Enhancing Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, NJ, PA, and DE
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1.0 STUDY AUTHORITY

In FY06, the Energy and Water Development Appropriations Act (PL 109-103) was passed, directing the Secretary to conduct, "at full federal expense, comprehensive analyses that examine multi-jurisdictional use and management of water resources on a watershed or regional scale". In response to this Act, the Philadelphia District submitted a proposal for a potential project in the Delaware River Basin entitled "Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, NJ, PA and DE" which would primarily address flood damage reduction and water supply issues. This study was one of five selected nationwide and was funded in the amount of $1,105,000.

2.0 STUDY PROPOSAL

The original proposal sent to the Secretary's office was developed in conjunction with the Delaware River Basin Commission (DRBC). The proposal described the study purpose as a collaborative effort with stakeholders to advance efforts of the DRBC's Water Resources Plan or "Basin Plan" in order to achieve integrated water resources management.

In an effort to accomplish this goal, the proposal consisted of three interdependent initiatives: long term sufficiency of water in the Delaware River Basin, long-term flow management, and provision of timely and easily accessible information to the public. Below is a brief description of each of these tasks.

Task 1, Long term sufficiency of water, involved several components. These included recently completed groundwater availability analyses, demand projections, plans for storage upgrades, and long term flow management strategies for the Delaware River. This initiative incorporated an analysis of existing reservoir storage and proposed supply enhancement projects as well as identification of supply enhancement needs to protect water delivery obligations, ensure drought preparedness, and meet evolving conditions.

Task 2, Effective, long-term flow management, had three major subtasks: (1) estuary inflow evaluation; (2) multi-jurisdictional flood mitigation plan; and (3) re-evaluation of DRBC's approach to Water Supply User Costs. The estuary inflow evaluation consisted of linking a one-dimensional hydrodynamic/salinity model in the estuary with the Operational Analysis and Simulation of Integrated Systems (OASIS) flow model. The Flood Mitigation Plan involved a flood vulnerability analysis and management capabilities based on review of existing state and Federal data from past disasters, repetitive loss claims and flow regime information. Subtask 3, Re-evaluation of DRBC's approach to Water Supply User Costs, was to re-evaluate the current rule which allocates costs to users on a pro rata basis as a function of DRBC's Salinity Repulsion policy. Alternative approaches would potentially result in different cost allocations and revenues.

Task 3, Provision of timely and easily accessible information to the public, was to be accomplished through the development of a website which would include all data collected in Tasks 1 and 2 and would be the key to implementing Objectives 5.3.2 and Goal 4.2 of the

DRBC's Basin Plan "Increase sharing of data, information, and ideas among Basin stakeholders and reduce duplication of effort".

3.0 BACKGROUND

In order to better understand how the study's tasks relate to the over arching Basin Plan it is critical to understand DRBC's role in managing water resources for the Basin.

The Delaware River Basin Commission which was founded in 1961, partly out of concern for water allocations and out-of-basin transfers in the New York portion of the basin, is an interstate-federal agency responsible for managing the water resources in the 13,539 square-mile Delaware River watershed. The DRBC is a unique institutional framework consisting of the Governors of the four Basin States (New York, New Jersey, Pennsylvania and Delaware) and a presidential appointee, which currently is the Commander of the North Atlantic Division, U. S. Army Corps of Engineers (USACE). The Commander represents not only USACE's interests, but those of all Federal agencies within the Basin.

In 1962, the newly formed DRBC instituted a Comprehensive Plan, initially based on the plan developed by USACE (House Document 522) for the immediate and long-range development and use of the water resources of the Basin. The Comprehensive Plan includes a dozen multi-purpose reservoir projects, including Tocks Island, a large impoundment planned for the Delaware River main stem.

The DRBC's Comprehensive Plan has been continuously maintained since the Commission was established in 1961. This includes the addition, change or deletion of components to reflect changing needs of a dynamic region and its people. This maintenance requires the delicate balance of many very complex technical, institutional, and political interests and concerns.

The Comprehensive Plan actually consists of a body of documents expressing a systematic set of policies and programs for the future, and the means for carrying them out. This includes statements of policy, criteria, and standards as well as all public and private projects and facilities that are required for the optimum planning, development, conservation, use, management, and control of the Basin's water resources. These include impoundments and regulatory measures ranging from various physical features of land management in the uppermost headwater areas, through small detention reservoirs in the intermediate upstream areas, to major impounding reservoirs in the principal water course areas. These policies, programs and projects are expressed through narrative text, maps, charts, schedules, budgets, and other means.

The Comprehensive Plan is dynamic, being periodically revised. The Plan continues to grow in scope as the Commission regularly adds new policies, criteria, standards, and projects. The Comprehensive Plan, therefore, goes beyond a presentation of programs and plans and includes administrative decisions governing water resources use, development, and conservation. From time to time specific projects, facilities and programs are incorporated, deleted, or modified to reflect changing conditions, research results, and new technology. The DRBC receives and considers proposals for changes and additions to the Comprehensive Plan from all interested persons, organizations, and groups. Projects are reviewed with the main purposes of determining whether the project will have a substantial effect on the water resources of the Basin; or substantially impair or conflict with the Comprehensive Plan.

In addition to the Comprehensive Plan, in 1999, the DRBC was tasked with the development of a Water Resources Plan. Together the Governors of the four Basin States, along with USACE, EPA Region II and Region III, and the National Park Service signed a resolution challenging the Basin community to develop a unifying vision; a comprehensive Water Resources Plan for the Delaware River Basin. The Water Resources Plan for the Delaware River Basin or the "Basin Plan" was a long-range goal-based plan developed by DRBC through a multi-party collaborative process. The four Basin States, along with the Corps and other interested federal and state agencies, local governments, academia, private industry and other major stakeholders participated in the plan's development and pledged to support the implementation after it's completion in 2004.

The purpose of the Basin Plan was to identify a set of objectives and strategies for achieving goals and desired results, to better coordinate ongoing efforts to preserve, protect, and enhance the water resources of the Basin, and to identify additional needs for more effective water resources management. In order to address these objectives, the Basin Plan developed five key result areas (KRAs) which are listed below:

KRA 1 Sustainable use and Supply of water
KRA 2 Waterway Corridor Management
KRA 3 Linking Land and Water Resources Management
KRA 4 Institutional Coordination and Cooperation
KRA 5 Education and Involvement for Stewardship

4.0 EVOLUTION OF OBJECTIVES:

As the first major undertaking in terms of advancing the Basin Plan, the Corps met with DRBC and other agencies to further refine the study's objectives. The three objectives as stated in the original proposal and as described in Section 2.0, are as follows: (1) Long term sufficiency of water, (2) Effective Long term flow management, and (3) provision of timely and easily accessible information to the public. Through discussions and further review of the Basin Plan the team felt it was necessary to further refine objective (2) Effective long term flow management. This objective was broken into three separate objectives, thereby creating a total of five objectives or tasks for this study. These three objectives include a multi-jurisdictional approach to flood risk management, an estuary inflow evaluation and a re-evaluation of user supply costs to support flow management and equitable allocation goals.

Of these five goals, flood risk management and water supply constitute approximately 75% of the total study efforts with flood risk management totaling almost 50%. It was clear from the onset of this study that flood risk management would be a primary concern of many of the residents within the watershed after the severe flooding they encountered during the September 2004, April 2005 and June 2006 storm events.

Below is a figure showing how the KRAs from the Basin Plan translate to the goals of this study.

Task 1: Long Term Sufficiency of Water Supply	⇨	KRA 1: Sustainable Use and Supply
Task 2: Flood Risk Management	⇨	KRA 2: Waterway Corridor Management
Task 3: Estuary Inflow	⇨	KRA 1: Sustainable Use and Supply
Task 4: User Supply Costs	⇨	KRA 1: Sustainable Use and Supply
Task 5: GIS/Public Outreach	⇨	KRA 5: Education and Involvement for Stewardship

5.0 STUDY AREA

The Delaware River is the longest "free-flowing" river in the eastern United States. It originates on the western slopes of the Catskill Mountains in eastern New York, at elevations ranging from 2,500 and 3,000 feet, mean sea level. The West Branch of the Delaware River and the East Branch of the Delaware River flow southwesterly and join at Hancock, New York, to form the Delaware River. From this point, the river flows southeasterly along the New York-Pennsylvania boundary to Port Jervis, New York where it emerges into the valley at an elevation of approximately 420 feet, thence flows southwesterly to Stroudsburg, Pennsylvania, where it turns sharply to the southeast and cuts through the mountains at the Delaware Water Gap, and continues in this general direction to Trenton, New Jersey. Its character changes at Trenton, where it flows over a series of rock ledges at the Fall Line and enters the tidal estuary. From Trenton to the vicinity of Wilmington, Delaware, the river flows southwesterly along the Fall Line, then turns oceanward to enter Delaware Bay at Liston Point, and finally reaches the ocean between Cape May, New Jersey and Cape Henelopen, Delaware. Below Port Jervis, New York, the river forms the boundary between New Jersey on the east, and Pennsylvania and Delaware on the West.

Between Hancock and Port Jervis, the river is joined by the Lackawaxen River in Pennsylvania and Mongaup River in New York. The Neversink River enters from the New York side at Port Jervis. No large tributaries enter the river between this point and the Delaware Water Gap. Downstream to Trenton, the Lehigh River enters from the west at Easton, Pennsylvania, and drainage from the east in New Jersey is mainly by the Paulins Kill, Beaver Brook, and the Pequest and Musconetcong Rivers. Other main tributaries from the west include the Schuylkill River at Philadelphia, Pennsylvania and the Christina River at Wilmington, Delaware.

The river is fed by 216 tributaries, the largest being the Schuylkill and Lehigh Rivers in Pennsylvania. In all, the basin contains 13,539 square miles, draining parts of Pennsylvania (6,422 square miles or 50.3 percent of the basin's total land area); New Jersey (2,969 square miles, or 23.3%); New York (2,362 square miles, 18.5%); and Delaware (1,002 square miles, 7.9%).

Almost ten percent of the nation's population relies on the waters of the Delaware River Basin for drinking and industrial use, yet the basin drains only four-tenths of one percent of the total continental U.S. land area.

Two stretches of the Delaware River, extending 107 miles from Hancock, N.Y. to the Delaware Water Gap, have been included in the National Wild and Scenic Rivers System. The two designated river corridors total 124,929 acres.

Currently the river has a 40’ channel as far inland as Philadelphia, allowing oceangoing vessels into its ports and a 35’ channel to Trenton, New Jersey. The Chesapeake and Delaware Canal connects the Delaware River below Wilmington Delaware, with Chesapeake Bay. The canal is also navigable by oceangoing vessels.

The Delaware River is the political divide between New York, Pennsylvania, New Jersey and Delaware. The land within these four states is further subdivided into 42 counties, and 838 cities, town, boroughs and townships. Congressional interest includes: Senators: Clinton (NY), Schumer (NY), Lautenberg (NJ), Menendez (NJ), Casey (PA), Specter (PA) Biden (DE) Carper (DE), Representatives Castle (DE-AL), Andrews (NJ-1), LoBiondo (NJ-2), Saxton (NJ-3), Smith (NJ-4), Garrett (NJ-5), Ferguson (NJ-7), Frelinghuysen (NJ-11), Holt (NJ-12), Hall (NY-19), Gillibrand (NY-20), Hinchey (NY-22), Brady (PA-1), Fattah (PA-2), Gerlach (PA-6), Sestak (PA-7), Murphy (PA-8), Carney (PA-10), Kanjorski (PA-11), Schwartz (PA-13), Dent (PA-15), Pitts (PA-16), Holden (PA-17).

6.0 STAKEHOLDER INVOLVEMENT

The primary stakeholder in this project was the DRBC and its Commissioners, which are comprised of the Governors of the four Basin States and a presidential appointee, representing all Federal Agencies within the basin.

The DRBC was involved in every aspect of this project from problem identification though the development of potential alternatives. As a lead water resource agency in the Basin, the DRBC helped coordinate study efforts with other ongoing studies such as Pennsylvania and New Jersey’s State Water Plans and other efforts. Team members also discussed issues and study findings with members of DRBC’s many committees, such as the Watershed Advisory Committee and Flood Advisory Committee. These committees are comprised of Federal, state, and local representatives as well as members of the public and private industry.

Other major stakeholders involved in this study include the U.S Geological Service (USGS), Federal Emergency Management Office (FEMA), New Jersey Department of Environmental Protection (NJDEP) National Weather Service, (NWS) and the Corps’ Hydrologic Engineering Center (HEC). In the true spirit of collaboration, each of these agencies provided not only their expertise to the project but also provided much of their own funding.

A few examples of these collaborative efforts include the following: discharge-frequency analysis, review of repetitive loss claims, and an updated regional skew analysis.

The discharge-frequency analysis involved work from the USGS, FEMA, NJDEP, NWS and DRBC, all of which worked closely with the Philadelphia District's Hydraulic & Hydrologic Branch to conduct a discharge-frequency analysis on eight gaging stations on the Delaware River in order to update the analysis conducted in the Delaware River Basin Study Report dated 1984.

FEMA also assisted with the repetitive loss claims which were used in further refining the study area for certain tasks, including the development of a solution matrix and the structure inventory. The Corps' Hydrologic Engineering Center also conducted a regional skew analysis, again to update the 1984 Basin Study.

7.0 EXPECTATIONS

The expectations of the stakeholders were clearly defined in the beginning of the process. The goal of this study was to further advance the efforts of the DRBC's Basin Plan through a reconnaissance level of effort in addressing water resource needs throughout the Basin. The team was to provide products and tools which could be used throughout the Basin. Some of these tools include integrated water resource computer models, structure inventory data (which is currently being used for flood risk management studies such as the Delaware River Basin Comprehensive, NJ feasibility study and the Upper Delaware feasibility study and for flood warning/forecasting tools such as the Delaware River Basin Comprehensive Watershed Flood Management Plan feasibility study), updated discharge-frequency curves and an updated skew analysis.

The following sections will describe in more detail the work that was done to develop each of these tools and identify alternatives for not only flood risk management but also long term sufficiency of water supply through the year 2030.

8.0 TASK 1: LONG TERM SUFFICIENCY OF WATER SUPPLY THROUGH THE YEAR 2030

8.1 Problem Identification. Water supply and storage have always been a key concern for the Basin but particularly during times of drought, especially during the 1930's and 1960's and more recently but to a lesser extent from 1981 through 1983. With water shortages of these magnitudes, total water use or non-consumptive use becomes a problem to many areas because the demand for water exceeds the available supply. Some of these problems are local, such as individual well failure or contamination. Other problems are area-wide such as aquifer depletion from excessive withdrawal or contamination. As a result, allocated diversions and reservoir releases are cut back, which spreads the problem beyond the geographical limits of the Basin. This situation intensifies due to groundwater failures and salinity intrusion into the already depleted sources of fresh water. Problems with un-sustained stream flow, treated waste assimilation, acid mine drainage, salinity intrusion, and even impeding of fish migration and production then result. Task 1 is aimed at addressing these concerns by looking at long-term supply and demand.

8.2 Water Supply/Demand Analysis. Planning and managing the water resources of the Delaware River Basin requires dealing with an extremely complex system of surface and ground waters. In an effort to more effectively evaluate water supply, the watershed was broken down to 147 sub-basins, as delineated by the USGS in a recent project undertaken to quantify ground water availability.

Once the Basin was broken into manageable watersheds, ground and surface water demands were compared separately against an assessment of ground and surface water availability thresholds. However, as available water supplies (and demands) are inherently dependent on climate conditions, a range of water availability thresholds were also developed. Once water supply and demand projections were calculated and water conservation plans were evaluated, areas of critical need were identified, and potential alternatives were assessed for the critical sub-basins and the three major rivers; the Delaware, Schuylkill and Lehigh.

8.3 Results of Watershed Analysis. The results of the basin wide water supply-demand evaluation identified several priority watersheds where the supply-demand balance indicated possible water supply problems. The location of these watersheds are shown in Figure 8.1 along with a graphic of the projected water use in each watershed that shows which sectors are driving water use. In total, eight watersheds have been identified, all of which are located in the lower half of the Basin.

Overall, in the year 2030, five of the watersheds show a potential problem based on ground water use, and three show a potential problem based on surface water use. No watershed was given priority status based on both ground water and surface water conditions. In general, the drivers of water demand in these watersheds fall into two categories: public water supply (due to projected population growth) and irrigation-related uses.

8.4 Results of River Analysis. The river analysis collected data for surface water withdrawals and consumptive use for each withdrawal point along the three rivers and deficits were calculated for each river. The accumulated additional flow needed at the downstream end of each river was used as the minimum value that any proposed water supply alternative or combination of alternatives had to meet. Figure 8.2 shows the location of each surface water withdrawal point along the three rivers.

As expected, deficiencies increased from the year 2003 to 2030 with most of the increase coming from the power sector. The Delaware River had one power-sector withdrawal point being identified as deficient in the vicinity of Trenton, NJ. The Schuylkill River increased from one to three withdrawal point deficiencies (again due to power-sector withdrawals) and the Lehigh River had no deficient withdrawal points through the year 2030.

Along with calculating deficiencies on the rivers through the year 2030, deficiencies were also calculated for several alternatives to simulate “drought-like” conditions. The results of this analysis showed that the number of withdrawal points in deficit increased along with the total magnitude of the deficit at the downstream end of the analysis.

Figure 8.1
Priority Watersheds

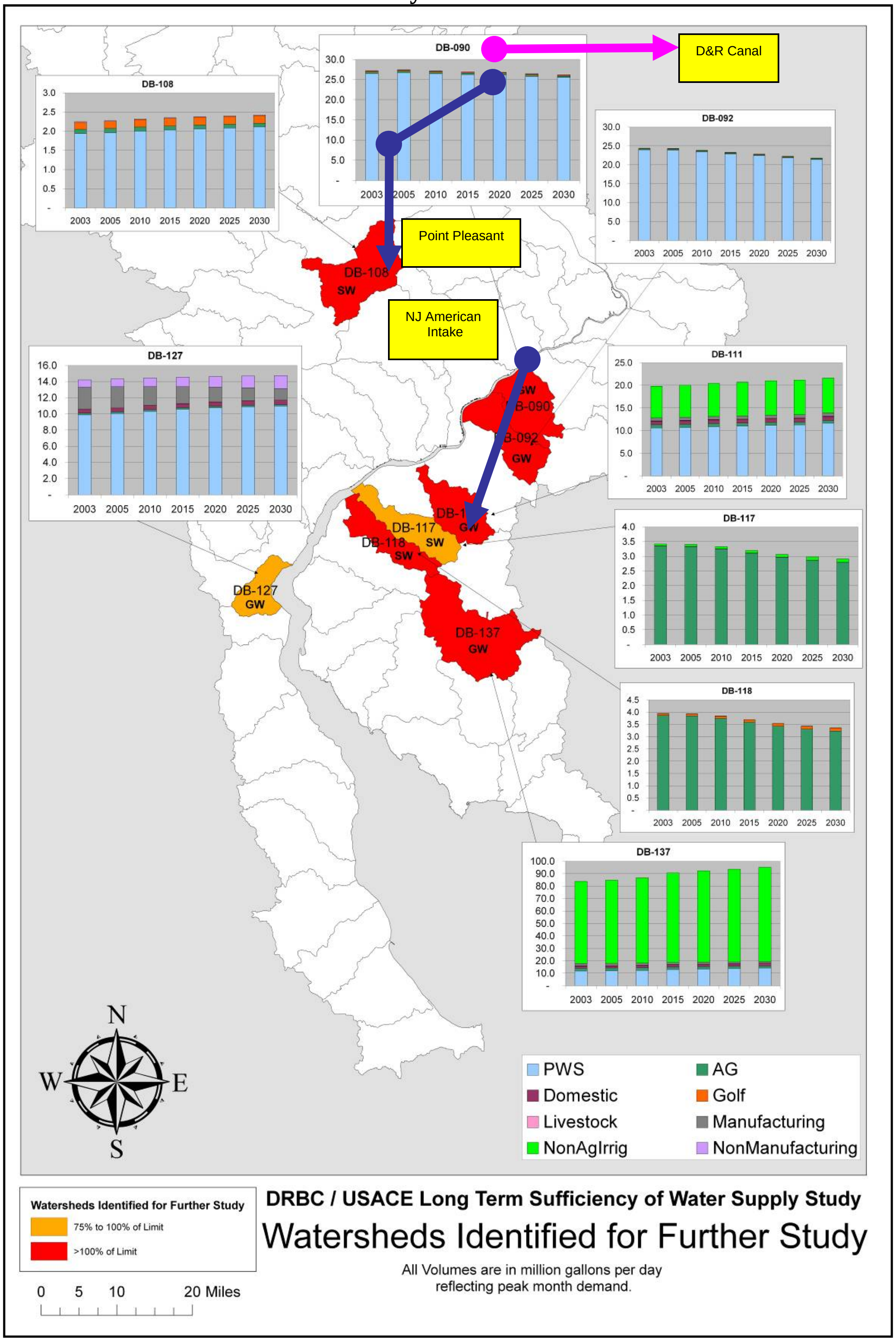


Figure 8.2
Surface Water Withdrawal Points for Schuylkill, Lehigh and Delaware Rivers

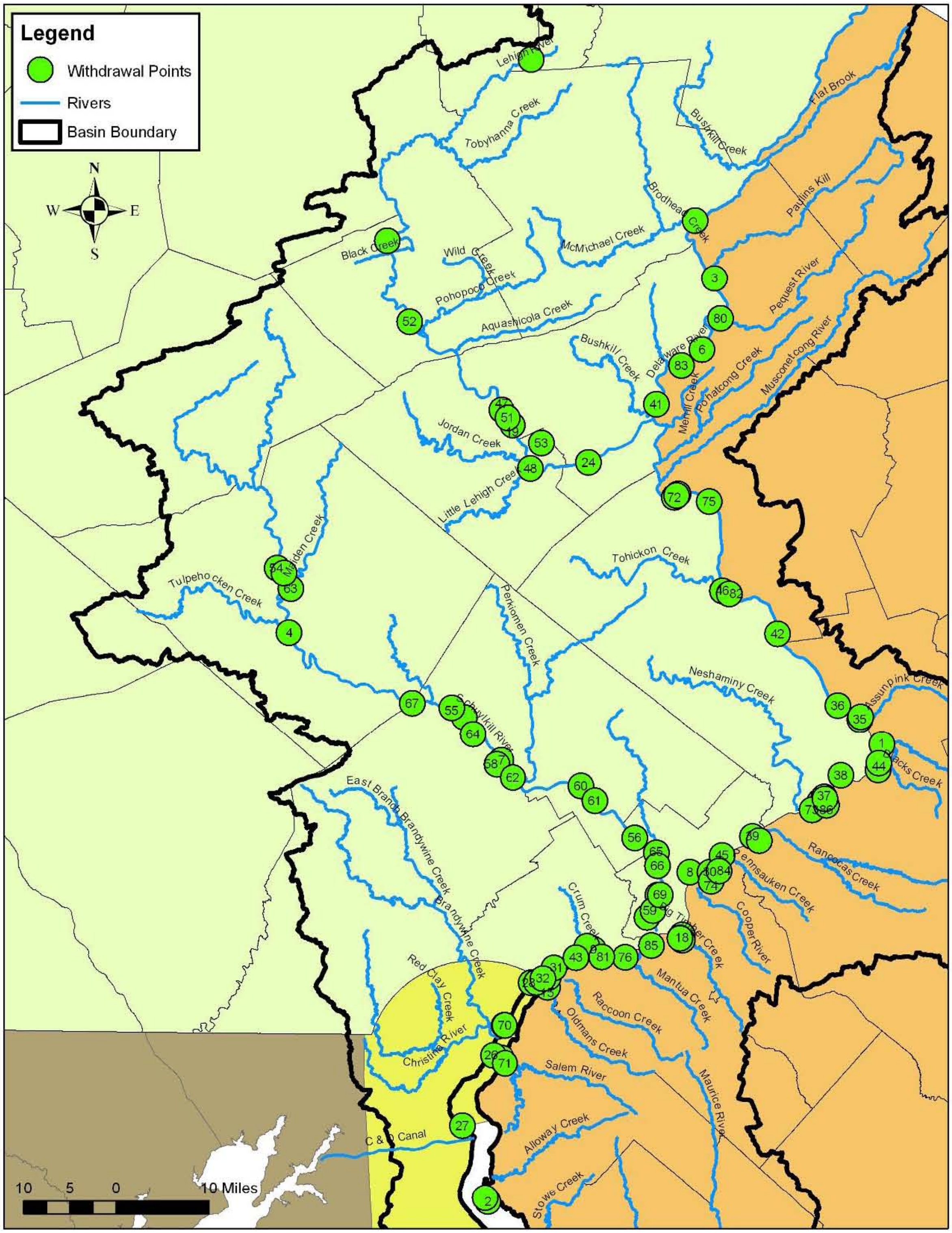


Figure 8.2

8.5 Potential Alternatives for Watershed and River Deficits. Several alternatives were examined that could potentially meet the surface and groundwater deficiencies previously identified at the high priority watersheds and along the Schuylkill and Delaware Rivers. Potential solutions were divided into two parts; expand supply alternatives and curtail demand alternatives.

Alternatives that expanded supply included such things as: aquifer storage and recovery (ASR), expansion of municipal systems, reuse of waste and storm water, mine reclamation, desalination, river diversions, and reservoir storage. Alternatives that curtail demand include: improved water accountability with reduced infrastructure losses, additional conservation, change water allocations, new regulations, and improved irrigation techniques.

For the purpose of this study only two alternatives were examined in detail that could meet the water supply deficiencies outlined previously in the Basin. These alternatives included diverting water from the Delaware River in order to alleviate deficits in nearby watersheds and increased reservoir storage in the Schuylkill River Basin. All other potential alternatives should be evaluated in future comprehensive Basin-wide water supply "feasibility-level" studies.

8.5.1 Delaware River Diversion. Two existing diversions were utilized in the analysis; New Jersey American Water Company's Tri-County Regional Pipeline, and the Point Pleasant Pumping Station. The alternatives investigated in this report were to increase the amount of water that each diversion takes from Delaware River in order to alleviate the deficits projected in year 2030 and potential deficits computed under simulated drought conditions. The increased diversion through the Tri-County Regional Pipeline would address the deficits computed for watersheds DB-90, DB-92, DB-111, DB-137, DB-117, and DB-118 in New Jersey. Water diverted by the Point Pleasant Pumping Station was assumed to alleviate the deficits calculated in watershed DB-108 and the Lower Schuylkill River below Perkiomen Creek in Pennsylvania.

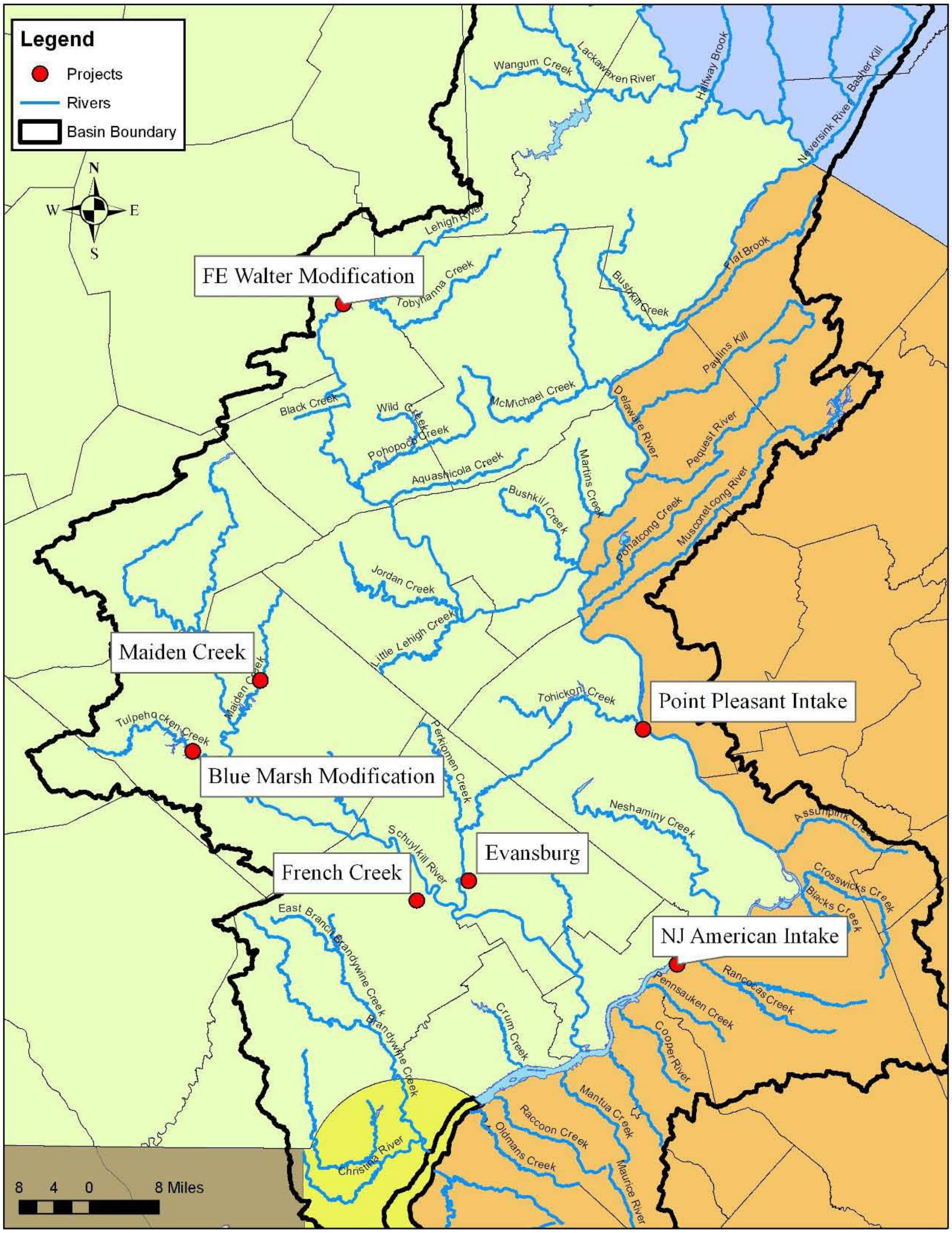
The analysis for the Delaware River in the year 2030, with the additional water being diverted from Point Pleasant and the Tri-County Regional Pipeline intakes, shows that no additional downstream withdrawal point becomes deficient when Point Pleasant and NJ American's Tri-County Regional Pipeline divert the 213 mgd total in order to meet the projected deficits in 2030 for Pennsylvania and New Jersey respectively. The only deficiency is at withdrawal point #1.

8.5.2 Reservoir Storage in the Schuylkill River Basin. Three reservoir projects identified in H.D. 522 were acknowledged as potential projects to consider for water supply flow augmentation in this analysis. These reservoirs, shown on Figure 8.3, include Maiden Creek, French Creek, and Evansburg. These projects were included as part of the 19 major dam projects recommended in H.D. 522 but never constructed for various reasons. However, with the increased demand for water by 2030 under drought scenarios these reservoirs should again be considered. In addition to these three reservoirs, modifying the existing Blue Marsh Reservoir should also be considered for water supply flow augmentation for the drought sensitivity analysis.

8.6 Need for Drought Analysis. Although the analysis showed no additional reservoir storage was necessary for water supply needs, flow augmentation on the Lehigh and Delaware Rivers as a result of modifying the existing FE Walter Reservoir was examined briefly. It was projected that 164 mgd of additional supply over a span of 120 days could be added to the Lehigh and Delaware Rivers from FE Walter Reservoir Modification. Although the analysis conducted for this report did not show a need for flow augmentation from FE Walter for water supply, it should be noted that the analysis did not account for the drought of record.

A comprehensive drought analysis that incorporates the drought of record along with possible synthetic droughts that could be worse than the drought of the record should be conducted and an examination of FE Walter Reservoir Modification should be done in this comprehensive basin-wide drought analysis. Also, needed is a drought sensitivity analysis of the other 137 watersheds that were not identified as being a high priority for the year 2030. This analysis was restricted to the ten watersheds identified as being deficient using projections out to the year 2030, and only examined reducing water availability in those ten identified watersheds in the lower portion of the Basin. It would be reasonable to expect that by reducing $Q_7 10$ and the 25-yearr baseflow by 25%, 50%, and 75% in the other 137 watersheds that additional deficits in the Basin would have to be addressed, and that FE Walter Reservoir Modification could be a possible solution to meet those deficits.

Figure 8.3 Proposed Projects



9.0 TASK 2: FLOOD RISK MANAGEMENT

9.1 Problem Identification. The Delaware River Basin has a long history of flooding dating back to the late 1800's. The Basin like all watersheds has been impacted by flooding because the people live, work, travel, and recreate in floodplains, and because their land use activities have increased the runoff from watersheds and changed the hydraulics of the floodplain itself.

Flooding in the Delaware River Basin is a result of excessive runoff produced by precipitation from either extra-tropical or tropical storms with the most damaging events being caused by tropical storms or remnants of hurricanes. The most widespread riverine flood event in the Delaware River Basin occurred in 1955, over fifty years ago. The National Weather Service has estimated repetition of this record flood event would cause $2.8 billion in damages in the Basin in today's dollars. And although flooding of this scope and magnitude are rare, damage and loss of life from more localized flooding occurs frequently. The remnants of Tropical Storm Allison caused $35 million in damages and resulted in seven deaths in Bucks and Montgomery Counties, PA in June of 2001, and more recently, the events of 2004, 2005 and 2006 also had devastating effects on the Basin causing a total of close to $745 million worth of damage in the states of New York, New Jersey and Pennsylvania.

Below are photos of Lambertville, NJ showing the extent of flooding during the 2006 event.


Figure 9.1 Lambertville-New Hope Bridge

Figure 9.2 Lambertville

Due to the sudden onslaught of storm events in the past four years this study took the opportunity to join forces with the Delaware River Basin's Interstate Flood Mitigation Task Force, FEMA, USGS, DRBC, HEC, DRBC's Flood Advisory Committee and other agencies and organizations in order to address some of the flooding issues within the Basin.

The Interstate Flood Mitigation Task Force was assembled in October 2006 and is comprised of 31 members including legislative, executive, federal, state and local government agencies as well as not-for-profit organizations. Through the task force, over

45 recommendations were made for a proactive, sustainable, and systematic approach to flood risk management. Recommendations address the following areas: Reservoir operations, structural and non-structural measures, storm water management, floodplain mapping, floodplain regulations and flood warning. Some of these recommendations, including the development of flood warning systems, are addressed later in this report.

Products from the flood risk management task include: (1) updated stage frequency curves, (2) updated skew analysis (3) identification of ten priority communities based on a review of FEMA's repetitive and severe repetitive loss claims (4) structure inventory for priority communities (5) potential solution matrix for priority communities.

The data collected, as part of this study, for the structure inventory is currently being used in the Delaware River Basin Comprehensive, NJ Feasibility Study, the Delaware River Basin Comprehensive, Watershed Flood Management Plan Feasibility Study and the Upper Delaware River Watershed, Livingston Manor Feasibility Study. The updated stage frequency curves and skew analysis will also be used by the Corps and USGS for future studies.

9.2 Discharge-Frequency Analysis. While this study was focusing efforts on updating the discharge-frequency analysis presented in Technical Appendix C of the Delaware River Basin Study Report, dated 1984, the Federal Emergency Management Agency (FEMA) had requested that the U.S. Geological Survey (USGS) update the frequency discharge values as a result of the three major flood events from September 2004 to June 2006 so that the flood insurance studies could be updated accordingly.

In order to prevent a duplication of efforts, the Corps in cooperation with USGS, FEMA, NJDEP and DRBC worked to update the discharge-frequency analysis for eight gaging stations on the Delaware River. The location of the eight gaging stations can be seen in Figure 9.3. Table 9.1 also shows USGS Station Number, Station Name, Drainage area and period of record in water years for these gages.

Throughout the process, the Corps and the USGS followed their own agency procedures to update the discharge-frequencies. The procedures between the two agencies were very similar in nature with the only notable difference being how to handle upstream regulation affects at the gage locations. Throughout the process the Corps and the USGS worked together extensively in order to come up with a set of discharge-frequency values that both agencies could agree upon.

The results of the Corps' and USGS' analyses were presented at a Delaware River Coordinating meeting which included representatives of the Corps, USGS, FEMA, FEMA contractors, Delaware River Basin Commission, New Jersey Department of Environmental Protection, and New Jersey Highlands Council. The result of this meeting was a consensus to adopt the proposed flood frequency figures developed by USGS for use in on going flood insurance studies and Corps' flood risk management studies. The results of these analysis are shown in Tables 9.2-9.4.

Figure 9.3
Delaware River USGS Streamflow Gaging Stations

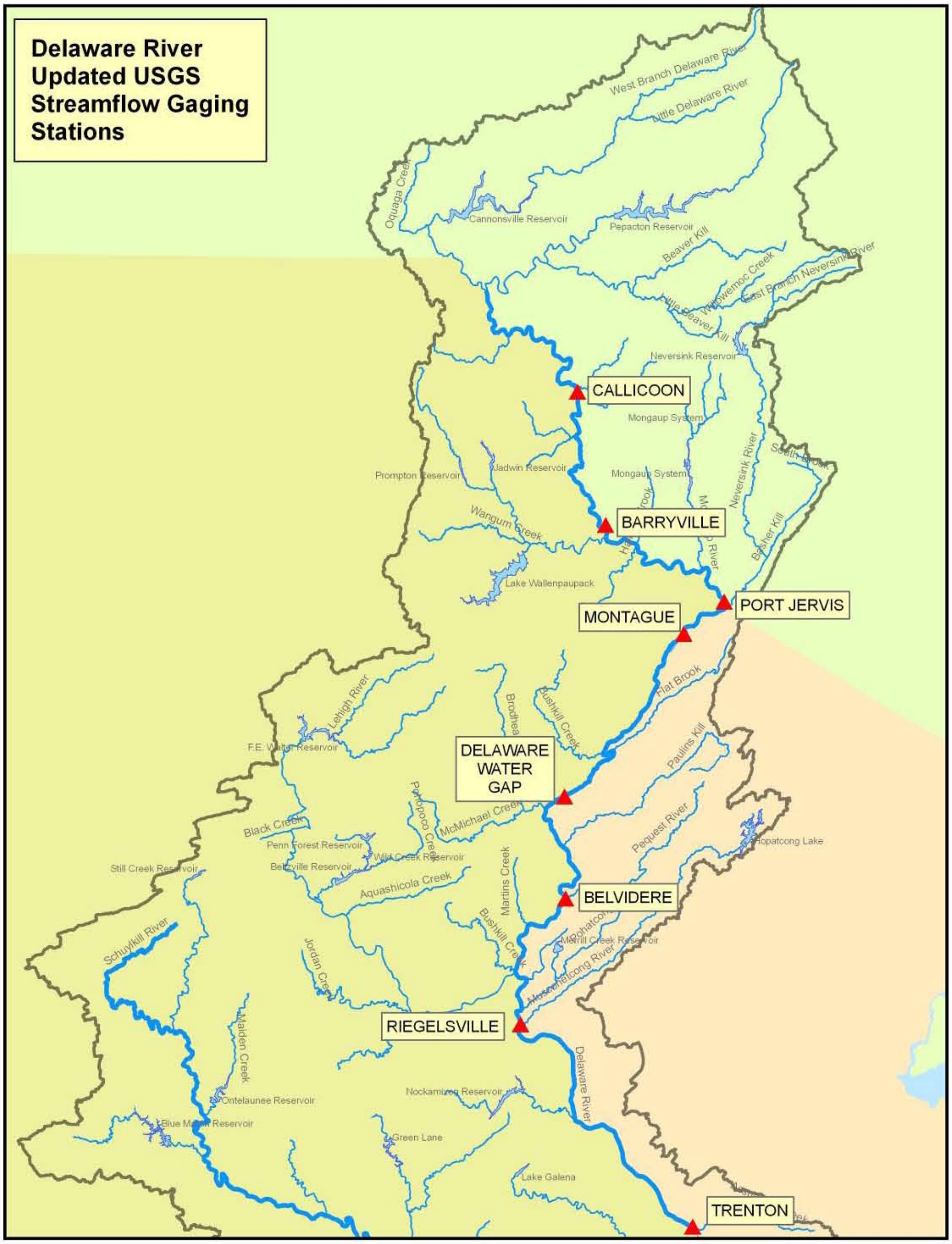


Table 9.1
Updated Delaware River Gaging Stations

USGS Station Number	Station name	Drainage area, in mi^2	Period of record, in water years[1]
01427510	Delaware River at Callicoon, N.Y.[2]	1,820	1976-2006
01428500	Delaware River above Lackawaxen River near Barryville, N.Y.	2,020	1941-2006
01434000	Delaware River at Port Jervis, N.Y.	3,070	1904-2006
01438500	Delaware River at Montague, N.J.[3]	3,480	1904, 1936-2006
01440200	Delaware River near Delaware Water Gap, Pa.	3,850	1955, 1964-1996, 2002-2006
01446500	Delaware River at Belvidere, N.J.	4,535	1904, 1923-2006
01457500	Delaware River at Riegelsville, N.J.	6,328	1841, 1904, 1907-2006
01463500	Delaware River at Trenton, N.J. [3]	6,780	1904, 1913-2006

[1]Water years run from October 1 to September 30 and are designated by the ending year.
[2]Records for station 01427410 and 01427510 were combined for the analysis for 01427510.
[3]Records for station 01462000 and 01463500 were combined for the analysis for 01463500.

Table 9.2
Unregulated Discharge Frequency Values for Delaware River from the Corps

USGS		Recurrence Interval							
Station Number	**Station Name**	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**200-year**	**500-year**
01427510	Delaware River at Callicoon, N.Y.	52,000	81,000	103,000	134,000	158,000	189,000	220,000	264,000
01428500	Delaware River above Lackawaxen River near Barryville, N.Y.	56,000	84,000	105,000	133,000	156,000	183,000	213,000	254,000
01434000	Delaware River at Port Jervis, N.Y.	78,000	120,000	149,000	191,000	223,000	261,000	300,000	354,000
01438500	Delaware River at Montague, N.J.	83,000	128,000	160,000	207,000	245,000	285,000	331,000	395,000
01440200	Delaware River near Delaware Water Gap, PA.	91,000	142,000	172,000	222,000	262,000	301,000	347,000	409,000
01446500	Delaware River at Belvidere, N.J.	94,000	140,000	172,000	221,000	259,000	296,000	341,000	404,000
01457500	Delaware River at Riegelsville, N.J.	108,000	159,000	194,000	246,000	290,000	328,000	372,000	432,000
01463500	Delaware River at Trenton, N.J.	109,000	160,000	195,000	247,000	290,000	326,000	374,000	441,000

Table 9.3
Regulated Discharge Frequency Values for Delaware River from the Corps

USGS Station Number	Station Name	Recurrence Interval 2-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
01427510	Delaware River at Callicoon, N.Y.	38,000	59,000	75,000	98,000	116,000	139,000	162,000	194,000
01428500	Delaware River above Lackawaxen River near Barryville, N.Y.	42,000	64,000	80,000	102,000	120,000	141,000	164,000	196,000
01434000	Delaware River at Port Jervis, N.Y.	56,000	87,000	108,000	139,000	162,000	190,000	219,000	258,000
01438500	Delaware River at Montague, N.J.	62,000	96,000	120,000	155,000	183,000	213,000	248,000	296,000
01440200	Delaware River near Delaware Water Gap, PA.	69,000	108,000	131,000	169,000	200,000	230,000	265,000	312,000
01446500	Delaware River at Belvidere, N.J.	74,000	111,000	136,000	175,000	205,000	234,000	270,000	320,000
01457500	Delaware River at Riegelsville, N.J.	87,000	129,000	158,000	200,000	236,000	267,000	303,000	352,000
01463500	Delaware River at Trenton, N.J.	90,000	132,000	161,000	204,000	240,000	270,000	310,000	365,000

Table 9.4
Regulated Discharge Frequency Values for Delaware River from the USGS[1]

USGS Station Number	Station Name	Recurrence Interval							
		2-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
01427510	Delaware River at Callicoon, N.Y.	40,100	62,300	78,600	101,000	118,000	137,000		185,000
01428500	Delaware River above Lackawaxen River near Barryville, N.Y.	44,100	67,100	83,600	106,000	124,000	142,000		188,000
01434000	Delaware River at Port Jervis, N.Y.	59,500	91,000	114,000	147,000	173,000	201,000		273,000
01438500	Delaware River at Montague, N.J.	65,200	101,000	127,000	164,000	194,000	226,000		308,000
01440200	Delaware River near Delaware Water Gap, PA.	71,800	110,000	139,000	178,000	210,000	244,000		332,000
01446500	Delaware River at Belvidere, N.J.	76,900	116,000	145,000	184,000	215,000	248,000		334,000
01457500	Delaware River at Riegelsville, N.J.	92,300	136,000	167,000	208,000	241,000	274,000		358,000
01463500	Delaware River at Trenton, N.J.	94,900	138,000	169,000	211,000	245,000	280,000		372,000

[1]Schopp, R.D., and Firda, G.D., 2008, Flood magnitude and frequency of the Delaware River in New Jersey, New York, and Pennsylvania: U.S. Geological Survey Open-File Report 2008-xxxx.

8.3 Skew Analysis. As part of this study, HEC conducted a generalized skew study in order to update the old regional skew maps. HEC last did a basin wide regional skew analysis in 1983 (HEC, Special Projects Memo No. 83-1) and the USGS and Corps agreed that the skew coefficients from the 1983 HEC study were outdated due to the changes within the basin.

Generalized skew coefficients are needed for a discharge-frequency analysis both at gaged sites and at ungaged sites. The skew analysis is ongoing and results of the analysis will be added to this report at a later date. The Corps will be sharing the skew analysis with all four USGS District Offices within the Basin when it becomes available so that the USGS can incorporate the results in future frequency-discharge analyses they conduct.

8.4 Identification of Priority Communities. In order to conduct a meaningful structure inventory the team used the same 147 sub-basin delineation as was used for the water supply task. Selection of this scale was appropriate for this regional study of the Delaware River Basin as it will provide a more detailed regional picture than what has been done before for the basin with previous studies and will show the regional magnitude and location of areas which have suffered repetitive flood damages in the past.

Once the basins were identified, an analysis of FEMA-designated repetitive and severe repetitive loss properties in the Delaware River Basin was conducted to identify critical floodprone areas. The analysis was based upon data received from FEMA regarding closed claims processed as part of the National Flood Insurance Program from January 1, 1978 to February 28, 2007. A limitation of the analysis is that it does not consider flood damages from uninsured structures. The analysis separately considered repetitive loss and severely repetitive loss structures. A repetitive loss property as defined by FEMA is a property that suffers two or more losses in which FEMA paid more than $1,000 for each loss. The losses also must be within 10-years of each other and be at least 10 days apart. A severely repetitive loss property as defined by FEMA is a property that suffers four or more losses with each loss exceeding $5,000 or when there are two or more losses in which the payout exceeded the property value.

The number of properties along with the dollar amounts in payouts made by FEMA were tabulated by basin. The categories used to evaluate each basin were:

- The number of structures.
- The number of structures per basin square mile.
- The total amount of payouts made.
- The total amount of payouts made per basin square mile.

Rankings were assigned for each category with a ranking of “1” being assigned to the basin with the highest value. A composite ranking for each basin was computed by taking an average ranking for all four categories combined. This was done for both repetitive loss and severely repetitive loss databases.

GIS was used extensively in the analysis. GIS was used to aggregate all of the individual claims by basin in order to come up with the number of claims and payout amounts by basin. GIS was also used to segregate the basin-wide claim data by municipality within each basin and was used to create all the maps. The data was segregated by municipality within each basin for informative purposes since some municipalities exist in two or more basins. Data was not aggregated strictly by municipality. That analysis was previously done by DRBC and can be found on their website. Tables 9.5-9.6 summarize the highest ranked basins for repetitive losses and severely repetitive losses respectively. Figures 9.4-9.5 graphically show the highest ranked basins for each database.

Basin DB-076 had both the highest repetitive and severely repetitive losses in the analysis by a large margin over other basins. Basin DB-076 is in Pennsylvania along the Delaware River and includes Lower Makefield, Upper Makefield, Solebury Townships along with the Boroughs of New Hope and Yardley. There were a total of 397 repetitive loss claims totaling $52.7 million dollars. The same basin had a total of 92 severe repetitive loss property claims that totaled close to $26 million dollars. These claims were from 1978 to 2007. The next closest basin for repetitive loss claims was DB-072 which had 179 property claims totaling $18.4 million dollars. Basin DB-072 is along the Delaware River and includes the townships of Bridgeton, Durham, Tinicum, and Williams in Bucks and Northampton counties in Pennsylvania. Basin DB-054 was the second highest severely repetitive loss basin in the analysis with 38 property claims totaling $8 million. It is along the Delaware River and covers the townships of Harmony and Pohatcong along with the city of Phillipsburg in New Jersey. Table 9.7 shows a breakout of the top ten municipalities in the basin with the highest number of designated loss properties.

Table 9.5

Repetitive Loss Rankings By Basin

Basin	No. of Properties	Total Payouts	No. of Properties By Basin Sq. Mi.	Total Payouts By Basin Sq. Mi.	No. of Properties Ranking	Total Payout Ranking	No. of Properties By Basin Sq. Mi. Ranking	Total Payouts By Basin Sq. Mi. Ranking	Overall Ranking
DB-076	397	$52,691,594	6.34	$841,665	1	1	1	1	1.0
DB-072	179	$18,464,204	2.86	$294,819	3	3	2	2	2.5
DB-089	120	$15,429,533	2.14	$274,527	6	4	5	3	4.5
DB-109	166	$21,277,991	1.28	$164,560	4	2	9	8	5.8
DB-053	106	$11,976,080	2.21	$249,450	8	8	4	4	6.0
DB-077	268	$10,940,292	2.80	$114,362	2	9	3	11	6.3
DB-054	112	$15,126,778	1.40	$189,314	7	5	7	7	6.5
DB-110	87	$13,186,735	1.37	$207,062	10	7	8	6	7.8
DB-112	126	$7,167,101	1.54	$87,871	5	13	6	18	10.5
DB-123	54	$13,771,330	0.96	$245,697	18	6	14	5	10.8
DB-078	67	$7,967,387	1.24	$147,531	12	12	11	10	11.3
DB-068	56	$8,612,556	0.96	$148,007	16	10	15	9	12.5
DB-084	88	$6,343,133	1.28	$92,426	9	15	10	16	12.5
DB-115	74	$6,702,501	1.12	$101,005	11	14	13	13	12.8
DB-091	63	$4,654,591	1.23	$90,740	14	21	12	17	16.0
DB-074	39	$5,883,983	0.72	$108,068	22	16	16	12	16.5
DB-125	33	$8,076,020	0.39	$95,063	27	11	24	15	19.3
DB-013	54	$3,436,102	0.59	$37,560	18	24	18	24	21.0
DB-048	38	$5,397,398	0.35	$50,371	23	19	27	20	22.3
DB-075	33	$4,898,234	0.43	$63,257	27	20	23	19	22.3
DB-104	62	$3,910,506	0.44	$27,996	15	23	22	29	22.3
DB-083	41	$2,136,254	0.63	$32,837	21	32	17	26	24.0
DB-067	55	$3,313,206	0.37	$22,281	17	25	25	34	25.3
DB-108	43	$2,337,306	0.51	$27,834	20	31	20	31	25.5
DB-120	67	$2,135,957	0.54	$17,314	12	33	19	40	26.0
DB-045	28	$5,498,886	0.25	$48,302	32	18	39	21	27.5
DB-052	37	$1,979,449	0.49	$26,397	24	34	21	32	27.8
DB-079	32	$5,517,496	0.22	$38,241	29	17	42	23	27.8
DB-069	29	$2,712,147	0.36	$33,216	31	30	26	25	28.0
DB-073	34	$3,161,101	0.30	$28,185	26	26	32	28	28.0

Table 9.6
Severely Repetitive Loss Rankings By Basin

Basin	No. of Properties	Total Payouts	No. of Properties By Basin Sq. Mi.	Total Payouts By Basin Sq. Mi.	No. of Properties Ranking	Total Payout Ranking	No. of Properties By Basin Sq. Mi. Ranking	Total Payouts By Basin Sq. Mi. Ranking	Overall Ranking
DB-076	92	$25,988,539	1.19	$335,622	1	1	1	1	1.0
DB-054	38	$8,106,996	0.79	$168,861	3	3	2	2	2.5
DB-109	48	$12,846,708	0.37	$99,354	2	2	3	3	2.5
DB-053	26	$4,705,687	0.35	$62,752	4	7	4	5	5.0
DB-072	23	$5,020,966	0.24	$51,745	5	6	7	7	6.3
DB-084	18	$2,247,034	0.28	$34,539	6	13	5	12	9.0
DB-110	13	$2,555,940	0.20	$40,134	8	12	8	9	9.3
DB-089	14	$2,713,750	0.17	$33,818	7	9	10	13	9.8
DB-123	7	$5,567,367	0.12	$99,329	18	4	13	4	9.8
DB-091	11	$2,567,091	0.17	$39,066	10	11	11	11	10.8
DB-078	9	$5,203,179	0.09	$54,390	12	5	21	6	11.0
DB-074	13	$3,513,572	0.12	$31,328	8	8	15	15	11.5
DB-048	8	$1,511,456	0.26	$50,033	16	21	6	8	12.8
DB-051	9	$1,640,927	0.18	$33,501	12	17	9	14	13.0
DB-067	11	$2,031,296	0.13	$24,249	10	15	12	18	13.8
DB-115	4	$2,633,487	0.06	$39,686	27	10	24	10	17.8
DB-069	7	$1,235,621	0.12	$21,234	18	22	14	19	18.3
DB-075	6	$1,669,901	0.11	$30,670	23	16	18	16	18.3
DB-079	6	$1,621,487	0.11	$30,025	23	18	17	17	18.8
DB-108	9	$968,301	0.11	$11,531	12	26	19	24	20.3
DB-112	8	$1,191,609	0.10	$14,609	16	23	20	22	20.3
DB-077	7	$858,845	0.11	$13,719	18	27	16	23	21.0
DB-013	9	$1,056,942	0.07	$7,980	12	24	23	27	21.5
DB-068	7	$1,584,089	0.05	$10,653	18	20	26	25	22.3
DB-045	7	$1,595,726	0.04	$9,173	18	19	28	26	22.8
DB-073	3	$972,742	0.05	$15,532	31	25	25	21	25.5
DB-124	3	$2,159,247	0.03	$20,762	31	14	38	20	25.8
DB-104	6	$836,559	0.04	$5,989	23	28	27	33	27.8

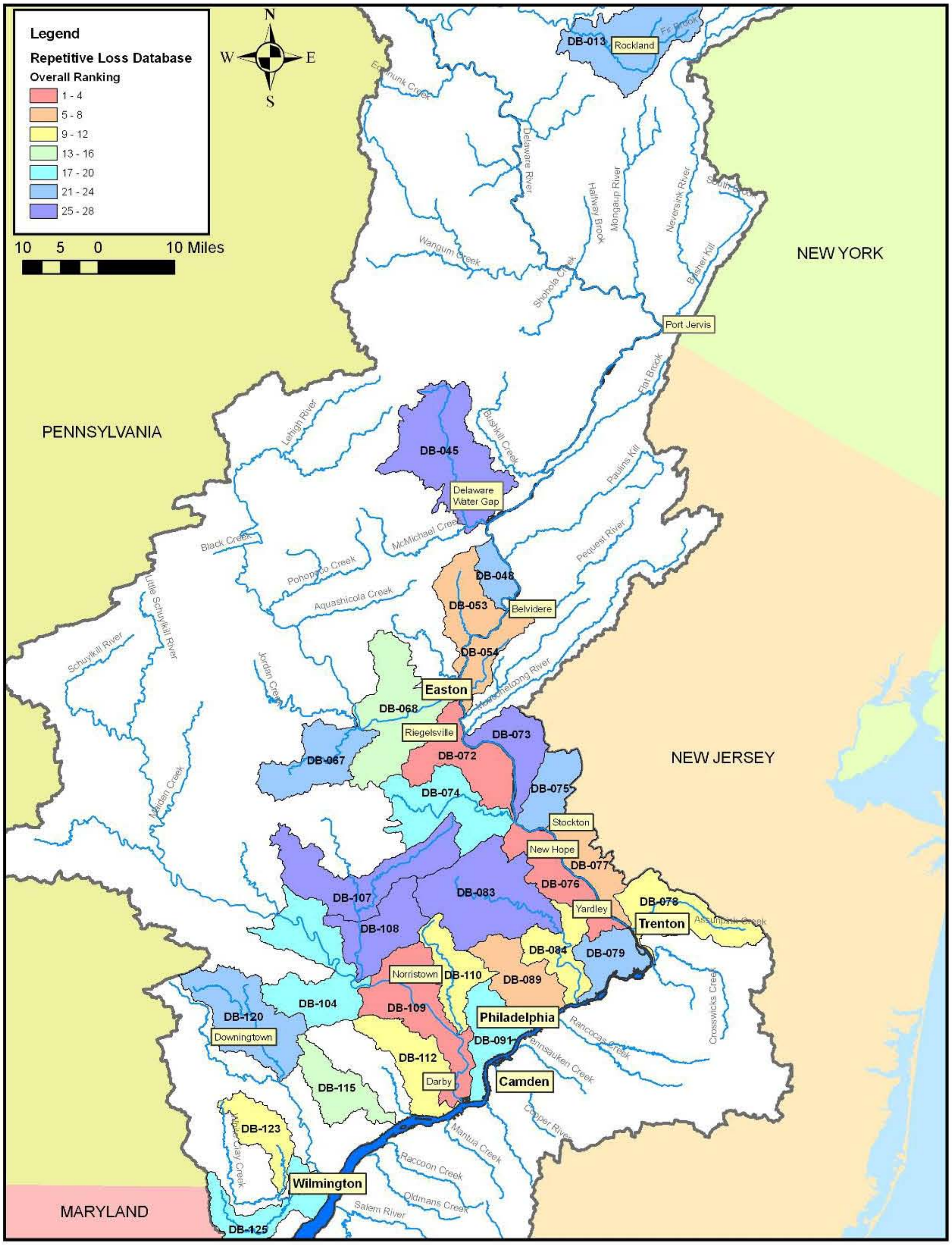


Figure 9.4 Highest Repetitive Loss Rankings by Basin

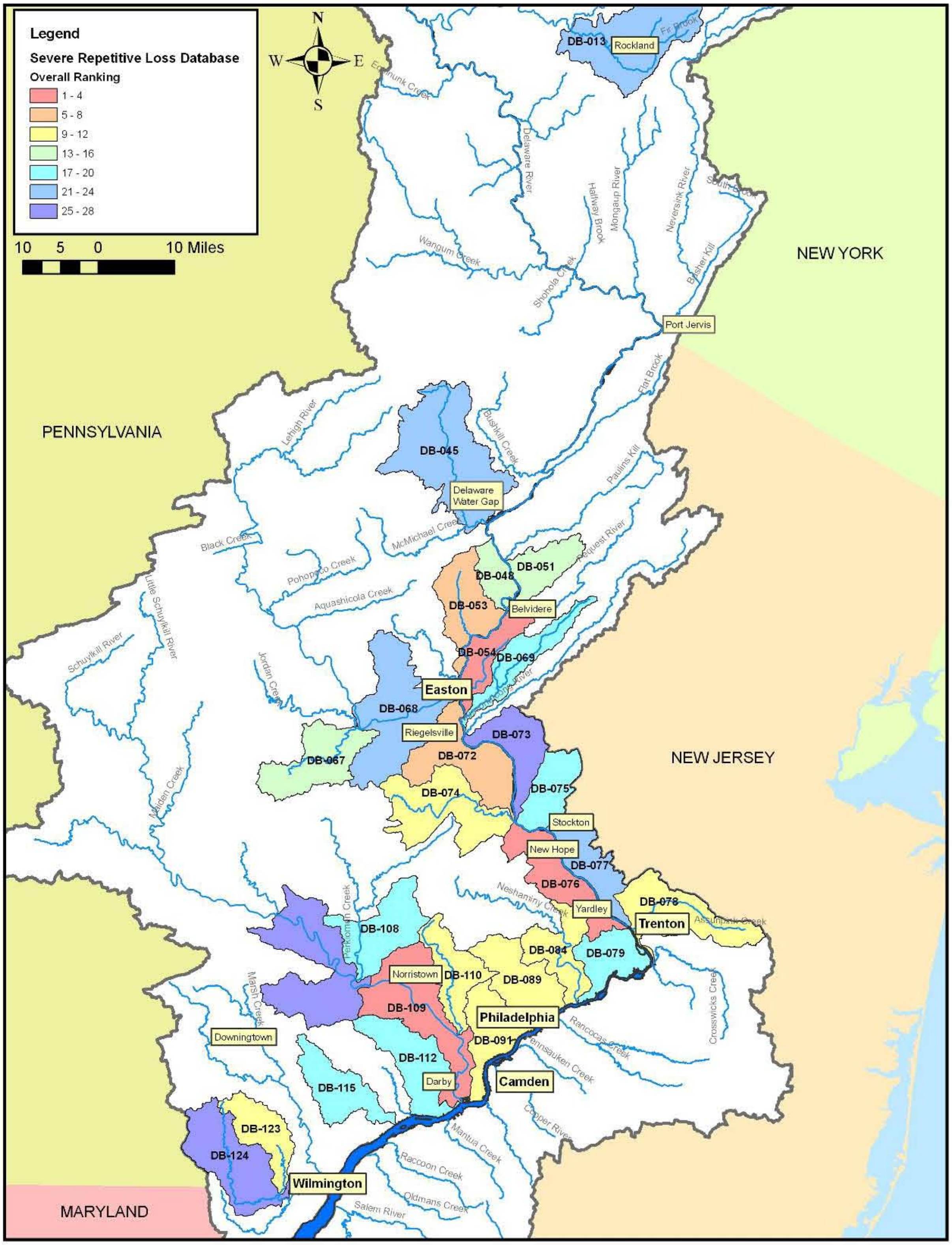


Figure 9.5 Highest Severe Repetitive Loss Rankings by Basin

Table 9.7
Repetitive & Severe Repetitive Loss Claims
Top Ten Municipalities in the Basin with Highest Number of Designated Loss Properties:

Municipality	Repetitive Loss Properties	Total Payouts for Repetitive Loss Properties
Trenton, NJ	176	$11,459,971
Yardley, PA	170	$19,282,322
Philadelphia, PA	95	$7,471,828
New Castle, DE	86	$18,101,486
Harmony, NJ	76	$11,095,956
West Norriton, PA	76	$7,493,477
New Hope, PA	71	$10,208,886
Upper Makefield, PA	66	$10,682,761
Lambertville, NJ	64	$3,348,860
Bridgeton, PA	59	$6,048,814

Municipality	Severe Repetitive Loss Properties	Total Payouts for Severe Repetitive Loss Properties
Yardley, PA	46	$11,206,158
West Norriton, PA	34	$5,580,246
Harmony, NJ	29	$5,878,462
Upper Makefield, PA	21	$5,872,833
Plumstead, PA	13	$3,513,572
Forks, PA	12	$2,858,239
Middletown, PA	12	$1,578,207
Allentown, PA	11	$1,685,403
Rockland, NY	10	$1,760,483
Solebury, PA	10	$4,436,010

Notes:

1. A property is considered a repetitive loss property by FEMA when there are 2 or more losses reported which were paid more than $1,000 for each loss. The 2 losses must be within 10 years of each other and be at least 10 days apart.
2. A property is considered a severe repetitive loss property by FEMA either when there are at least 4 losses each exceeding $5000 or when there are 2 or more losses where the building payments exceed the property value.
3. Claims were mapped and summaries compiled using Lat/Long coordinate points provided by FEMA. On occasion, the Lat/Long location does not match the FEMA assigned community name for specific claims.
4. Information was compiled by DRBC staff, April 2007. A complete analysis table is available online at http://www.state.nj.us/drbc/Flood_Website/floodclaims_home.htm
5. This analysis does not capture uninsured flood damage.

Based on the results of these claims and discussions with Federal, state and local agencies, the towns of Yardley, New Hope, Easton and Upper Makefield, PA; Lambertville, Stockton, Belvidere and Harmony, NJ; and Rockland and Colchester, NY were identified as priority sites for flood risk management efforts. The locations of these ten communities are displayed on the map in Figure 9.6.

Figure 9.6 Key Flood Prone Areas used for Structure Inventories and Solution Matrix

9.5 Structure Inventory for Ten Priority Communities. The structure inventory conducted for these ten communities accounted for nearly 25% of the total project cost and almost 50% of the flood risk management task. The structure inventory was essential an essential tool for assisting locals in the evaluation of potential projects.

The inventory was conducted for all residential, commercial and industrial structures within the 100-year floodplain for the ten priority communities, totaling approximately 2,000 structures. Table 9.8 shows a breakdown of the number of structures per community.

Table 9.8
Summary of Structure Inventory

Community	Number of Structures Inventoried
Pennsylvania	
Yardley	302
New Hope	155
Upper Makefield	366
Easton	99
New Jersey	
Lambertville	175
Harmony	146
Stockton	131
Belvidere	93
New York	
Rockland	338
Colchester	70

The structure inventory involved locating structures in the 100 year floodplain on an aerial photograph such as shown in Figure 9.7. Each structure inventoried was photographed and given a unique structure identification number which was then placed into a Geographic Information System (GIS) database. Data collected for each structure consisted of ground, first floor and zero damage elevations and sufficient data to determine depreciated replacement costs using the Marshall & Swift Residential and Commercial Estimator programs and a May 2008 Price Level. Data input included such things as number of stories, square footage, quality, basement, garages, exterior (siding, brick) etc.

Figure 9.7

Notes

1. Vertical elevations referenced to the National Geodetic Vertical Datum (NGVD 29).

2. Project limits within study communities established using Federal Emergency Management Agency (FEMA) developed Q3 digital 100-year flood hazard area boundaries and verified by inspection of effective FEMA Flood Insurance Rate Map (FIRM) Panels.

3. Structure inventory data collection preformed by Michael Baker Jr., Inc. with support from Rowbeer Consulting, P.C. in March and April of 2008.

Legend

- Residential Structure
- Commercial Structure
- Structure Elevation Higher than Floodplain
- Restricted Access/ Entry Refused
- Structure No Longer Exists
- Structure Footprint
- Project Limits

200 100 0 200
Feet

US Army Corps of Engineers
Philadelphia District

Delaware River Basin
Structure Inventory

Easton, PA
Sheet 1 of 2

Baker

In addition to depreciated replacement costs, each structure was also assigned a generic depth-damage curve. These curves are assigned to a structure based on structure type (residential or commercial) number of stories and whether a structure has a basement. The example in Table 9.9 shows the percentage of damage for structure and content for a 2 story residential structure with no basement. The first and third columns in the table show elevation relative to the first floor while the second and fourth columns show the percentage of damage based on elevation of flooding. For example, when the first floor receives one foot of water 24 percent of the structure's depreciated replacement cost is expected to be damaged while 31 percent of the contents are damaged. This data will enable the end user the ability to determine dollar damages for each structure based on the depth of flooding.

Table 9.9
Sample Depth Damage Curve

Residential Structures S03 (2 story, no basement)		Residential Contents (S04)	
Depth (ft)	Damage (%)	Depth (ft)	Damage (%)
-2	.00	-2	0
-1	.01	-1	0
0	.10	0	.22
1	.24	1	.31
2	.30	2	.40
3	.36	3	.54
4	.39	4	.61
5	.42	5	.37
6	.47	6	.76
7	.49	7	.81
8	.56	8	.88
9	.64	9	.88
10	.67	10	.96

The data gathered for this task will ultimately enable local officials and other water resources planners the ability to estimate dollar damages for given levels of flooding. Currently this information is being shared with other ongoing efforts and studies such as the Delaware River Basin Comprehensive, New Jersey Study, which is being cost-shared with the New Jersey Department of Environmental Protection; the Delaware River Basin, Watershed Flood Management Plan and the Upper Delaware Watershed, Livingston Manor Feasibility Study. The Watershed Flood Management Plan will use this information to develop flood inundation mapping for use as a planning and emergency management tool for 100+ miles of the main stem Delaware River and will be accessible within a GIS environment.

As part of this study, a series of flood events are run through the hydraulic model to compute a series of water surface profiles. The water surface profiles are then used to develop corresponding flood inundation maps and depth grids by draping the flood layer on the digital topography.

A database of structures located in frequently flooded areas (10 priority communities) in conjunction with the depth of flooding generated by each water surface profile, is used to calculate damage estimates to structure and contents for each of the buildings in the database. Damage estimates can be calculated by single structure or groups of buildings at the user's discretion or by local municipality, county, or state-wide.

The functionality of the GIS-based inundation maps centers on the user entering river stages at any of the forecast points located within the project area. A known or forecasted stage at one or more of the gage locations produces the appropriate flood inundation layer as a depth grid. Inundation depth grids, flood impact response tables, and flood damage tables are produced from the input stage. Using the depth grid and underlying base data, determination of extent and depth of flooding as it impacts buildings and transportation systems and expected damages to structures and contents are readily available through the GIS.

8.6 Solution Matrix. As part of this effort, a reconnaissance level potential solution matrix was developed for the ten priority communities. The matrix provides problem identification for each of the ten priority communities and identifies potential structural and non-structural alternatives which should be evaluated in future studies. The matrix also provides recommendations from previous reports. The potential recommendations were developed through a literature review, discussions with local municipalities, states and other Federal agencies as well as a review of proposed flood mitigation plans being developed for FEMA.

Many of the alternatives which were evaluated in earlier studies were found to have benefit to cost ratios (BCRs) less than 1.0. However they should be re-evaluated due to changing conditions (revised discharge frequency curves, new guidance and the possibility of a multi-purpose project (environmental restoration with incidental flood damage reduction benefits). Although some of these alternatives may still not be economically feasible under the Corps' guidelines they should be evaluated further.

Table 9.10
Potential Solution Matrix for Top 10 Priority Communities

	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
LAMBERTVILLE, NJ				
Alexauken Creek	Alexauken Creek backflows through the storm sewer system and surcharges near North Union and Cherry Street when Delaware River rises above flood stage.			(1) Install backflow prevention device behind CVS Pharmacy (2) Study of sanitary sewage backflow
Ely Creek	Ely Creek surcharges to North Union Street flooding residential and commercial properties when Delaware River rises above flood stage.			(1) Install backflow prevention device within the Niece Lumberyard and a portable pump.
Swan Creek	Swan Creek surcharges onto North Union Street and vicinity when Delaware River rises above flood stage, flooding residential and commercial structures.	(1) Two new levees on Swan Creek (2) Floodproofing, raising and buyouts of structures along Swan Creek	.30 to 1 .65 to 1	(1) Install flood gate and lift station at Swan Creek.
Delaware River	Flooding of Lambert Lane and Cherry Street			(1) Possible raising of structures
STOCKTON, NJ				
	Delaware River flooding along South Main Street and Mill Street flooding Stockton Fire Department, Borough Hall and residential structures	(1) 2900' levee (2) flood proofing	(1) .07 to 1 (2) .02 to 1	(1) Relocate or floodproof Fire Department (2) Floodproof Borough Hall

	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
STOCKTON, NJ (Continued)				
				(3) Residential property Acquisition of approximately 5 repetitive loss properties along Mill Street (4) Flood proof sewer pump station (5) Improve canal banks to serve as levee
	Backflow from Canal causes storm drains to backup along North and South Railroad Avenues			(1) Install backflow prevention device
HARMONY, NJ				
	Flooding along Goat Farm Road	(1)Levee (2) flood proofing, floodwall, evacuation	(1) unjustified (2) 1.81 to 1	(1) Buyout for 10 properties along Goat Farm Road (2) Debris control (3) Potential Section 206 (Aquatic Habitat) for abandoned quarry could produce limited flood damage reduction benefits. (4) Combination of flood proofing/floodwall/evacuation

	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
	Pequest Creek	(1) channel excavation & removal of 2 check dams (2) two levees on either side of Pequest (3) nonstructural measures	(1) 1.6 to 1 (2) .04 to 1 (3) .13 to 1	(1) Removal of dams (2) channel excavation
	Pophandusing Brook			(1) Flap gates/ storm water outlets (2) Review of nonstructural flood control measures
YARDLEY, PA				
	Delaware River	floodproofing, elevation	.66 to 1	(1) Temporary levee/floodwall between River Road and the banks of the Delaware River (2)Flap gates and a series of pumps for interior drainage (3) Eliminate flow restriction from Conrail Embankment. (4) Raise or relocate structures above flood hazard
	Delaware Canal			(1) Repair aqueduct, improve number of wastegates, raising towpath (2) Increase capacity of overflow from Canal into Brock Creek

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
	Delaware Canal (Continued)			(3) Increase number of wastegates-additional relief gates at the canal aqueduct over Brock Creek (4) Raise the grade and increase stability of towpath in low areas. (5) Additional weirs or overflows should be considered both upstream of Yardley and in the vicinity of Lock 5 (6) Stabilitze the Canal bank opposite Silver Creek (7) Flood proofing techniques used to protect the residential properties from Delaware river floodwater will have coincidental benefits from flows overtopping the Canal.
	Bock and Brock Creek	two levees above Brock Creek	.14 to 1	(1) Debris removal (particularly in vicinity of aqueduct) (2) Deepening of streambed to increase flow capcity for Brock Creek may be a viable short term solution. (3) Need to investigate the feasibility of utilizing flood proofing techniques for residential properties. (4) stream restoration/increase riparian buffers

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
NEW HOPE, PA				
	Mainstem Delaware	Levee 5% of structures in 25 year floodplain needed floodproofing or floodwalls	0.67 1.95 to 1	(1) Temporary floodwall coupled with a permanent base and some permanent floodwalls should be investigated. (2) Addition of permanent or temporary pumping stations
	Aquetong Creek	levees/floodwalls above and below Aquetong Creek	.20 to 1	(1) Stop gate repair on the canal near Center Bridge
	Delaware Canal			(5) May want to check Locks to ensure they are in proper working order
EASTON, PA				
	Mainstem Delaware	(1) Levee (2) 12% of structures in 50 year flood event needed floodproofing or floodwalls	.06 to 1 .64 to 1	(1) Flap gates/ storm water outlets
	Lehigh	(1)Flood warning system-never implemented due to lack of sponsor for O&M (2) fifteen foot sheetpile wall-provided no flood protection		(1) flood warning system

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
EASTON, PA (Continued)				
	Bushkill Creek			(1) Levee-floodwall system (2) flap gates/ storm water outlets (3) Review of potential debris blockage and limited channel modification (4) Raising and floodproofing (5) Barriers placed along the bridge should and approaches along with portable pumps
UPPER MAKEFIELD, PA				
	Mainstem Delaware-Damages clustered at 6 locations Houghs & Jericho Creeks	floodproofing, elevations	.87 to 1	(1) Ring levees should be considered around damage clusters. (2) Temporary floodwall coupled with permanent base (3) Pipe extensions for flapgates/ stormwater outlets (4) Permanent or temporary pumping stations Erosion, not flooding appears to be larger problem than flooding

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
	Downs Brook, Ice Jams on East Branch Beaverkill and Spill from Pepacton Dam	Levee, floodwall	.2 to 1	(1) Streambank ecosystem restoration could restore the natural channel thereby improving stream flow capacity (2) sheet pile levee in Downsville (3) Channel modification of Downs Brook (4) High flow diversion
	Hamlet of Cooks Falls-Level of damages precludes significant structural alternatives			(1) Floodproofing, ring levees or grading by homeowners may be warranted
	Hamlet of Horton-Level of damages precludes significant structural alternatives.			(1) Floodproofing, ring levees or grading by homeowners may be warranted
	Hamlet of Shinopple-Level of damages precludes significant structural alternatives			(1) Floodproofing, ring levees or grading by homeowners may be warranted
	Hamlet of Corbett-Level of damages precludes significant structural alternatives.			(1) Floodproofing, ring levees or grading by homeowners may be warranted

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
ROCKLAND, NY				
	Hamlet of Livingston Manor	(1) system of levees, channel relocation and a flume and wall structure (2) levee around Willowemoc Hodel, modify Rock Avenue Bridge, levee, pumping stations	(1) 1.3 to 1 (2) .29 to 1	(1) Restore the Little Beaver Kill (2) Create wetlands at former borrow pits (3) Short floodwall along low spot on Pearl Street (4) Replace existing Main Street bridge to enlarge opening (5) Realign mouth of Little Beaver kill (6) Connect ponds at base of mountain as high flow channel (7)Create flood plain by removing material and lowering ground elevations (8) Reduce backwater at NYS Route 17 bridge downstream of the sewage treatment plant where it cuts across the floodplain of Willowemoc Creek.

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
ROCKLAND, NY (Continued)				
	Hamlet of Rockland			(1) Evaluate backwater conditions at Junction pool (2) Flood proofing, ring levees or grading by homeowners may be warranted.
	Hamlet of Roscoe			(1) Evaluate NYS Route 17 embankment as a levee along Wilowemoc Creek (2) Design lift station/interior drainage plan for Roscoe Central Business District (3) Evaluate backwater conditions at Junction Pool (4) Flood proofing, ring levees or grading by homeowners may be warranted.
	Hamlet of Lewbeach			(1) Floodproofing, ring levees or grading by homeowners may be warranted

* Reverse 911 and/or floodwarning systems should be considered for all ten priority communities.
Buyouts or raising of structures should be considered for all communities when no structural solutions are deemed feasible.
Environmental restoration projects should be evaluated for all communities, particularly when structural alternatives alone are not sufficient for BCR justification.

10.0 TASK 3: ESTUARY INFLOW EVALUATION

Salinity, whether caused by sea-water intrusion or by the discharge of wastewaters containing dissolved solids, is a major concern in the Delaware Estuary. The estuary serves as a source of water supply for municipalities and industries, and as a habitat for many fish and wildlife species. Salinity is of concern in the Estuary not only because of the damage and associated costs to the residents, municipalities, and industries in the region but also because of health problems associated with a high-sodium water supply.

The distribution of salinity in the estuary is for the most part a result of the interaction of freshwater flow and saltwater inflow. Freshwater flows come from the headwaters of the Delaware River, from tributaries, as direct runoff from the land, and from groundwater seepage. Sea salts in detectable concentrations have been observed in the tidal Delaware River as far upstream as Philadelphia's primary water intake at Torresdale.

In order to consider a flow management plan for salinity intrusion it is critical to have the proper modeling in place. To construct such a model, this task linked three existing water resources computer models: the Operational Analysis and Simulation of Integrated Systems (OASIS flow model) one-dimensional reservoir operating model, The Dynamic Estuary Model Hydrodynamics Program (DYNHYD5) hydrodynamic model and the TOXI5 chloride transport model (the latter two are collectively referred to as “the estuary salinity model”). Linking these models will enable engineers to better predict the effects of reservoir operating program alternatives on salinity concentrations within the estuary and thus will enhance the ability of the DRBC staff to furnish the commissioners with the technical support they require to make informed flow management policy decisions; and in particular, this project is needed for the DRBC staff to provide the Commission with the support that it has recently requested for the development of flood mitigation operating plans for existing reservoirs.

In addition to linking these three models, DRBC team members received training in the operation of this program and have also received training on the use and operation of the Curvilinear Hydrodynamics in 3-Dimensions (CH3D) model for personal computers.

11.0 TASK 4: RE-EVALUATION OF USER SUPPLY COSTS TO SUPPORT FLOW MANAGEMENT AND EQUITABLE ALLOCATION GOALS

While the DRBC does not own or operate any of the dams within the Basin, it has purchased a portion of the storage in two Corps of Engineers reservoirs. This storage is financed through a surface water charging program and consists of 9.2 billion gallons in Beltzville Reservoir and 2.6 billion gallons in Blue Marsh Reservoir.

By Resolution No. 64-16A in 1964, the DRBC authorized a water charging program. It provided for the revenues generated by the program to be used for repayment of the non-federal share of the investment cost of water supply storage facilities associated with federal projects within the Basin. In anticipation of DRBC investment in storage at the Beltzville Lake and Blue Marsh Reservoir projects in Pennsylvania, the DRBC by

Resolution No. 1971-4 defined, among other things, the means by which it would establish water charging rates.

These rates have not changed since their inception almost 40 years ago. However, due to ever changing demands in water supply and the potential need for additional storage, this study took the opportunity to review projected costs for water supply and alternate rate calculation methods in order to meet these costs.

In order to determine funds needed by DRBC to meet costs through the year 2030, cost data was developed for the following:

- Estimated annual operation, maintenance, and administrative costs
- Estimated major repair/upgrade costs
- Current replacement costs for both dams and facilities
- Projected costs to meet increased demand

11.1 Estimated Annual Operation, Maintenance and Administrative Costs. The estimated joint use annual operation, maintenance, and administrative cost were projected from actual costs in fiscal year 2006 and 2007. The costs used are representative of the joint use general operation and maintenance costs for each project. The costs were then escalated from their respective fiscal years to Fiscal Year 2030 by compounding the costs based on a 3.18% per annum rate of inflation. The rate of inflation is based on an annualized rate of inflation calculated from the Construction Cost Index for last 10 years from July 1996 to July 2006 as published by Engineering News-Record. It is assumed that the inflation trend for the last 10 years will continue into the future. From these calculations no major increase in these general operations and maintenance costs are expected, however there is no guarantee of future budget levels or required costs.

11.2 Estimated Major Repair/Upgrade Costs. The estimated costs for major repair/upgrades at both Beltzville and Blue Marsh Lakes were developed from a list of backlog maintenance items and utilizing engineering judgment in order to predict the need for major repair or upgrades of certain components or systems. The estimated costs for each item were developed based on either past experience or engineering estimates. These costs are subject to change based on factors such as long term inflation rates and the competitive market.

11.3 Projected Costs to Meet Increased Demand. Based on the results of this study there are no non-power sector water supply deficiencies in the Schuylkill River Basin by the year 2030. However, if the potential power demands on the Schuylkill River were not met by power transmission from out of the basin, the water deficiency for this sector would be 518 mgd by the year 2030. Therefore, based on the assumption that power demands will be met outside of the basin, no additional needs for water supply were identified.

11.4 Determining Need to Update Surface Water Rates for Basin Users.

Based on the water supply needs identified through 2030, expected operation and maintenance costs and estimated repair and replacement costs, it does not appear necessary to update surface water rates to basin users at this time. However, should additional water supply needs be identified under a thorough drought analysis, the DRBC may need to re-evaluate these costs at a future date.

12.0 TASK 5: GEOGRAPHIC INFORMATION SYSTEM (GIS)/PUBLIC ACCESS TO INFORMATION

One of the most important aspects of this study is to ensure that the work conducted here continues beyond this study in aiding other Federal, state, and local agencies in their work. The GIS component of this study provides a centralized location where data gathered for this study is being made available to the public. The website is located on the Philadelphia District's project website. The site contains generalized information about the project along with a map gallery showing the results of the water supply analysis. The flood risk management section provides interactive maps that will allow the user to search the FEMA repetitive and severe repetitive loss claims by dollar amount or storm event to determine areas hardest hit. It is the hope of the team that this study will demonstrate the importance of data sharing and unified data collection.

13.0 CHALLENGES

The greatest challenge facing this project delivery team was the shear size of the Basin and the overwhelming number of water resource related problems. Despite a budget of over a million dollars, the team had a difficult time conducting a detailed analysis for each of the five tasks. Because this study went in several different directions (water supply, flood risk management, estuary inflow, etc..) the team was unable to focus on one particular problem to the point of being able to develop conclusive results with recommendations for construction.

And although this study was not intended to be a typical feasibility study, the team often found that residents and other agencies expected more out of this study than it was able to provide with the limited funding and time constraints.

14.0 LESSONS LEARNED

Lessons learned through this effort include the need for unified data collection, the ability to collaborate with others and the need to have one entity responsible for bringing these resources together. An agency such as the Delaware River Basin Commission, which represents all State and Federal Agencies within the Basin, provides a great benefit in that they can reduce the risk of duplicative efforts among agencies, help with mediation when necessary and can assist with the development of new meta-data standards for data collection. The team has learned that agencies such as the DRBC are imperative for a successful study effort and if agencies such as DRBC do not exist in a Basin a task force or some other unifying organization is critical for project success.

15.0 CONTINUATION OF COLLABORATIVE EFFORTS:

As part of the collaborative process for this effort, team members will continue to join forces with the Delaware River Basin Interstate Flood Mitigation Task Force, the DRBC, DRBC's Flood Advisory Committee, Water Management Advisory Committee, and other committees and other Federal, state and local government agencies as well as not-for-profit organizations to address the water resource needs of the Basin.

Over the past years, many agencies' water resources projects and programs have contributed to meeting the needs of the people and resources of the Delaware River Basin. Examples include the construction and maintenance of reservoirs and/or flood damage reduction projects (USACE and local projects), DRBC regulation of consumptive water use and mitigation, construction of acid mine drainage abatement and abandoned mine land reclamation projects, water quality gauging and monitoring, planning and construction of environmental restoration projects, and implementing migratory fish passage at the Fairmount Dam along the Schuylkill River.

Coordination and collaboration are routine through the regular DRBC meetings, the Water Quality Advisory Committee (WQAC), Flood Advisory Committee (FAC) and the many other DRBC sub-committees. The USACE will also continue participating in the many ad-hoc advisory groups which are formed when specific issues arise and will actively participate in the preparation of technical documents addressing these issues, such as the Flood Mitigation Task Force Report, Flexible Flow Management Plan, and others.

It is important that USACE continues this effort by seeking opportunities for multi-party collaboration involving Federal, regional, state, local, and non-governmental organizations (NGOs). Potential collaboration within the Delaware River Basin could include: Ducks Unlimited, Trout Unlimited, The Nature Conservancy, Eastern and Western Pennsylvania Coalitions for Abandoned Mine Reclamation, Wildlands Conservancy, Pennsylvania Organization for Watersheds and Rivers, and many others.

There are many ongoing activities and successful efforts in the Delaware River Basin. Many needs remain, and new ones will be identified. However, with a common vision, consistent and open dialogue, and adequate resources, the positive impacts from individual and collective activities and coordination will continue to sustain the Delaware River as a valuable natural resource in the region and nation.

16.0 SUMMARY

The USACE is only one of many important entities contributing to the Strategic Vision of the Delaware River Basin. Partnerships are growing stronger through stakeholder involvement and Federal agency collaboration, the river is being viewed by many more agencies as a comprehensive unit with inter-related needs and solutions, and future projects and initiatives are encompassing these ideals. It is important to recognize that even with a long-term plan and good intentions, it is imperative that USACE and their partners have adequate funding, resources, and staff to implement the Strategic Vision.

Through continued involvement and leadership, USACE can support the Strategic Vision and priorities and serve as a lead facilitator to recast the importance of a comprehensive and holistic approach to achieve long-term and sustainable environmental, economic, human, and social benefits. Furthermore, through collaborative and creative formulation of programs and projects that support the Vision, USACE should be better positioned to garner Federal funding to address watershed-based priorities that are broadly endorsed by the collective interests of many partners within the Delaware River Basin.

17.0 STUDY RECOMMENDATIONS AND ROAD AHEAD

Although this report does not make recommendations for future construction projects, it does make recommendations for future studies. Below is a summary of potential future efforts which should be evaluated further. Of all the efforts listed below, the detailed drought analysis is one of the most critical. Without realizing the potential water supply deficits during a drought of record, the Basin may be ill prepared for what could potentially be a devastating event.

17.1 Detailed Drought Analysis. A comprehensive drought analysis that incorporates the drought of record along with possible synthetic droughts that could be worse than the drought of the record should be conducted and an examination of FE Walter Reservoir Modification should be done in this comprehensive basin-wide drought analysis. This is a very important and worthwhile effort

17.2 Drought Sensitivity Analysis of 137 Watersheds Not Evaluated Under This Study. This analysis was restricted to the ten watersheds identified as being deficient using projections out to the year 2030, and only examined reducing water availability in those ten identified watersheds in the lower portion of the Basin. It would be reasonable to expect that by reducing water levels in the other 137 watersheds that additional deficits in the Basin would be identified. One possible solution to meet these needs could be the FE Walter Reservoir Modification.

17.3 Comprehensive Basin-wide Water Supply "Feasibility-Level" Study. A comprehensive basin-wide "feasibility-level" study should be conducted to evaluate alternatives that expand supply or curtail demand. Alternatives that expand supply include such things as: aquifer storage and recovery (ASR), expansion of municipal systems, reuse of waste and storm water, mine reclamation, desalination, river diversions, and reservoir storage. Alternatives that curtail demand include: improved water accountability with reduced infrastructure losses, additional conservation, change water allocations, new regulations, and improved irrigation techniques.

17.4 French Creek, Maiden Creek, Evansburg and Blue Marsh Modification. These three reservoirs in combination with modification to the existing Blue Marsh Reservoir should be considered for water supply flow augmentation for the drought sensitivity analysis.

17.5 Flood Warning/Forecasting Tool for Entire Delaware River Basin. Flood Inundation Mapping similar to that being developed for the Delaware River Basin Comprehensive, Watershed Flood Management Plan should be developed for the entire mainstem Delaware to be used as a planning and emergency management tool.

Using the depth grid and underlying base data, determination of extent and depth of flooding as it impacts buildings and transportation systems and expected damages to structures and contents could be made readily available through the GIS.

17.6 Detailed Flood Risk Management Feasibility Studies for Priority Communities. Due to ever changing conditions, such as increased development, changed land use, increased property values, updated stage frequency curves and other contributing factors, these communities and others should be re-evaluated through detailed studies. These sites should be re-evaluated using the potential recommendations provided in the solution matrix and flood mitigation plans being developed by the communities. Multi-purpose projects (environmental restoration/flood damage reduction) should be considered for many of these projects, as should flood warning/forecasting tools.

17.7 Detailed Feasibility Studies for Additional Flood Prone Communities. Detailed studies should be conducted for the ten priority communities, and additional flood prone communities beyond the ten priority communities identified in this report. This study limited flood risk management evaluations to only ten communities due to funding constraints. However, results from the repetitive and severe repetitive loss claims, evaluated in this report, show a need for additional detailed studies that go beyond these ten priority communities.

17.8 Periodic Update of Multi-jurisdictional Study. This study proved to be an excellent opportunity for the Corps to participate in a collaborative effort with several Federal, State and local agencies to develop a watershed study. The study has created invaluable tools to help guide the efforts of future studies throughout the Basin. However, due to the dynamic conditions of the watershed a need has been expressed to update this report periodically to incorporate these changes as well as to show how site-specific projects have impacted the watershed.