Flood Warning Improvement Recommendations for the Delaware River Basin
Year 1 Report
Implementation Priorities for Delaware River Basin Flood Task Force Action Plan Recommendations FW-1.1, FW-2, and FW-7.2

Prepared by NOAA/National Weather Service – Eastern Division
In Cooperation With
The United States Geological Survey
And the
Delaware River Basin Commission

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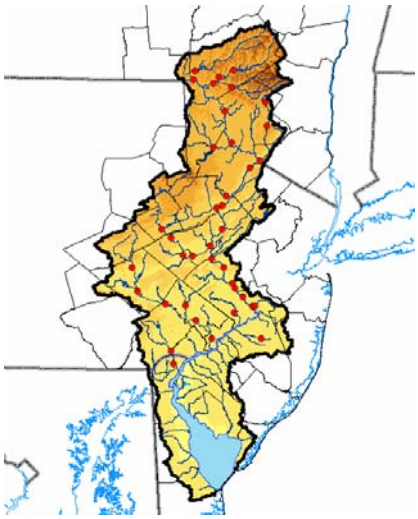

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Executive Summary

This report recommends a set of actions for improving river flood forecasts and warnings in the Delaware River Basin. The report presents the results of work to address Recommendations FW-1.1, FW-2, and FW-7.2 of the Interstate Flood Mitigation Task Force Action Plan developed in response to three devastating flood events along the main stem Delaware River between September 2004 and July 2006. The three Task Force recommendations focused on updating precipitation and stream gage inventories, evaluating the basin's river flood warning network, and recommending steps to address deficiencies and improve flood warning services. This report summarizes the updated gage inventories and lists a series of specific steps necessary for improvement of the gage network and expansion of flood forecasting services.

The project was completed under direction of National Oceanic and Atmospheric Administration (NOAA)'s National Weather Service (NWS) – Eastern Region Headquarters, Hydrologic Services Division, and the report was written through NOAA contract support to the Eastern Region Headquarters. The updated precipitation gage inventories and flood warning network evaluations were completed by the Middle Atlantic River Forecast Center at State College, PA, and the Weather Forecast Offices at Binghamton, NY and Mt. Holly, NJ, and coordinated through the support contractors. The updated stream gage inventory was completed by support contractors and coordinated with the U.S. Geological Survey Water Science Centers in Delaware/Maryland, New Jersey, New York, and Pennsylvania. The Delaware River Basin Commission (DRBC) provided all GIS files and converted inventory spreadsheets to GIS form. The commission also provided the files from their previous gage inventory work as a starting point for updating.

The report provides background information on the NWS's role in flood warning and summarizes activities of the DRBC's Flood Advisory Committee and the Interstate Flood Mitigation Task Force related to flood warning. The current status of the precipitation, snow monitoring, and stream gage network is presented along with the status of the basin's flood forecast points. Recommendations are then made for addressing deficiencies in precipitation gaging, stream gaging and improvement of flood forecasting services. The appendices included with the report provide maps with the locations of precipitation and stream gages, snow monitoring sites, and flood forecast points. Maps showing general locations of all improvements related to specific gages or forecast points are included in Appendix D, along with a summary index of the improvements.

The 44 improvements/recommendations in this report are the result of the first year of work under a multi-year program to address the flood warning recommendations of the Interstate Flood Mitigation Task Force Report. The focus of this report is on river flood warning, which applies to the larger watersheds in the Delaware River Basin, where there are forecast points with generally six hours or more of lead time. Evaluations and recommendations for expanding flood forecast services for small streams and for improved flash flood warning will be addressed as funding is obtained for subsequent years of work.

It should be noted, that as this report was being written, several currently operating stream gages in the Delaware Basin were being threatened by budget shortfalls. This presents an especially challenging situation for sustaining the existing baseline network of river gages while

recommending improvements as noted in this report. A list of stream gages for which operation is classified by the USGS as threatened is provided in Table B-1

The maps and files developed for this report generally represent gage status and forecast services as of June 2009, or more current where possible. Changes in funding and equipment are on-going and inventories should be updated frequently to remain accurate. For this reason, this report recommends annual updating of precipitation, stream gage, and flood forecast point files in order to support accurate GIS mapping and evaluation.

Authorization, Funding Source and Participants

Authority for this work is provided under NOAA's programmatic responsibilities authorizing meteorological and hydrological forecasting services for the United States. This report was produced under contract to NOAA with funding provided by the U.S. Department of Commerce fiscal year 2008 budget, which contained an appropriation for the improvement of flood warning in the Delaware River Basin. The report addresses Recommendations FW-1.1, FW-2, and FW-7.2 of the Interstate Flood Mitigation Task Force Action Agenda completed in July of 2007. Additional task force recommendations continue to be addressed outside of the scope of this contract. The Interstate Flood Mitigation Task Force was coordinated by the Delaware River Basin Commission in response to three severe main stem floods between September 2004 and July 2006.

Participants in this work included the National Weather Service (NWS), the United States Geological Survey (USGS), and the Delaware River Basin Commission (DRBC). NWS participation included the Eastern Division Headquarters, Middle Atlantic River Forecast Center (MARFC), and the Weather Forecast Offices (WFO's) at Binghamton (BGM) and Philadelphia/Mount Holly (PHI). United States Geological Survey participants included the Maryland/Delaware, New Jersey, New York, and Pennsylvania Water Science Centers. Participation at the DRBC included the Water Management, Planning Implementation and Information Technology, and Communications branches. Inputs were also received through the DRBC Flood Advisory Committee, whose mission includes recommendations for improved flood warning in the Delaware River Basin.

Project Background

Importance of Flood Warning and the Data Collection Network

The purpose of flood warning is to maximize the lead time available for property owners, emergency personnel, and citizens in or near the flood plain so that actions can be taken to protect lives and property. Flood warning increases the time window for emergency communication, evacuation, road closures, and other actions. Benefit to cost ratios provided by flood warning systems have exceeded 10 to 1.

Advances in computing speed and digital information technology during recent years have provided new opportunities for improved flood warning products as well as faster and broader distribution of flood warning information. NOAA's Advanced Hydrologic Prediction Services (AHPS) has been developed around this technology in the Delaware River Basin and other river basins around the country. The three recent main stem floods have provided tests for the flood warning system and highlighted improvement needs.

Maintenance and improvement of the flood warning system requires the collection and transmission of accurate and reliable precipitation and streamflow data. The network of gages and telemetry is part of the infrastructure of the flood warning system and serves multiple purposes, because it also provides hydrologic information for water supply, recreation, ecological evaluation, and climate analysis. Funding for the operation and maintenance of gages is determined on an annual basis and is provided by federal, state, and local sources throughout the Delaware Basin. Potential loss of funding for stream gage operation is a frequent issue.

The National Weather Service Role in Flood Warning

NOAA's NWS is responsible for issuing flood warnings in the Delaware River Basin and throughout the United States. In preparing flood warnings, the Weather Service depends on a network of automated precipitation and stream gages, Doppler radar (NEXRAD), precipitation and temperature forecasts, snowpack monitoring, and soil moisture monitoring, as well as data from volunteer observers. The data collection is a cooperative effort. In addition to the NWS, precipitation monitoring and reporting is conducted by federal, state, and county agencies, as well as privately in the case of volunteer observers. Real time stream and stage gages automatically record data and are equipped with telemetry to provide this information primarily through satellite communications. The real time stream gage network is operated by the USGS, with many of the gages funded through agreements between the USGS and federal, state, or local cooperating agencies.

Historical and real-time precipitation and stream flow data are used to calibrate and run the hydrologic model used by the NWS to generate river flood forecasts. The forecasts for the Delaware River Basin are made and evaluated by the NWS's MARFC and then provided to the Basin's two WFO's: Binghamton, New York and Philadelphia\Mount Holly, New Jersey. The WFO's may modify the forecasts based on knowledge of local conditions prior to issue. River flood forecasts, which are the subject of the recommendations in this report, are made every six hours prior to and during flood events. Additional detail about the three types of flood warnings issued by the NWS namely: River Flood, Small Stream\Headwaters Flood, and Flash Flood, is provided in the section of this report entitled "NOAA/NWS Flood Warning Operations in the Delaware River Basin."

The Delaware River Basin Commission Flood Advisory Committee

The DRBC's Flood Advisory Committee (FAC) was formed in March of 2000. In its mission statement, the primary objective of the FAC is:

"…assessment, evaluation, and recommending improvements in the Basin's flood warning system…"

The FAC has provided a forum for coordination among organizations in the Delaware River Basin with flood warning as well as flood mitigation planning responsibilities. The list of member organizations includes:

- Delaware Department of Natural Resources and Environmental Control
- New Jersey Department of Environmental Protection
- New York Department of Environmental Conservation
- Pennsylvania Department of Environmental Protection
- New York City Department of Environmental Protection
- Delaware Emergency Management Agency
- New Jersey State Office of Emergency Management
- New York State Office of Emergency Management
- Pennsylvania State Emergency Management Agency
- Federal Emergency Management Agency
- U.S. Department of Agriculture Natural Resources Conservation Service
- U.S. Geological Survey

- National Weather Service
- U.S. Army Corps of Engineers
- National Park Service
- Delaware River Joint Toll Bridge Commission
- Hydroelectric Industry
- One Municipal or County Emergency Representatives from Each Basin State

The FAC meets quarterly in public sessions at the DRBC's headquarters in West Trenton, New Jersey.

The 2002 Flood Warning Recommendations Report

In 2002, the DRBC, with the guidance of the FAC, developed a set of flood warning recommendations which were compiled in a report entitled: "Recommendations to address Flood Warning Deficiencies in the Delaware River Basin." The recommendations addressed specific monitoring deficiencies and as well as more general improvements to the overall flood warning system.

The first set of recommendations in the 2002 report (S-1 through S-8) addressed: "… known equipment deficiencies in the current day to day operations of the basin-wide river flood warning network." These recommendations included such measures as installation new precipitation gages, equipping existing stream gages with satellite telemetry, re-establishment of discontinued gages, and development of E-19 flood impact statements at potential flood forecast points.

The second set of recommendations (G-1 thru G-6), focused on inventory, evaluation, and modernization to take advantage of improved technology. These recommendations included inventory and evaluation of the Basin's precipitation and stream gage networks, evaluation of flood forecast points, establishment of a coordinated flood warning education and outreach program, improved headwaters flood warning using GIS and NEXRAD Radar, prototype flood inundation mapping at flood forecast points, extension of stream gage rating curves, and expanded snowpack monitoring.

The 2002 Flood Warning Recommendations Report provided a reference for the Interstate Flood Mitigation Task Force in developing its 2007 Action Agenda. In addition, the inventory and evaluation work performed for this current project was initially recommended in the 2002 report.

Interstate Flood Mitigation Task Force and Action Agenda

The Interstate Flood Mitigation Task Force was coordinated by the DRBC at the request of the four basin state governors in response to three severe main stem floods that occurred between September 2004 and July 2006. The floods produced the highest stages along the main stem Delaware River since the record flood of 1955 and caused hundreds of millions of dollars in damages. The Task Force produced an Action Agenda, completed in July of 2007, with a total of 45 recommendations grouped into six categories of flood loss reduction. The six categories in included:

- Reservoir Operations
- Structural and Non-Structural Measures
- Stormwater Management

- Floodplain Mapping
- Floodplain Regulation
- Flood Warning

Subcommittees were formed to draft recommendations for each of the six categories. The recommendations were finalized by the full Task Force and approved by the DRBC after a series of three public briefings.

A total of 14 recommendations were developed within the flood warning category. Some of the recommendations have multiple components. The recommendations include:

FW-1: Inventory and Evaluate Precipitation Observing Stations in the Basin (Consists of two components, FW-1.1 and FW-1.2)
FW-2: Evaluate River Gage Network
FW-3: Extend Rating Tables
FW-4: Flood Harden Gages at Key Forecast Locations
FW-5: Improve Flash Flood Forecasting
FW-6: Develop an Implementation Plan for the NWS Site Specific Model
FW-7: Evaluate River Forecast Points (Two Components; FW-7.1 and FW-7.2)
FW-8: Provide River Forecasts with Confidence Level Information
FW-9: Develop Flood Forecast Inundation Maps
FW-10: Maintain Up-to-Date High Hazard Dam Emergency Action Plan (EAP) Documents
FW-11: Establish a Coordinated Flood Warning Education and Outreach Program
FW-12: Develop a Flood Coordination Mechanism
FW-13: Ice Jam Monitoring and Communications Plan
FW-14: Coastal Flooding Impacts

The details on each of these recommendations, including description of multiple components, and the lead organizations responsible for implementation are provided in the Action Plan, which is available on the DRBC web site at:
http://www.state.nj.us/drbc/FloodWebsite/taskforce/index.htm

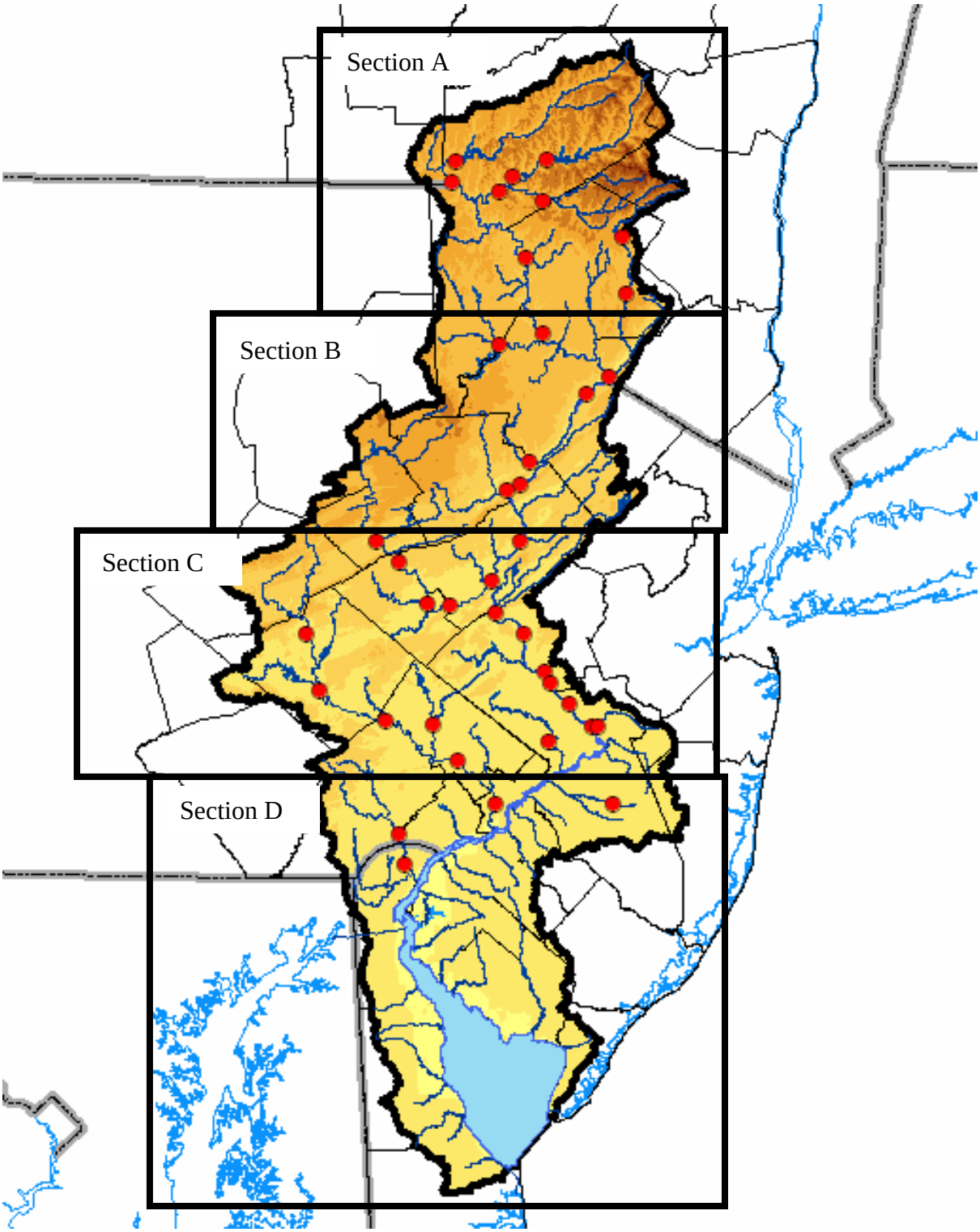
The experience of the three main stem floods demonstrated the continuing need for accurate and reliable river flood warning information in the Delaware River Basin and identified improvement needs such as gage hardening, rating curve extension, and the need for higher internet network capacity during flood events. The subsequent comprehensive review and recommendations by the Interstate Flood Mitigation Task Force and the adoption by the DRBC of the Action Agenda reinforced support for continued improvement of the flood warning system.

2008 Federal Appropriation and First Year Implementation
The U.S. Department of Commerce fiscal year 2008 budget contained an appropriation specifically directed toward flood warning improvements in the basin. Interstate Flood Mitigation Task Force Action Plan flood warning recommendations being addressed under this 2008 appropriation include FW-1, FW-2, FW-7, FW-4, FW-9, and FW-11. Work on recommendation FW-9 (flood inundation mapping) was conducted by the NWS and U.S. Army Corps of Engineers (USACOE) in 2008 and 2009 and is nearing completion. Work by the USGS on recommendations FW-4 (stream gage hardening) and FW-3 (extension of stream gage

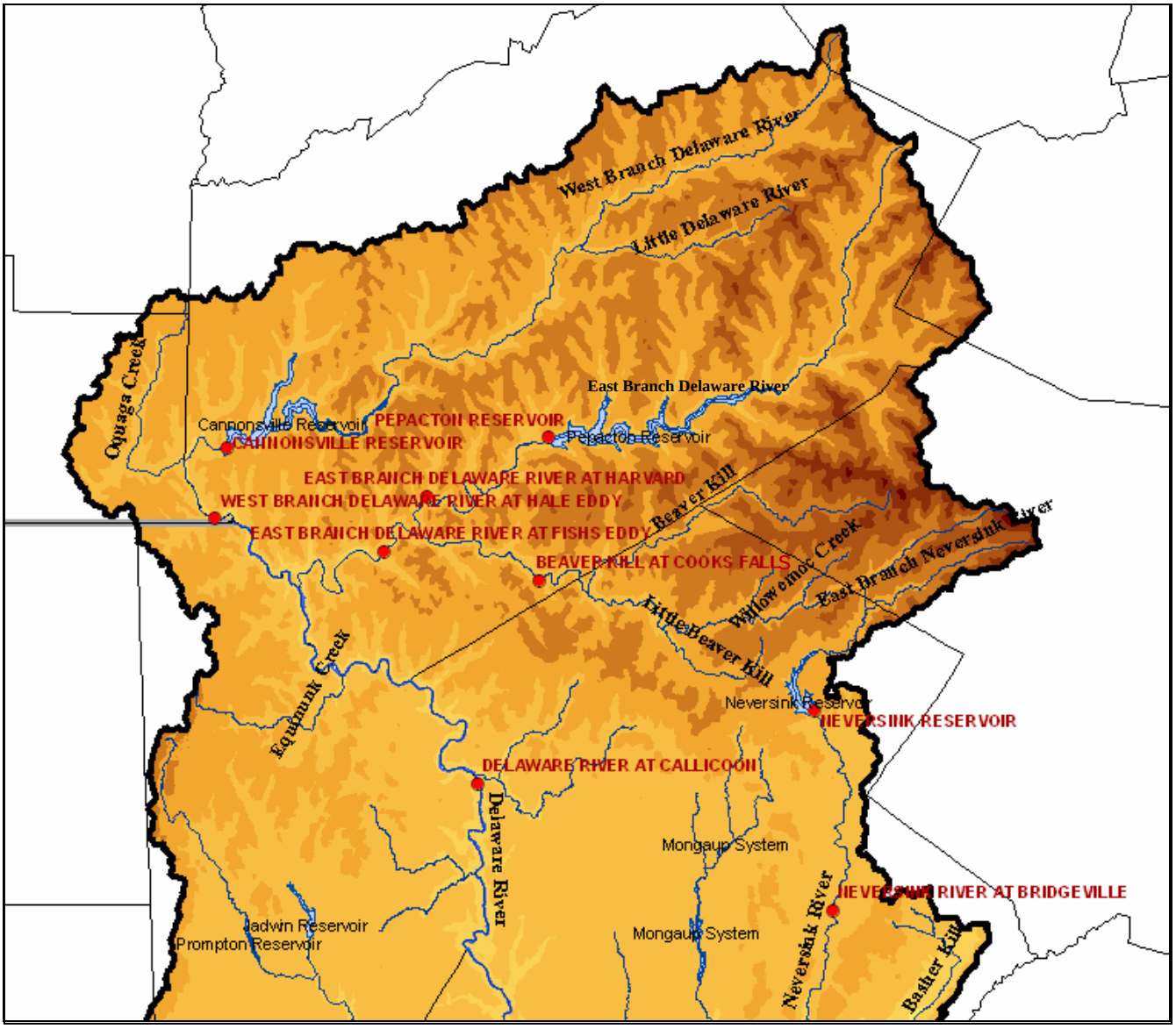
ratings) began in 2008 and is ongoing as of September 2009, with additional funding required for completion. The objective of this report is to address recommendations FW-1.1, FW-2, and FW-7.2.

Delaware River Basin Reference Map

Enlargements of the index map sections below are provided on pages 10-13. The maps show the basin's larger streams and existing river flood forecast points as of June 2009.



Section A
Major Streams and River Flood Forecast Points



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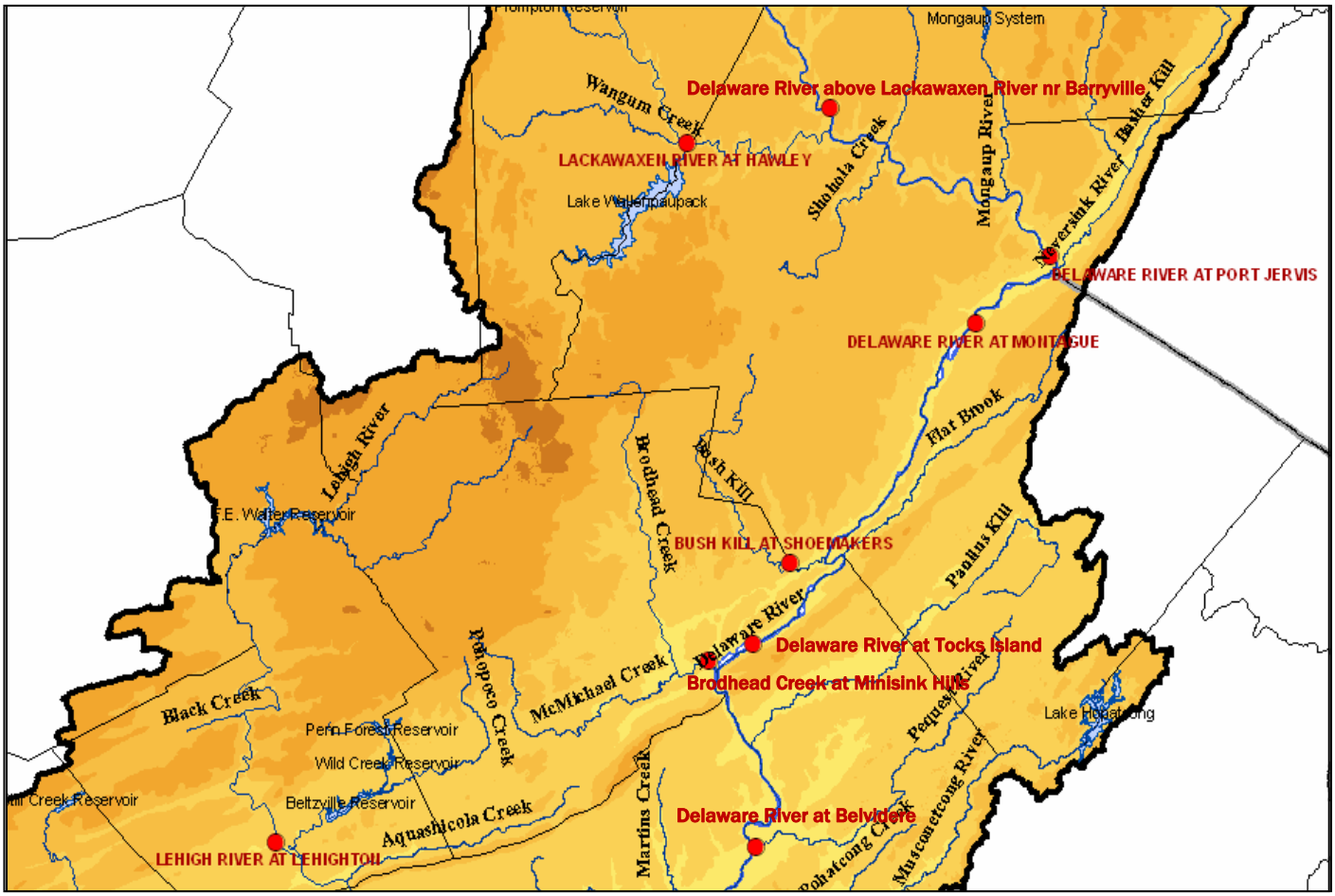
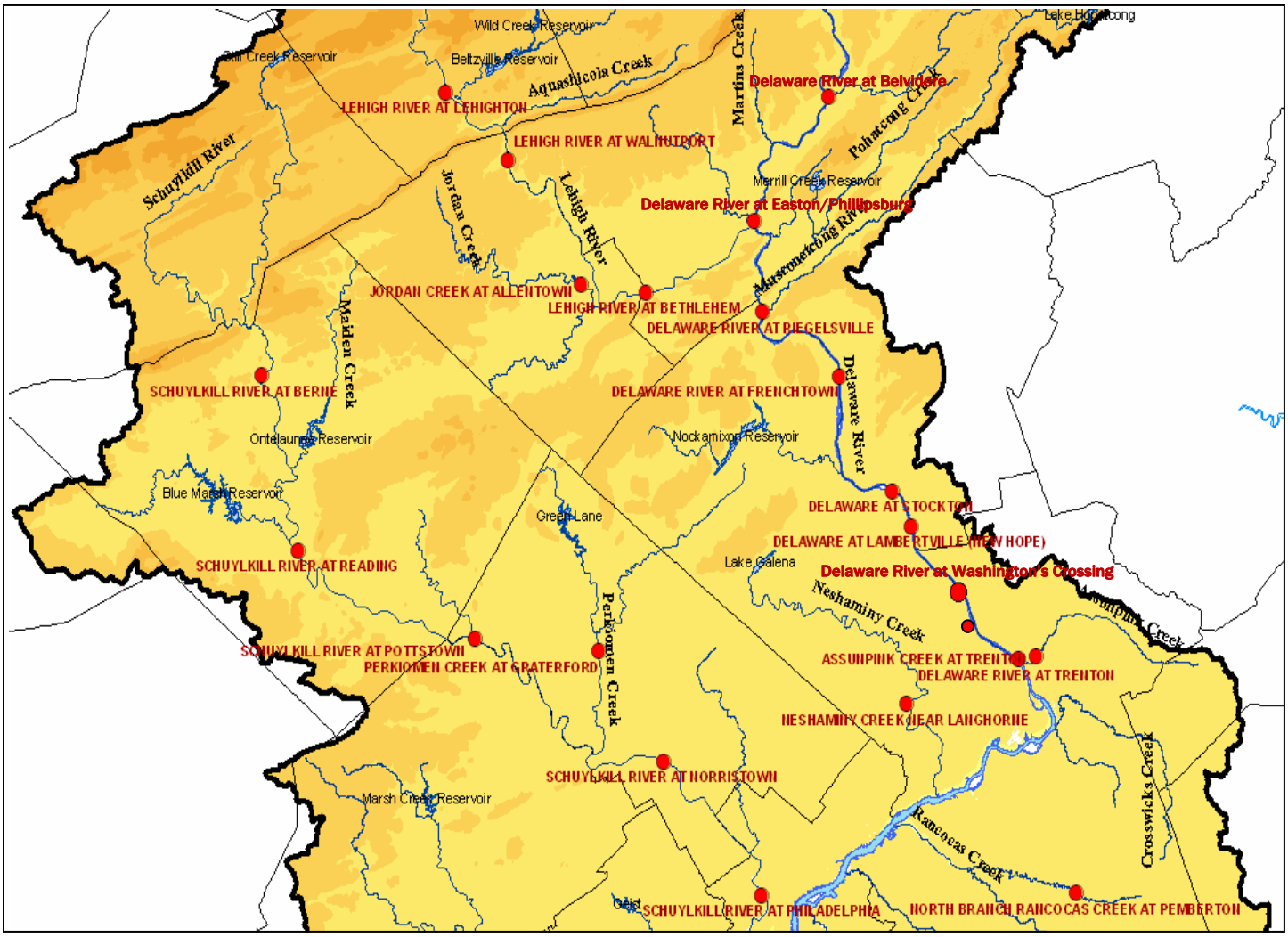
Major Streams and River Flood Forecast Points

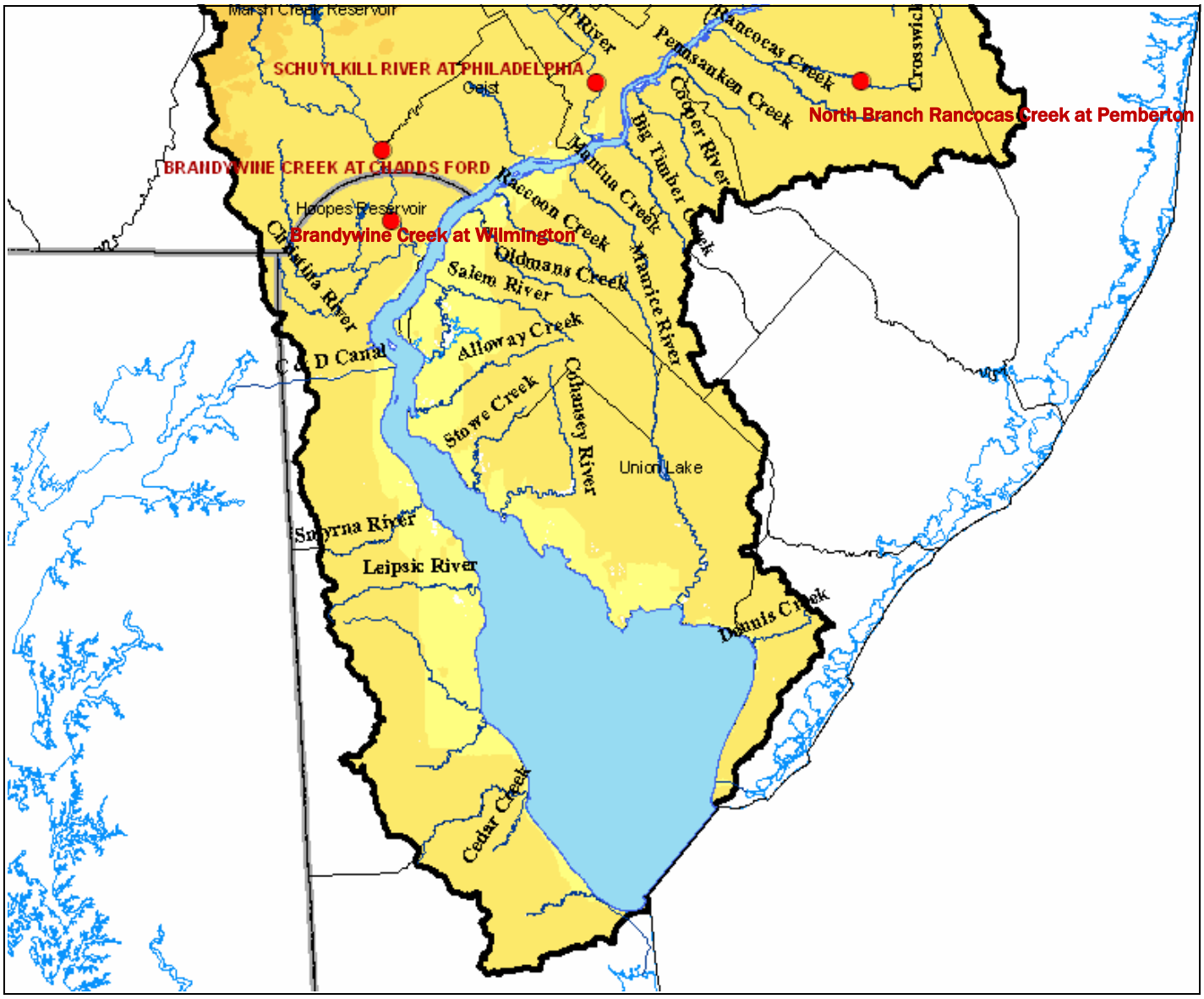


Section C
Major Streams and River Flood Forecast Points



Note: The Delaware River at Washington's Crossing, NJ/PA will not be equipped with real time stage monitoring until completion of bridge construction work in 2010. The site is included on this map because it currently serves as a flood forecast point. Flood stages are forecast by the MARFC using a stage vs. stage rating referenced to the real time gage for the Delaware River at Trenton, NJ, and manual wire weight gage measurements conducted by the Delaware River Joint Toll Bridge Commission.

Section D
Major Streams and River Flood Forecast Points



Work Description

This project addresses recommendations FW-1.1, FW-2, and FW-7.2 of the Interstate Flood Mitigation Task Force Action Agenda.

It is important to note that FY08 funding covers only the inventory and evaluation of precipitation gages used by the NWS in its forecast modeling. The results of that evaluation are included in this report. Gages outside of the NWS network have yet to be inventoried. This would require additional future funding resources and would be included in the evaluation of non-NWS precipitation gages specified in Recommendation FW-1.2.

It should also be noted that FY08 funding includes an evaluation and prioritization for the establishment of new or expanded river forecasts in the Delaware River Basin (Recommendation 7.2). It does not cover improvements in Flash Flood Forecasting (Recommendation FW-5), or site-specific forecasts for small rivers/streams and headwater points (Recommendation FW-6). These would require additional future funding resources.

The three recommendations addressed in this report, which are provided in the Interstate Flood Mitigation Task Force Action Agenda, are listed below.

FW-1.1
Recommendation FW-1.1 is to develop of a comprehensive inventory of precipitation observing station (automated and spotters) gages in the Delaware River Basin. The purpose of this inventory is to provide the information necessary to evaluate the existing precipitation network, maximize it for flood forecasting and identify areas for improvement. As noted previously, this report covers only the inventory and evaluation of precipitation gages used by the NWS in forecast modeling.

FW-2
The existing river gage network in the basin should be evaluated for locations and telemetry deficiencies (e.g. backup communications, reporting - frequency 4 hr to 1 hr, and rating curves). Evaluate the deficiencies and develop an implementation plan for upgrades based on flood forecasting requirements and user input.

FW-7.2
Evaluate and prioritize needs for establishment of new forecast points in basin. Determine need for upgrading existing stream gages or adding new gages.

Deliverables
The deliverables for the project include the following:

- GIS layers and attribute tables for stream gages, precipitation gages, flood forecast points, political and watershed boundaries, elevation, and flood insurance claims.
- Spreadsheet files for precipitation, snowpack monitoring, and stream gage inventories.

- A report containing:
  a) The gage inventory and gap analysis for the precipitation and stream gage sites, including an evaluation of Integrated Flood Observing and Warning System (IFLOWS) gages in the precipitation network.
  b) Priorities for filling the gaps or adding new gages.
  c) An inventory of existing river flood forecast sites and proposed new forecast sites indicating priorities for implementation.

NOAA/NWS Flood Warning Operations in the Delaware River Basin

The NWS issues three general categories of flood warning products in the Delaware River Basin. These include river flood warning, small stream/headwater flood warning, and flash flood warning. Although this report focuses on recommendations to improve river flood warning, a summary of each of the three categories is provided here to provide context.

River flood warnings are issued for stream gages along the basin's larger rivers and streams. The river forecasts are prepared at selected stream gage locations by the MARFC and flood warnings are issued if necessary by the two WFO's BGM and PHI.

Small stream/headwater forecasts (also referred to in this report as Site-Specific flood forecasts) are prepared for stream gage locations in smaller watersheds which respond more quickly to rainfall. These forecasts are issued by WFOs BGM and PHI using guidance developed by the MARFC. Detailed analysis of small stream forecasting using site-specific models will be covered by Recommendation FW-6 of the Interstate Flood Mitigation Task Force Report.

Flash flood warnings are different from river and headwaters flood warning in that they are issued over local or county-wide areas for generalized flood conditions rather than specific stage forecasts for a particular location. Detailed analysis of flash flood warning in the basin will be covered under Recommendation FW-5 of the Interstate Flood Mitigation Task Force Report.

River Flood Warning

In the Delaware River Basin, river forecasts are issued at stream gage locations along the main stem Delaware River and larger tributaries. River forecast points are established based on factors including potential risk to life and property, availability of historic flow record and existing or potential availability of real time data, hydrologic response time, flood frequency, and drainage area size. River forecasts for the Delaware River Basin are prepared by the MARFC located in State College, PA. The forecasts generated by the MARFC use a six hour time-step rainfall/runoff model, and contain stage and /or flow forecasts for specific locations based on existing and forecast hydrometeorologic conditions. The model runs and subsequent forecasts are updated as needed every six hours to account for changes in observed flow conditions, forecast precipitation, and accumulated rainfall. The forecasts are issued to the Weather Forecasts Offices (WFO's) in Binghamton, NY (BGM) and Mt. Holly, NJ (PHI). The two WFOs use the contents of the river forecasts to prepare Flood Warnings (FLW), Flood Statements (FLS), River Statements (RVS), as well as other products available to the public. River forecast points are classified as crest-only, flood-only, and daily points. For the crest-only points, only the peak flood crest stage is forecast. For flood-only locations, flood hydrographs with six hour time steps are provided only during flood events or high water conditions. For daily locations, flow and stage forecasts are prepared routinely during both flood and non-flood conditions and updated as often as every six hours when needed. Details on the current river flood forecast points in the Delaware River Basin are provided in the subsequent section of this report entitled "Inventory of Existing Gages and River Flood Forecast Points."

Small Stream/Headwater Flood Warning – Site Specific

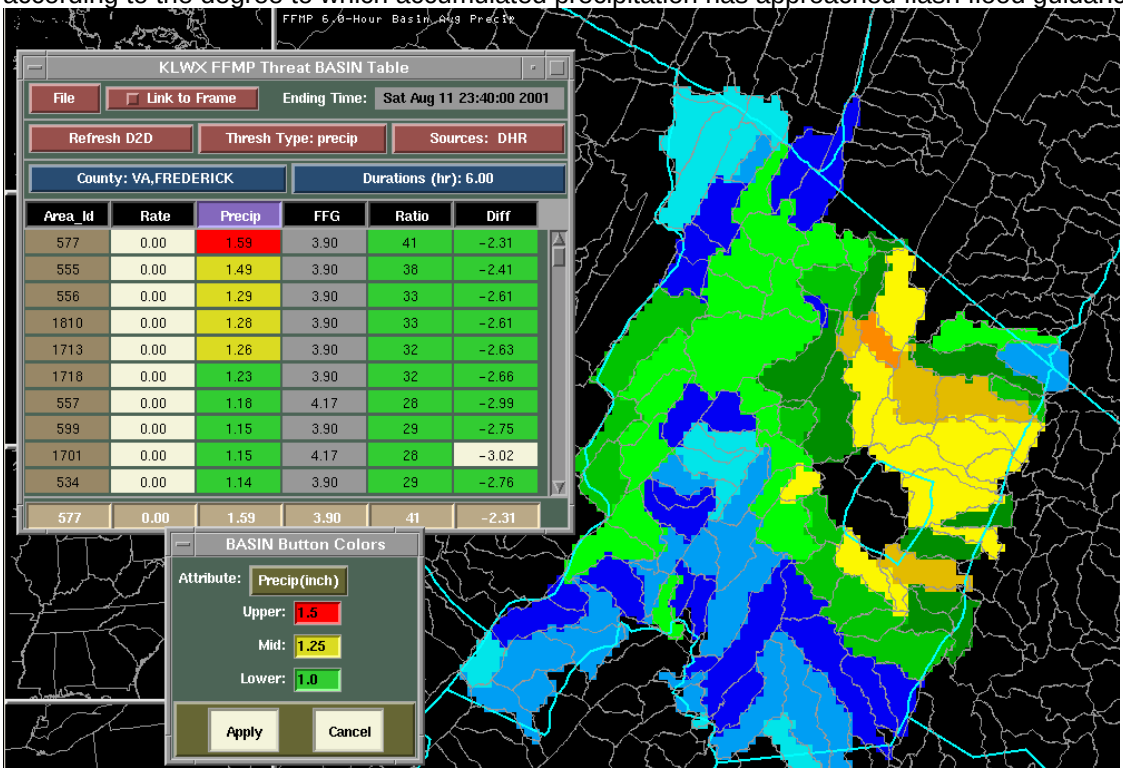
Small stream/headwater flood forecasts are generally issued by WFOs for specific locations along smaller streams with hydrologic response times of less than six hours. Since the 6-hour time step used by the River Forecast Center model is too long to be effective for these fast-responding streams, flood forecasts for these locations are not made by the MARFC using that model, but are generated at the WFO's BGM and PHI using a method developed for faster responding streams. The site-specific application, known as the Site Specific Hydrologic Prediction System (SSHP) has been developed by the NWS. The SSHP uses a 1-hour time step for its model computations. The current SSHP application for sites in the Delaware Basin relies on the antecedent precipitation index model developed by MARFC and operated within the NWS Advanced Weather Interactive Processing System (AWIPS) as well as on Crest Stage relationships for other nearby gages if available. High resolution gridded flash flood guidance and 1-hr. unit hydrographs are used to generate site-specific flood forecasts. The locations of existing site-specific forecast points are shown in the subsequent section of this report entitled "Inventory of Existing Gages and River Flood Forecast Points."

Flash Flood Warning

Flash flood warning is distinct from small stream/headwaters flood warning in that the flood warnings are not issued for a specific stream gage point, but are issued for areas such as counties or watersheds. Flash flood warnings are based on monitoring of antecedent moisture conditions and forecasted and accumulated rainfall. The Flash Flood Monitoring Program (FFMP) has been developed by the NWS as a means for the WFO's to quickly identify small watersheds where accumulated precipitation is approaching or exceeds that required to cause flash flood conditions.

The FFMP is an integrated suite of multi-sensor data to provide forecasters a tool that detects, analyzes, and monitors precipitation and generates short-term warning guidance for flash flooding automatically within AWIPS. The goal is to enable the WFOs to provide flash flood warning at the local level for small rapidly responding watersheds. FFMP uses high resolution GIS databases of small watersheds, gridded flash flood guidance from the MARFC, and NEXRAD radar rainfall estimates. FFMP ranks the probability of flash flooding for specific basins within a county to allow for specific warnings of flooding on small streams. As shown in Figure 1, the program's graphical user interface provides color coded tabulations, for each small watershed, of the degree to which precipitation has approached flash flood guidance values. The system enables the WFOs to better monitor developing conditions and issue flash flood warnings for smaller areas than was previously possible. A sample product is provided in Figure 1.

Figure 1: Sample Product of the Flash Flood Monitoring and Prediction Program
Display showing the 6 - hour accumulated precipitation for watersheds within a county in the state of Virginia. The Basin Tables are also shown. The basins on the map and the tables are color coded according to the degree to which accumulated precipitation has approached flash flood guidance values.



Reference: Filliaggi, M.T., Smith, S.B., Churma, M., Meteorological Development Laboratory, National Weather Service, Silver Spring, Maryland, Xin, L, SAIC, Silver Spring, Maryland, Glaudemans, M., Hydrologic Research Laboratory, National Weather Service, Silver Spring, Maryland, FLASH FLOOD MONITORING AND PREDICTION VERSION 2.0: CONTINUED AWIPS MODERNIZATION, http://www.nws.noaa.gov/mdl/pubs/Documents/Papers/FiliaggiFFMP2_0.pdf

Inventory of Existing Gages and River Flood Forecast Points

This section presents information on the existing gages and flood forecast points used by the NWS for flood forecasting activities in the Delaware River Basin. Because they are the basis for display of the flood warning network information, the GIS data layers assembled for the project are described in the initial subsection. After a summary of the development steps for each inventory, descriptions of the precipitation, snow monitoring, real time stream and flood warning point networks (as of June 2009) are provided. General location maps showing the distribution of gages and forecast points in the Delaware River Basin are included in Appendices A thru C.

GIS Data Layer Assembly

To provide a means of displaying and analyzing the flood warning network and associated gages, a set of GIS data layers was provided to the study contractors by the Delaware River Basin Commission. The study contractors provided the updated gage inventory files developed during the project to the DRBC for preparation of the GIS layers for the gage inventories. The GIS data layers include:

1) Real Time USGS Stream Gages and Flood Forecast Points. Sources: USGS, NWS
2) Precipitation Gages used by the NWS. Source: NWS
3) Snow depth monitoring gages and observation points. Sources: New York City Department of Environmental Protection (DEP), NWS, USACOE
4) Rivers and Streams (USGS National Hydrography Dataset). Source: USGS
5) Major Reservoirs. Source: DRBC
6) Watershed Boundaries (HUC11) and Delaware River Basin Boundary. Source: DRBC
7) National Elevation Dataset (30 Meter) Source: USGS
8) State, County and Local Political Boundaries. Source: DRBC
9) FEMA Flood Insurance Claims for Calendar Years 1978-2007: Source: Federal Emergency Management Agency (FEMA)

The updated precipitation, stream gage, and snow depth monitoring files, which were developed in spreadsheet form, were converted by the DRBC to GIS layers (shapefiles) which include all of the data fields for each gage inventory. These gage inventory layers, in combination with the other data layers provided by the DRBC, were used to prepare each of the maps in Appendices A thru C. All flood forecast points, both river and site-specific, were included as a sub-category within the real time stream gage inventory file and can be displayed with GIS mapping software using the stream gage GIS layer. Data fields for the precipitation, snow monitoring, and real time stream flow inventories are listed in the following subsections.

The GIS layers have application that extend beyond flood warning, due to the multiple uses of precipitation and stream gage information in water resources management. Although the maps presented in this report are at a general, basin-wide scale, the information can be displayed at the county or HUC 11 watershed level using GIS software. The GIS layers were developed with ESRI's ArcGIS and can be viewed with ArcMap Version 9.2 software. In order keep the information current, this report includes a recommendation (G1) for annual updating of the gage inventory files.

Precipitation Gage Network

Development of the Inventory

The original precipitation gage spreadsheet file was obtained from the DRBC based on previous inventory work. The data fields in the precipitation file were modified and the file was reviewed and updated by the MARFC, who coordinated with the WFO's (BGM and PHI). The file was modified to include those stations used by the NWS Field Offices in their forecasting operations. Precipitation gages outside of the NWS network are not included in the inventory. Data fields were included to indicate if snow depth or snowfall amount are measured at the gage site. A separate inventory was developed for snow monitoring and is discussed in the Snow Monitoring Points subsection.

Data fields included in the inventory are as follows:

- Station Name
- NOAA Handbook 5 ID Number
- State
- County
- Latitude
- Longitude
- Monitoring Program Name
- Elevation
- Transmission Interval
- Snowfall Monitoring Capability
- Snow Depth Monitoring Capability

Network Description

This section and Appendix A provide information on the current (June 2009) precipitation gages in the Delaware River Basin. Figure A-1 shows the distribution of the more than 300 gages, of which approximately half report rainfall on an hourly basis, and half report daily observations. The precipitation gages are operated under programs coordinated by federal, state and local cooperators. Several of the larger programs are listed below.

Automated Surface Observing Systems (ASOS)

These gages are operated under a joint effort of the NWS, the Federal Aviation Administration, and the Department of Defense. The ASOS system serves as the nation's primary surface weather observing network.. The ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities. ASOS uses a heated tipping-bucket to measure precipitation. The ASOS gages are in the process of being converted from heated tipping bucket to weighing bucket- PLUVIO gages ASOS precipitation accumulation reports are routinely generated hourly, and at 15-minute intervals when the precipitation accumulation exceeds local threshold values. There are 37 ASOS gages distributed throughout the Delaware River Basin. ASOS reports hourly and special observations via the Advanced Weather Interactive Processing System (AWIPS) networks. The gage locations are shown on Figure A-2.

Integrated Flood Observing and Warning System (IFLOWS)

IFLOWS is a cooperative venture between the NWS, states and counties for the purpose of reducing the annual loss of life from flash floods and reduce property damage. The network consists of automated self-reporting radio real-time precipitation and streamflow gages that provide data for flood and flash flood warnings. The gages can be located in remote or high elevation areas where observations are not readily available. To accomplish these goals IFLOWS uses communications technology and software to collect real time sensor data, and disseminate the data in real-time among government organizations responsible for public safety. The precipitation gages are primarily tipping bucket rain gages that report every .04 inch of rainfall. Communications of data over the network is normally by radio or satellite. Reports of data are received every 15 minutes which makes IFLOWS an excellent source of information for detecting flash floods. Of the 59 IFLOWS precipitation gages located within or near the Delaware River Basin, 28 are used by MARFC in river forecast operations. The locations of these gages are shown on Figure A-2. IFLOWS gages provide a significant portion of the high elevation precipitation data for the Pennsylvania and New Jersey portions of the Delaware basin, with an average elevation of 1420 ft.

Cooperative Observer Program (CO-OP)

The cooperative observer program is administered by the NWS and is implemented through a nation-wide network of volunteer observers who make daily reports of rainfall, snowfall, temperature, and river levels. The specific types of gages approved for measuring precipitation are: Non-recording: 1) Eight inch gage and 2) Four-inch plastic gage; Recording (Weighing Type): 1) Fischer & Porter gauge 2) Universal Gage. Co-op network observers that support the NWS river program normally report data each day to NWS offices. Some of these observers also report when specific criteria are met or exceeded (i.e. every 6 hours when heavy rain or flooding is forecasted or reported). Readings are taken at or near the cooperators home, or place of business. Many observers transmit their reports by touch-tone telephone to an NWS computer, and nearly all observers mail monthly reports to the National Climatic Data Center to be archived and published. The NWS provides training to the cooperators under the program. There are 38 cooperative observer stations used for the Delaware River Basin. The station locations are provided on Figure A-3.

Community Collaborative Rain, Hail, and Snow Network (COCORAHS)

COCORAHS is a non-profit, community-based network of volunteers working together to measure and map precipitation (rain, snow and hail). The network originated with the Colorado Climate Center at Colorado State University in 1998 due in part to a devastating flood that occurred in the previous year. Since then, the network has expanded rapidly with over 6,500+ observers in 26 states. There are 117 COCORAHS observers in the Delaware River Basin. Information is reported on a daily basis. The locations of the stations are shown on Figure A-3.

COCORAHS now has 46 states as part of its network, with a goal of reaching 20,000 observers by 2010.

In addition to the programs described above, gages are operated and the information reported to the NWS by several organizations. The number of gages reported in the Delaware Basin by each of these organizations as of September 2009 is listed below:

USGS	32 gages
USACOE – Philadelphia	7 gages
Delaware Earth Observing System (DEOS)	7 gages
New York City DEP	38 gages
Other Federal and State	17 gages

Figure A-4 shows the gages operated by the USGS, USACOE, State of Delaware, and New York City DEP.

Snow Monitoring Points

Development of the Inventory

A data field was included in the updated precipitation gage inventory file to indicate whether snow depth is monitored at precipitation gage sites. In addition, a separate inventory was created to include the snow monitoring sites surveyed in headwaters of the reservoirs owned by the USACOE and the New York City DEP. The location of these sites is shown on Figure A-4. The data fields in this inventory include the station name, latitude, longitude, operator, and monitoring frequency.

Network Description

The NWS monitors snow depth and water equivalent of snowpack in order to factor snowmelt into flood forecasts. Data is generally collected by the USACOE and NYCDEP on a bi-weekly schedule. In addition to on-the-ground monitoring, NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) conducts airborne surveys of snow water equivalent using gamma radiation remote sensing. The data are included in the National Snow Analysis, which provides graphic and tabular snow depth and water equivalent information on a daily basis. The NOHRSC incorporates the results of on-the-ground snow monitoring with the airborne survey data and hydrometeorological conditions to model snow water equivalent. The NOHRSC provides snow survey information on-line at:
http://www.nohrsc.nws.gov/.

Real Time Stream Gages

Development of the Inventory

The initial stream gage file was obtained from the DRBC based on previous inventory work by the staff in coordination with the four USGS Water Science Centers. The data fields were

modified by the study contractors, and incorporated data field recommendations provided by the DRBC and USGS. Only real time stream (stage and/or discharge) or lake level gages are included in the inventory. The data fields included in the updated inventory are as follows

- USGS Station Identification Number
- Station Name
- NOAA Handbook 5 ID Code
- State
- County
- Stream Name
- Latitude
- Longitude
- Gage Datum
- Datum Reference
- Drainage Area at Station
- Indication whether site is a Flood Forecast Point (Yes or No)
- Type of Flood Forecast Point (River or Site Specific)
- Flood Stage if known
- URL Address for Real Time Information from USGS
- URL for NOAA AHPS Real Time Information (If a flood forecast point)
- Type of Telemetry
- Type of Gage (Discharge or Stage)
- Reporting Interval (1-Hour, or 4-Hour)
- Period of Record
- Number of Years of Record
- Funding Source
- Comments

Using these data fields, a draft revised inventory was completed by the study support contractors and provided to each of the four USGS Water Science Centers for review. Each of the Water Science Centers provided additional information which was incorporated in the final inventory.

Network Description

This section and Appendix B provide information on the current (June 2009) real stream gages in the Delaware River Basin. The locations of real time stream flow gages, stage only stream gages, lake level gages, and auto-tide gages in the Delaware River Basin are shown on Figure B-1. All of the gages are operated by the USGS, with the exception of the lake level gages at the three New York City Delaware Basin Reservoirs (Cannonsville, Pepacton, and Neversink), which are operated by the New York City DEP. As of June 2009, the network consisted of 166 real time stream discharge gages, 10 lake level gages, 6 stage only stream gages, and 14 auto-tide gages. Note that the number of real time gages includes five gages for which funding was discontinued during 2009 as listed in Table B-1.

Real time stream and stage gages automatically record data and are equipped with telemetry to provide this information primarily through satellite communications. Data is generally collected

every 15 minutes and transmitted from the gaging station to a satellite at 1-hour, 3-hour, or 4-hour intervals. Once reported, the discharge and/or stage information is then available on-line via the real time streamflow information web site provided by the USGS: http://waterdata.usgs.gov/nwis/rt. Figure B-2 shows the reporting interval of the real time gages in the Delaware River Basin. As of September 2009, approximately 75 percent of the gages reported at 1-hour intervals. The representativeness of the flow statistics at a particular stream gage improves with increasing length of the flow record at the gage.

Many stream gages also have telephone communications which enables them to be polled for the current stage at more frequent intervals than once per hour. This capability is especially useful in flood forecasting for fast responding basins and is valuable as a backup to satellite communications systems. In the Delaware River Basin, approximately 50 percent of the real time gages and 70 percent of the flood forecast points, respectively, were equipped with telephones as of June 2009. Figure B-2 shows the location of these gages. The NYCDEP reported that As of 9/30/09, telephone service for twelve NYCDEP sponsored gages will be discontinued to reduce costs. This includes the West Branch Delaware River at Walton, NY, which is recommended as a new river flood forecast point in this report. The list also includes Dry Brook at Arkville, NY and the East Branch Delaware River at Margaretville, NY, which are both recommended by this report for establishing site-specific forecast points. The list of affected gages is included in Table B-2.

Figure B-3 classifies the Delaware River Basin stream gages based on the total number of years of record at a given site. As of June 2009, 54 of the basin's stream gages have accumulated 60 years or more of record.

Flood Forecast Points

Categories

There are two types of flood forecast points for which flood warnings are issued by the NWS in the Delaware Basin: official "River Forecast Points"; and "Site-Specific Forecast Points". These are discussed in the Section on NOAA/NWS Flood Warning operations in the Delaware River Basin. The River Forecast Points can be further classified as to type and frequency. "Daily River forecast points" are routinely issued on a daily basis during flood and non-flood conditions. "Flood Only" points are issued only when high-water or flooding is occurring or forecast to occur. "Crest Only" points are locations where only a flood peak river stage is issued during a flood event, not a forecast time-series.

Development of the Inventory

The real time stream gage file was developed to include data fields indicating whether a particular gage serves as a river or site-specific flood forecast point. The MARFC and WFO's BGM and PHI provided listings of all flood forecast points, which were subsequently designated in the stream gage file.

Network Description

As of June 2009, there are 39 river flood forecast points in the Delaware Basin. These include one "crest only" point, 17 "flood only" points, and 21 "daily" points. An example of a "crest only" point is the Delaware River at Easton/Phillipsburg, NJ. An example of a "flood only"

point is the Delaware River at Port Jervis, NY. An example of a “daily” point is the Delaware River at Trenton, NJ.

Figure C-1 shows the location of the three categories of river flood forecast points. In addition to the river forecast points, there are seven site-specific flood forecast points located on tributary streams in the lower half of the basin. Figures C-2 thru C-5 show the locations of the river and site-specific forecast points in the basin. Tables C-1 and C-2 provide USGS site numbers, name, state, county, and funding sources for the discharge and/or stage gage at each flood forecast point.

Evaluation and Recommendations

Coordination and Methodology

The updated precipitation, stream gage, and flood forecast point inventories for the Delaware River Basin were used to perform an evaluation of the river flood warning network.

The NWS Field Offices, (WFO's BGM and PHI and the MARFC) were provided with the updated precipitation gage, stream gage and flood forecast point inventories and were requested to evaluate the existing precipitation and stream gage networks for any deficiencies, and to identify areas for improvement to maximize the networks for river flood forecasting operations in the Basin. Additionally, the WFOs BGM and PHI were asked to prioritize the need for new river flood forecast points. Information received from these two WFOs was then sent to MARFC for evaluation.

In addition to the request for NWS Field Office input, each of the four basin state USGS Water Science Centers were requested to provide input on stream gage deficiencies, anticipated gage improvements, and potential funding shortfalls for operation and maintenance of existing stream gages.

Recommendations from the 2002 Flood Warning Report and the Interstate Flood Mitigation Task Force Report were also considered in the evaluation.

Precipitation Gage Network (Including Snowpack Monitoring)

Evaluation Criteria

Evaluation of the precipitation network was performed by the NWS field offices, MARFC in coordination with the WFO's BGM and PHI. The field offices use both real-time precipitation data and NEXRAD radar accumulated precipitation in their daily river forecast operations and are best able to judge the deficiencies of the data network. The field office evaluation or gap analysis, which involved an assessment of deficiencies and recommendations for improvements, was performed for existing forecast operations and consideration was also given to the precipitation gages required for additional forecast points.

Recommendations

The precipitation gage recommendations are listed in priority order based on the identified deficiencies. The highest priority recommendations are marked "High Priority" to the right of the recommendation and the recommendation number is bolded. Within a given recommendation, such as recommendation P1, the order in which individual sites are addressed (a, b, c, etc.) is not prioritized and is given equal weighting pending an implementation plan (if approved). The precipitation gage network recommendations related to river flood forecast operations are listed below. The general location of each recommended improvement is shown in Appendix D, Figures D-1 and D-2, and a reference index of the improvements is provided in Table D-1.

P1) Install new weighing-bucket precipitation gages at the following locations: **High Priority**

a) Willowemoc Creek watershed in the Livingston Manor, NY vicinity
To improve real time monitoring in the Beaverkill watershed.

b) Delaware River above the Lackawaxen River near Barryville, NY
To improve real time monitoring along the main stem Delaware River.

c) Delaware River at Fishs Eddy, NY
To improve real time monitoring for the lower reach of the East Branch Delaware River.

d) Mongaup River at Mongaup Valley, NY
To improve real time monitoring in the Mongaup River watershed. Only one real time gage currently exists.

e) Neversink River Bridgeville, NY
To improve real time monitoring in the Neversink River watershed downstream of Neversink Reservoir.

f) Neshaminy Creek at Rushland or at Penns Park, PA
To improve real time monitoring in the middle portion of the Neshaminy Creek watershed.

g) Manatawny Creek near Spangsville, PA
There are no real time precipitation gages in the Manatawny Creek watershed, which is tributary to the Schuylkill River.

In addition to providing real time information for forecasting purposes, these additional gages would be useful for improved calibration of radar rainfall estimates. The weighing bucket gages (known as PLUVIO gages) are recommended, but there may not be an option for heating due to a lack of AC power at some locations. Use of a brine solution in the non-heated gages and a way to address bridging at the mouth of the rain gage may be needed

Note that Recommendation FW-1.2 of the Interstate Flood Mitigation Task Force Action Plan calls for evaluation of non-NWS network gages and could determine the suitability of such gages for addressing these recommended additions.

P2) Install automated snow pillow monitors in the Lackawaxen River Basin in the vicinity of:

a) Equinunk, PA
b) Hawley, PA

Automated snow monitoring at these locations would allow expansion of real time snowpack monitoring into the central portion of the upper Delaware River Basin, a location where significant snowpack accumulates. Two snow pillow monitors were recently installed by New York City DEP in the Pepacton and Neversink Reservoir Watersheds. The real time gages are useful for snowmelt modeling and for calibration of snowpack modeling performed by the NOHRSC.

Real Time Stream Gage Network

Evaluation Criteria

Evaluation of the stream gage network was based on inputs from the four USGS Water Science Centers, the NWS field offices, the MARFC and WFO's, and gaps in coverage noted by the project support contractors. The evaluation or gap analysis, which involved an assessment of deficiencies and recommendations for improvements, was performed for existing forecast operations and consideration was also given to the stream gages required for additional forecast points.

Recommendations

The stream gage recommendations related to river flood forecast operations are listed in priority order based on the identified deficiencies. The highest priority recommendations are marked "High Priority" to the right of the recommendation and the recommendation number is bolded. Within a recommendation, such as recommendation S1, the order in which individual sites are addressed (a, b, c, etc.) is not prioritized and given equal weighting pending an implementation plan (if approved). The general location of each recommended improvement is shown in Appendix D, Figures D-1 and D-2, and a reference index of the improvements is provided in Table D-1.

S1) Develop and/or regularly maintain full rating curves (the relationship between river flow and river stage) for the stream gages listed below. Each of these gages serves as a river flood forecast point. Maintaining full rating curves improve the accuracy of river flood forecasts**:** **High Priority**

a) Delaware River at Delaware Water Gap/Tocks Island, NJ
b) Delaware River at New Hope/Lambertville, NJ
c) Delaware River at Stockton, NJ
d) Delaware River at Riegelsville, NJ
e) Delaware River at Montague, NJ
f) Brandywine Creek at Wilmington, DEL
g) N.B. Rancocas Creek at Pemberton, NJ

The NWS considers it very important that frequent measurements and updates are made to the rating for Tocks Island/Delaware Water Gap due to its key location in the mid-Delaware basin, and its significant contribution to downstream response. Real-time discharges made available online on the USGS website would be valuable.

The development of stage-discharge relationships for the New Hope/Lambertville and Stockton gages would also improve forecasting capability. Presently, forecasts are based on in-house empirical ratings derived from historical Riegelsville and Trenton data, but official continuously maintained ratings would be highly desirable as they would enable MARFC to model these points and improve the timing and accuracy of forecasts.

Maintaining the rating at the Riegelsville gage is also critical. This gage is used not only as the basis for downstream forecasts, but for forecasts upstream at Easton/Phillipsburg as well, since stage forecasts there are based on a crest-crest relationship with the Riegelsville gage, with manual adjustments applied as necessary to address the Lehigh River backwater influence. The situation with maintaining the rating at Riegelsville is unusual in that the Musconetcong River empties into the Delaware River 600' downstream of the Riegelsville gage, yet its flow is included in Riegelsville's streamflow records, and its rating curve. From a forecasting standpoint, the contribution from the Musconetcong is small (only 2% of the drainage area above Riegelsville), and has even less impact during high water events, since its flow will almost always pass through the downstream forecast points well before the main flood producing crest from the Delaware River arrives. Therefore, the NWS does not consider a separate rating curve necessary, since the relative contribution from the Musconetcong is considerably less than the inherent error in the curve itself. Resources should be devoted to assuring that the existing rating curve receives high priority for measurements and updating, and that real-time discharge data is made available online.

At the present time, stage vs. discharge relationships exist only for the Delaware Water Gap/Tocks Island, NJ and Riegelsville, NJ gages. New funding would need to be secured for the development of ratings for the New Hope/Lambertville, NJ and Stockton, NJ gages, as well as to extend and improve the ratings for the Tocks Island, NJ and Riegelsville, NJ gages

The seven gages listed in recommendations S1 are among 21 gages throughout the Delaware River Basin identified by the USGS in 2009 as requiring rating curve extension. The work, requiring an estimated total of $210,000 is not funded as of September 2009. The gages are listed here for reference:

01428750 West Br Lackawaxen River at Aldenville, PA
01432110 Lackawaxen River at Rowland, PA
01438500 Delaware River at Montague, NJ
01440200 Delaware River at Tocks Island, NJ
01440485 Swiftwarer Creek at Swiftwater, PA
01441495 Pocono Creek near Stroudsburg, PA
01451650 Little Lehigh Creek near Allentown, PA
01454700 Lehigh River at Glendon, PA.
01457500 Delaware River at Riegelsville, NJ
01464645 North Br Neshaminy Cr near New Britain, PA
01464720 North Br Neshaminy Cr at Chalfont, PA
01464750 Neshaminy Creek at Rushland, PA
01465200 Neshaminy Creek near Penns Park, PA
01467000 N.B. Rancocas Creek at Pemberton, NJ
01470500 Schuylkill River at Berne, PA
01470960 Tulpehocken Creek at Dam near Reading, PA
01471875 Manatawny Creek at Spangsville, PA
01472000 Schuylkill River at Pottstown, PA
01472199 West Br Perkiomen Creek at Hillegass, P
01472620 East Br Perkiomen Creek at Dublin, PA

01481500 Brandywine Creek at Wilmington, DEL

S2) Install new stream gages at the following locations: **High Priority**

a) Willowemoc Creek near Livingston Manor, NY
b) Little Beaver Kill upstream of Livingston Manor, NY

Gaging in the vicinity of Livingston Manor, NY has been requested by local officials to improve river and flood information. The June 2006 flood event caused record flooding in the Willowemoc Creek watershed. There is currently no real time stream gage in this watershed. The USGS noted that these new gages could be located in the vicinity of old discontinued gages or moved to alternate locations for better warning or hydrologic conditions.

S3) Flood harden the stream gages listed below. Flood hardening improves the reliability of the gage operations during flood events so that the real time stream stage and discharge reports can be incorporated in forecasting and used to monitor conditions: **High Priority**

a) Flat Brook near Flatbrookville, NJ
b) Musconetcong River at the outlet to Lake Hopatcong, NJ

S4) The USGS Stream Gage for the Mongaup River downstream of Rio Reservoir, NY should be re-activated. This would provide observed data for the discharges from the Mongaup River downstream of the Mongaup reservoir system and would be useful for Delaware River main stem flood forecasts. **High Priority**

Forecast Points

Evaluation Criteria

Evaluation of flood forecast points was performed by the National Weather Service field offices, MARFC in coordination with the WFO's BGM and PHI. Deficiencies such as physical gaps in coverage, limited forecast services (crest only vs. flood only forecasts vs. daily forecasts), and opportunities for expansion of probability forecasting were considered by the MARFC and WFOs in the evaluation of needs to improve forecast operations.

The factors considered for establishing new river forecast point include the following:

a) NWS Field Recommendations
b) Drainage Area
c) Response Time Generally Greater Than Six Hours
d) Flood Damage Potential – Risk to Life and Property
e) Current or Potential Availability of Real Time Data
f) Availability of Historical Data

g) Flood Frequency
h) Local or Regional Interest

There are many real time stream gages that fall short of meeting the drainage area and response time guidelines for establishing river flood forecast points. These gages may be considered as candidates for forecast points under the small stream/headwaters flood warning category, which is recommendation FW-6 of the Flood Mitigation Task Force Action Plan. Two such locations have been recommended by the study support contractors for further evaluation for application of site-specific models. In some cases, real time gages may not currently exist in areas of high flood damage potential. This does not eliminate the potential for establishing a flood forecast point if real time monitoring support can be funded and developed. Examples include several lower Delaware River flood forecast points, which have been supported using correlations to nearby real time gages. This consideration would also apply to the evaluation of potential small stream/headwaters flood forecast points under recommendation FW-6 of the Flood Mitigation Task Force Action Plan.

Recommendations

The flood forecast point recommendations are listed in priority order based on the identified deficiencies. The highest priority recommendations are marked "High Priority" to the right of the recommendation and the recommendation number is bolded. Within a recommendation, such as recommendation F1, the order in which individual sites are addressed (a, b, c, etc.) is not prioritized and given equal weighting pending an implementation plan (if approved). The flood forecast point recommendations are listed below. The general location of each recommended improvement is shown in Appendix D, Figures D-1 and D-2, and a reference index of the improvements is provided in Table D-1.

F1) Convert the Delaware River at Easton/Phillipsburg, NJ from a crest-only forecast point to a flood-only point. . **High Priority**

Expansion of forecast services at this location to provide a more complete forecast time-series (hydrographs) during high water would provide more detailed information on the forecast timing and duration of flooding to the public. This is the only remaining crest-only river flood forecast points in the basin. This reach of the main stem Delaware River experienced major damage during the 2004-2006 flooding.

F2 Establish a river flood forecast point at the following sites: **High Priority**

a) West Branch Delaware at Walton, NY.
b) Neversink River at Goddefroy, NY

The village of Walton, in Delaware County, NY was heavily damaged during the floods of 1996 and 2006. A forecast point on the Neversink River at Goddefroy would be very beneficial to the city of Port Jervis in Orange County, NY. The length of gage record, watershed response time, and potential for flood damage supports establishing a river flood forecast point at these locations.

F3) Extend forecasts from 48 hours to 72 hours time-series for:

a) North Branch Rancocas Creek at Pemberton, NJ
b) Schuylkill River at Reading, PA.

Both of these stations are presently flood-only forecast points and have been recommended for migration to daily forecasting points based on past events and community needs to serve users with expanded forecast services. Extension of forecasts from 48 hours to 72 hour time-series would expand the available time window for response to potential flood conditions by a full day.

F4) Produce site-specific forecasts for:

a) East Branch Delaware at Margareteville, NY.
b) Dry Brook at Arkville, NY

At this time, the watersheds upstream of the Arkville, NY and Margareteville, NY stream gages are too small and too fast-responding to establish river flood forecast points. In the future, advances in distributed modeling by MARFC may assist in forecasting for small, fast-responding basins such as these. In the interim, site-specific forecast models can be applied for flood forecasting at these two sites.

F5) In coordination with the NYCDEP and county emergency management, evaluate the following river reaches for additional development of flood impact (E-19) information for on-line availability with AHPS products:

a) West Branch Delaware River between Cannonsville Reservoir and the river forecast point at Hale Eddy, NY.
b) East Branch Delaware River between Pepacton Reservoir and the river forecast point at Harvard, NY.
c) Neversink River between Neversink Reservoir and the river forecast point at Bridgeville, NY.

Action stage, flood stage, moderate flood stage, and major flood stage have previously been established for the three respective downstream gages at Hale Eddy, Harvard, and Bridgeville. Flood impact tables have also been established for these three sites, and could be evaluated for additional information in the upstream reaches between the gage and each respective reservoir.

F6) Develop an implementation plan for the Site Specific Hydrologic Prediction System (SSHP) in the Delaware Basin. This is recommendation FW-6 in the Interstate Flood Mitigation Task Force Action Agenda. Stream gages on many of the smaller watersheds in the Delaware River Basin do not meet the criteria for establishing river flood forecast

points due to shorter response times, yet could be candidates for application of the SSHP, due to the history of flooding and potential for flood damage. Flood frequency data compiled by the NWS, flood insurance claims information, and the availability of NWS headwater guidance products and observational data can be used to evaluate potential sites for SSHP application.

F7) Evaluate the development of AHPS probability forecasts for the following locations:

a) Delaware River at Easton/Phillipsburg, NJ
b) Delaware River at Frenchtown, NJ
c) Delaware River at New Hope/Lambertville, NJ
d) Delaware River at Stockton, NJ
e) Delaware River at Washington's Crossing, NJ

The Easton/Phillipsburg, NJ site is recommended for conversion from crest-only to flood-only forecast points under Recommendation F1. The four other sites have been converted to flood only points. The addition of probability forecasting capability would provide information of the potential range of flood levels for given events. It would provide these locations with the criteria to qualify as new Advanced Hydrologic Prediction Services (AHPS) forecast point similar to the other forecast locations on the main stem Delaware River. The criteria of an AHPS forecast point is a probability chart and a hydrograph display of observed and/or forecast information.

General Recommendations

Evaluation Criteria
Additional generalized flood warning improvements were evaluated and prioritized based on program needs, recommendations identified during past flood events, the length of time required for implementation, and cost factors. The highest priority recommendations are marked "High Priority" to the right of the recommendation and the recommendation number is bolded.

Recommendations:

G1) Update and maintain the inventory of Existing Gages and River Flood Forecast Points on an annual basin, including the associated GIS files. This will provide for up-to-date display and analysis, aid in tracking progress made toward implementing recommendations, and help identify additional needs. All inventory and GIS files prepared for this report will be made available to the DRBC, USGS and NWS.

High Priority

G2) Develop a public information brochure or web page documenting the steps and considerations in establishing flood warning points, and providing background on flood warning services. River flood warning, small stream/headwaters flood warning, and flash flood warning should be included. This information would be useful to communities interested in improving flood warning services for flood-prone areas. Much of the information required for this outreach is available, but would be condensed and focused

on usefulness at the community level in a manner similar to the National Weather Service's "Flood Ready" community program. **High Priority**

G3) Build upon the existing ice jam observation network for the main stem Delaware River as monitored by the NWS and National Park Service (along the Upper Delaware River). Observations at the Delaware River Joint Toll Bridge Commission (DRJTBC) bridges could be reported by the DRJTBC to the NWS WFO's. Reports of ice jams should be relayed by the NWS to the respective USGS Water Science Centers so that backwater effects at stream gaging stations can be identified and reported with on-line USGS stream flow information. **High Priority**

G4) Complete work to increase Data Collection Platform (DCP) reporting frequency at stream gages from 3 or 4 hours to 1 hour. This work by the USGS Water Science Centers is in progress. In addition, where currently existing, telephone connectivity to stream gages should be maintained.

G5) In order to lengthen the lead time for response to potential river flooding, and to provide additional forecast information, MARFC should continue its effort to convert all forecast points from crest-only, or 48-hour forecast points, to a full 72- hour time series forecast.

G6) Continue development of probability based ensemble hydrologic forecasts at, and downstream of the New York City reservoirs in the Delaware River Basin. WFO BGM reports that the New York City DEP and the Delaware County, NY Office of Emergency Management have requested the need for ensemble forecasts at the three Delaware Basin reservoirs as well as forecast points downstream of the reservoirs. Probability based ensemble forecasts beyond 72 hours would be valuable for both flood warning and for management of reservoir releases.

G7) Continue development and advances in distributed hydrologic modeling (to provide the capability to issue flood forecasts for small, fast-responding basins. Distributed modeling would be useful for remodeling rivers/streams that respond rapidly to runoff at existing forecast points. The time-step for modeling would be reduced, probably to 1 hour. Distributed modeling makes better use of the high resolution precipitation estimates produced by WSR-88D radars and automated rainfall sensors. The Beaver Kill at Cooks Falls, NY is a fast responding flood forecast point and considered a good candidate for initial application of distributed modeling.

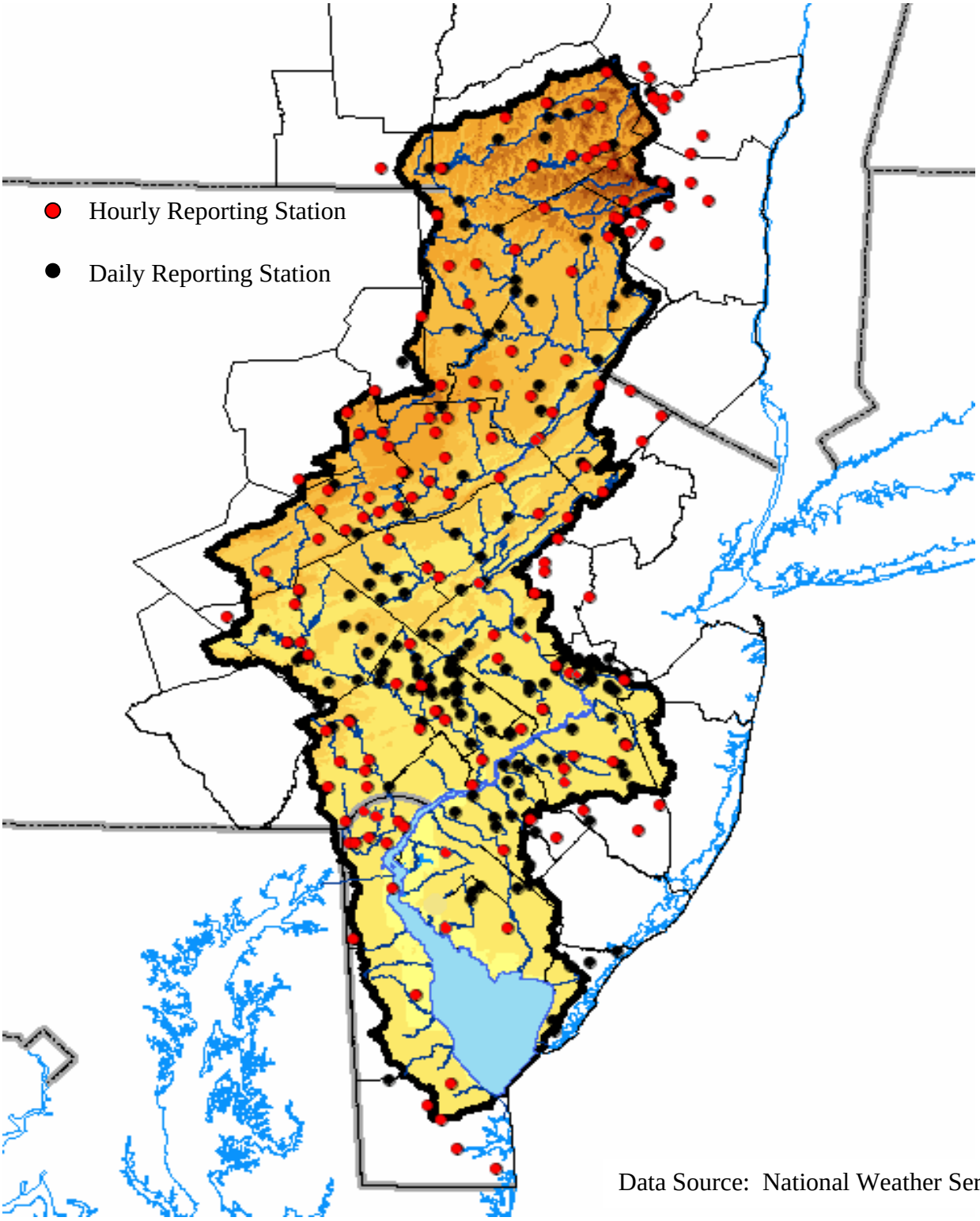
List of Acronyms

AHPS	NOAA's Advanced Hydrologic Prediction Services
AWIPS	Advanced Weather Interactive Processing System
BGM	Binghamton National Weather Service Forecast Office
COCORAHS	Community Collaborative Rain Hail and Snow Network
CO-OP	NWS Cooperative Observer Program
DEOS	State of Delaware Earth Observing System
DRBC	Delaware River Basin Commission
FAC	DRBC Flood Advisory Committee
FFMP	Flash Flood Monitoring Program
FLS	Flood Statements
FLW	Flood Warnings
GIS	Geographic Information System
IFLOWS	Integrated Flood Observing and Warning System
MARFC	Middle Atlantic River Forecast Center – National Weather Service
NEXRAD	Doppler radar
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NOS	National Ocean Service
NYSDEC	New York State Department of Environmental Conservation
NWS	National Weather Service
NYCDEP	New York State Department of Environmental Protection
PHI	Philadelphia/Mount Holly National Weather Service Forecast Office
PADEP	Pennsylvania Department of Environmental Protection
RFC	River Forecast Center (The MARFC covers the Delaware River Basin
RVS	River Statements
SSHP	Site Specific Hydrologic Prediction System
USACOE	United States Army Corps of Engineers
USGS	United States Geological Survey
WFO	Weather Forecast Office – National Weather Service
WSR-88D	Weather Surveillance Radar (NEXRAD)

Appendix A: Precipitation Gages in the Delaware River Basin

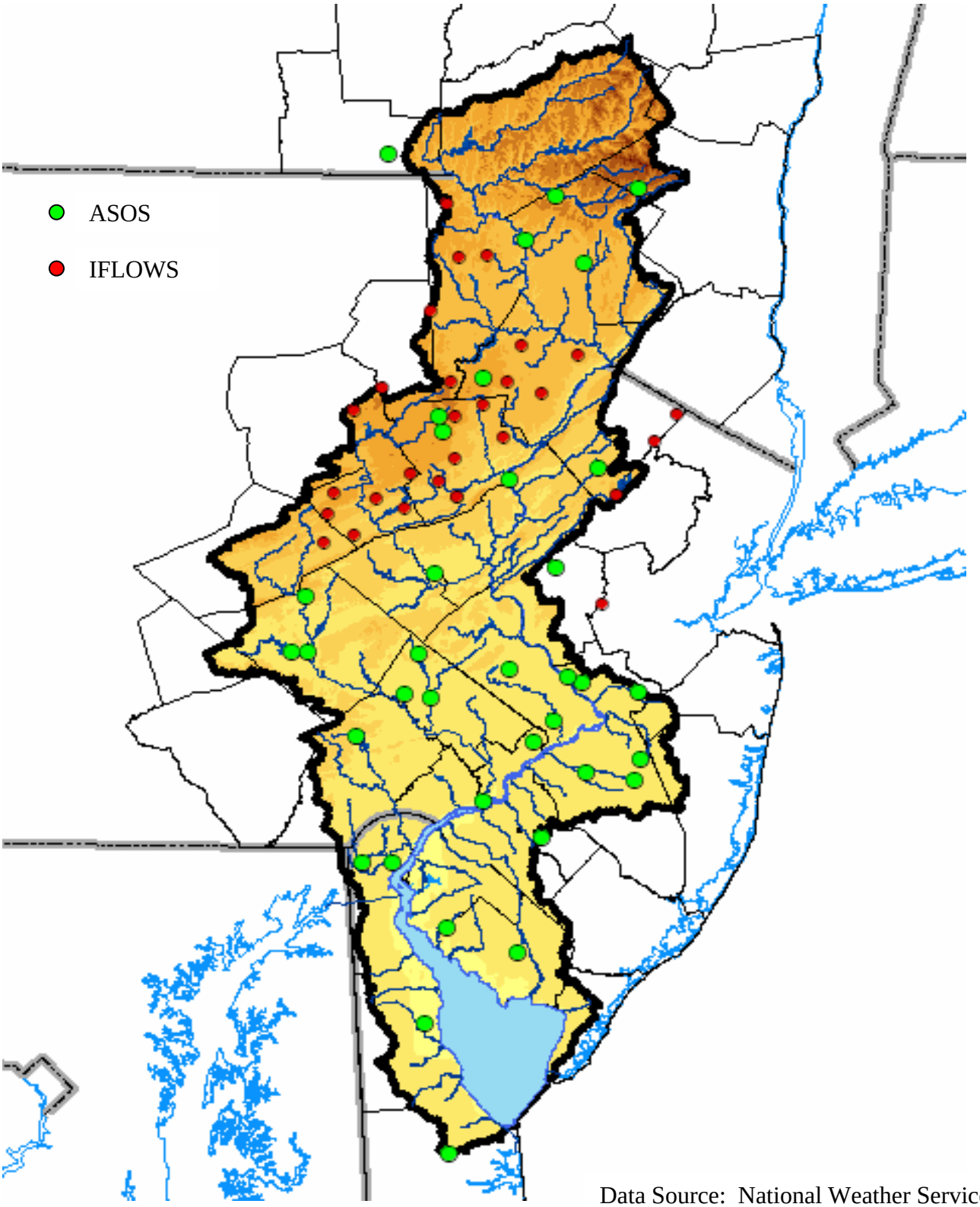
The maps in Appendix A have been created from the updated precipitation gage inventory developed for this project. The National Weather Service Mid-Atlantic River Forecast Center developed the precipitation gage update from an earlier file created by the DRBC with inputs from the WFO's at Binghamton and Mt. Holly. The precipitation inventory and maps include precipitation gages used by the National Weather Service in forecasting operations, but do not include all precipitation gages in the Delaware River Basin. Snow depth and snow water-equivalent monitoring sites have also been inventoried and are included in the GIS database. The maps provide a general illustration of precipitation gage distribution. The GIS attribute files developed from the updated inventory can be used for more detailed mapping and analysis using the data fields included in the inventory. The stream gage inventory and associated GIS files have been provided to the National Weather Service, Delaware River Basin Commission and U. S. Geological Survey.

Figure A-1: Location of All Precipitation Gages Used by the National Weather Service for Delaware River Basin Forecasting



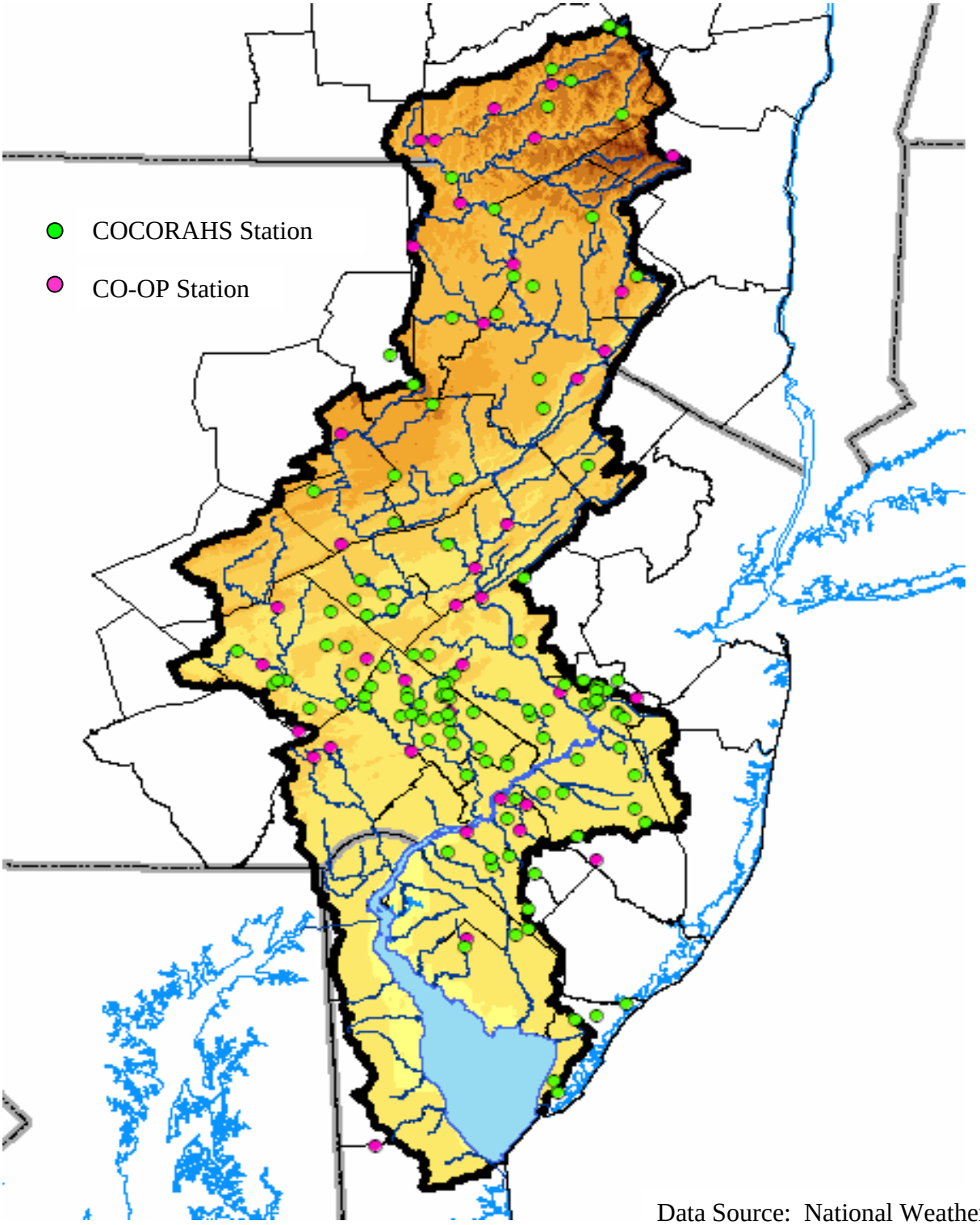
Data Source: National Weather Service

Figure A-2: Location of ASOS and IFLOWS Gages Used by the National Weather Service for the Delaware River Basin



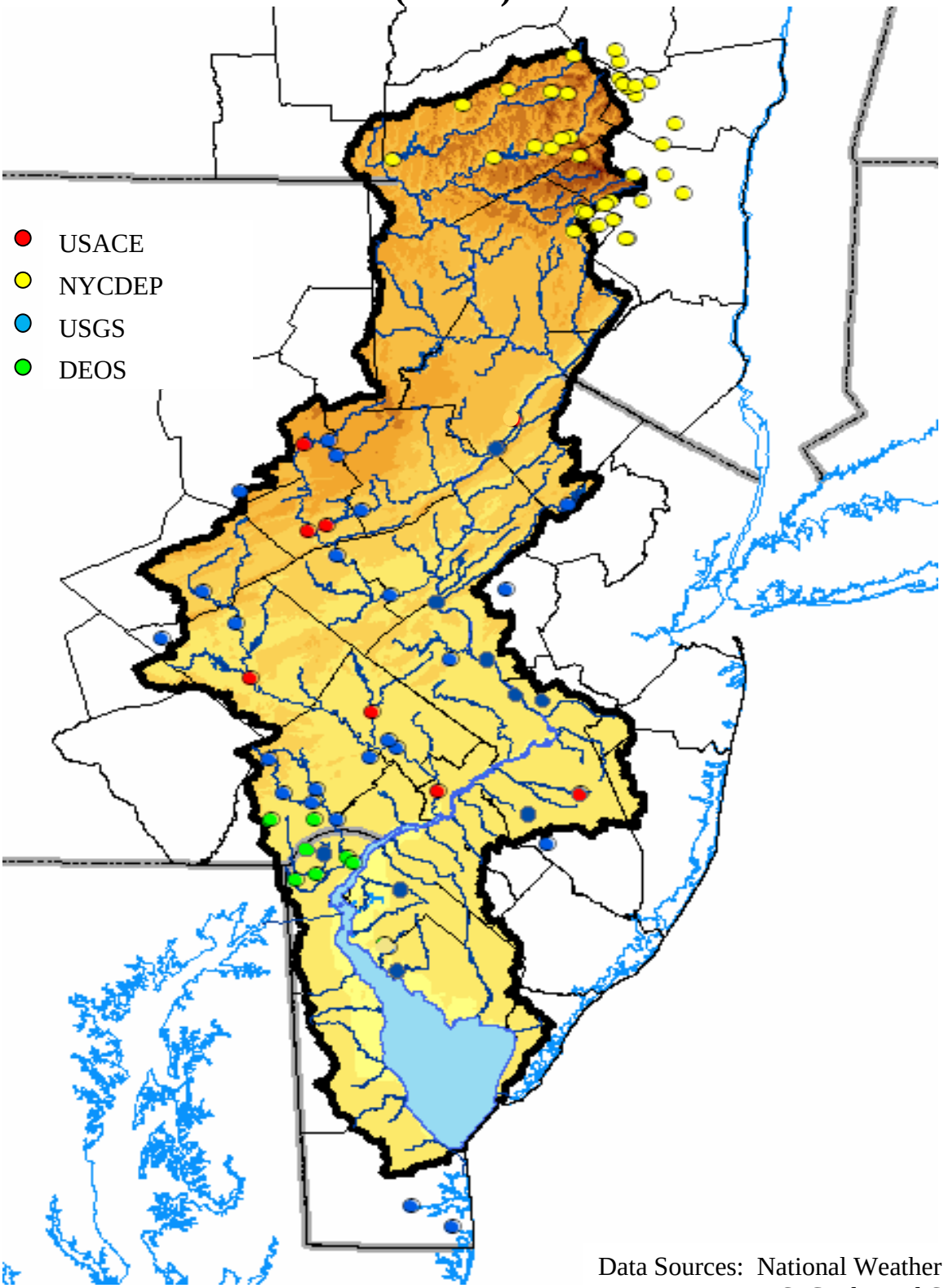
Data Source: National Weather Service

Figure A-3: Location of CO-OP and COCORAHS Precipitation Gages Used by the National Weather Service for the Delaware River Basin



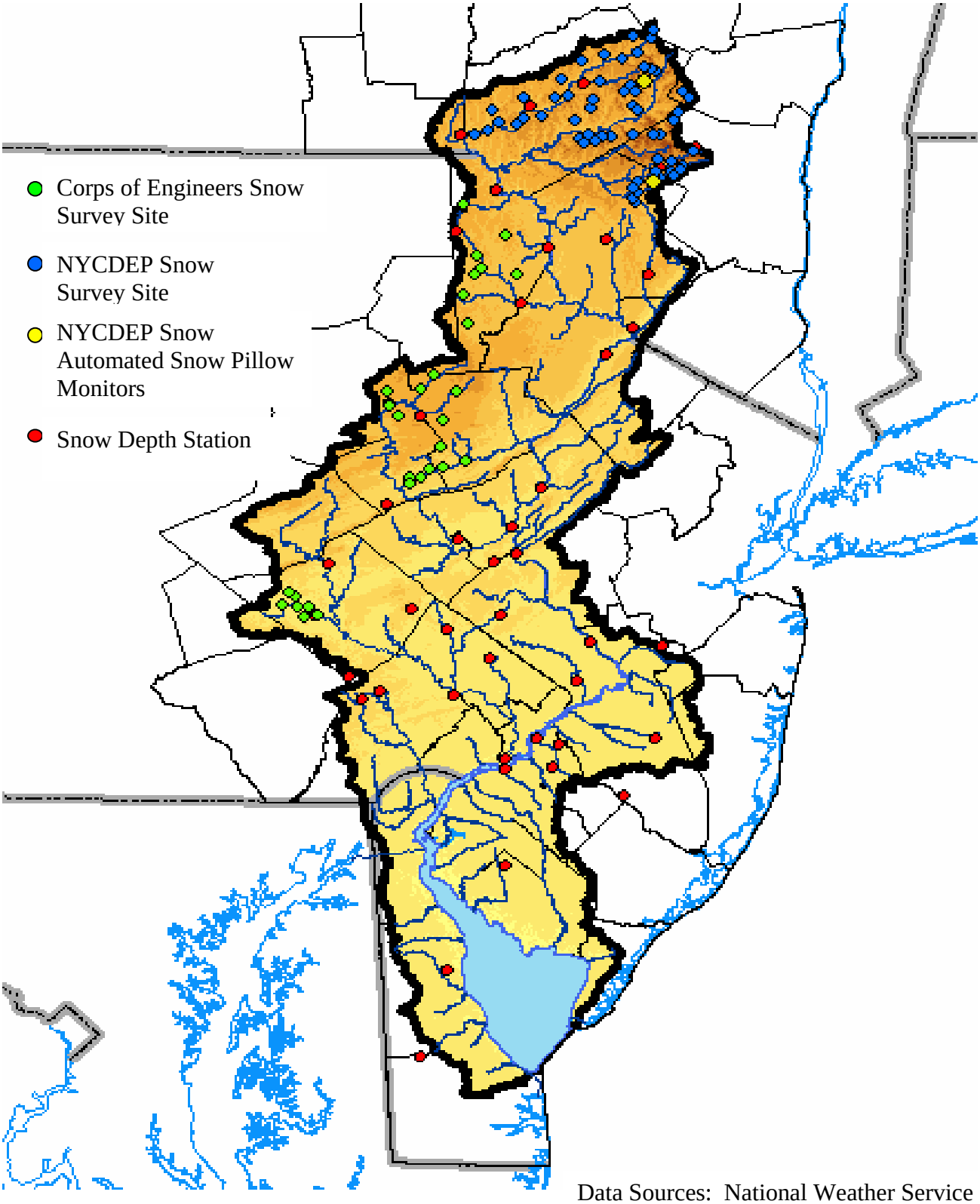
Data Source: National Weather Service

Figure A-4: Location Precipitation Gages Operated by U.S. Army Corps of Engineers, New York City DEP, U.S. Geological Survey, and the State of Delaware (DEOS) and Used in NWS Forecasting



Data Sources: National Weather Service
U.S. Geological Survey

Figure A-5: Location of Snow Depth and Snow Water Equivalent Monitoring Sites Used by the National Weather Service for the Delaware River Basin

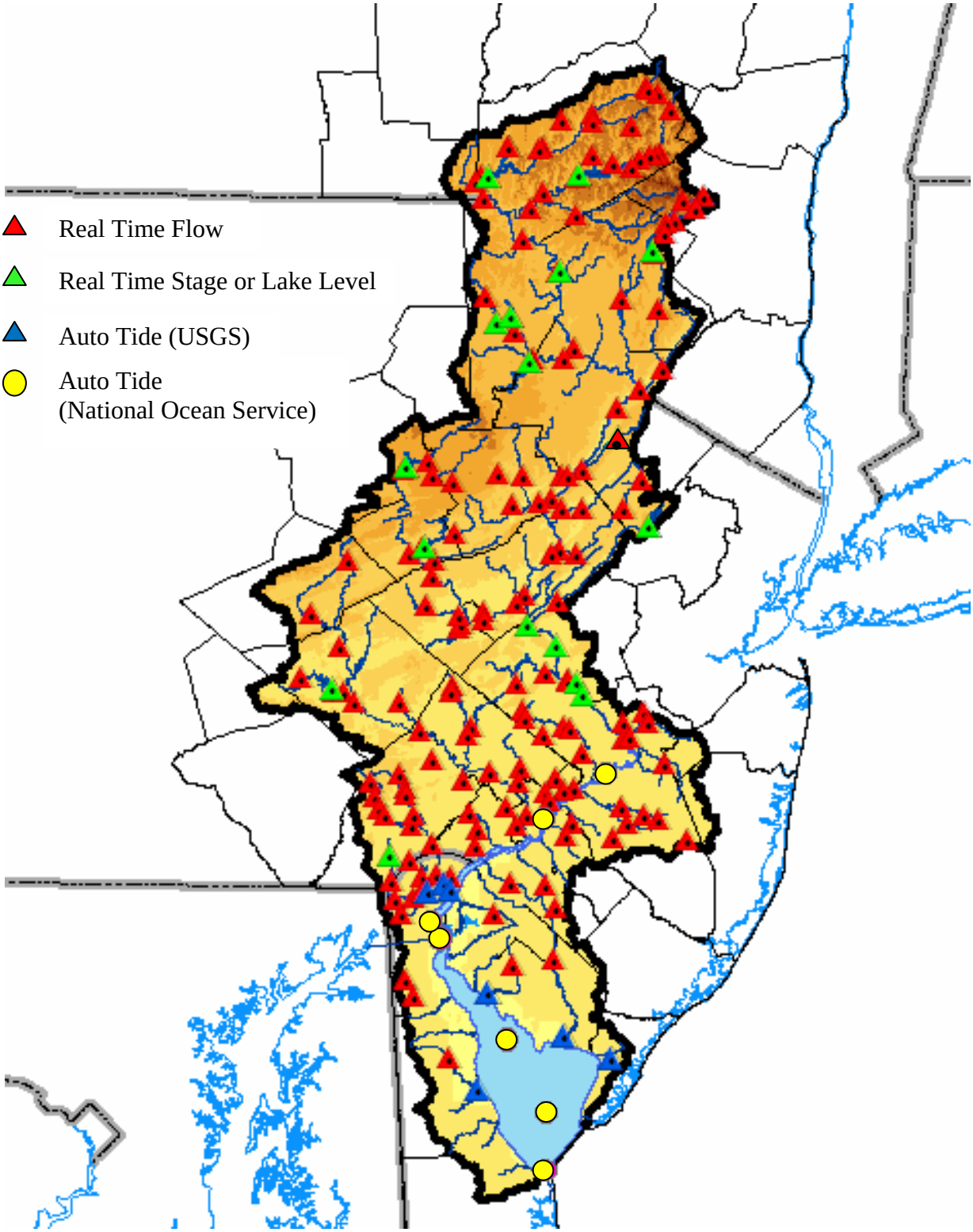


Data Sources: National Weather Service
NYCDEP, USACOE

Appendix B: Real Time Stream Gages in the Delaware River Basin

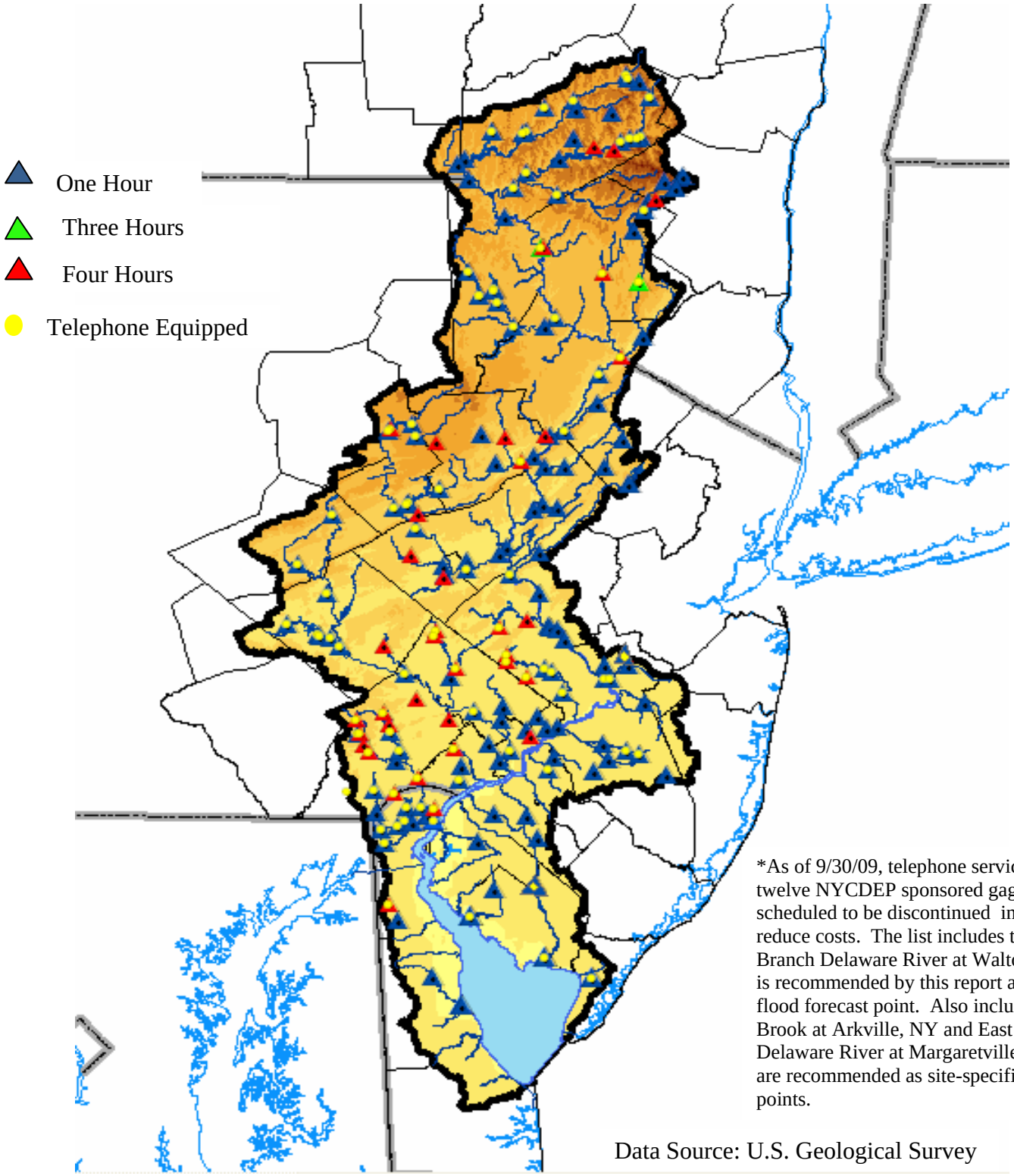
Real time stream flow and stage gages automatically record data and are equipped with telemetry to provide this information primarily through satellite communications. The maps in Appendix B have been created from the updated stream gage inventory developed for this project. The maps provide a general illustration of stream gage distribution. The GIS attribute files developed from the updated inventory can be used for more detailed mapping and analysis using the data fields included in the inventory. The stream gage inventory and associated GIS files have been provided to the National Weather Service, Delaware River Basin Commission and U. S. Geological Survey. Note that for the purposes of these maps, the term “stream gage” refers to gages that measure stream discharge, stage or lake level, or tide level.

Figure B-1: Location of Real Time Stream Gages in the Delaware River Basin as of June 2009



Data Source: U.S. Geological Survey

Figure B-2: Reporting Interval of USGS Real Time Gages as of June 2009

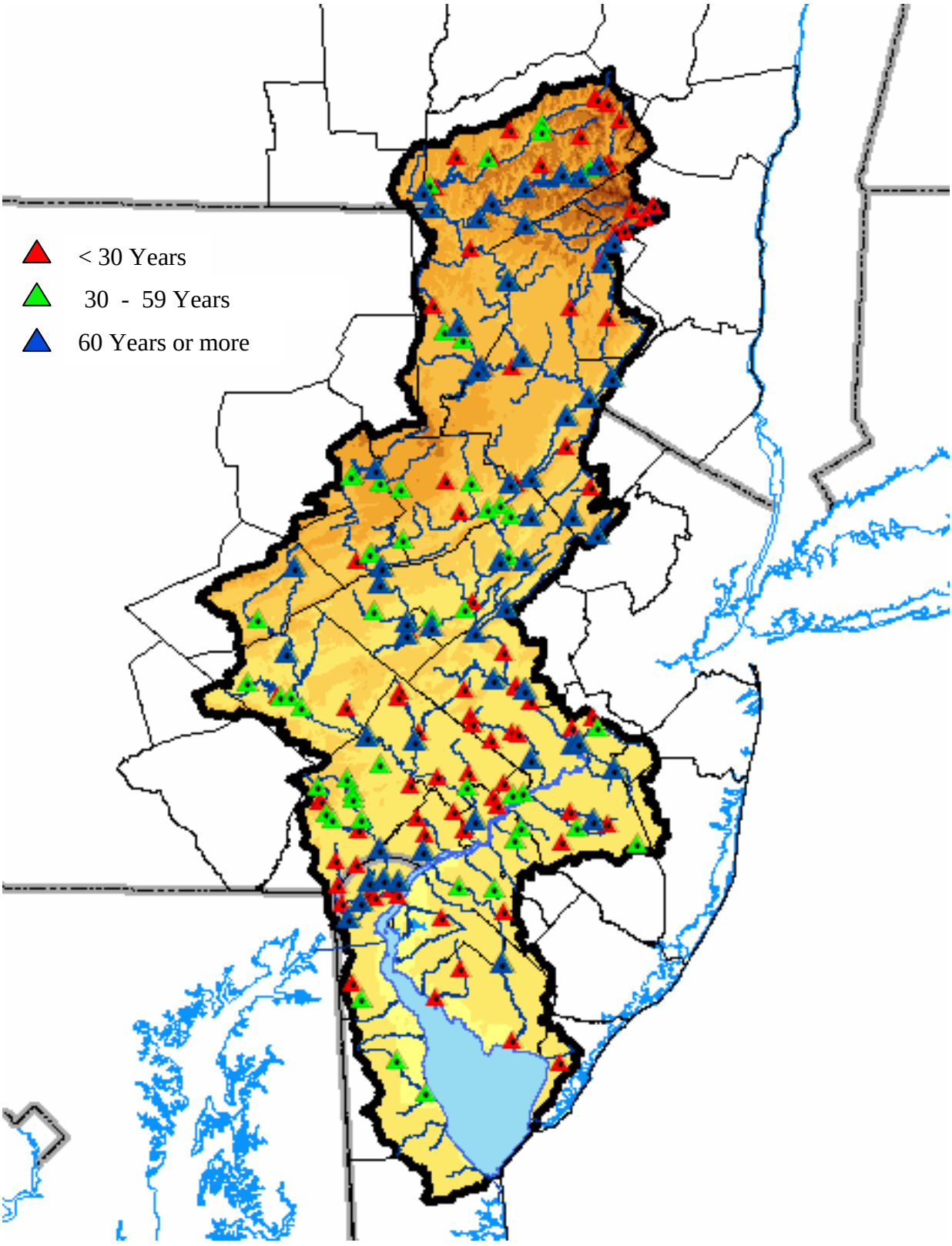


*As of 9/30/09, telephone service for twelve NYCDEP sponsored gages was scheduled to be discontinued in order to reduce costs. The list includes the West Branch Delaware River at Walton, NY, which is recommended by this report as a new river flood forecast point. Also included are Dry Brook at Arkville, NY and East Branch Delaware River at Margaretville, NY, which are recommended as site-specific forecast points.

Data Source: U.S. Geological Survey

Note: The reporting interval is the time between reports to the satellite. Flow and stage data is generally collected at 15 minute intervals. Telephone equipped gages can be polled to provide stage information as needed during storm events.

Figure B-3: Number of Years of Gage Record for USGS Gages as of June 2009



Data Source: U.S. Geological Survey

Table B-1: Stream Gages Classified as Threatened by the USGS As of September 30, 2009

Station ID	Station Name	Record	Status
01426000	Oquaga Creek at Deposit, NY	63 Years	To be discontinued Sept. 30, 2009
01422738	Wolf Creek at Mundale, NY	11 Years	Discontinued June 30, 2009
01415460	Terry Clove Kill near DeLancey, NY	1 year	Discontinued June 30, 2009
01422389	Coulter Brook near Bovina Center, NY	12 years	Discontinued June 30, 2009
01421614	Town Brook Tributary southeast of Hobart	11 years	Discontinued June 30, 2009

Source: http://water.usgs.gov/osw/ny_base.html

Table B-2: Stream Gages Facing Discontinuation of Telephone Service on September 30, 2009

01413088	E Br Delaware R at Roxbury, NY
01413398	Bush Kill nr Arkville, NY
01413408	Dry Brook at Arkville, NY
01413500	E Br Delaware R at Margaretville, NY
01414000	Platte Kill at Dunraven, NY
01421610	W Br Delaware R at Hobart, NY
01421618	Town Brook, southeast of Hobart, NY
01421900	West Branch Delaware River upstream from Delhi, NY
01422738	Wolf Cr at Mundale, NY -- station discontinued 6/30/2009
01422747	East Br east of Walton, NY
01423000	W Br Delaware R at Walton, NY
01435000	Neversink River near Claryville, NY

Source: NYCDEP

Notes:
1) The West Branch Delaware River at Walton, NY is recommended by this report as a new river flood forecast point.
2) The East Branch of the Delaware River at Margaretville, NY and Dry Brook at Arkville, NY are recommended by this report as new site-specific flood forecast points.
3) None of the other stations listed are either existing or proposed flood forecast points.
3) The stations listed in the above tables have been supported by the NYCDEP as the cooperator with the USGS.

Appendix C: Flood Forecast Points in the Delaware River Basin

The maps and Tables in Appendix C have been created from the updated stream gage inventory and flood forecast point information obtained for this project. The maps provide general information on the flood forecast point distribution. The GIS attribute files developed from the updated stream gage inventory can be used for more detailed mapping and analysis. Information on flood forecast points is contained within the updated stream gage inventory file. The stream gage inventory file and associated GIS files have been provided to the National Weather Service, Delaware River Basin Commission and U. S. Geological Survey.

Figure C-1: Location of River Flood Forecast Points in the Delaware River Basin as of June 2009

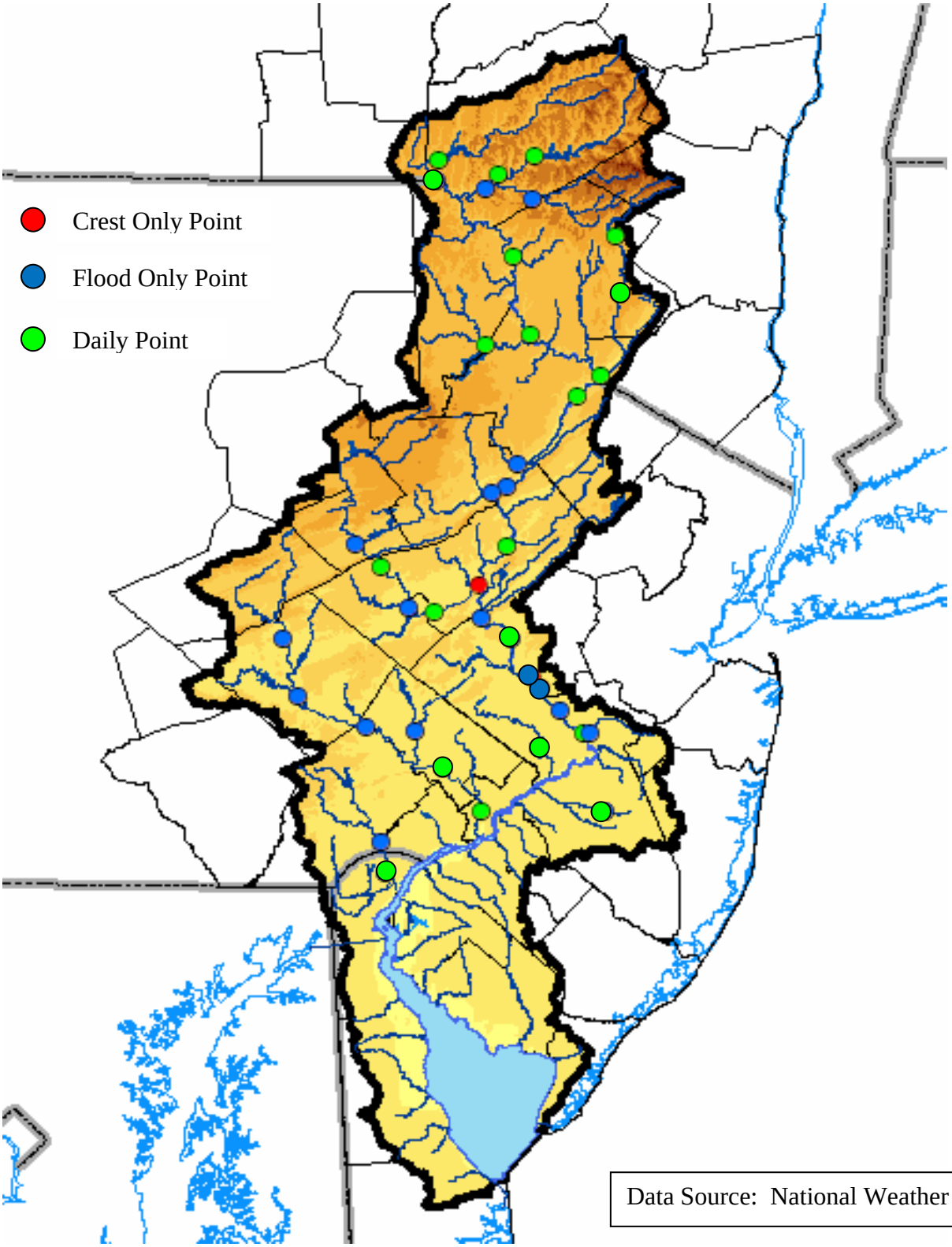
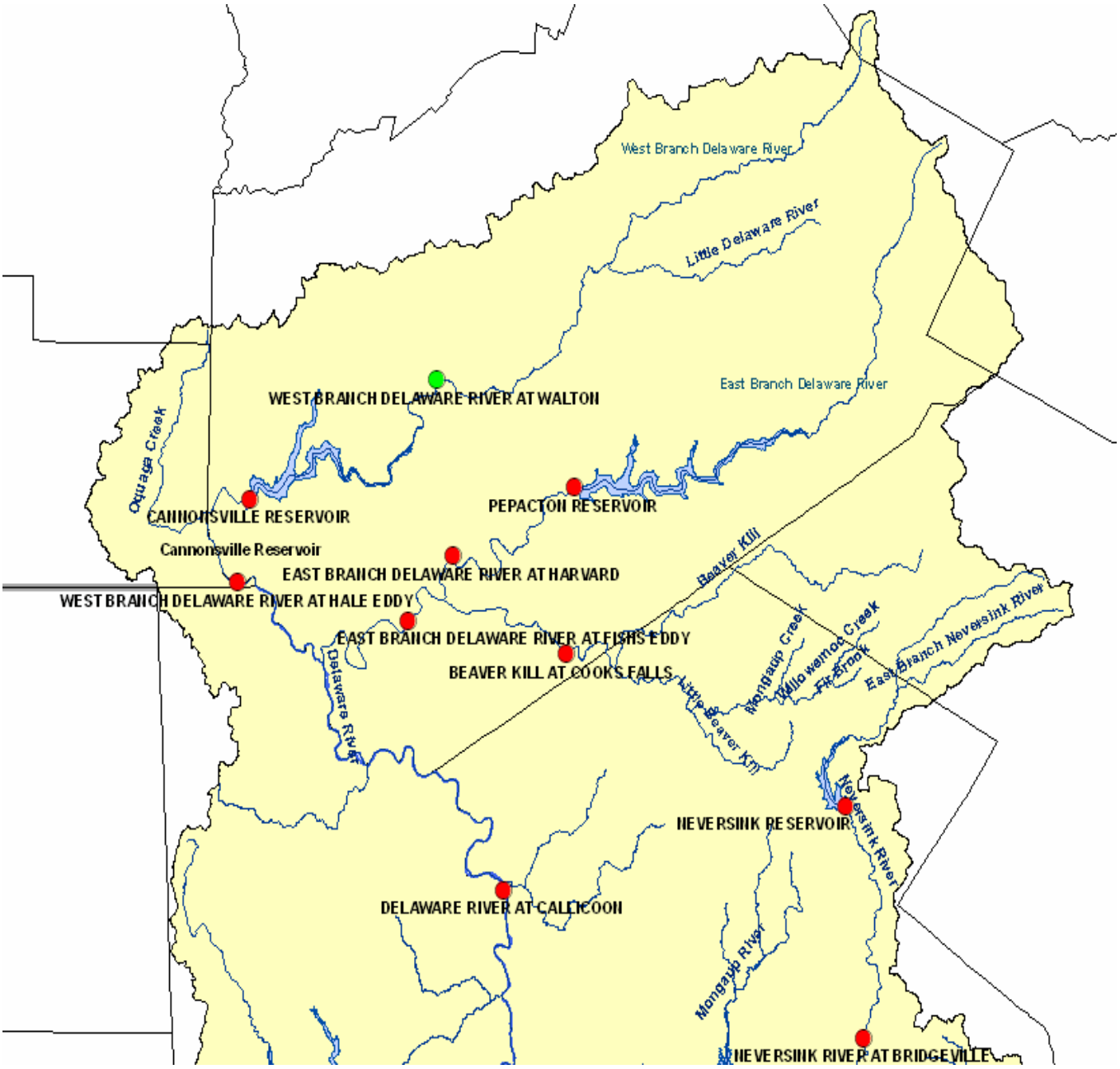


Figure C-2: Location of River and Site Specific Flood Forecast Points in the Delaware as of June 2009

River Flood Forecast Point

Site Specific Flood Forecast Point

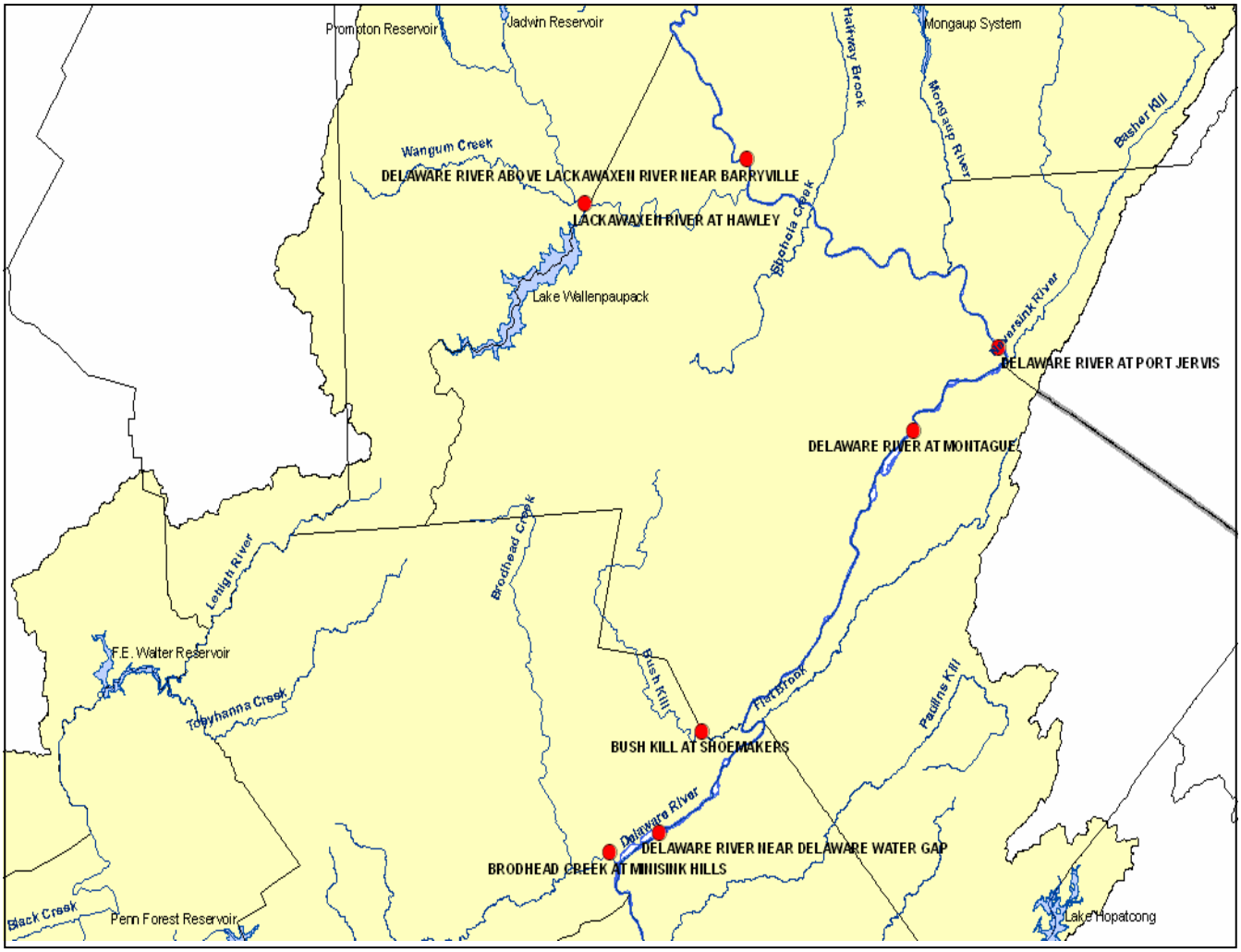


Data Sources: U.S. Geological Survey, National Weather Service

Figure C-3: Location of River and Site Specific Flood Forecast Points in the Delaware River Basin

River Flood Forecast Point

Site Specific Flood Forecast Point

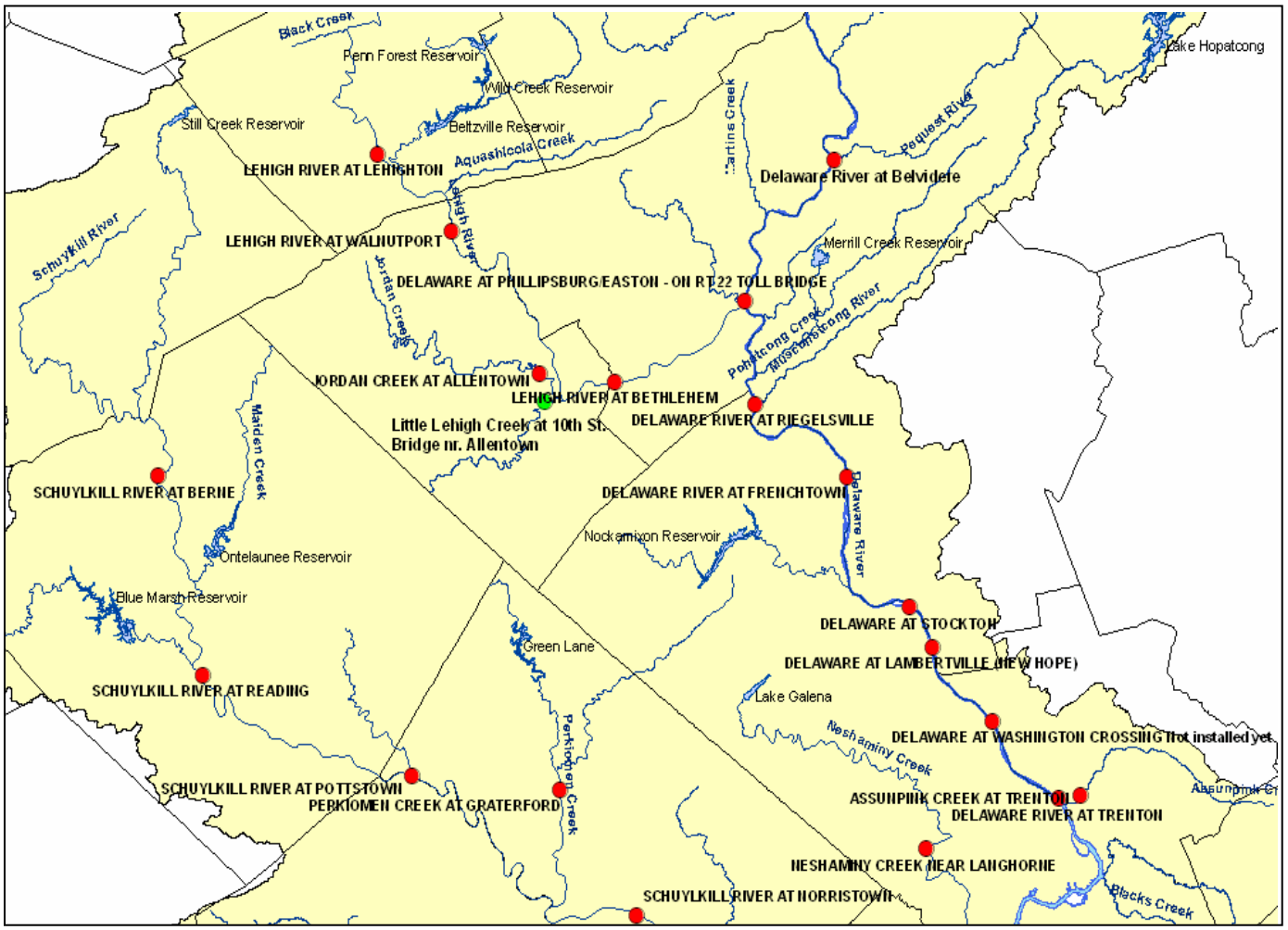


Data Sources: U.S. Geological Survey,
National Weather Service

Figure C-4: Location of Delaware River Basin River and Site Specific Flood Forecast Points as of June 2009

River Flood Forecast Point

Site Specific Flood Forecast Point

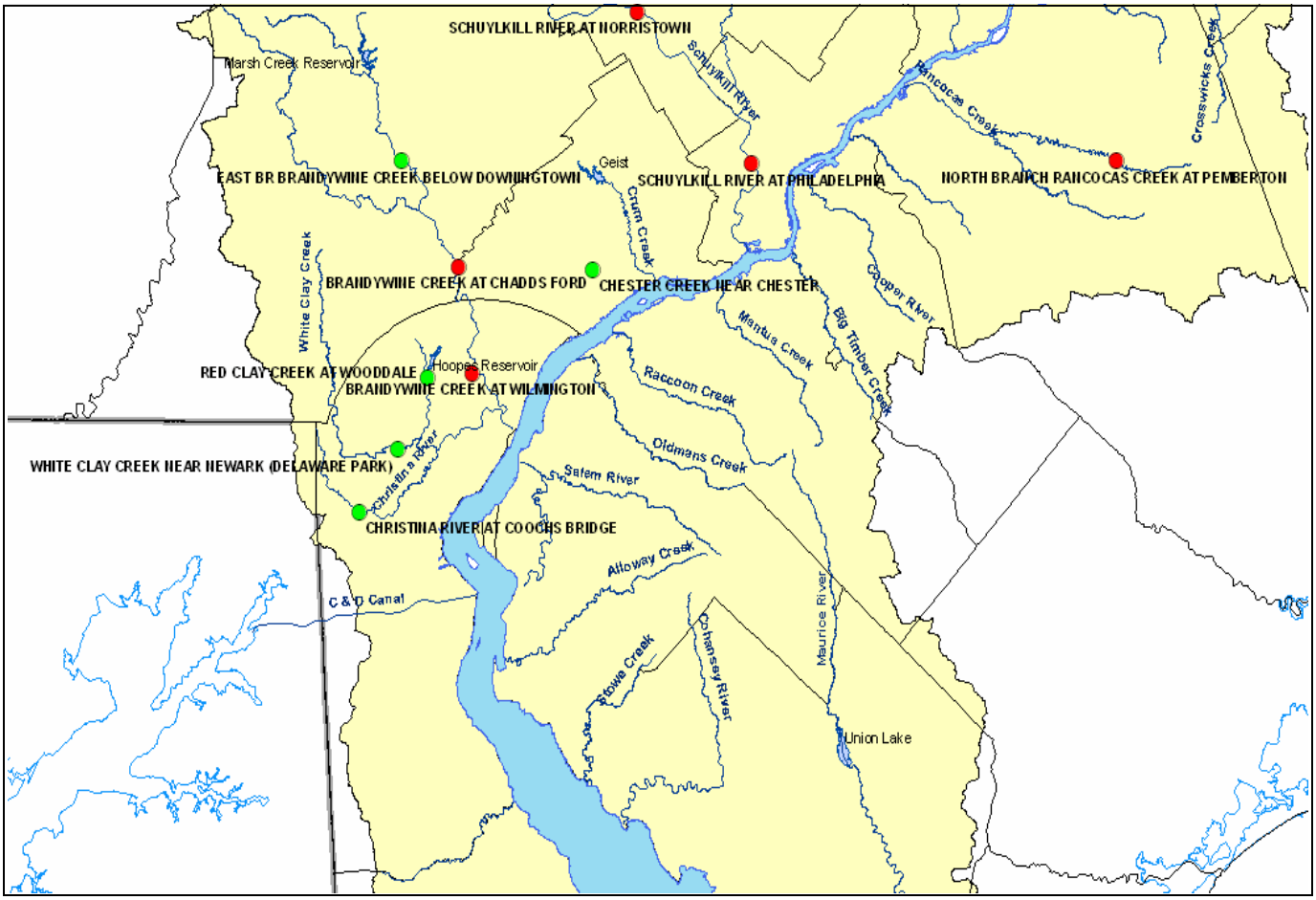


Data Sources: U.S. Geological Survey,
National Weather Service

Figure C-5: Location of Delaware River Basin River and Site Specific Flood Forecast Points as of June 2009

River Flood Forecast Point

Site Specific Flood Forecast Point



Data Sources: U.S. Geological Survey,
National Weather Service

Table C-1:
Delaware River Basin River Flood Forecast Points as of June 2009

USGS_GAGE	NAME	STATE	COUNTY	FUNDING SOURCE
01481500	BRANDYWINE CREEK AT WILMINGTON	DE	NEW CASTLE	DELAWARE GEOLOGICAL SURVEY, USGS, CITY OF WILMINGTON
01438500	DELAWARE RIVER AT MONTAGUE	NJ	PIKE	USGS -DELAWARE RIVER MASTER
01440200	DELAWARE RIVER NEAR DELAWARE WATER GAP	NJ	WARREN	USGS
01446995	DELAWARE AT PHILLIPSBURG/EASTON - ON RT 22 TOLL BRIDGE	NJ	WARREN	DELAWARE RIVER JOINT TOLL BRIDGE COMMISSION
01446500	DELAWARE RIVER AT BELVIDERE	NJ	WARREN	NJDEP, USGS
01457500	DELAWARE RIVER AT RIEGELSVILLE	NJ	BUCKS	USGS
01458500	DELAWARE RIVER AT FRENCHTOWN	NJ	HUNTERDON	USGS
01461500	DELAWARE AT STOCKTON	NJ	HUNTERDON	DELAWARE RIVER JOINT TOLL BRIDGE COMMISSION, NJDEP
01462000	DELAWARE AT LAMBERTVILLE (NEW HOPE)	NJ	HUNTERDON	DELAWARE RIVER JOINT TOLL BRIDGE COMMISSION, NJDEP
01462500	DELAWARE AT WASHINGTON CROSSING	NJ	MERCER	DELAWARE RIVER JOINT TOLL BRIDGE COMMISSION, NJDEP
01463500	DELAWARE RIVER AT TRENTON	NJ	MERCER	DRBC, USACOE, USGS
01464000	ASSUNPINK CREEK AT TRENTON	NJ	MERCER	NJDEP, USGS
01467000	NORTH BRANCH RANCOCAS CREEK AT PEMBERTON	NJ	BURLINGTON	NJDEP
	PEPACTON RESERVOIR	NY	DELAWARE	NYCDEP
01417500	EAST BRANCH DELAWARE RIVER AT HARVARD	NY	DELAWARE	NYSDEC, USGS
01420500	BEAVER KILL AT COOKS FALL	NY	DELAWARE	NATIONAL STREAMFLOW INFORMATION PROGRAM (USGS)
01421000	EAST BRANCH DELAWARE RIVER AT FISHS EDDY	NY	DELAWARE	NYCDEP, USGS
	CANNONSVILLE RESERVOIR	NY	DELAWARE	NYCDEP
01426500	WEST BRANCH DELAWARE RIVER AT HALE EDDY	NY	DELAWARE	NYCDEP, NYSDEC, USGS
01427510	DELAWARE RIVER AT CALLICOON	NY	WAYNE (PA)	NYCDEP, NYSDEC, USGS
01428500	DELAWARE RIVER ABOVE LACKAWAXEN RIVER NEAR BARRYVILLE	NY	SULLIVAN	NYCDEP, USGS
01434000	DELAWARE RIVER AT PORT JERVIS	NY	PIKE (PA)	NATIONAL STREAMFLOW INFORMATION PROGRAM (USGS)
	NEVERSINK RESERVOIR	NY	SULLIVAN	NYCDEP
01436690	NEVERSINK RIVER AT BRIDGEVILLE	NY	SULLIVAN	NYSDEC, USGS
01431500	LACKAWAXEN RIVER AT HAWLEY	PA	WAYNE	USGS, USACOE, PPL HOLTWOOD
01439500	BUSH KILL AT SHOEMAKERS	PA	MONROE	PADEP, USGS
01442500	BRODHEAD CREEK AT MINISINK HILLS	PA	MONROE	PADEP, USGS
01449000	LEHIGH RIVER AT LEHIGHTON	PA	CARBON	USACE
01451000	LEHIGH RIVER AT WALNUTPORT	PA	NORTHAMPTON	USACOE, PADEP, USGS
01452000	JORDAN CREEK AT ALLENTOWN	PA	LEHIGH	CITY OF ALLENTOWN, PADEP, USGS
01453000	LEHIGH RIVER AT BETHLEHEM	PA	LEHIGH	USACE, PADEP, USGS
01465500	NESHAMINY CREEK NEAR LANGHORNE	PA	BUCKS	BUCKS COUNTY, PADEP, USGS
01470500	SCHUYLKILL RIVER AT BERNE	PA	BERKS	USACOE, PADEP, USGS
01471510	SCHUYLKILL RIVER AT READING	PA	BERKS	USACOE
01472000	SCHUYLKILL RIVER AT POTTSTOWN	PA	MONTGOMERY	USACOE, DRBC, PADEP
01473000	PERKIOMEN CREEK AT GRATERFORD	PA	MONTGOMERY	PADEP, USACOE, USGS
01473500	SCHUYLKILL RIVER AT NORRISTOWN	PA	MONTGOMERY	USACOE, USGS
01474500	SCHUYLKILL RIVER AT PHILADELPHIA	PA	PHILADELPHIA	CITY OF PHILADELPHIA, USACOE, USGS
01481000	BRANDYWINE CREEK AT CHADDS FORD	PA	DELAWARE	PADEP, CHESTER COUNTY, CITY OF WILMINGTON, USGS

Table C-2: Site Specific Flood Forecast Points as of June 2009

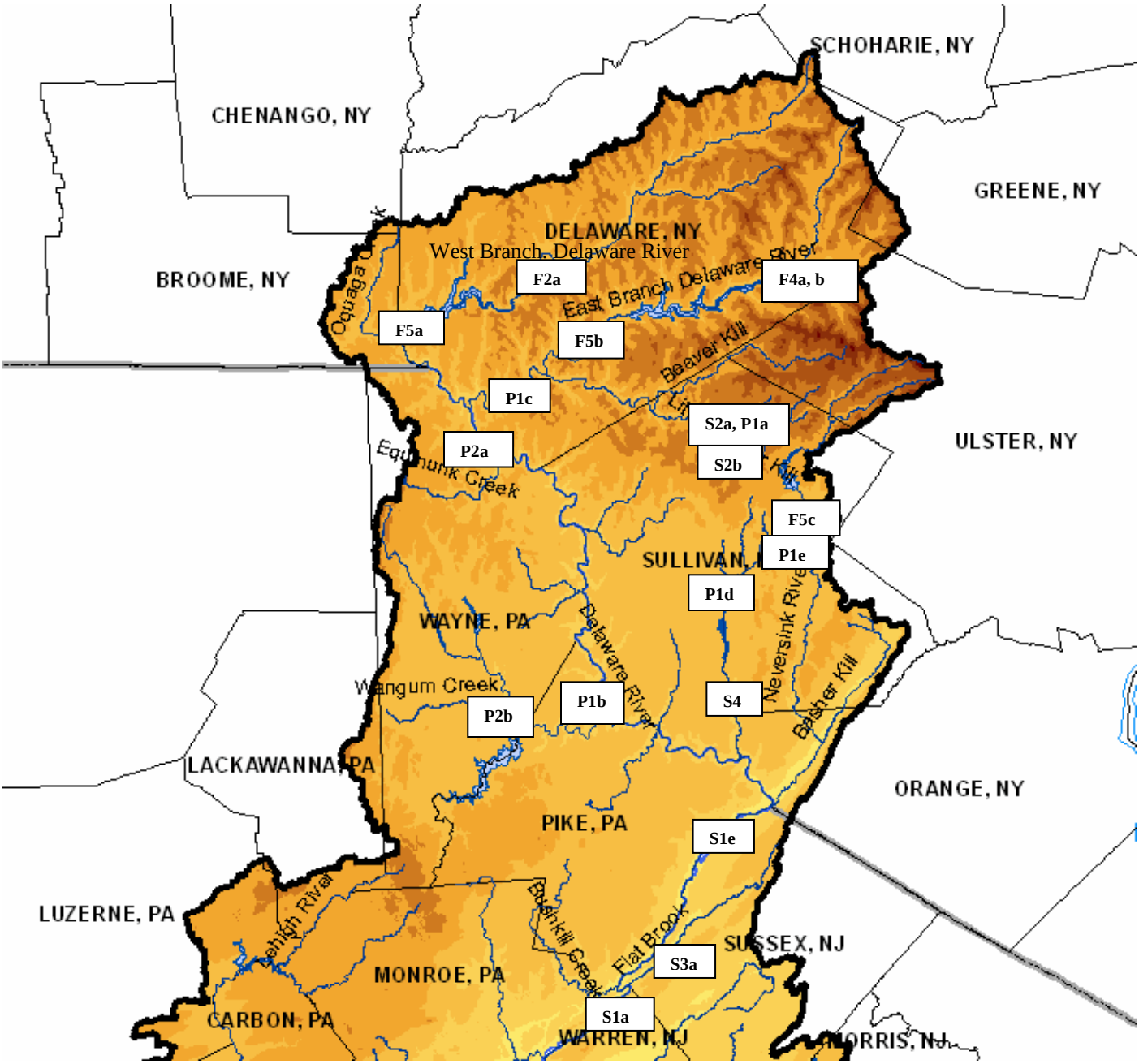
USGS_GAGE	NAME	STATE	COUNTY	FUNDING_SO
01478000	CHRISTINA RIVER AT COOCHS BRIDGE	DE	NEW CASTLE	DGS, USGS
01479000	WHITE CLAY CREEK NEAR NEWARK (DELAWARE PARK)	DE	NEW CASTLE	DGS,USGS
01480000	RED CLAY CREEK AT WOODDALE	DE	NEW CASTLE	DGS, USGS
01451650	LITTLE LEHIGH CREEK AT TENTH ST. BR. AT ALLENTOWN	PA	LEHIGH	CITY OF ALLENTOWN
01477000	CHESTER CREEK NEAR CHESTER	PA	DELAWARE	PADEP, DRBC, USGS
01480870	EAST BR BRANDYWINE CREEK BELOW DOWNINGTOWN	PA	CHESTER	CHESTER COUNTY, USGS
01423000	WEST BR DELAWARE RIVER AT WALTON	NY	DELAWARE	NYSDEC, NYCDEP, USGS

Flood Forecasts for site specific locations are prepared by either the NWS Mtl Holly or Binghamton Weather Forecast Offices. These forecasts are for locations with shorter response times than river forecast points.

Appendix D: Recommended Flood Forecasting Improvements in the Delaware River Basin

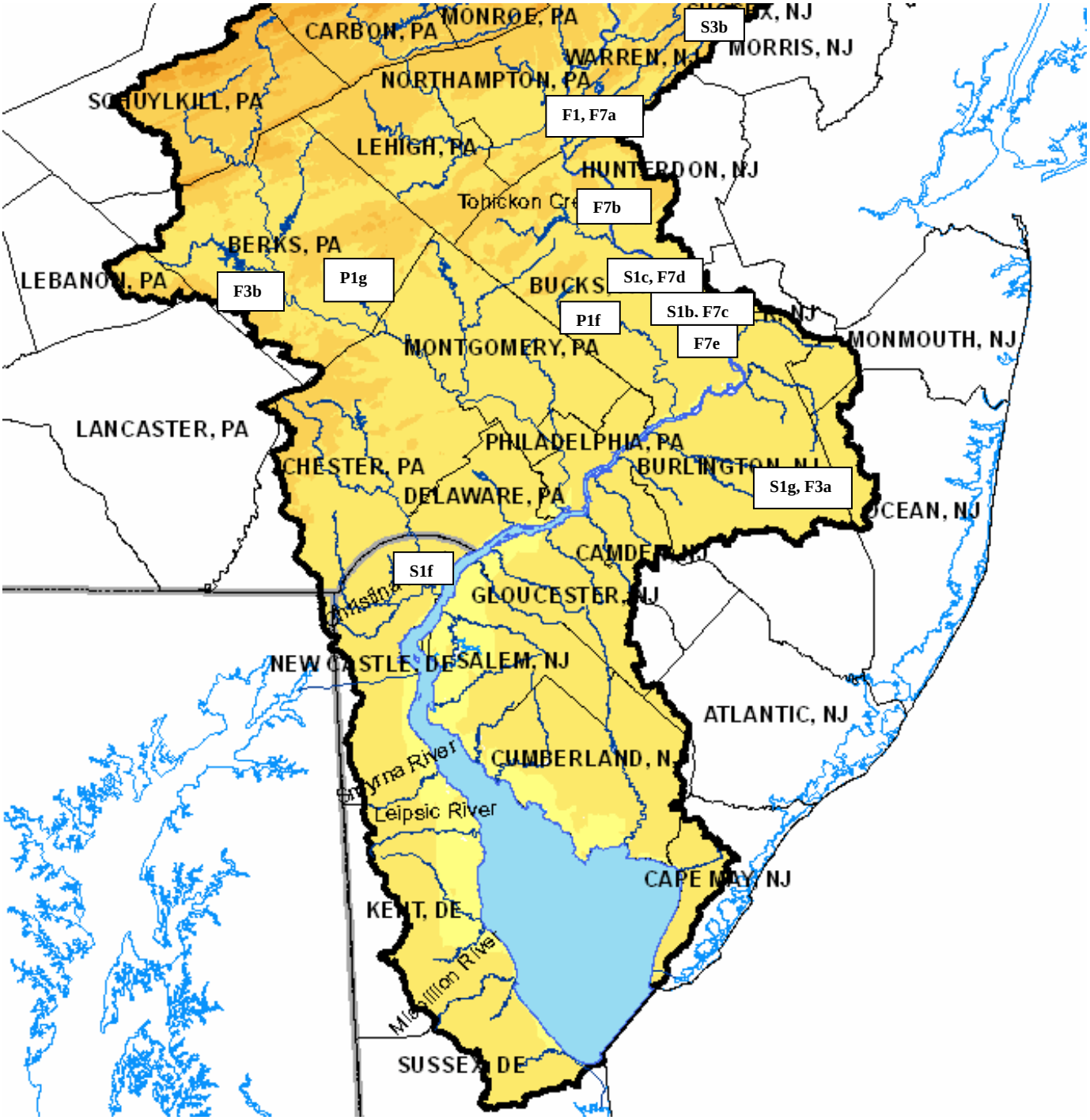
Appendix D includes two reference maps showing the relative location of flood warning improvements recommended in this report. The maps cover the northern and southern halves of the Delaware River Basin. Labeling of the improvements is consistent with the designations in the report. The general improvements, listed on page 15 of the report, are not tied to a particular location and are not shown on the maps. In addition, the evaluation required for Recommendation F-6 applies to small watersheds throughout basin and the recommendation is not mapped. For reference, Table D-1 provides a summary index of the improvements.

Figure D-1: Recommended Flood Forecast Improvements Upper Delaware River Basin



Recommended improvements are labeleled consistent with the Evaluation and Recommendations section of the report. Labels indicate the general location of the recommended improvements. Table D-1 provides and index of the recommendations.

Figure D-2: Recommended Flood Forecast Improvements Lower Delaware River Basin



Recommended improvements are labeleled consistent with the Evaluation and Recommendations section of the report. Labels indicate the general location of the recommended improvements. Table D-1 provides an index of the recommendations.

Table D-1: Index of Recommended Flood Forecast Improvements for the Delaware River Basin

Precipitation Gages

P1a New precipitation gage – Willowemoc Watershed in the Livingston Manor, NY vicinity
P1b New precipitation gage – Delaware River above Lackawaxen River near Barryville, PA
P1c New precipitation gage – Delaware River at Fishs Eddy, NY
P1d New precipitation gage – Mongaup River at Mongaup Valley, NY
P1e New precipitation gage – Neversink River at Bridgeville, NY
P1f New Precipitation gage – Neshaminy Creek at Rushland or Penns Park. PA
P1g New Precipitation gage – Manatawny Creek near Spangsville, PA
P2a Automated Snow Monitor – Equinunk vicinity, PA
P2b Automated Snow Monitor – Hawley vicinity, PA

Stream Gages

S1a Extend and maintain rating curve – Delaware River at Tocks Island/Delaware Water Gap
S1b Extend and maintain rating curve – Delaware River at New Hope/Lambertville, NJ
S1c Extend and maintain rating curve – Delaware River at Stockton, NJ
S1d Extend and maintain rating curve – Delaware River at Reigelsville, NJ
S1e Extend and maintain rating curve – Delaware River at Montague, NJ
S1f Extend and maintain rating curve – Brandywine Creek at Wilmington, DE
S1g Extend and maintain rating curve – North Branch Rancocas Creek at Pemberton, NJ
S2a Install new stream gage – Willowemoc Creek near Livingston Manor, NY
S2b Install new stream gage – Little Beaver Kill near Livingston Manor, NY
S3a Flood hardening – Flat Brook, NJ
S3b Flood hardening – Mucsonnetcong River at outlet to Lake Hopatcong, NJ
S4 Re-activate stream gage on Mongaup river downstream of Rio Reservoir

Flood Forecast Points

F1 Convert from crest only to flood only forecast point – Delaware River at Easton/Phillipsburg
F2a Establish a River Flood Forecast Point - West Branch Delaware River at Walton, NY
F2b Establish a River Flood Forecast Point - Neversink River at Goddefroy, NY
F3a Extend forecasting from 48 to 72 hours – North Branch Rancocas Ck. At Pemberton, NJ
F3b Extend forecasting from 48 to 72 hours – Schuylkill River at Reading, PA
F4a Establish site specific flood forecast point - East Branch Delaware River at Margarettville, NY
F4b Establish site specific flood forecast point – Dry Brook at Arkville, NY
F5a Evaluate Stage vs. Flood Impact – West Branch Delaware upstream of Hale Eddy
F5b Evaluate Stage vs. Flood Impact – East Branch Delaware upstream of Harvard
F5c Evaluate Stage vs. Flood Impact – Neversink River upstream of Bridgeville
F6 Develop Implementation Plan for SSHP. Include small watersheds throughout the basin in the evaluation.

Table D-1: Index of Recommended Flood Forecast Improvements for the Delaware River Basin

Flood Forecast Points (Continued)

F7a Evaluate for probability forecasting – Delaware River at Easton/Phillipsburg
F7b Evaluate for probability forecasting – Delaware River at Frenchtown
F7c Evaluate for probability forecasting – Delaware River at New Hope/Lambertville
F7d Evaluate for probability forecasting – Delaware River at Stockton, NJ
F7e Evaluate for probability forecasting – Delaware River at Washington's Crossing, PA

General Recommendations

G1 Update and maintain the gage and flood forecast point inventories and GIS on an annual basis.
G2 Develop public information documenting steps and considerations for establishing flood forecast points.
G3 Expand ice observation network
G4 Continue work to increase stream gage reporting frequency from 4 hours to 1 hour. Maintain existing telephone capabilities.
G5 Continue work to extend forecast to 72 hours for all river flood forecast points.
G6 Continue development of probability based ensemble forecasting.
G7 Continue development of distributed hydrologic modeling for application to small streams.

Appendix E: Recent Stream Gage and Forecast Point Upgrades in the Delaware River Basin by MARFC and the USGS

During the preparation of this report the NWS and USGS have continued to work towards improving services in the Delaware River Basin. Some of this recent work relates to activities outside the scope of this report as well as specific report recommendations. The following work was reported as of September 30, 2009.

Work reported by the NWS Middle Atlantic River Forecast Center.

- Migrated Riegelsville from a crest only forecast point to a flood only forecast point.
- Added a new headwater point for the Schuylkill River at Landingville, PA.
- Extended forecasts from 48 to 72 hours for the Delaware River at Riegelsville, PA. Frenchtown and Washington Crossing were converted from crest-only to flood-only points on 4/2/2009 (MARFC does not forecast discharge at Frenchtown and Washington Crossing, only stage. In the absence of stage-discharge ratings for these gages, it was determined that they were close enough to the existing forecast points at Riegelsville and Trenton, respectively, that satisfactory stage-stage relationships could be developed for the historical range of levels. The USGS does not yet operate a stage-only gage at the Washington Crossing Bridge. Stage readings are taken manually from a wire weight gage by the Delaware River Joint Toll Bridge Commission (DRJTBC). A continuous recorder will not be installed until after bridge construction is completed in the fall of 2010. The DRJTBC funds the operation of a stage-only gage with satellite telemetry at the Frenchtown gage.

As a direct response to flood warning recommendation FW-7 of the Interstate Flood Task Force Action Plan, the NWS completed the following forecast upgrades: 1) Conversion of the following river forecast points from flood only to daily forecast services: Schuylkill River at Reading, PA, Delaware River at Riegelsville, NJ, North Branch Rancocas Creek at Pemberton, NJ, Schuylkill River at Norristown, PA, Delaware River at Tock's Island, PA, Brandywine Creek at Wilmington, DE, the Neshaminy Creek at Langhorne, PA, West Branch of the Delaware River at Hale Eddy, NY, and Neversink River at Bridgeville, NY. 2) Conversion of services from crest only to flood only forecasting along the Delaware River at: Easton/Phillipsburg, NJ. Frenchtown, NJ, Stockton, NJ, New Hope/Lambertville, NJ, and Washington's Crossing, NJ.

The following were reported by the USGS Water Science Centers:

- The Delaware River gages at Trenton, NJ and Reigelsville, NJ were flood hardened during 2008.
- All gages in the New Jersey portion of the Delaware River Basin have been upgraded with high data rate radios.
- The USGS is in the process of increasing the transmission rates from stream gages from 4 hours to 1 hour intervals. As of September 2009, this work was completed for the New Jersey portion of the Delaware River Basin and is in progress in the other basin states.

As of September 2009, approximately 75 percent of the basins real time stream, stage, and lake level gages operated by the USGS transmitted at 1 hour intervals.

- The Mantua Creek at Pitman, NJ gage (01475000) will be relocated due to construction of a new bridge. The relocation is expected during 2009.