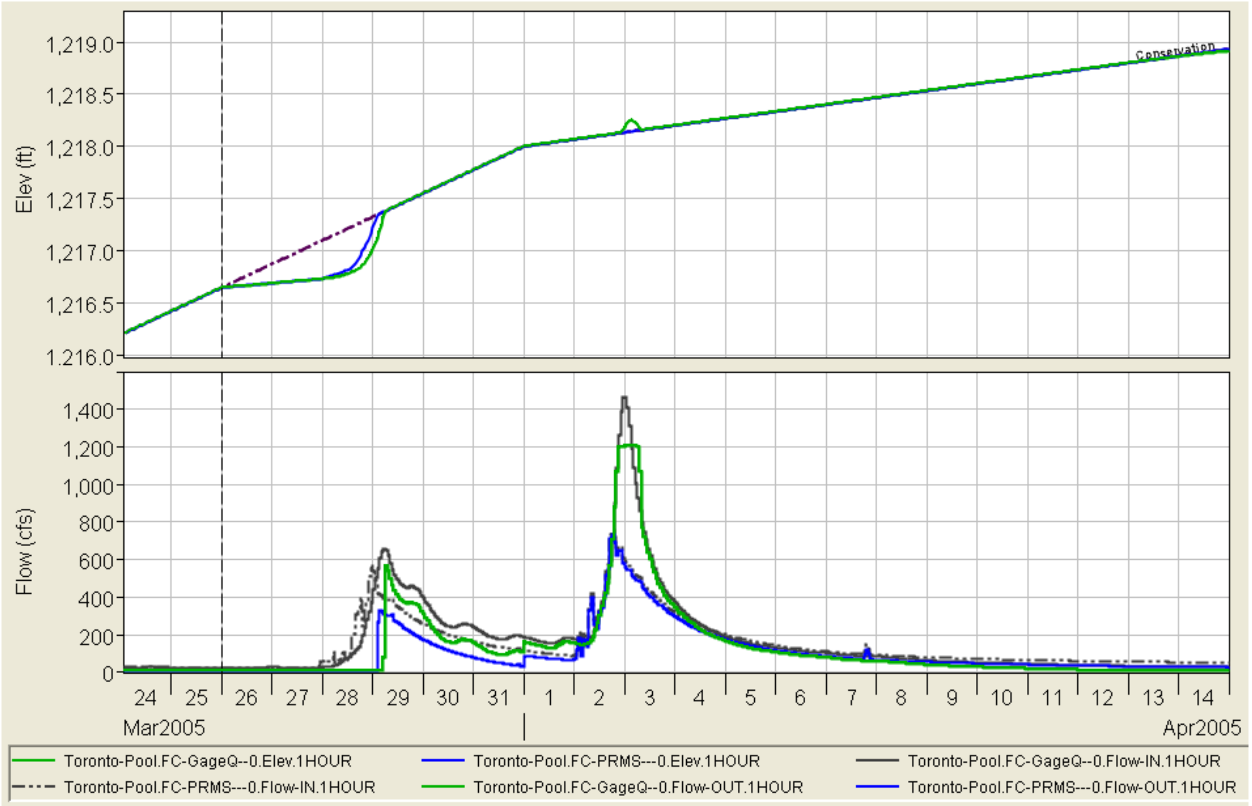


Figure 5.44 Toronto Reservoir Plot – 2005 Event

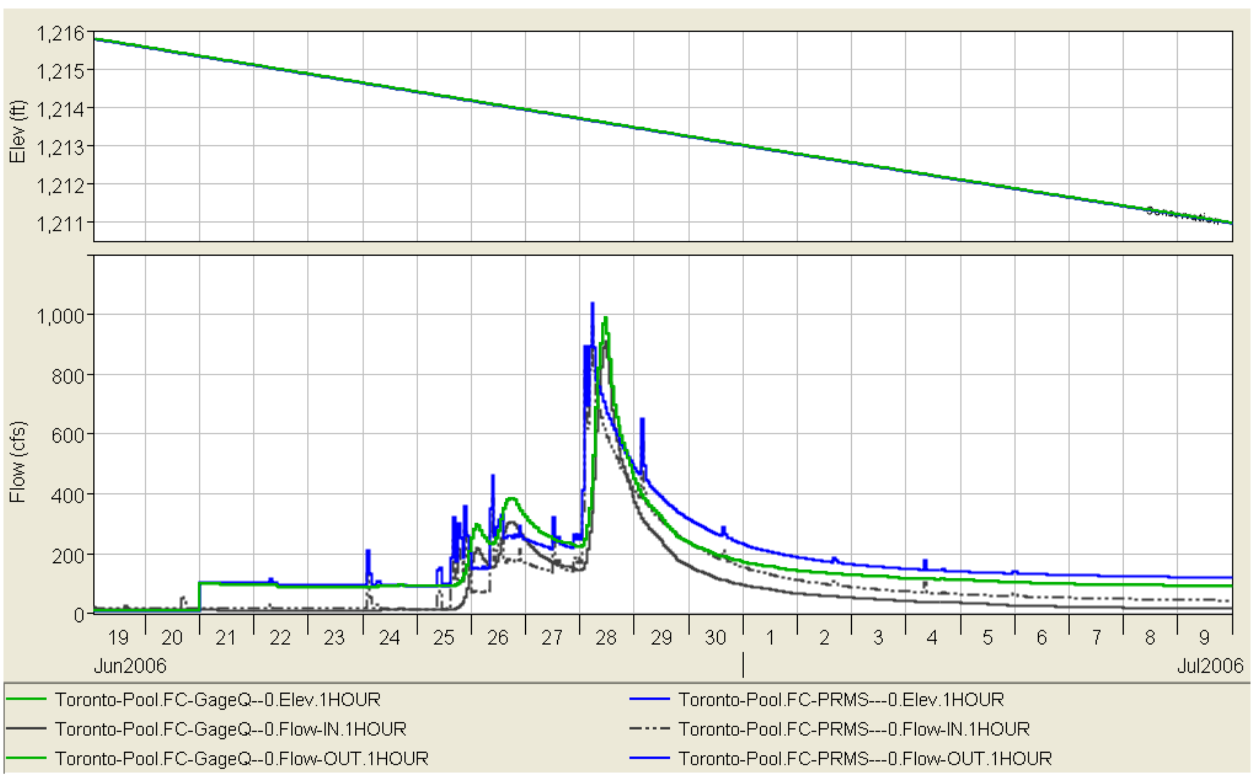


Figure 5.45 Toronto Reservoir Plot – 2006 Event

5.2.3.2 Swinging Bridge

Inflow to Swinging Bridge was derived from the USGS gage at Mongaup Valley. The operations manual in use at the time of the three events indicates that inflow can be estimated as approximately 1.68 times the Mongaup Valley gage. The current operators use a factor of 1.55 to estimate, therefore, the model uses a factor of 1.55. The nearest downstream gage to assess the validity of that assumption is the Port Jervis gage and, as illustrated in Figure 5.46 through Figure 5.48, the model does well at reproducing the observed flows at that location.

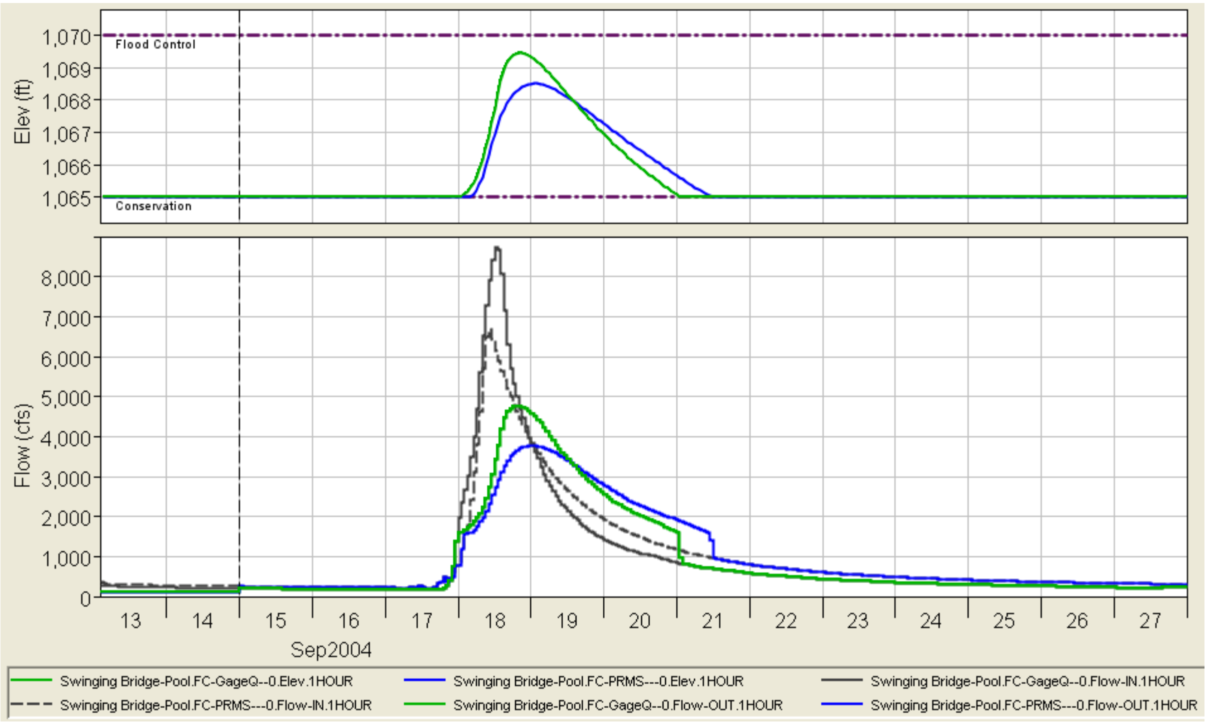


Figure 5.46 Swinging Bridge Reservoir Plot – 2004 Event

Other information gathered regarding operation of Swinging Bridge during the three events includes:

- The 2004 event passed through the system without adverse incident.
- The 2005 event caused a sinkhole to form in the main penstock to the power house resulting in permanent closure of the penstock. This event was also reported to produce pool elevations in excess of the 1,072.5 feet trigger elevation of the flashboards. However, they did not fall as designed and were removed after the event.
- As a result of the 2005 event, the flashboards were still absent at the time of the 2006 event and the release capacity of the powerhouse was reduced by approximately 68% due to the loss of Penstock 1.

The 2005 event was difficult to simulate without additional observed information. For example, the model uses the seasonally varying target pool as the starting condition of the reservoir pool. This is a reasonable assumption since hydropower operators typically want to maintain as high a head on the reservoir as they can to maximize power generation. With this starting condition and the 1.55 factor on the Mongaup Valley gage as inflow, the pool elevation at Swinging Bridge

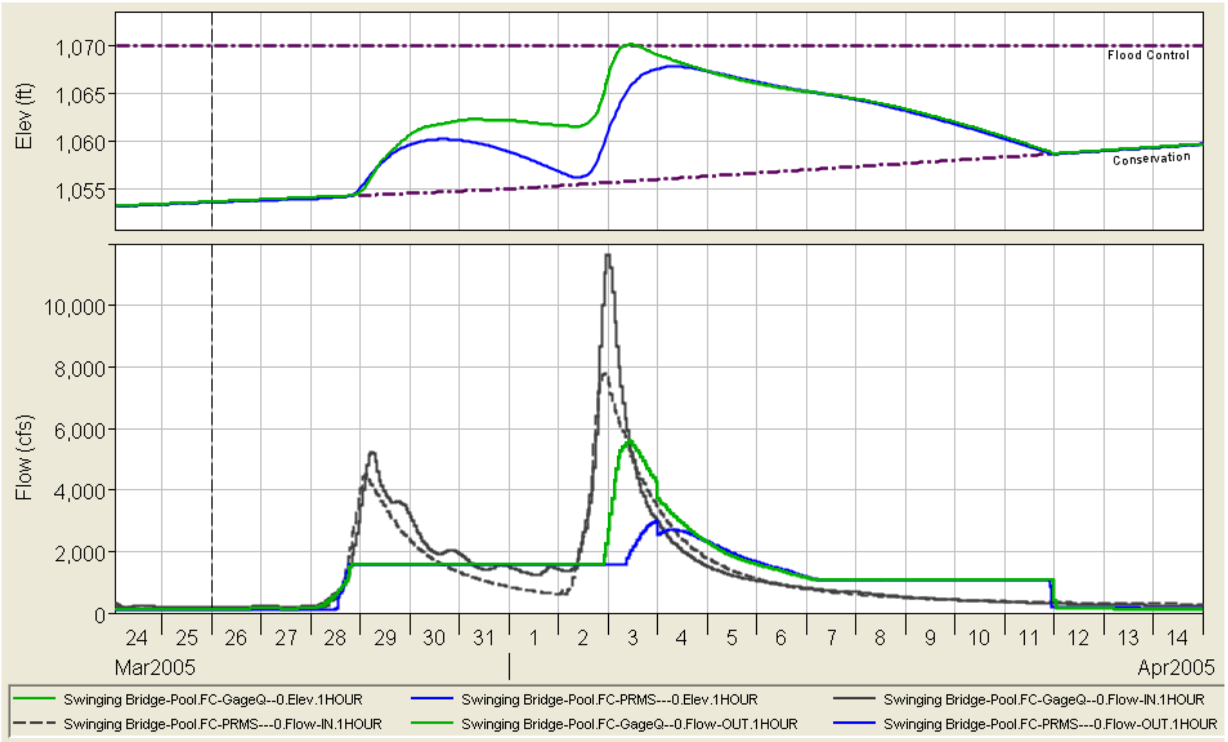


Figure 5.47 Swinging Bridge Reservoir Plot – 2005 Event

barely reaches the top of the flashboards, 2.5 feet shy of the flashboard trigger elevation. A significantly higher starting condition or inflow would have been needed to cause the pool to reach the reported elevation.

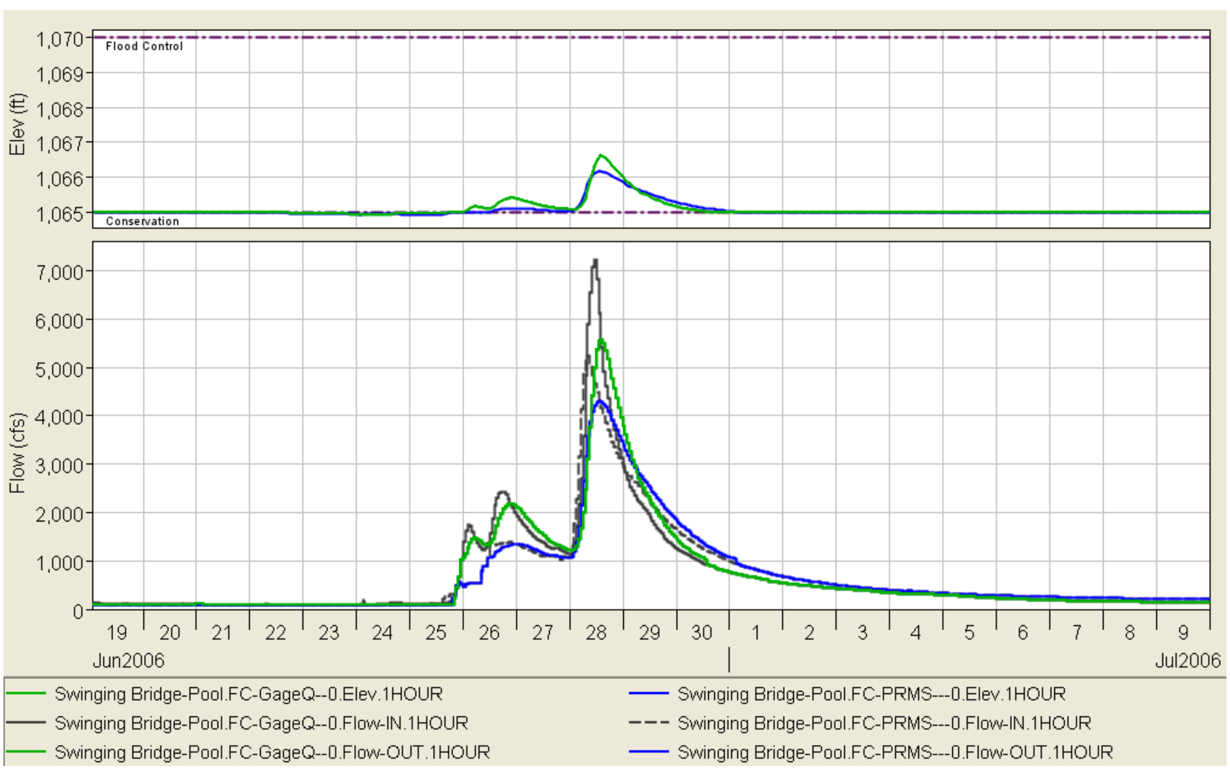


Figure 5.48 Swinging Bridge Reservoir Plot – 2006 Event

5.2.3.3 Rio

As with Swinging Bridge, the 2004 event passed through Rio Reservoir without incident. Figure 5.49 shows the model results at Rio for the 2004 event.

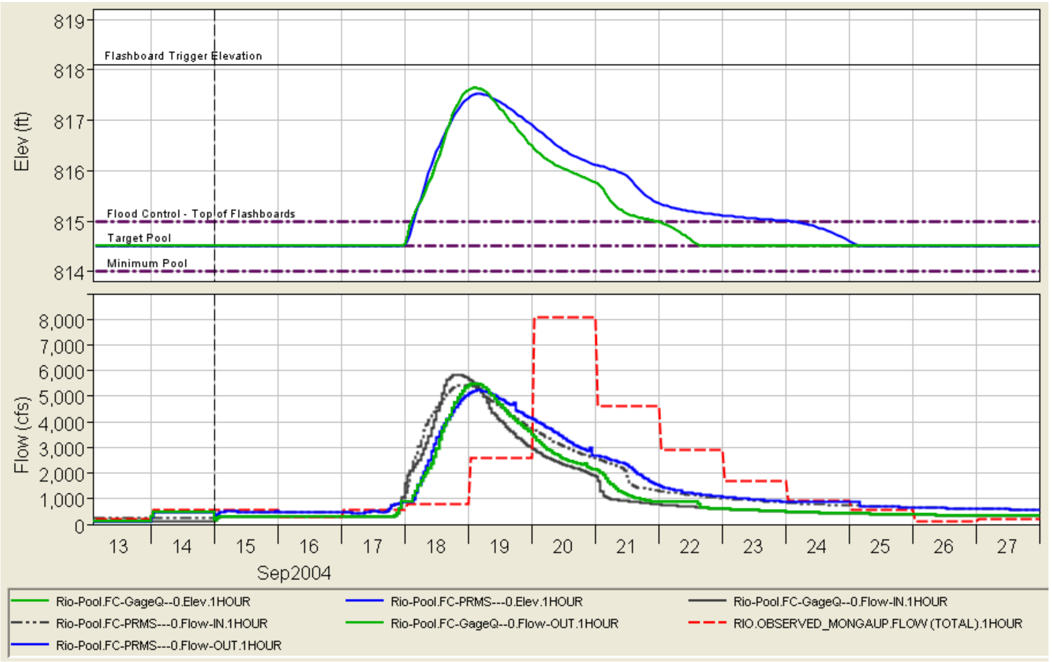


Figure 5.49 Rio Reservoir Plot – 2004 Event

The 2005 event was reported to produce pool elevations in excess of the flashboard trigger elevation of 818 feet, but the flashboards did not fa1l as designed here, either. Using the seasonally varying target pool elevation as a starting condition, the peak pool elevation reached

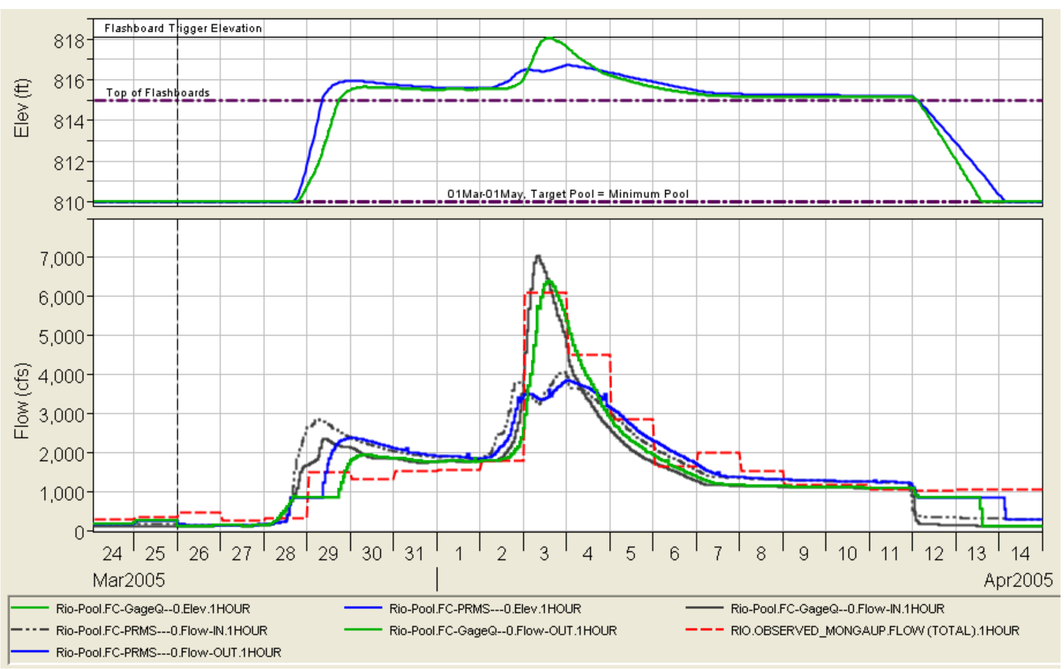


Figure 5.50 Rio Reservoir Plot – 2005 Event

in the model exceeded 818 feet and triggered the flashboards. However, the large pulse of water that was produced did not appear in the daily release record for Rio nor in the hourly flow record at Port Jervis, both of which correlate with the report of the flashboard failure. To mimic the flashboard failure in the model, the flashboard trigger was set artificially higher in the model. As can be seen in Figure 5.50 and Figure 5.53, the resulting releases produced a good match to the observed record at both Rio and Port Jervis.

After the 2005 event, due to damage at Swinging Bridge and presumed failure of the flashboarded spillways at both Swinging Bridge and Rio, the flashboards were removed at both reservoirs until repairs were complete at Swinging Bridge. At the time of the 2006 event, the flashboarded spillways had still not been rebuilt. This situation was modeled by initializing the state of the flashboards to DOWN, starting the pool at spillway crest, and not allowing the flashboards to reset during the simulation. Figure 5.51 shows that the model did not match the observed release record at Rio, but, at Port Jervis the simulated flows matched observed well (see Figure 5.54). Possible reasons for this include: the observed record at Rio may reflect only the powerhouse flows or the inflows to Rio were substantially smaller due to significantly altered operations at Swinging Bridge.

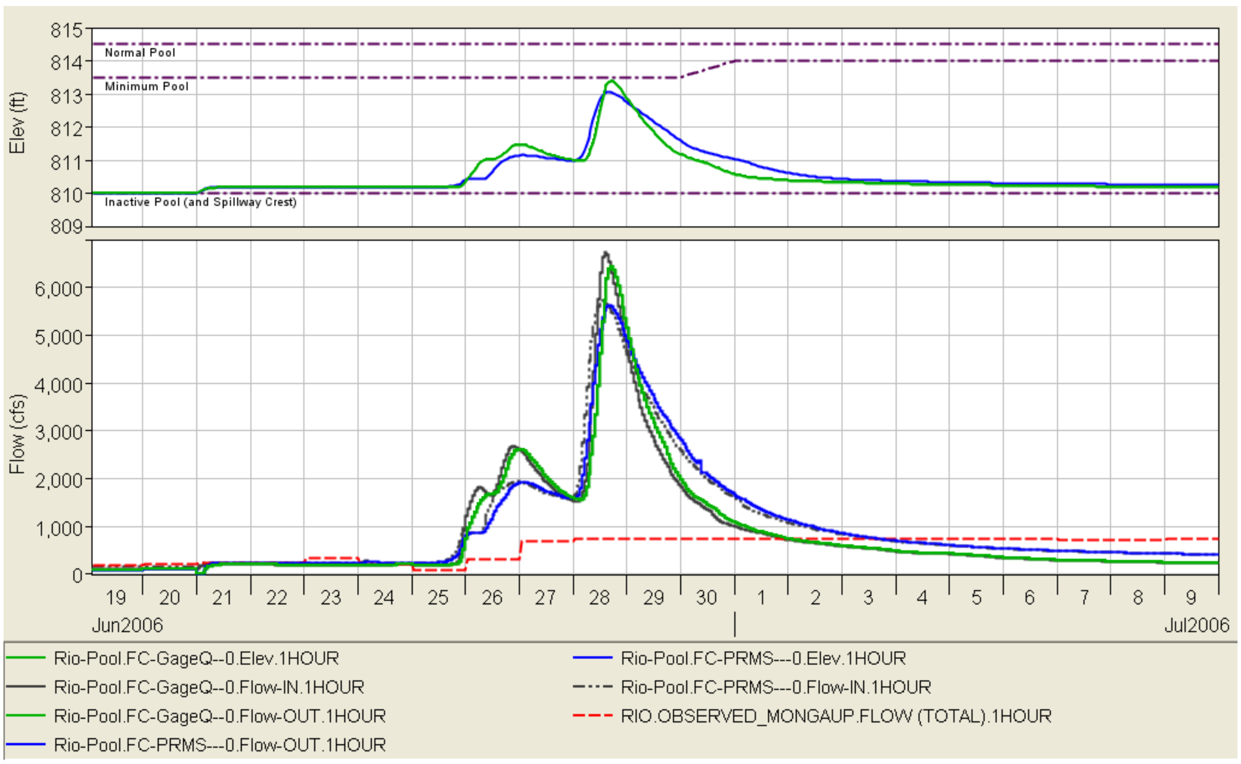


Figure 5.51 Rio Reservoir Plot – 2006 Event

5.2.3.4 Port Jervis

Port Jervis is the streamflow gage station downstream of the Mongaup River system. As the next major gage on the main stem Delaware below Barryville, this gage includes flow entering from the Lackawaxen and Mongaup Rivers as well as local flow from smaller tributaries. These two basins were probably the most difficult to model due to limited observed data and their inflows contribute more than 20% of the total flow at Port Jervis Figure 5.52 through Figure

5.54 illustrate how well the *FC-GageQ* model results compare to the observed flows for all three events, demonstrating that the model adequately represents the reservoir operation and impact of the flows from the Lackawaxen and Mongaup basins.

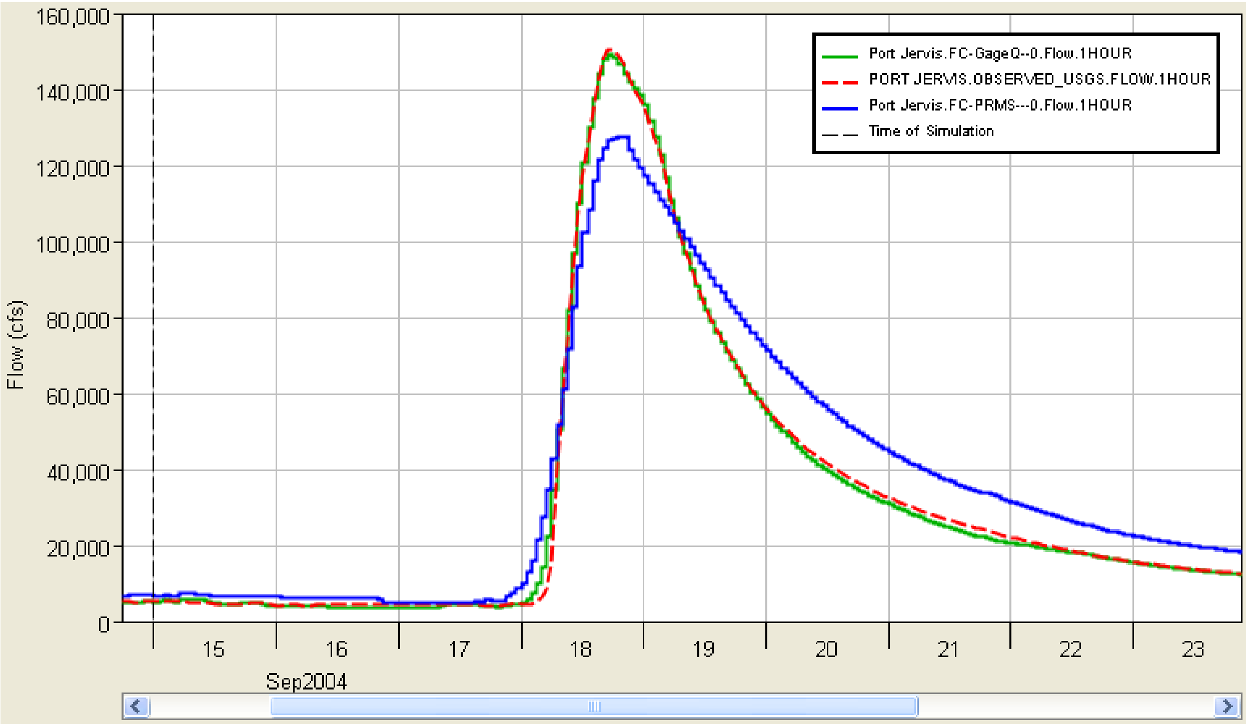


Figure 5.52 Port Jervis Operations Plot – 2004 Event

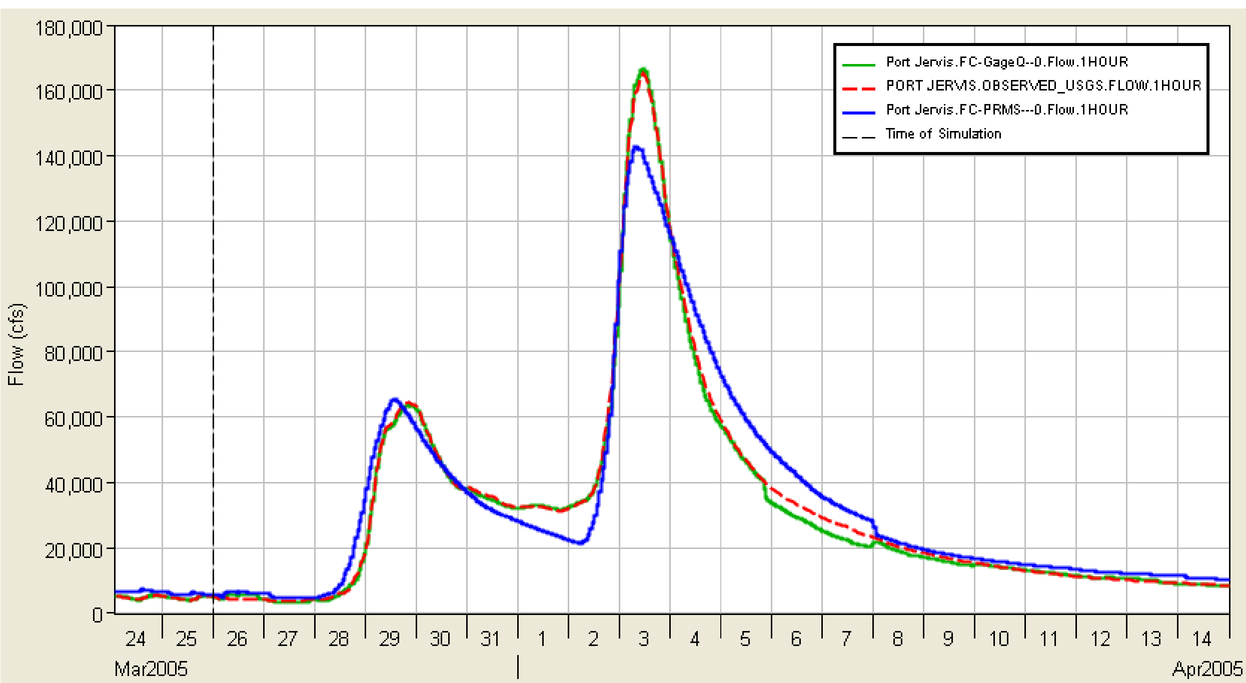


Figure 5.53 Port Jervis Operations Plot – 2005 Event

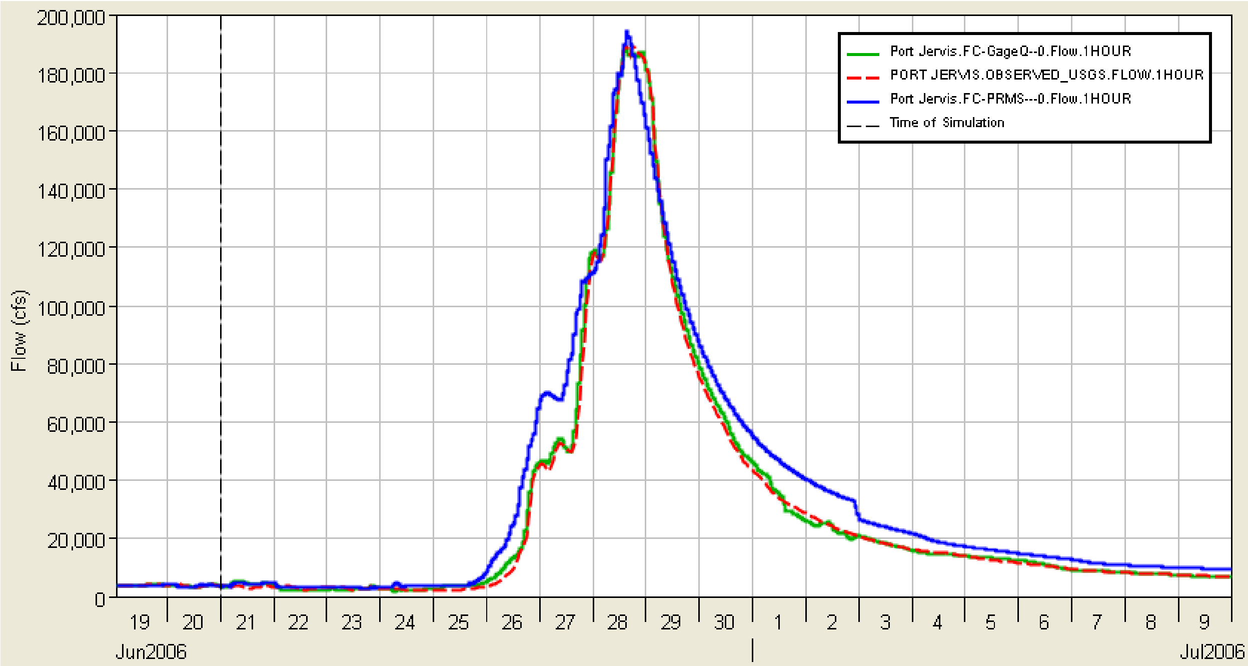


Figure 5.54 Port Jervis Operations Plot – 2006 Event

5.2.4 Lehigh River Basin

The reservoirs in the Lehigh River basin are owned and operated by the US Army Corps of Engineers, Philadelphia District. They are multipurpose reservoirs with significant storage reserved for flood damage reduction and well-defined operating plans. These operating plans have been included in the model for F.E. Walter and Beltzville Reservoirs. However, as with all plans that involve human intervention and decision making, simulating what an operator actually does during an event is difficult. The following plots show that the model is accurately simulating the operating plan for these reservoirs. Differences between simulated and observed operation are primarily because the operators must use estimated information to make operating decisions while the model has limited perfect foresight of the local flows when making release decisions for downstream operation.

5.2.4.1 F.E. Walter

F.E. Walter's flood control operating plan includes constraints for stage at Lehighton, Walnutport, and Bethlehem. Maximum stage is the operating criteria for each of these locations, and responsibility for controlling for these locations is shared with Beltzville Reservoir. In all three events, Walnutport was the controlling constraint. Results for F.E. Walter for all three events are shown in Figure 5.55 through Figure 5.57.

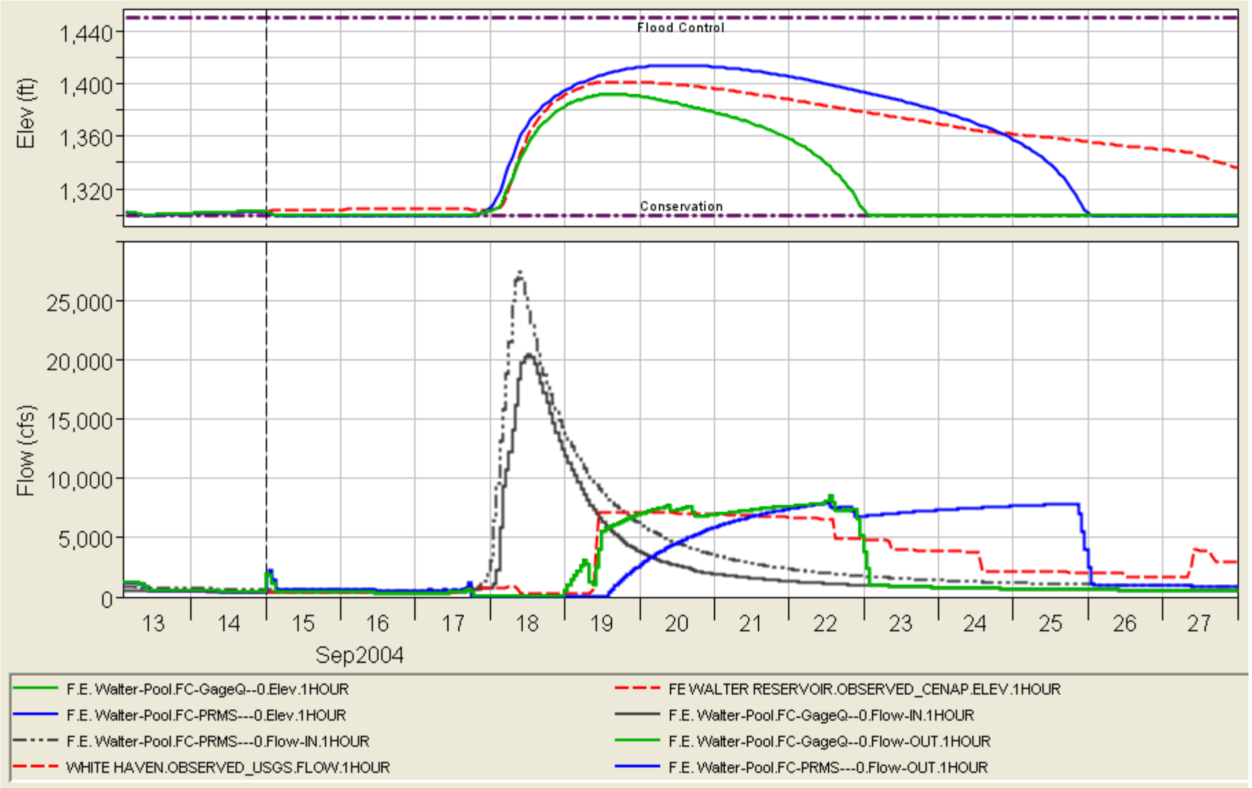


Figure 5.55 F.E. Walter Reservoir Plot – 2004 Event

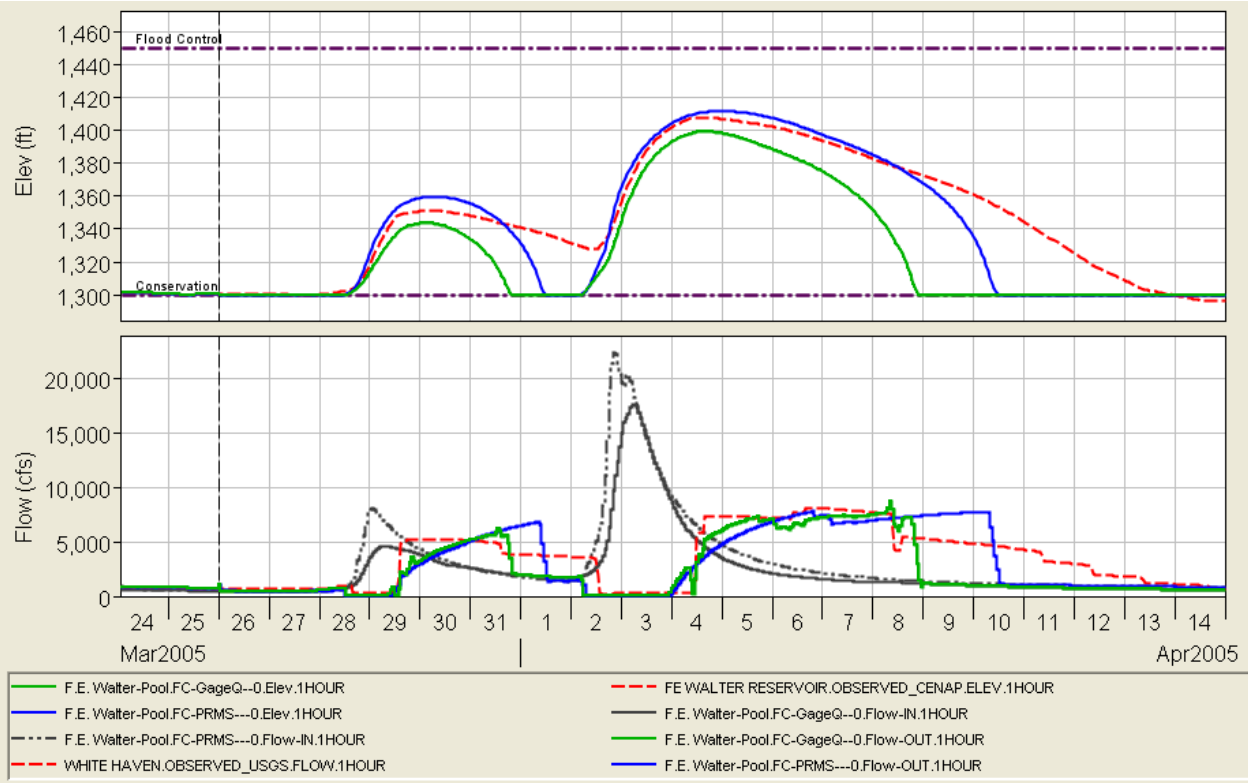


Figure 5.56 F.E. Walter Reservoir Plot – 2005 Event

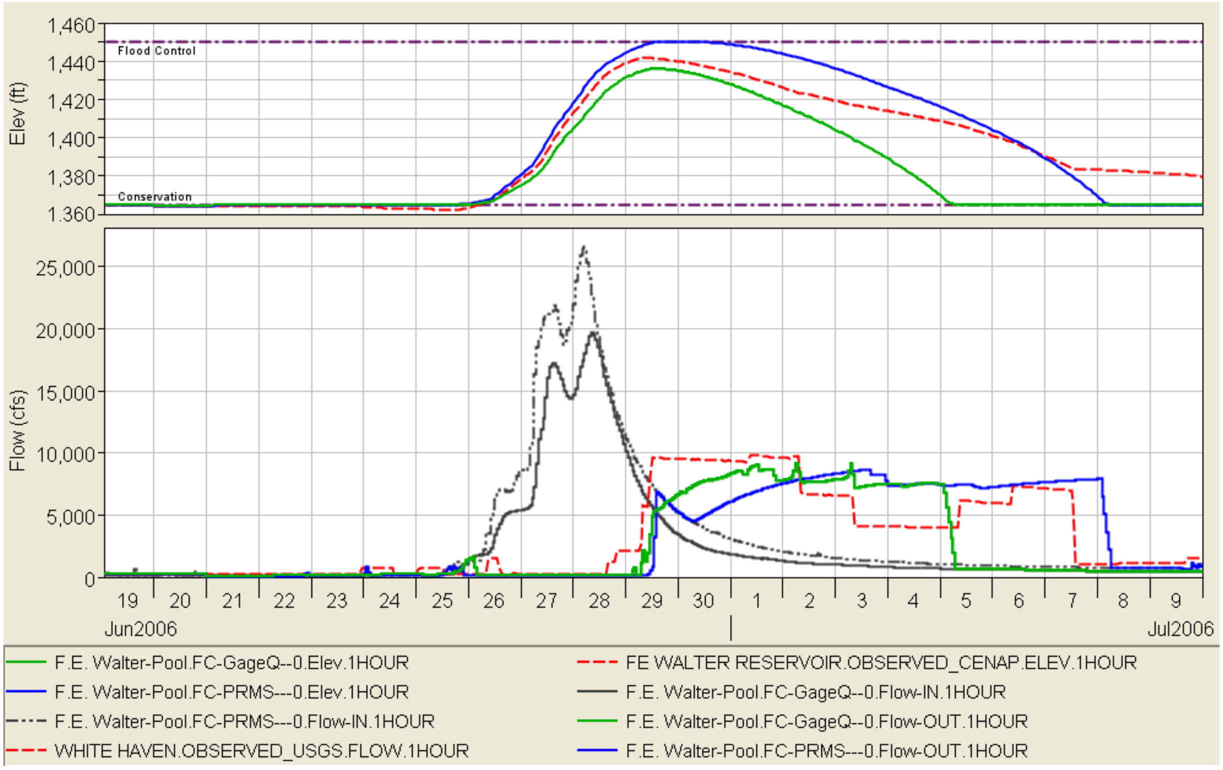


Figure 5.57 F.E. Walter Reservoir Plot – 2006 Event

5.2.4.2 Lehighton

Figure 5.58 through Figure 5.60 show that although flows at Lehighton exceeded the flood storage initiation stage, this was due to high intervening local flow below the reservoir and not reservoir releases.

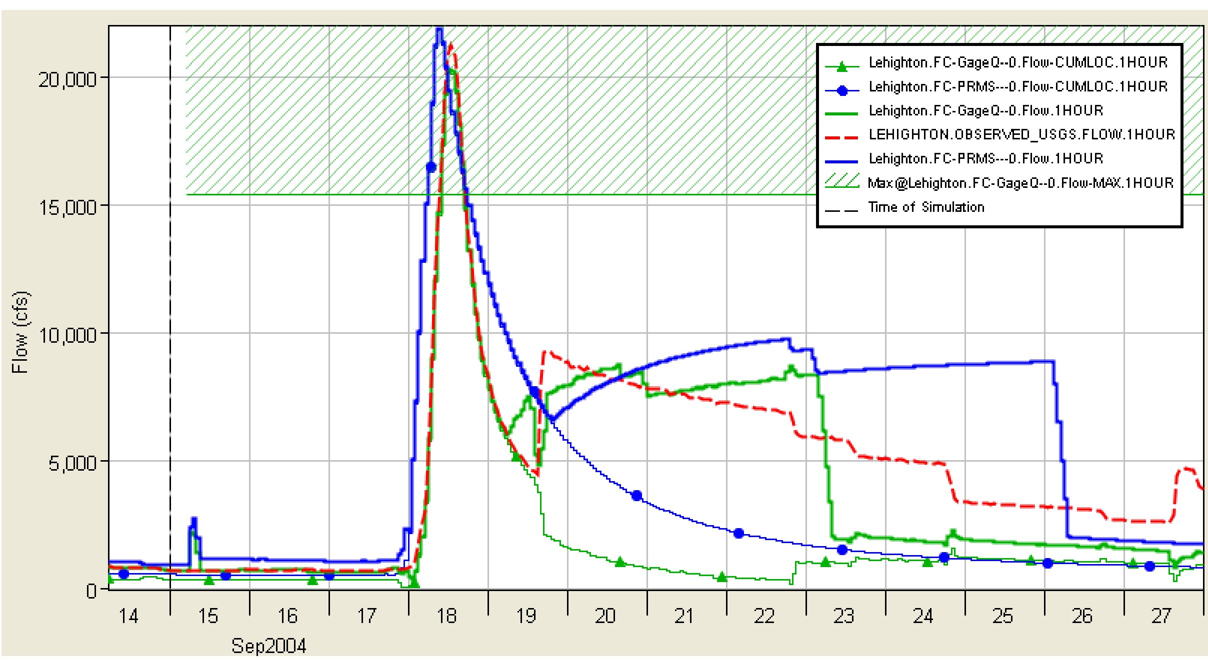


Figure 5.58 Lehighton Operations Plot – with cumulative local flow added – 2004 Event

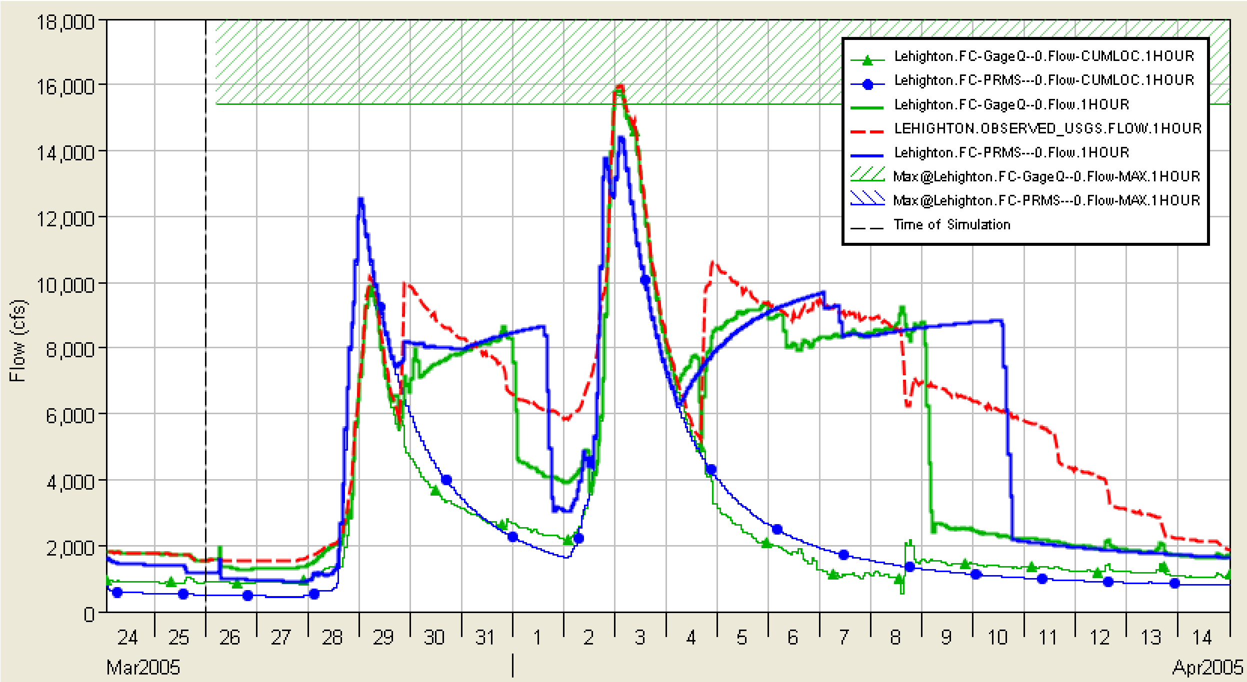


Figure 5.59 Lehighton Operations Plot – with cumulative local flow added – 2005 Event

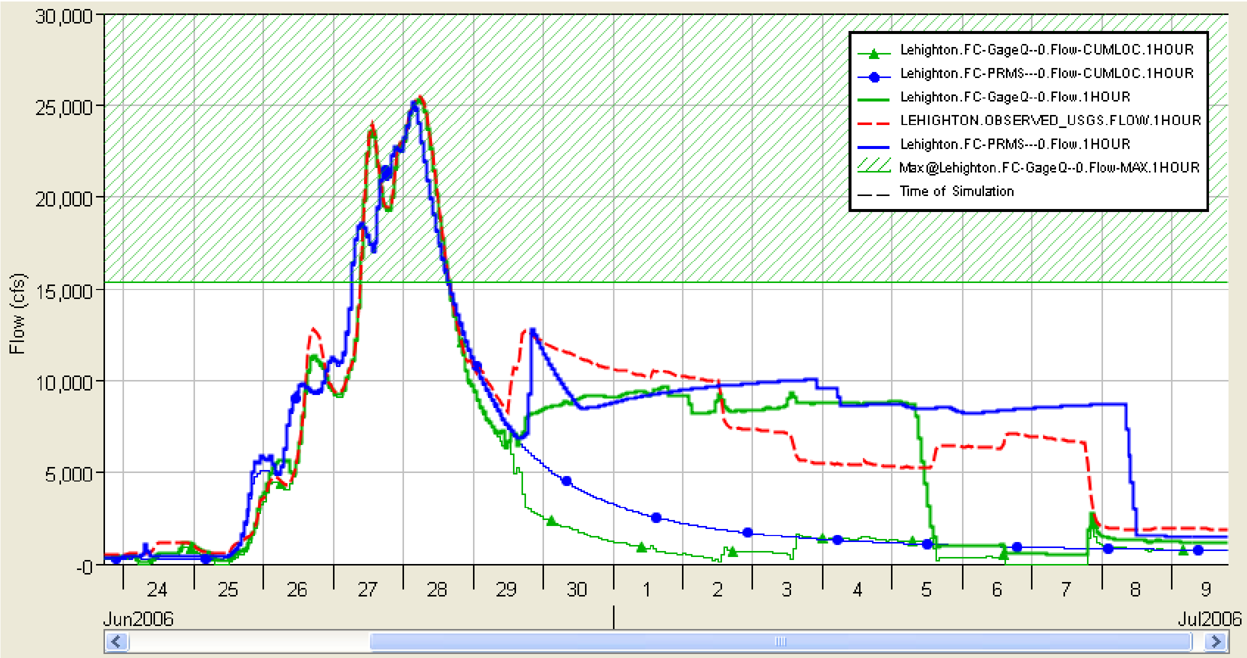


Figure 5.60 Lehighton Operations Plot – with cumulative local flow added – 2006 Event

5.2.4.3 Beltzville

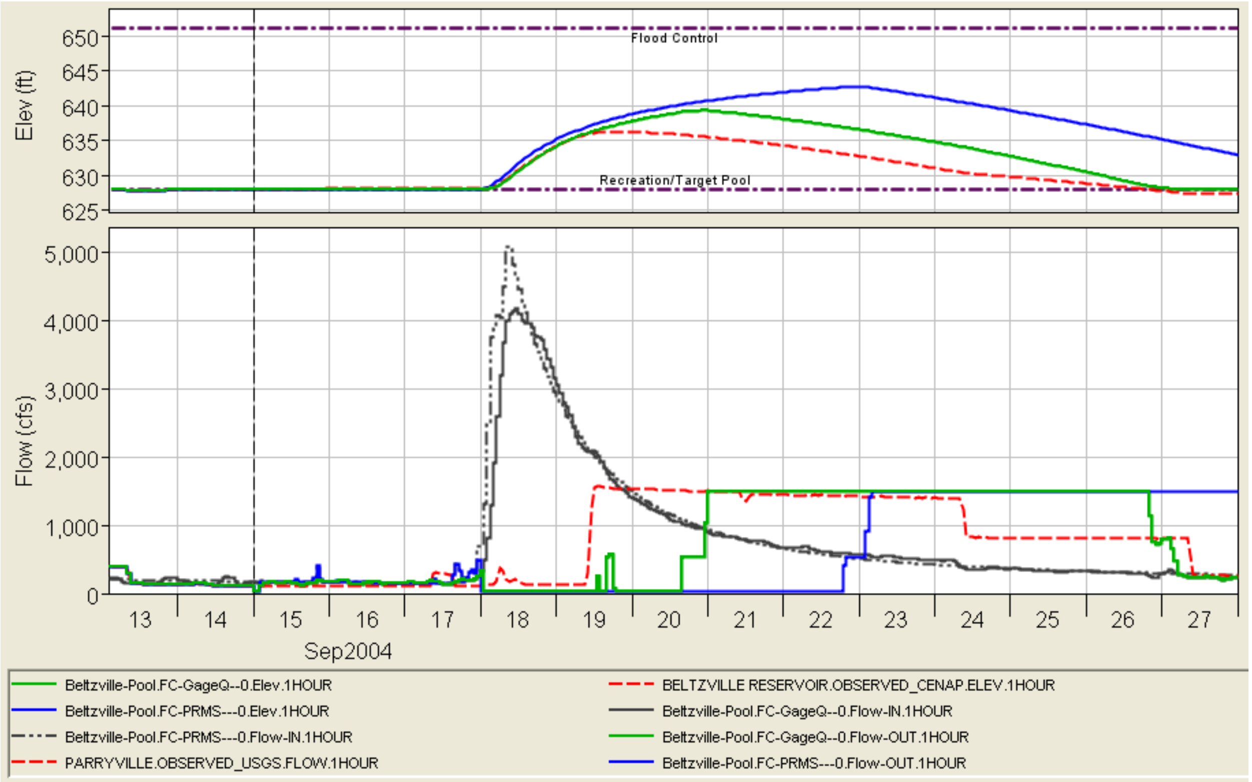


Figure 5.61 Beltzville Reservoir Plot – 2004 Event

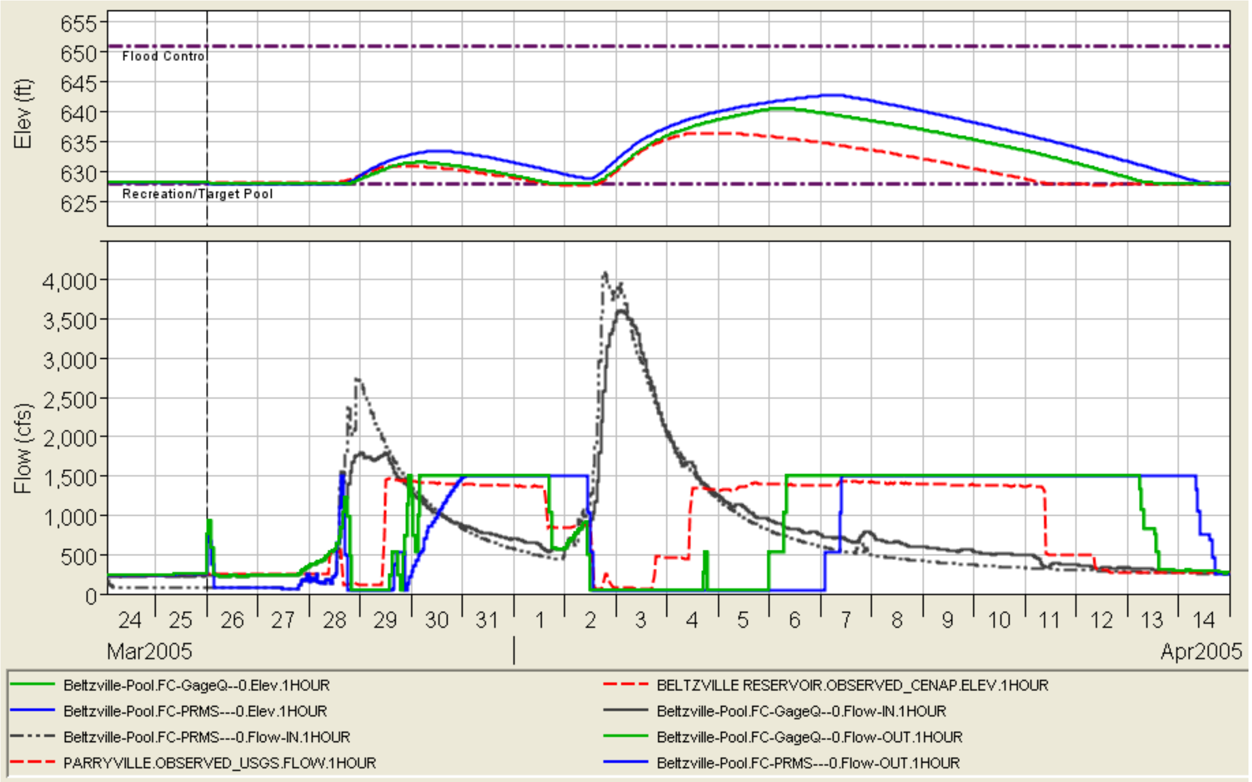


Figure 5.62 Beltzville Reservoir Plot – 2005 Event

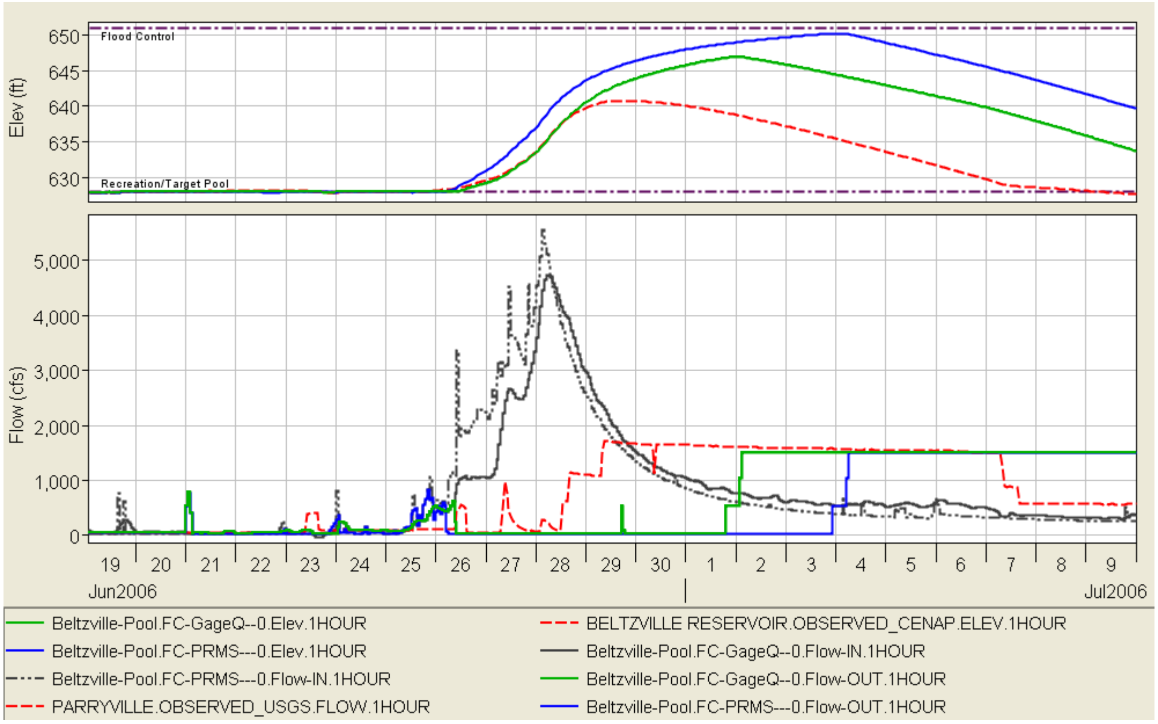


Figure 5.63 Beltzville Reservoir Plot – 2006 Event

5.2.4.4 Walnutport

As previously mentioned Beltzville and F.E. Walter work together to mitigate flooding at Walnutport and Bethlehem on the Lehigh River. Figures 5.64 though 5.66 shows that during the three modeled events, Walnutport was the controlling operational constraint and the model adequately simulates how the reservoirs operated for flows at this location.

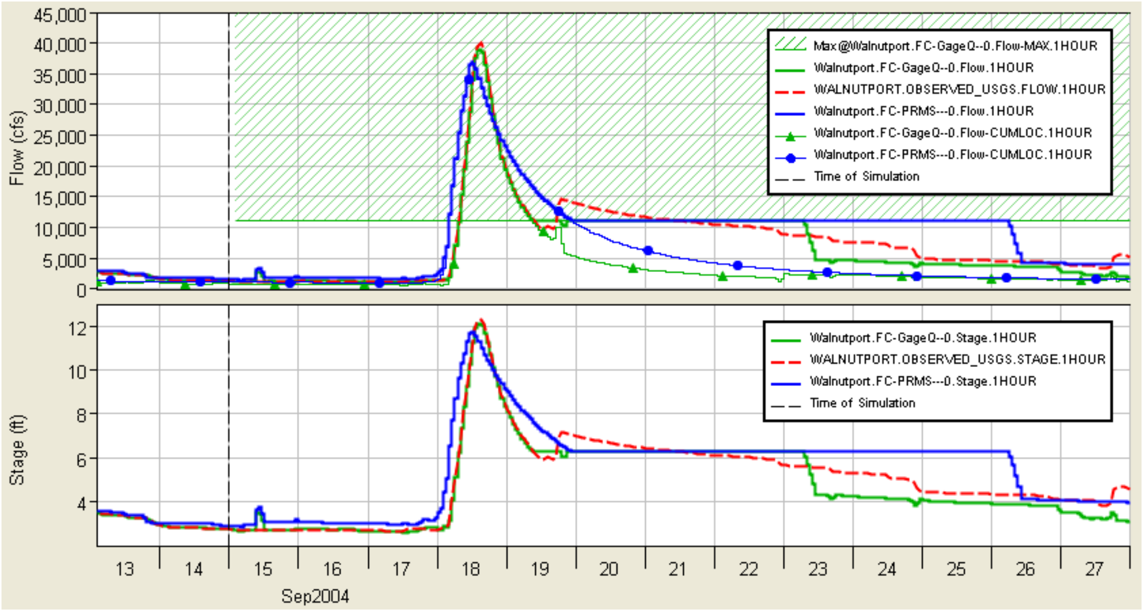


Figure 5.64 Walnutport Operations Plot – with cumulative local flow added – 2004 Event

Although flows at Walnutport and Bethlehem exceeded flood stage during these events, this was due to the local flow below the reservoirs. In each case, the reservoirs gates were closed and all inflow was stored to limit the peak of the flood event.

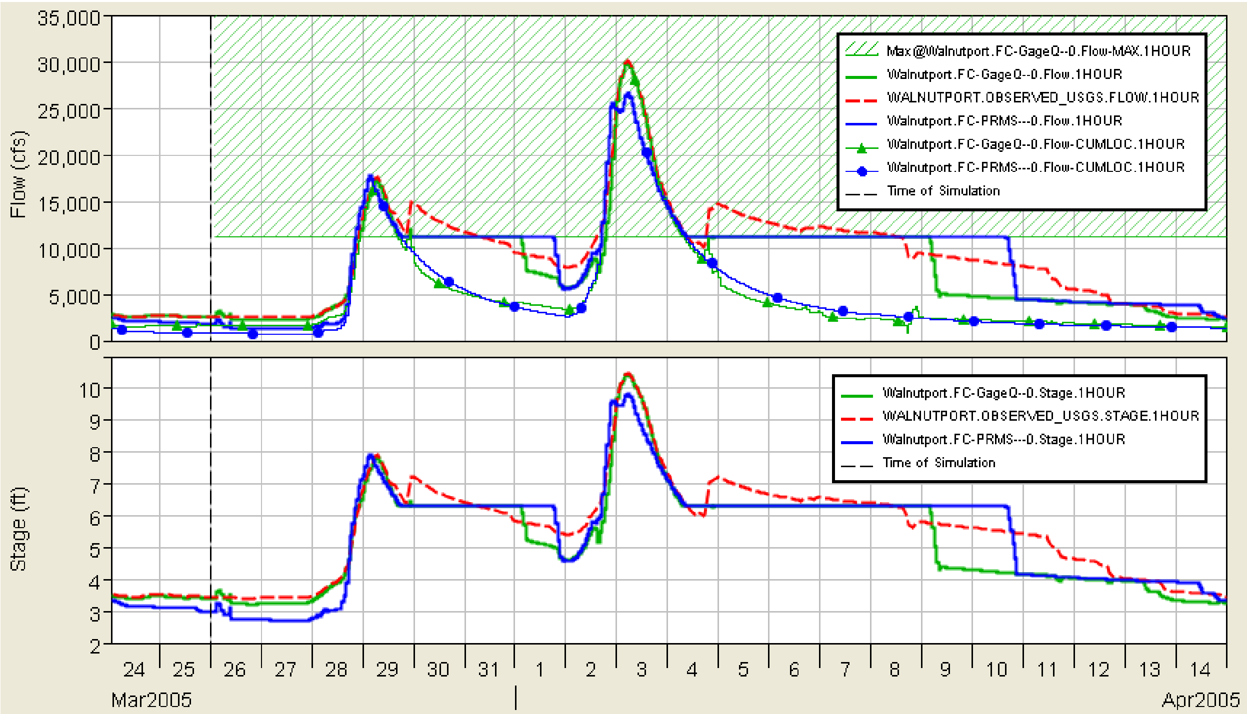


Figure 5.65 Walnutport Operations Plot – with cumulative local flow added – 2005 Event

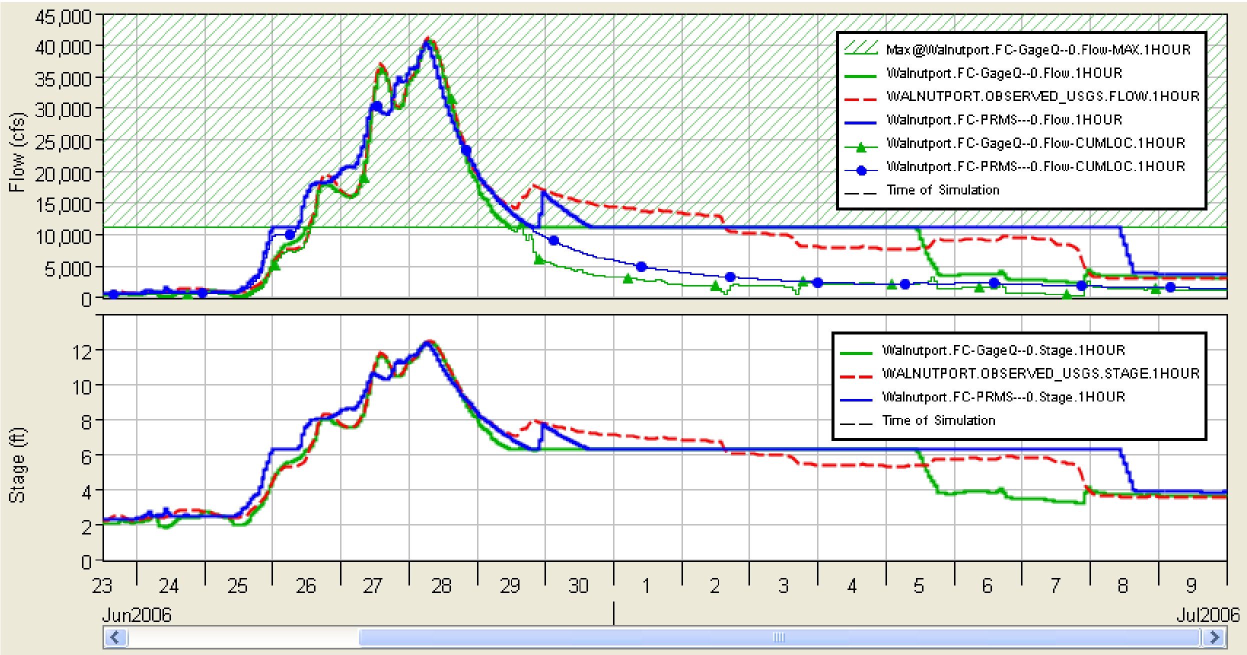


Figure 5.66 Walnutport Operations Plot – with cumulative local flow added – 2006 Event

5.2.4.5 Bethlehem

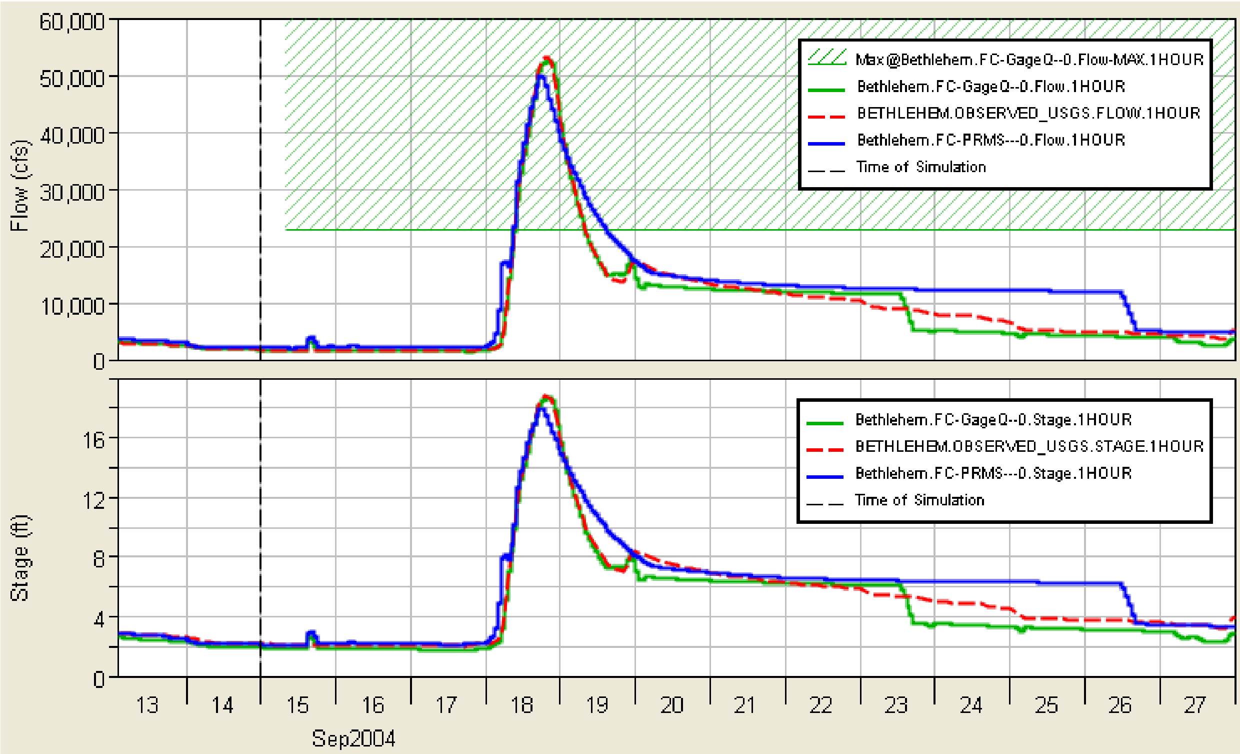


Figure 5.67 Bethlehem Operations Plot – Flow and Stage – 2004 Event

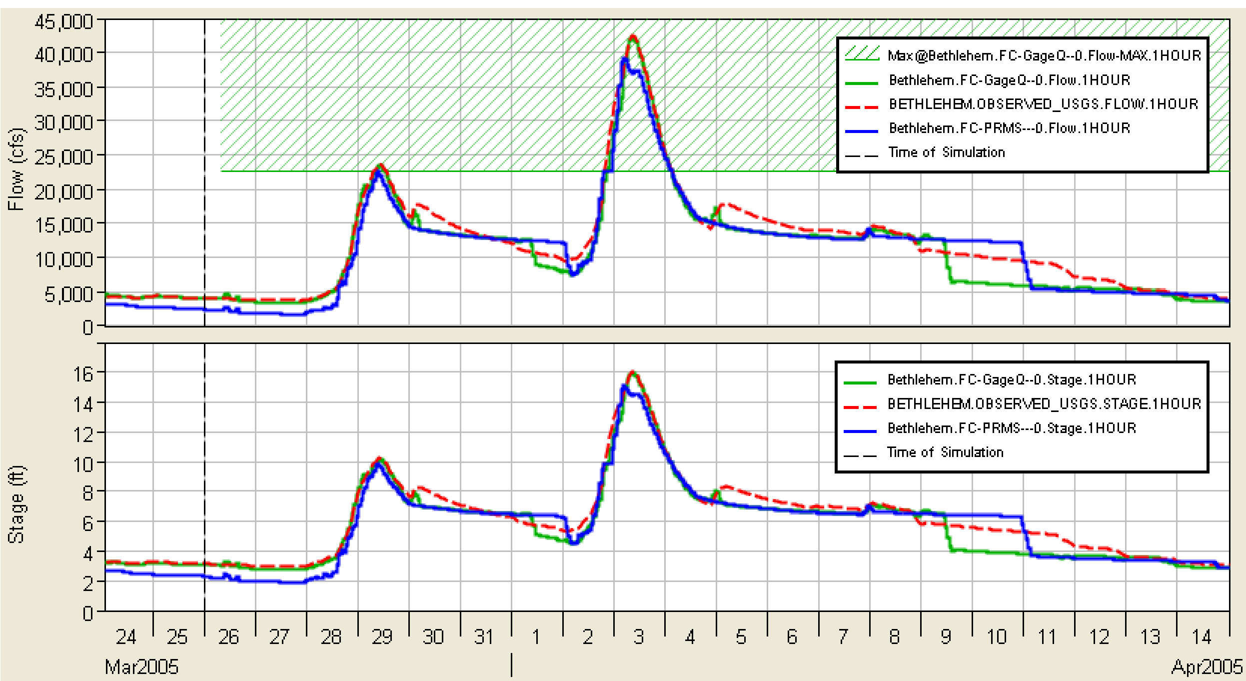


Figure 5.68 Bethlehem Operations Plot– Flow and Stage – 2005 Event

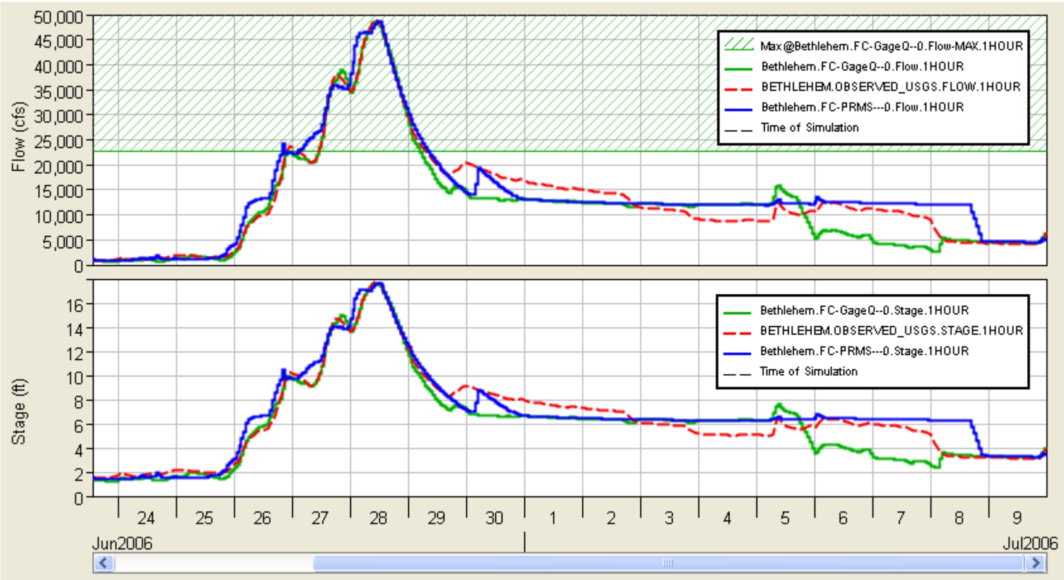


Figure 5.69 Bethlehem Operations Plot – Flow and Stage – 2006 Event

5.2.5 Mainstem Delaware River Basin

5.2.5.1 Montague

The Montague gage is the next major gaging station downstream of Port Jervis on the Delaware River. The Neversink River enters above Montague. Montague is an operational point for low flows on the Delaware River, but not for high flows.

Similar to Port Jervis, all three events are well represented by the *FC-GageQ* alternative. This is exhibited in Figures 5.70 through 5.72.

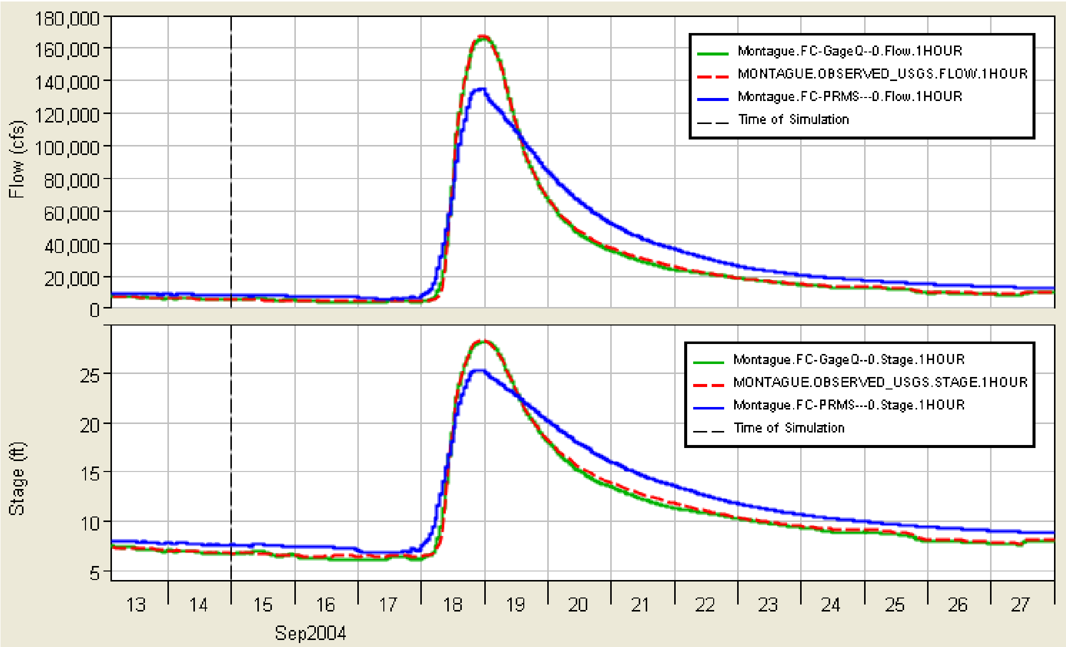


Figure 5.70 Montague Flow and Stage – 2004 Event

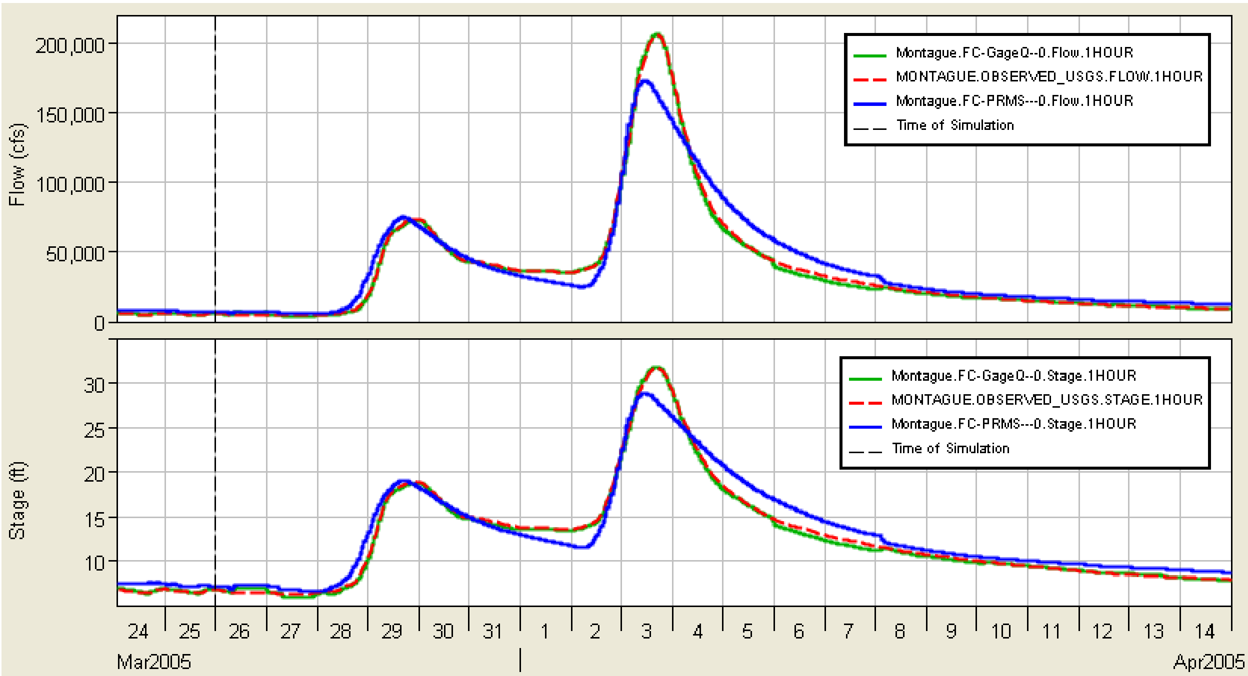


Figure 5.71 Montague Flow and Stage – 2005 Event

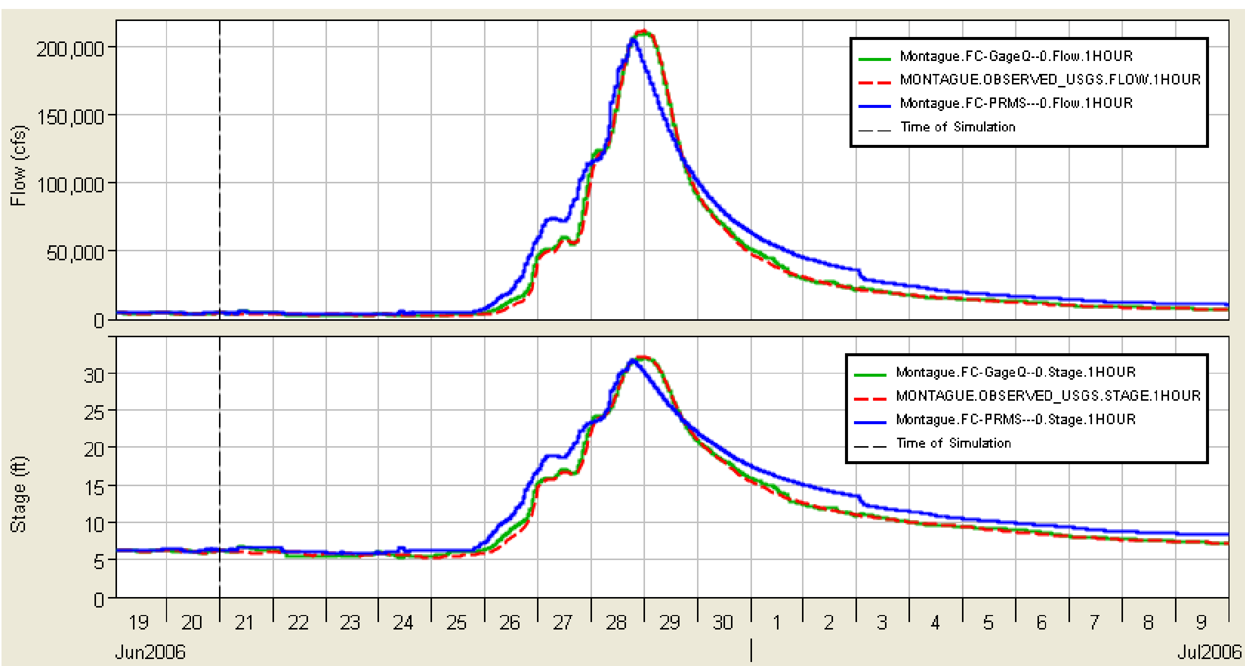


Figure 5.72 Montague Flow and Stage – 2006 Event

5.2.5.2 Belvidere

The gage at Belvidere captures all intervening flow downstream of Montague. Observed data from gages on the larger tributaries entering this reach of the Delaware were used to represent the tributary contributions. Local inflows from the smaller, ungaged tributaries were calculated by routing the combination of the Montague and larger tributary gage records to Belvidere and subtracting the routed flow from the Belvidere record.

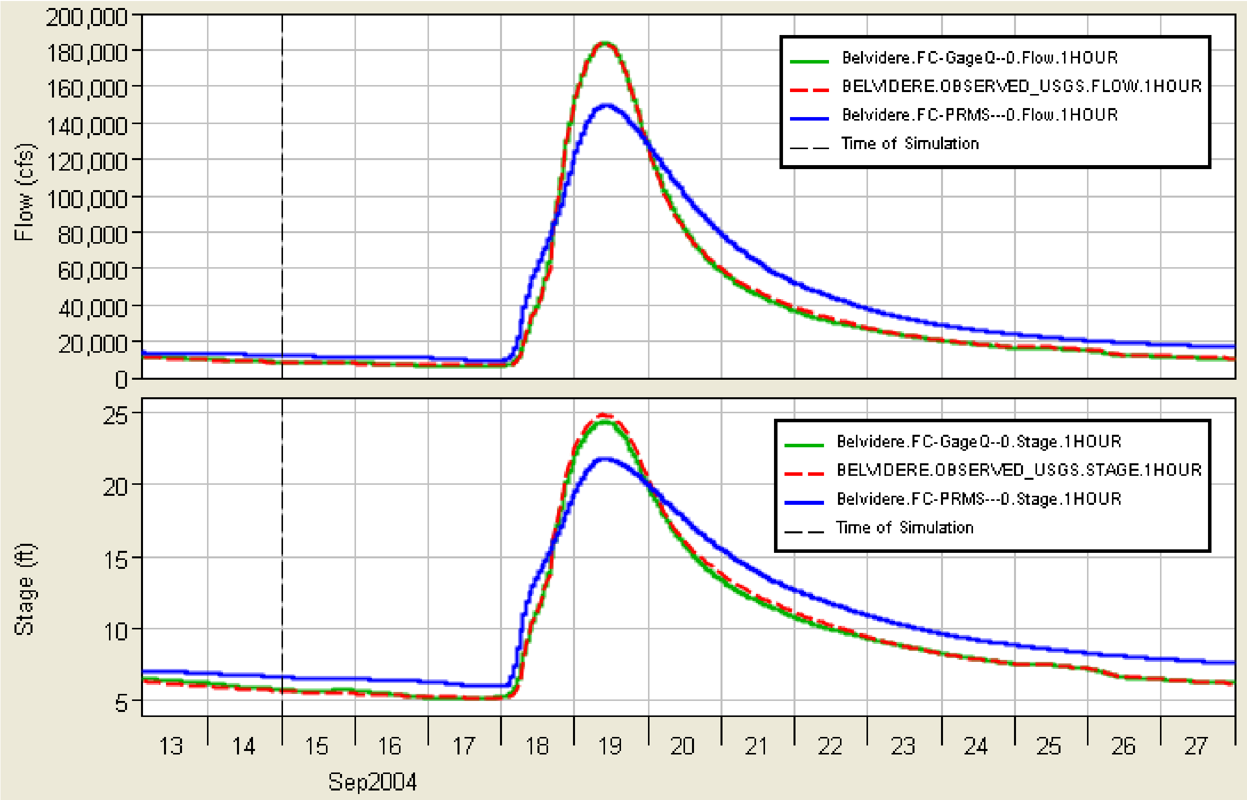


Figure 5.73 Belvidere Flow and Stage – 2004 Event

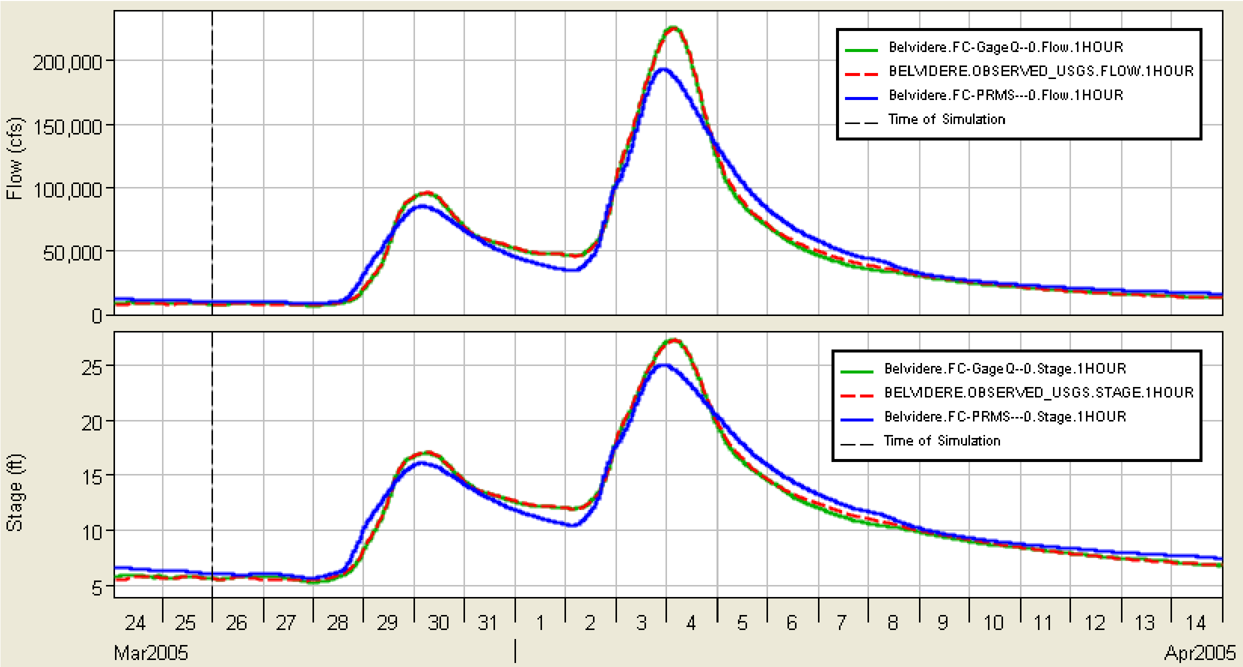


Figure 5.74 Belvidere Flow and Stage – 2005 Event

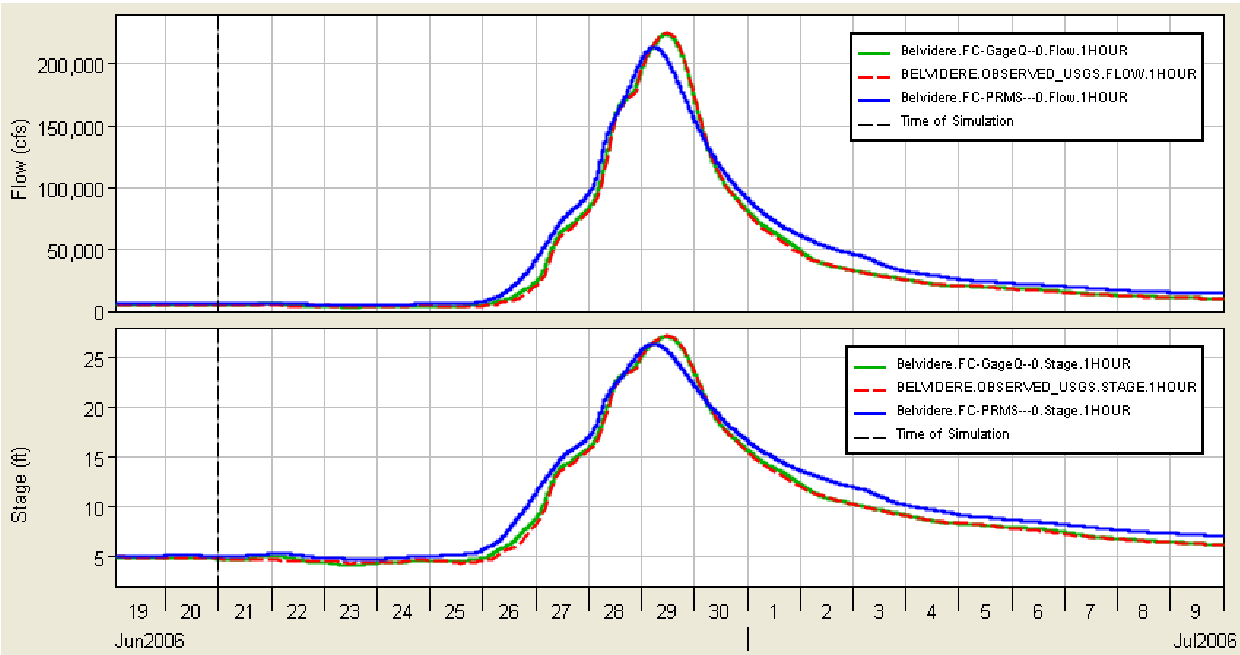


Figure 5.75 Belvidere Flow and Stage – 2006 Event

5.2.5.3 Merrill Creek

Merrill Creek Reservoir is an off stream pumped storage project built by the some of the power companies to provide low flow augmentation during drought conditions, allowing them to offset their consumptive use resulting from power generation. The natural creek in which the reservoir was constructed has a very small contributing basin which is easily managed by the six feet of flood control storage at Merrill Creek. An emergency spillway which discharges into Lopatcong Creek was included in the reservoir "just in case" but it is not expected to ever flow. The conservation pool is filled by a pumped diversion from the Delaware River. Neither the emergency spillway nor the pumped diversion were represented in the model as the reservoir did not spill and the pumps are not used during high flows in the Delaware River or flood operation of the reservoir.

The operation plan for Merrill Creek indicates that most non-flood releases are made to meet low flow augmentation requirements to manage the salt front in the lower Delaware River. At all times, Merrill Creek must maintain an at-site minimum flow of 3 cfs. Flood operations simply identify a maximum release of 20 cfs.

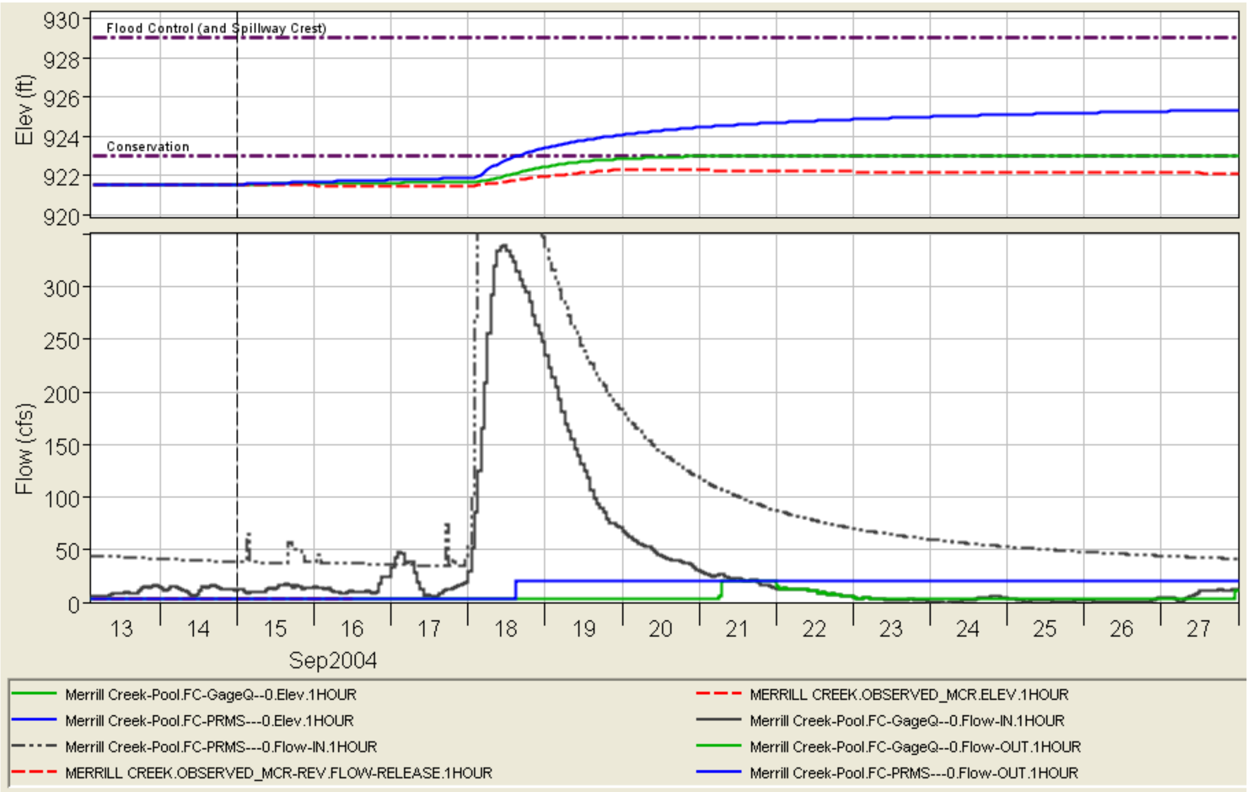


Figure 5.76 Merrill Creek Reservoir Plot – 2004 Event

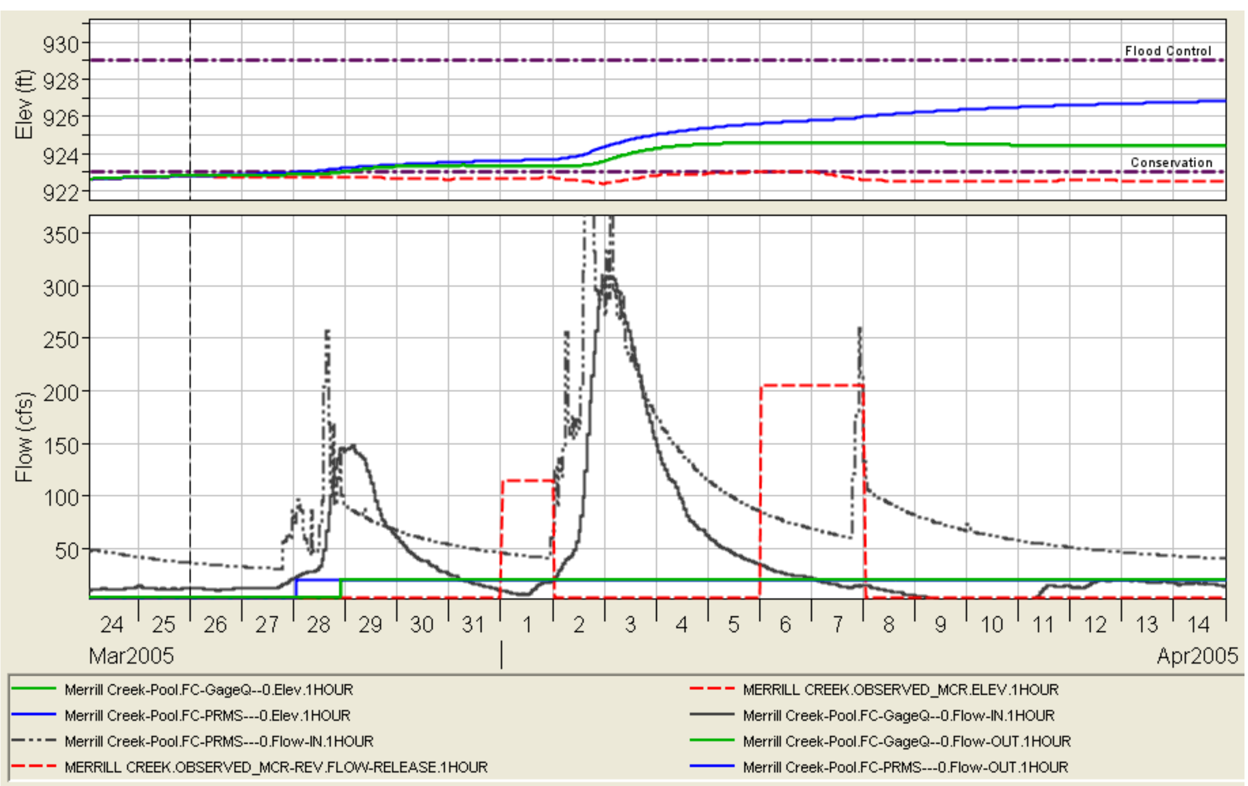


Figure 5.77 Merrill Creek Reservoir Plot – 2005 Event

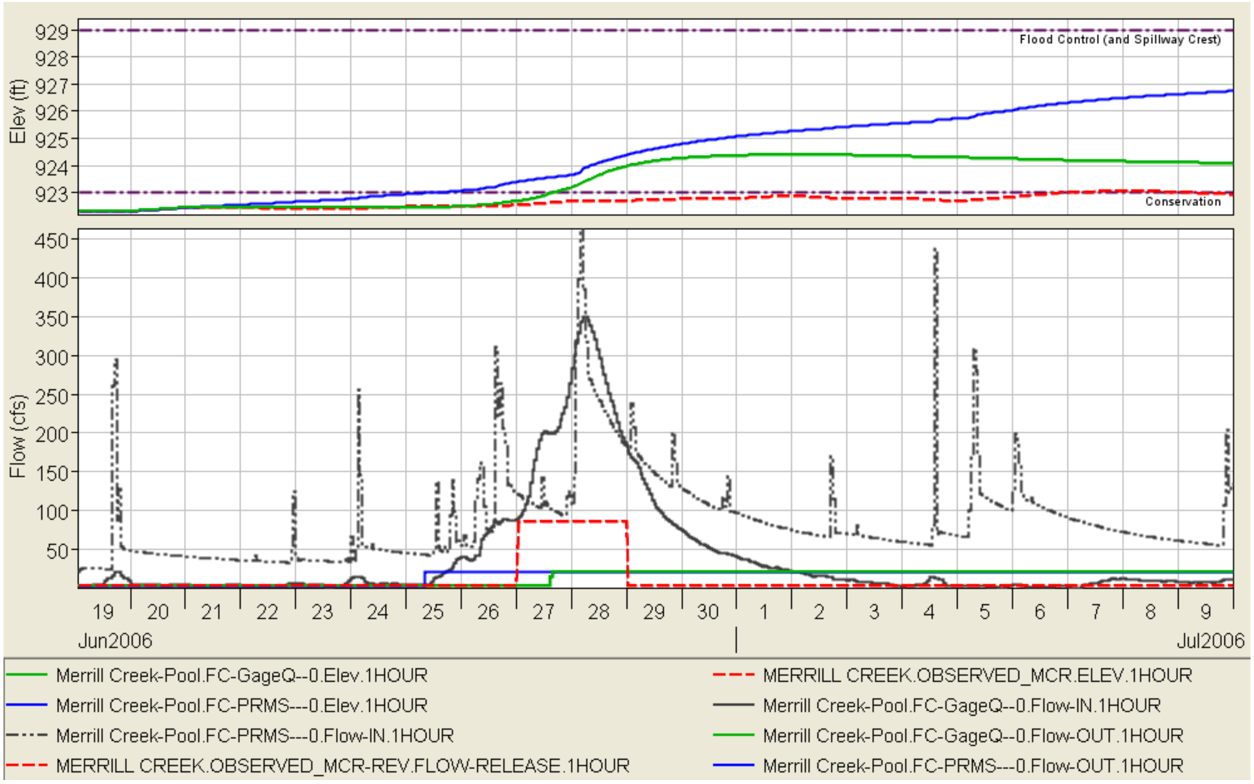


Figure 5.78 Merrill Creek Reservoir Plot – 2006 Event

5.2.5.4 Riegelsville

The Riegelsville gage is located on the Delaware River just upstream of the confluence with the Musconetcong River. Several tributaries enter the Delaware upstream of this gage including the Lehigh River. Riegelsville is a primary forecast location for the NWS River Forecast Center. The stages at several downstream locations for which there are no established rating curves are estimated using regression relationships based on the stage at Riegelsville. Using the rating curve for Riegelsville, *FC-GageQ* alternative of the model under-predicts the peak stage at Riegelsville by approximately six percent in comparison with the observed record.

The rating curve at Riegelsville is not consistently maintained by the USGS. Because the Riegelsville stage is so important for the prediction of stage at other NWS flood forecast locations, the rating curve at Riegelsville was evaluated by DRBC personnel. It was decided that since the simulated flow at Belvidere and Bethlehem were within approximately one percent of the observed flows and attenuation in the river could account for not observing an increase in flow due to the small tributaries between Belvidere, Bethlehem and Riegelsville, the flows in the Riegelsville rating curve in the model were reduced by six percent such that lower flows would produce higher observed stages and allow better predictions of stages at the locations without rating curves. For reference, the original rating curve was placed at the Del+Musconetcong junction because the reported flow at the Riegelsville gage includes flow from the Musconectong.

Figure 5.79 through Figure 5.81 show simulated flow and stage at Riegelsville for each of the three events modeled. The simulated stages illustrated were produced using the modified rating curve. The observed flows illustrated were produced by the USGS using the original rating curve.

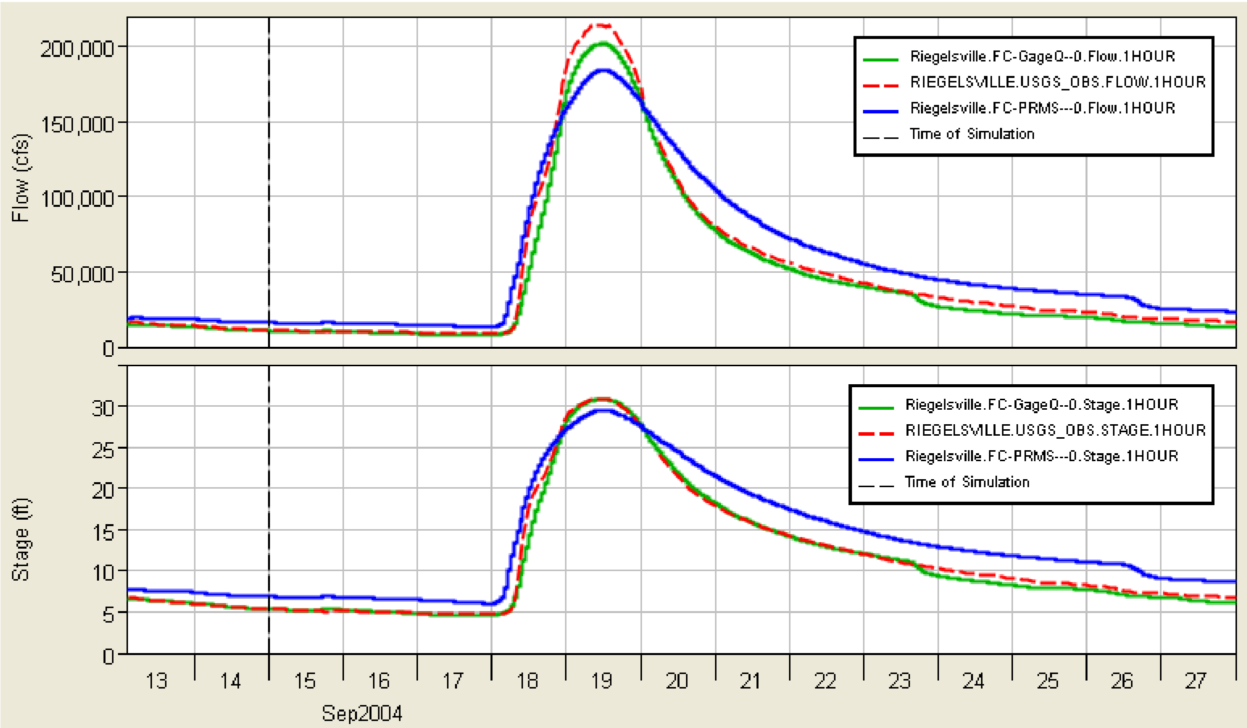


Figure 5.79 Riegelsville Flow and Stage – 2004 Event

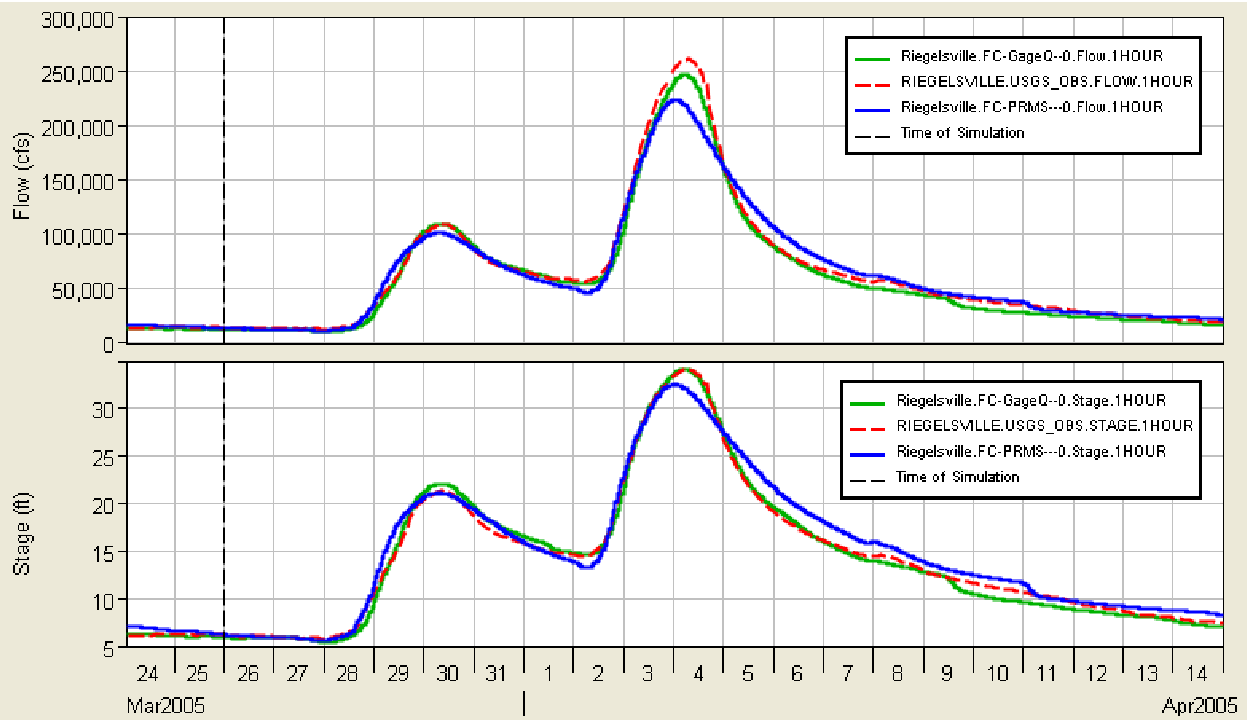


Figure 5.80 Riegelsville Flow and Stage – 2005 Event

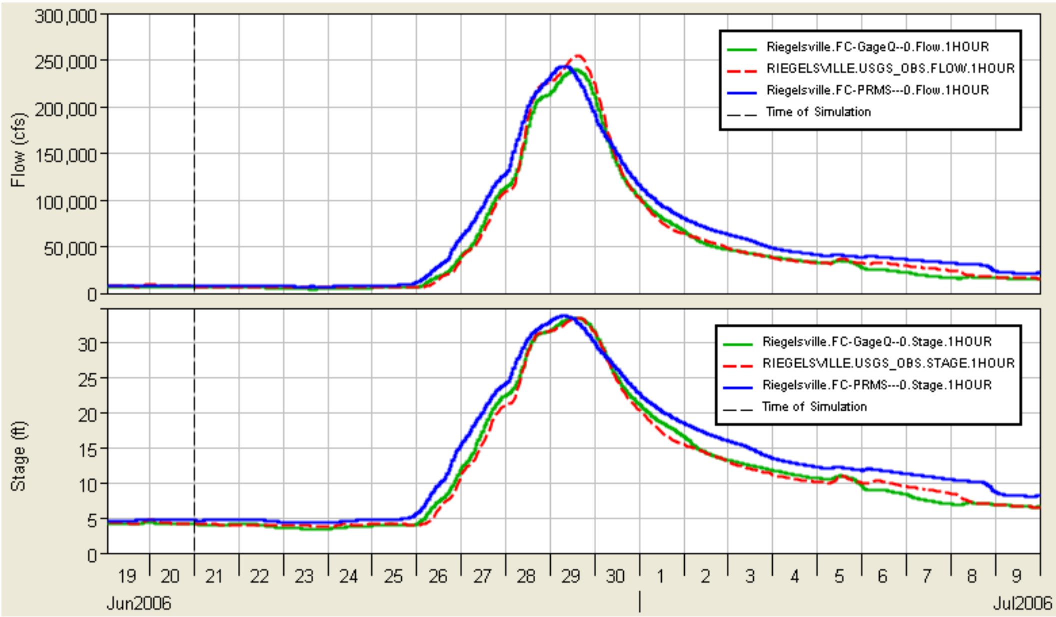


Figure 5.81 Riegelsville Flow and Stage – 2006 Event

5.2.6 Nockamixon

Nockamixon Reservoir is located on Tohickon Creek in Nockamixon State Park, Pennsylvania. Although it was built primarily as a recreation reservoir, it does have a flood control pool of approximately 15 feet. However, flood control operations call for the closure of the primary flow augmentation outlets and allow the spillway to discharge inflow up to spillway capacity. Nockamixon has a minimum release requirement of 11 cfs. A sixteen-inch cone valve is used to meet the minimum flow requirement at all times, even during flood operations. Observed data was not available for Nockamixon Reservoir.

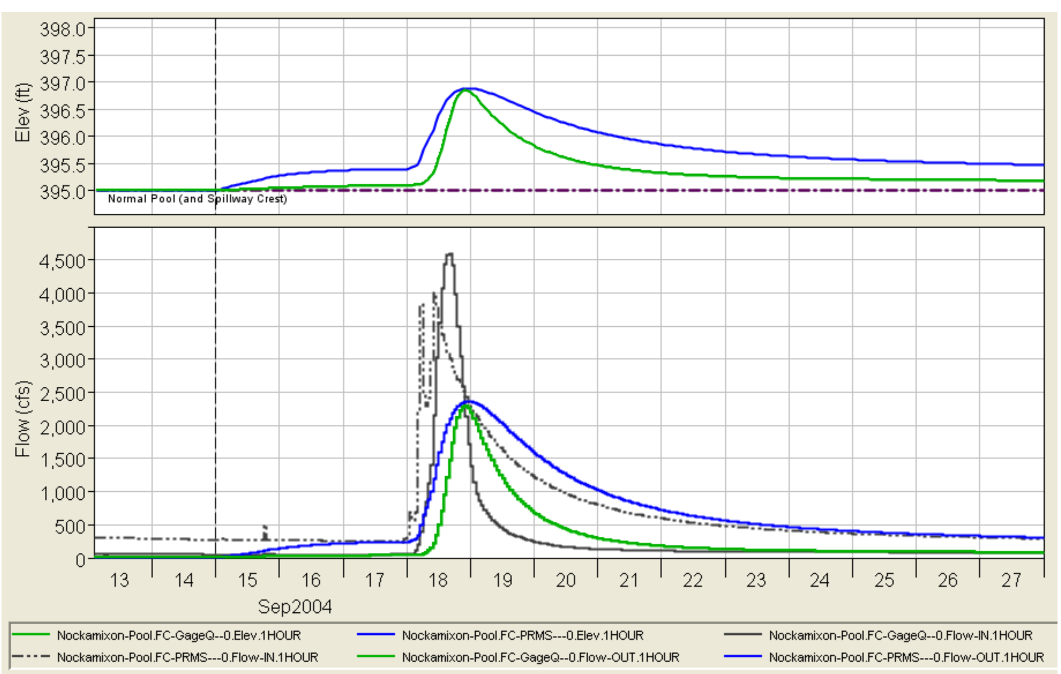


Figure 5.82 Nockamixon Reservoir Plot – 2004 Event

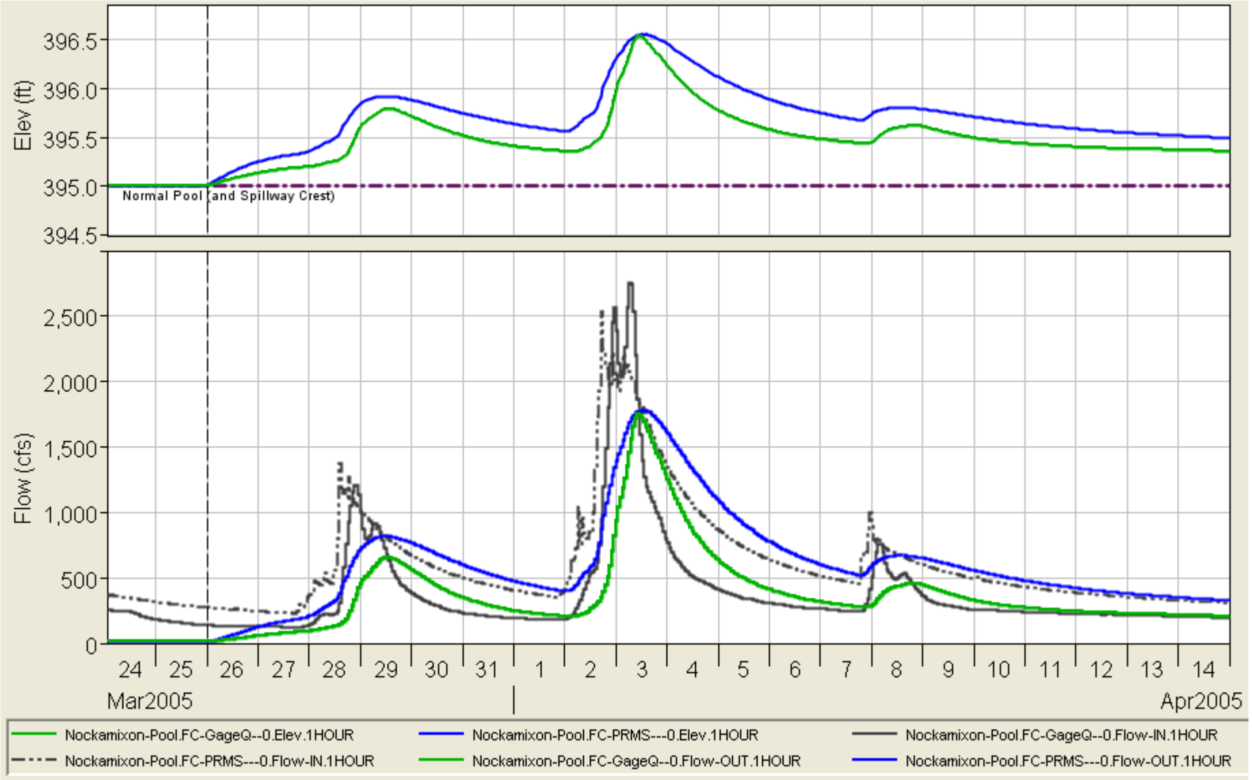


Figure 5.83 Nockamixon Reservoir Plot – 2005 Event

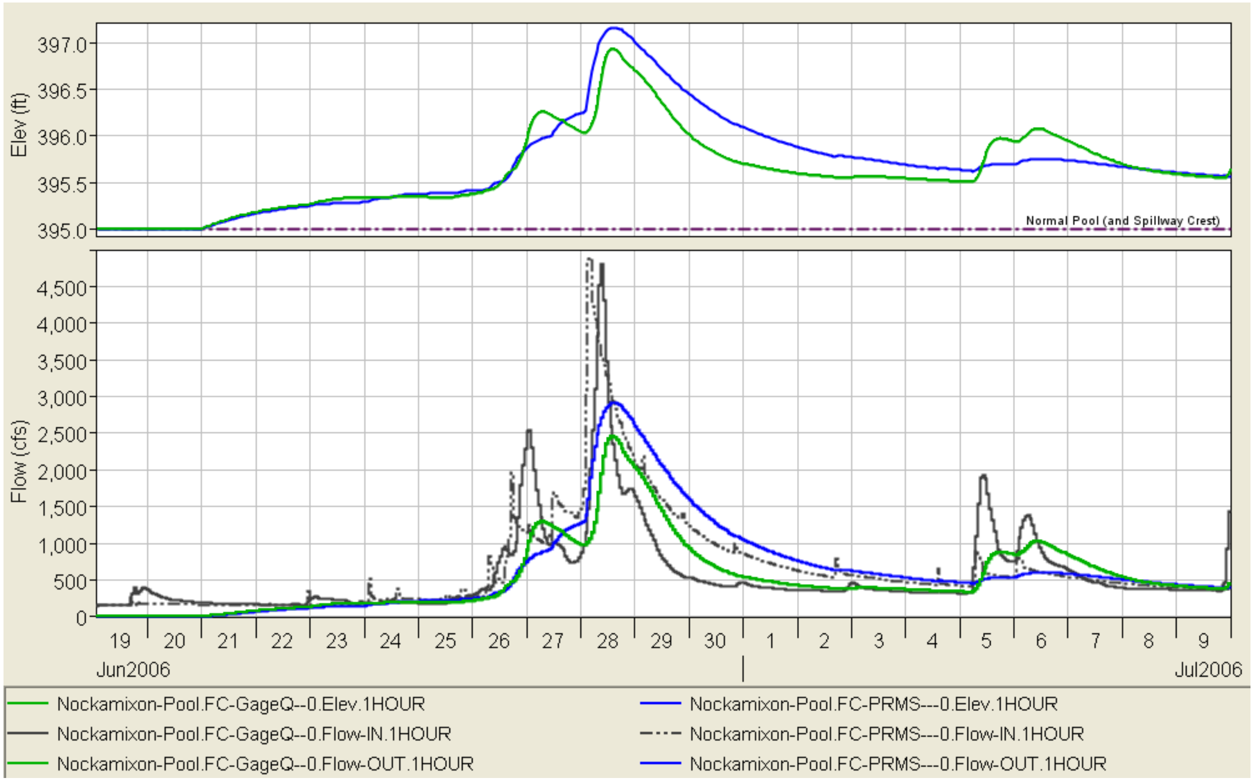


Figure 5.84 Nockamixon Reservoir Plot – 2006 Event

5.2.7 Trenton

Trenton is the downstream-most point in the model and the downstream-most gage location on the Delaware that is not affected by tides. Trenton is also a major forecast location for the NWS. As illustrated in Figures 5.85 through 5.87, the model results for both alternatives compare favorably to the observed record at Trenton.

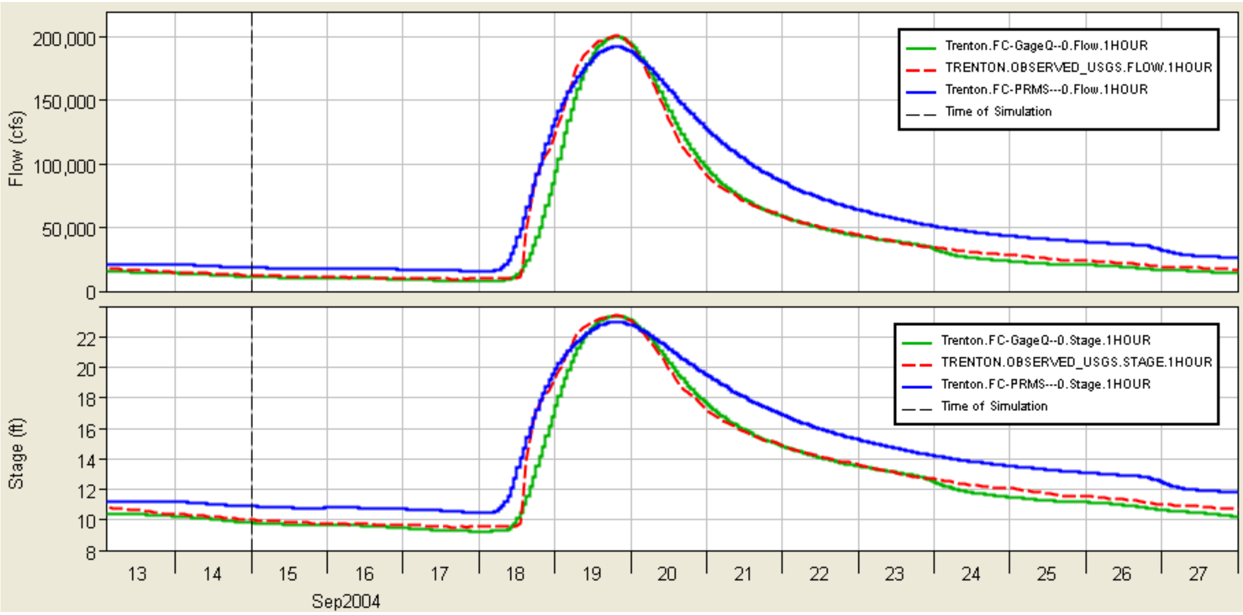


Figure 5.85 Trenton Flow and Stage – 2004 Event

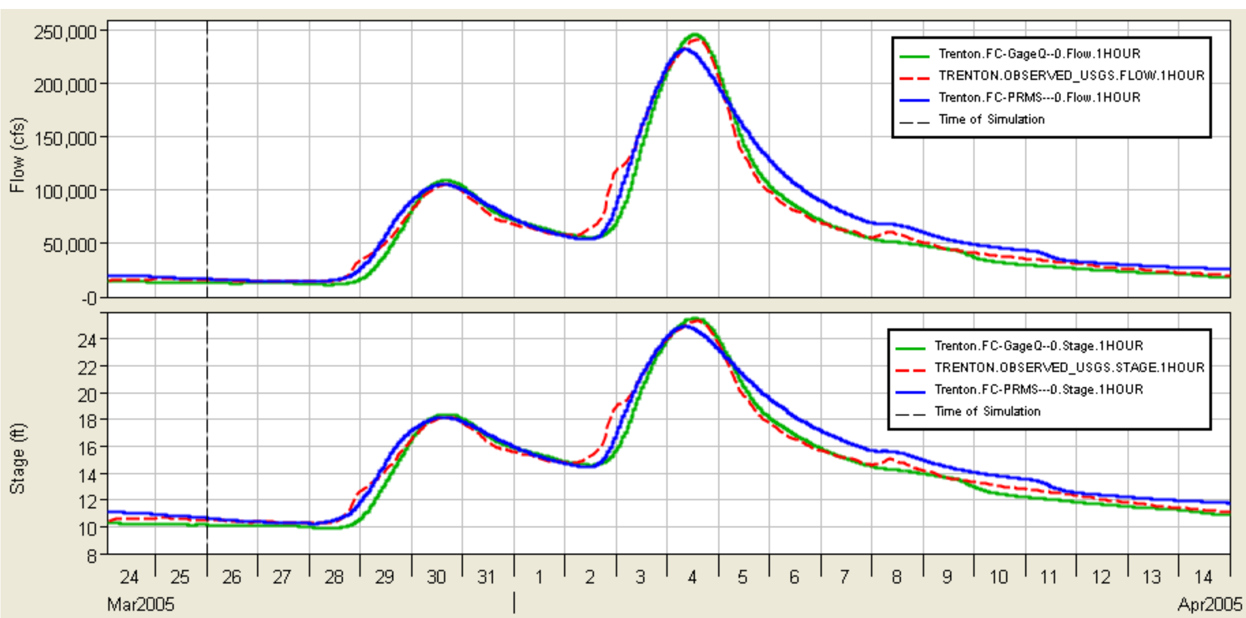


Figure 5.86 Trenton Flow and Stage – 2005 Event

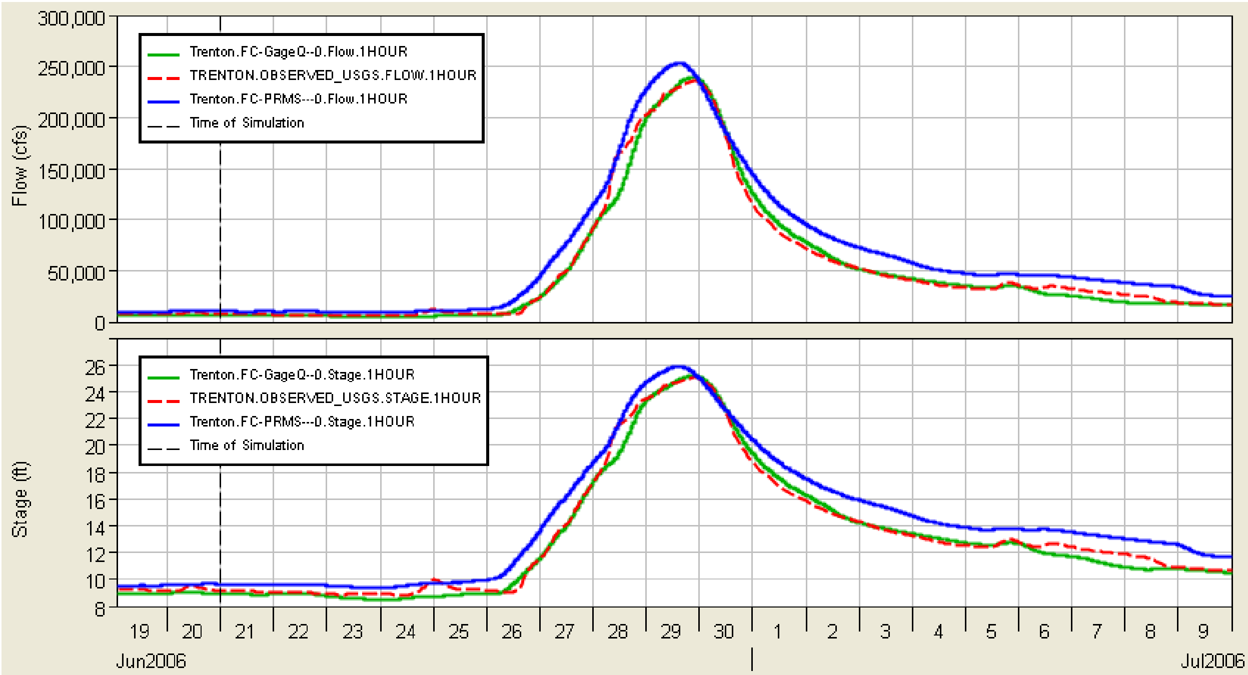


Figure 5.87 Trenton Flow and Stage – 2006 Event

Chapter 6

Summary

6.1 Model Summary

The reservoir simulation and routing model developed by the USACE, Hydrologic Engineering Center as a component of the Delaware River Flood Analysis Model simulates the operation of thirteen reservoirs in the basin and the routing of their releases along with intervening local flows through the river system down to Trenton. The purpose of the model is to serve as the basis for analysis of alternative flood risk management strategies.

Data for the model was provided by the US Geological Survey, the US Army Corps of Engineers, Philadelphia District, the National Weather Service, and the Delaware River Basin Commission and its partner agencies. Streamflows downstream of the reservoirs on the main stem Delaware River and some of its major tributaries are well gaged. However, some of the major tributaries as well as most of the minor tributaries are not well gaged which made modeling of the reservoir operations and routing on these streams challenging.

At the request of the Delaware River Basin Commission, two base alternatives were developed. In the model, these alternatives were named *FC-PRMS* and *FC-GageQ*. Both alternatives simulate the individual reservoir flood operating policies in effect at the time of the three events studies.

The *FC-PRMS* alternative uses inflows computed by the PRMS-based hydrology model developed by the USGS as the rainfall-runoff component of the Flood Analysis Model. The objective of the PRMS model was to produce inflow for HEC-ResSim that could be used to adequately represent the flows that would be experienced in the basin under a selected set of hydrologic conditions. Due to uncertainties in rainfall-runoff modeling, the DRBC determined that the *FC-PRMS* alternative did not satisfactorily reproduce the peak flows or total volumes that occurred during the three major flood events of 2004, 2005 and 2006.

The *FC-GageQ* alternative uses gaged and derived-from-gaged inflows. The objective of this alternative was to reduce the uncertainty and error contributed by the rainfall-runoff modeling by using the observed flow record to develop the inflows to the model and to carefully configure the operations in order to reproduce as closely as possible the observed flow in the system. With only one exception (described in Chapter 4), all operational adjustments made in the *FC-GageQ* alternative are reflected in the FC-PRMS alternative.

6.2 Recommended Application of the Model

Due to the different sources of inflows, the recommended uses of each alternative are different. The use of inflows produced by a rainfall-runoff model makes the *FC-PRMS* alternative appropriate for investigating the response of the reservoir system to differing inflow scenarios. The PRMS model could be used to develop an assortment of inflow data sets for the ResSim model representing different rainfall intensities, storm centerings and distribution, soil moisture conditions, and other variations on basin conditions.

On the other hand, the *FC-GageQ* alternative which uses observed and derived-from-observed inflow is designed specifically for its current inflow data set. This alternative would be appropriate to use in investigating the impacts of changes in initial reservoir conditions or different reservoir operating plans.

6.3 Recommendations for Model Enhancements

Although the model is ready for use by the DRBC in their flood operations analysis of the Delaware River system above Trenton, the following suggestions for further enhancement to the model could be pursued should data and resources become available.

The flood operation of Lake Wallenpaupack could also be expanded. The current operation defined in the model is a simplification of the complex operating guidelines described in the Lake Wallenpaupack Emergency Action Plan (EAP). The EAP describes a release decision policy that relies on consensus by a number of managers, each responsible for a different aspect of the Lake Wallenpaupack Hydropower System who must take into account situational factors that are outside the scope of the model. With the assistance of the operators of Lake Wallenpaupack, it may be possible to redevelop the flood operations in the model so that the key factors that influence release decisions at the lake could be accounted for and the appropriate release for each trigger level defined.

At the time this model was developed, the new owners of the reservoirs in the Mongaup River Basin were just beginning to process the records they inherited. With experience and reorganization, the new owners will likely be able to play a more active role in describing the behavior of the Mongaup Reservoirs during high flow conditions and provide more data for development of a more robust operating scheme for the model. One of the key elements of a new operating scheme could be improvement of the scripts that model the flashboard operation. These scripts currently assume that when the flashboards fall, they all fall at once. In reality, this is rarely the case. Enhancements to the scripts and the operation set could be added to define a more incremental falling behavior of the flashboards.

Lastly, the remaining three reservoirs that exist in the basin could be added to the model. While none of these reservoirs is currently tasked to operate to reduce flood peaks in the rivers downstream of them, any reservoir, large or small, can have an impact on flood flow routing in a system. That impact is typically related to the lag and attenuation of the flood hydrograph as it is routed through a reservoir pool, possibly resulting in a small reduction in peak flows at damage centers. In addition, as with the 13 other reservoirs in the basin, possible changes in operating schemes could be investigated at these reservoirs to determine if they could play a more active role in reducing flood risk.

Chapter 7

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Appendix A

Scope of Work
Delaware River Basin Flood Analysis Model

Originally Prepared and Approved – 6 Aug 2007
Revised and Approved – 29 Feb 2008

U.S. Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center

DELAWARE RIVER BASIN

FLOOD ANALYSIS MODEL

Scope of Work

Prepared for

Delaware River Basin Commission

Submitted by:
U.S. Geological Survey
U.S. Army Corps of Engineers – Hydrologic Engineering Center
NOAA - National Weather Service

corrected February 29, 2008

DELAWARE RIVER BASIN
FLOOD ANALYSIS MODEL

Problem:

Three major main stem floods between September of 2004 and June of 2006 have focused attention on the potential effects of storage volumes (voids) in major reservoirs within the Delaware River Basin on downstream discharges. Some of the major reservoirs were designed and built for flood control purposes while others were designed for water supply, hydropower, and recreation.

Evaluation of alternative operational scenarios for this complex reservoir system can be improved by use of a physically-based flood analysis model that simulates runoff and streamflow routing, incorporating the impact of storage in and discharge from major reservoirs.

DRBC Resolution 2006-20 authorizes the Executive Director of the Delaware River Basin Commission (DRBC) to develop a flood analysis model for the basin. Complex models that represent rainfall and snowmelt runoff, reservoir hydraulics, and flow routing are required and need to be combined into a single flood analysis model. The tool is needed to allow:

- The DRBC and others the capability to evaluate the potential for the basin's major reservoirs to be operated for flood mitigation;
- The DRBC and others to evaluate the feasibility of various reservoir operating alternatives;
- The DRBC and others to evaluate the effect of reservoir voids of different magnitudes on streamflow at locations downstream from the reservoirs;
- The DRBC and others the ability to examine, modify, and improve the model and datasets as new information and technology become available; and
- The DRBC and others to use the output from the tool as an educational instrument for demonstrating the operations of reservoirs and basin hydrology.

In cooperation with the Delaware River Basin Commission (DRBC), the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE) - Hydrologic Engineering Center (HEC), and the NOAA's National Weather Service (NWS) will develop an integrated flood analysis model for the Delaware River Basin to allow evaluation of flood operations at individual reservoirs and the reservoir system.

Purpose:

Develop a flood analysis model that will allow the evaluation of existing reservoirs for flood mitigation. The model will provide data to evaluate the effects of various reservoir operating alternatives on flooding at locations downstream of the reservoirs. The tool will incorporate rainfall/runoff processes, reservoir operations and flow routing components into a model for simulation of flood hydrographs at USGS stream gage locations and co-located NWS flood forecast points on the Delaware River and its tributaries.

Objectives:

1. Construct a rainfall/runoff and snowmelt model for the non-tidal Delaware River Basin to Trenton, New Jersey, for the non-tidal Schuylkill River Basin, and for the non-tidal Christina River Basin.
2. Construct reservoir simulation models for 15 reservoirs in the Delaware River Basin, as designated by the DRBC.
3. Construct a flow routing model for the Delaware River and major tributaries above Trenton, as well as for the non-tidal Schuylkill and Christina Rivers.
4. Integrate datasets for rainfall/runoff and snowmelt, reservoir simulation, and routing models into a common database structure and framework.
5. Integrate the rainfall/runoff, reservoir simulation, and flow routing models into a single operational tool that will incorporate a graphical user interface for input parameters and datasets as well as output from the models. The modeling system will be modular and allow future

incorporation of improved algorithms and improved datasets, such as higher-resolution digital elevation models (DEM's). As an initial step, the model components will first be applied to a pilot watershed to avoid incompatibility and integration issues, and to provide opportunities for reviewer inputs on the final model development approach. The pilot application will provide a test of model function and integration of features rather than calibration.

Approach:

The multi-agency project team will include participation of NWS, HEC, and USGS. Project coordination will be provided by the USGS Pennsylvania Water Science Center, with additional USGS contributions by the New Jersey and New York Water Science Centers, National Research Program, and Office of Surface Water. HEC will have lead responsibility for the reservoir and flow-routing models, and will contribute to all project products. USACE Philadelphia District will provide information on USACE reservoirs in the basin. The NWS Middle Atlantic River Forecast Center (MARFC), as well as Eastern Region Headquarters and Office of Hydrologic Development, will focus primarily, but not exclusively, on assisting with the flow-routing model components. Ongoing advisory input will be sought from staff of the Delaware River Basin Commission, the USGS Delaware River Master, and the Delaware River Basin Commission Flood Advisory Committee.

Task 1 –Database Development and Maintenance:

A unified relational database will be constructed for the flood analysis model. The database will contain all data needed to simulate streamflow using the rainfall/runoff, reservoir, and flow-routing components described in following tasks. This database will provide a controlled system to quality assure input information and minimize redundancy in compiling input data that may be used in more than one model component. Many of the spatial GIS coverages needed have already been compiled for USGS projects in the Basin such as the ongoing National Water Quality Assessment (Fischer and others, 2004) and the SPARROW basin-scale nutrient transport model (Chepiga and others, 2004). Streamflow routing model datasets are in use for current river forecasting by MARFC. Additional datasets will include USACE reservoir storage curves and operation rules, radar and gage precipitation, stream gage rating curves, digital elevation model, streams, hydrologic response units, streamflow-routing parameters and coefficients. USGS will lead this task.

Description of Subtasks:

1.1 Determine required data sets needed for model development, design database structure, and identify format and metadata requirements.

Deliverable: Electronic text file including description of database structure

Expected Completion: Sep 07

Responsible Party: USGS

1.2 Acquire available data sets including spatial datasets such as the 1:24,000 National Hydrography Dataset (NHD) and Delaware Basin NAWQA land use and other coverages.

Deliverable: Electronic database files

Expected Completion: Nov 07

Responsible Party: USGS; DRBC will provide reservoir physical and operational data (including elevation, storage, area of the pool, dam elevation and length, outlet capacity tables, pool levels for operation (top of flood, top of con, top of power, inactive, etc) and release objective and constraints) and diversion data (including demand and conduit capacity).

1.3 Populate and update working database and spatial database, fill data gaps using appropriate procedures.

Deliverable: Electronic database files

Expected Completion: Jan 08

Responsible Party: USGS

1.4 Quality assure and maintain the database, incorporate new datasets from modeling tasks, or from outside efforts

Deliverable: Electronic database files

Expected Completion: Jan 09

Responsible Party: USGS

Task 2 – Rainfall/Runoff Model Development:

The USGS Precipitation Runoff Modeling System (PRMS) will be used for the rainfall/runoff model component (Leavesley and others, 1983). PRMS is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow (Leavesley and others, 1983; Leavesley and Saindon, 1995).

Geospatial datasets for the rainfall/snowmelt/runoff model component using the USGS Precipitation Runoff Modeling System (PRMS) include:

raster (e.g.: NEXRAD) precipitation and gage precipitation
air temperature
solar radiation (estimated where unavailable)
digital elevation model (DEM)
hydrologic response units (sub-watersheds)
stream locations
land use

Description of Subtasks:

2.1 Construct pilot watershed PRMS model for part of Delaware River Basin

Deliverable: Presentation of pilot model construction and preliminary results for the East and West Branches of the Delaware River, electronic datafiles for use in other model components

Expected Completion: Nov 07

Responsible Party: USGS

2.2 Construct full Delaware River Basin PRMS model above Trenton

Deliverable: Electronic model files

Expected Completion: Feb 08

Responsible Party: USGS

2.3 Calibrate and verify PRMS model discharges using three recent high-flow events

Deliverable: Electronic model files

Expected Completion: Mar 08

Responsible Party: USGS

2.4 Construct, calibrate and verify PRMS model for Schuylkill Basin

Deliverable: Electronic model files

Expected Completion: Apr 08

Responsible Party: USGS

2.5 Construct, calibrate and verify PRMS model for Christina Basin

Deliverable: Electronic model files

Expected Completion: May 08

Responsible Party: USGS

Task 3 – Reservoir Simulation and Flow Routing – (HEC-ResSim):

HEC will lead development and application of HEC-ResSim for simulation of reservoirs and flow routing. HEC-ResSim (USACE, 2007) was developed to assist in planning studies for evaluating proposed reservoirs in a system and to assist in sizing the flood control and conservation storage requirements for each project. HEC-ResSim will be used to determine the influence of major reservoirs on streamflow in the basin and evaluate selected alternative reservoir release rules to mitigate downstream flooding.

HEC will coordinate with the DRBC, USGS and NWS in the creation of a HEC-ResSim model of the Delaware River Basin. See Appendix A for a list of the reservoirs to be modeled.

Description of Subtasks:

3.1. Gather and analyze data required for flow-routing and reservoir modeling. These data include:

- time-series data (computed inflow and incremental local flow hydrographs from PRMS, observed flow hydrographs, observed reservoir pool elevations and releases and the associated computed reservoir inflows, etc.) for the three major flood events that have occurred within the last 4 years,
- physical and operational reservoir data including reservoir pool definition (elevation-storage-area tables), outlet capacity curves, hydropower plant data (outflow and generation capacities, efficiency, losses, etc), operational zones, minimum and maximum release requirements, etc.,
- rating curves at each stream gage location, and
- routing reach parameters from existing NWS forecasting models.

Other resources that will be needed include reservoir regulation manuals or other descriptions of the current reservoir operational objectives and constraints, and geo-referenced map files of the Delaware River Basin including a rivers and streams map file, a lakes map file that identifies the reservoir locations and extents, and, if available, a watershed boundary map file that may include the sub-basin delineations, a stream gage locations map file, and a state boundaries map file.

Deliverable: Electronic data files

Expected Completion: Jan 08

Responsible Party: HEC, with data from DRBC and USACE Philadelphia District

3.2. Develop a model schematic that identifies the key locations in the watershed. Key locations include reservoirs, gage locations, control points, forecast points, and any other locations that are needed as data transfer points between the PRMS model and the HEC-ResSim model or for information for the analysis of results. Geo-referenced map files (identified in step 1) will be used as the background of the model schematic and for delineation of the stream alignment (the framework or skeleton upon which the model schematic is created). The map files will be obtained from and/or shared with the PRMS modelers so that both models will use the same units and spatial transformation.

Deliverable: Model schematic map (digital) and definitions (text file)

Expected Completion: Feb 08

Responsible Party: HEC

3.3. HEC, in cooperation with USGS, and in consultation with NWS, will evaluate the use of several alternative approaches for flow routing in the main channel and major tributaries of the Delaware River. HEC-ResSim contains seven methods for routing streamflow (Coefficient, Muskingum, Muskingum-Cunge 8-pt Channel, Muskingum-Cunge Prismatic Channel, Modified Puls, SSARR, and Working R&D Routing), each method with its own set of routing parameters. In addition, the NWS variable lag & K routing method will be incorporated into HEC-ResSim so that existing operational parameters developed by NWS can be used, where applicable.

Deliverable: Updated executables for HEC-ResSim with NWS flow routing

Expected Completion: Nov 07

Responsible Party: HEC, with input from NWS

3.4. Define the physical and operational data for each major reservoir in the basin. Physical reservoir data include: reservoir pool storage definition, dam elevation and length, outlets and their release capacities, and power plant data (if applicable). Defining the operational data includes specifying the operation zones or levels, the rules that constrain the releases for each zone, and a release allocation strategy that indicates how the releases will be allotted to the available outlets.

Deliverable: Datasets for reservoir simulation with HEC-ResSim

Expected Completion: Apr 08

Responsible Party: HEC, in cooperation with DRBC and input from USACE Philadelphia District

3.5. For each river junction that will receive incremental local inflow (i.e., subbasin runoff from hydrologic model), identify the source and an appropriate ratio (usually 1.0). In addition to key control point locations, the NWS forecast locations and USGS gage locations will be identified and included as junctions. Discharge to stage conversion at relevant locations will be computed from available rating curves.

Deliverable: Datasets for local inflow in HEC-ResSim and table of ratios

Expected Completion: Apr 08

Responsible Party: HEC, in consultation with USGS

3.6. Demonstration of the model for the "pilot" basin will be done by simulation of three selected high-flow events using observed (flow and reservoir elevation & releases) datasets from NWS, USGS, and USACE Philadelphia District.

Deliverable: Electronic model files

Expected Completion: Nov 07

Responsible Party: HEC

3.7. Verification of the models for the Delaware Basin to Trenton, the Schuylkill Basin, and the Christina Basin will be done by simulation of three selected high-flow events using observed (flow and reservoir elevation & releases) datasets from NWS, USGS, and USACE Philadelphia District. A single alternative will be developed to represent the current conditions and operations in the watershed. It is expected to be the basis for future modeling efforts by the DRBC.

Deliverable: Electronic model files

Expected Completion: Jun 08

Responsible Party: HEC

Task 4 – Integration of the model components into the Modular Modeling System (MMS):

The Modular Modeling System (MMS) (Leavesley and others, 1996) is an open-source computer software system developed to (1) provide the integrated software environment needed to develop, test, and evaluate physical-process algorithms; (2) facilitate integration of user-selected algorithms into operational physical-process models; and (3) provide a common framework in which to apply historic or new models and analyze their results. MMS uses a library that contains modules for simulating a variety of physical processes (Leavesley and others, 1996). The MMS will be used to link all simulation models utilized in the system to a common database (Task 1) and to a graphical user interface (Task 5) for user interactions and the analysis of simulation results. This will provide a database-centered approach to support model applications and analysis. PRMS is currently incorporated in MMS, and interfaces will be developed to incorporate HEC-ResSim complete with the newly integrated flow routing algorithms into

MMS, as needed. Data interfaces for DSS format data, used by HEC-ResSim, have already been developed for MMS. USGS will lead this task.

Description of Subtasks:

4.1. Construct interfaces to prepare model input from common database

Deliverable: Updated MMS files
Expected Completion: Nov 07
Responsible Party: USGS

4.2. Construct interfaces to read model component output and convert to common database structure

Deliverable: Updated MMS files
Expected Completion: Nov 07
Responsible Party: USGS

4.3. Construct interfaces to link output from one model component to input for another model component. Such links include:

- discharge output from PRMS linked to reservoir inflow for HEC-ResSim
- incremental local flow from PRMS linked to flow routing in HEC-ResSim

Deliverable: Updated MMS files
Expected Completion: Nov 07
Responsible Party: USGS, in consultation with HEC

4.4. Construct interfaces to prepare model results for graphical display in the common database format

Deliverable: Update MMS and GUI tool files
Expected Completion: Jul 08
Responsible Party: USGS

Task 5 – Graphical User Interface (GUI) Development:

A graphical user interface (GUI) that will enable a user to modify input data, apply the linked flood analysis model, and analyze the results will be developed by USGS. A user's guide explaining how to use the GUI and documenting the capabilities and functionality of the flood analysis model will be written. The GUI will:

- Package the rainfall/runoff, reservoir simulation, and flow routing model components into a single management tool to provide the technical support for evaluating potential flood operating scenarios.
- Have a pre-processor graphical user interface to facilitate alternative flood scenario simulations by incorporating the following;
  1. User friendly input for climatic data to facilitate simulation of historic flood events, snowmelt or other user defined scenarios.
  2. The capability to simulate single or multiple storms over a 10-day period.
  3. The functionality to allow the user to simulate flood events under varied reservoir pool void and operating conditions.
  4. The functionality to allow the user to change predefined operating rules of existing reservoirs.
- Have post-processing capabilities to display:
  1. A selectable map of the basin showing the reservoirs and forecast points.
  2. Graphical display of the hydrograph for USGS gaging stations and co-located NWS flood forecast points, including a display of water elevation showing the stream cross section for the gage location where available.

- Provide other options, such as historic rainfall and snowmelt event hydrographs at gaging stations and NWS forecast points for selection by the user to compare to user generated hydrographs using different reservoir operation scenarios.

Description of Subtasks:

5.1. Modify existing GUI for pilot application

Deliverable: Updated GUI tool files
Expected Completion: Nov 07
Responsible Party: USGS

5.2. Design and program custom DRBC user input interface

Deliverable: Electronic GUI files
Expected Completion: May 08
Responsible Party: USGS, in consultation with DRBC

5.3. Design and program custom DRBC graphical output components of GUI

Deliverable: Electronic GUI files
Expected Completion: May 08
Responsible Party: USGS, in consultation with DRBC

5.4. Revise and improve GUI input and output components based on advisory input from DRBC and others

Deliverable: Final GUI electronic files
Expected Completion: Jul 08
Responsible Party: USGS

Implementation Strategy

The implementation strategy includes an initial focus on a flood analysis model for the East and West Branches of the Delaware River. This "pilot basin" approach will avoid late-stage incompatibility and integration issues between model components and provide DRBC and advisors with an opportunity for timely input on the final basin-wide approach.

A coordination meeting of the USGS and HEC modelers and a DRBC representative will be held at the onset of the project to identify the key locations (subtask 3.2) and to establish a naming convention for these locations and other model elements. Both the pilot basin and the overall watershed will be addressed.

Project progress and plans will be communicated via scheduled monthly teleconferences and project milestones which will involve face-to-face meetings among project participants.

- **Milestone 1** will occur about 4 months after the agreement is signed (Nov 07) and will involve a presentation of the integrated model, including rainfall and snowmelt runoff, reservoir simulation, and flow routing for the selected "pilot" basin. After successful completion of this milestone, including an advisory peer review, the model will be expanded to the entire study area.
- **Milestone 2** will be 11 to 13 months into the project (Aug 08). It is anticipated the Delaware Basin model will be completed and discussion will focus on calibration and operation of the model and details associated with the products.
- **Milestone 3** will occur 18 months after the project start (Jan 09) and will include presentation of model results and product deliverable.

Products:

A joint USGS/HEC Report will be written that will document the flood analysis model development, including the rainfall/runoff, reservoir simulation, and flow routing components. This final report will also present results of selected applications to evaluate the impact of reservoir operations on flood mitigation. A users' guide will be written and included as an appendix of the joint final report. USGS will prepare an Open-File report on development of the rainfall/runoff model and documentation of the model database. HEC will prepare a report on the reservoir modeling and flow routing, focusing primarily on the aspects or features that subsequent modelers will need to be aware of as further alternatives are developed. At least one journal article or technical conference presentation will be written describing the integrated model of runoff, stream flow routing, and reservoir storage and releases in the Delaware River Basin.

USGS and HEC will deliver and install the flood analysis model, with all necessary input files and software components, on DRBC computer systems, and train DRBC staff in its operation. USGS and HEC will prepare presentations suitable for delivery to the public that describe model development, calibration, verification, and results of simulation of historic high flow events such as the floods of September 2004, April 2005, and June 2006.

In summary, project products will include:

- Documentation of the model development, model assumptions, model database, and model calibration and verification in a joint USGS/HEC report (Draft in Dec 08).
- A user's guide for running the flood analysis model. The user's guide will document the capabilities and functionality of the tool. The user's guide will be included in the final report (Draft in Dec 08).
- A USGS Open-File report on details of rainfall/runoff modeling and the model database (Draft in Jul 08).
- A HEC report on reservoir modeling and flow routing (Draft in Jul 08).
- Journal article or technical conference presentation (Draft in Jan 09).
- Delivery of the model in a package that will allow modification, additional simulation, expansion, and distribution by DRBC. USGS products are generally public domain. HEC-ResSim software is free and models developed using these tools can be used by anyone. (Initial version Jul 08, with ongoing updates).
- Development and, if requested, delivery of public presentations for DRBC on modeling results (Dec 07, Aug 08, Jan 09).

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Budget:

Total (gross) costs by Task are shown in Table 1.

Table 1: Summary of estimated budget (in gross dollars) by Task.

Tasks	Total Cost
Database Development	$80,000
Rainfall/Runoff Model Development	$220,000
Reservoir Simulation and Flow Routing Model Development	$209,000
Model Integration and GUI Tool Development	$35,000
Products & Management	$191,000
NOAA-NWS In-kind services (divided among proj. tasks)	$30,000 (estimated value)
Total	$765,000

Funds to conduct the proposed work will be provided by DRBC with additional funds and in-kind support from USGS and USACE, and in-kind support by NWS. USGS funds would come from the Federal-State Cooperative Program and are subject to the availability of funds. NWS staff availability may be affected by operational needs during hydrologic events. Funding sources for the project are listed in table 2.

Table 2: Summary of estimated funding (in gross dollars) ([1]*USGS contribution is subject to availability of Federal-Cooperative Program funds;* [2] *scheduling of NWS in-kind support is subject to staff availability due to hydrologic events;* [3]*Estimated monetary value for NOAA NWS's in-kind services provided;* [4]*Proposed cost-sharing agreement between DRBC and USACE)*

Agencies	Total
DRBC	$500,000
USGS Match[1] & in-kind	$100,000 $35,000
NOAA's NWS in-kind [2] (about ⅓ FTE)	$30,000[3]
USACE[4]	$100,000
Total contribution	$765,000

Project Timeline

The project will be completed 18 months from the signing of the Joint Funding Agreement.

Table 3: Timeline for project (indicates approximate timing of review meetings w/ DRBC, USACE, and USGS)

TASKS	Agency Responsible	Months after agreement is signed																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		2007					2008												'09
		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1. Database Development	USGS																		
2. Rainfall/Runoff Model Development	USGS																		
3. Reservoir Sim. Flow Routing Model Develop.	USACE																		
4. Model Integration	USGS																		
5. GUI Tool Development	USGS																		
Implementation Strategy	USACE USGS				"PILOT"							Basin Model Complete							
Product prep./delivery	USACE USGS					Pres								Pres.					Rpt

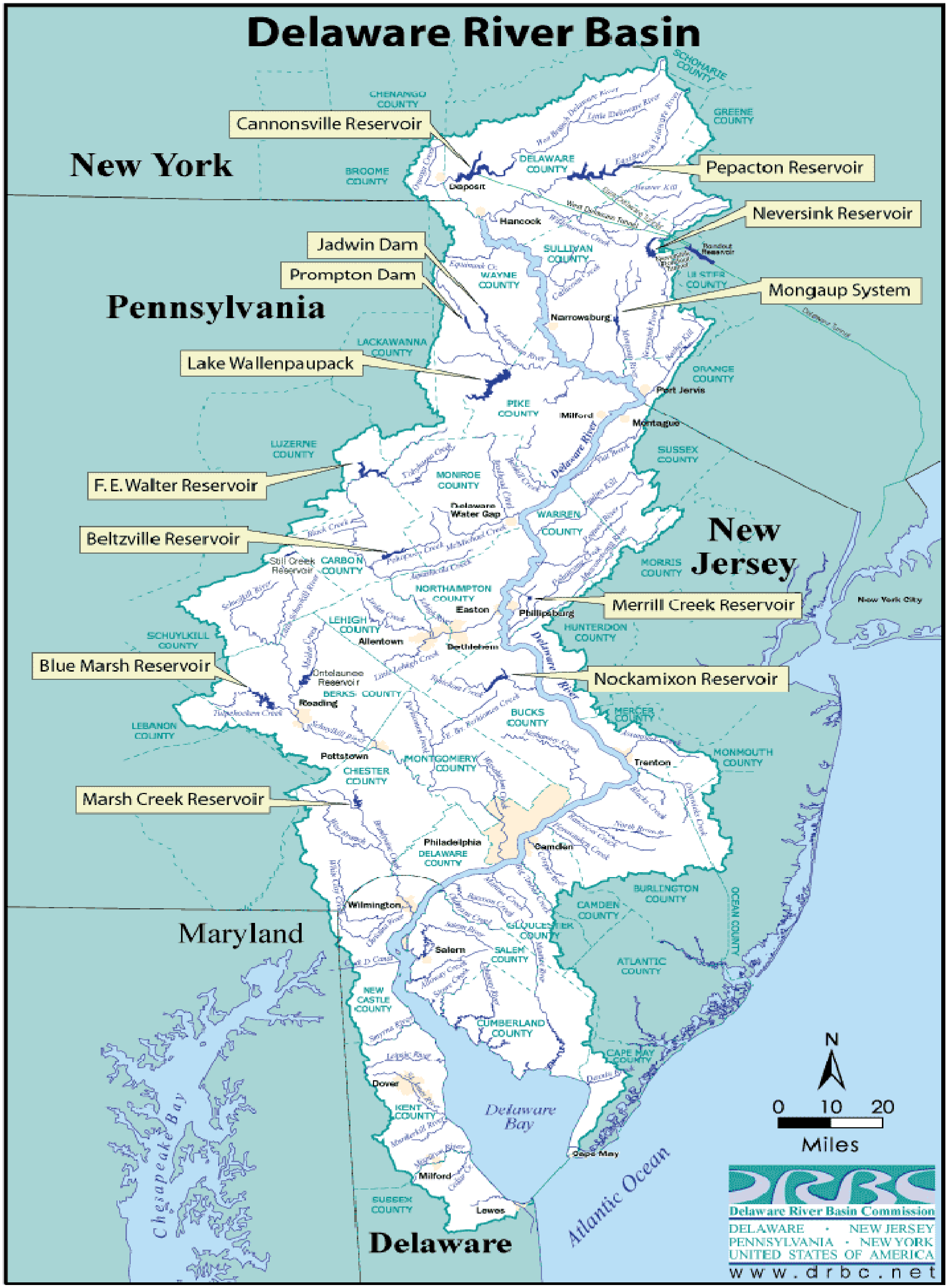

Figure 1: Map of Delaware River Basin showing major reservoirs (DRBC, 2007)

Exhibit A1 - The Delaware River Basin Model(s)

The Delaware River Basin extends into four states along northeast coast of the U.S. The river's headwaters are primarily in New York and Pennsylvania and the lower basin covers parts of New Jersey and Delaware. The river ends at the Delaware Bay which flows into the Atlantic Ocean, the tidal influence of which extends up river as far as Trenton, NJ.

The DRBC has identified three major subbasins of the Delaware River to be represented by the hydrologic and reservoir simulation model(s): 1) the middle and upper portion of the Delaware River Basin ending at Trenton; 2) the Schuylkill River basin ending at the confluence with the Delaware River; and, 3) the Christina River Basin ending at its confluence with the Delaware River.

A list of reservoirs that exist within the three basins was provided by the DRBC (see Table A1-1). The list includes a total of 26 reservoirs, 15 of which have been identified to be of primary interest for the study. 8 reservoirs are of secondary interest, but funding limitations precludes them from being included in the reservoir operations model. The remaining 3 reservoirs were identified as being located in small sub-basins that are not modeled as part of this study.

Table A1-1 – Reservoirs in the Delaware River Basin: Purpose, Capacity, and Location DRBC 3/21/07

	RESERVOIR *, **	PURPOSE[1]	STORAGE (MG)		LOCATION
			WS/WSA/P total usable	FL	STREAM, COUNTY, STATE
	PRIMARILY WATER SUPPLY RESERVOIRS				
1	Penn Forest (2) D	WS	6,510	-	Wild Creek; Carbon, PA
2	Wild Creek (2) D	WS	3,910	-	Wild Creek; Carbon, PA
3	Still Creek (2) S	WS	2,701	-	Still Creek; Schuylkill, PA
4	Ontelaunee (2) S	WS	3,793	-	Martins Creek; Berks, PA
5	Green Lane (2) S	WS	4,376	-	Perkiomen Creek; Montgomery, PA
	Geist (nw)	WS	3,512	-	Crum Creek; Delaware, PA
6	Edgar Hoopes (2) C	WS	2,199	-	Trib. of Red Clay Creek; New Castle, DE
	Union Lake (nw)	WS	3,177	-	Maurice River; Cumberland, NJ
7	Hopatcong (2) D	WS[2]	5,995	-	Musconetcong River; Sussex, Morris, NJ
8	Nockamixon (1) D	WS[3]	11,990	-	Tohickon Creek; Bucks, PA
	Subtotal:		*48,164*		
	NEW YORK CITY RESERVOIRS, WATER SUPPLY AND FLOW AUGMENTATION				
9	Cannonsville (1) D	WS, WSA	98,400	-	W. Br. Delaware River; Delaware, NY
10	Neversink (1) D	WS, WSA	35,581	-	Neversink River; Sullivan, NY
11	Pepacton (1) D	WS, WSA	147,926	-	E. Br. Delaware River; Delaware, NY
	Subtotal:		*281,907*		
	HYDROELECTRIC POWER GENERATION RESERVOIRS				
12	Lake Wallenpaupack (1) D	P	29,813	-	Wallenpaupack Creek; Wayne, PA
13 14 15	Mongaup System (1) D Resv's Rio, Toronto, & Swinging Bridge	P	15,314	-	Mongaup River; Sullivan, NY
	Subtotal:		*45,127*		

Table A1-1 – Reservoirs in the Delaware River Basin: Purpose, Capacity, and Location DRBC 3/21/07

...CONTINUED…

	RESERVOIR *, **	PURPOSE[1]	STORAGE (MG)		LOCATION
			WS/WSA/P total usable	FL	STREAM, COUNTY, STATE
	MULTIPURPOSE OR FLOOD LOSS REDUCTION RESERVOIRS				
16	Prompton (1) D	FL	none	6,614	W. Br. Lackawaxen River; Wayne, PA
17	Beltzville (1) D	WSA, FL	12,978	8,797	Pohopoco Creek; Carbon, PA
18	Marsh Creek (1) C	WS,WSA,FL[5]	4,040	1,160	Marsh Creek; Chester, PA
	Chambers Lake (2) (Hibernia Dam)	WS,WSA	383	-	Birch Run; Chester, PA
19	Blue Marsh (1) S	WSA,FL	4,757	10,554	Tulpehocken Creek; Berks, PA
	Lake Galena (nw)	WS,FL	1,629	1,127	N. Br. Neshaminy Creek; Bucks, PA
20	Francis E. Walter (1) D	FL	none	35,190	Lehigh River; Luzerne, Carbon, PA
21	Jadwin (1) D	FL	none	7,983	Dyberry Creek; Wayne, PA
22	Merrill Creek (1) D	WSA	15,640	-	Merrill Creek; Hunterdon, NJ
	Subtotal:		*39,427*	*71,425*	
	Total Storage		**414,625**		

[1] Purposes:

WS-Water supply primarily for local use.

WSA- Water supply primarily for flow augmentation to replace consumptive uses and meet instream needs.

FL- Flood loss reduction.

(Many of these reservoirs are also designed to enhance fish and wildlife habitat and increase recreational opportunities).

P- Hydroelectric Power Generation

[2] Used for water supply only on an emergency basis

[3] Used for flow maintenance during drought emergencies

[4] Authorized storage; 28,200 acre-feet to spillway crest

[5] Used for flow maintenance in Brandywine Creek

* The number in the ( )s indicates modeling priority.

** The letter indicates major sub-basin:

D = Delaware, S = Schuylkill, C = Christina

nw: Reservoir not located within modeled sub-basins

Table A1-2 – Simplified list of the Priority 1 and 2 reservoirs in the Delaware River Basin listed by major subbasin. The Priority 1 reservoirs will be modeled, the Priority 2 reservoirs will not.

Delaware Basin above Trenton	Schuylkill Basin	Christina Basin
Priority 1 (reservoirs to be modeled)		
Nockamixon	Blue Marsh	Marsh Creek
Cannonsville (NY)		
Neversink (NY)		
Pepacton (NY)		
Lake Wallenpaupack		
Mongaup – *Rio*		
Mongaup – *Toronto*		
Mongaup - *Swinging Bridge*		
Prompton		
Beltzville		
Francis E Walter		
Jadwin		
Merrill Creek		
Basin Total = 13	1	1
Priority 2 (reservoirs for future consideration)		
Penn Forest	Still Creek	Edgar Hoopes
Wild Creek	Green Lane	Chambers Lake
Hopatcong	Ontelaunee	(Hibernia Dam)
Basin Total = 3	3	2
The following reservoirs will not be modeled		
Geist		
Union Lake		
Lake Galena		

Appendix B

Model Data

The data used in the model to define the reservoirs, reaches, and junctions are tabulated below. These tables do not include operational information which was summarized in Chapter 4, nor is the input and observed time-series data included. This data can be accessed directly from the model.

B.1 Reservoir Pool and Outlet Data

B.1.1 Upper Basin Reservoirs

Cannonsville

Cannonsville - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1035	1534.4	500
1040	3130.3	730
1045	6966.4	830
1050	11324	940
1055	16326	1070
1060	22096	1240
1065	28786	1450
1070	36581	1670
1075	45419	1880
1080	55301	2070
1085	66073	2250
1090	77950	2470
1095	90992	2700
1100	105232	2940
1105	120423	3120
1110	136565	3310
1115	153628	3480
1120	171520	3650
1125	190271	3830
1130	209789	3980
1135	230136	4170
1140	251311	4350
1145	273499	4570
1150	296853	4820
1155	321619	5070
1160	347704	5400

Cannonsville - Release Works	
Elevation (ft)	Max capacity (cfs)
1030	1032
1035	1141
1040	1217
1045	1295
1050	1368
1055	1439
1060	1510
1065	1566
1070	1631
1075	1691
1080	1750
1085	1803
1090	1857
1095	1910
1100	1960
1105	2014
1110	2060
1115	2109
1120	2160
1125	2202
1130	2243
1135	2285
1140	2331
1145	2371
1150	2421

Cannonsville - Spillway	
Elevation (ft)	Outflow (cfs)
1150	0
1150.1	21
1150.2	60
1150.3	112
1150.4	175
1150.5	247
1150.6	329
1150.7	419
1150.8	516
1150.9	620
1151	731
1151.2	973
1151.4	1240
1151.6	1530
1151.8	1840
1152	2180
1152.2	2530
1152.4	2910
1152.6	3300
1152.8	3720
1153	4150
1153.5	5310
1154	6570
1154.5	7930
1155	9390
1155.5	10940

Cannonsville - Tunnel-Diversion	
Elevation (ft)	Max Capacity (cfs)
1040	618.9
1050	634.4
1060	649.8
1070	665.3
1080	680.8
1090	696.2
1100	711.7
1110	727.2
1120	734.9
1130	750.4
1140	758.1
1150	773.6

Cannonsville - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1163	363356	5600
1175	440000	6500

Cannonsville - Release Works	
Elevation (ft)	Max capacity (cfs)

Cannonsville - Spillway	
Elevation (ft)	Outflow (cfs)
1156	12570
1156.5	14280
1157	16080
1157.5	17950
1158	19910
1158.5	22550
1159	25780
1159.5	29400
1160	33380
1160.5	37650
1161	42220
1161.5	47050
1162	52120
1162.5	57440
1163	62970
1175	250000

Cannonsville - Tunnel-Diversion	
Elevation (ft)	Max Capacity (cfs)

Pepacton

Pepacton - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1145	6137.8	1000
1152	10772	1360
1160	22188	1580
1170	39404	1880
1180	59720	2160
1190	83228	2500
1195	96148	2660
1200	109743	2800
1205	124106	2950
1210	139205	3100
1215	155009	3230
1220	171551	3400
1225	188798	3560
1230	206812	3720
1235	225747	3900
1240	245725	4100
1245	266686	4310
1250	288628	4500
1255	311492	4700
1260	335736	4900
1265	360594	5100
1270	386372	5300
1275	413072	5490
1280	440998	5690
1285	469846	5870
1290	498693	6050
1304	600000	6700

Pepacton - Release Works	
Elevation (ft)	Max capacity (cfs)
1140	367
1145	387
1150	406
1155	424
1160	441
1165	458
1170	474
1175	489
1180	504
1185	519
1190	533
1195	547
1200	561
1205	574
1210	587
1215	599
1220	612
1225	624
1230	636
1235	647
1240	659
1245	670
1250	681
1255	692
1260	703
1265	713
1270	724
1275	734
1280	744

Pepacton - Spillway	
Elevation (ft)	Outflow (cfs)
1280	0
1280.1	70
1280.2	200
1280.3	375
1280.4	585
1280.5	825
1280.6	1095
1280.7	1395
1280.8	1715
1280.9	2065
1281	2435
1281.2	3245
1281.4	4130
1281.6	5100
1281.8	6140
1282	7255
1282.2	8440
1282.4	9695
1282.6	11015
1282.8	12390
1283	13830
1283.5	17700
1284	21910
1284.5	26450
1285	31300
1304	200000

Pepacton - Tunnel-Diversion	
Elevation (ft)	Max Capacity (cfs)
1152	753.5
1160	762.8
1170	773.6
1180	789.1
1190	796.8
1200	804.5
1210	820
1220	835.5
1230	843.2
1240	851
1250	874.2
1260	881.9
1270	889.6
1280	897.4

Neversink

Pepacton - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1145	6137.8	1000
1152	10772	1360
1160	22188	1580
1170	39404	1880
1180	59720	2160
1190	83228	2500
1195	96148	2660
1200	109743	2800
1205	124106	2950
1210	139205	3100
1215	155009	3230
1220	171551	3400
1225	188798	3560
1230	206812	3720
1235	225747	3900
1240	245725	4100
1245	266686	4310
1250	288628	4500
1255	311492	4700
1260	335736	4900
1265	360594	5100
1270	386372	5300
1275	413072	5490
1280	440998	5690
1285	469846	5870
1290	498693	6050
1304	600000	6700

Pepacton - Release Works	
Elevation (ft)	Max capacity (cfs)
1140	367
1145	387
1150	406
1155	424
1160	441
1165	458
1170	474
1175	489
1180	504
1185	519
1190	533
1195	547
1200	561
1205	574
1210	587
1215	599
1220	612
1225	624
1230	636
1235	647
1240	659
1245	670
1250	681
1255	692
1260	703
1265	713
1270	724
1275	734
1280	744

Pepacton - Spillway	
Elevation (ft)	Outflow (cfs)
1280	0
1280.1	70
1280.2	200
1280.3	375
1280.4	585
1280.5	825
1280.6	1095
1280.7	1395
1280.8	1715
1280.9	2065
1281	2435
1281.2	3245
1281.4	4130
1281.6	5100
1281.8	6140
1282	7255
1282.2	8440
1282.4	9695
1282.6	11015
1282.8	12390
1283	13830
1283.5	17700
1284	21910
1284.5	26450
1285	31300
1304	200000

Pepacton - Tunnel-Diversion	
Elevation (ft)	Max Capacity (cfs)
1152	753.5
1160	762.8
1170	773.6
1180	789.1
1190	796.8
1200	804.5
1210	820
1220	835.5
1230	843.2
1240	851
1250	874.2
1260	881.9
1270	889.6
1280	897.4

B.1.2 Lackawaxen Basin Reservoirs

Prompton

Prompton - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1090	0	0
1091	1	1
1092	2	2
1093	5	3
1094	8	4
1095	13	5
1096	18	6
1097	25	7
1098	32	8
1099	41	9
1100	50	10
1101	63	16
1102	82	22
1103	107	28
1104	138	34
1105	175	40
1106	219	48
1107	271	56
1108	331	64
1109	399	72
1110	475	80
1111	562	93
1112	661	106
1113	774	119
1114	899	132
1115	1038	145
1116	1192	164
1117	1366	183
1118	1558	202
1119	1770	221
1120	2000	240
1121	2246	252
1122	2504	264
1123	2775	277
1124	3058	290
1125	3355	303
1126	3661	310
1127	3975	317
1128	4296	325
1129	4625	333
1130	4962	341
1131	5307	349
1132	5660	357
1133	6021	366

Prompton - Main Intake	
Elevation (ft)	Outflow (cfs)
1125	0
1126.2	80
1127.5	200
1128	300
1128.5	450
1129.5	700
1131	1100
1132.5	1400
1132.7	1550
1135	2500
1160	2900
1168.4	3050
1188.5	3400
1205	3650

Prompton - Spillway	
Elevation (ft)	Outflow (cfs)
1205	0
1206	199.99
1207	300
1208	500
1209	850
1210	1250
1211	1850
1212	2450
1212.9	3000
1214.2	4000
1215.5	5000
1219	8000
1220.2	9000
1223	11800
1224.2	13000
1226	15000

Prompton - Low Level Intake	
Elevation (ft)	Outflow (cfs)
1122.8	0
1122.9	5
1122.92	6
1123	8
1123.06	9
1123.18	10
1123.25	11
1123.36	13
1123.46	15
1123.5	16
1123.57	17
1123.65	18
1123.7	20
1123.78	21
1123.79	21
1123.82	22
1123.91	23
1124.06	26
1124.13	27
1124.49	33
1124.54	34
1124.61	35
1125	40

Prompton - Pool			Prompton - Main Intake		Prompton - Spillway		Prompton - Low Level Intake	
Elevation (ft)	**Storage (ac-ft)**	**Area (acre)**	**Elevation (ft)**	**Outflow (cfs)**	**Elevation (ft)**	**Outflow (cfs)**	**Elevation (ft)**	**Outflow (cfs)**
1134	6392	375						
1135	6771	384						
1136	7159	391						
1137	7553	398						
1138	7955	405						
1139	8364	413						
1140	8781	421						
1141	9205	428						
1142	9637	435						
1143	10075	442						
1144	10521	450						
1145	10975	458						
1146	11438	467						
1147	11909	476						
1148	12390	485						
1149	12880	495						
1150	13380	505						
1151	13888	512						
1152	14404	519						
1153	14926	526						
1154	15456	533						
1155	15992	540						
1156	16536	547						
1157	17086	554						
1158	17644	561						
1159	18208	568						
1160	18780	575						
1161	19359	583						
1162	19946	591						
1163	20541	599						
1164	21144	607						
1165	21755	615						
1166	22374	623						
1167	23001	631						
1168	23636	639						
1169	24279	648						
1170	24932	657						
1171	25593	665						
1172	26262	673						
1173	26939	681						
1174	27624	690						
1175	28319	699						
1176	29021	706						
1177	29731	713						
1178	30447	720						
1179	31171	727						
1180	31901	734						
1181	32639	741						

Prompton - Pool				Prompton - Main Intake			Prompton - Spillway			Prompton - Low Level Intake	
Elevation (ft)	**Storage (ac-ft)**	**Area (acre)**		**Elevation (ft)**	**Outflow (cfs)**		**Elevation (ft)**	**Outflow (cfs)**		**Elevation (ft)**	**Outflow (cfs)**
1182	33383	748									
1183	34135	755									
1184	34893	762									
1185	35659	770									
1186	36433	777									
1187	37213	784									
1188	38001	791									
1189	38795	798									
1190	39597	805									
1191	40405	812									
1192	41221	819									
1193	42043	826									
1194	42873	833									
1195	43709	840									
1196	44552	846									
1197	45402	853									
1198	46258	860									
1199	47122	868									
1200	47995	877									
1201	48876	886									
1202	49767	895									
1203	50666	904									
1204	51575	913									
1205	52492	922									
1206	53419	932									
1207	54357	943									
1208	55305	954									
1209	56265	965									
1210	57235	976									
1211	58216	986									
1212	59207	996									
1213	60209	1007									
1214	61221	1018									
1215	62245	1029									
1216	63278	1038									
1217	64321	1047									
1218	65373	1057									
1219	66435	1067									
1220	67507	1077									
1221	68588	1086									
1222	69679	1095									
1223	70778	1104									
1224	71886	1113									
1225	73005	1123									
1226	74133	1134									
1227	75273	1146									
1228	76425	1158									
1229	77589	1170									

Prompton - Pool			Prompton - Main Intake		Prompton - Spillway		Prompton - Low Level Intake	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)
1230	78765	1182						
1231	79952	1191						
1232	81148	1201						
1233	82354	1211						
1234	83570	1221						
1235	84796	1231						
1236	86031	1239						
1237	87274	1247						
1238	88585	1255						
1239	89784	1264						
1240	91053	1273						

Jadwin

Prompton - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1090	0	0
1091	1	1
1092	2	2
1093	5	3
1094	8	4
1095	13	5
1096	18	6
1097	25	7
1098	32	8
1099	41	9
1100	50	10
1101	63	16
1102	82	22
1103	107	28
1104	138	34
1105	175	40
1106	219	48
1107	271	56
1108	331	64
1109	399	72
1110	475	80
1111	562	93
1112	661	106
1113	774	119
1114	899	132
1115	1038	145
1116	1192	164
1117	1366	183
1118	1558	202
1119	1770	221
1120	2000	240
1121	2246	252
1122	2504	264
1123	2775	277
1124	3058	290
1125	3355	303
1126	3661	310
1127	3975	317
1128	4296	325
1129	4625	333
1130	4962	341
1131	5307	349
1132	5660	357
1133	6021	366
1134	6392	375
1135	6771	384

Prompton - Main Intake	
Elevation (ft)	Outflow (cfs)
1125	0
1126.2	80
1127.5	200
1128	300
1128.5	450
1129.5	700
1131	1100
1132.5	1400
1132.7	1550
1135	2500
1160	2900
1168.4	3050
1188.5	3400
1205	3650

Prompton - Spillway	
Elevation (ft)	Outflow (cfs)
1205	0
1206	199.99
1207	300
1208	500
1209	850
1210	1250
1211	1850
1212	2450
1212.9	3000
1214.2	4000
1215.5	5000
1219	8000
1220.2	9000
1223	11800
1224.2	13000
1226	15000

Prompton - Low Level Intake	
Elevation (ft)	Outflow (cfs)
1122.8	0
1122.9	5
1122.92	6
1123	8
1123.06	9
1123.18	10
1123.25	11
1123.36	13
1123.46	15
1123.5	16
1123.57	17
1123.65	18
1123.7	20
1123.78	21
1123.79	21
1123.82	22
1123.91	23
1124.06	26
1124.13	27
1124.49	33
1124.54	34
1124.61	35
1125	40

Prompton - Pool			Prompton - Main Intake		Prompton - Spillway		Prompton - Low Level Intake	
Elevation (ft)	**Storage (ac-ft)**	**Area (acre)**	**Elevation (ft)**	**Outflow (cfs)**	**Elevation (ft)**	**Outflow (cfs)**	**Elevation (ft)**	**Outflow (cfs)**
1136	7159	391						
1137	7553	398						
1138	7955	405						
1139	8364	413						
1140	8781	421						
1141	9205	428						
1142	9637	435						
1143	10075	442						
1144	10521	450						
1145	10975	458						
1146	11438	467						
1147	11909	476						
1148	12390	485						
1149	12880	495						
1150	13380	505						
1151	13888	512						
1152	14404	519						
1153	14926	526						
1154	15456	533						
1155	15992	540						
1156	16536	547						
1157	17086	554						
1158	17644	561						
1159	18208	568						
1160	18780	575						
1161	19359	583						
1162	19946	591						
1163	20541	599						
1164	21144	607						
1165	21755	615						
1166	22374	623						
1167	23001	631						
1168	23636	639						
1169	24279	648						
1170	24932	657						
1171	25593	665						
1172	26262	673						
1173	26939	681						
1174	27624	690						
1175	28319	699						
1176	29021	706						
1177	29731	713						
1178	30447	720						
1179	31171	727						
1180	31901	734						
1181	32639	741						
1182	33383	748						
1183	34135	755						

Prompton - Pool			Prompton - Main Intake		Prompton - Spillway		Prompton - Low Level Intake	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)
1184	34893	762						
1185	35659	770						
1186	36433	777						
1187	37213	784						
1188	38001	791						
1189	38795	798						
1190	39597	805						
1191	40405	812						
1192	41221	819						
1193	42043	826						
1194	42873	833						
1195	43709	840						
1196	44552	846						
1197	45402	853						
1198	46258	860						
1199	47122	868						
1200	47995	877						
1201	48876	886						
1202	49767	895						
1203	50666	904						
1204	51575	913						
1205	52492	922						
1206	53419	932						
1207	54357	943						
1208	55305	954						
1209	56265	965						
1210	57235	976						
1211	58216	986						
1212	59207	996						
1213	60209	1007						
1214	61221	1018						
1215	62245	1029						
1216	63278	1038						
1217	64321	1047						
1218	65373	1057						
1219	66435	1067						
1220	67507	1077						
1221	68588	1086						
1222	69679	1095						
1223	70778	1104						
1224	71886	1113						
1225	73005	1123						
1226	74133	1134						
1227	75273	1146						
1228	76425	1158						
1229	77589	1170						
1230	78765	1182						
1231	79952	1191						

Prompton - Pool			Prompton - Main Intake		Prompton - Spillway		Prompton - Low Level Intake	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)	Elevation (ft)	Outflow (cfs)
1232	81148	1201						
1233	82354	1211						
1234	83570	1221						
1235	84796	1231						
1236	86031	1239						
1237	87274	1247						
1238	88585	1255						
1239	89784	1264						
1240	91053	1273						

Lake Wallenpaupack

Lake Wallenpaupack - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1145	0	0
1150	20000	2300
1160	52000	4600
1162	61391	4690
1164	70996	4780
1166	80909	4880
1168	90975	4970
1170	101102	5060
1172	111229	5150
1174	121664	5240
1176	132098	5320
1178	142839	5400
1180	153580	5480
1182	164628	5560
1184	175676	5640
1186	186724	5720
1188	198079	5790
1190	209741	5840
1192	221402	5890
1194	233371	5940
1196	245340	6000
1198	257615	6050
1200	269584	6100

Lake Wallenpaupack - Pipeline	
Elevation (ft)	Max capacity (cfs)
1164.9	1200
1170	1400
1180	1600
1185	1750
1189	1800

Lake Wallenpaupack - Gated Spillway	
Elevation (ft)	Max capacity (cfs)
1176	0
1177.83	1000
1178.9	2000
1180.01	3250
1181.16	4750
1182.36	6500
1183.61	8500
1184.9	10750
1186.23	13250
1187.6	16000
1189.01	19000
1190.16	22250
1190.69	25750
1191.3	29500
1191.98	33500
1192.77	37750
1194.38	42250
1199.35	47618

B.1.3 Mongaup Basin Reservoirs

Toronto

Toronto - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1165	0	
1170	918.27	
1175	2066.1	
1180	3214	
1185	5050.5	
1190	7001.8	
1195	9297.5	
1200	11938	
1205	14922	
1210	18021	
1215	21350	
1220	25023	
1222.5	26860	
1225	28007	
1231	33250	

Toronto - Upper Gate	
Elevation (ft)	Max capacity (cfs)
1180	0
1180.5	50
1181.2	75
1182	100
1182.5	125
1183.5	150
1184.5	175
1186	200
1187	225
1188.5	250
1190.5	275
1192	300
1194	325
1198	375
1202.5	425
1207	475
1214.5	550
1222.5	625
1224	640

Toronto - Lower Gate	
Elevation (ft)	Max capacity (cfs)
1146	0
1146.2	50
1147	75
1147.5	100
1148.5	125
1150	150
1151.5	175
1153.5	200
1155.3	225
1158	250
1160	275
1163	300
1166	325
1172.5	375
1180.5	425
1189	475
1203.5	550
1219.5	625
1223	640

Toronto - Spillway	
Elevation (ft)	Max capacity (cfs)
1215	0
1215.5	80
1216	180
1216.5	300
1217	440
1217.5	610
1218	800
1218.5	1020
1219	1250
1219.5	1500
1220	1750
1220.5	2050
1221	2350
1221.5	2650
1222	2950
1222.5	3250
1223	3600
1224	4300
1225	5000

Swinging Bridge

Swinging Bridge - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1010	229.57	
1015	918.27	
1020	2295.7	
1022	2754.8	
1025	3673.1	
1030	5739.2	
1035	8034.9	
1040	10101	
1045	12856	
1048	14692	
1050	16070	
1055	19513	
1060	23646	
1065	28007	
1070	32979	
1072	34435	
1075	37420	
1080	41781	

Swinging Bridge - Spillway Gated	
Elevation (ft)	Max capacity (cfs)
1065	0
1065.5	300
1066	500
1066.6	800
1066.9	1000
1067.5	1400
1068	1800
1068.5	2200
1069	2750
1069.5	3250
1070	3900
1070.5	4600
1071	5500
1071.5	6500
1072	7600
1072.1	7980
1072.4	8840
1072.5	9200
1073	10800

Swinging Bridge - Spillway Flashboarded	
Elevation (ft)	Max capacity (cfs)
1065	0
1065.5	1100
1066	2300
1066.6	3700
1066.9	4300
1067.5	5500
1068	6500
1068.5	7500
1069	8350
1069.5	9250
1070	10000
1070.5	10700
1071	11200
1071.5	11600
1072	12000
1072.1	12020
1072.4	12160
1072.5	12200
1073	12800

Swinging Bridge - Power Conduit	
Elevation (ft)	Max capacity (cfs)
1048	1570
1073	1570

Rio

Rio - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
720	0	
730	344.35	
740	734.62	
750	1239.7	
755	1561.1	
760	1836.6	
765	2180.9	
770	2754.8	
775	3443.5	
780	4132.2	
785	5280.1	
790	6542.7	
798.5	9182.7	
805	11478	
810	13085	
815	15152	
821	19978	

Rio - Dam - Spillway	
Elevation (ft)	Max capacity (cfs)
810	0
810.5	1000
811	1600
811.5	2700
812	3400
812.5	4300
813	5500
813.5	6800
814	8200
814.5	9600
815	11250
815.5	13000
816	14500
817	18100
818	21800
820	29800
822	38500
823	43000

Rio - Dam - Power Conduit	
Elevation (ft)	Max capacity (cfs)
810	870
815	870

B.1.4 Lehigh Basin Reservoirs

F.E. Walter

F.E. Walter - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1245	0	0
1246	2	1
1247	4	1
1248	5	2
1249	7	3
1250	9	4
1251	13	4
1252	18	4
1253	22	4
1254	26	5
1255	31	5
1256	38	6
1257	46	7
1258	53	8
1259	61	9
1260	68	10
1261	83	12
1262	98	14
1263	113	16
1264	128	18
1265	143	20
1266	166	21
1267	188	22
1268	211	23
1269	233	24
1270	256	25
1271	286	27
1272	316	29
1273	346	31
1274	376	33
1275	406	35
1276	443	36
1277	481	37
1278	518	38
1279	556	39
1280	593	40
1281	638	42
1282	683	44
1283	728	46
1284	773	48
1285	818	50
1286	873	52
1287	928	54
1288	983	56

F.E. Walter - Flood Control System	
Elevation (ft)	Max capacity (cfs)
1300	9600
1310	10500
1320	11400
1330	12000
1340	12600
1350	13050
1360	13500
1370	13950
1380	14400
1390	15000
1400	15600
1410	15900
1420	16500
1430	17100
1440	17700
1450	18300

F.E. Walter - Ogee Spillway	
Elevation (ft)	Outflow (cfs)
1450	0
1451	2000
1452	4000
1453	7000
1454	12000
1455	16000
1456	22000
1457	28000
1458	35000
1459	42000
1460	50000
1461	59000
1462	68000
1463	78000
1464	88000
1465	98000
1466	109000
1467	120000
1468	132000
1469	144000
1470	156000
1471	169000
1472	180000

F.E. Walter - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1289	1038	58
1290	1093	60
1291	1150	62
1292	1223	64
1293	1288	66
1294	1353	68
1295	1418	70
1296	1493	72
1297	1568	74
1298	1643	76
1299	1718	78
1300	1793	80
1301	1883	84
1302	1973	88
1303	2063	92
1304	2153	96
1305	2243	100
1306	2353	104
1307	2463	108
1308	2573	112
1309	2683	116
1310	2793	120
1311	2923	124
1312	3053	128
1313	3183	132
1314	3313	136
1315	3443	140
1316	3593	144
1317	3743	148
1318	3893	152
1319	4043	156
1320	4193	160
1321	4366	165
1322	4538	170
1323	4711	175
1324	4883	180
1325	5056	185
1326	5253	190
1327	5451	195
1328	5648	200
1329	5846	205
1330	6043	210
1331	6268	216
1332	6493	222
1333	6718	228
1334	6943	234
1335	7168	240
1336	7423	246
1337	7678	252

F.E. Walter - Flood Control System	
Elevation (ft)	Max capacity (cfs)

F.E. Walter - Ogee Spillway	
Elevation (ft)	Outflow (cfs)

F.E. Walter - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1338	7933	258
1339	8188	264
1340	8443	270
1341	8733	278
1342	9023	286
1343	9313	294
1344	9603	302
1345	9893	310
1346	10223	318
1347	10533	326
1348	10883	334
1349	11213	342
1350	11543	350
1351	11921	361
1352	12298	372
1353	12676	383
1354	13053	394
1355	13431	405
1356	13863	416
1357	14296	427
1358	14728	438
1359	15161	449
1360	15593	460
1361	16085	472
1362	16577	485
1363	17069	498
1364	17561	511
1365	18053	524
1366	18609	537
1367	19164	549
1368	19720	562
1369	20275	574
1370	20831	587
1371	21449	600
1372	22068	612
1373	22686	625
1374	23305	637
1375	23923	650
1376	24598	660
1377	25273	670
1378	25948	680
1379	26623	690
1380	27298	700
1381	28023	710
1382	28748	720
1383	29473	730
1384	30198	740
1385	30923	750
1386	31698	760

F.E. Walter - Flood Control System	
Elevation (ft)	Max capacity (cfs)

F.E. Walter - Ogee Spillway	
Elevation (ft)	Outflow (cfs)

F.E. Walter - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
1387	32473	770
1388	33248	780
1389	34023	790
1390	34798	800
1391	35628	812
1392	36458	824
1393	37288	836
1394	38118	848
1395	38948	860
1396	39838	872
1397	40728	884
1398	41618	896
1399	42508	908
1400	43398	920
1401	44354	934
1402	45310	949
1403	46266	963
1404	47222	978
1405	48178	992
1406	49194	1002
1407	50210	1011
1408	51226	1021
1409	52242	1030
1410	53258	1040
1411	54338	1056
1412	55418	1072
1413	56498	1088
1414	57578	1104
1415	58658	1120
1416	59818	1136
1417	60978	1152
1418	62138	1168
1419	63298	1184
1420	64458	1200
1421	65705	1219
1422	66953	1238
1423	68200	1257
1424	69448	1276
1425	70695	1295
1426	72038	1314
1427	73380	1333
1428	74723	1352
1429	76065	1371
1430	77408	1390
1431	78853	1412
1432	80298	1432
1433	81743	1456
1434	83188	1478
1435	84633	1500

F.E. Walter - Flood Control System	
Elevation (ft)	Max capacity (cfs)

F.E. Walter - Ogee Spillway	
Elevation (ft)	Outflow (cfs)

F.E. Walter - Pool		
Elevation (ft)	**Storage (ac-ft)**	**Area (acre)**
1436	86188	1522
1437	87743	1544
1438	89298	1566
1439	90853	1588
1440	92408	1610
1441	94073	1632
1442	95738	1654
1443	97403	1676
1444	99086	1698
1445	100733	1720
1446	102508	1742
1447	104283	1764
1448	106058	1786
1449	107833	1808
1450	109608	1830
1451	111496	1853
1452	113383	1876
1453	115271	1899
1454	117158	1922
1455	119046	1945
1456	121048	1968
1457	123051	1991
1458	125053	2014
1459	127056	2037
1460	129058	2060
1461	131171	2081
1462	133283	2102
1463	135396	2123
1464	137508	2144
1465	139621	2165
1466	141850	2191
1467	144080	2217
1468	146309	2242
1469	148539	2268
1470	150768	2294
1471	153149	2329
1472	155529	2363
1473	157910	2398
1474	160290	2432

F.E. Walter - Flood Control System	
Elevation (ft)	**Max capacity (cfs)**

F.E. Walter - Ogee Spillway	
Elevation (ft)	**Outflow (cfs)**

Beltzville

Beltzville - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
501	0	0
502	1	1
503	2	2
504	4	3
505	8	4
506	12	4
507	17	5
508	24	6
509	31	7
510	39	8
511	49	11
512	61	13
513	75	15
514	91	17
515	109	20
516	131	23
517	155	25
518	181	28
519	211	31
520	243	33
521	277	36
522	315	40
523	357	43
524	402	47
525	451	51
526	503	54
527	559	58
528	619	62
529	683	66
530	752	71
531	825	76
532	904	81
533	988	87
534	1078	93
535	1174	100
536	1277	106
537	1387	113
538	1503	119
539	1625	125
540	1753	132
541	1888	137
542	2028	143
543	2174	149
544	2326	155
545	2484	161
546	2647	165

Beltzville - Water Quality	
Elevation (ft)	Max capacity (cfs)
515.4	0
516	50
518	75
525	125
530	150
535	175
541	200
547	225
555	250
564	275
573	300
583	325
594	350
606	375
618	400
631	425
645	450
651	460

Beltzville - Flood Control System	
Elevation (ft)	Max capacity (cfs)
503.3	0
506	280
509	400
518	600
527.5	800
540	1100
560	1290
580	1560
610	1900
651	2350

Beltzville - Spillway	
Elevation (ft)	Outflow (cfs)
651	0
652	200
652.5	400
653	800
653.5	1400
654	2000
654.5	2800
655	3600
655.5	4700
656	5600
656.5	6700
657	7900
657.7	10000
658.4	12000
659.1	14000
659.7	16000
660.8	20000
661.9	24000
662.9	28000
663.8	32000
664.7	36000
665.6	40000
666.5	44000
667.1	47000

Beltzville - Pool			Beltzville - Water Quality		Beltzville - Flood Control System		Beltzville - Spillway	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Outflow (cfs)
547	2814	170						
548	2987	175						
549	3164	179						
550	3345	184						
551	3532	190						
552	3725	195						
553	3923	201						
554	4127	207						
555	4337	213						
556	4551	216						
557	4770	221						
558	4993	226						
559	5222	231						
560	5456	237						
561	5695	241						
562	5939	247						
563	6189	253						
564	6445	259						
565	6707	266						
566	6976	272						
567	7261	278						
568	7533	285						
569	7821	291						
570	8115	298						
571	8417	306						
572	8727	314						
573	9045	322						
574	9371	330						
575	9706	339						
576	10049	347						
577	10400	355						
578	10758	362						
579	11124	369						
580	11496	376						
581	11876	384						
582	12264	392						
583	12660	400						
584	13064	408						
585	13476	416						
586	13897	425						
587	14326	434						
588	14764	442						
589	15210	450						
590	15664	458						
591	16127	467						
592	16559	477						
593	17081	487						
594	17572	496						

Beltzville - Pool			Beltzville - Water Quality		Beltzville - Flood Control System		Beltzville - Spillway	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Outflow (cfs)
595	18072	504						
596	18580	512						
597	19097	521						
598	19623	531						
599	20159	542						
600	20707	553						
601	21266	565						
602	21836	576						
603	22418	588						
604	23012	599						
605	23617	611						
606	24234	623						
607	24863	635						
608	25505	649						
609	26160	661						
610	26827	674						
611	27507	686						
612	28200	700						
613	28907	714						
614	29629	729						
615	30365	743						
616	31115	757						
617	31879	772						
618	32659	787						
619	33403	802						
620	34163	818						
621	34989	834						
622	35831	850						
623	36689	866						
624	37563	882						
625	38454	899						
626	39361	915						
627	40284	931						
628	41223	947						
629	42178	964						
630	43151	981						
631	44141	1000						
632	45151	1020						
633	46182	1042						
634	47235	1064						
635	48312	1089						
636	49408	1103						
637	50521	1123						
638	51654	1144						
639	52808	1164						
640	53983	1185						
641	55177	1204						
642	56391	1224						

Beltzville - Pool			Beltzville - Water Quality		Beltzville - Flood Control System		Beltzville - Spillway	
Elevation (ft)	Storage (ac-ft)	Area (acre)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Max capacity (cfs)	Elevation (ft)	Outflow (cfs)
643	57626	1245						
644	58881	1266						
645	60158	1287						
646	61455	1308						
647	62773	1328						
648	64111	1348						
649	65470	1370						
650	66852	1393						
651	68254	1411						
652	69676	1433						
653	71120	1456						
654	72591	1485						
655	74091	1516						
656	75617	1536						
657	77166	1561						
658	78741	1590						
659	80344	1616						
660	81974	1643						
661	83629	1667						
662	85309	1693						
663	87016	1721						
664	88751	1750						
665	90517	1781						
666	92309	1804						
667	94126	1830						
668	95970	1857						
669	97841	1885						
670	99739	1912						
671	101666	1942						
672	103625	1976						

B.1.5 Mainstem Reservoirs

Merrill Creek

Merrill Creek - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
770	0	0
780	1500	60
790	2915.4	116
800	4235.1	147
810	5861.6	177
820	7795	210
830	10066	244
840	12674	278
850	15651	317
860	19058	364
870	22894	405
880	27190	452
890	31947	501
900	37195	551
910	42934	595
920	49102	640
923	51036	653
929	55056	683

Merrill Creek - Controlled Outlet	
Elevation (ft)	Max capacity (cfs)
790	0
923	162
929	168

Nockamixon

Nockamixon - Pool		
Elevation (ft)	Storage (ac-ft)	Area (acre)
312	0	0
325.5	398.95	80
340	1933.4	170
360	7733.6	500
365	10465	610
370	13749	730
375	17646	850
380	22280	980
385	27589	1180
390	33451	1300
395	40202	1450
400	47875	1650
405	56774	1850
410	66595	2150
412	71500	2300

Nockamixon - Diversion Tunnel	
Elevation (ft)	Max capacity (cfs)
311	0
312	10
313	150
314	300
316	700
318	1200
320	1850
321	2150
323	2800
324	3100
326	3600
328	4050
330	4450
332	4750
334	5100
336	5400
338	5700
340	6000
341	6150
343	6400
344	6500
395	6500

Nockamixon - 10in Cone Valve	
Elevation (ft)	Max capacity (cfs)
325.58	0
326	1
327.5	1.6
336	5.5
337.5	6
338.5	6.2
350	7.6
370	9.2
390	10.8
393	11
400	11.5

Nockamixon - Spillway		
Outlet Elevation (ft)	Weir Coef.	Weir Length (ft)
395	2.6	350

B.2 Junction Rating Curves

B.2.1 Upper Basin Junctions

Hale Eddy Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.3	70	4	1250	6.8	4480	9.6	9410
1.4	86	4.1	1330	6.9	4630	9.7	9620
1.5	104	4.2	1420	7	4780	9.8	9820
1.6	123	4.3	1510	7.1	4930	9.9	10000
1.7	145	4.4	1600	7.2	5090	10	10200
1.8	168	4.5	1700	7.3	5240	10.1	10500
1.9	193	4.6	1790	7.4	5400	10.2	10700
2	220	4.7	1890	7.5	5560	10.3	10900
2.1	249	4.8	1990	7.6	5730	10.4	11100
2.2	280	4.9	2100	7.7	5890	10.5	11400
2.3	313	5	2190	7.8	6060	10.6	11600
2.4	348	5.1	2300	7.9	6230	10.7	11800
2.5	385	5.2	2420	8	6400	10.8	12000
2.6	423	5.3	2520	8.1	6570	10.9	12300
2.7	464	5.4	2640	8.2	6750	11	12500
2.8	507	5.5	2760	8.3	6920	11.1	12700
2.9	552	5.6	2880	8.4	7100	11.2	13000
3	601	5.7	3000	8.5	7280	11.3	13200
3.1	654	5.8	3120	8.6	7470	11.4	13400
3.2	709	5.9	3250	8.7	7650	11.5	13700
3.3	767	6	3380	8.8	7840	11.6	13900
3.4	828	6.1	3510	8.9	8030	11.7	14200
3.5	892	6.2	3640	9	8220	11.8	14400
3.6	958	6.3	3780	9.1	8420	11.9	14600
3.7	1030	6.4	3910	9.2	8610	12	14900
3.8	1100	6.5	4050	9.3	8810	12.1	15100
3.9	1170	6.6	4190	9.4	9010	12.2	15400
		6.7	4340	9.5	9210	12.3	15700

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
12.4	15900	14.3	21200	16.2	28400	18.1	37500
12.5	16200	14.4	21500	16.3	28800	18.2	38000
12.6	16400	14.5	21800	16.4	29300	18.3	38600
12.7	16700	14.6	22200	16.5	29700	18.4	39100
12.8	17000	14.7	22500	16.6	30200	18.5	39700
12.9	17200	14.8	22900	16.7	30600	18.6	40300
13	17500	14.9	23200	16.8	31100	18.7	40900
13.1	17800	15	23600	16.9	31500	18.8	41500
13.2	18000	15.1	24000	17	32000	18.9	42200
13.3	18300	15.2	24400	17.1	32500	19	42800
13.4	18600	15.3	24700	17.2	32900	19.1	43400
13.5	18900	15.4	25100	17.3	33400	19.2	44000
13.6	19100	15.5	25500	17.4	33900	19.3	44700
13.7	19400	15.6	25900	17.5	34400	19.4	45300
13.8	19700	15.7	26300	17.6	34900	19.5	46000
13.9	20000	15.8	26700	17.7	35400	20.8	55000
14	20300	15.9	27100	17.8	35900		
14.1	20600	16	27500	17.9	36400		
14.2	20900	16.1	27900	18	36900		

Harvard Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2.1	47	5.4	1740	8.7	5500	12	11100
2.2	64	5.5	1830	8.8	5650	12.1	11300
2.3	84	5.6	1910	8.9	5790	12.2	11500
2.4	105	5.7	2000	9	5940	12.3	11700
2.5	130	5.8	2090	9.1	6090	12.4	11900
2.6	156	5.9	2190	9.2	6240	12.5	12100
2.7	185	6	2280	9.3	6390	12.6	12300
2.8	216	6.1	2380	9.4	6540	12.7	12600
2.9	249	6.2	2470	9.5	6700	12.8	12800
3	284	6.3	2570	9.6	6860	12.9	13000
3.1	322	6.4	2680	9.7	7020	13	13200
3.2	361	6.5	2780	9.8	7180	13.1	13400
3.3	403	6.6	2880	9.9	7340	13.2	13600
3.4	447	6.7	2990	10	7500	13.3	13800
3.5	493	6.8	3100	10.1	7670	13.4	14100
3.6	541	6.9	3210	10.2	7840	13.5	14300
3.7	591	7	3320	10.3	8000	13.6	14500
3.8	643	7.1	3440	10.4	8180	13.7	14700
3.9	697	7.2	3550	10.5	8350	13.8	15000
4	753	7.3	3670	10.6	8520	13.9	15200
4.1	811	7.4	3790	10.7	8700	14	15400
4.2	871	7.5	3910	10.8	8870	14.1	15600
4.3	933	7.6	4030	10.9	9050	14.2	15900
4.4	997	7.7	4160	11	9230	14.3	16100
4.5	1060	7.8	4290	11.1	9420	14.4	16300
4.6	1130	7.9	4410	11.2	9600	14.5	16600
4.7	1200	8	4540	11.3	9790	14.6	16800
4.8	1270	8.1	4680	11.4	9970	14.7	17100
4.9	1350	8.2	4810	11.5	10200	14.8	17300
5	1420	8.3	4940	11.6	10400	14.9	17500
5.1	1500	8.4	5080	11.7	10500	15	17800
5.2	1580	8.5	5220	11.8	10700	15.1	18000
5.3	1660	8.6	5360	11.9	10900	15.2	18300

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
15.3	18500	15.8	19800	16.3	21200	16.8	22600
15.4	18800	15.9	20100	16.4	21500	16.9	23000
15.5	19000	16	20300	16.5	21800	17	23300
15.6	19300	16.1	20600	16.6	22000	22.9	41000
15.7	19500	16.2	20900	16.7	22300		

Fishs Eddy Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
3.25	213	6.5	3200	9.8	12400	13.1	28400
3.3	226	6.6	3390	9.9	12800	13.2	28900
3.4	254	6.7	3580	10	13200	13.3	29500
3.5	285	6.8	3770	10.1	13600	13.4	30000
3.6	318	6.9	3970	10.2	14000	13.5	30500
3.7	355	7	4180	10.3	14500	13.6	31100
3.8	394	7.1	4390	10.4	14900	13.7	31600
3.9	436	7.2	4610	10.5	15300	13.8	32100
4	482	7.3	4830	10.6	15700	13.9	32700
4.1	531	7.4	5060	10.7	16200	14	33200
4.2	583	7.5	5300	10.8	16600	14.1	33700
4.3	640	7.6	5540	10.9	17100	14.2	34300
4.4	701	7.7	5790	11	17600	14.3	34800
4.5	765	7.8	6040	11.1	18000	14.4	35400
4.6	834	7.9	6310	11.2	18500	14.5	35900
4.7	908	8	6570	11.3	19000	14.6	36500
4.8	986	8.1	6840	11.4	19500	14.7	37000
4.9	1070	8.2	7120	11.5	20000	14.8	37600
5	1160	8.3	7410	11.6	20500	14.9	38100
5.1	1250	8.4	7700	11.7	21000	15	38700
5.2	1350	8.5	8000	11.8	21500	15.1	39200
5.3	1460	8.6	8300	11.9	22000	15.2	39800
5.4	1570	8.7	8610	12	22500	15.3	40300
5.5	1680	8.8	8930	12.1	23100	15.4	40900
5.6	1810	8.9	9250	12.2	23600	15.5	41400
5.7	1940	9	9580	12.3	24100	15.6	42000
5.8	2070	9.1	9920	12.4	24600	15.7	42500
5.9	2220	9.2	10300	12.5	25200	15.8	43100
6	2370	9.3	10600	12.6	25700	15.9	43700
6.1	2530	9.4	11000	12.7	26200	16	44200
6.2	2690	9.5	11300	12.8	26800	16.1	44800
6.3	2850	9.6	11700	12.9	27300	16.2	45400
6.4	3030	9.7	12100	13	27800	16.3	45900

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
16.4	46500	17.9	55100	19.4	64700	20.9	74100
16.5	47100	18	55700	19.5	65300	21	74700
16.6	47600	18.1	56300	19.6	66000	21.1	75400
16.7	48200	18.2	56900	19.7	66600	21.2	76000
16.8	48800	18.3	57600	19.8	67300	21.3	76600
16.9	49300	18.4	58200	19.9	67900	21.4	77200
17	49900	18.5	58800	20	68600	21.5	77800
17.1	50500	18.6	59500	20.1	69200	21.6	78500
17.2	51100	18.7	60100	20.2	69800	21.7	79100
17.3	51600	18.8	60800	20.3	70400	21.8	79700
17.4	52200	18.9	61400	20.4	71000	21.9	80400
17.5	52800	19	62100	20.5	71700	22	81000
17.6	53400	19.1	62700	20.6	72300	24.2	94000
17.7	54000	19.2	63400	20.7	72900		
17.8	54500	19.3	64000	20.8	73500		

Bridgeville Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
4.3	47	7.6	1790	10.9	5030	14.2	9480
4.4	64	7.7	1870	11	5140	14.3	9630
4.5	84	7.8	1950	11.1	5260	14.4	9780
4.6	106	7.9	2030	11.2	5380	14.5	9940
4.7	132	8	2110	11.3	5500	14.6	10100
4.8	160	8.1	2200	11.4	5630	14.7	10200
4.9	191	8.2	2280	11.5	5750	14.8	10400
5	224	8.3	2370	11.6	5870	14.9	10600
5.1	261	8.4	2450	11.7	6000	15	10700
5.2	300	8.5	2540	11.8	6130	15.1	10900
5.3	342	8.6	2630	11.9	6250	15.2	11000
5.4	386	8.7	2720	12	6380	15.3	11200
5.5	434	8.8	2820	12.1	6510	15.4	11400
5.6	484	8.9	2910	12.2	6640	15.5	11500
5.7	537	9	3000	12.3	6780	15.6	11700
5.8	593	9.1	3100	12.4	6910	15.7	11900
5.9	651	9.2	3200	12.5	7040	15.8	12000
6	713	9.3	3290	12.6	7180	15.9	12200
6.1	777	9.4	3390	12.7	7310	16	12400
6.2	844	9.5	3490	12.8	7450	16.1	12500
6.3	907	9.6	3600	12.9	7590	16.2	12700
6.4	967	9.7	3700	13	7730	16.3	12900
6.5	1030	9.8	3800	13.1	7870	16.4	13000
6.6	1090	9.9	3910	13.2	8010	16.5	13200
6.7	1150	10	4020	13.3	8150	16.6	13400
6.8	1220	10.1	4120	13.4	8290	16.7	13700
6.9	1290	10.2	4230	13.5	8440	16.8	13900
7	1350	10.3	4340	13.6	8580	16.9	14100
7.1	1420	10.4	4450	13.7	8730	17	14300
7.2	1500	10.5	4570	13.8	8880	17.1	14600
7.3	1570	10.6	4680	13.9	9030	17.2	14800
7.4	1640	10.7	4790	14	9180	17.3	15000
7.5	1720	10.8	4910	14.1	9330	17.4	15300

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
17.5	15500	19.2	19900	20.9	24800	22.6	30300
17.6	15800	19.3	20200	21	25100	22.7	30600
17.7	16000	19.4	20400	21.1	25400	22.8	31000
17.8	16300	19.5	20700	21.2	25700	22.9	31300
17.9	16500	19.6	21000	21.3	26100	23	31700
18	16800	19.7	21300	21.4	26400	23.1	32000
18.1	17000	19.8	21600	21.5	26700	23.2	32400
18.2	17300	19.9	21800	21.6	27000	23.3	32700
18.3	17500	20	22100	21.7	27300	23.4	33100
18.4	17800	20.1	22400	21.8	27600	23.5	33400
18.5	18000	20.2	22700	21.9	28000	23.6	33800
18.6	18300	20.3	23000	22	28300	23.7	34200
18.7	18500	20.4	23300	22.1	28600	23.8	34500
18.8	18800	20.5	23600	22.2	29000	23.9	34900
18.9	19100	20.6	23900	22.3	29300	24	35200
19	19300	20.7	24200	22.4	29600		
19.1	19600	20.8	24500	22.5	30000		

Callicoon Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2.7	310	6	11200	9.3	33200	12.6	60400
2.8	419	6.1	11800	9.4	33900	12.7	61300
2.9	536	6.2	12400	9.5	34700	12.8	62200
3	660	6.3	12900	9.6	35400	12.9	63100
3.1	790	6.4	13500	9.7	36200	13	64000
3.2	958	6.5	14100	9.8	36900	13.1	65000
3.3	1100	6.6	14600	9.9	37700	13.2	65900
3.4	1250	6.7	15200	10	38500	13.3	66800
3.5	1430	6.8	15900	10.1	39300	13.4	67800
3.6	1600	6.9	16400	10.2	40000	13.5	68700
3.7	1770	7	17100	10.3	40800	13.6	69700
3.8	1970	7.1	17700	10.4	41600	13.7	70600
3.9	2210	7.2	18300	10.5	42400	13.8	71600
4	2460	7.3	19000	10.6	43200	13.9	72500
4.1	2780	7.4	19700	10.7	44000	14	73500
4.2	3110	7.5	20300	10.8	44900	14.1	74500
4.3	3430	7.6	21000	10.9	45700	14.2	75500
4.4	3800	7.7	21700	11	46500	14.3	76400
4.5	4180	7.8	22300	11.1	47300	14.4	77400
4.6	4540	7.9	23000	11.2	48200	14.5	78400
4.7	4960	8	23700	11.3	49000	14.6	79400
4.8	5390	8.1	24400	11.4	49800	14.7	80400
4.9	5790	8.2	25100	11.5	50700	14.8	81400
5	6260	8.3	25800	11.6	51600	14.9	82400
5.1	6730	8.4	26500	11.7	52400	15	83400
5.2	7180	8.5	27300	11.8	53300	15.1	84400
5.3	7680	8.6	28000	11.9	54100	15.2	85500
5.4	8210	8.7	28700	12	55000	15.3	86500
5.5	8670	8.8	29500	12.1	55900	15.4	87500
5.6	9190	8.9	30200	12.2	56800	15.5	88500
5.7	9660	9	31000	12.3	57700	15.6	89600
5.8	10200	9.1	31700	12.4	58600	15.7	90600
5.9	10700	9.2	32500	12.5	59500	15.8	91700

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
15.9	92700	19.3	131000	22.7	173000
16	93800	19.4	132000	22.8	174000
16.1	94800	19.5	133000	22.9	176000
16.2	95900	19.6	134000	23	177000
16.3	96900	19.7	136000		
16.4	98000	19.8	137000		
16.5	99100	19.9	138000		
16.6	100000	20	139000		
16.7	101000	20.1	140000		
16.8	102000	20.2	142000		
16.9	103000	20.3	143000		
17	105000	20.4	144000		
17.1	106000	20.5	145000		
17.2	107000	20.6	146000		
17.3	108000	20.7	148000		
17.4	109000	20.8	149000		
17.5	110000	20.9	150000		
17.6	111000	21	151000		
17.7	112000	21.1	153000		
17.8	113000	21.2	154000		
17.9	115000	21.3	155000		
18	116000	21.4	156000		
18.1	117000	21.5	158000		
18.2	118000	21.6	159000		
18.3	119000	21.7	160000		
18.4	120000	21.8	161000		
18.5	121000	21.9	163000		
18.6	123000	22	164000		
18.7	124000	22.1	165000		
18.8	125000	22.2	167000		
18.9	126000	22.3	168000		
19	127000	22.4	169000		
19.1	128000	22.5	170000		
19.2	130000	22.6	172000		

B.2.2 Lackawaxen Basin Junctions

Hawley Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
0.5	1.9	3.6	816	6.7	3530	9.8	8050
0.6	3	3.7	871	6.8	3650	9.9	8220
0.7	4.6	3.8	929	6.9	3780	10	8390
0.8	6.9	3.9	988	7	3910	10.1	8570
0.9	10	4	1050	7.1	4040	10.2	8750
1	16	4.1	1110	7.2	4170	10.3	8930
1.1	22	4.2	1180	7.3	4300	10.4	9110
1.2	30	4.3	1250	7.4	4430	10.5	9290
1.3	40	4.4	1320	7.5	4560	10.6	9470
1.4	52	4.5	1390	7.6	4690	10.7	9650
1.5	66	4.6	1460	7.7	4830	10.8	9830
1.6	81	4.7	1540	7.8	4960	10.9	10000
1.7	99	4.8	1620	7.9	5100	11	10200
1.8	119	4.9	1700	8	5240	11.1	10400
1.9	141	5	1780	8.1	5390	11.2	10600
2	166	5.1	1860	8.2	5530	11.3	10800
2.1	194	5.2	1950	8.3	5680	11.4	11000
2.2	224	5.3	2040	8.4	5820	11.5	11200
2.3	254	5.4	2130	8.5	5970	11.6	11400
2.4	286	5.5	2230	8.6	6120	11.7	11500
2.5	321	5.6	2320	8.7	6270	11.8	11700
2.6	358	5.7	2420	8.8	6420	11.9	11900
2.7	397	5.8	2520	8.9	6570	12	12200
2.8	436	5.9	2620	9	6730	12.1	12400
2.9	478	6	2730	9.1	6890	12.2	12600
3	522	6.1	2840	9.2	7050	12.3	12800
3.1	568	6.2	2950	9.3	7210	12.4	13000
3.2	615	6.3	3060	9.4	7370	12.5	13200
3.3	662	6.4	3170	9.5	7540	12.6	13400
3.4	712	6.5	3290	9.6	7710	12.7	13600
3.5	763	6.6	3410	9.7	7880	12.8	13800

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
12.9	14100	16.3	22500	19.7	32800	23.1	45100
13	14300	16.4	22700	19.8	33100	23.2	45400
13.1	14500	16.5	23000	19.9	33500	23.3	45800
13.2	14700	16.6	23300	20	33800	23.4	46200
13.3	14900	16.7	23600	20.1	34100	23.5	46600
13.4	15200	16.8	23900	20.2	34500	23.6	47000
13.5	15400	16.9	24100	20.3	34800	23.7	47400
13.6	15600	17	24400	20.4	35200	23.8	47800
13.7	15900	17.1	24700	20.5	35500	23.9	48200
13.8	16100	17.2	25000	20.6	35800	24	48600
13.9	16300	17.3	25300	20.7	36200	24.1	49000
14	16600	17.4	25600	20.8	36500	24.2	49400
14.1	16800	17.5	25900	20.9	36900	24.3	49800
14.2	17000	17.6	26200	21	37300	24.4	50200
14.3	17300	17.7	26500	21.1	37600	24.5	50700
14.4	17500	17.8	26800	21.2	38000	24.6	51100
14.5	17800	17.9	27100	21.3	38300	24.7	51500
14.6	18000	18	27400	21.4	38700	24.8	51900
14.7	18300	18.1	27700	21.5	39000		
14.8	18500	18.2	28000	21.6	39400		
14.9	18800	18.3	28300	21.7	39800		
15	19000	18.4	28600	21.8	40100		
15.1	19300	18.5	28900	21.9	40500		
15.2	19500	18.6	29200	22	40900		
15.3	19800	18.7	29600	22.1	41200		
15.4	20000	18.8	29900	22.2	41600		
15.5	20300	18.9	30200	22.3	42000		
15.6	20600	19	30500	22.4	42400		
15.7	20800	19.1	30800	22.5	42700		
15.8	21100	19.2	31100	22.6	43100		
15.9	21400	19.3	31500	22.7	43500		
16	21600	19.4	31800	22.8	43900		
16.1	21900	19.5	32100	22.9	44300		
16.2	22200	19.6	32500	23	44700		

B.2.3 Lehigh Basin Junctions

White Haven Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2	2.7	4.3	845	6.6	4050	8.9	11500
2.1	4.7	4.4	930	6.7	4300	9	11800
2.2	7.8	4.5	1020	6.8	4600	9.1	12000
2.3	12	4.6	1110	6.9	4900	9.2	12300
2.4	19	4.7	1200	7	5300	9.3	12500
2.5	28	4.8	1300	7.1	5700	9.4	12800
2.6	43	4.9	1400	7.2	6100	9.5	13000
2.7	63	5	1500	7.3	6500	9.6	13300
2.8	83	5.1	1620	7.4	6850	9.7	13600
2.9	105	5.2	1740	7.5	7200	9.8	13800
3	131	5.3	1860	7.6	7550	9.9	14100
3.1	158	5.4	1990	7.7	7900	10	14400
3.2	188	5.5	2130	7.8	8200	10.1	14600
3.3	222	5.6	2280	7.9	8500	10.2	14900
3.4	260	5.7	2430	8	8800	10.3	15200
3.5	302	5.8	2590	8.1	9100	10.4	15400
3.6	350	5.9	2750	8.2	9400	10.5	15700
3.7	403	6	2920	8.3	9700	10.6	16000
3.8	462	6.1	3100	8.4	10000	12.26666667	21000
3.9	526	6.2	3280	8.5	10300		
4	595	6.3	3460	8.6	10600		
4.1	675	6.4	3650	8.7	10900		
4.2	760	6.5	3850	8.8	11200		

Lehighton Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.4	84	4.7	2750	8	11000	11.3	19700
1.5	104	4.8	2930	8.1	11200	11.4	20000
1.6	126	4.9	3110	8.2	11500	11.5	20200
1.7	152	5	3300	8.3	11800	11.6	20500
1.8	181	5.1	3500	8.4	12000	11.7	20800
1.9	214	5.2	3700	8.5	12300	11.8	21000
2	248	5.3	3910	8.6	12500	11.9	21300
2.1	284	5.4	4130	8.7	12800	12	21600
2.2	323	5.5	4350	8.8	13100	12.1	21900
2.3	365	5.6	4580	8.9	13300	12.2	22100
2.4	410	5.7	4830	9	13600	12.3	22400
2.5	459	5.8	5080	9.1	13900	12.4	22600
2.6	512	5.9	5330	9.2	14100	12.5	22900
2.7	568	6	5600	9.3	14400	12.6	23200
2.8	628	6.1	5830	9.4	14600	12.7	23400
2.9	692	6.2	6070	9.5	14900	12.8	23700
3	760	6.3	6320	9.6	15100	12.9	24000
3.1	834	6.4	6570	9.7	15400	13	24200
3.2	913	6.5	6830	9.8	15700	13.1	24500
3.3	997	6.6	7090	9.9	15900	13.2	24700
3.4	1090	6.7	7360	10	16200	13.3	25000
3.5	1180	6.8	7630	10.1	16500	13.4	25200
3.6	1280	6.9	7910	10.2	16800	13.5	25500
3.7	1380	7	8200	10.3	17000	13.6	25800
3.8	1490	7.1	8470	10.4	17300	13.7	26000
3.9	1600	7.2	8750	10.5	17600	13.8	26300
4	1720	7.3	9030	10.6	17900	13.9	26500
4.1	1850	7.4	9310	10.7	18100	14	26800
4.2	1980	7.5	9600	10.8	18400	18.4	40000
4.3	2120	7.6	9870	10.9	18600		
4.4	2270	7.7	10100	11	18900		
4.5	2420	7.8	10400	11.1	19200		
4.6	2580	7.9	10700	11.2	19400		

Parryville Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2.09	0.33	3.1	168	4.2	710	5.3	1320
2.1	0.43	3.2	207	4.3	765	5.4	1380
2.2	2.5	3.3	249	4.4	820	5.5	1440
2.3	6.1	3.4	297	4.5	875	5.6	1500
2.4	12	3.5	345	4.6	930	5.7	1560
2.5	21	3.6	393	4.7	985	5.8	1620
2.6	33	3.7	443	4.8	1040	5.9	1690
2.7	51	3.8	491	4.9	1100	6	1750
2.8	73	3.9	545	5	1150	11.4	5000
2.9	100	4	600	5.1	1210		
3	133	4.1	655	5.2	1260		

Walnutport Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.5	115	3.5	2820	5.5	8320	7.5	15900
1.6	156	3.6	3060	5.6	8650	7.6	16300
1.7	204	3.7	3320	5.7	8980	7.7	16700
1.8	262	3.8	3580	5.8	9320	7.8	17100
1.9	331	3.9	3810	5.9	9700	7.9	17600
2	409	4	4050	6	10100	8	18000
2.1	498	4.1	4290	6.1	10500	8.1	18400
2.2	597	4.2	4550	6.2	10800	8.2	18900
2.3	707	4.3	4800	6.3	11200	8.3	19300
2.4	828	4.4	5070	6.4	11600	8.4	19800
2.5	961	4.5	5340	6.5	12000	8.5	20200
2.6	1100	4.6	5620	6.6	12400	8.6	20700
2.7	1260	4.7	5910	6.7	12800	8.7	21100
2.8	1430	4.8	6200	6.8	13100	8.8	21600
2.9	1600	4.9	6490	6.9	13500	8.9	22000
3	1770	5	6780	7	13900	9	22500
3.1	1960	5.1	7080	7.1	14300	9.1	23000
3.2	2160	5.2	7380	7.2	14700	9.2	23500
3.3	2370	5.3	7690	7.3	15100	9.3	24000
3.4	2590	5.4	8000	7.4	15500	9.4	24400

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
9.5	24900	11.7	36600	13.9	49700	16.1	65200
9.6	25400	11.8	37200	14	50400	16.2	65900
9.7	25900	11.9	37700	14.1	51000	16.3	66700
9.8	26400	12	38300	14.2	51600	16.4	67500
9.9	26900	12.1	38900	14.3	52300	16.5	68300
10	27500	12.2	39400	14.4	52900	16.6	69100
10.1	28000	12.3	40000	14.5	53600	16.7	69800
10.2	28500	12.4	40600	14.6	54200	16.8	70600
10.3	29000	12.5	41200	14.7	54900	16.9	71400
10.4	29500	12.6	41800	14.8	55500	17	72200
10.5	30100	12.7	42400	14.9	56300	17.1	73000
10.6	30600	12.8	43000	15	57000	17.2	73900
10.7	31200	12.9	43600	15.1	57700	17.3	74700
10.8	31700	13	44200	15.2	58400	17.4	75500
10.9	32200	13.1	44800	15.3	59200	17.5	76300
11	32800	13.2	45400	15.4	59900	17.6	77100
11.1	33300	13.3	46000	15.5	60600	17.68	77800
11.2	33800	13.4	46600	15.6	61400		
11.3	34400	13.5	47200	15.7	62100		
11.4	34900	13.6	47800	15.8	62900		
11.5	35500	13.7	48500	15.9	63600		
11.6	36000	13.8	49100	16	64400		

Bethlehem Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
0.68	170	4.3	7010	8	17000	11.7	28200
0.7	181	4.4	7260	8.1	17300	11.8	28500
0.8	243	4.5	7500	8.2	17600	11.9	28800
0.9	313	4.6	7730	8.3	17900	12	29100
1	401	4.7	7970	8.4	18200	12.1	29500
1.1	503	4.8	8200	8.5	18500	12.2	29800
1.2	610	4.9	8440	8.6	18800	12.3	30100
1.3	743	5	8680	8.7	19100	12.4	30400
1.4	895	5.1	8920	8.8	19400	12.5	30700
1.5	1060	5.2	9170	8.9	19700	12.6	31100
1.6	1240	5.3	9410	9	20000	12.7	31400
1.7	1390	5.4	9650	9.1	20300	12.8	31700
1.8	1560	5.5	9900	9.2	20600	12.9	32000
1.9	1730	5.6	10200	9.3	20900	13	32400
2	1920	5.7	10400	9.4	21200	13.1	32700
2.1	2100	5.8	10700	9.5	21500	13.2	33000
2.2	2280	5.9	11000	9.6	21800	13.3	33300
2.3	2480	6	11300	9.7	22100	13.4	33700
2.4	2680	6.1	11600	9.8	22400	13.5	34000
2.5	2930	6.2	11800	9.9	22700	13.6	34300
2.6	3130	6.3	12100	10	23000	13.7	34600
2.7	3320	6.4	12400	10.1	23300	13.8	35000
2.8	3520	6.5	12700	10.2	23600	13.9	35300
2.9	3720	6.6	13000	10.3	23900	14	35600
3	3930	6.7	13300	10.4	24200	14.1	36000
3.1	4170	6.8	13500	10.5	24500	14.2	36300
3.2	4390	6.9	13800	10.6	24800	14.3	36600
3.3	4620	7	14100	10.7	25100	14.4	37000
3.4	4860	7.1	14400	10.8	25400	14.5	37300
3.5	5100	7.2	14700	10.9	25700	14.6	37600
3.6	5350	7.3	15000	11	26000	14.7	38000
3.7	5580	7.4	15300	11.1	26300	14.8	38300
3.8	5820	7.5	15600	11.2	26600	14.9	38700
3.9	6060	7.6	15800	11.3	26900	15	39000
4	6300	7.7	16100	11.4	27200	15.1	39300
4.1	6540	7.8	16400	11.5	27600	15.2	39700
4.2	6770	7.9	16700	11.6	27900	15.3	40000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
15.4	40300	18.1	50400	20.8	61700	23.5	76100
15.5	40700	18.2	50800	20.9	62200	23.6	76800
15.6	41000	18.3	51100	21	62600	23.7	77400
15.7	41400	18.4	51500	21.1	63100	23.8	78000
15.8	41700	18.5	51900	21.2	63600	23.9	78700
15.9	42100	18.6	52300	21.3	64100	24	79300
16	42400	18.7	52700	21.4	64600	24.1	80000
16.1	42800	18.8	53100	21.5	65000	24.2	80600
16.2	43100	18.9	53500	21.6	65500	24.3	81300
16.3	43500	19	53900	21.7	66000	24.4	81900
16.4	43900	19.1	54300	21.8	66500	24.5	82600
16.5	44300	19.2	54700	21.9	67000	24.6	83200
16.6	44600	19.3	55100	22	67500	24.7	83900
16.7	45000	19.4	55500	22.1	68000	24.8	84500
16.8	45400	19.5	55900	22.2	68600	24.9	85200
16.9	45800	19.6	56300	22.3	69100	25	85900
17	46100	19.7	56700	22.4	69700	25.1	86500
17.1	46500	19.8	57100	22.5	70200	25.2	87200
17.2	46900	19.9	57500	22.6	70800	25.3	87900
17.3	47300	20	57900	22.7	71300	25.4	88600
17.4	47700	20.1	58400	22.8	71900	25.5	89300
17.5	48100	20.2	58800	22.9	72400	25.6	89900
17.6	48400	20.3	59300	23	73000	25.7	90600
17.7	48800	20.4	59800	23.1	73600	25.8	91300
17.8	49200	20.5	60200	23.2	74200	25.9	92000
17.9	49600	20.6	60700	23.3	74900		
18	50000	20.7	61200	23.4	75500		

B.2.4 Mainstem Junctions

Barryville Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.5	277	4.9	4650	8.3	16100	11.7	32400
1.6	312	5	4890	8.4	16600	11.8	32900
1.7	351	5.1	5130	8.5	17000	11.9	33400
1.8	392	5.2	5380	8.6	17400	12	34000
1.9	438	5.3	5640	8.7	17900	12.1	34500
2	487	5.4	5910	8.8	18300	12.2	35000
2.1	541	5.5	6170	8.9	18800	12.3	35600
2.2	599	5.6	6450	9	19200	12.4	36100
2.3	661	5.7	6730	9.1	19700	12.5	36600
2.4	728	5.8	7020	9.2	20100	12.6	37200
2.5	801	5.9	7310	9.3	20600	12.7	37700
2.6	879	6	7610	9.4	21000	12.8	38300
2.7	962	6.1	7920	9.5	21500	12.9	38800
2.8	1050	6.2	8230	9.6	22000	13	39400
2.9	1150	6.3	8540	9.7	22400	13.1	39900
3	1250	6.4	8870	9.8	22900	13.2	40500
3.1	1360	6.5	9200	9.9	23400	13.3	41000
3.2	1470	6.6	9530	10	23800	13.4	41600
3.3	1600	6.7	9870	10.1	24300	13.5	42200
3.4	1730	6.8	10200	10.2	24800	13.6	42700
3.5	1870	6.9	10600	10.3	25300	13.7	43300
3.6	2020	7	10900	10.4	25800	13.8	43900
3.7	2170	7.1	11300	10.5	26300	13.9	44400
3.8	2340	7.2	11700	10.6	26800	14	45000
3.9	2510	7.3	12000	10.7	27300	14.1	45600
4	2700	7.4	12400	10.8	27800	14.2	46200
4.1	2890	7.5	12800	10.9	28300	14.3	46700
4.2	3100	7.6	13200	11	28800	14.4	47300
4.3	3310	7.7	13600	11.1	29300	14.5	47900
4.4	3540	7.8	14000	11.2	29800	14.6	48500
4.5	3750	7.9	14400	11.3	30300	14.7	49100
4.6	3970	8	14900	11.4	30800	14.8	49700
4.7	4190	8.1	15300	11.5	31300	14.9	50300
4.8	4410	8.2	15700	11.6	31800	15	50900

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
15.1	51500	18.5	72900	21.9	96300	28.1	143000
15.2	52100	18.6	73500	22	97000	28.3	145000
15.3	52700	18.7	74200	22.1	97700	28.5	147000
15.4	53300	18.8	74900	22.2	98500	28.7	148000
15.5	53900	18.9	75500	22.3	99200	28.9	150000
15.6	54500	19	76200	22.4	99900	29.1	152000
15.7	55100	19.1	76900	22.5	101000	29.3	153000
15.8	55700	19.2	77500	22.7	102000	29.5	155000
15.9	56300	19.3	78200	22.9	104000	29.7	156000
16	56900	19.4	78900	23.1	105000	29.9	158000
16.1	57500	19.5	79600	23.3	106000	30.1	160000
16.2	58200	19.6	80200	23.5	108000	30.3	161000
16.3	58800	19.7	80900	23.7	109000	30.5	163000
16.4	59400	19.8	81600	23.9	111000	30.7	165000
16.5	60000	19.9	82300	24.1	112000	30.9	166000
16.6	60600	20	83000	24.3	114000	31.1	168000
16.7	61300	20.1	83700	24.5	115000	31.3	170000
16.8	61900	20.2	84400	24.7	117000	31.5	172000
16.9	62500	20.3	85000	24.9	118000	31.7	173000
17	63200	20.4	85700	25.1	120000	31.9	175000
17.1	63800	20.5	86400	25.3	121000	32.1	177000
17.2	64400	20.6	87100	25.5	123000	32.3	178000
17.3	65100	20.7	87800	25.7	125000	32.5	180000
17.4	65700	20.8	88500	25.9	126000	32.7	182000
17.5	66400	20.9	89200	26.1	128000	32.9	184000
17.6	67000	21	89900	26.3	129000	33.1	185000
17.7	67600	21.1	90600	26.5	131000	33.3	187000
17.8	68300	21.2	91300	26.7	132000	33.5	189000
17.9	68900	21.3	92000	26.9	134000		
18	69600	21.4	92700	27.1	136000		
18.1	70200	21.5	93400	27.3	137000		
18.2	70900	21.6	94200	27.5	139000		
18.3	71600	21.7	94900	27.7	140000		
18.4	72200	21.8	95600	27.9	142000		

Port Jervis Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.69	535	5.3	10700	9	34800	12.7	68500
1.7	543	5.4	11200	9.1	35600	12.8	69500
1.8	632	5.5	11700	9.2	36300	12.9	70600
1.9	729	5.6	12200	9.3	37100	13	71700
2	836	5.7	12800	9.4	37900	13.1	72700
2.1	952	5.8	13300	9.5	38700	13.2	73800
2.2	1080	5.9	13900	9.6	39500	13.3	74900
2.3	1210	6	14400	9.7	40400	13.4	76000
2.4	1360	6.1	15000	9.8	41200	13.5	77100
2.5	1520	6.2	15600	9.9	42000	13.6	78300
2.6	1690	6.3	16200	10	42900	13.7	79400
2.7	1870	6.4	16800	10.1	43700	13.8	80500
2.8	2060	6.5	17400	10.2	44600	13.9	81700
2.9	2270	6.6	18000	10.3	45400	14	82800
3	2490	6.7	18600	10.4	46300	14.1	84000
3.1	2720	6.8	19300	10.5	47200	14.2	85100
3.2	2970	6.9	20000	10.6	48100	14.3	86300
3.3	3220	7	20600	10.7	49000	14.4	87500
3.4	3500	7.1	21300	10.8	49900	14.5	88700
3.5	3780	7.2	22000	10.9	50800	14.6	89800
3.6	4090	7.3	22700	11	51700	14.7	91000
3.7	4400	7.4	23400	11.1	52600	14.8	92300
3.8	4740	7.5	24200	11.2	53500	14.9	93500
3.9	5080	7.6	24900	11.3	54500	15	94700
4	5400	7.7	25500	11.4	55400	15.1	95900
4.1	5730	7.8	26200	11.5	56400	15.2	97200
4.2	6070	7.9	26900	11.6	57400	15.3	98400
4.3	6450	8	27500	11.7	58300	15.4	99700
4.4	6810	8.1	28200	11.8	59300	15.5	101000
4.5	7220	8.2	28900	11.9	60300	15.6	102000
4.6	7600	8.3	29600	12	61300	15.7	103000
4.7	8030	8.4	30400	12.1	62300	15.8	105000
4.8	8430	8.5	31100	12.2	63300	15.9	106000
4.9	8880	8.6	31800	12.3	64300	16	107000
5	9340	8.7	32500	12.4	65300	16.1	109000
5.1	9780	8.8	33300	12.5	66400	16.2	110000
5.2	10300	8.9	34000	12.6	67400	16.3	111000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
16.4	113000	18.7	145000	21	182000	23.3	222000
16.5	114000	18.8	147000	21.1	183000	23.4	224000
16.6	115000	18.9	148000	21.2	185000	23.5	226000
16.7	117000	19	150000	21.3	187000	23.6	227000
16.8	118000	19.1	151000	21.4	188000	23.7	229000
16.9	119000	19.2	153000	21.5	190000	23.8	231000
17	121000	19.3	154000	21.6	192000	23.9	233000
17.1	122000	19.4	156000	21.7	193000	24	235000
17.2	123000	19.5	157000	21.8	195000	24.1	237000
17.3	125000	19.6	159000	21.9	197000	24.2	239000
17.4	126000	19.7	161000	22	199000	24.3	241000
17.5	128000	19.8	162000	22.1	200000	24.4	242000
17.6	129000	19.9	164000	22.2	202000	24.5	244000
17.7	131000	20	165000	22.3	204000	24.6	246000
17.8	132000	20.1	167000	22.4	206000	24.7	248000
17.9	133000	20.2	168000	22.5	207000	24.8	250000
18	135000	20.3	170000	22.6	209000	24.9	252000
18.1	136000	20.4	172000	22.7	211000	25	254000
18.2	138000	20.5	173000	22.8	213000		
18.3	139000	20.6	175000	22.9	215000		
18.4	141000	20.7	177000	23	216000		
18.5	142000	20.8	178000	23.1	218000		
18.6	144000	20.9	180000	23.2	220000		

Montague Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
4.04	600	7.7	8680	11.4	24300	15.1	46000
4.1	663	7.8	9010	11.5	24800	15.2	46700
4.2	773	7.9	9350	11.6	25400	15.3	47400
4.3	891	8	9690	11.7	25900	15.4	48000
4.4	1020	8.1	10000	11.8	26400	15.5	48700
4.5	1150	8.2	10400	11.9	27000	15.6	49400
4.6	1290	8.3	10700	12	27500	15.7	50100
4.7	1430	8.4	11100	12.1	28000	15.8	50700
4.8	1590	8.5	11500	12.2	28600	15.9	51400
4.9	1740	8.6	11800	12.3	29200	16	52100
5	1910	8.7	12200	12.4	29700	16.1	52800
5.1	2080	8.8	12600	12.5	30300	16.2	53500
5.2	2260	8.9	13000	12.6	30800	16.3	54200
5.3	2450	9	13400	12.7	31400	16.4	54900
5.4	2640	9.1	13800	12.8	32000	16.5	55600
5.5	2840	9.2	14200	12.9	32600	16.6	56300
5.6	3040	9.3	14600	13	33100	16.7	57100
5.7	3250	9.4	15000	13.1	33700	16.8	57800
5.8	3470	9.5	15400	13.2	34300	16.9	58500
5.9	3690	9.6	15800	13.3	34900	17	59200
6	3920	9.7	16300	13.4	35500	17.1	60000
6.1	4150	9.8	16700	13.5	36000	17.2	60700
6.2	4390	9.9	17100	13.6	36600	17.3	61400
6.3	4640	10	17600	13.7	37200	17.4	62200
6.4	4890	10.1	18000	13.8	37800	17.5	62900
6.5	5150	10.2	18500	13.9	38400	17.6	63700
6.6	5410	10.3	19000	14	39100	17.7	64400
6.7	5680	10.4	19400	14.1	39700	17.8	65200
6.8	5960	10.5	19900	14.2	40300	17.9	65900
6.9	6240	10.6	20400	14.3	40900	18	66700
7	6520	10.7	20800	14.4	41500	18.1	67500
7.1	6820	10.8	21300	14.5	42200	18.2	68300
7.2	7110	10.9	21800	14.6	42800	18.3	69000
7.3	7420	11	22300	14.7	43400	18.4	69800
7.4	7720	11.1	22800	14.8	44100	18.5	70600
7.5	8040	11.2	23300	14.9	44700	18.6	71400
7.6	8360	11.3	23800	15	45400	18.7	72200

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
18.8	73000	22.6	107000	26.4	146000	30.2	188000
18.9	73800	22.7	108000	26.5	147000	30.3	190000
19	74600	22.8	109000	26.6	148000	30.4	191000
19.1	75400	22.9	110000	26.7	150000	30.5	192000
19.2	76200	23	111000	26.8	151000	30.6	193000
19.3	77000	23.1	112000	26.9	152000	30.7	194000
19.4	77800	23.2	113000	27	153000	30.8	195000
19.5	78600	23.3	114000	27.1	154000	30.9	197000
19.6	79500	23.4	115000	27.2	155000	31	198000
19.7	80300	23.5	116000	27.3	156000	31.1	199000
19.8	81100	23.6	117000	27.4	157000	31.2	200000
19.9	82000	23.7	118000	27.5	158000	31.3	201000
20	82800	23.8	119000	27.6	159000	31.4	203000
20.1	83700	23.9	120000	27.7	161000	31.5	204000
20.2	84500	24	121000	27.8	162000	31.6	205000
20.3	85400	24.1	122000	27.9	163000	31.7	206000
20.4	86300	24.2	123000	28	164000	31.8	208000
20.5	87200	24.3	124000	28.1	165000	31.9	209000
20.6	88100	24.4	125000	28.2	166000	32	210000
20.7	89000	24.5	126000	28.3	167000	32.1	211000
20.8	89900	24.6	127000	28.4	168000	32.2	212000
20.9	90800	24.7	128000	28.5	169000	32.3	214000
21	91700	24.8	129000	28.6	170000	32.4	215000
21.1	92600	24.9	130000	28.7	172000	32.5	216000
21.2	93500	25	131000	28.8	173000	32.6	217000
21.3	94400	25.1	132000	28.9	174000	32.7	219000
21.4	95400	25.2	133000	29	175000	32.8	220000
21.5	96300	25.3	134000	29.1	176000	32.9	221000
21.6	97200	25.4	136000	29.2	177000	33	222000
21.7	98200	25.5	137000	29.3	178000	33.1	224000
21.8	99100	25.6	138000	29.4	179000	33.2	225000
21.9	100000	25.7	139000	29.5	180000	33.3	226000
22	101000	25.8	140000	29.6	182000	33.4	227000
22.1	102000	25.9	141000	29.7	183000	33.5	229000
22.2	103000	26	142000	29.8	184000	33.6	230000
22.3	104000	26.1	143000	29.9	185000	33.7	231000
22.4	105000	26.2	144000	30	186000	33.8	232000
22.5	106000	26.3	145000	30.1	187000	33.9	234000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
34	235000	34.5	242000	35	248000
34.1	236000	34.6	243000	35.1	250000
34.2	238000	34.7	244000	35.2	251000
34.3	239000	34.8	246000	36.8	267000
34.4	240000	34.9	247000		

Tocks Island Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
4.2	190	7.9	10700	11.6	30700	15.3	54200
4.3	304	8	11200	11.7	31300	15.4	54800
4.4	425	8.1	11600	11.8	32000	15.5	55500
4.5	550	8.2	12000	11.9	32700	15.6	56100
4.6	680	8.3	12500	12	33400	15.7	56700
4.7	814	8.4	12900	12.1	34100	15.8	57400
4.8	950	8.5	13400	12.2	34800	15.9	58000
4.9	1120	8.6	13800	12.3	35500	16	58700
5	1310	8.7	14300	12.4	36200	16.1	59300
5.1	1500	8.8	14800	12.5	36900	16.2	60000
5.2	1690	8.9	15200	12.6	37500	16.3	60600
5.3	1900	9	15700	12.7	38100	16.4	61200
5.4	2140	9.1	16200	12.8	38700	16.5	61800
5.5	2390	9.2	16700	12.9	39300	16.6	62500
5.6	2650	9.3	17200	13	39900	16.7	63100
5.7	2890	9.4	17700	13.1	40500	16.8	63800
5.8	3170	9.5	18200	13.2	41100	16.9	64400
5.9	3460	9.6	18800	13.3	41700	17	65000
6	3760	9.7	19300	13.4	42300	17.1	65700
6.1	4070	9.8	19800	13.5	42900	17.2	66300
6.2	4380	9.9	20400	13.6	43500	17.3	67000
6.3	4710	10	20900	13.7	44100	17.4	67600
6.4	5040	10.1	21500	13.8	44800	17.5	68200
6.5	5380	10.2	22100	13.9	45400	17.6	68900
6.6	5740	10.3	22700	14	46000	17.7	69500
6.7	6100	10.4	23200	14.1	46600	17.8	70200
6.8	6460	10.5	23800	14.2	47200	17.9	70800
6.9	6820	10.6	24400	14.3	47900	18	71500
7	7180	10.7	25000	14.4	48500	18.1	72100
7.1	7550	10.8	25600	14.5	49100	18.2	72800
7.2	7930	10.9	26200	14.6	49700	18.3	73400
7.3	8310	11	26800	14.7	50400	18.4	74000
7.4	8700	11.1	27500	14.8	51000	18.5	74600
7.5	9090	11.2	28100	14.9	51600	18.6	75300
7.6	9490	11.3	28700	15	52300	18.7	75900
7.7	9900	11.4	29400	15.1	52900	18.8	76600
7.8	10300	11.5	30000	15.2	53500	18.9	77200

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
19	77900	21.9	97200	27.1	140000	32.9	210000
19.1	78500	22	97900	27.3	142000	33.1	213000
19.2	79200	22.1	98700	27.5	143000	33.3	216000
19.3	79800	22.2	99400	27.7	145000	33.5	219000
19.4	80500	22.3	100000	27.9	147000	33.7	222000
19.5	81100	22.4	101000	28.1	149000	33.9	225000
19.6	81800	22.5	102000	28.3	151000	34.1	228000
19.7	82500	22.7	103000	28.5	154000	34.3	231000
19.8	83100	22.9	105000	28.7	156000	34.5	234000
19.9	83800	23.1	106000	28.9	159000	34.7	237000
20	84400	23.3	108000	29.1	161000	34.9	240000
20.1	85100	23.5	109000	29.3	163000	35.1	243000
20.2	85800	23.7	111000	29.5	166000	35.3	246000
20.3	86400	23.9	112000	29.7	168000	35.5	249000
20.4	87100	24.1	114000	29.9	171000	35.7	252000
20.5	87800	24.3	116000	30.1	173000	35.9	255000
20.6	88400	24.5	117000	30.3	176000	36.1	259000
20.7	89100	24.7	119000	30.5	178000	36.3	262000
20.8	89800	24.9	121000	30.7	181000	36.5	265000
20.9	90500	25.1	122000	30.9	183000	36.7	268000
21	91100	25.3	124000	31.1	186000	36.9	272000
21.1	91800	25.5	126000	31.3	189000	37.1	275000
21.2	92500	25.7	128000	31.5	191000	37.3	278000
21.3	93200	25.9	129000	31.7	194000	37.5	282000
21.4	93800	26.1	131000	31.9	197000	37.7	285000
21.5	94500	26.3	133000	32.1	199000	37.9	288000
21.6	95200	26.5	135000	32.3	202000	38	290000
21.7	95900	26.7	136000	32.5	205000		
21.8	96600	26.9	138000	32.7	207000		

Belvidere Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2.6	820	6.3	10700	10	31200	13.7	61800
2.7	935	6.4	11100	10.1	31900	13.8	62700
2.8	1060	6.5	11600	10.2	32600	13.9	63600
2.9	1190	6.6	12000	10.3	33300	14	64500
3	1330	6.7	12400	10.4	34000	14.1	65500
3.1	1480	6.8	12900	10.5	34700	14.2	66400
3.2	1640	6.9	13300	10.6	35500	14.3	67300
3.3	1800	7	13800	10.7	36200	14.4	68300
3.4	1970	7.1	14300	10.8	36900	14.5	69200
3.5	2160	7.2	14800	10.9	37700	14.6	70200
3.6	2350	7.3	15200	11	38500	14.7	71200
3.7	2550	7.4	15700	11.1	39200	14.8	72100
3.8	2760	7.5	16200	11.2	40000	14.9	73100
3.9	2980	7.6	16700	11.3	40800	15	74100
4	3200	7.7	17300	11.4	41600	15.1	75100
4.1	3440	7.8	17800	11.5	42400	15.2	76100
4.2	3680	7.9	18300	11.6	43200	15.3	77100
4.3	3940	8	18900	11.7	44000	15.4	78100
4.4	4200	8.1	19400	11.8	44800	15.5	79100
4.5	4460	8.2	20000	11.9	45700	15.6	80100
4.6	4740	8.3	20500	12	46500	15.7	81100
4.7	5020	8.4	21100	12.1	47400	15.8	82200
4.8	5310	8.5	21700	12.2	48200	15.9	83200
4.9	5610	8.6	22300	12.3	49100	16	84200
5	5910	8.7	22900	12.4	49900	16.1	85300
5.1	6230	8.8	23500	12.5	50800	16.2	86300
5.2	6550	8.9	24100	12.6	51700	16.3	87400
5.3	6880	9	24700	12.7	52600	16.4	88500
5.4	7220	9.1	25400	12.8	53500	16.5	89500
5.5	7570	9.2	26000	12.9	54400	16.6	90600
5.6	7930	9.3	26600	13	55300	16.7	91700
5.7	8300	9.4	27300	13.1	56200	16.8	92800
5.8	8680	9.5	27900	13.2	57200	16.9	93900
5.9	9060	9.6	28500	13.3	58100	17	95000
6	9450	9.7	29200	13.4	59000	17.1	96000
6.1	9860	9.8	29900	13.5	60000	17.2	97100
6.2	10300	9.9	30500	13.6	60900	17.3	98100

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
17.4	99200	21.2	143000	25	193000	28.8	250000
17.5	100000	21.3	144000	25.1	195000	28.9	252000
17.6	101000	21.4	145000	25.2	196000	29	253000
17.7	102000	21.5	147000	25.3	198000	29.1	255000
17.8	103000	21.6	148000	25.4	199000	29.2	257000
17.9	105000	21.7	149000	25.5	201000	29.3	258000
18	106000	21.8	151000	25.6	202000	29.4	260000
18.1	107000	21.9	152000	25.7	203000	29.5	261000
18.2	108000	22	153000	25.8	205000	29.6	263000
18.3	109000	22.1	154000	25.9	206000	29.7	265000
18.4	110000	22.2	156000	26	208000	29.8	266000
18.5	111000	22.3	157000	26.1	209000	29.9	268000
18.6	112000	22.4	158000	26.2	211000	30	270000
18.7	113000	22.5	160000	26.3	212000	30.1	271000
18.8	115000	22.6	161000	26.4	214000	30.2	273000
18.9	116000	22.7	162000	26.5	215000	30.3	275000
19	117000	22.8	163000	26.6	217000	30.4	277000
19.1	118000	22.9	165000	26.7	218000	30.5	279000
19.2	119000	23	166000	26.8	220000	30.6	280000
19.3	120000	23.1	167000	26.9	221000	30.7	282000
19.4	121000	23.2	169000	27	223000	30.8	284000
19.5	123000	23.3	170000	27.1	224000	30.9	286000
19.6	124000	23.4	171000	27.2	226000	31	288000
19.7	125000	23.5	173000	27.3	227000	31.1	290000
19.8	126000	23.6	174000	27.4	229000	31.2	292000
19.9	127000	23.7	175000	27.5	230000	31.3	294000
20	128000	23.8	177000	27.6	232000	31.4	296000
20.1	130000	23.9	178000	27.7	233000	31.5	298000
20.2	131000	24	180000	27.8	235000	31.6	300000
20.3	132000	24.1	181000	27.9	236000	31.7	302000
20.4	133000	24.2	182000	28	238000	31.8	304000
20.5	134000	24.3	184000	28.1	239000	31.9	306000
20.6	136000	24.4	185000	28.2	241000	32	308000
20.7	137000	24.5	186000	28.3	242000	32.1	310000
20.8	138000	24.6	188000	28.4	244000	32.2	312000
20.9	139000	24.7	189000	28.5	246000	32.3	314000
21	141000	24.8	191000	28.6	247000	32.4	316000
21.1	142000	24.9	192000	28.7	249000	32.5	318000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
32.6	320000	36.1	400000	39.6	495000	43.1	602000
32.7	322000	36.2	403000	39.7	498000	43.2	606000
32.8	325000	36.3	405000	39.8	501000	43.3	609000
32.9	327000	36.4	408000	39.9	504000	43.4	612000
33	329000	36.5	410000	40	507000	43.5	615000
33.1	331000	36.6	413000	40.1	510000	43.6	619000
33.2	333000	36.7	415000	40.2	513000	43.7	622000
33.3	335000	36.8	418000	40.3	516000	43.8	625000
33.4	337000	36.9	420000	40.4	519000	43.9	628000
33.5	339000	37	423000	40.5	522000	44	632000
33.6	341000	37.1	426000	40.6	525000	44.1	635000
33.7	344000	37.2	428000	40.7	528000	44.2	638000
33.8	346000	37.3	431000	40.8	531000	44.3	642000
33.9	348000	37.4	434000	40.9	534000	44.4	645000
34	350000	37.5	437000	41	537000	44.5	648000
34.1	352000	37.6	439000	41.1	540000	44.6	652000
34.2	355000	37.7	442000	41.2	543000	44.7	655000
34.3	357000	37.8	445000	41.3	546000	44.8	659000
34.4	359000	37.9	447000	41.4	549000	44.9	662000
34.5	362000	38	450000	41.5	552000	45	665000
34.6	364000	38.1	453000	41.6	555000	45.1	669000
34.7	366000	38.2	456000	41.7	558000	45.2	672000
34.8	369000	38.3	458000	41.8	561000	45.3	676000
34.9	371000	38.4	461000	41.9	564000	45.4	679000
35	373000	38.5	464000	42	567000	45.5	683000
35.1	376000	38.6	467000	42.1	571000	45.6	686000
35.2	378000	38.7	470000	42.2	574000	45.7	690000
35.3	381000	38.8	472000	42.3	577000	45.8	693000
35.4	383000	38.9	475000	42.4	580000	45.9	696000
35.5	385000	39	478000	42.5	583000	46	700000
35.6	388000	39.1	481000	42.6	586000		
35.7	390000	39.2	484000	42.7	589000		
35.8	393000	39.3	487000	42.8	593000		
35.9	395000	39.4	489000	42.9	596000		
36	398000	39.5	492000	43	599000		

Riegelsville Official Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
1.6	1080	5.3	11100	9	26800	12.7	46400
1.7	1230	5.4	11500	9.1	27200	12.8	46900
1.8	1370	5.5	11900	9.2	27700	12.9	47500
1.9	1530	5.6	12300	9.3	28200	13	48100
2	1680	5.7	12600	9.4	28700	13.1	48700
2.1	1850	5.8	13000	9.5	29200	13.2	49300
2.2	2030	5.9	13500	9.6	29700	13.3	49900
2.3	2210	6	13900	9.7	30200	13.4	50500
2.4	2400	6.1	14200	9.8	30700	13.5	51100
2.5	2600	6.2	14600	9.9	31200	13.6	51700
2.6	2810	6.3	15000	10	31700	13.7	52400
2.7	3030	6.4	15400	10.1	32300	13.8	53000
2.8	3250	6.5	15800	10.2	32800	13.9	53600
2.9	3480	6.6	16200	10.3	33300	14	54200
3	3720	6.7	16600	10.4	33800	14.1	54800
3.1	3970	6.8	17000	10.5	34300	14.2	55400
3.2	4230	6.9	17400	10.6	34900	14.3	56100
3.3	4500	7	17900	10.7	35400	14.4	56700
3.4	4770	7.1	18300	10.8	35900	14.5	57300
3.5	5050	7.2	18700	10.9	36400	14.6	57900
3.6	5340	7.3	19100	11	36900	14.7	58600
3.7	5640	7.4	19500	11.1	37500	14.8	59200
3.8	5950	7.5	20000	11.2	38000	14.9	59900
3.9	6270	7.6	20400	11.3	38500	15	60500
4	6600	7.7	20800	11.4	39100	15.1	61100
4.1	6900	7.8	21300	11.5	39600	15.2	61800
4.2	7200	7.9	21700	11.6	40100	15.3	62400
4.3	7550	8	22200	11.7	40700	15.4	63100
4.4	7900	8.1	22600	11.8	41200	15.5	63700
4.5	8250	8.2	23100	11.9	41800	15.6	64400
4.6	8600	8.3	23500	12	42300	15.7	65000
4.7	8950	8.4	24000	12.1	42900	15.8	65700
4.8	9300	8.5	24400	12.2	43400	15.9	66300
4.9	9650	8.6	24900	12.3	44000	16	67000
5	10000	8.7	25300	12.4	44600	16.1	67700
5.1	10400	8.8	25800	12.5	45200	16.2	68400
5.2	10700	8.9	26300	12.6	45800	16.3	69000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
16.4	69700	19.9	97100	26.5	162000	33.5	253000
16.5	70400	20	98000	26.7	164000	33.7	256000
16.6	71100	20.1	98900	26.9	166000	33.9	259000
16.7	71800	20.2	99700	27.1	168000	34.1	262000
16.8	72500	20.3	101000	27.3	171000	34.3	265000
16.9	73200	20.5	102000	27.5	173000	34.5	268000
17	73900	20.7	104000	27.7	175000	34.7	271000
17.1	74600	20.9	106000	27.9	178000	34.9	274000
17.2	75300	21.1	108000	28.1	180000	35.1	277000
17.3	76000	21.3	110000	28.3	182000	35.3	280000
17.4	76700	21.5	111000	28.5	185000	35.5	284000
17.5	77400	21.7	113000	28.7	187000	35.7	287000
17.6	78100	21.9	115000	28.9	190000	35.9	290000
17.7	78800	22.1	117000	29.1	192000	36.1	293000
17.8	79600	22.3	119000	29.3	194000	36.3	296000
17.9	80300	22.5	121000	29.5	197000	36.5	300000
18	81000	22.7	122000	29.7	199000	36.7	303000
18.1	81800	22.9	124000	29.9	202000	36.9	306000
18.2	82600	23.1	126000	30.1	204000	37.1	310000
18.3	83500	23.3	128000	30.3	207000	37.3	313000
18.4	84300	23.5	130000	30.5	210000	37.5	316000
18.5	85100	23.7	132000	30.7	213000	37.7	320000
18.6	86000	23.9	134000	30.9	215000	37.9	323000
18.7	86800	24.1	136000	31.1	218000	38.1	326000
18.8	87600	24.3	138000	31.3	221000	38.3	330000
18.9	88500	24.5	140000	31.5	224000	38.5	333000
19	89300	24.7	142000	31.7	227000	38.7	337000
19.1	90200	24.9	144000	31.9	229000	38.9	340000
19.2	91000	25.1	146000	32.1	232000	39	342000
19.3	91900	25.3	148000	32.3	235000		
19.4	92800	25.5	150000	32.5	238000		
19.5	93600	25.7	153000	32.7	241000		
19.6	94500	25.9	155000	32.9	244000		
19.7	95400	26.1	157000	33.1	247000		
19.8	96200	26.3	159000	33.3	250000		

Riegelsville Modified Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
2.6	820	6.3	10700	10	31200	13.7	61800
2.7	935	6.4	11100	10.1	31900	13.8	62700
2.8	1060	6.5	11600	10.2	32600	13.9	63600
2.9	1190	6.6	12000	10.3	33300	14	64500
3	1330	6.7	12400	10.4	34000	14.1	65500
3.1	1480	6.8	12900	10.5	34700	14.2	66400
3.2	1640	6.9	13300	10.6	35500	14.3	67300
3.3	1800	7	13800	10.7	36200	14.4	68300
3.4	1970	7.1	14300	10.8	36900	14.5	69200
3.5	2160	7.2	14800	10.9	37700	14.6	70200
3.6	2350	7.3	15200	11	38500	14.7	71200
3.7	2550	7.4	15700	11.1	39200	14.8	72100
3.8	2760	7.5	16200	11.2	40000	14.9	73100
3.9	2980	7.6	16700	11.3	40800	15	74100
4	3200	7.7	17300	11.4	41600	15.1	75100
4.1	3440	7.8	17800	11.5	42400	15.2	76100
4.2	3680	7.9	18300	11.6	43200	15.3	77100
4.3	3940	8	18900	11.7	44000	15.4	78100
4.4	4200	8.1	19400	11.8	44800	15.5	79100
4.5	4460	8.2	20000	11.9	45700	15.6	80100
4.6	4740	8.3	20500	12	46500	15.7	81100
4.7	5020	8.4	21100	12.1	47400	15.8	82200
4.8	5310	8.5	21700	12.2	48200	15.9	83200
4.9	5610	8.6	22300	12.3	49100	16	84200
5	5910	8.7	22900	12.4	49900	16.1	85300
5.1	6230	8.8	23500	12.5	50800	16.2	86300
5.2	6550	8.9	24100	12.6	51700	16.3	87400
5.3	6880	9	24700	12.7	52600	16.4	88500
5.4	7220	9.1	25400	12.8	53500	16.5	89500
5.5	7570	9.2	26000	12.9	54400	16.6	90600
5.6	7930	9.3	26600	13	55300	16.7	91700
5.7	8300	9.4	27300	13.1	56200	16.8	92800
5.8	8680	9.5	27900	13.2	57200	16.9	93900
5.9	9060	9.6	28500	13.3	58100	17	95000
6	9450	9.7	29200	13.4	59000	17.1	96000
6.1	9860	9.8	29900	13.5	60000	17.2	97100
6.2	10300	9.9	30500	13.6	60900	17.3	98100

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
17.4	99200	21.2	143000	25	193000	28.8	250000
17.5	100000	21.3	144000	25.1	195000	28.9	252000
17.6	101000	21.4	145000	25.2	196000	29	253000
17.7	102000	21.5	147000	25.3	198000	29.1	255000
17.8	103000	21.6	148000	25.4	199000	29.2	257000
17.9	105000	21.7	149000	25.5	201000	29.3	258000
18	106000	21.8	151000	25.6	202000	29.4	260000
18.1	107000	21.9	152000	25.7	203000	29.5	261000
18.2	108000	22	153000	25.8	205000	29.6	263000
18.3	109000	22.1	154000	25.9	206000	29.7	265000
18.4	110000	22.2	156000	26	208000	29.8	266000
18.5	111000	22.3	157000	26.1	209000	29.9	268000
18.6	112000	22.4	158000	26.2	211000	30	270000
18.7	113000	22.5	160000	26.3	212000	30.1	271000
18.8	115000	22.6	161000	26.4	214000	30.2	273000
18.9	116000	22.7	162000	26.5	215000	30.3	275000
19	117000	22.8	163000	26.6	217000	30.4	277000
19.1	118000	22.9	165000	26.7	218000	30.5	279000
19.2	119000	23	166000	26.8	220000	30.6	280000
19.3	120000	23.1	167000	26.9	221000	30.7	282000
19.4	121000	23.2	169000	27	223000	30.8	284000
19.5	123000	23.3	170000	27.1	224000	30.9	286000
19.6	124000	23.4	171000	27.2	226000	31	288000
19.7	125000	23.5	173000	27.3	227000	31.1	290000
19.8	126000	23.6	174000	27.4	229000	31.2	292000
19.9	127000	23.7	175000	27.5	230000	31.3	294000
20	128000	23.8	177000	27.6	232000	31.4	296000
20.1	130000	23.9	178000	27.7	233000	31.5	298000
20.2	131000	24	180000	27.8	235000	31.6	300000
20.3	132000	24.1	181000	27.9	236000	31.7	302000
20.4	133000	24.2	182000	28	238000	31.8	304000
20.5	134000	24.3	184000	28.1	239000	31.9	306000
20.6	136000	24.4	185000	28.2	241000	32	308000
20.7	137000	24.5	186000	28.3	242000	32.1	310000
20.8	138000	24.6	188000	28.4	244000	32.2	312000
20.9	139000	24.7	189000	28.5	246000	32.3	314000
21	141000	24.8	191000	28.6	247000	32.4	316000
21.1	142000	24.9	192000	28.7	249000	32.5	318000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
32.6	320000	36.1	400000	39.6	495000	43.1	602000
32.7	322000	36.2	403000	39.7	498000	43.2	606000
32.8	325000	36.3	405000	39.8	501000	43.3	609000
32.9	327000	36.4	408000	39.9	504000	43.4	612000
33	329000	36.5	410000	40	507000	43.5	615000
33.1	331000	36.6	413000	40.1	510000	43.6	619000
33.2	333000	36.7	415000	40.2	513000	43.7	622000
33.3	335000	36.8	418000	40.3	516000	43.8	625000
33.4	337000	36.9	420000	40.4	519000	43.9	628000
33.5	339000	37	423000	40.5	522000	44	632000
33.6	341000	37.1	426000	40.6	525000	44.1	635000
33.7	344000	37.2	428000	40.7	528000	44.2	638000
33.8	346000	37.3	431000	40.8	531000	44.3	642000
33.9	348000	37.4	434000	40.9	534000	44.4	645000
34	350000	37.5	437000	41	537000	44.5	648000
34.1	352000	37.6	439000	41.1	540000	44.6	652000
34.2	355000	37.7	442000	41.2	543000	44.7	655000
34.3	357000	37.8	445000	41.3	546000	44.8	659000
34.4	359000	37.9	447000	41.4	549000	44.9	662000
34.5	362000	38	450000	41.5	552000	45	665000
34.6	364000	38.1	453000	41.6	555000	45.1	669000
34.7	366000	38.2	456000	41.7	558000	45.2	672000
34.8	369000	38.3	458000	41.8	561000	45.3	676000
34.9	371000	38.4	461000	41.9	564000	45.4	679000
35	373000	38.5	464000	42	567000	45.5	683000
35.1	376000	38.6	467000	42.1	571000	45.6	686000
35.2	378000	38.7	470000	42.2	574000	45.7	690000
35.3	381000	38.8	472000	42.3	577000	45.8	693000
35.4	383000	38.9	475000	42.4	580000	45.9	696000
35.5	385000	39	478000	42.5	583000	46	700000
35.6	388000	39.1	481000	42.6	586000		
35.7	390000	39.2	484000	42.7	589000		
35.8	393000	39.3	487000	42.8	593000		
35.9	395000	39.4	489000	42.9	596000		
36	398000	39.5	492000	43	599000		

Trenton Rating Table

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
7.15	1000	10.8	17900	14.5	54700	18.2	106000
7.2	1090	10.9	18700	14.6	55900	18.3	108000
7.3	1290	11	19500	14.7	57100	18.4	110000
7.4	1510	11.1	20300	14.8	58400	18.5	111000
7.5	1750	11.2	21100	14.9	59600	18.6	113000
7.6	1990	11.3	21900	15	60900	18.7	114000
7.7	2240	11.4	22800	15.1	62100	18.8	116000
7.8	2510	11.5	23700	15.2	63400	18.9	118000
7.9	2800	11.6	24600	15.3	64700	19	119000
8	3100	11.7	25500	15.4	65900	19.1	121000
8.1	3410	11.8	26400	15.5	67200	19.2	123000
8.2	3730	11.9	27300	15.6	68500	19.3	124000
8.3	4080	12	28300	15.7	69900	19.4	126000
8.4	4450	12.1	29200	15.8	71200	19.5	128000
8.5	4830	12.2	30100	15.9	72500	19.6	130000
8.6	5230	12.3	31100	16	73900	19.7	131000
8.7	5610	12.4	32000	16.1	75200	19.8	133000
8.8	6040	12.5	33000	16.2	76600	19.9	135000
8.9	6490	12.6	33900	16.3	78000	20	137000
9	6950	12.7	34900	16.4	79400	20.1	138000
9.1	7430	12.8	35900	16.5	80800	20.2	140000
9.2	7930	12.9	36900	16.6	82200	20.3	142000
9.3	8450	13	37900	16.7	83600	20.4	144000
9.4	8980	13.1	38900	16.8	85100	20.5	146000
9.5	9530	13.2	40000	16.9	86500	20.6	148000
9.6	10100	13.3	41000	17	88000	20.7	149000
9.7	10700	13.4	42100	17.1	89500	20.8	151000
9.8	11300	13.5	43200	17.2	90900	20.9	153000
9.9	11900	13.6	44300	17.3	92400	21	155000
10	12500	13.7	45400	17.4	93900	21.1	157000
10.1	13200	13.8	46500	17.5	95400	21.2	159000
10.2	13900	13.9	47600	17.6	97000	21.3	160000
10.3	14600	14	48800	17.7	98500	21.4	162000
10.4	15300	14.1	49900	17.8	100000	21.5	164000
10.5	16000	14.2	51100	17.9	102000	21.6	166000
10.6	16600	14.3	52300	18	103000	21.7	168000
10.7	17100	14.4	53500	18.1	105000	21.8	170000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
21.9	172000	25.7	250000	29.5	344000	33.3	458000
22	173000	25.8	252000	29.6	346000	33.4	461000
22.1	175000	25.9	255000	29.7	349000	33.5	464000
22.2	177000	26	257000	29.8	352000	33.6	467000
22.3	179000	26.1	259000	29.9	355000	33.7	470000
22.4	181000	26.2	261000	30	358000	33.8	474000
22.5	183000	26.3	264000	30.1	361000	33.9	477000
22.6	185000	26.4	266000	30.2	363000	34	480000
22.7	187000	26.5	268000	30.3	366000	34.1	484000
22.8	189000	26.6	270000	30.4	369000	34.2	487000
22.9	191000	26.7	273000	30.5	372000	34.3	490000
23	193000	26.8	275000	30.6	375000	34.4	493000
23.1	195000	26.9	277000	30.7	378000	34.5	497000
23.2	197000	27	280000	30.8	381000	34.6	500000
23.3	199000	27.1	282000	30.9	384000	34.7	503000
23.4	201000	27.2	285000	31	387000	34.8	507000
23.5	203000	27.3	287000	31.1	390000	34.9	510000
23.6	205000	27.4	289000	31.2	393000	35	514000
23.7	207000	27.5	292000	31.3	396000	35.1	517000
23.8	209000	27.6	294000	31.4	399000	35.2	520000
23.9	211000	27.7	297000	31.5	402000	35.3	524000
24	213000	27.8	299000	31.6	405000	35.4	527000
24.1	215000	27.9	302000	31.7	408000	35.5	531000
24.2	218000	28	304000	31.8	411000	35.6	534000
24.3	220000	28.1	307000	31.9	414000	35.7	538000
24.4	222000	28.2	309000	32	417000	35.8	541000
24.5	224000	28.3	312000	32.1	420000	35.9	544000
24.6	226000	28.4	314000	32.2	423000	36	548000
24.7	228000	28.5	317000	32.3	426000	36.1	551000
24.8	230000	28.6	319000	32.4	429000	36.2	555000
24.9	232000	28.7	322000	32.5	432000	36.3	558000
25	235000	28.8	325000	32.6	435000	36.4	562000
25.1	237000	28.9	327000	32.7	439000	36.5	566000
25.2	239000	29	330000	32.8	442000	36.6	569000
25.3	241000	29.1	332000	32.9	445000	36.7	573000
25.4	243000	29.2	335000	33	448000	36.8	576000
25.5	246000	29.3	338000	33.1	451000	36.9	580000
25.6	248000	29.4	341000	33.2	454000	37	583000

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
37.1	587000	39.4	673000	41.7	764000	44	861000
37.2	591000	39.5	677000	41.8	768000	44.1	865000
37.3	594000	39.6	680000	41.9	772000	44.2	870000
37.4	598000	39.7	684000	42	776000	44.3	874000
37.5	601000	39.8	688000	42.1	780000	44.4	878000
37.6	605000	39.9	692000	42.2	785000	44.5	883000
37.7	609000	40	696000	42.3	789000	44.6	887000
37.8	612000	40.1	700000	42.4	793000	44.7	891000
37.9	616000	40.2	704000	42.5	797000	44.8	896000
38	620000	40.3	708000	42.6	801000	44.9	900000
38.1	624000	40.4	712000	42.7	805000	45	905000
38.2	627000	40.5	716000	42.8	810000	45.1	909000
38.3	631000	40.6	720000	42.9	814000	45.2	914000
38.4	635000	40.7	724000	43	818000	45.3	918000
38.5	639000	40.8	728000	43.1	822000	45.4	923000
38.6	642000	40.9	732000	43.2	827000	45.5	927000
38.7	646000	41	736000	43.3	831000	45.6	931000
38.8	650000	41.1	740000	43.4	835000	45.7	936000
38.9	654000	41.2	744000	43.5	839000	45.8	940000
39	657000	41.3	748000	43.6	844000	45.9	945000
39.1	661000	41.4	752000	43.7	848000	46	950000
39.2	665000	41.5	756000	43.8	852000		
39.3	669000	41.6	760000	43.9	857000		

B.3 Reaches and Routing Parameters (alphabetic listing)

Reach Name	Routing	Parameters
Allentown to Lehigh+Jordan	Null	
Barryville to Del+Lackawaxen	Null	
Beltzville_OUT to Parryville	Null	
Belvidere to Easton	Muskingum	3, 0.1, 1
Bethlehem to Del+Lehigh	Muskingum	2, 0.1, 1
Bloomsbury to Del+Musconetcong	Muskingum	2, 0.1, 1
Bridgeville to Godeffroy	Muskingum	6, 0.1, 2
Callicoon to Barryville	Lag & K	L=3
Cannonsville_OUT to Stilesville	Null	
Cooks Falls to Del_EB+Beaver Kill	Lag & K	L=3
Del+Brodhead to Belvidere	Muskingum	5, 0.3, 1
Del+Bush Kill to Tocks Island	Muskingum	3, 0.3, 1
Del+Lackawaxen to Del+Mongaup	Lag & K	L=2
Del+Lehigh to Del+Pohatcong	Muskingum	1, 0.1, 1
Del+Mongaup to Port Jervis	Null	
Del+Musconetcong to Frenchtown	Muskingum	2, 0.1, 1
Del+Neversink to Montague	Lag & K	L=3
Del+Pohatcong to Riegelsville	Null	
Del+Tohickon to Stockton	Null	
Del_EB+Beaver Kill to Fishs Eddy	Null	
Downsville to Harvard	Muskingum	4, 0.4, 4
Easton to Del+Lehigh	Null	
F.E. Walter_OUT to White Haven	Null	
Fishs Eddy to Hancock	Null	
Frenchtown to Del+Tohickon	Muskingum	2, 0.1, 1
Godeffroy to Del+Neversink	Lag & K	L=1
Hale Eddy to Hancock	Null	
Hancock to Callicoon	Lag & K	L=3
Harvard to Del_EB+Beaver Kill	Null	
Hawley to Lack+Wallenpaupack	Null	
Honesdale to Lack_WB+Dyberry	Null	
Jadwin_OUT to Honesdale	Null	
Lack+Wallenpaupack to Del+Lackawaxen	Lag & K	L=3
Lack_WB+Dyberry to Hawley	Lag & K	L=6
Lake Wallenpaupack_OUT to Lack+Wallenpaupack	Null	
Lehigh+Jordan to Bethlehem	Lag & K	L=1
Lehigh+Pohopoco to Walnutport	Lag & K	L=3
Lehighton to Lehigh+Pohopoco	Null	
Merrill Creek_OUT to Pohat+Merrill	Lag & K	L=1
Minisink Hills to Del+Brodhead	Null	
Mongaup+Black Lake Cr to Rio_IN	Muskingum	1, 0.1, 1
Montague to Del+Bush Kill	Muskingum	5, 0.3, 1
Neversink Gage to Bridgeville	Lag & K	L=3
Neversink_OUT to Neversink Gage	Null	

Reach Name	Routing	Parameters
New Hope to Washingtons Crossing	Null	
Nockamixon_OUT to Del+Tohickon	Muskingum	2, 0.1, 1
Parryville to Pohopoco Mouth	Null	
Pepacton_OUT to Downsville	Null	
Pohat+Merrill to Del+Pohatcong	Muskingum	2, 0.1, 1
Pohopoco Mouth to Lehigh+Pohopoco	Null	
Port Jervis to Del+Neversink	Null	
Prompton Gage to Lack_WB+Dyberry	Null	
Prompton_OUT to Prompton Gage	Null	
Riegelsville to Del+Musconetcong	Null	
Rio_OUT to Del+Mongaup	Null	
Shoemakers to Del+Bush Kill	Null	
Stilesville to Hale Eddy	Lag & K	L=0, K...0-300:6.0;300-999999:3.0
Stockton to New Hope	Muskingum	2, 0.1, 1
Swinging Bridge_OUT to Mongaup+Black Lake Cr	Null	
Tocks Island to Del+Brodhead	Null	
Toronto_OUT to Mongaup+Black Lake Cr	Muskingum	1, 0.1, 1
Walnutport to Lehigh+Jordan	Lag & K	L=5
Washingtons Crossing to Trenton	Muskingum	3, 0.1, 1
White Haven to Lehighton	Lag & K	L=6