Enhancing Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, NJ, PA, and DE
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LIST OF ACRONYMS

ASR	Aquifer Storage and Recovery
AWWA	American Water Works Association
COMM	Commercial
DNREC	Department of Natural Resources and Environmental Control
DRBC	Delaware River Basin Commission
DYNHYD5	Dynamic Estuary Model Hydrodynamics Program
FAC	Flood Advisory Committee
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GWPA	Ground Water Protected Area
HEC	Hydrologic Engineering Center
HUC	Hydrologic Unit Code
KRA	Key Result Area
Mg/D	Million Gallons per Day
NECIA	The Northeast Climate Impacts Assessment
NGO	non-Governmental Organization
NJDEP	New Jersey Department of Environmental Protection
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
OASIS	Operational Analysis & Simulation of Integrated Systems
PADEP	Pennsylvania Department of Environmental Protection
PWD	Philadelphia Water Department
PWR	Power
PWS	Public Water Sector
QA/QC	Quality Assurance/Quality Control
SPF	Standard Project Flood
TOXIC5	Chloride Transport Model
USGS	U. S. Geological Survey
WMAC	Water Management Advisory Committee
WQAC	Water Quality Advisory Committee
WSCC	Water Supply Coordination Council

EXECUTIVE SUMMARY

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 risk management and water supply issues. This study was one of five selected nationwide and was funded in the amount of $1,105,000.

The five goals of this study include Long Term Sufficiency of Water Supply through the year 2030, Flood Risk Management, Estuary Inflow, Re-evaluation of User Supply Costs to Support Flow Management and Equitable Allocation Goals, and GIS/Public Outreach. These five tasks will be defined further in the report.

The major stakeholders in this project were the Delaware River Basin Commission (DRBC), 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, many of these agencies provided not only their expertise to the project but also provided much of their own funding.

TASK 1: LONG TERM SUFFICIENCY OF WATER SUPPLY

Task 1 is aimed at addressing long-term supply and demand through the year 2030. 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 three major rivers; the Delaware, Schuylkill and Lehigh.

The results of the basin wide water supply-demand evaluation identified several priority watersheds where the supply-demand balance indicated possible water supply problems. In total, eight watersheds have been identified, all of which are located in the lower half of the Basin.

The results of the river analysis showed the Delaware River had one power-sector withdrawal point being identified as deficient in the vicinity of Trenton, NJ, while the Schuylkill River increased from one to three withdrawal point deficiencies and the Lehigh River had no deficient withdrawal points through the year 2030.

Potential Alternatives for Water Supply 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. These alternatives include the diversion of water from the Delaware River and reservoir storage in the Schuylkill River Basin to include the Maiden Creek, French Creek and Evansburg Reservoirs and modification to Blue Marsh. It is recommended that all of these alternatives and others not mentioned be examined in detail in a comprehensive Basin-wide water supply "feasibility-level" study.

TASK 2: FLOOD RISK MANAGEMENT

This study looked at several different aspects of flood risk management, including updating flood frequency curves, conducting a skew analysis, and identifying priority sites for which a solution matrix and structure inventory were completed. These priority sites include the towns of Yardley, New Hope, Upper Makefield and Easton, PA; Lambertville, Harmony, Stockton and Belvidere, NJ; as well as Rockland and Colchester, NY.

TASK 3: ESTUARY INFLOW EVALUATION

In order to consider a flow management plan for salinity intrusion, this study 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.

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 with rates which have not changed since their inception.

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. Based on information gathered in this report it does not appear necessary to update surface water rates to basin users. However, additional water supply needs should be re-evaluated under a thorough drought analysis and may thereby require an update to this evaluation.

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 does not become "just another study" but continues beyond this study in aiding other Federal, state, and local agencies in their work. The public access component of this study provides an opportunity to share data gathered for this study with local communities/state and Federal agencies for on-going and future study efforts. It's the team's hope that this study will demonstrate the importance of data sharing and unified data collection.

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.

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 Modification should be done in this comprehensive basin-wide drought analysis.

2. Drought sensitivity analysis of 137 watersheds not evaluated under this study

The 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-yr 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 Modification could be a possible solution to meet those deficits.

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.

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.

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.

6. Detailed feasibility studies for priority communities in Pennsylvania and New York

Detailed studies should be conducted for the priority communities located in Pennsylvania and New York (Delaware River Basin Comprehensive, NJ is already reviewing New Jersey sites). These sites should be re-evaluated using multi-purpose projects (environmental restoration/flood damage reduction) rather than the traditional single purpose projects that many were originally evaluated under. Projects with negative Federal interest should still be evaluated by locals and other means of sponsorship should be pursued.

1.0 INTRODUCTION

1.1 STUDY PURPOSE

The Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, PA, NJ and DE study was conducted as a complimentary report to the Delaware River Basin Commissions (DRBC)'s Water Resources Plan for the Delaware River Basin, a long-range goal-based plan developed with the collaboration of New York, New Jersey, Delaware, and Pennsylvania through the DRBC.

This study is aimed at advancing critical initiatives of the Basin Plan relating to (1) establishing sustainable water use and supply, (2) helping prioritize near and long term investment needs for storage and flood risk management projects, (3) supporting a collective problem-solving initiative now underway that will revise reservoir release regimes to better serve human and ecological needs and (4) preparing a preliminary report on flood vulnerability and management capacity in the wake of some of the worst flooding the Basin has seen in the past fifty years.

1.2 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 risk management and water supply issues. This study was one of five selected nationwide and was funded in the amount of $1,105,000.

1.3 STAKEHOLDER INVOLVEMENT

The primary stakeholder in this project was the DRBC and its Commissioners, which are comprised of the Governors and their representatives from the four Basin States (New York, New Jersey, Pennsylvania and Delaware) and a Federal Representative which is the Commander of the Army Corps of Engineers' North Atlantic Division.

The DRBC was involved in every aspect of this project from problem identification though the development of potential alternatives. As one of the lead water resource agencies in the Basin, the DRBC assisted in the collaboration with state, local and other Federal Agencies in order to coordinate ongoing efforts.

It was through DRBC's Watershed Advisory Committee, Flood Advisory Committee and other such committees that the team was able to discuss on-going issues and study findings with members of academia, private industry, all levels of government and private citizens. And it's due to DRBC's 40+ years of experience as a key partner in numerous water related projects within the Basin that they proved to be an invaluable partner in this process.

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 (DEP) National Weather Service, (NWS) and the Corps' Hydrologic Engineering Center (HEC). And 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: conducting a discharge-frequency analysis, reviewing repetitive loss claims, and updating a 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 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, while the Corps' Hydrologic Engineering Center conducted a regional skew analysis, again to update the 1984 Basin Study.

1.4 STUDY PROPOSAL

The initial proposal sent to the Secretary's office described the study purpose as a collaborative effort with stakeholders to advance efforts of the Delaware River Basin Commission'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: (1)long term sufficiency of water in the Delaware River Basin, (2)long-term flow management, and (3) 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: This study was to involve recently completed groundwater availability analyses, demand projections and decree parties' 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: This task had three major subtasks; (1) estuary inflow evaluation, (2) multi-jurisdictional flood risk management 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 Risk Management 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 and finally, subtask three 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 accessibly information to the public: This task involved the distribution of both data collected and generated for this study to local communities and other agencies to assist in ongoing and future studies and reduce the potential for duplication of effort.

In order to better understand the importance of these tasks it is critical to understand DRBC's role in managing water resources for the Basin and how all of the study's tasks relate to the overarching Basin Plan.

1.5 MANAGING WATER RESOURCES IN 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 is the Commander of the North Atlantic Division, 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.

One of the purposes of the Multi-jurisdictional Use and Management study is to provide water resource management alternatives that may be used to update the DRBC Comprehensive Plan. The study can be used to evolve the Comprehensive Plan in the areas of water supply and flood mitigation. Facilities or programs in these areas resulting from the study may be incorporated in the Comprehensive Plan to provide long term management of Water Resources.

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.

The purpose of this study 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

1.6 EVOLUTION OF OBJECTIVES

As the first major undertaking in terms of advancing the Basin Plan, the Corps met with DRBC and other agencies to focus the study's efforts on key goals addressed in the Basin Plan. Through further review of the original proposal, it was determined that Task 1 (Long Term sufficiency of water) and Task 3 (Provision of timely and easily accessibly information to the public) would remain as originally described in the original proposal. However, Task 2 (Effective, long-term flow management) which consisted of three sub-tasks (1) estuary inflow evaluation, (2) multi-jurisdictional flood risk management and (3) re-evaluation of DRBC's approach to Water Supply User Costs would be broken into three separable tasks rather than sub-tasks. This decision was in part due to the recent flood events which had occurred in 2004, 2005 and 2006 causing devastation throughout the Basin. Due to concerns from the locals, it was essential that the study not only evaluated water supply in-depth but also took a closer look at flood risk management.

The following sections of this report will provide problem identification for each task, a review of the analysis conducted and will summarize the findings of the analysis with a list of potential alternatives that should be evaluated in greater detail.

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

1.7 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).

2.0 LONG TERM SUFFICIENCY OF WATER SUPPLY THROUGH 2030

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.

While three of the four Basin-states are currently undertaking their own water supply planning efforts, this study is intended to complement the work underway and also provide a uniform Basin perspective. Efforts have been made to coordinate this study with the work of the individual states. A brief summary of the water supply work ongoing in the states of Delaware, New Jersey and Pennsylvania is provided below.

Delaware. Delaware has taken a regional approach to water supply planning, through its Water Supply Coordinating Council (WSCC) which initially focused on expanding water supplies in northern New Castle County. Ten projects were identified for development to help ensure demand would be met through 2020, this includes the 317 million gallon Newark Reservoir, the first in Delaware for over 70 years, which came online in 2006. Once all projects are online, an additional 2 billion gallons of storage will be available for northern New Castle County. In 2003, legislation directed the WSCC to expand water supply planning to three other key areas of the state, southern New Castle County, central Kent County and coastal Sussex County. Planning work in these areas is currently underway and on schedule for completion by the end of 2009, at which point the authorization for the WSCC will expire. A separate study of ground water availability conducted by the Army Corps of Engineers concluded that groundwater withdrawals in Delaware affect the aquifer system in Maryland and New Jersey.

New Jersey. New Jersey is planning to release its latest Statewide Water Supply Plan in 2008. New Jersey's assessment will include a comparison of consumptive and depletive water demands versus water availability using the low flow margin method (a measure based on September median flow minus $Q_7 10$). The plan will also include an assessment of water demand versus infrastructure capacity. Two scenarios of future water demand have been developed, one is a projection to the year 2020 and the other is a "full allocation" scenario, where water demand is modeled based on water allocation permit limits.

Pennsylvania. Act 220 legislation in Pennsylvania led to the creation of a new State Water Plan which is due for release in 2008. At the heart of the plan is a GIS-based water budget assessment which evaluates the water balance at over 10,000 "pour points" across the state. Net water withdrawals (water withdrawn minus discharges) are compared to an availability threshold of 50% (30% in carbonate areas) of the $Q_7$10 value. A number of watersheds have been identified statewide (six in the Delaware River Basin portion of the state) for closer scrutiny in the "final verification" phase. These watersheds will be evaluated for potential consideration as Critical Water Planning Areas. Watersheds receiving such designation will require a Critical Area Resource Plan to be developed, which will identify the exact nature of the supply-demand imbalance and will identify potential mitigation strategies.

2.1 WATER AVAILABILITY ANALYSIS

2.1.1 Basin Delineation In assessments of water supply and demand, the selection of an appropriate watershed scale is a key factor that will determine the applicability of the study's findings. The choice of scale must be consistent with the objectives of the study and the data that are available for the assessment.

An analysis of alternative watershed scales in the Delaware River Basin was performed as part of this study. It should be noted that for some of the smaller watershed scales, there is a lack of consistency between Basin states in delineating watersheds. The maps presented in figures 2.1-2.6 below, illustrate watershed delineations for the Delaware River Basin that have been used in previous studies; they do not necessarily conform exactly to the delineations developed by the United States Geological Survey (USGS) and the Natural Resources Conservation Service (NRCS), which are the two main agencies responsible for developing watershed delineations.

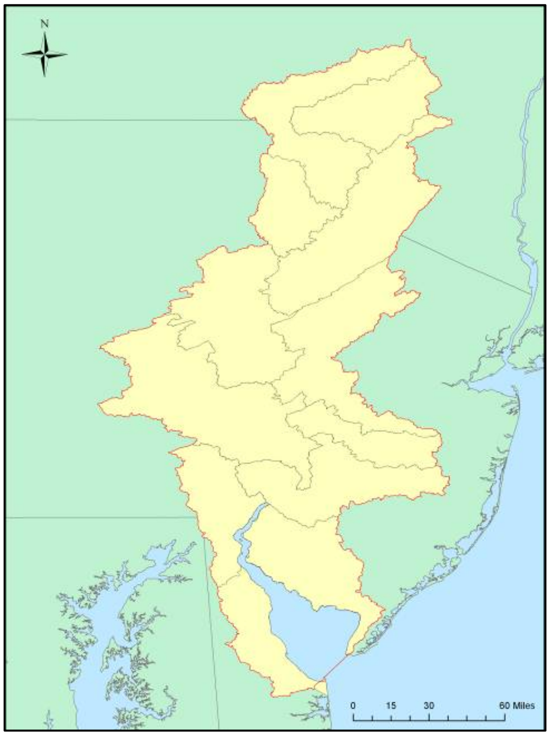

Figure 2.1 HUC 8 Watersheds:

Figure 2.2 HUC 11 Watersheds:

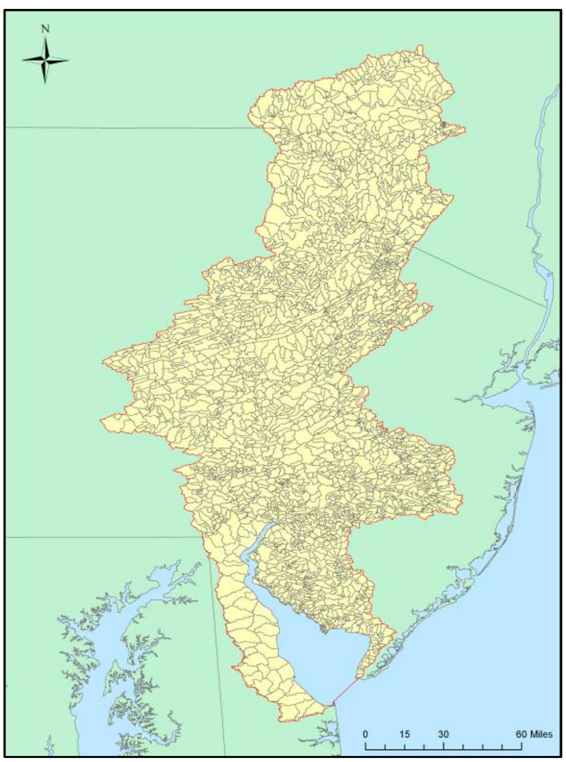

Figure 2.3 HUC 14 Watersheds:

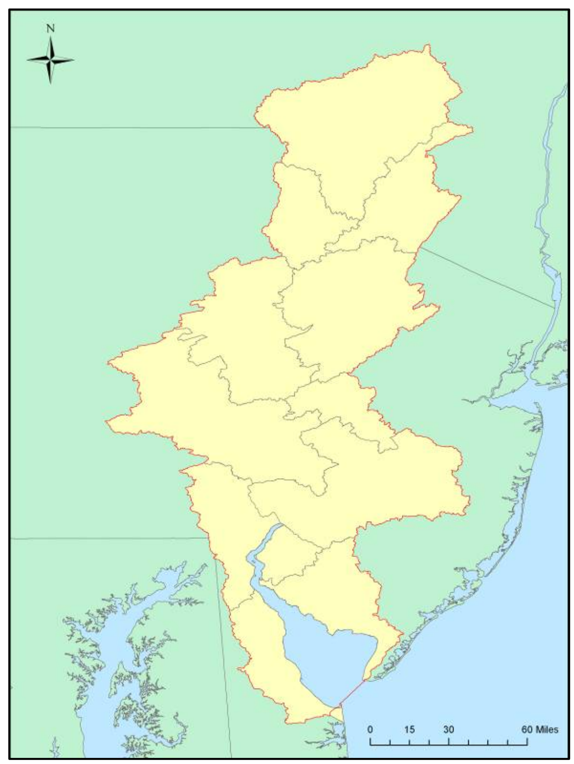

Figure 2.4 Basin Plan Sub-basins:

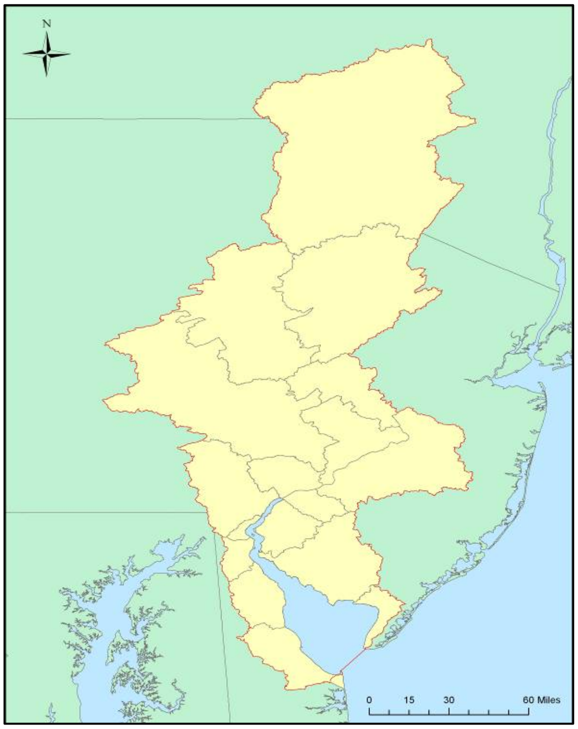

Figure 2.5 Flow Management Sub-basins

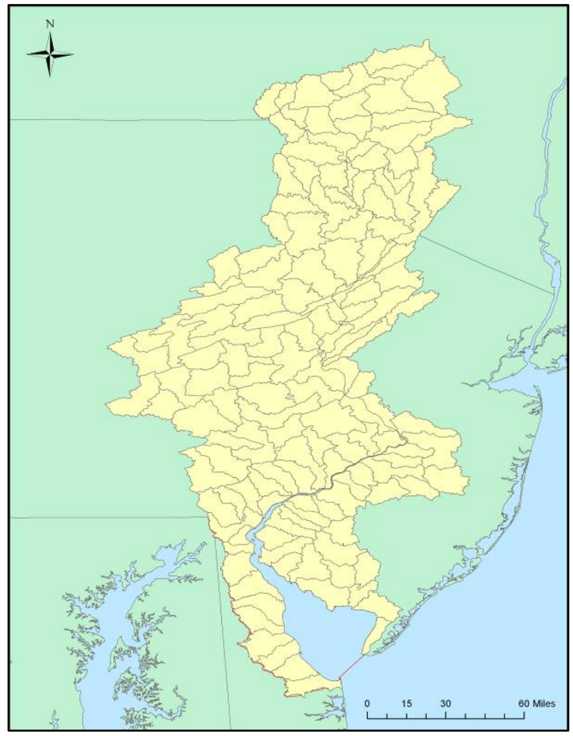

Figure 2.6* USGS Ground-Water Avail. Sub-basins

Basic descriptive statistics for each of the watershed scale classifications are shown in Table 2.1. Based on a review of the alternative sub-basin scales, it was recommended that this study use the 147 sub-basins delineated by the USGS in a recent project undertaken to quantify ground-water availability[1] for the entire Delaware River Basin. This approach is appropriate for the purposes of this study as there are sufficient data available to support an assessment of supply and demand issues at this scale. In addition, the use of 147 sub-basins will provide a more detailed regional picture than in previous studies conducted for the Delaware River Basin. A detailed map of the 147 watersheds is shown in Figure 2.7; Table 2.2 is a reference table to the map that includes the basin ID, location, size and key streams in each watershed.

[1] Sloto, R. A. and Buxton, D. E., 2006 , Estimated Ground-Water Availability in the Delaware River Basin, 1997-2000: U.S. Geological Survey Scientific Investigations Report 2006-5125 Version 1.1

Table 2.1
Summary of Watershed Scale Characteristics

Scale	Count	Mean Size (sq mi.)	Median Size (sq mi.)	Max Size (sq mi.)	Min Size (sq mi.)
HUC 8	12	1,070	1,073	1,910	542
HUC 11	236	54.5	32.9	536	1.2
HUC 14	3,237	2.0	3.9	56.2	0.1
Basin Plan SB	10	1,287	1,406	2,028	449
Flow Mgmt SB	17	757	449	3,430	38
USGS Study SB	147	87	82	210	18

Figure 2.7 Delineation of Sub-Basins

Table 2.2
Basin Identification

Basin ID No.	Drain-age Area (mi^2)	State	Streams
DB-001	144.0	NY	Upper part of West Branch Delaware River
DB-002	52.3	NY	Little Delaware River
DB-003	82.8	NY	Middle part of West Branch Delaware River
DB-004	53.1	NY	Upper part of West Branch Delaware River and East Branch Delaware River
DB-005	123.0	NY	Lower part of West Branch Delaware River
DB-006	39.2	NY	Cold Spring Creek, Butler Brook, Bone Creek
DB-007	67.8	NY	Oquaga Creek
DB-008	42.5	NY	Whitaker Brook, Rhoads Creek, Cadosia Creek, City Brook, Read Creek (tributaries to Delaware River)
DB-009	62.1	PA/NY	Faulkner Brook, Balls Creek, Shehawken Creek, Sherman Creek
DB-010	210.0	NY	Upper part of East Branch Delaware River above Platte Kill
DB-011	161.0	NY	Upper part of East Branch Delaware River and tributaries to Pepacton Reservoir
DB-012	97.1	NY	Upper part of Beaver Kill
DB-013	133.0	NY	Willowemoc Creek
DB-014	91.5	NY	Middle part of East Branch Delaware River below Pepacton Reservoir
DB-015	70.0	NY	Lower part of Beaver Kill
DB-016	78.5	NY	Lower part of East Branch Delaware River
DB-017	82.5	NY	Hankins Creek, Basket Creek, Hoolihan Creek, Abe Lord Creek, Humphries Creek, Blue Mill Stream (tributaries to Delaware River)
DB-018	122.0	PA	Equinunk Creek
DB-019	35.7	NY	East Branch Callicoon Creek
DB-020	76.2	NY	North Branch Callicoon Creek
DB-021	25.8	NY	Unnamed tributaries to Delaware River
DB-022	80.1	PA	Calkins Creek, Cooley Creek, Hollister Creek, Beaverdam Creek, Peggy Run (tributaries to Delaware River)
DB-023	59.2	NY	Ten Mile River
DB-024	39.4	PA	Masthope Creek, Westcolong Creek (tributaries to Delaware River)
DB-025	92.2	PA	West Branch Lackawaxen River
DB-026	70.0	PA	Dyberry Creek
DB-027	82.2	PA	Middle Creek
DB-028	126.0	PA	Lackawaxen River
DB-029	88.8	NY	Fish Cabin Creek, Mill Brook, Halfway Brook, Beaver Brook, Narrow Falls Brook, Grassy Swamp Brook (tributaries to Delaware River)
DB-030	67.5	PA	West Branch Wallenpaupack Creek
DB-031	160.0	PA	Wallenpaupack Creek
DB-032	92.6	PA	Shohola Creek, Panther Creek (tributaries to Delaware River)
DB-033	77.9	NY	Mongaup River above Swinging Bridge Reservoir
DB-034	40.3	NY	Mongaup River tributaries to Swinging Bridge Reservoir
DB-035	111.0	NY	Mongaup River below Swinging Bridge Reservoir, Shingle Kill
DB-036	80.2	PA	Walker Lake Creek, Pond Eddy Creek, Cummins Creek, Sawkill Creek, Craword Branch (tribu-taries to Delaware River)
DB-037	92.7	NY	Neversink River above Neversink Reservoir
DB-038	197.0	NY/NJ	Neversink River below Neversink Reservoir
DB-039	72.5	NY	Basher Kill

Table 2.2
Basin Identification (Continued)

Basin ID No.	Drain-age Area (mi^2)	State	Streams
DB-040	88.5	PA	Raymondskill Creek, Dingmans Creek, Conashaugh Creek, Dry Brook, Adams Creek, Hornbecks Creek, Toms Creek (tributaries to Delaware River)
DB-041	17.9	NJ	Unnamed tributaries to Delaware River
DB-042	66.2	NJ	Flat Brook
DB-043	158.0	PA	Bush Kill
DB-044	30.7	NJ	Vancampens Brook, Dunnfield Creek, and tributaries to Delaware River
DB-045	174.0	PA	Brodhead Creek
DB-046	114.0	PA	Pocono Creek
DB-047	34.8	PA	Cherry Creek, Caledonia Creek (tributaries to Delaware River)
DB-048	30.2	PA	Slateford Creek, Jacoby Creek, Allegheny Creek (tributaries to Delaware River)
DB-049	107.0	NJ	Paulins Kill above Stillwater Village, Trout Brook
DB-050	69.8	NJ	Paulins Kill below Stillwater Village
DB-051	48.8	NJ	Stony Brook, Delawanna Creek, Beaver Brook
DB-052	120.0	NJ	Pequest River
DB-053	74.9	PA	Martins Creek, Mud Run (tributaries to Delaware River)
DB-054	47.9	NJ	Pophandusing Brook, Buckhorn Creek, Lopatcong Creek, and tributaries to Delaware River
DB-055	79.9	PA	Bush Kill
DB-056	93.2	PA	Upper part of Lehigh River
DB-057	129.0	PA	Tobyhanna Creek
DB-058	91.1	PA	Bear Creek
DB-059	49.4	PA	Middle part of Lehigh River above Sandy Run
DB-060	149.0	PA	Middle part of Lehigh River above Black Creek
DB-061	117.0	PA	Middle part of Lehigh River above Pohopoco Creek
DB-062	111.0	PA	Pohopoco Creek
DB-063	113.0	PA	Lower part of Lehigh River
DB-064	78.3	PA	Aquashicola Creek
DB-065	91.8	PA	Lower part of Lehigh River above Little Lehigh Creek
DB-066	106.0	PA	Jordan Creek
DB-067	83.8	PA	Little Lehigh Creek
DB-068	149.0	PA	Lower part of Lehigh River below Little Lehigh Creek
DB-069	58.2	NJ	Pohatcong Creek
DB-070	81.7	NJ	Musconetcong River above Trout Brook
DB-071	73.9	NJ	Musconetcong River below and including Trout Brook
DB-072	96.9	PA	Frya Run, Cooks Creek, Tinicum Creek, and tributaries to Delaware River
DB-073	62.5	NJ	Harihokake Creek, Nishisakawick Creek, and tributaries to Delaware River
DB-074	112.0	PA	Tohickon Creek
DB-075	54.4	NJ	Lockatong Creek, Wickecheoke Creek, and tributaries to Delaware River
DB-076	77.3	PA	Geddes Run, Hickory Creek, Paunnacussing Creek, Aquetong Creek, Hollow Run, Pidcock Creek, Jericho Creek, Houghs Creek, Dyers Creek
DB-077	62.5	NJ	Alexauken Creek, Moores Creek, Jacobs Creek, and tributaries to Delaware River
DB-078	95.7	NJ	Assunpink Creek
DB-079	54.0	PA	Martins Creek and tributaries to Delaware River

Table 2.2
Basin Identification (Continued)

Basin ID No.	Drain-age Area (mi^2)	State	Streams
DB-080	144.0	NJ	Crosswicks Creek
DB-081	52.3	NJ	Crafts Creek, Black Creek, and tributaries to Delaware River
DB-082	53.1	NJ	Assiscunk Creek and tributaries to Delaware River
DB-083	168.0	PA	Neshaminy Creek above Little Neshaminy Creek
DB-084	65.1	PA	Neshaminy Creek below Little Neshaminy Creek
DB-085	110.0	NJ	North Branch Rancocas Creek above New Lisbon Dam, Greenwood Branch
DB-086	68.6	NJ	South Branch Rancocas Creek above Bobbys Run
DB-087	76.0	NJ	South Branch Rancocas Creek above South West Branch
DB-088	95.8	NJ	Rancocas Creek main stem with North Branch below New Lisbon Dam and South Branch below Bobbys Run
DB-089	80.2	PA	Poquessing Creek, Pennypack Creek, and tributaries to Delaware River
DB-090	56.2	NJ	Pennsauken Creek, Pompeston Creek, and tributaries to Delaware River
DB-091	65.7	PA	Frankford Creek and tributaries to Delaware River
DB-092	51.3	NJ	Cooper River
DB-093	98.9	NJ	Woodbury Creek, Big Timber Creek, Newton Creek, and tributaries to Delaware River
DB-094	137.0	PA	Little Schuylkill River
DB-095	66.9	PA	Upper part of Schuylkill River above Pottsville
DB-096	138.0	PA	Upper part of Schuylkill River below Pottsville
DB-097	107.0	PA	Tributaries to middle part of Schuylkill River
DB-098	90.8	PA	Maiden Creek above Sacony Creek
DB-099	125.0	PA	Maiden Creek below Sacony Creek
DB-100	131.0	PA	Upper part of Tulpehocken Creek above Blue Marsh Reservoir
DB-101	88.3	PA	Lower part of Tulpehocken Creek below Blue Marsh Reservoir
DB-102	170.0	PA	Tributaries to middle part of Schuylkill River
DB-103	91.5	PA	Manatawny Creek
DB-104	140.0	PA	Lower part of Schuylkill River and tributaries above Skippack Creek
DB-105	70.2	PA	French Creek
DB-106	144.0	PA	West Branch Perkiomen Creek
DB-107	134.0	PA	Perkiomen Creek above and including East Branch
DB-108	84.0	PA	Perkiomen Creek below East Branch
DB-109	129.0	PA	Lower part of Schuylkill River and tributaries below Skippack Creek
DB-110	63.7	PA	Wissahickon Creek
DB-111	50.2	NJ	Mantua Creek
DB-112	81.6	PA	Darby Creek
DB-113	41.0	NJ	Cedar Swamp, Repaupo Creek, Clonmell Creek, and tributaries to Delaware River
DB-114	77.2	PA	Crum Creek, Ridley Creek, Marcus Hook Creek
DB-115	66.4	PA	Chester Creek
DB-116	40.9	PA/DE	Naamans Creek, Shellpot Creek, and tributaries to Delaware River
DB-117	49.7	NJ	Raccoon Creek, Birch Creek
DB-118	44.0	NJ	Oldmans Creek
DB-119	72.0	NJ	Salem River above dam, Salem Canal, and tributaries to Delaware Bay
DB-120	123.0	PA	East Branch Brandywine Creek
DB-121	135.0	PA	West Branch Brandywine Creek
DB-122	65.2	PA/DE	Brandywine Creek (main stem)
DB-123	56.1	PA/DE	Red Clay Creek

Table 2.2
Basin Identification (Continued)

Basin ID No.	Drain-age Area (mi^2)	State	Streams
DB-124	104.0	PA/DE	White Clay Creek
DB-125	85.0	DE	Christina River and tributaries to Delaware River
DB-126	68.8	NJ	Salem River below dam and tributaries to Delaware Bay
DB-127	31.5	DE	Army Creek, Red Lion Creek, Dragon Creek, and tributaries to Delaware River
DB-128	32.4	DE	C and D Canal and tributaries to Delaware Bay
DB-129	77.7	NJ	Alloway Creek, Hope Creek, and tributaries to Delaware Bay
DB-130	91.1	DE	Augustine Creek, Appoquinimik River, Blackbird Creek, and tributaries to Delaware Bay
DB-131	55.2	NJ	Stow Creek and tributaries to Delaware Bay
DB-132	99.7	DE	Smyrna River, Duck Creek, Mill Creek, and tributaries to Delaware Bay
DB-133	107.0	NJ	Cohansey River
DB-134	111.0	NJ	Back Creek, Cedar Creek, Nantuxent Creek, Dividing Creek, and tributaries to Delaware Bay
DB-135	101.0	DE	Leipsic River, Simons River, Little River, and tributaries to Delaware Bay
DB-136	75.9	NJ	Scotland Run, Still Run, Little Ease Run
DB-137	115.0	NJ	Maurice River above Sherman Avenue Bridge and Muddy Run
DB-138	69.7	NJ	Maurice River above Menantico Creek
DB-139	75.4	NJ	Menantico Creek, Manumuskin River
DB-140	48.9	NJ	Maurice River below Menantico Creek
DB-141	86.5	NJ	West Creek, East Creek, Dennis Creek, and tributaries to Delaware Bay
DB-142	45.2	NJ	Tributaries to Delaware Bay
DB-143	88.3	DE	Saint Jones River
DB-144	104.0	DE	Murderkill River
DB-145	74.8	DE	Misspillion River and tributaries to Delaware Bay
DB-146	83.3	DE	Cedar Creek, Slaughter Creek, Primehook Creek, and tributaries to Delaware Bay
DB-147	83.5	DE	Round Pole Branch and tributaries to Delaware Bay

Once sub-basins were identified, the team assessed current and future water demands for key water using sectors in the Basin through the year 2030 and evaluated them against indicators of ground and surface water availability through a river analysis for the Delaware, Schuylkill and Lehigh Rivers and a watershed analysis for each of the 147 sub-basins. The analysis quantifies the following:

- Withdrawals and consumptive use
- Peak month and average annualized demand
- Surface and ground water supply

This report serves as a reconnaissance level summary of water supply and demand for the 147 sub-basins and the Delaware, Schuylkill and Lehigh Rivers and should not be considered to be all inclusive in its recommendations for meeting water deficits, but should rather be considered as an aid in assisting future water supply planning efforts.

2.1.2 Ground-Water Availability. Different methods were used to estimate ground-water availability for the region underlain by fractured rocks in the upper part of the basin and for surficial aquifers in the region underlain by unconsolidated sediments in the lower part of the basin. The methodology is similar to that used for the DRBC's Ground-Water Protected Area (GWPA) in southeastern Pennsylvania. The DRBC delineated the GWPA in 1980 in response to increases in population and water demand in the region, which were responsible for interference and conflict among users of the same ground water resource. The GWPA Regulations were amended in 1998 to include numerical withdrawal limits (equivalent to the 1-year-in-25-year baseflow rate) for the 76 subbasins and establish a potentially stressed watershed status corresponding to 75% of the withdrawal limit. Figure 2.8 shows the GWPA delineation and also another area vulnerable to ground water withdrawals, the New Jersey Water Supply Critical Area 2 where additional management efforts are in place to protect ground water resources.

In the USGS report, estimates of ground-water availability for the 109 watersheds underlain by fractured rocks were based on lithology and physiographic province. Lithology was generalized by grouping geologic units into 14 categories on the basis of rock type and physiographic province. Twenty-three index streamflow-gaging stations were identified to represent the 14 categories. A base-flow-recurrence analysis was performed to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each index station. A GIS analysis then used lithology and base flow at the index stations to determine the average annual base flow for each of the 109 watersheds.

Ground-water availability for watersheds underlain by unconsolidated surficial aquifers was based on predominant surficial geology and land use, which were determined from statistical analyses to be the most significant controlling factors of base flow. Twenty-one index streamflow-gaging stations were selected to represent the 13 categories of predominant surficial geology and land use for the 38 Coastal Plain watersheds. A base-flow-recurrence analysis was also used to determine the average annual 2-, 5-, 10-, 25-, and 50-year-recurrence intervals for each group of predominant surficial geology and land use.

The range of recurrence intervals are chosen to be representative of the quantity of ground water available for each watershed over a range of climatic conditions. The recurrence intervals are considered to be relative indicators of climatic difference; for example, the 2-year-recurrence value represents wetter years and the 50-year-recurrence value represents drier years. The DRBC uses the 25-year-recurrence interval to set withdrawal limits for each of the sub-basins delineated in the GWPA. For the purposes of this study, the 25-year-recurrence interval will be used as the primary benchmark for evaluating ground-water availability. The choice of this indicator is based primarily upon its use for ground water management purposes in the GWPA over the past decade.

Table 2.3 displays ground-water availability for each of the 147 watersheds of the Delaware River Basin. Both million gallons per square mile per day ($MG/mi^2/d$) and million gallons per day (MG/d), were calculated for each watershed.

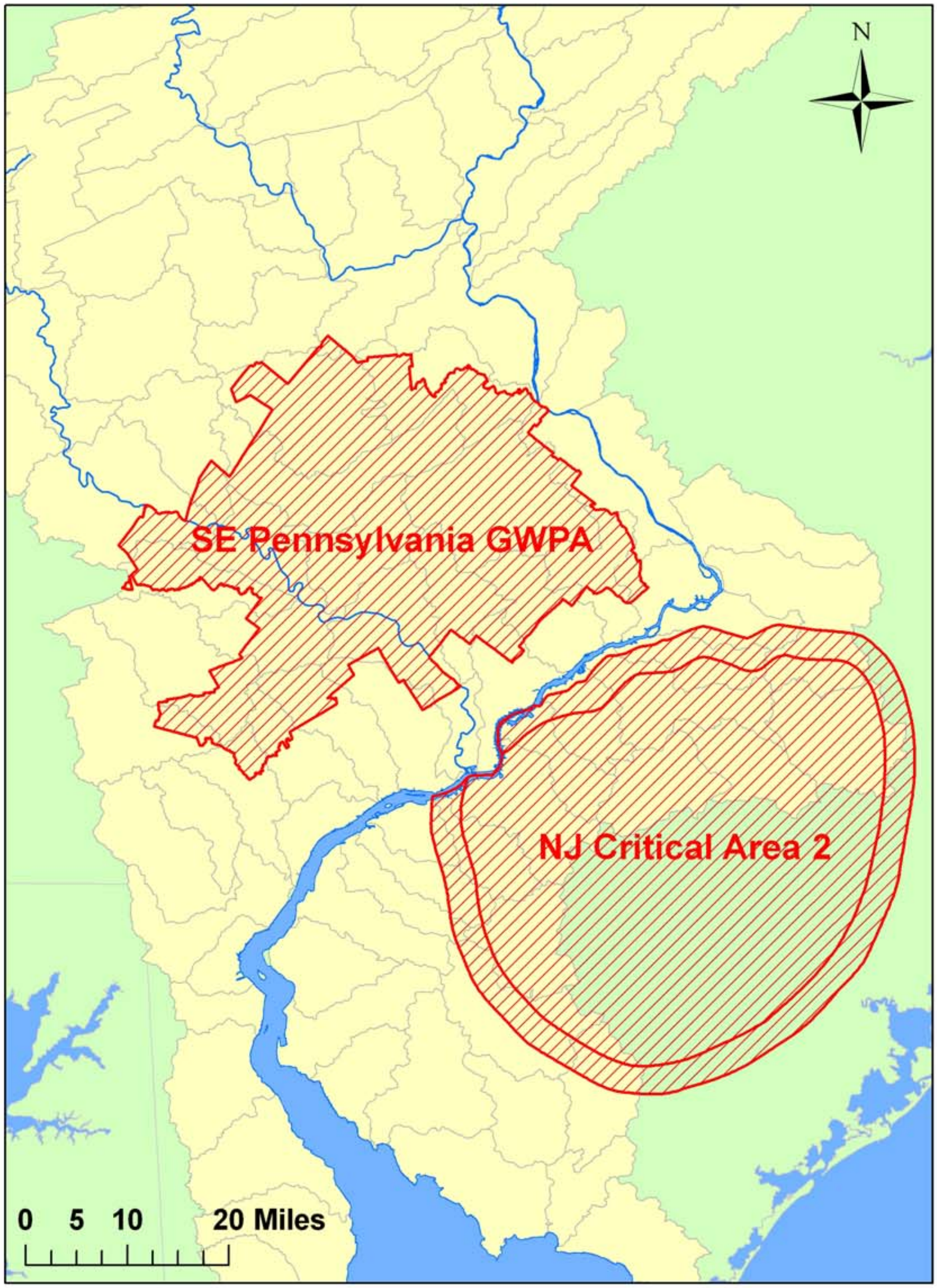

Figure 2.8 The Ground Water Protected Area (GWPA) in southeastern Pennsylvania and the New Jersey Water Supply Critical Area 2

Table 2.3
Ground Water Availability

	MG/mi²/d			MG/d		
Basin ID number	**2-yr RI**	**10-yr RI**	**25-yr RI**	**2-yr RI**	**10-yr RI**	**25-yr RI**
DB-001	0.687	0.492	0.403	98.833	70.812	57.975
DB-002	0.687	0.492	0.403	35.923	25.738	21.072
DB-003	0.687	0.492	0.403	56.948	40.802	33.405
DB-004	0.687	0.492	0.403	36.488	26.143	21.403
DB-005	0.701	0.501	0.412	85.938	61.452	50.562
DB-006	0.691	0.495	0.406	27.121	19.418	15.915
DB-007	0.704	0.503	0.415	47.727	34.063	28.109
DB-008	0.763	0.542	0.456	32.396	23.003	19.336
DB-009	0.855	0.620	0.537	53.101	38.500	33.315
DB-010	0.695	0.497	0.408	146.043	104.389	85.730
DB-011	0.697	0.498	0.410	112.480	80.354	66.110
DB-012	0.753	0.524	0.446	73.123	50.846	43.342
DB-013	0.748	0.515	0.442	99.120	68.221	58.493
DB-014	0.721	0.514	0.426	66.000	47.030	38.994
DB-015	0.711	0.477	0.414	49.735	33.347	28.947
DB-016	0.744	0.513	0.439	58.341	40.225	34.425
DB-017	0.636	0.394	0.356	52.506	32.470	29.341
DB-018	0.870	0.635	0.550	108.894	79.447	68.870
DB-019	0.586	0.347	0.318	20.882	12.358	11.331
DB-020	0.692	0.444	0.396	52.699	33.865	30.208
DB-021	0.573	0.336	0.309	14.805	8.667	7.973
DB-022	0.874	0.639	0.553	70.010	51.172	44.328
DB-023	0.578	0.340	0.312	34.250	20.152	18.504
DB-024	0.875	0.639	0.554	34.486	25.211	21.842
DB-025	0.874	0.640	0.554	80.574	59.058	51.089
DB-026	0.875	0.639	0.554	61.233	44.765	38.783
DB-027	0.865	0.648	0.555	71.134	53.252	45.633
DB-028	0.874	0.640	0.554	110.184	80.656	69.825
DB-029	0.718	0.504	0.423	63.784	44.811	37.563
DB-030	0.861	0.651	0.555	58.151	43.954	37.503
DB-031	0.865	0.647	0.555	138.249	103.418	88.688
DB-032	0.874	0.640	0.554	80.937	59.247	51.291
DB-033	0.705	0.502	0.415	54.946	39.124	32.354
DB-034	0.695	0.497	0.408	28.037	20.060	16.478
DB-035	0.711	0.507	0.420	78.688	56.122	46.459
DB-036	0.840	0.624	0.537	67.432	50.064	43.093
DB-037	0.727	0.516	0.430	67.388	47.772	39.855
DB-038	0.708	0.514	0.427	139.729	101.457	84.311
DB-039	0.725	0.531	0.445	52.533	38.478	32.285
DB-040	0.826	0.617	0.530	73.178	54.682	46.943

Table 2.3
Ground Water Availability (Continued)

	MG/mi²/d			MG/d		
Basin ID number	2-yr RI	10-yr RI	25-yr RI	2-yr RI	10-yr RI	25-yr RI
DB-041	0.810	0.610	0.522	14.562	10.965	9.386
DB-042	0.715	0.530	0.459	47.373	35.133	30.427
DB-043	0.864	0.635	0.549	136.037	99.967	86.432
DB-044	0.671	0.499	0.431	20.598	15.309	13.216
DB-045	0.857	0.634	0.546	149.126	110.217	95.020
DB-046	0.841	0.626	0.539	95.793	71.257	61.312
DB-047	0.734	0.547	0.472	25.556	19.025	16.436
DB-048	0.532	0.415	0.358	16.081	12.543	10.817
DB-049	0.582	0.426	0.354	62.388	45.672	37.906
DB-050	0.579	0.424	0.351	40.425	29.632	24.503
DB-051	0.583	0.425	0.352	28.543	20.831	17.234
DB-052	0.670	0.454	0.361	80.643	54.629	43.530
DB-053	0.559	0.421	0.356	41.934	31.603	26.672
DB-054	0.688	0.452	0.349	33.023	21.685	16.777
DB-055	0.588	0.423	0.346	46.983	33.828	27.653
DB-056	0.864	0.651	0.557	80.503	60.646	51.925
DB-057	0.860	0.650	0.555	110.996	83.928	71.602
DB-058	0.895	0.650	0.574	81.566	59.261	52.264
DB-059	0.913	0.650	0.583	45.118	32.101	28.782
DB-060	0.899	0.650	0.575	134.059	97.035	85.792
DB-061	0.866	0.636	0.555	101.570	74.601	65.142
DB-062	0.846	0.629	0.541	93.828	69.812	60.014
DB-063	0.677	0.516	0.447	76.495	58.280	50.473
DB-064	0.793	0.590	0.508	62.126	46.190	39.801
DB-065	0.579	0.421	0.347	53.134	38.683	31.810
DB-066	0.566	0.419	0.348	60.011	44.385	36.851
DB-067	0.688	0.451	0.348	57.619	37.796	29.151
DB-068	0.658	0.436	0.339	97.858	64.882	50.464
DB-069	0.686	0.464	0.372	39.914	26.982	21.647
DB-070	0.682	0.485	0.413	55.694	39.585	33.706
DB-071	0.666	0.459	0.373	49.254	33.924	27.572
DB-072	0.448	0.303	0.251	43.455	29.389	24.312
DB-073	0.372	0.254	0.213	23.298	15.933	13.347
DB-074	0.313	0.211	0.175	35.100	23.633	19.650
DB-075	0.364	0.246	0.207	19.836	13.407	11.290
DB-076	0.449	0.300	0.253	34.752	23.193	19.588
DB-077	0.356	0.240	0.202	22.267	15.055	12.651
DB-078	1.028	0.822	0.671	98.343	78.636	64.191
DB-079	0.524	0.331	0.290	28.307	17.886	15.657
DB-080	0.563	0.379	0.327	81.231	54.683	47.181
DB-081	0.563	0.379	0.327	29.462	19.833	17.112
DB-082	0.774	0.558	0.504	41.104	29.633	26.765

Table 2.3
Ground Water Availability (Continued)

	MG/mi²/d			MG/d		
Basin ID number	**2-yr RI**	**10-yr RI**	**25-yr RI**	**2-yr RI**	**10-yr RI**	**25-yr RI**
DB-083	0.439	0.298	0.252	73.923	50.090	42.496
DB-084	0.543	0.359	0.312	35.349	23.358	20.298
DB-085	0.774	0.558	0.504	85.399	61.566	55.608
DB-086	0.774	0.558	0.504	53.119	38.295	34.589
DB-087	0.774	0.558	0.504	58.862	42.435	38.329
DB-088	0.774	0.558	0.504	74.174	53.474	48.299
DB-089	0.540	0.348	0.303	43.332	27.964	24.343
DB-090	0.619	0.443	0.393	34.790	24.898	22.088
DB-091	0.523	0.330	0.289	34.381	21.701	18.988
DB-092	0.619	0.443	0.393	31.752	22.724	20.159
DB-093	0.619	0.443	0.393	61.238	43.826	38.880
DB-094	0.849	0.615	0.543	116.230	84.167	74.311
DB-095	0.915	0.650	0.584	61.182	43.463	39.033
DB-096	0.832	0.610	0.534	115.183	84.428	73.866
DB-097	0.562	0.424	0.360	60.311	45.569	38.661
DB-098	0.526	0.419	0.367	47.744	38.030	33.282
DB-099	0.607	0.431	0.349	76.133	53.985	43.814
DB-100	0.605	0.427	0.344	79.278	55.953	45.077
DB-101	0.588	0.427	0.355	51.949	37.743	31.339
DB-102	0.525	0.356	0.297	89.166	60.395	50.370
DB-103	0.616	0.425	0.351	56.368	38.926	32.116
DB-104	0.458	0.299	0.250	63.963	41.703	34.865
DB-105	0.527	0.346	0.300	36.986	24.287	21.087
DB-106	0.433	0.300	0.253	62.436	43.193	36.479
DB-107	0.341	0.231	0.193	45.698	30.979	25.838
DB-108	0.325	0.219	0.183	27.288	18.420	15.357
DB-109	0.552	0.357	0.302	71.313	46.114	39.039
DB-110	0.534	0.349	0.292	33.993	22.254	18.616
DB-111	0.619	0.443	0.393	31.048	22.220	19.712
DB-112	0.524	0.331	0.289	42.713	26.975	23.608
DB-113	1.169	0.780	0.688	47.958	32.000	28.225
DB-114	0.523	0.330	0.289	40.387	25.492	22.306
DB-115	0.524	0.331	0.289	34.750	21.946	19.207
DB-116	0.514	0.325	0.284	21.033	13.295	11.626
DB-117	0.524	0.353	0.344	26.055	17.553	17.105
DB-118	0.524	0.353	0.344	23.077	15.546	15.150
DB-119	1.169	0.780	0.688	84.120	56.128	49.508
DB-120	0.543	0.343	0.292	66.972	42.279	36.062
DB-121	0.532	0.336	0.290	71.788	45.289	39.198
DB-122	0.524	0.331	0.289	34.146	21.564	18.872
DB-123	0.533	0.336	0.291	29.890	18.860	16.304

Table 2.3
Ground Water Availability (Continued)

	MG/mi^2/d			MG/d		
Basin ID number	2-yr RI	10-yr RI	25-yr RI	2-yr RI	10-yr RI	25-yr RI
DB-124	0.534	0.337	0.291	55.511	35.044	30.252
DB-125	0.519	0.328	0.287	44.122	27.851	24.385
DB-126	1.169	0.780	0.688	80.458	53.684	47.352
DB-127	0.823	0.633	0.532	25.925	19.940	16.759
DB-128	0.548	0.340	0.278	17.736	11.004	8.997
DB-129	1.169	0.780	0.688	90.859	60.625	53.474
DB-130	0.465	0.309	0.234	42.361	28.149	21.317
DB-131	0.765	0.540	0.482	42.259	29.830	26.626
DB-132	0.548	0.340	0.278	54.641	33.901	27.719
DB-133	0.862	0.560	0.509	92.363	60.004	54.539
DB-134	0.765	0.540	0.482	84.959	59.971	53.530
DB-135	0.465	0.309	0.234	46.712	31.041	23.507
DB-136	0.739	0.511	0.458	56.124	38.808	34.783
DB-137	0.739	0.511	0.458	84.764	58.612	52.533
DB-138	0.739	0.511	0.458	51.482	35.599	31.907
DB-139	0.739	0.511	0.458	55.735	38.540	34.542
DB-140	1.169	0.780	0.688	57.216	38.176	33.673
DB-141	1.169	0.780	0.688	101.140	67.484	59.524
DB-142	1.169	0.780	0.688	52.860	35.270	31.110
DB-143	0.465	0.309	0.234	41.065	27.288	20.665
DB-144	0.465	0.309	0.234	48.433	32.185	24.373
DB-145	0.465	0.309	0.234	34.774	23.108	17.499
DB-146	0.465	0.309	0.234	38.723	25.732	19.486
DB-147	0.548	0.340	0.278	45.762	28.392	23.215

2.1.3 Surface Water Availability. In contrast to Ground-water availability estimates, data for surface water availability for the 147 watersheds was not readily available for use in this study. A literature review[2,3,4] was undertaken to determine the appropriate methodologies and level of effort necessary to undertake a surface water evaluation. The cited approaches generally rely on multivariate regression equations for regional areas in Pennsylvania and Delaware, or individual stream statistics for streams in New Jersey and are necessarily data-intensive. Consistent with the scope of this study, it was determined that the approach used for estimating ground-water availability could be adapted to provide an estimation of surface-water availability. Therefore, the same set of index streamflow gages were chosen (based on the ground-water methodology report) along with geology (in combination with land-use in the coastal plain) to determine surface-water availability for each of the 147 study watersheds. For more detail on the choice of streamflow gages see the USGS report on Ground-Water Availability.[5]

Daily surface water data were downloaded from the USGS website and analyses were performed to extract statistics that would be representative of surface water availability during periods of low-flow. These statistics were as follows:

- $Q_7 10$
- 95% flow exceedence value
- September Median Flow minus $Q_7 10$

The $Q_7 10$ can be thought of as the lowest stream flow for seven consecutive days that would be expected to occur once in ten years. The 95% flow exceedence value is the flow that is exceeded 95% of the time. The September Median Flow minus the $Q_7 10$ is calculated by finding the median value for September flows for the period of record and subtracting the $Q_7 10$.

$Q_7 10$ analysis was generated from a recurrence interval plot of the Weibull plotting position ((Rank/(n+1)) for each annual 7-day average lowest flow. Flow exceedence values were obtained from a flow duration curve. The statistics were calculated for each of the index gages, and were normalized for contributing drainage area, to generate a figure in terms of million gallons per day per square mile of drainage area. These values were then applied to each watershed based on a GIS analysis of the lithology of the 109 fractured rock watersheds and the predominant surficial geology and land use for the 38 Coastal Plain watersheds. The relationship between the three resulting low-flow statistics for the 49 index stations can be seen graphically in Figure 2.9.

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[2] Stuckey, Marla H. 2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams, 2006-5130

[3] Gillespie, B. D.; Schopp, R. 1982, D. *Low-flow characteristics and flow duration of New Jersey streams*

[4] Carpenter, David H.; Hayes, Donald C. 1996, *Low-flow characteristics of streams in Maryland and Delaware*

[5] Sloto, R.A. and Buxton, D.E. 2006, Estimated Ground-Water Availability in the Delaware River Basin, 1997-2000; U.S. Geological Survey Scientific Investigations Report 2006-5125 Version 1.1

These water availability statistics were chosen to provide a range of values representative of low-flows. The statistics are all metrics that have been used in previous or current studies in the Delaware River Basin. For the purposes of this study the $Q_7 10$ was chosen as an indicator of water availability under low flow conditions; its application will be discussed later in this report. As noted earlier, the approach to quantifying low flow water availability varies among the different states and planning efforts. Studies are ongoing in the Delaware River Basin and elsewhere to better quantify water availability and specifically to account for ecological instream flow needs.

Currently, many of these instream flow needs are being met through releases from the reservoirs within the Basin. The Delaware River Basin has 26 major reservoirs with a total water supply storage capacity of over 414 billion gallons. Table 2.4 shows a listing of these reservoirs, their purpose, location and capacity.

Releases from these reservoirs have helped maintain flow targets during dry conditions and have also provided a means of compensation for consumptive use and any exportation of water in the lower half of the Basin. Releases are made from Blue Marsh Lake and Beltzville Reservoirs, located in the lower basin, to maintain target flows. Portions of the storage in these two Corps' reservoirs have been purchased by the DRBC for this purpose. The storage has been financed through a surface water charging program in which surface users pay for the volume of water withdrawn and consumed. This water charging program will be discussed in more detail in Section 5.0.

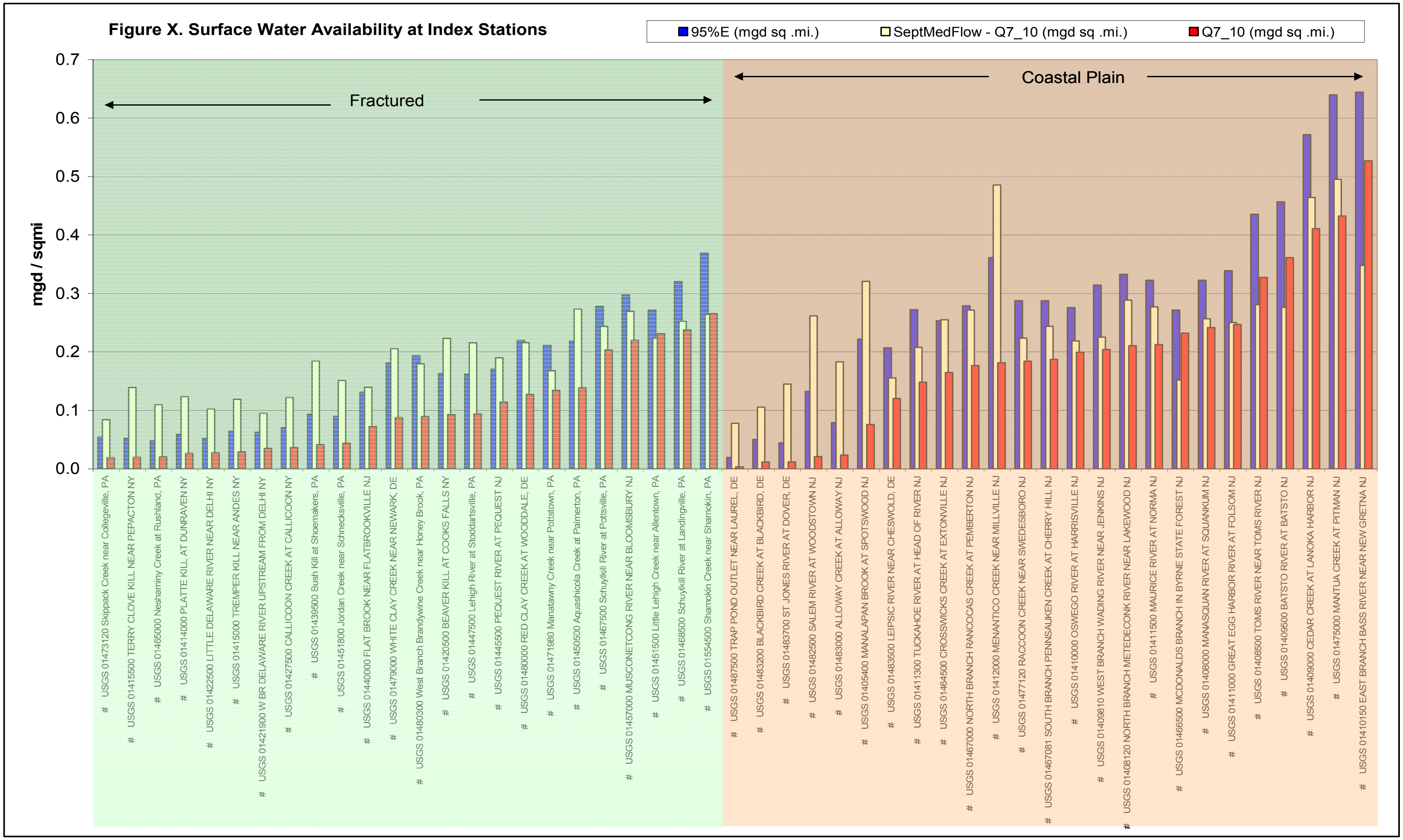


Figure 2.9 Surface Water Availability at Index Stations

Table 2.4
Major Reservoirs in the Delaware River Basin

NAME	LOCATED ON	STORAGE (MG)	PURPOSE	OWNER
Cannonsville Reservoir	WEST BRANCH DELAWARE RIVER	95706	WS,WSA	New York City Water Supply
Pepacton Reservoir	EAST BRANCH DELAWARE RIVER	140190	WS,WSA	New York City Water Supply
Neversink Reservoir	NEVERSINK RIVER	34941	WS,WSA	New York City Water Supply
Jadwin Reservoir	DYBERRY CREEK (LACKAWAXEN RIVER)	7985	FL	Army Corps of Engineers
Prompton Reservoir	WEST BRANCH LACKAWAXEN RIVER	16849/1115CP	FL	Army Corps of Engineers
Lake Wallenpaupack	WALLENPAUPACK CREEK (LACKAWAXEN RIVER)	35451	P	PPL
Mongaup System		26773	P	Alliance Energy New York
Swinging Bridge	MONGAUP RIVER			
Toronto	BLACK LAKE CREEK (MONGAUP RIVER)			
Cliff Lake	BLACK LAKE CREEK (MONGAUP RIVER)			
F.E. Walter Reservoir	LEHIGH RIVER	36077/652CP	FL,REC	United States Army Corps of Engineers
Penn Forest Reservoir	WILD CREEK (LEHIGH RIVER)	6032	WS	City of Bethlehem
Wild Creek Reservoir	WILD CREEK (LEHIGH RIVER)	3911	WS	City of Bethlehem
Beltzville Reservoir	POHOPOCO CREEK (LEHIGH RIVER)	20792/13443CP	FL,WS,WSA REC	United States Army Corps of Engineers
Merrill Creek Reservoir	MERRILL CREEK (POHATCONG CREEK)	15665	WSA	Merrill Creek Owners Group
Lake Hopatcong	MUSCONETCONG RIVER	7459	WS	
Nockamixon Reservoir	TOHICKON CREEK	21672	WS	PA DCNR
Lake Galena	N. BRANCH NESHAMINY CREEK	1629	WS	Bucks County, PA
Still Creek Reservoir	STILL CREEK (SCHUYLKILL RIVER)	2701	WS	Borough of Tamaqua
Ontelaunee Reservoir	MAIDEN CREEK (SCHUYLKILL RIVER)	3580	WS	Reading Area Water Authority
Blue Marsh Lake	TULPEHOCKEN CREEK (SCHUYLKILL RIVER)	16295	FL,WS,WSA REC	Army Corps of Engineers
Green Lane Reservoir	PERKIOMEN CREEK (SCHUYLKILL RIVER)	4377	WS	Aqua Pennsylvania Water Co
Bradshaw Reservoir	PERKIOMEN CREEK (SCHUYLKILL RIVER)	25	WS,P	Exelon Corporation
Geist (aka Springton) Reservoir	CRUM CREEK	3513	WS	Aqua Pennsylvania Water Co
Marsh Creek Reservoir	MARSH CREEK (CHRISTINA RIVER)	7232	WS,WSA,FL	PA DCNR
Hoopes Reservoir	RED CLAY CREEK (CHRISTINA RIVER)	2000	WS	City of Wilmington, DE
Chambers Lake Near Wagontown	BIRCH RUN (CHRISTINA RIVER)	652	WS, FL, REC	Chester County, PA
Union Lake	MAURICE RIVER	3177	WS	NJ DEP

STORAGE: MG, MILLION GALLONS; CP, CONSERVATION POOL
PURPOSE: WS, WATER SUPPLY, WSA, WATER-SUPPLY AUGMENTATION; FL, FLOOD STORAGE; P, HYDROPOWER; REC, RECREATION

2.1.4 Affects of Climate Variability. Once water availability was calculated, the affects of climate variability were added to the equation. A literature review was conducted to review the current state of knowledge on climate variability in the Delaware River Basin. There was little consensus among the articles as to what degree future climate variability will impact streamflow and groundwater in the region; however, several articles agreed on some general trends in climate variability. Where the articles disagreed on was the magnitudes of the climate variability trends. Also, most of the articles projected longer-term climate variability trends well beyond the year 2030 with very little information given up to year 2030.

The current state of knowledge is heavily dependent upon the results of computer climate models and assumptions made regarding future trends in emissions. Different climate models and emission scenarios give different results, and there is no consensus as to which climate model or emission scenario is more likely.

During the literature review, articles were found that summarized results for the Mid Atlantic region from several different climate models and emission scenarios. Many of the articles predicted earlier peaks in streamflow in the Spring and later peaks in the Fall. As for the low-flow period in the Summer, the current state of knowledge is suggesting that its period could be extended but this probably would not be observable until the end of the century and not by the year 2030. All of these conclusions are dependent upon future trends in emissions. Lower emission scenarios produce less dramatic results in the computer models than higher emission scenarios.

Generally speaking, some other trends that many articles agreed upon were:

- Minimum winter temperatures are likely to increase slightly in the region.
- Annual mean precipitation is likely to increase.
- Snow season length and depth is likely to decrease.

Only one reviewed article quantified by how much if at all how all of these climate variability trends would impact the $Q_7 10$ low-flow quantity which was used to calculate water availability in this Study. The Northeast Climate Impacts Assessment (NECIA) team published a report in July 2007 called “Confronting Climate Change in U.S Northeast: Science Impacts, and Solutions”. In that report, the authors state that by the end of the century under a high emission scenario they examined, the streamflow during the lowest week of the year was projected to drop 10%.

It can be argued that the change in seasonality of streamflow probably would have a very minimal impact if any at all on the $Q_7 10$ along with slightly wetter, less snow winters. For purposes of this Study, it was assumed that projections of available water supply in the Year 2030 would be reduced by 5%. This is a conservative assumption based upon the literature review of the current state of knowledge on climate variability. To reduce $Q_7 10$ by more than 5% is probably over-estimating the potential impacts of climate variability by the Year 2030.

Besides available streamflow in the Year 2030, climate variability can impact other areas in water supply that were incorporated in the analysis such as groundwater baseflows in New Jersey and Delaware, which rely on ground water sources for their water supply. It was assumed that the 25-yr baseflow which was used in the analysis would also be reduced by 5% for the Year 2030.

Reservoir storage capacities at reservoirs identified as potential alternative sources for water supply were also adjusted to account for climate variability. The average 120-day yields used in the analysis was also reduced by 5%.

Climate variability could also potentially impact Delaware River salinity. In April 2007 a re-evaluation of the salinity numerical model for the Delaware River was conducted as part of the Delaware Deepening Project. The re-evaluation examined what the salinity impacts on the Delaware River would be for fresh water flows from the drought of the 1960's. The re-evaluation also considered what would happen if the Delaware River navigation channel was deepened five feet, if consumptive use increased to projected levels for the year 2040, and if sea-level rose 0.547 feet and 0.492 feet at the Delaware and Chesapeake Bay boundaries of the model respectively. These sea-level values represent potential sea-level conditions in the year 2040 based upon the historical information that mean sea-level has increased 1.273 feet over the past 100 years in the region. These three scenarios were examined independently and if they were all to occur together. The model showed that when all the scenarios were combined together that the chlorinity value at river mile 98 increased to 140 ppm.

DRBC regulates flows at Trenton, NJ based upon a running 7- and 30-day average chlorinities at river mile 98. The present water quality standards supported by DRBC call for 30-day average chlorinity at river mile 98 to be below 180 ppm, however, there have been discussions that the 30-day chlorinity standard should be more restrictive and lowered to 150 ppm chlorinity.

The increased salinity level of 140 ppm as produced by the model is still below the current 30-day standard of 180 ppm and the more restrictive 150 ppm standard being discussed as well.

2.2 WATER DEMAND

2.2.1 Existing Conditions. As can be seen in Figure 2.10, over 8.5 billion gallons of water per day are withdrawn from the Basin (as of 2003) with 92% of those withdrawals coming from surface water and 8% coming from ground water. Figure 2.10 shows that the greatest volume of water use (over 70%) is for thermoelectric power generation in the year 2003.

Although this sector is the largest user of water, it is comprised of a relatively small number of individual facilities. And although some of these are located on the mainstem Delaware River and its tributaries, the majority are located in the estuary where withdrawals have limited impact on downstream users.

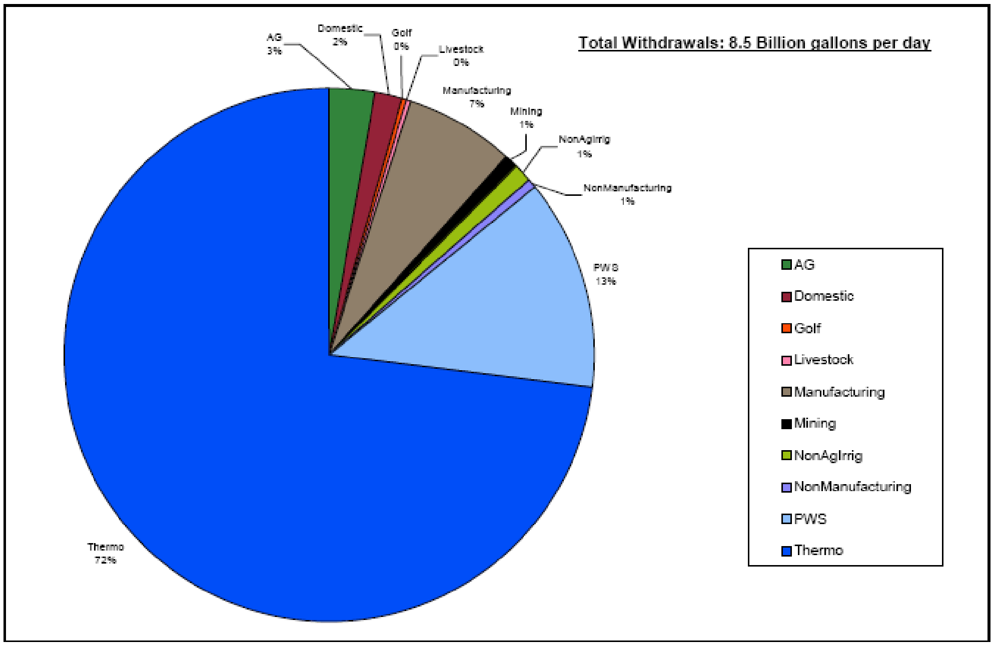


Figure 2.10 Water Withdrawals in the Delaware River Basin (2003)

2.2.2 Forecasting Future Demand. Understanding future water demands is vital in ensuring an adequate and reliable water supply for all users of the resource. Water demand forecasting methodologies vary from the simplistic (such as extrapolation of past trends) to complex, sector-specific, multivariate models which attempt to use multiple explanatory variables to forecast future demand. No single approach fits all applications, and the more complex the model, the more data intensive it becomes. In defining the applicable methodology for this project, an assessment of recent water demand forecasting efforts in each of the Basin states was undertaken. At the same time, an assessment of the available data and their accuracy was also conducted.

Outlined below is a brief summary of each of the Basin states' approaches to water demand forecasting.

Delaware. In response to the drought of 1999, a Water Supply Task Force presented a number of options for increasing supply in Northern New Castle County, Delaware. A Water Supply Coordinating Council was created, consisting of public agencies, water purveyors, and the public, to work cooperatively to develop estimates of future water demand and implement the selected water supply options. The work focused on enhancing public water supplies and relied upon future population as a driver of water demand. Agricultural irrigation demands were also evaluated, with future water demands based upon trends in agricultural land. Water use records from water users are reported to the Delaware Department of Natural Resources and Environmental Control (DNREC). Records for the year 2003 were available and used in this study; a limited amount of QA/QC work was required to address known problems with the reported data. These issues were resolved by working with DNREC staff.

New Jersey. New Jersey has developed water demand projections as part of its State-wide Water Plan. A focus has been placed on the growth in the public water supply sector; agricultural demand has been forecast based on trend extrapolation, no industrial or commercial forecasts (for those industries with their own sources of supply) have been developed. The primary driver of future demand for public supply is population change, based on forecasts developed by Metropolitan Planning Organizations at the municipal level. A core assumption for existing and future water use is a demand of 100 gallons per capita per day. Water use records from water users are reported to the New Jersey Department of Environmental Protection (NJDEP). Records were available for 2003 and were used in this study following a significant amount of QA/QC.

New York. No statewide water supply planning efforts, including water demand forecasting, are currently underway in New York. Water use data were obtained from DRBC's own water use databases and other sources such as the EPA Envirofacts database. Some of these data reflected 2001 water use instead of the target base year of 2003, but as the total withdrawal from water users (not including the export to New York City) in the New York portion of the Basin is small (less than 0.5% of total basin water use) this was not significant.

Pennsylvania. Pennsylvania's Act 220 Water Resources legislation calls for the development of a new State Water Plan. As part of this process, DRBC worked in conjunction with the Pennsylvania Department of Environmental Protection (PADEP) and the consulting firm CDM, to develop methodologies for projecting water demands for a number of water use sectors. This work provides the basis for several of the methodologies used in this study. The forecasting methodologies developed for the State Water Plan process typically follow the same general approach for each water use sector, which is to identify a key water use factor (e.g., per employee water use) and its corresponding "driver of demand" (e.g., forecasted number of employees). Each sector was studied separately to identify the most applicable factors and drivers. Water use records from water users are reported to the Pennsylvania Department of Environmental Protection (PADEP) and were available for the year 2003. As part of its ongoing support of the State Water Plan, the DRBC has been working with PADEP to improve data reliability; as such little additional QA/QC effort was required.

2.2.2.1 Methodology Used For Watershed Analysis. Following a review of the methods employed and data available in each state, it was determined that a disaggregated demand forecasting methodology should be applied. This methodology calls for each water use sector to be forecast separately, using drivers of demand most applicable to that sector. Although obtaining reliable and current water use data is still an ongoing challenge in the Delaware River Basin, the data available has improved significantly in recent years. For the purposes of this study, water user records for 2003 were deemed to be reliable for estimates of current water use and as a platform from which to project future water use.

For any given sector (e.g., public water supply), identifying a single methodology to apply Basin-wide presents a number of challenges; while it is advantageous for reasons of consistency to apply a single methodology across all four states, the differences in data quality and data availability between the states would lead to a "lowest common denominator" forecast methodology and would ultimately result in less credible forecasts. Therefore, methodologies have been selected that take advantage of the different types of data available in each state. These data requirements and key drivers of demand used for this study are shown in Table 2.5.

2.2.2.1.1 Population Growth. As can be seen in Table 2.5, one of the key drivers in calculating demand for public water supply is population growth. This makes it an integral component when projecting future water demand. The boundary of the Delaware River Basin contains portions of Delaware, New Jersey, New York and Pennsylvania. Numerous population projections by state agencies and research organizations within the Basin were reviewed for use in this study. As each agency or research publication pertained to a particular state, uniformity of projection methods across the entire basin was not possible. The best available projection figures were selected based on the needs of this project.

The most applicable population figures were allocated to the 147 watersheds using GIS. To minimize the assumptions that arise when allocating figures across a geographic boundary, the finest geographic boundaries available were selected. Population projections for New Jersey and Pennsylvania were found at the municipal level. Delaware had county level population projections which also included figures for major cities, three of which are found within the basin. Projections for the New York portion of the basin were only available at the county level. However, due to the lack of major cities and the overall distribution of the population in this region of the basin, these figures are believed adequate for the purposes of this study. Final population figures broken down to sub-basin can be found in Technical Appendix A.

Table 2.5
Summary of Data Requirements and Key Water Demand Drivers for Each Water Use Sector

	Sector	State	Sub-components	Data Required	Key Demand Drivers
Water Purveyor		PA	Residential	PWS Water Use records	
				Water Purveyor service areas (GIS)	
				Allocation of use by end-user types	
				Census data	Population projections (developed by each state)
			Non-Residential (Manufacturing)	Employment data (Manufacturing)	Manufacturing employment projections
			Non-Residential (Non-manufacturing)	Employment data (Non-manufacturing)	Non-manufacturing employment projections
		NJ, DE		PWS Water Use records	
				Water Purveyor service areas (GIS)	
				Census data	Population projections (developed by each state)
		NY		PWS Water Use records	
				Census data	Population projections (developed by each state)
Self-Supplied	Domestic	ALL		Domestic use estimates adapted from USGS report[5]	Population projections (developed by each state)
	Industry	NJ, PA		Water Use records Employment data (Manufacturing)	Manufacturing employment projections
		DE		Water Use records Employment data (Manufacturing)	Trend extrapolation of manufacturing employment data
		NY		Water Use records	Held constant
	Commercial (inc. Golf & Non Ag. Irrigation)	NJ, PA		Water Use records Employment data (Non-Manufacturing)	Non-manufacturing employment projections
		DE		Water Use records Employment data (Manufacturing)	Trend extrapolation of manufacturing employment data

[5] Estimated Ground-Water Availability for the Delaware River Basin 1997-2000

Table 2.5
Summary of Data Requirements and Key Water Demand Drivers for Each Water Use Sector

	Sector	State	Sub-components	Data Required	Key Demand Drivers
Self-Supplied		NY		Water Use records	Held constant
	Thermoelectric	ALL		Water Use records DoE Energy Information Administration Data Consumptive Use info - (site specific) DRBC dockets	Trend extrapolation: water use 1994 - 2003 Rate of growth consistent with EIA forecasts of MW demand growth for Mid-Atlantic Region
	Hydroelectric	ALL		Water Use records	Held constant
	Mining	PA, NJ[6]		Water Use records Consumptive Use info - (site specific for biggest uses) Employment data (Mining)	Mining employment projections
		DE, NY		Water Use records Consumptive Use info - (site specific for biggest uses)	Held constant
	Agriculture	ALL	Crops	Irrigated acreage (USDA Ag. Census) Water withdrawals (USDA Ag. Census) Crop type distribution (USDA Ag. Census) Water Use coefficients (Ag. Census)	USDA projections of water withdrawals
		ALL	Livestock	Head count by animal type (USDA Ag. Census) Water use by animal type (PSU)	USDA projections

Definitions: Self-supplied: Water users responsible for their own sources of supply, e.g., a residential dwelling with its own well, or an industry with its own water intake
Demand Drivers: An explanatory variable that is primarily responsible for changes in demand, e.g., population projections are the primary driver for changes in residential water demand

[6] Employment projections were used, where available, for counties in New Jersey; elsewhere held constant

2.2.2.1.2 Water Conservation. Another key driver for calculating water demand is the inclusion of existing water conservation programs. The Delaware River Basin Commission has a well-established and comprehensive water conservation program which has for many years provided water resources protection and improved drought preparedness and response. Water conservation has become an integral component of the Commission's strategy to manage water supplies throughout the Basin and includes both regulatory and educational initiatives.

It is the policy of the Commission to require maximum feasible efficiency in the use of water on the part of water users throughout the Basin. The Commission works towards this through its regulatory program. Under Section 3.8 entitled 'Referral and Review' of the Delaware River Basin Compact, the Commission is charged with reviewing and approving all projects having a substantial effect on the water resources of the Delaware River Basin. The Commission's regulatory program covers the following general areas which are discussed in more detail in Technical Appendix A:

- Source and Service metering
- Water loss, leak detection and repair
- Water conservation performance standards for plumbing fixtures and fittings
- Conservation oriented pricing structures; and
- Requirements for water conservation plans and water user education.

Based on these current conservation practices, DRBC staff knowledge and a review of a key water conservation publication[7], a set of "baseline" water conservation assumptions was developed for use in the water demand projection model. The set of baseline assumptions is intended to reflect ongoing water conservation efforts in the Delaware River Basin and the general trend is that conservation efforts and impacts are likely to increase over time. The baseline scenario can be thought of as a projection of trends in water conservation. To some degree, the impact of water conservation is likely to offset some of the additional water demand which may occur due to the impacts of other factors (e.g., population increases). Estimating future water use reductions through conservation is a complex task. The assumptions used in this investigation provide a starting point and can be refined by future studies.

In watersheds that indicate a significant level of stress, additional water conservation efforts may be feasible and may help reduce demand and improve the supply-demand balance.

Table 2.6 shows the baseline water conservation assumptions developed for use in the water demand projection model.

[7] Vickers, A.L. Handbook of Water Use and Conservation, 2001. Water Plow Press.

Table 2.6
Water Conservation Assumptions by Sector

Sector	2005	2010	2015	2020	2025	2030	Tot. Consv. Impact
Public Water Supply (PWS)	0%	1%	2%	3%	4%	5%	14.2%
Non-Manufacturing	0%	1%	2%	2%	2%	2%	8.7%
Manufacturing	0%	1%	2%	2%	2%	2%	8.7%
Thermoelectric	0%	0%	0%	0%	0%	0%	0.0%
Hydroelectric	0%	0%	0%	0%	0%	0%	0.0%
Mining	0%	0%	0%	0%	0%	0%	0.0%
Agriculture	0%	0%	2%	4%	5%	5%	15.1%
Livestock	0%	0%	1%	1%	1%	1%	3.9%
Non-Ag. Irrigation	0%	1%	1%	2%	2%	2%	7.8%
Golf	0%	1%	1%	2%	2%	3%	8.7%
Self-Supplied Residential	0%	1%	1%	1%	1%	1%	4.9%

2.2.3 Results of Water Demand Forecasting and Water Availability Analysis

Figure 2.11 shows the anticipated change in peak month water demand for the 147 watersheds between the base year 2003 and the end of the projection period 2030 without factoring in the impact of water conservation. Figure 2.12 shows the change including the impacts of conservation. It should be noted that these two figures show no indication of water availability; only changes in demand based on the drivers of water demand explained in Table 2.5. This is useful for understanding where water demand increases and other associated water resource issues are likely to occur in the future. All subsequent analysis will be performed using the demand changes that include the impact of water conservation.

Projected Change in Peak Month Water Demand 2003-2030

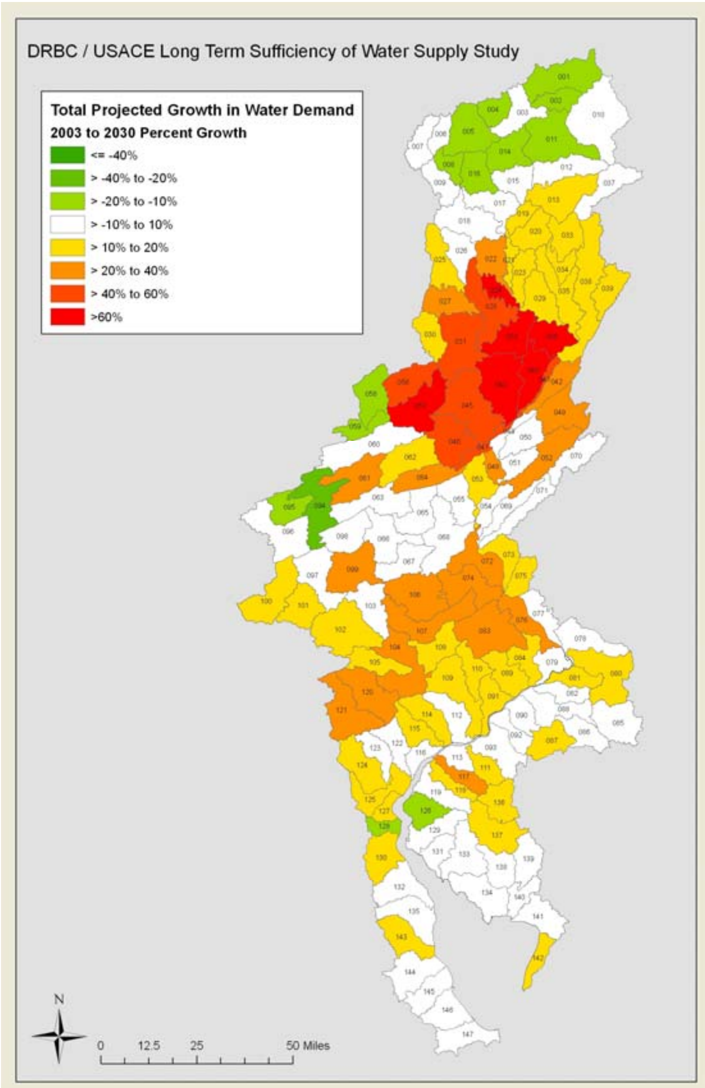


Figure 2.11 Excluding Water Conservation

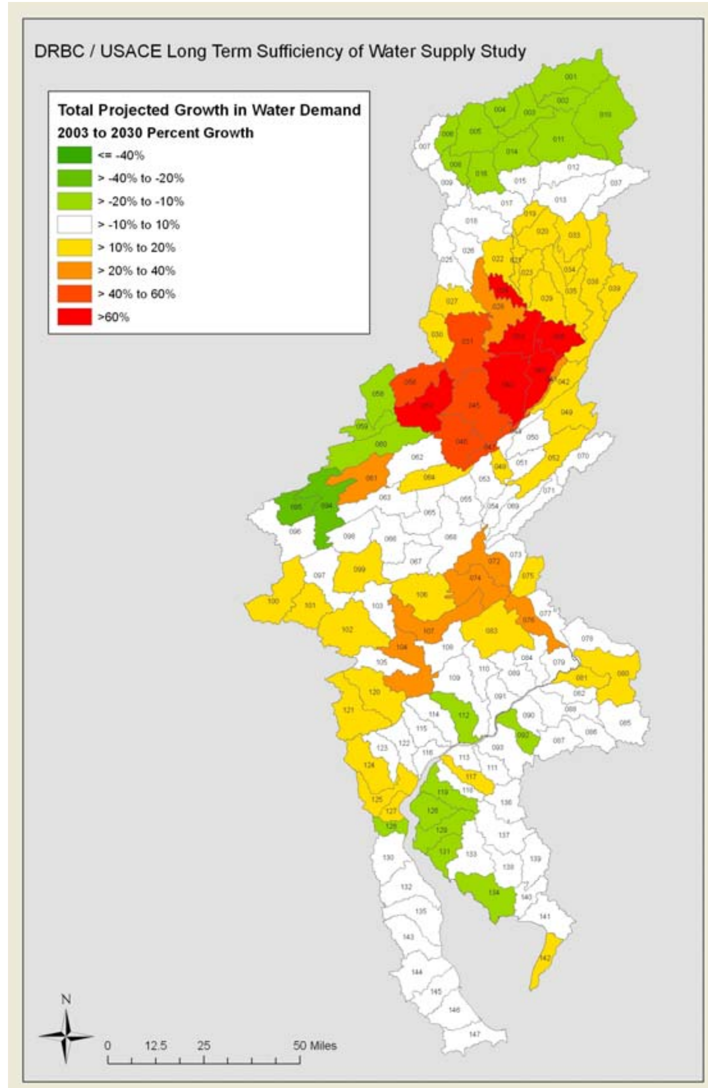


Figure 2.12 Including Water Conservation

Figures 2.13 and 2.14 show the projected trend in water demand, including the impact of baseline water conservation assumptions, which are used in the water supply deficiency analysis. It shows that thermoelectric power demand accounts for the majority of water withdrawals; it also shows that the majority of the increase in demand is attributable to the projected growth in the thermoelectric sector. It is evident that the projected demand for the Delaware River Basin is very sensitive to assumptions about future growth in the thermoelectric sector. The demand projections used in this study were derived by extrapolation of past trends in water demand by this sector in the Delaware River basin over the period 1994 to 2003. This growth trend is consistent with an independent study by the U.S. Department of Energy, Energy Information Administration which projects future growth in demand for megawatts of energy. The growth projections used were for the Mid Atlantic region which includes the Delaware River Basin. Since deregulation of the power generation industry, predicting the location of future energy generation has become more complex. For the purposes of this study future growth was assumed to be accommodated at existing facilities. Further study is recommended to better understand the extent and possible location of additional power generation in the Delaware River Basin, as it has the potential to significantly impact water availability.

In order to see more clearly, the trends in other sectors, Figure 2.14 shows the same data as Figure 2.13, but excludes the thermoelectric sector. It is notable that without the inclusion of thermoelectric demands, water demand from the other sectors is projected to decrease by 8.5% over the projected period.

Figure 2.15 and 2.16 show an assessment of peak month ground-water availability for the 147 watersheds. Figure 2.15 shows the base year assessment (2003) and Figure 2.16 shows the projected 2030 assessment. The assessment compares the sum of ground-water withdrawals for the watershed against the 1-in-25 year baseflow recurrence interval. The assessment is consistent with known areas that are sensitive to ground-water withdrawals, namely the Ground Water Protected Area (GWPA) in southeastern Pennsylvania and the New Jersey Water Supply Critical Area 2.

Figures 2.17 and 2.18 show an assessment of peak month surface water availability for the 147 watersheds. Figure 2.17 shows the base year assessment (2003) and Figure 2.18 shows the projected 2030 assessment. The assessment compares the sum of consumptive surface water withdrawals for the watershed against the $Q_7 10$ value computed for the mouth of the watershed. Consumptive use is used rather than total withdrawals recognizing that surface water is often withdrawn and discharged multiple times (i.e., the discharge from upstream users add to the flow available for downstream users).

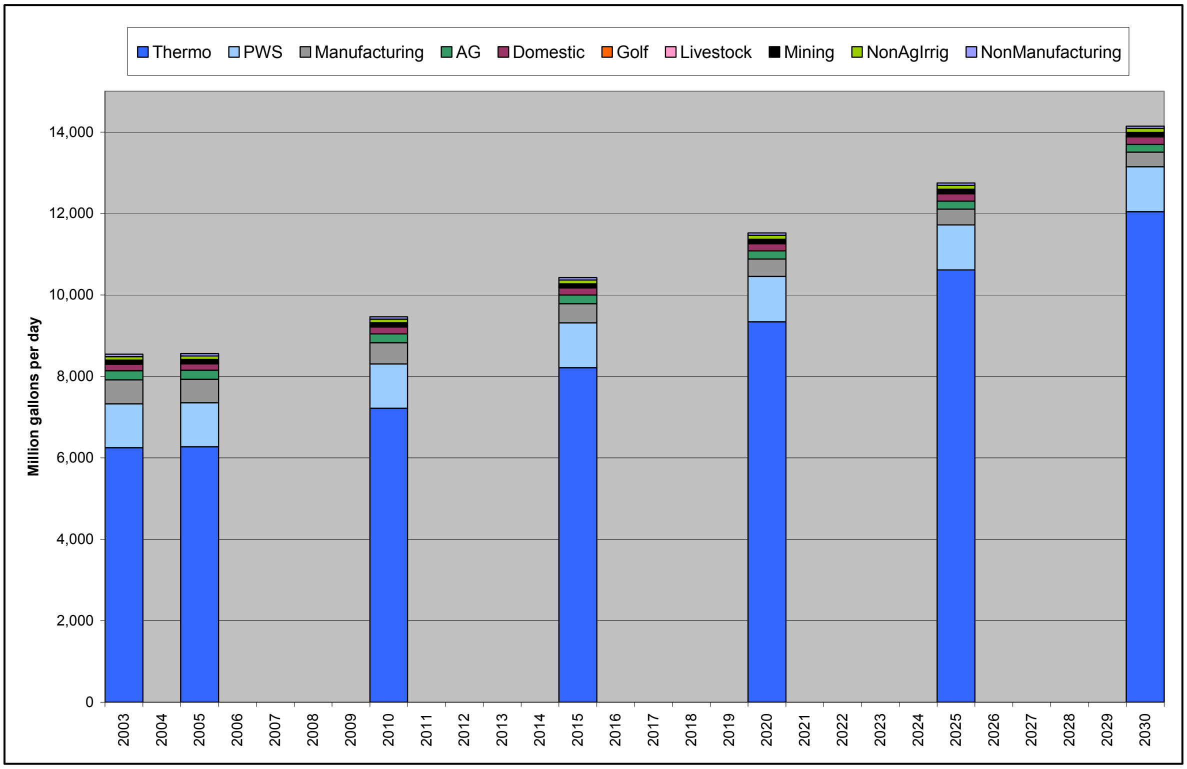


Figure 2.13 Projected Trend in Peak Month Water Withdrawals, by sector: 2003 – 2030

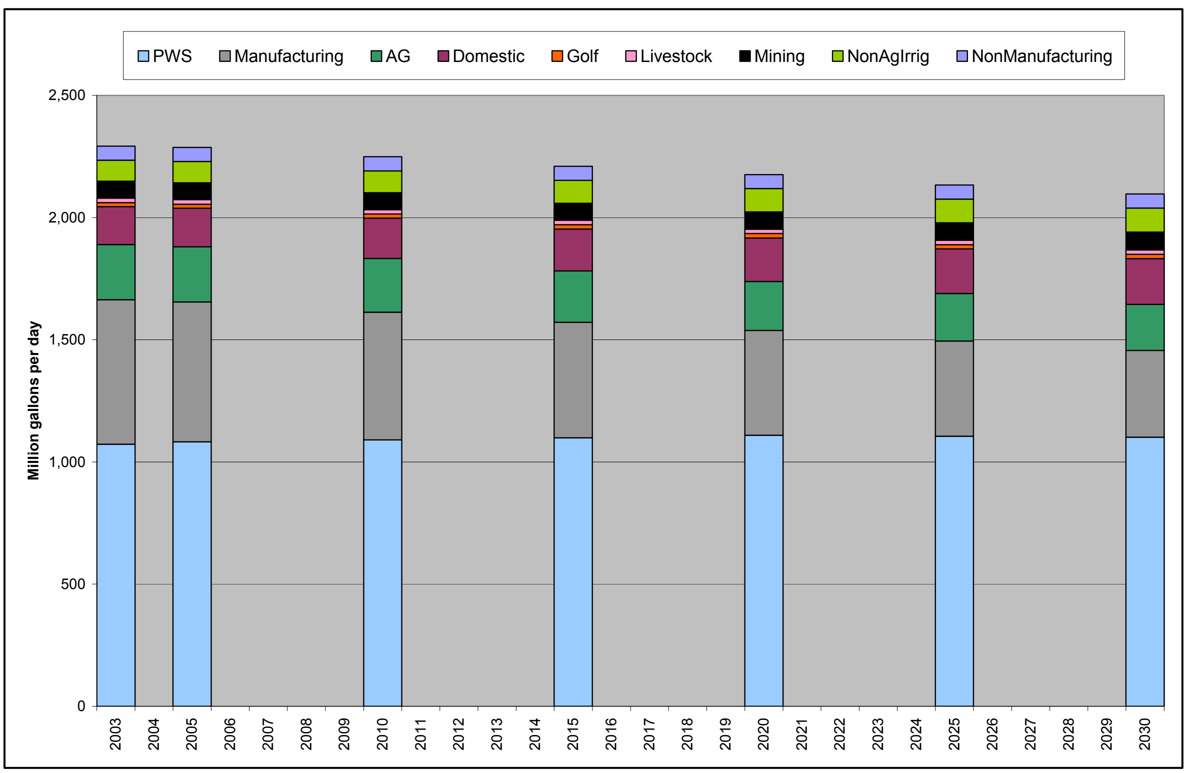


Figure 2.14 Projected Trend in Peak Month Water Withdrawals (excluding Thermoelectric), by sector: 2003 – 2030

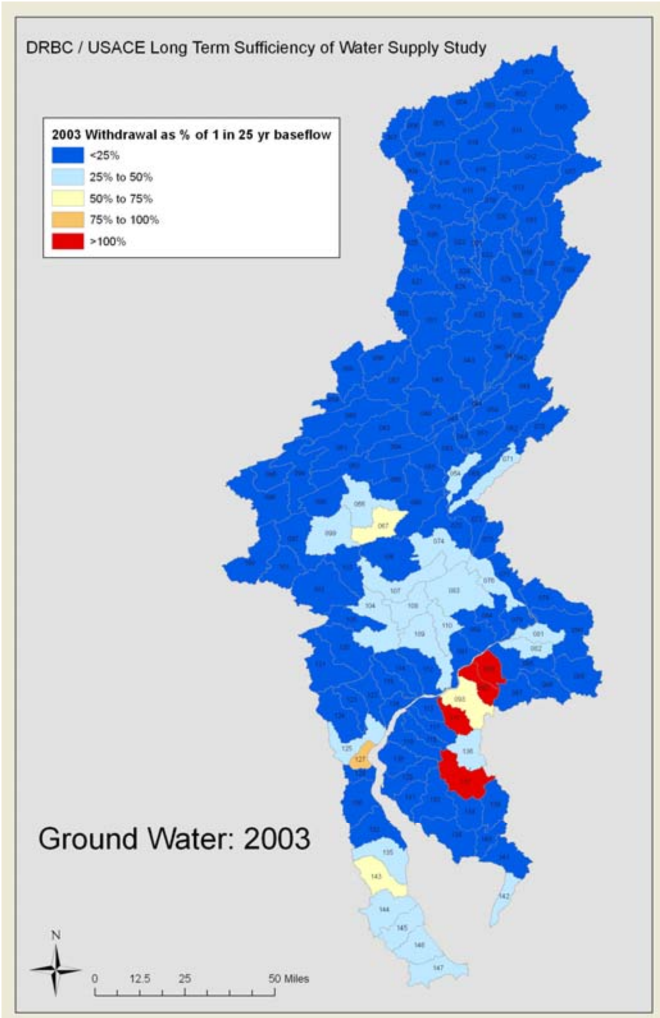


Figure 2 .15 Year 2003

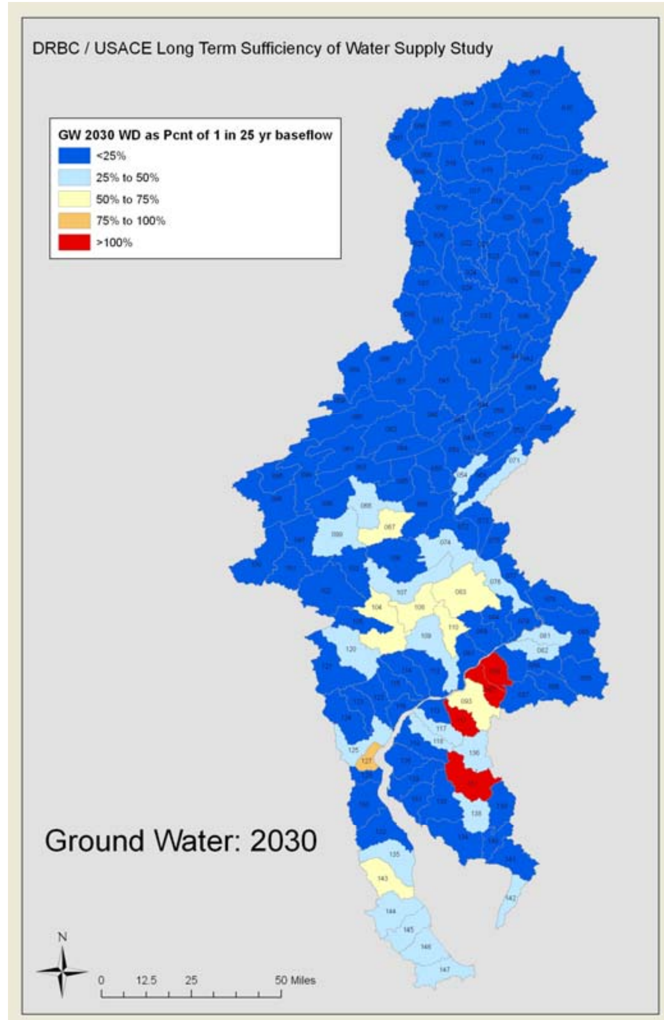


Figure 2.16 Year 2030

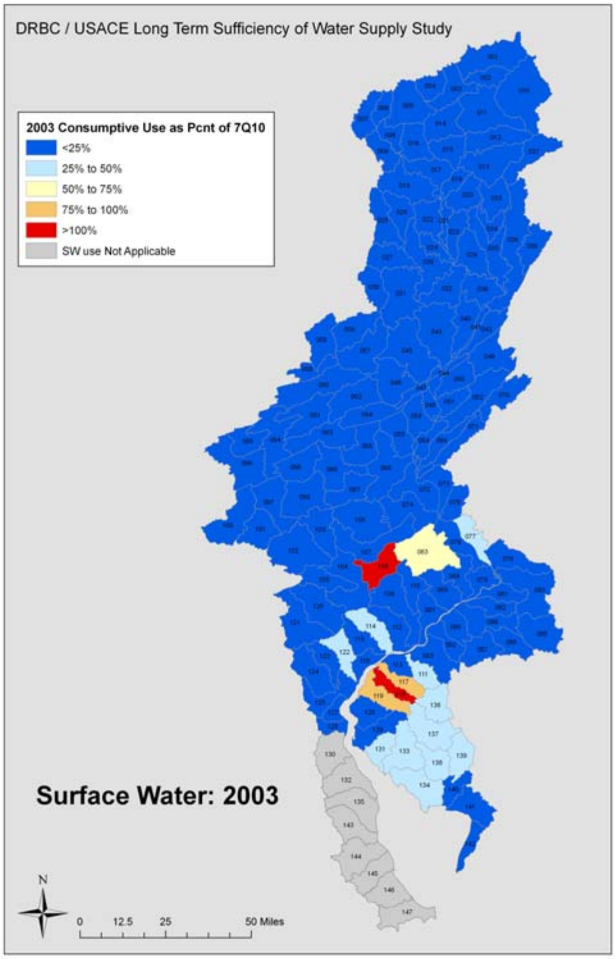


Figure 2.17 Year 2003

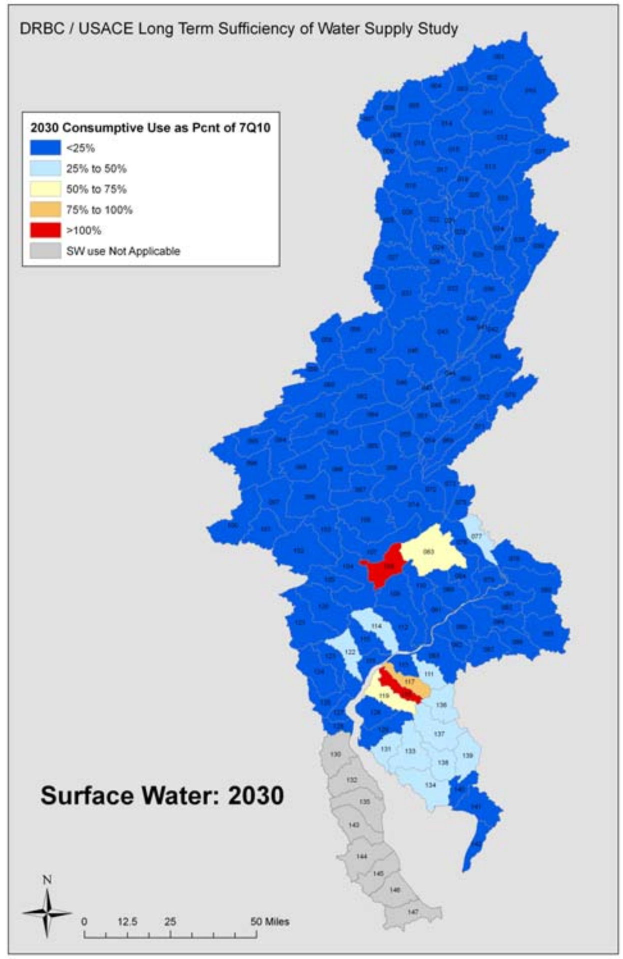


Figure 2.18 Year 2030

* Surface water use was not applicable in certain coastal watersheds in Delaware; these watersheds were excluded from the surface water assessment.

2.2.4 Sensitivity Analysis. In order to deal with the inherent uncertainty in water demand projections it is often useful to use a scenario-based approach. This can typically involve the use of varying growth factors or other drivers of demand. This is often a useful approach in any forecasting exercise and is one way to test the sensitivity of a water demand projection to its underlying assumptions. In addition to helping manage uncertainty, scenarios are also useful from a water resources management perspective as they can be used to determine not only the most likely (or forecast) future demand, but also what is required to reach a desired future demand. For example, if the available water supply is limited, alternative scenarios can illustrate what steps may be needed to constrain water demand; this may mean limiting opportunities for additional (new) demand, or requiring more efficient use by existing water users or adding new sources of supply. Policy decisions can then be made with the objective of reaching the most desirable outcome.

The water demand projection tool developed for the purposes of this study has been designed to accommodate the modeling of alternative scenarios. Some examples of factors that can be adjusted in the projection model include water conservation assumptions, consumptive use estimates and average versus seasonal demands. The scope for adjusting underlying assumptions in the projection model is extensive; within the scope of this study, peak month estimates of water demand were used as these are a more appropriate measure than annual average demands against which to compare water availability at times of low flow (which typically coincides with periods of increased water demand). The sensitivity of the demand projections to water conservation efforts was also examined and results are provided below. For the purposes of comparison to water availability the water demand numbers used include an estimate of the impacts of water conservation, recognizing that water conservation is a well-established practice and is likely to result in increased water efficiency as more efficient technologies replace less efficient ones. Further studies could build on this approach to investigate a range of alternative scenarios varying multiple parameters.

2.2.5 Summary of Total Withdrawals and Consumptive Use by Watershed. Tables 2.7 and 2.8 show a summary of current and future water use, aggregated to the watershed scale, for the eight watersheds identified for further study. Table 2.7 shows Annual MGD for total withdrawals and consumptive use for ground and surface water, while Table 2.8 shows Peak MGD (July) for total withdrawals and consumptive use for ground and surface water. (Complete tables are displayed in Technical Appendix A)

Table 2.7
Current and Future Water Use, Aggregated to the Watershed Scale

		Total Withdrawals: Annual MGD							Consumptive Use: Annual MGD						
Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030	2003	2005	2010	2015	2020	2025	2030
DB-090	GW	21.004	21.198	20.976	20.762	20.651	20.341	20.078	2.222	2.241	2.217	2.192	2.178	2.144	2.116
DB-090	SW	0.542	0.540	0.528	0.507	0.488	0.472	0.462	0.487	0.486	0.475	0.457	0.439	0.425	0.416
DB-092	GW	18.399	18.344	17.975	17.575	17.253	16.829	16.503	1.925	1.919	1.880	1.838	1.803	1.758	1.724
DB-092	SW	0.712	0.707	0.686	0.657	0.629	0.605	0.583	0.350	0.348	0.340	0.326	0.313	0.302	0.294
DB-108	GW	6.025	6.129	6.327	6.454	6.580	6.582	6.586	0.635	0.645	0.665	0.677	0.690	0.689	0.689
DB-108	SW	15.290	15.476	15.799	16.029	16.272	16.465	16.675	1.597	1.616	1.650	1.673	1.696	1.715	1.734
DB-111	GW	11.665	11.806	12.051	12.245	12.467	12.590	12.860	4.594	4.654	4.763	4.857	4.945	4.977	5.044
DB-111	SW	1.273	1.273	1.256	1.220	1.185	1.159	1.143	0.893	0.889	0.870	0.834	0.800	0.775	0.757
DB-117	GW	2.551	2.638	2.863	3.070	3.253	3.597	3.759	0.430	0.440	0.462	0.480	0.496	0.531	0.548
DB-117	SW	0.940	0.936	0.914	0.876	0.838	0.811	0.792	0.846	0.842	0.823	0.788	0.754	0.730	0.713
DB-118	GW	1.978	2.037	2.176	2.356	2.495	2.623	2.765	0.399	0.406	0.419	0.434	0.445	0.456	0.470
DB-118	SW	1.097	1.092	1.068	1.026	0.984	0.953	0.932	0.987	0.983	0.962	0.923	0.885	0.858	0.839
DB-127	GW	11.308	11.367	11.401	11.411	11.422	11.429	11.431	1.057	1.067	1.081	1.092	1.102	1.110	1.117
DB-127	SW	0.829	0.796	0.713	0.632	0.561	0.497	0.441	0.094	0.090	0.082	0.073	0.065	0.059	0.053
DB-137	GW	35.702	36.112	36.877	38.428	39.143	39.684	40.369	22.954	23.242	23.822	24.926	25.402	25.725	26.174
DB-137	SW	2.982	2.968	2.897	2.774	2.653	2.563	2.502	2.684	2.671	2.607	2.496	2.388	2.307	2.252

*All figures are annual averages (Million gallons/per day), and are listed by source type, ground water (GW) and surface water (SW).

Table 2.8
Current and Future Water Use, Aggregated to the Watershed Scale

		Total Withdrawals: Peak MGD (July)							Consumptive Use: Peak MGD (July)						
Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030	2003	2005	2010	2015	2020	2025	2030
DB-090	GW	27.198	27.435	27.167	26.923	26.811	26.452	26.192	3.214	3.239	3.203	3.165	3.142	3.095	3.060
DB-090	SW	2.110	2.104	2.055	1.973	1.895	1.834	1.792	1.899	1.893	1.850	1.776	1.705	1.651	1.613
DB-092	GW	24.380	24.302	23.823	23.266	22.818	22.237	21.771	2.774	2.766	2.711	2.645	2.590	2.522	2.467
DB-092	SW	1.891	1.879	1.827	1.749	1.674	1.611	1.560	1.206	1.200	1.171	1.122	1.075	1.038	1.010
DB-108	GW	7.179	7.308	7.558	7.723	7.886	7.892	7.899	0.794	0.807	0.831	0.845	0.860	0.859	0.857
DB-108	SW	19.704	19.943	20.359	20.652	20.961	21.203	21.465	2.248	2.275	2.321	2.351	2.381	2.400	2.421
DB-111	GW	19.796	20.023	20.409	20.692	21.013	21.178	21.645	8.191	8.292	8.466	8.609	8.740	8.780	8.889
DB-111	SW	4.131	4.117	4.033	3.878	3.728	3.616	3.540	3.486	3.471	3.391	3.248	3.111	3.008	2.937
DB-117	GW	4.098	4.228	4.564	4.868	5.139	5.680	5.925	1.087	1.101	1.132	1.151	1.165	1.220	1.242
DB-117	SW	3.798	3.783	3.701	3.552	3.407	3.307	3.236	3.418	3.404	3.331	3.197	3.066	2.976	2.913
DB-118	GW	3.611	3.705	3.921	4.196	4.400	4.591	4.805	1.100	1.109	1.121	1.129	1.129	1.133	1.147
DB-118	SW	4.386	4.368	4.273	4.103	3.936	3.812	3.731	3.947	3.931	3.846	3.693	3.542	3.431	3.358
DB-127	GW	237.552	241.466	247.930	253.478	257.830	260.960	262.865	23.794	24.190	24.845	25.406	25.846	26.164	26.360
DB-127	SW	1.444	1.388	1.246	1.106	0.983	0.874	0.778	0.186	0.180	0.165	0.149	0.135	0.123	0.112
DB-137	GW	83.778	84.795	86.772	90.618	92.340	93.583	95.229	63.057	63.844	65.435	68.448	69.727	70.586	71.802
DB-137	SW	11.856	11.799	11.515	11.018	10.536	10.176	9.930	10.671	10.619	10.363	9.916	9.482	9.158	8.937

*All figures are peak averages using the month of July (Million gallons/per day), and are listed by source type, ground water (GW) and surface water (SW).

2.2.2.2 River Analysis for Surface Water Withdrawals. In addition to the surface water withdrawals analysis performed on the 147 watersheds an additional analysis was undertaken. Within the Delaware River Basin there are 91 surface water intakes that withdraw water from the Delaware, Lehigh or Schuylkill rivers. These withdrawal points are affected by all upstream water uses and sizeable drainage areas and thus, applying them to any one of the 147 watershed delineations of this study was not appropriate. Consequently a different approach was developed for determining surface water supply availability for water withdrawals located on the three largest rivers in the basin.

The $Q_7$10 was chosen as the statistic representative of surface water availability during periods of low-flow. The first step in the river analysis was to select a stream gage on each of the three big rivers for use as a reference gage. Each gage was selected based on a robust period of record. The following USGS stream gages were chosen:

- Delaware River at Trenton, NJ # 01463500 Period of Record: 1980-2006
- Lehigh River at Glendon, PA # 01454700 Period of Record: 1967-2006
- Schuylkill River at Pottstown, PA # 01472000 Period of Record: 1928-2006

For each reference gage, all upstream consumptive use associated with surface water withdrawals located on the given river was added to the $Q_7$10 recorded at the gage. This provided an estimate of “natural” $Q_7$10 at the reference gage. This number was then divided by the total drainage area to the gage and the resulting ratio (MGD/Square Mile) was applied to the drainage are of each surface water withdrawal point along that river (calculated based on a GIS analysis), providing an estimation of “natural” $Q_7$10 at each surface water withdrawal point along the big rivers. In the final step of the analysis, the natural $Q_7$10 value was modified for each withdrawal point to represent the water available at that point under $Q_7$10 conditions, taking into account the activity of upstream users. The adjustment is made by subtracting all upstream consumptive use from the natural $Q_7$10 value; this adjustment reflects the fact that upstream consumptive use removes water from the river, making it unavailable for downstream users. To create an indicator of availability, the withdrawal value at each point is expressed as a percentage of the modified $Q_7$10 value.

Of the 91 surface water intakes located on the three major rivers of the Delaware River Basin, the above analysis was performed on 71. Twenty surface water withdrawals were not analyzed because they are located in the estuary portion of the basin, downstream of the mouth of the Schuylkill River. Demand estimates and forecasts were conducted for these points, but water availability analysis was not. It was recognized that extrapolation of a $Q_7$10 statistic to a tidal region was not applicable. Surface water withdrawals in these regions are already capable of dealing with issues of salinity and thus water supply was not considered a primary concern in this portion of the estuary.

The results of this analysis are shown in Figures 2.19 and 2.20

Peak Month Surface Water Availability for the Delaware, Lehigh and Schuylkill Rivers.

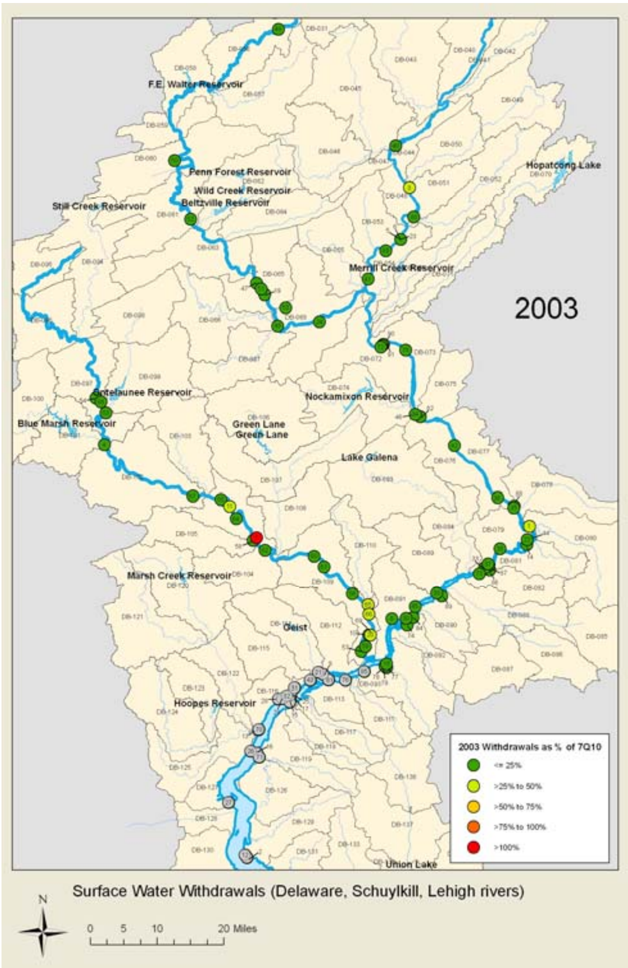


Figure 2.19 2003

Figure 2.20 2030

2.3 CALCULATING WATER SUPPLY DEFICITS

2.3.1 Water Supply Deficits in Watersheds Identified for Further Study

The results of the basinwide water supply-demand evaluation identified several watersheds where the supply-demand balance indicated possible water supply problems.
The location of these watersheds are shown in Figure 2.21 along with a graphic of the projected water use in each watershed that shows which sectors are driving water use. In total, ten watersheds have been identified, all of which are located in the lower half of the Basin.

Water supply deficits were quantified for all eight watersheds identified in Figure 2.21. In general, deficits were calculated by computing the amount of $Q_7 10$ needed for surface water watersheds and the amount of baseflow needed for ground water watersheds in order to lower utilization below the adopted threshold value of 75%.

An interior watershed was identified for further study if:

$$\frac{\sum SurfaceWaterConsumptiveUse}{Q710} \geq 75\%$$

or:

$$\frac{\sum GroundWaterWithdrawals}{25yrBaseflow} \geq 75\%$$

Deficits were computed using withdrawals and consumptive use values generated for the years 2003 and 2030 respectively along with the alternatives of reducing the $Q_7 10$ and baseflow quantities by 25%, 50%, and 75% from their 2003 values. These percent reduction alternatives were done to simulate drought conditions in the watersheds and to check the sensitivity of the calculated water supply deficit to hypothetical reductions in supply. These percent reductions were not intended to represent conditions similar to the 1960s drought of record in the Basin. They were intended to be utilized as a screening tool in this reconnaissance level analysis.

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 flagged 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 and irrigation-related uses. Five of the watersheds (DB-090, DB-092, DB-108, DB-111 and DB-127) have public water supply as their largest use sector. Two of these watersheds (DB-090 and DB-092) show water demand from the public water supply sector projected to go down by 2030, which is likely to alleviate pressure on the watershed but is not sufficient to reduce demand enough to change the overall level of stress; the remaining three watersheds are projected to show increases in water demand for public water supply, due primarily to population growth.

There was only one basin in Pennsylvania that was identified as being deficient, DB-108. The basin is located on the lower Perkiomen Creek in the Schuylkill River Basin. A single surface water withdrawal accounts for over 85% of total surface water diversions for this basin. However, the Perkiomen Creek is augmented by a diversion of water from the Delaware River (via the East Branch of the Perkiomen Creek) and the upstream Green Lane Reservoir also provides water for drinking water supply, therefore the actual impacts of water use in this watershed are already mitigated.

Water demand for the public water supply sector in watershed DB-111, is also projected to increase by 2030. The sector is comprised of a number of water purveyors in Gloucester and Camden counties, NJ. These are primarily municipal supply systems that may be able to achieve reductions in water use by improving water supply infrastructure, in addition to other end-use water conservation efforts. A further examination of the socio-economic composition of the communities supplied by these systems may help determine the most effective methods of water conservation.

Further south in the Basin, several watersheds showing potential stress have significant water demands coming from the agricultural and non-agricultural irrigation sectors. In the two watersheds (DB-117 and DB-118) where agricultural water demand is the dominant sector, the projected trend in withdrawals is one of decline. It should be noted that agricultural water use has been derived from estimates based on U.S. Agricultural Census data, whereas other sectors have actual water withdrawal data (locations and volumes) available and therefore provide more accurate accounting of water demand. Further study to confirm water use is recommended in the watersheds where a significant portion of the water use has been estimated.

In watershed DB-137 the majority of water demand (>75%) is for non-agricultural use; this demand is driven by one nursery operation with multiple ground water sources. This sector is projected to increase in water use and is expected to account for the majority of the overall 15% increase in water demand in this watershed.

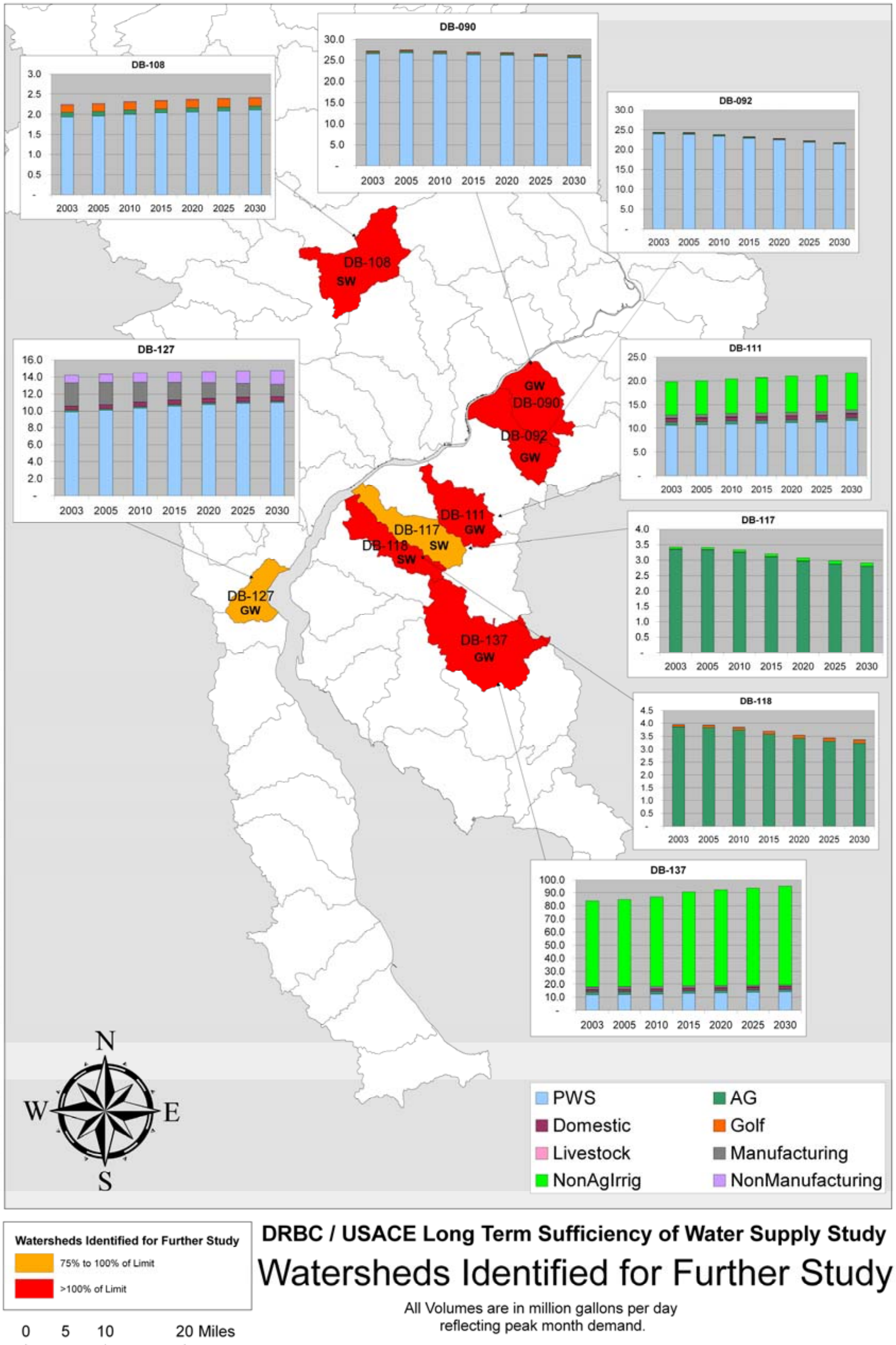


Figure 2.21. Watersheds Identified for Further Study

Tables 2.9 to 2.11 summarize the withdrawals, consumptive uses, and calculated deficits for the eight watersheds and Figures 2.22 to 2.27 graphically show the surface and ground water deficits for the eight watersheds. As Figure 2.21 shows, basin DB-108 in Pennsylvania was surface water deficient by 1.35 MGD in year 2003 and projected to be 1.67 MGD deficient in the year 2030. Reducing the $Q_7 10$ in this basin by 25%, 50%, and 75% increases the deficit from 1.35 MGD to 2.0 MGD, 2.41 MGD, and 2.82 MGD respectively.

The two New Jersey basins that are surface water deficient (DB-117 and DB-118) need a total of 2.85 MGD in year 2003 and 1.74 MGD in year 2030. This reduction can be explained by the fact that the projected withdrawals and consumptive use values for year 2030 are lower than the values used for 2003. The four New Jersey basins that are ground water deficient (DB-90, DB-92, DB-111 and DB-137) need a total of 90.4 MGD for year 2003 and it increases to 109.36 MGD in year 2030. Combining the surface water and ground water deficiencies for the New Jersey basins gives 93.3 MGD in year 2003 and 111.1 MGD in year 2030. The hypothetical 25%, 50%, and 75% reductions in $Q_7 10$ and 25-year baseflow supply values increase the amount of water needed by these basins to 135.4 MGD, 165.76, and 196.12 MGD respectively

There is one watershed in the State of Delaware (DB-127) identified as being deficient in ground water. The ground water deficient watershed in Delaware (DB-127) needs 0.43 MGD using 2003 values and projected to need 1.77 MGD in year 2003. Refer to Technical Appendix A for additional tables and graphs summarizing in more detail withdrawals, consumptive uses, and deficit quantities for these eight watersheds.

Table 2.9
Withdrawals at Identified Surface Water Deficient Basins

Basins	Year 2003 ∑WD (mgd)	Year 2003 ∑CU (mgd)	Year 2030 ∑WD (mgd)	Year 2030 ∑CU (mgd)
DB-108	19.70	2.25	21.46	2.42
PA TOTAL	**19.70**	**2.25**	**21.46**	**2.42**
DB-117	3.80	3.42	3.24	2.91
DB-118	4.39	3.95	3.73	3.36
NJ TOTAL	**8.18**	**7.37**	**6.97**	**6.27**

∑WD = Cumulative Withdrawals within Basin *∑CU = Cumulative Consumptive Use Within Basin*

Table 2.10
Withdrawals at Identified Ground Water Deficient Basins

Basins	Year 2003 ∑WD (mgd)	Year 2003 ∑CU (mgd)	Year 2030 ∑WD (mgd)	Year 2030 ∑CU (mgd)
DB-90	27.20	3.21	26.19	3.06
DB-92	22.90	2.63	20.53	2.34
DB-111	19.80	8.19	21.64	8.89
DB-137	83.78	63.06	95.23	71.80
NJ TOTAL	**153.67**	**77.09**	**163.60**	**86.09**
DB-127	12.89	1.33	13.27	1.40
DE TOTAL	**12.89**	**12.89**	**12.89**	**12.89**

∑WD = Cumulative Withdrawals within Basin *∑CU = Cumulative Consumptive Use Within Basin*

Table 2.11
Combined SW and GW Deficits at Various Percent Reductions in Supply

State	Basin	Water Deficiency	Supply Deficit (mgd)				
			Year 2003	5% Red. (2030)	25% Red.	50% Red.	75% Red.
PA	DB-108	SW	1.35	1.67	2	2.41	2.82
PA TOTAL			**1.35**	**1.67**	**2**	**2.41**	**2.82**
NJ	DB-117	SW	0.91	0.42	1.15	2.06	2.97
NJ	DB-118	SW	1.95	1.33	1.99	2.82	3.65
NJ SW TOTAL			**2.85**	**1.74**	**3.14**	**4.88**	**6.62**
NJ	DB-90	GW	14.18	13.94	18.36	23.88	29.4
NJ	DB-92	GW	10.37	8.22	12.25	17.29	22.33
NJ	DB-111	GW	6.68	10.13	14.08	19	23.93
NJ	DB-137	GW	59.17	77.07	87.57	100.71	113.84
NJ GW TOTAL			**90.4**	**109.36**	**132.26**	**160.88**	**189.51**
NJ TOTAL			**93.26**	**111.1**	**135.4**	**165.76**	**196.12**
DE	DB-127	GW	0.43	1.77	5.12	9.31	13.5
DE TOTAL			**0.43**	**1.77**	**5.12**	**9.31**	**13.5**

SW Water Deficiency - Basin is Identified as being Deficient ($Q_7 10$) in Surface Water in Order to Meet SW Needs
GW Water Deficiency - Basin is Identified as being Deficient (25-yr Baseflow) in Ground Water in Order to Meet GW Needs

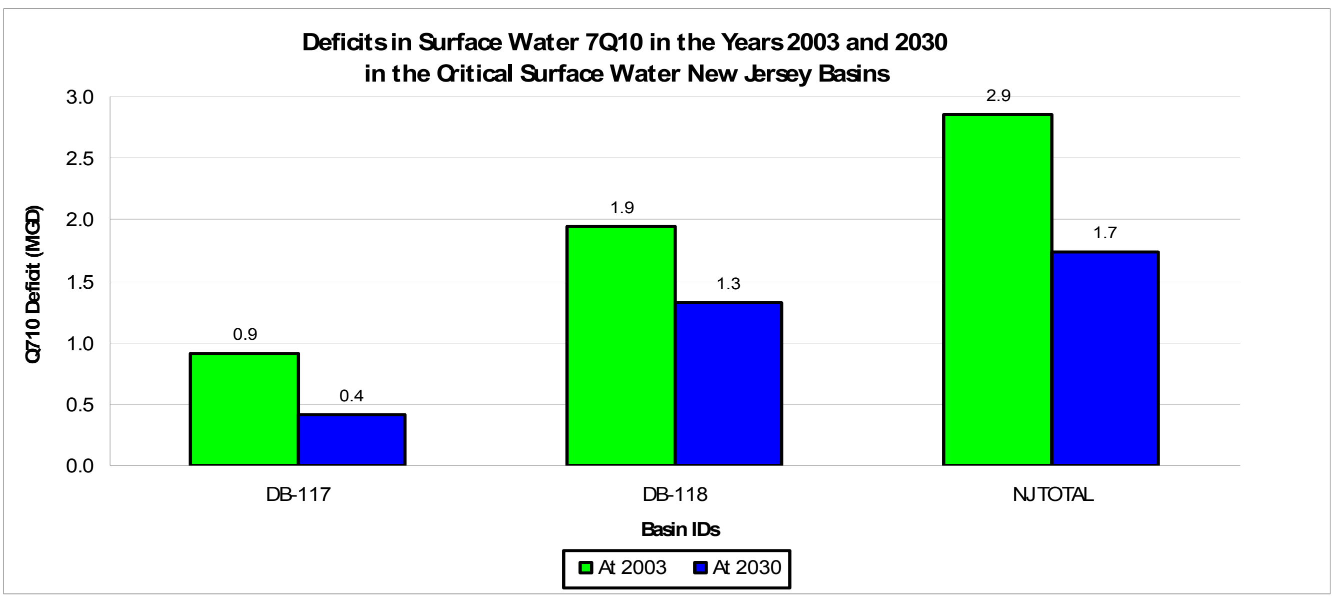


Figure 2.22
The deficits in 2030 are less than they are in 2003 because projected demands for these basins in 2030 are less than the demands in 2003. The Q710 in 2030 was reduced by 5% from the 2003 value in order to account for climate variability.

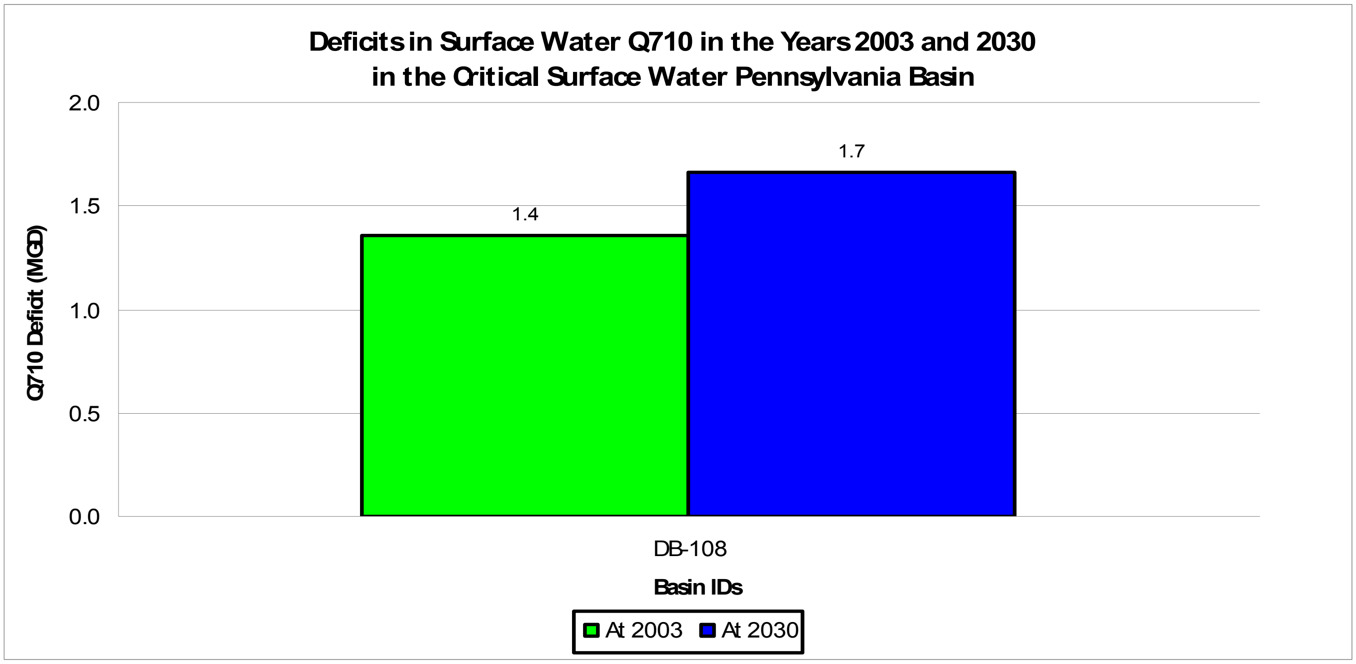


Figure 2.23
The $Q_7$10 *in 2030 was reduced by 5% from the 2003 value in order to account for climate variability.*

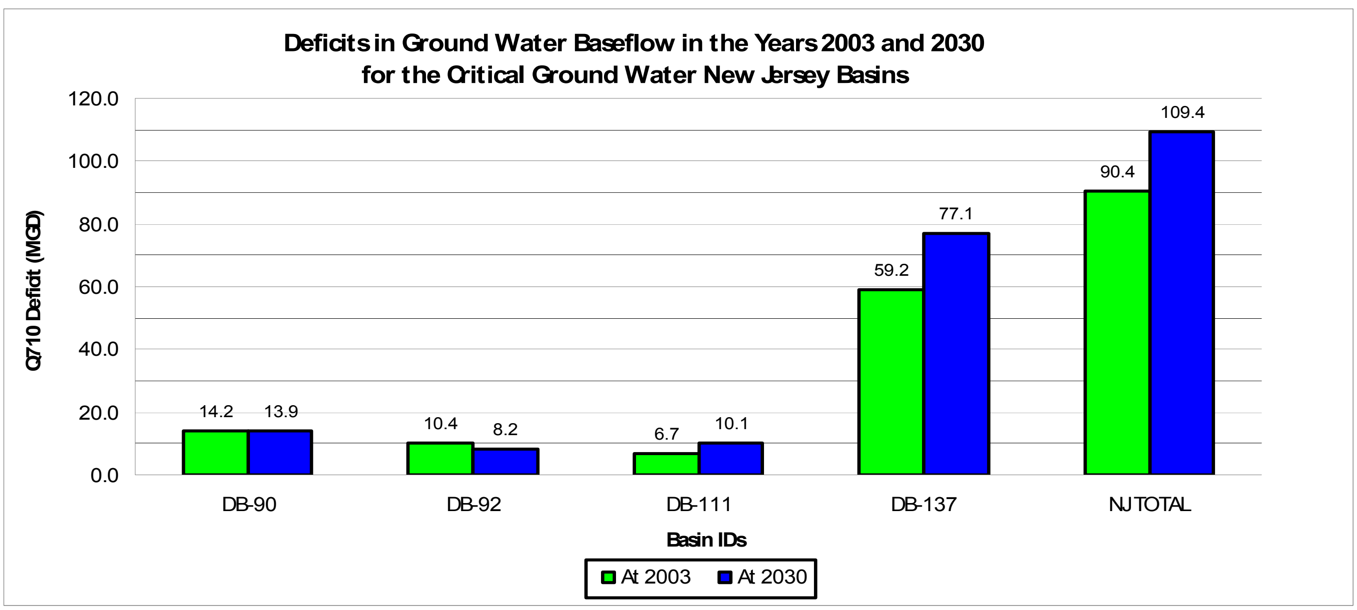


Figure 2.24
The deficit in 2030 is less than it is in 2003 for basins DB-90 and DB-92 because projected demands for the basins in 2030 are less than the demands in 2003. The baseflow in 2030 was reduced by 5% from the 2003 water supply value in order to account for climate variability.

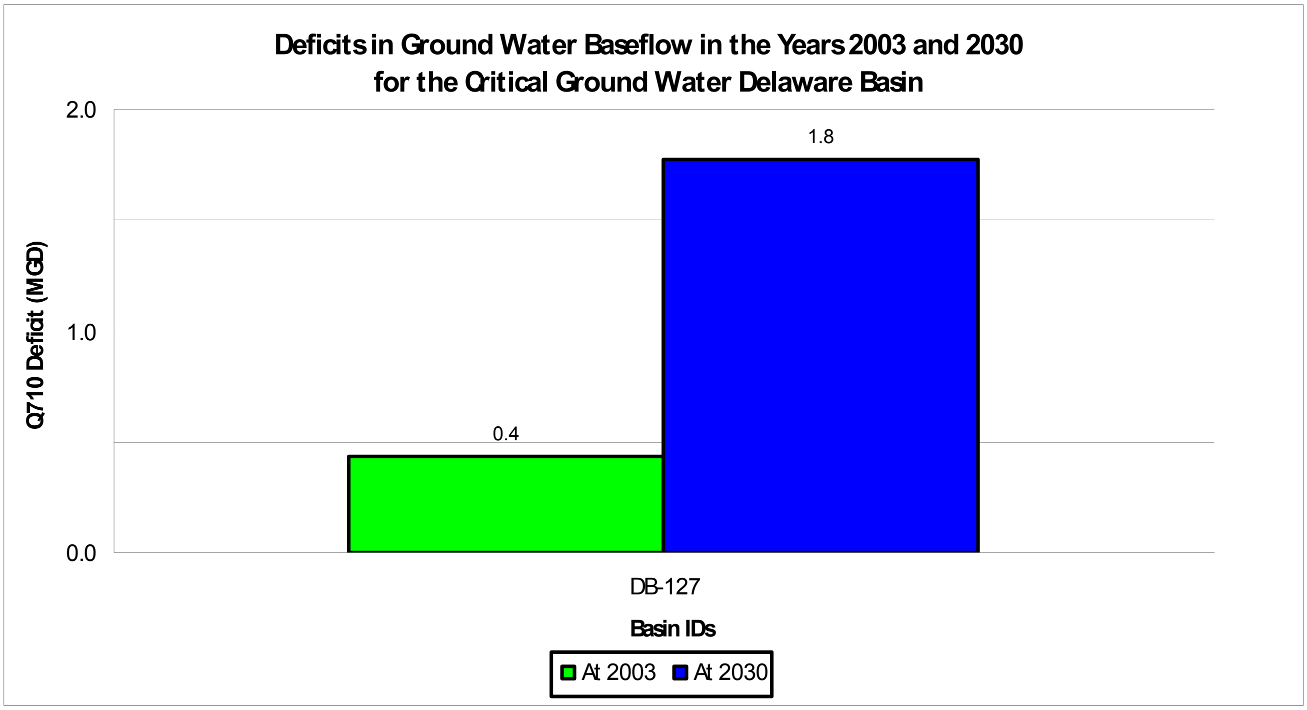


Figure 2.25

The baseflow in 2030 was reduced by 5% from the 2003 water supply value in order to account for climate variability.

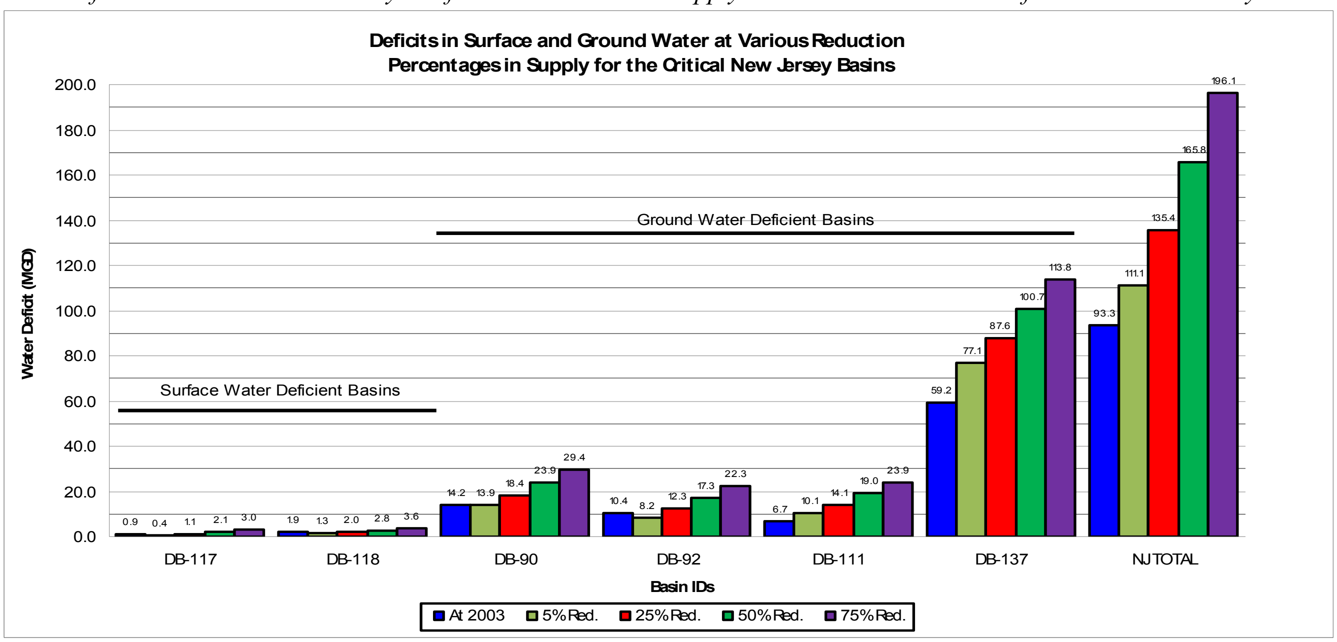


Figure 2.26

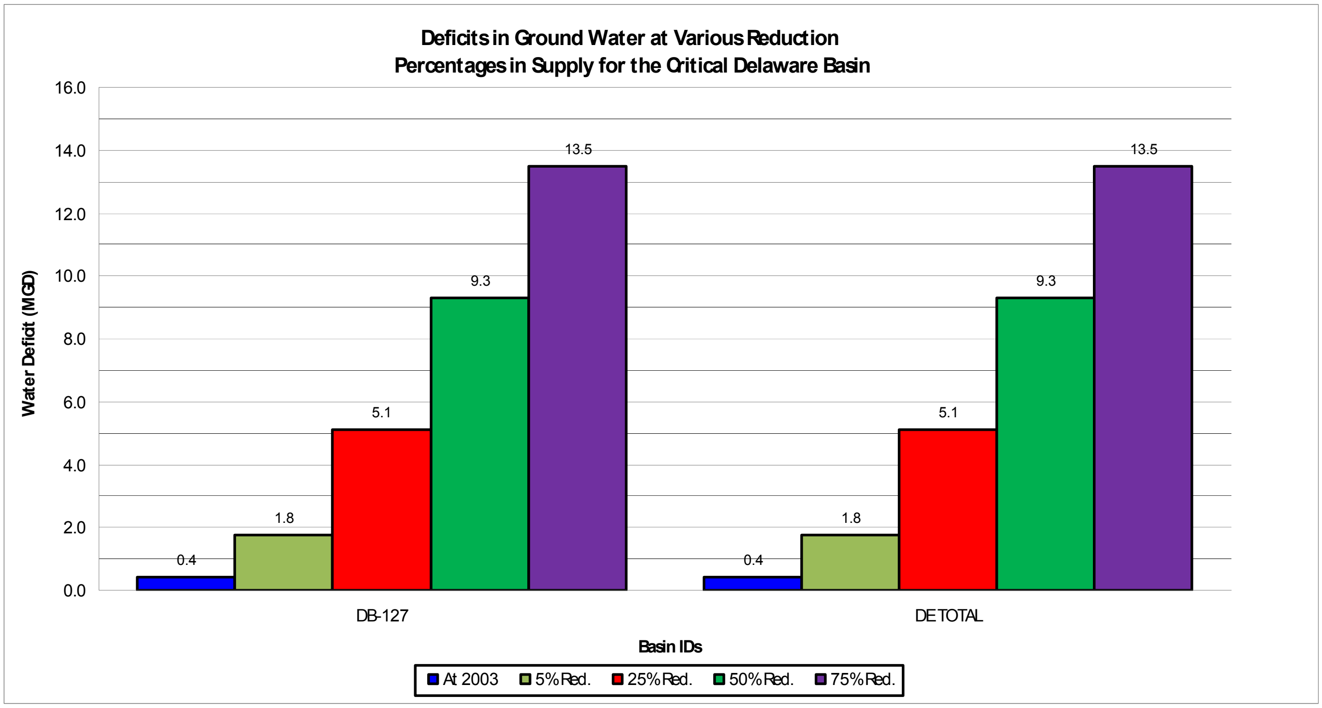


Figure 2.27

2.3.2 Calculating Water Deficiencies for the Delaware, Schuylkill and Lehigh Rivers

In addition to a watershed analysis, the team obtained data of surface water withdrawals for the Delaware, Lehigh, and Schuylkill Rivers. This data included the quantity of water withdrawn from the river in 2003 and projected to be withdrawn in 2030. Consumptive use quantities for each surface water withdrawal in the year 2003 along with a projected value for 2030 were also obtained. Figure 2.29 shows the locations of each surface water withdrawal point along the three rivers. The seven-day, consecutive low flow with a ten year return frequency statistic ($Q_7 10$) was used as the water supply parameter for the river analysis. The $Q_7 10$ statistic is a commonly used low-flow statistic in determining water supply adequacy. It should be noted that the $Q_7 10$ does not represent the drought of record for the Basin which occurred in the 1960s. Flows in the Delaware and Schuylkill Rivers during the drought of the 1960s were smaller than the computed $Q_7 10$ in each river.

The additional flows needed to meet water supply deficits at the $Q_7 10$ level were quantified at a given withdrawal point if:

$$\frac{Withdrawal(WD)}{7Q10 - \sum ConsumptiveUseUpstreamWithdrawalPo\text{int}(CU)} \geq 75\%$$

Additional flows needed to alleviate water supply deficits were computed for the year 2003, projected conditions in the year 2030, and several “simulated” drought conditions (which will be discussed later). In general, the additional flows needed were calculated by computing the amount of $Q_7 10$ needed in order to lower utilization below the adopted threshold value of 75%.

Re-arranging the above equation and adding a term to represent the amount of water needed to add to the $Q_7 10$ to alleviate the deficit gives the expression used at each point.

$$AdditionalFlowNeeded = 1.34 * WD + \sum CU - 7Q10$$

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.

It was assumed for the river analysis that the computed additional flow needed at withdrawal points for the power sector would be isolated from deficits computed for all other withdrawal points. The reasoning behind this assumption was that power generation can be considered to be mobile in nature. In other words, if it was projected that additional power would be need to be generated at a given location; the additional generation could come from another location on the power grid within the Basin where water is more plentiful and not necessarily at the same location along the river. An example of an alternative location within the basin is at the Delaware River Estuary. Therefore, the additional water needed by the power sector in order to meet future demands may not materialize because the power sector could meet those demands by other means. It was assumed that projected increases in power generation output at existing facilities would not stress river segments that are already projected to be stressed. A reasonable assumption was made that any potential alternative source(s) of water that was deemed necessary in order to alleviate deficits would not be evaluated based upon the downstream power sector but would be based upon meeting the needs of public water supply and other sectors and be sized accordingly.

Thermoelectric power generation is the largest water use sector in the Delaware River Basin. Thermoelectric power generation, and the water demands for this sector, have shown a steady increase in recent decades and are projected to continue to increase. Managing the anticipated growth of the thermoelectric power sector will play an important role in providing a sustainable water supply for all water use sectors.

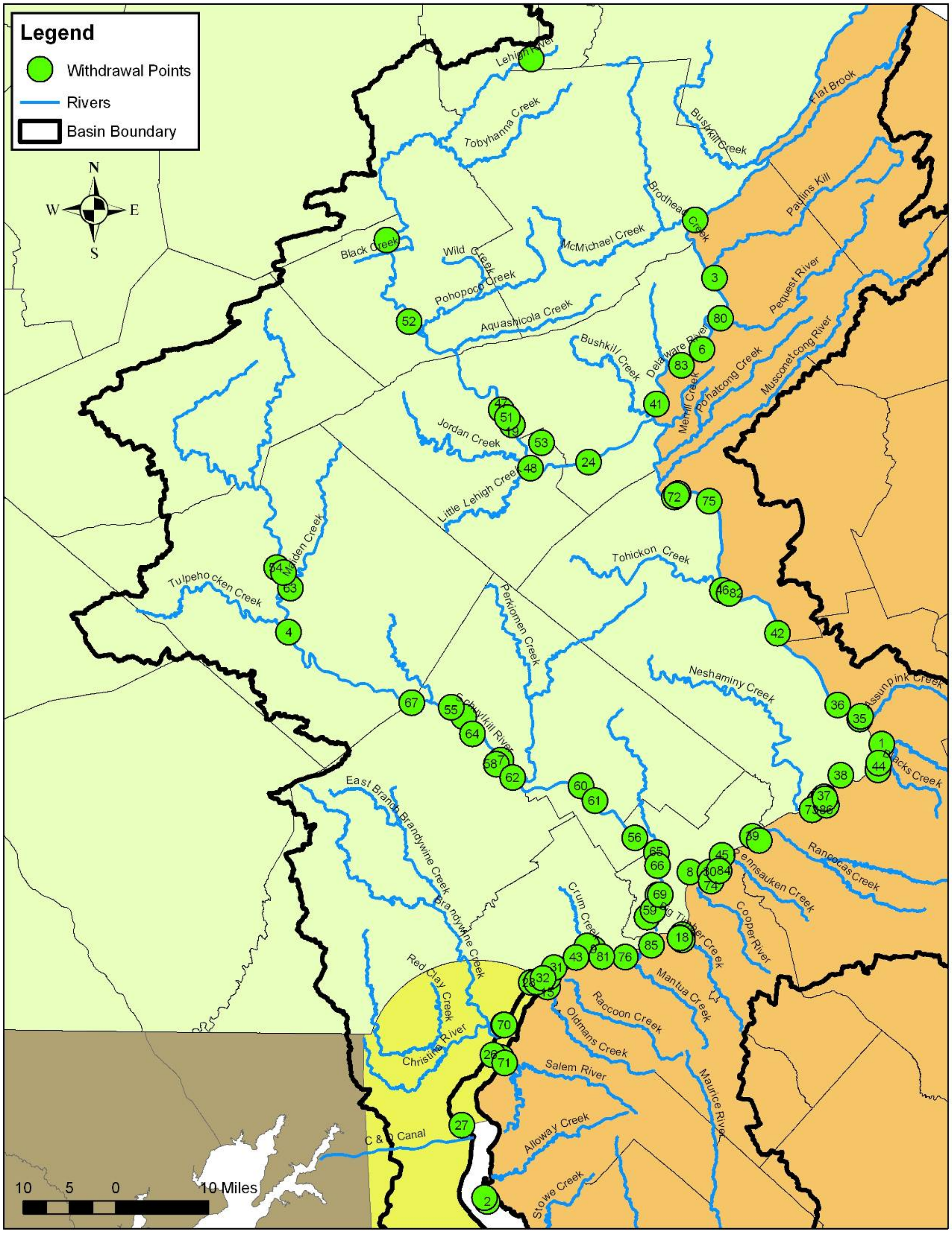


Figure 2.28: Location of Withdrawal Points on Delaware, Schuylkill, and Lehigh Rivers

2.3.2.1 Deficiencies in Year 2003. Utilizing the existing data for the year 2003, existing deficiencies if any were calculated for the Delaware, Schuylkill and Lehigh Rivers. As shown in Table 12, the Delaware River did not have any identified deficient withdrawal points in 2003. This was true for the power sector and all other sectors incorporated into the analysis. The Schuylkill River in the year 2003 also did not have any points where additional flow was needed to supplement the natural $Q_7 10$ for non-power sectors. The only deficiency on the Schuylkill River was at a single power sector withdrawal located just upstream of the Perkiomen Creek. The additional flow needed at that withdrawal point was calculated to be 90 mgd (Table 2.13). As with the Delaware River, the Lehigh River did not have any deficiencies identified at withdrawal points in the year 2003 (Table 2.14).

Figures were created that summarized the tabular analysis done for each river. The figures summarized the $Q_7 10$, withdrawals, consumptive uses, and deficits by reach that were shown on each table. Reaches were defined as shown in Figures 2.29-2.30 for the Schuylkill and Delaware Rivers respectively. Figure 2.30 corresponds to the analysis done in Table 2.12 and shows that there were no deficits on the Delaware River in 2003. Figure 2.32 corresponds to the analysis done in Table 2.13 and shows the power-sector deficit of 90 mgd in Reach 2 between the Tulpehocken and Perkiomen Creeks.

Table 2.12
Delaware River Year 2003 Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2003 (mgd)	Cumul. Consumptive Use Above Withdrawal Point for Year 2003 (mgd)	Withdrawal at Point for Year 2003 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
USGS GAGE @ DELAWARE WATER GAP							
40	GOLF	978.37	0.00	0.31	0.03	0.00	0.00
BRODHEAD CREEK							
3	PWR	1114.06	0.28	305.24	27.41	0.00	0.00
80	MANUF	1117.74	1.55	1.82	0.16	0.00	0.00
5	PWR	1163.12	2.10	26.04	2.24	0.00	0.00
6	PWR	1163.12	2.41	8.81	0.76	0.00	0.00
23	PWR	1163.12	4.75	0.00	0.00	0.00	0.00
83	RES. INTAKE	1163.12	4.75	0.00	0.00	0.00	0.00
41	PWS	1185.39	4.75	8.03	0.68	0.00	0.00
LEHIGH RIVER							
75	MANUF	1633.87	7.71	0.00	0.00	0.00	0.00
72	PWR	1633.87	7.71	0.99	0.06	0.00	0.00
90	AG	1633.87	7.90	0.00	0.00	0.00	0.00
91	AG	1633.87	7.90	0.00	0.00	0.00	0.00
34	PWS	1684.80	7.90	17.38	1.04	0.00	0.00
TOHICKON CREEK							
46	PWS	1684.80	9.63	21.57	1.29	0.00	0.00
DELAWARE & RARITAN CANAL - NODE 82 WITHDRAWAL							
82	PWS	1685.50	11.79	91.52	5.47	0.00	0.00
42	PWS	1708.01	103.32	0.01	0.00	0.00	0.00
88	PWS	1730.67	103.32	30.46	1.87	0.00	0.00
36	PWS	1730.67	103.32	2.96	0.18	0.00	0.00
USGS GAGE AT TRENTON							
35	PWS	1730.72	106.36	3.03	0.19	0.00	0.00
ASSUNIPINK CREEK							
1	PWR	1761.68	106.67	631.62	38.16	0.00	0.00
22	PWR	1804.79	110.27	0.21	0.01	0.00	0.00
44	COMM	1804.79	110.34	45.89	2.71	0.00	0.00
14	PWR	1805.01	114.93	42.85	2.54	0.00	0.00
38	PWS	1805.01	115.52	7.73	0.46	0.00	0.00

Table 2.12
Delaware River Year 2003 Water Supply Conditions (Continued)

Map ID	Water Use Type	Natural Q710 for Year 2003 (mgd)	Cumul. Consumptive Use Above Withdrawal Point for Year 2003 (mgd)	Withdrawal at Point for Year 2003 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
37	PWS	1821.66	116.29	5.45	0.32	0.00	0.00
87	PWS	1821.67	116.84	0.00	0.00	0.00	0.00
33	MANUF	1822.53	116.84	0.42	0.02	0.00	0.00
86	PWS	1835.24	116.88	1.78	0.10	0.00	0.00
73	PWR	1836.23	117.06	0.05	0.00	0.00	0.00
NESHAMINY CREEK							
39	PWS	1990.99	117.11	157.72	8.42	0.00	0.00
89	PWS	1993.07	132.88	19.59	1.05	0.00	0.00
45	MANUF	2012.21	134.84	1.48	0.08	0.00	0.00
84	MANUF	2023.09	134.85	0.20	0.01	0.00	0.00
30	MANUF	2023.09	134.87	19.77	1.05	0.00	0.00
74	MINING	2032.82	136.85	0.00	0.00	0.00	0.00
8	PWR	2035.00	136.85	97.93	5.16	0.00	0.00
18	PWR	2054.11	138.23	15.94	0.83	0.00	0.00
77	MANUF	2054.12	138.31	0.00	0.00	0.00	0.00
78	MANUF	2054.13	138.31	0.00	0.00	0.00	0.00
79	MANUF	2054.13	138.31	0.00	0.00	0.00	0.00
SCHUYLKILL RIVER							
TOTALS			**138.31**	**1566.80**		**0.00**	**0.00**

Bold values denote where utilization exceeds 75%
Consumptive Use, Withdrawals, and Q710 Values from Year 2003

Table 2.13
Schuylkill River Year 2003 Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2003 (mgd)	Cumul. Consumptive Use Above Withdrawal Point for Year 2003 (mgd)	Withdrawal at Point for Year 2003 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
54	AG	60.94	0.00	0.00	0.00	0.00	0.00
68	MANUF	61.02	0.00	0.00	0.00	0.00	0.00
MIADEN CREEK							
63	MANUF	93.18	0.00	0.40	0.43	0.00	0.00
4	PWR	96.75	0.04	16.62	17.19	0.00	0.00
TULPEHOCKEN CREEK - BLUE MARSH RESERVOIR							
USGS GAGE AT READING							
67	PWS	152.60	1.47	4.57	3.03	0.00	0.00
MANATAWNY CREEK							
USGS GAGE AT POTTSTOWN							
55	MANUF	167.28	1.92	0.12	0.07	0.00	0.00
11	PWR	169.99	1.94	43.01	25.60	0.00	0.00
64	PWS	172.96	35.86	2.10	1.53	0.00	0.00
58	PWS	175.98	36.07	3.23	2.31	0.00	0.00
7	**PWR**	**176.02**	**36.40**	**171.62**	**122.92**	**90.35**	**0.00**
62	PWS	188.14	37.34	25.00	16.58	0.00	0.00
PERKIOMEN CREEK							
60	PWS	257.40	39.84	10.75	4.94	0.00	0.00
USGS GAGE AT NORRISTOWN							
61	MANUF	258.84	40.91	0.28	0.13	0.00	0.00
56	MANUF	272.20	40.94	6.48	2.80	0.00	0.00
WISSAHICKON CREEK							
65	PWS	274.57	41.01	85.22	36.49	0.00	0.00
66	PWS	274.96	126.24	55.63	37.40	0.00	0.00
USGS GAGE AT PHILADELPHIA							
20	PWR	275.94	181.86	33.99	36.13	0.00	0.00
69	PWR	275.94	181.90	3.75	3.99	0.00	0.00
10	PWR	275.94	182.24	22.52	24.03	0.00	0.00
59	MANUF	277.46	182.32	4.00	4.20	0.00	0.00
57	MANUF	277.58	183.45	15.87	16.86	0.00	0.00
DELAWARE RIVER							
TOTALS			**183.45**	**505.16**		**90.35**	**0.00**

Bold values denote withdrawal point where utilization exceeds 75%
Consumptive Use, Withdrawals, and Q710 Values from Year 2003

Table 2.14
Lehigh River Year 2003 Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2003 (mgd)	Cumul. Consumptive Use Above Withdrawal Point for Year 2003 (mgd)	Withdrawal at Point for Year 2003 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector(mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors(mgd)
49	GOLF	3.72	0.00	0.00	0.00	0.00	0.00
FE WALTER RESERVOIR							
50	PWR	86.94	0.00	0.00	0.00	0.00	0.00
52	MANUF	142.42	0.00	0.00	0.00	0.00	0.00
USGS GAGE AT LEHIGHTON							
POHOPOCO CREEK - BELTZVILLE RESERVOIR							
47	PWR	229.73	0.00	3.08	1.34	0.00	0.00
51	PWR	230.09	0.31	0.73	0.32	0.00	0.00
19	PWR	230.21	0.38	1.40	0.61	0.00	0.00
48	RES. INTAKE	230.21	1.78	0.00	0.00	0.00	0.00
JORDAN CREEK							
53	PWS	299.12	1.78	0.12	0.04	0.00	0.00
USGS GAGE AT BETHLEHEM							
24	PWR	313.42	1.79	0.54	0.17	0.00	0.00
DELAWARE RIVER							
TOTALS			**1.79**	**5.87**		**0.00**	**0.00**

Consumptive Use, Withdrawals, and Q710 Values from Year 2003

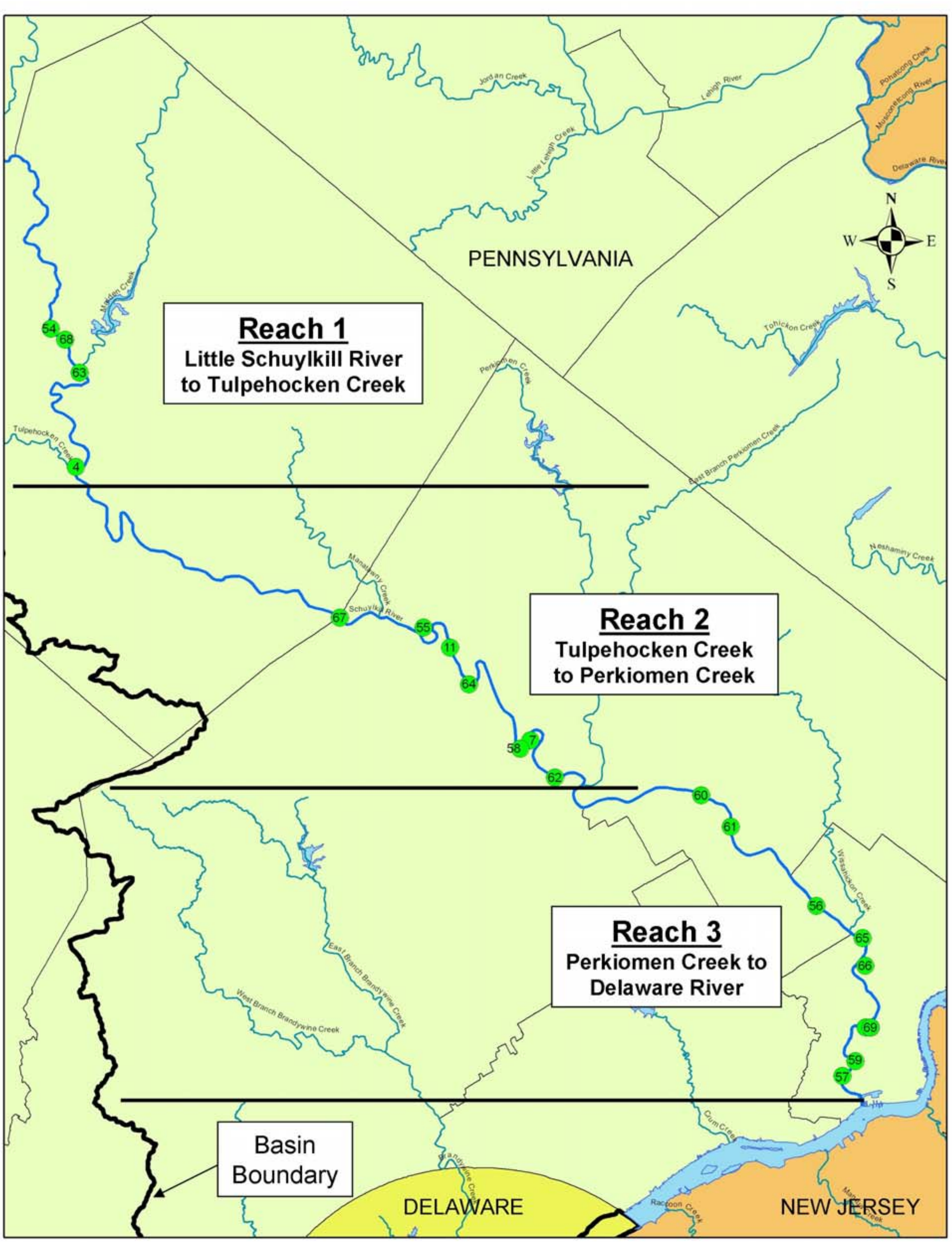


Figure 2.29: Schuylkill River Reaches

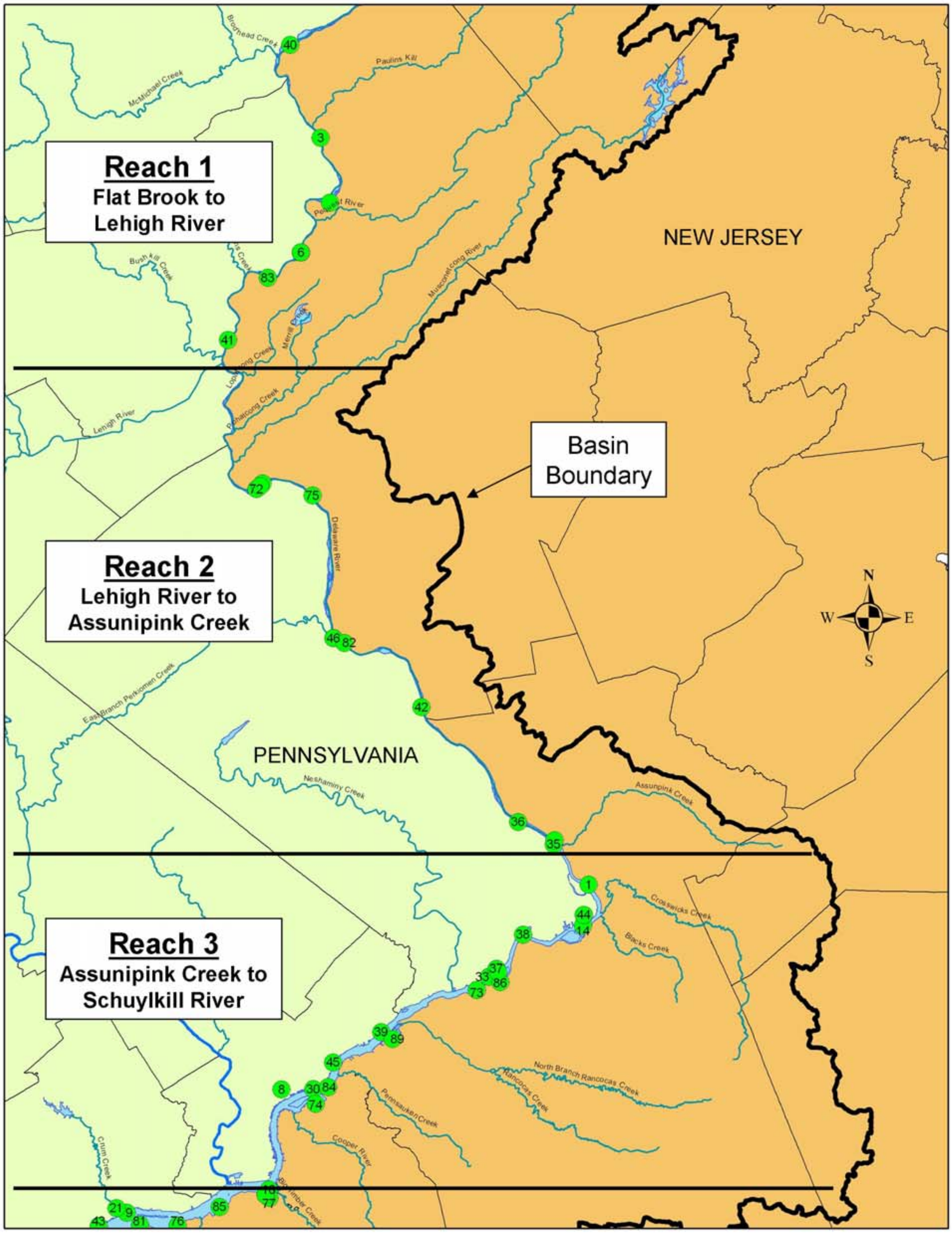
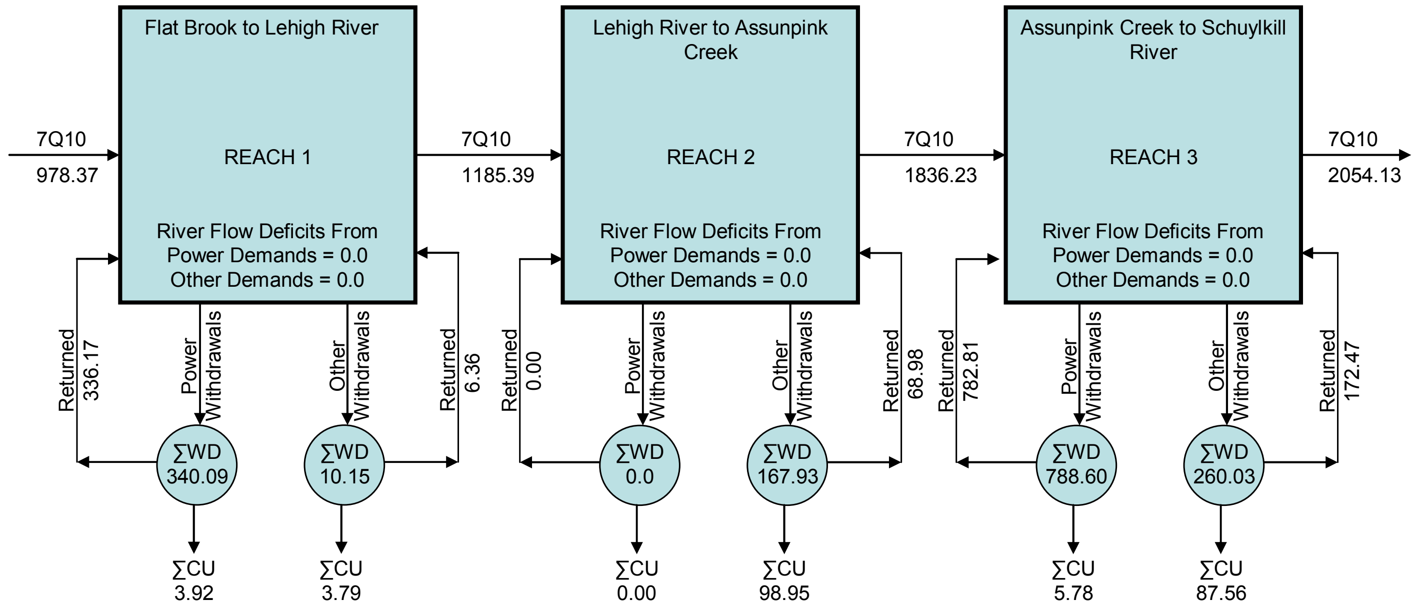


Figure 2.30 Delaware River Reaches

DELAWARE RIVER BASIN

DEMANDS: 2003 Values for Withdrawals and Consumptive Uses
SUPPLY: 2003 Values for 7Q10



KEY
7Q10 = Low Flow Indicator of a 7-Day Average Flow with a 10-Year Return Period
Power = Demands Placed Upon River from the Power Sector
Other = Demands Placed Upon River from Golf, Agricultural, Public Water Supply etc ...Sectors
∑WD = Cumulative Surface Water Withdrawals within Reach
∑CU = Cumulative Consumptive Use of Withdrawals within Reach
All Values Expressed as MGD

Figure 2.31 Delaware River Year 2003 Water Supply Conditions

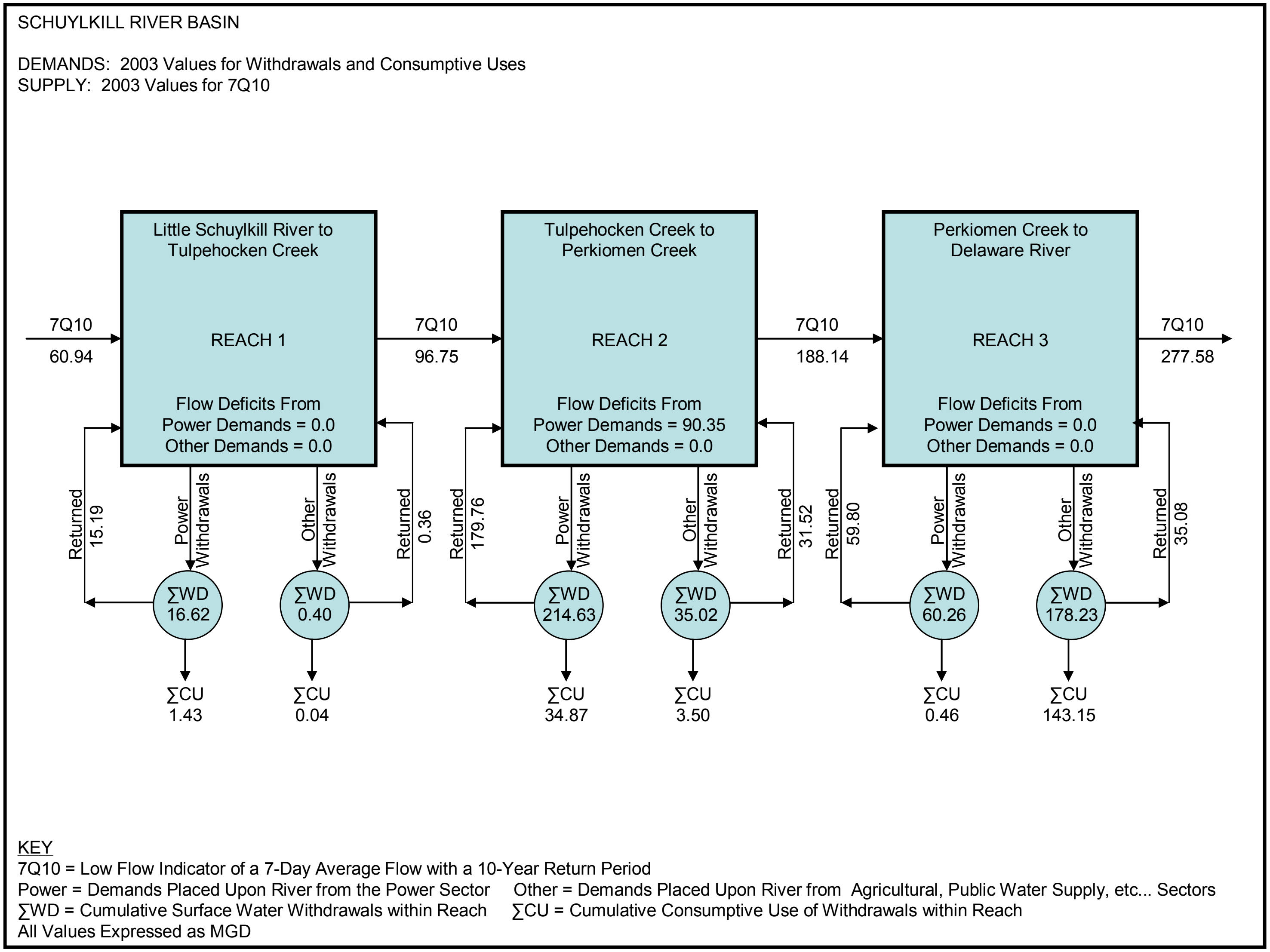


Figure 2.32: Schuylkill River Year 2003 Water Supply Conditions

2.3.2.2 Deficiencies in Year 2030. As expected, deficiencies increased in the year 2030. The increased deficiencies along the rivers were attributable to two factors. First, as previously mentioned in the report, the analysis accounted for climate variability by reducing the natural $Q_7 10$ values at each withdrawal point as shown in Tables 2.12-2.14 by 5%. Secondly, as was previously shown as well, demands are projected to increase on the rivers in the year 2030. The combination of potentially lower supplies and higher demands resulted in the higher deficiencies.

Projecting conditions out to the year 2030 on the Delaware River resulted in one power-sector withdrawal point being identified as deficient in the vicinity of Trenton, NJ. The deficiency on the Delaware River at that point was calculated to be 278 mgd (Table 2.15). This deficiency did not exist in the year 2003. Figure 2.33 corresponds to the analysis shown in Table 2.15 and shows that the deficit is between the Lehigh River and Assunipink Creek on the Delaware.

In 2030 on the Schuylkill River, the number of deficient withdrawal points for the power sector increased to three from the one deficient withdrawal point identified in year 2003. The total deficiency at all three withdrawal points at the downstream end of the Schuylkill was calculated to be 518 mgd (Table 2.16). This was an increase of 428 mgd over the year 2003 results for the Schuylkill River. Figure 2.34 corresponds to the analysis shown in Table 2.16. As the figure shows, 418 mgd of the 518mgd deficit was in Reach 2 between the Tulpehocken and Perkiomen Creeks. The remaining 100 mgd deficit was from withdrawal points downstream of the Perkiomen Creek which did not have any withdrawal points in deficit in the year 2003 as shown in Figure 2.34. Also, in comparing Figure 2.33 to Figure 2.34 it can be seen that the deficit in Reach 2 increased 328 mgd from its 2003 level.

The Lehigh River did not have any deficient withdrawal points projected in the year 2030 (Table 2.17) as it did in year 2003. Therefore, it can be concluded that based on this analysis there is sufficient water in the Lehigh River in order to keep utilization at each withdrawal point below the threshold value of 75% of the natural $Q_7 10$ in the year 2003 and projected in the year 2030.

Table 2.15
Delaware River Year 2030 Projected Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
USGS GAGE @ DELAWARE WATER GAP							
40	GOLF	929.45	0.00	0.44	0.05	0.00	0.00
BRODHEAD CREEK							
3	PWR	1058.36	0.39	614.71	58.10	0.00	0.00
80	MANUF	1061.85	2.97	1.45	0.14	0.00	0.00
5	PWR	1104.96	3.41	0.00	0.00	0.00	0.00
6	PWR	1104.96	3.41	15.00	1.36	0.00	0.00
23	PWR	1104.96	7.39	2.04	0.19	0.00	0.00
83	RES. INTAKE	1104.96	8.24	0.00	0.00	0.00	0.00
41	PWS	1126.12	8.24	7.84	0.70	0.00	0.00
LEHIGH RIVER							
75	MANUF	1552.17	13.39	0.00	0.00	0.00	0.00
72	PWR	1552.17	13.39	3.11	0.20	0.00	0.00
90	AG	1552.17	13.96	0.00	0.00	0.00	0.00
91	AG	1552.17	13.96	0.00	0.00	0.00	0.00
34	PWS	1600.56	13.96	18.80	1.18	0.00	0.00
TOHICKON CREEK							
46	PWS	1600.56	15.84	24.80	1.57	0.00	0.00
DELAWARE & RARITAN CANAL - NODE 82 WITHDRAWAL							
82	PWS	1601.23	18.32	100.96	6.38	0.00	0.00
42	PWS	1622.61	119.28	0.01	0.00	0.00	0.00
88	PWS	1644.14	119.29	29.69	1.95	0.00	0.00
36	PWS	1644.14	119.29	3.18	0.21	0.00	0.00
USGS GAGE AT TRENTON							
35	PWS	1644.19	122.25	3.00	0.20	0.00	0.00
ASSUNIPINK CREEK							
1	**PWR**	**1673.60**	**122.55**	**1364.69**	**87.99**	**277.64**	**0.00**
22	PWR	1714.56	130.34	4.30	0.27	0.00	0.00
44	COMM	1714.56	131.88	43.50	2.75	0.00	0.00
14	PWR	1714.76	136.23	95.87	6.07	0.00	0.00
38	PWS	1714.76	137.55	7.93	0.50	0.00	0.00
37	PWS	1730.58	138.34	5.95	0.37	0.00	0.00

Table 2.15
Delaware River Year 2030 Projected Water Supply Conditions (Continued)

Map ID	Water Use Type	Natural Q710 for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
87	PWS	1730.59	138.93	0.00	0.00	0.00	0.00
33	MANUF	1731.40	138.93	0.40	0.02	0.00	0.00
86	PWS	1743.48	138.97	2.18	0.14	0.00	0.00
73	PWR	1744.42	139.19	0.00	0.00	0.00	0.00
NESHAMINY CREEK							
39	PWS	1891.44	139.19	140.83	8.04	0.00	0.00
89	PWS	1893.41	153.27	18.07	1.04	0.00	0.00
45	MANUF	1911.60	155.08	0.77	0.04	0.00	0.00
84	MANUF	1921.94	155.08	0.16	0.01	0.00	0.00
30	MANUF	1921.94	155.10	10.28	0.58	0.00	0.00
74	MINING	1931.18	156.13	0.00	0.00	0.00	0.00
8	PWR	1933.25	156.13	0.00	0.00	0.00	0.00
18	PWR	1951.40	156.13	30.89	1.72	0.00	0.00
77	MANUF	1951.41	156.29	0.00	0.00	0.00	0.00
78	MANUF	1951.42	156.29	0.00	0.00	0.00	0.00
79	MANUF	1951.42	156.29	0.00	0.00	0.00	0.00
SCHUYLKILL RIVER							
TOTALS			**156.29**	**2550.83**		**277.64**	**0.00**

Bold values denote where utilization exceeds 75%
Consumptive Use, Withdrawals, and Q710 Values from Year 2030
Q710 Values Reduced by 5% from 2003 Values to Account for Climate Variability in Year 2030

Table 2.16
Schuylkill River Year 2030 Projected Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
54	AG	57.89	0.00	0.00	0.00	0.00	0.00
68	MANUF	57.97	0.00	0.00	0.00	0.00	0.00
MIADEN CREEK							
63	MANUF	88.52	0.00	0.34	0.39	0.00	0.00
4	PWR	91.91	0.03	33.82	36.81	0.00	0.00
TULPEHOCKEN CREEK - BLUE MARSH RESERVOIR							
USGS GAGE AT READING							
67	PWS	144.97	2.94	4.78	3.37	0.00	0.00
MANATAWNY CREEK							
USGS GAGE AT POTTSTOWN							
55	MANUF	158.92	3.42	0.12	0.07	0.00	0.00
11	PWR	161.49	3.43	84.41	53.40	0.00	0.00
64	PWS	164.31	70.01	2.71	2.87	0.00	0.00
58	PWS	167.18	70.28	3.67	3.78	0.00	0.00
7	**PWR**	**167.22**	**70.65**	**384.20**	**397.84**	**418.26**	**0.00**
62	PWS	178.73	72.76	27.28	25.74	0.00	0.00
PERKIOMEN CREEK							
60	PWS	244.53	75.48	11.87	7.02	0.00	0.00
USGS GAGE AT NORRISTOWN							
61	MANUF	245.90	76.67	0.27	0.16	0.00	0.00
56	MANUF	258.59	76.70	6.31	3.47	0.00	0.00
WISSAHICKON CREEK							
65	PWS	260.85	76.77	76.09	41.34	0.00	0.00
66	PWS	261.21	152.86	49.67	45.84	0.00	0.00
USGS GAGE AT PHILADELPHIA							
20	**PWR**	**262.14**	**202.53**	**71.28**	**119.59**	**35.91**	**0.00**
69	PWR	262.14	202.64	11.18	18.78	0.00	0.00
10	**PWR**	**262.14**	**203.36**	**91.64**	**155.89**	**64.01**	**0.00**
59	MANUF	263.59	203.66	2.08	3.47	0.00	0.00
57	MANUF	263.70	204.25	8.25	13.88	0.00	0.00
DELAWARE RIVER							
TOTALS			**204.25**	**869.98**		**518.18**	**0.00**

Bold values denote where utilization exceeds 75%
Consumptive Use, Withdrawals, and Q710 Values from Year 2030
Q710 Values Reduced by 5% from 2003 Values to Account for Climate Variability in Year 2030

Table 2.17 Lehigh River Year 2030 Water Supply Conditions

Map ID	Water Use Type	Natural Q710 for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural Q710 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector(mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors(mgd)
49	GOLF	3.53	0.00	0.00	0.00	0.00	0.00
FE WALTER RESERVOIR							
50	PWR	82.59	0.00	0.00	0.00	0.00	0.00
52	MANUF	135.30	0.00	0.00	0.00	0.00	0.00
USGS GAGE AT LEHIGHTON							
POHOPOCO CREEK - BELTZVILLE RESERVOIR							
47	PWR	218.24	0.00	3.14	1.44	0.00	0.00
51	PWR	218.59	0.31	0.57	0.26	0.00	0.00
19	PWR	218.70	0.37	2.39	1.09	0.00	0.00
48	RES. INTAKE	218.70	2.76	0.00	0.00	0.00	0.00
JORDAN CREEK							
53	PWS	284.16	2.76	0.09	0.03	0.00	0.00
USGS GAGE AT BETHLEHEM							
24	PWR	297.75	2.77	2.33	0.79	0.00	0.00
DELAWARE RIVER							
TOTALS			**2.77**	**8.52**		**0.00**	**0.00**

Consumptive Use, Withdrawals, and Q710 Values from Year 2030
Q710 Values Reduced by 5% from 2003 Values to Account for Climate Variability in Year 2030

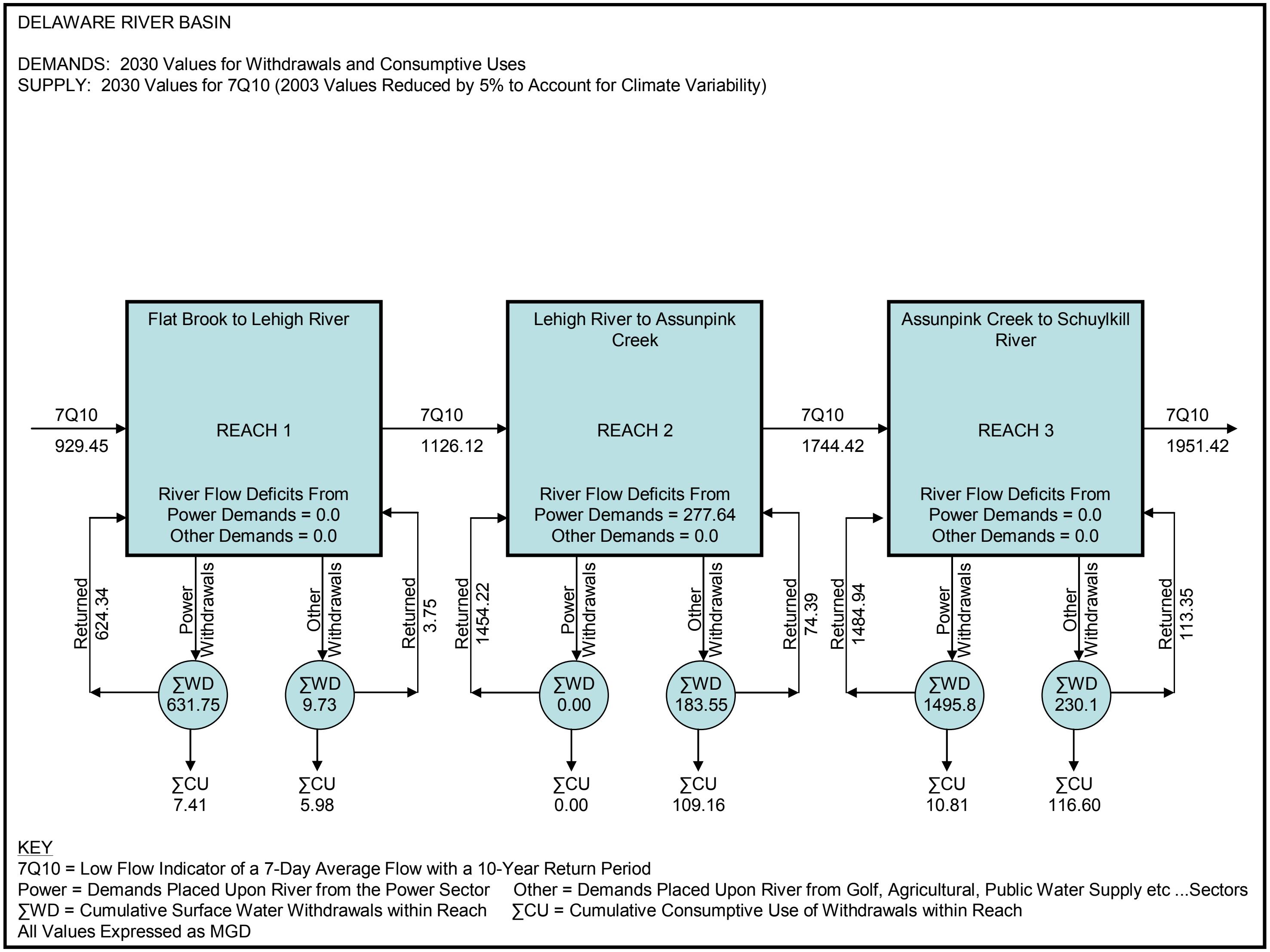


Figure 2.33: Delaware River Year 2030 Water Supply Conditions

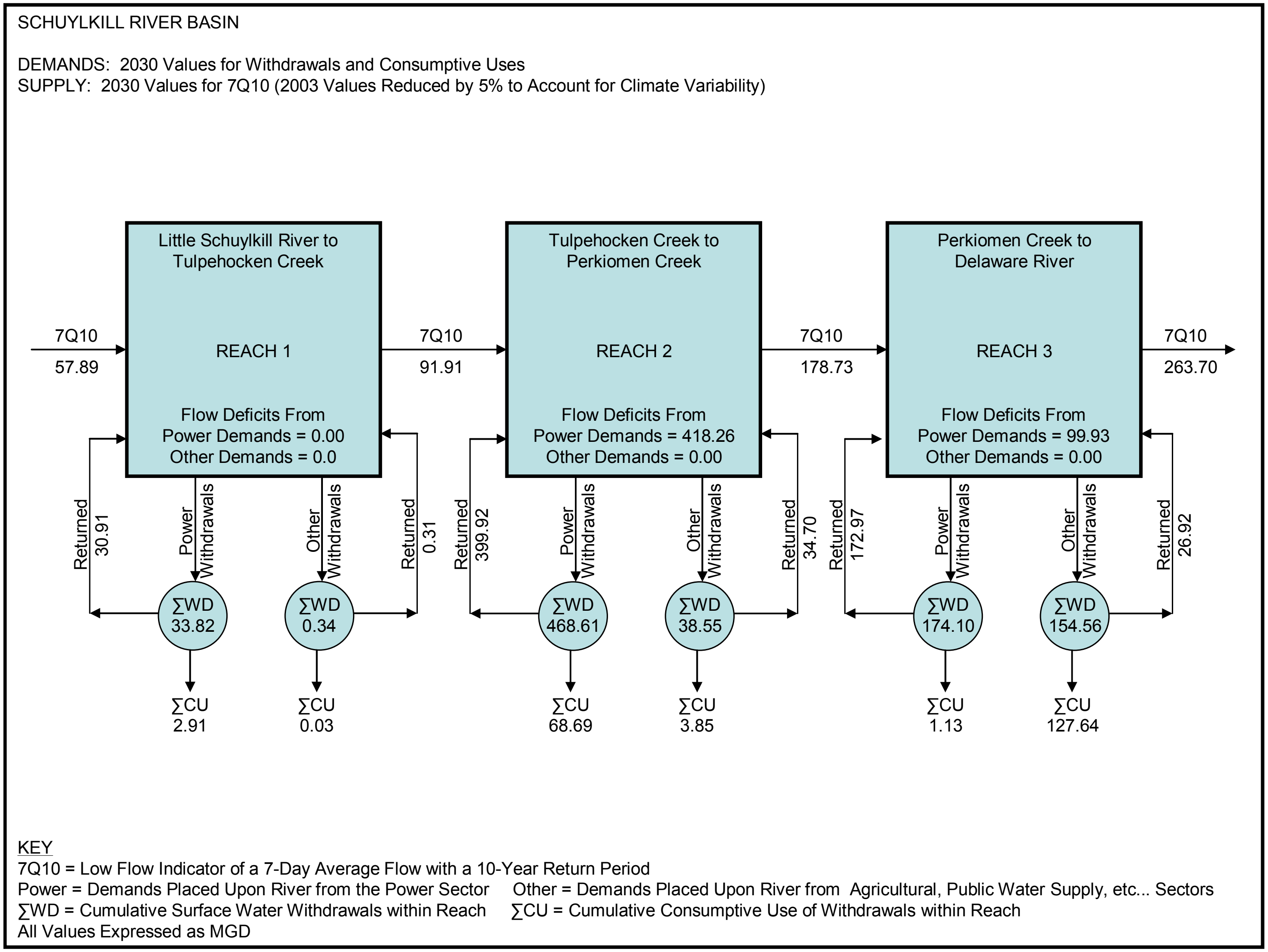


Figure 2.34: Schuylkill River Year 2030 Water Supply Conditions

2.3.2.3 Deficiencies Under Drought Conditions Along with calculating deficiencies on the rivers in the years 2003 and 2030, deficiencies were also calculated for several alternatives that assumed reduced $Q_7 10$ flows to simulate "drought-like" conditions. This analysis was done to check the sensitivity of the results to variable levels of water availability. The $Q_7 10$ calculated for the year 2003 was reduced by 25%, 50%, and 75% on the Delaware River and was reduced by 25%, and 50% for the Schuylkill and Lehigh Rivers. Withdrawals and consumptive use values projected for the year 2030 were also used in drought sensitivity analysis. Tables 2.18-2.20 summarize the $Q_7 10$ at each withdrawal point for the various reductions made at the Delaware, Schuylkill and Lehigh Rivers, respectively.

This sensitivity analysis was not intended to serve as a comprehensive drought analysis for the rivers nor were they intended to represent flows along the rivers corresponding to the 1960s drought of record. The $Q_7 10$ and reductions of it were intended to serve as a screening parameter at a reconnaissance level to see what if any alternative sources of water would be needed.

The results of the drought sensitivity analysis showed that when the $Q_7 10$ was reduced by 50% on the Delaware River, the number of withdrawal points in deficit increased along with the total magnitude of the deficit at the downstream end of the analysis. Table 2.21 shows that by reducing the $Q_7 10$ on the Delaware River by 50%, flow at two withdrawal points is deficient and the total deficit at the downstream end of the analysis is 1337 mgd. Previously, Table 2.12 showed no deficit on the Delaware River in year 2003. The corresponding graphic to Table 2.21 is shown in Figure 2.35.

Reducing the $Q_7 10$ on the Schuylkill River by 50% also increased the deficit on the river as shown in Table 2.21. The total deficit on the Schuylkill River increased from 90 mgd in 2003 to 1096 mgd. The 50% reduction in $Q_7 10$ also resulted in other withdrawal points being deficient other than the ones for the power sector. Approximately, 139 mgd of the 1096 mgd total was attributable to sectors other than the power sector. The remaining 957 mgd came from the power sector and was an increase of 867 mgd from the 2003 levels. Figure 2.36 corresponds to the analysis shown in Table 2.22.

On the Lehigh River, reducing the $Q_7 10$ by 50% did not reduce the flow enough so that a withdrawal point was identified as being deficient. Table 2.23 shows that even when the $Q_7 10$ was reduced by 50%, no additional flow was needed at the withdrawal points.

Similar tables and figures for the 25% and 75% reductions done in the drought sensitivity analysis are presented in Technical Appendix A.

Table 2.18
Delaware River $Q_7 10$ with Reductions

Map ID	Vicinity of	2003 (mgd)	Reduction of 2003 Q710 (mgd) by:			
			5% (2030)	25%	50%	75%
40	Brodhead Creek	978.37	929.45	733.78	489.18	244.59
3		1114.06	1058.36	835.55	557.03	278.52
80		1117.74	1061.85	838.31	558.87	279.44
5		1163.12	1104.96	872.34	581.56	290.78
6		1163.12	1104.96	872.34	581.56	290.78
23		1163.12	1104.96	872.34	581.56	290.78
83		1163.12	1104.96	872.34	581.56	290.78
41	Lehigh River	1185.39	1126.12	889.04	592.70	296.35
75		1633.87	1552.17	1225.40	816.93	408.47
72		1633.87	1552.17	1225.40	816.93	408.47
90		1633.87	1552.17	1225.40	816.93	408.47
91		1633.87	1552.17	1225.40	816.93	408.47
34		1684.80	1600.56	1263.60	842.40	421.20
46	Tohickon Creek	1684.80	1600.56	1263.60	842.40	421.20
82	D&R Canal	1685.50	1601.23	1264.13	842.75	421.38
42		1708.01	1622.61	1281.01	854.01	427.00
88		1730.67	1644.14	1298.00	865.33	432.67
36		1730.67	1644.14	1298.00	865.33	432.67
35	USGS Gage at Trenton	1730.72	1644.19	1298.04	865.36	432.68
1		1761.68	1673.60	1321.26	880.84	440.42
22		1804.79	1714.56	1353.60	902.40	451.20
44		1804.79	1714.56	1353.60	902.40	451.20
14		1805.01	1714.76	1353.76	902.51	451.25
38		1805.01	1714.76	1353.76	902.51	451.25
37		1821.66	1730.58	1366.25	910.83	455.42
87		1821.67	1730.59	1366.26	910.84	455.42
33		1822.53	1731.40	1366.89	911.26	455.63
86		1835.24	1743.48	1376.43	917.62	458.81
73	Neshaminy Creek	1836.23	1744.42	1377.17	918.11	459.06
39		1990.99	1891.44	1493.24	995.49	497.75
89		1993.07	1893.41	1494.80	996.53	498.27
45		2012.21	1911.60	1509.15	1006.10	503.05
84		2023.09	1921.94	1517.32	1011.55	505.77
30		2023.09	1921.94	1517.32	1011.55	505.77
74		2032.82	1931.18	1524.62	1016.41	508.21
8		2035.00	1933.25	1526.25	1017.50	508.75
18		2054.11	1951.40	1540.58	1027.05	513.53
77		2054.12	1951.41	1540.59	1027.06	513.53
78		2054.13	1951.42	1540.60	1027.07	513.53
79	Schuylkill River	2054.13	1951.42	1540.60	1027.07	513.53

Table 2.19
Schuylkill River Q_710 with Reductions

Map ID	Vicinity of	2003 (mgd)	Reductions of Q_710 (mgd) by: 5% (2030)	25%	50%
54		60.94	57.89	45.70	30.47
63	Maiden Creek	61.02	57.97	45.76	30.51
68		93.18	88.52	69.88	46.59
4	Tulpehocken Creek	96.75	91.91	72.56	48.37
67	Manatawny Creek	152.60	144.97	114.45	76.30
55	USGS Gage at Pottstown	167.28	158.92	125.46	83.64
11		169.99	161.49	127.49	84.99
64		172.96	164.31	129.72	86.48
58		175.98	167.18	131.98	87.99
7		176.02	167.22	132.01	88.01
62	Perkiomen Creek	188.14	178.73	141.10	94.07
60		257.40	244.53	193.05	128.70
61		258.84	245.90	194.13	129.42
56		272.20	258.59	204.15	136.10
65	Wissahickon Creek	274.57	260.85	205.93	137.29
66		274.96	261.21	206.22	137.48
20	USGS Gage at Phila.	275.94	262.14	206.95	137.97
69		275.94	262.14	206.95	137.97
10		275.94	262.14	206.95	137.97
59		277.46	263.59	208.10	138.73
57	Delaware River	277.58	263.70	208.19	138.79

Table 2.20
Lehigh River Q_710 with Reductions

Map ID	Vicinity of	2003 (mgd)	Reduction of Q_710 (mgd) by: 5% (2030)	25%	50%
49	Upstream of FE Walter Res.	3.72	3.53	2.79	1.86
50		86.94	82.59	65.21	43.47
52	USGS Gage at Lehighton	142.42	135.30	106.82	71.21
47		229.73	218.24	172.30	114.87
51		230.09	218.59	172.57	115.05
19	Hokendauqua Creek	230.21	218.70	172.66	115.11
48	Jordan Creek	230.21	218.70	172.66	115.11
53		299.12	284.16	224.34	149.56
24	Saucon Creek	313.42	297.75	235.07	156.71

Table 2.21

Water Supply Conditions on the Delaware River when $Q_7 10$ Reduced by 50%

Map ID	Water Use Type	50% Reduction in Natural $Q_7 10$ (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
USGS GAGE @ DELAWARE WATER GAP							
40	GOLF	489.18	0.00	0.44	0.09	0.00	0.00
BRODHEAD CREEK							
3	**PWR**	**557.03**	**0.39**	**614.71**	**110.43**	**267.07**	**0.00**
80	MANUF	1061.85	2.97	1.45	0.14	0.00	0.00
5	PWR	1104.96	3.41	0.00	0.00	0.00	0.00
6	PWR	1104.96	3.41	15.00	1.36	0.00	0.00
23	PWR	1104.96	7.39	2.04	0.19	0.00	0.00
83	RES. INTAKE	581.56	8.24	0.00	0.00	0.00	0.00
41	PWS	592.70	8.24	7.84	1.34	0.00	0.00
LEHIGH RIVER							
75	MANUF	816.93	13.39	0.00	0.00	0.00	0.00
72	PWR	1552.17	13.39	3.11	0.20	0.00	0.00
90	AG	1552.17	13.96	0.00	0.00	0.00	0.00
91	AG	1552.17	13.96	0.00	0.00	0.00	0.00
34	PWS	842.40	13.96	18.80	2.27	0.00	0.00
TOHICKON CREEK							
46	PWS	842.40	15.84	24.80	3.00	0.00	0.00
DELAWARE & RARITAN CANAL - NODE 82 WITHDRAWAL							
82	PWS	842.75	18.32	100.96	12.25	0.00	0.00
42	PWS	854.01	119.28	0.01	0.00	0.00	0.00
88	PWS	865.33	119.29	29.69	3.98	0.00	0.00
36	PWS	865.33	119.29	3.18	0.43	0.00	0.00
USGS GAGE AT TRENTON							
35	PWS	865.36	122.25	3.00	0.40	0.00	0.00
ASSUNIPINK CREEK							
1	**PWR**	**880.84**	**122.55**	**1364.69**	**179.97**	**1070.40**	**0.00**

Table 2.21
Water Supply Conditions on the Delaware River when $Q_7 10$ Reduced by 50%
(Continued)

Map ID	Water Use Type	50% Reduction in Natural $Q_7 10$ (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
22	PWR	902.40	130.34	4.30	0.56	0.00	0.00
44	COMM	1714.56	131.88	43.50	2.75	0.00	0.00
14	PWR	1714.76	136.23	95.87	6.07	0.00	0.00
38	PWS	1714.76	137.55	7.93	0.50	0.00	0.00
37	PWS	1730.58	138.34	5.95	0.37	0.00	0.00
87	PWS	1730.59	138.93	0.00	0.00	0.00	0.00
33	MANUF	1731.40	138.93	0.40	0.02	0.00	0.00
86	PWS	917.62	138.97	2.18	0.28	0.00	0.00
73	PWR	918.11	139.19	0.00	0.00	0.00	0.00
NESHAMINY CREEK							
39	PWS	995.49	139.19	140.83	16.45	0.00	0.00
89	PWS	996.53	153.27	18.07	2.14	0.00	0.00
45	MANUF	1911.60	155.08	0.77	0.04	0.00	0.00
84	MANUF	1921.94	155.08	0.16	0.01	0.00	0.00
30	MANUF	1921.94	155.10	10.28	0.58	0.00	0.00
74	MINING	1931.18	156.13	0.00	0.00	0.00	0.00
8	PWR	1933.25	156.13	0.00	0.00	0.00	0.00
18	PWR	1951.40	156.13	30.89	1.72	0.00	0.00
77	MANUF	1951.41	156.29	0.00	0.00	0.00	0.00
78	MANUF	1027.07	156.29	0.00	0.00	0.00	0.00
79	MANUF	1027.07	156.29	0.00	0.00	0.00	0.00
SCHUYLKILL RIVER							
TOTALS			**156.29**	**2550.83**		**1337.47**	**0.00**

Table 2.22
Water Supply Conditions on the Schuylkill River when Q710 Reduced by 50%

Map ID	Water Use Type	50% Reduction in Natural $Q_7 10$ (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
54	AG	30.47	0.00	0.00	0.00	0.00	0.00
68	MANUF	30.51	0.00	0.00	0.00	0.00	0.00
MAIDEN CREEK							
63	MANUF	46.59	0.00	0.34	0.74	0.00	0.00
4	PWR	48.37	0.03	33.82	69.96	0.00	0.00
TULPEHOCKEN CREEK							
USGS GAGE AT READING							
67	PWS	76.30	2.94	4.78	6.52	0.00	0.00
MANATAWNY CREEK							
USGS GAGE AT POTTSTOWN							
55	MANUF	83.64	3.42	0.12	0.15	0.00	0.00
11	**PWR**	**84.99**	3.43	84.41	**103.49**	**31.54**	**0.00**
64	PWS	86.48	70.01	2.71	16.46	0.00	0.00
58	PWS	87.99	70.28	3.67	20.70	0.00	0.00
7	**PWR**	**88.01**	**70.65**	**384.20**	**2212.75**	**497.46**	**0.00**
62	**PWS**	**94.07**	72.76	27.28	**128.00**	**0.00**	**15.24**
PERKIOMEN CREEK							
60	PWS	128.70	75.48	11.87	22.31	0.00	0.00
USGS GAGE AT NORRISTOWN							
61	MANUF	129.42	76.67	0.27	0.51	0.00	0.00
56	MANUF	136.10	76.70	6.31	10.63	0.00	0.00
WISSAHICKON CREEK							
65	**PWS**	**137.29**	76.77	76.09	**125.74**	**0.00**	**41.45**
66	**PWS**	**137.48**	152.86	49.67	**-322.81**	**0.00**	**81.94**
USGS GAGE AT PHILADELPHIA							
20	**PWR**	**137.97**	**202.53**	**71.28**	**-110.41**	**160.09**	**0.00**
69	**PWR**	**137.97**	202.64	11.18	**-17.28**	**79.65**	**0.00**
10	**PWR**	**137.97**	**203.36**	**91.64**	**-140.14**	**188.18**	**0.00**
59	MANUF	138.73	203.66	2.08	-3.20	0.00	0.00
57	MANUF	138.79	204.25	8.25	-12.61	0.00	0.00
DELAWARE RIVER							
TOTALS			**204.25**	**869.98**		**956.93**	**138.63**

Table 2.23
Water Supply Conditions on the Lehigh River when $Q_7$10 Reduced by 50%

Map ID	Water Use Type	50% of Natural $Q_7$10 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Withdrawal as Percentage of Natural $Q_7$10 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
49	GOLF	1.86	0.00	0.00	0.00	0.00	0.00
FE WALTER RESERVOIR							
50	PWR	43.47	0.00	0.00	0.00	0.00	0.00
52	MANUF	71.21	0.00	0.00	0.00	0.00	0.00
USGS GAGE AT LEHIGHTON							
POHOPOCO CREEK - BELTZVILLE RESERVOIR							
47	PWR	114.87	0.00	3.14	2.74	0.00	0.00
51	PWR	115.05	0.31	0.57	0.49	0.00	0.00
19	PWR	115.11	0.37	2.39	2.08	0.00	0.00
48	RES. INTAKE	115.11	2.76	0.00	0.00	0.00	0.00
JORDAN CREEK							
53	PWS	149.56	2.76	0.09	0.06	0.00	0.00
USGS GAGE AT BETHLEHEM							
24	PWR	156.71	2.77	2.33	1.51	0.00	0.00
DELAWARE RIVER							
TOTALS			**2.77**	**8.52**		**0.00**	**0.00**

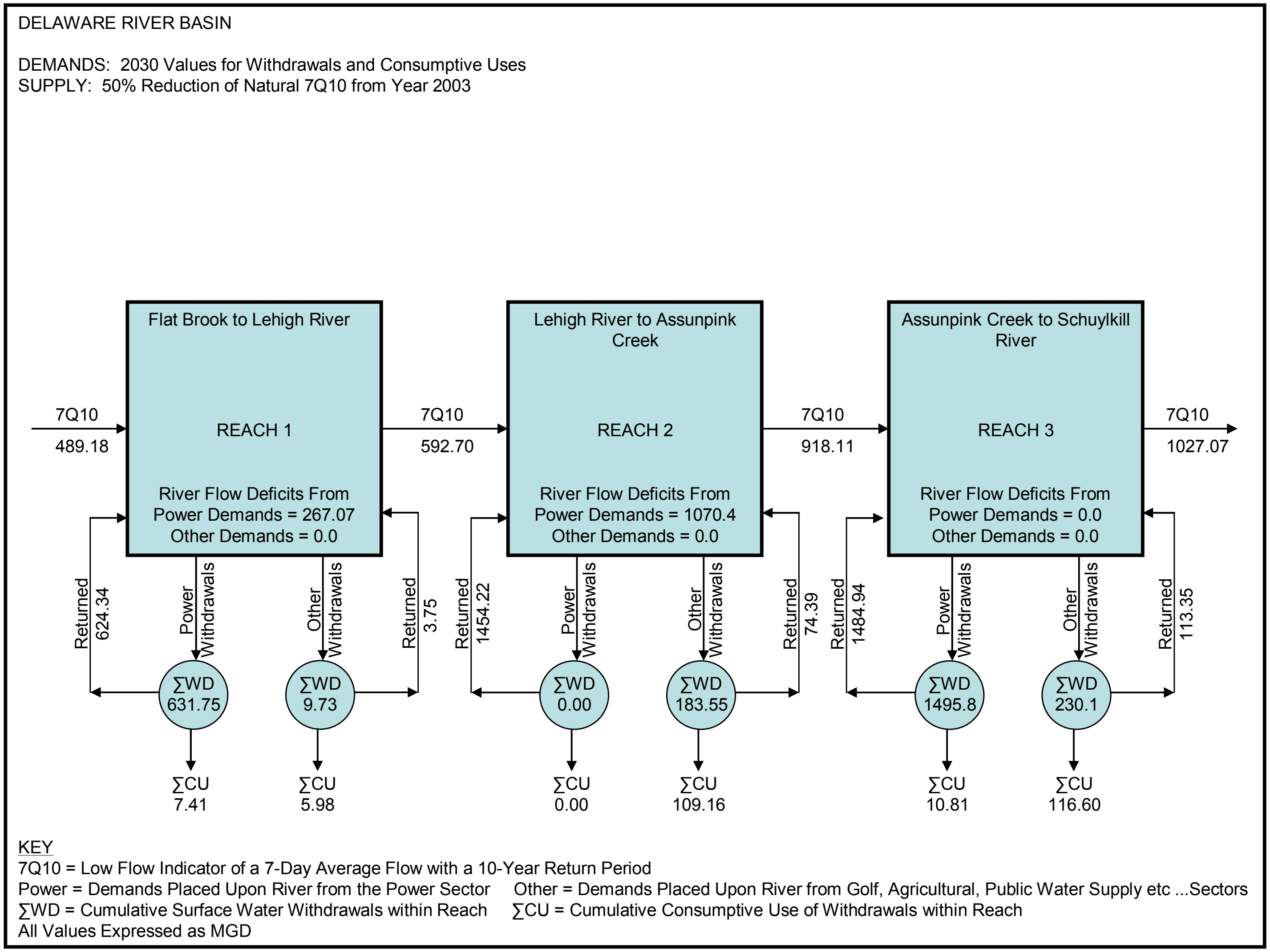


Figure 2.35 Water Supply Conditions on the Delaware River when Q710 Reduced by 50%

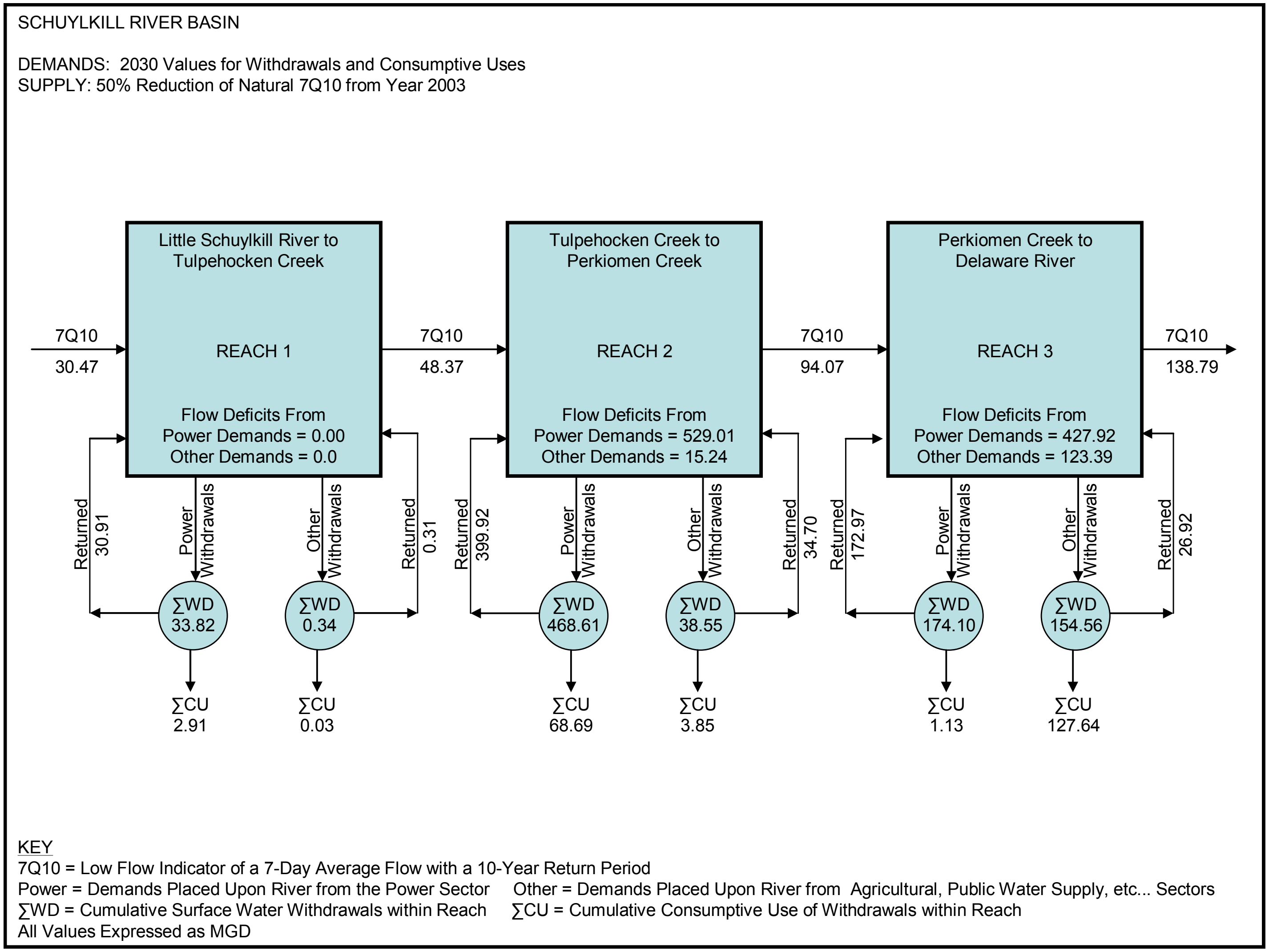


Figure 2.36 Water Supply Conditions on the Schuylkill River when $Q_7 10$ Reduced by 50%

2.4 POTENTIAL ALTERNATIVES FOR WATER SUPPLY

Several alternatives were examined that could potentially meet the surface and groundwater deficiencies previously identified in watersheds identified for further study 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.

Only two alternatives were examined in detail that could meet the water supply deficiencies outlined previously in the Basin. The alternatives examined in detail were diverting water from the Delaware River and reservoir storage in the Schuylkill River Basin. It was beyond the scope of this report to examine each alternative in detail. It is recommended that all of these alternatives and others not mentioned be examined in detail in a comprehensive Basin-wide water supply "feasibility-level" study. A brief description of each alternative follows.

2.4.1 Expand Supply Alternatives.

2.4.1.1 Aquifer Storage and Recovery (ASR). ASR involves injecting water into an aquifer through wells or by surface spreading and infiltration and then pumping it out when needed. Essentially the aquifer functions as a "water bank". Water is injected in times of surplus when precipitation is high and is pumped out of the aquifer during times when available water is low and demand is high which is typically in the summer. Artesian Water Company in the State of Delaware currently operates ASR wellfields and is in the process of expanding the use of them in order to increase water supply in Delaware. One possible alternative that could meet the previously identified deficits in watershed DB-127 could be Delaware's expanded ASR program.

2.4.1.2 Expansion of Municipal Systems. Expansion of Municipal System involves interconnections between multiple water distribution systems to cover a larger geographical area and also involves expanding water distribution systems to areas that are serviced by wells. The concept behind this alternative is moving water from areas where it is more plentiful to areas where water availability is limited. Interconnections between systems that are operated by different purveyors are currently being done in some areas of need in the State of New Jersey, for example.

2.4.1.3 Reuse of Waste and Storm Water. There are a variety of water sources that may be supplied as reuse water, including waste water (from sewerage systems), drainage water, and storm water. Sewerage systems collect and treat waste water to primary, secondary, or tertiary levels. Storm water may also be collected using infrastructure separate to sewerage systems and, depending on its intended use, may or may not be treated before being supplied as reuse water. Drainage water is collected in regional drains managed by irrigation/rural water providers. This water may be supplied as reuse water to customers or discharged to the environment. Typically this practice has been focused at a very small scale. Potentially reuse of waste and storm water at a watershed scale could make available a large quantity of water to many of the high water-use sectors in the Basin such as power and irrigation.

2.4.1.4 Mine Reclamation. What to do with flooded abandoned mines in the State of Pennsylvania has been an ongoing problem for the State. Pennsylvania Department of Environment (PADEP) estimates that there are between 10,000 and 15,000 abandoned underground mines in the state, many of which are within the confines of the Delaware River Basin. Utilization of flooded abandoned mines as an alternative water supply source could potentially augment downstream water supply in the Basin significantly. The practice of using water from a flooded mine is currently being done in the Schuylkill River Basin by Exelon Corporation for their Limerick Generating Station. Exelon is augmenting flows in the Schuylkill River to support the needs of the Limerick Station from the Wadesville mine pool which is located at the Schuylkill River headwaters. Further detailed investigations are needed to see if this practice could be expanded in the Basin.

2.4.1.5 Desalination. Treating saline water by either distillation or reverse osmosis is more expensive relatively compared to other alternatives. Typically desalination is only economically practical in arid regions of the world such as in the Middle East. Emerging technologies may make desalination more practical economically and expand its uses as a viable alternative in areas where it was previously dismissed. Further investigation is needed.

2.4.1.6 Delaware River Diversions. Diverting river water through pipelines from the Delaware River to other parts of the Basin is currently being implemented and was investigated in further detail as a possible alternative to meeting the watershed deficits calculated in New Jersey and Pennsylvania.

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 was 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. Figure 2.37 shows the conceptual plan for these two diversions.

Table 2.24 summarizes 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. The table 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. The deficiency increased by the 102 mgd that is being diverted upstream of the point at Point Pleasant.

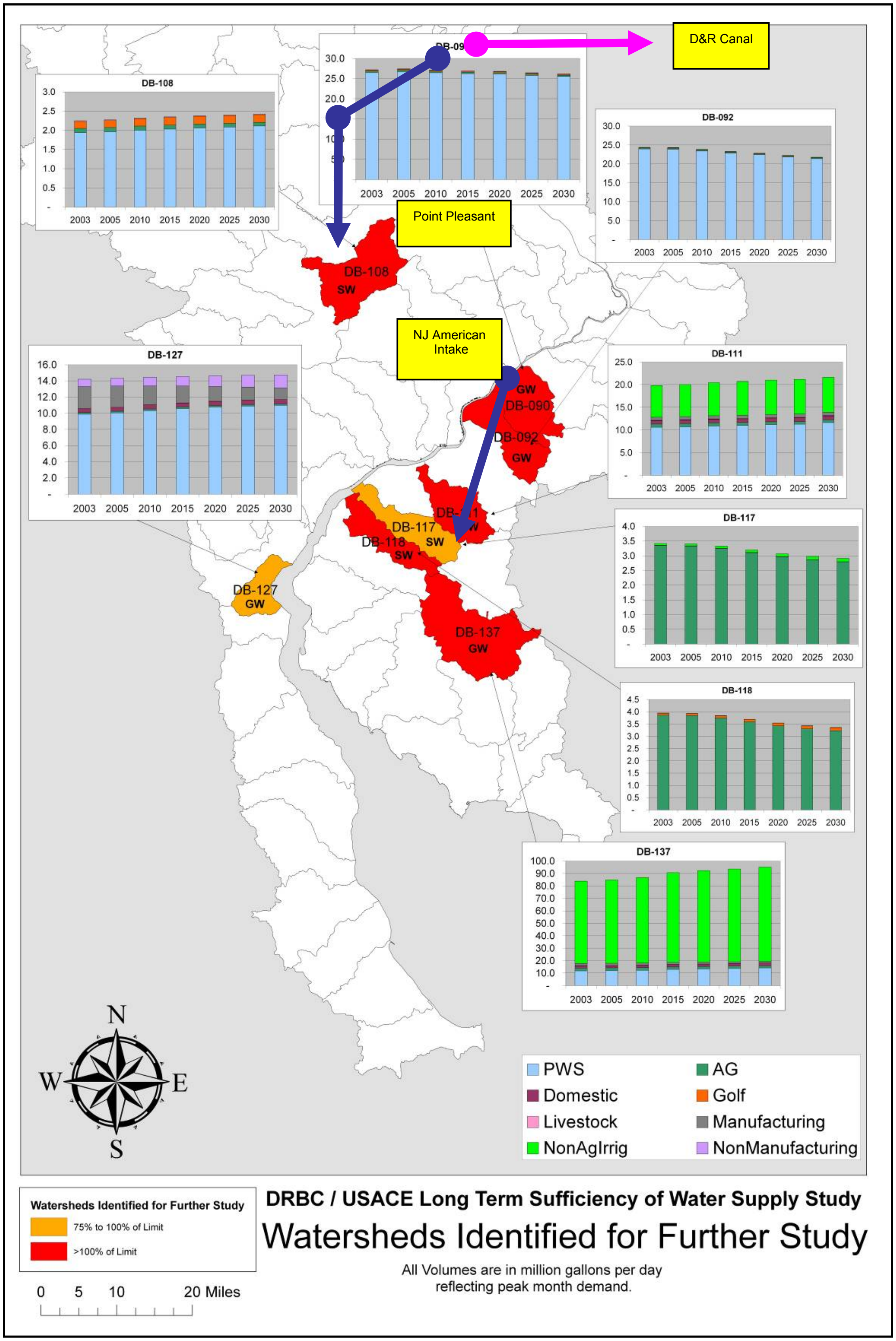


Figure 2.37: Delaware River Diversions Utilized in Analysis

Table 2.25 summarizes a drought sensitivity analysis for the Delaware River. Four parameters were reduced by 50% for this analysis. They were the $Q_7$10 in the Delaware River, the $Q_7$10 in the previously identified surface water deficient watersheds in New Jersey and Pennsylvania, the 25-year baseflow for the previously identified ground water deficient watersheds in New Jersey, and the $Q_7$10 in the Schuylkill River. The consumptive uses and withdrawal quantities were kept at projected 2030 levels for this analysis. Decreasing all of these parameters, increased the total deficit to be met by the Delaware River from 213 mgd to 292 mgd. As the table shows, the increased deficit did not increase the number of downstream withdrawal points on the Delaware as being deficient. Only two points were identified as being deficient, and they were the same two points identified previously in Table 2.21 from the power sector. The magnitude of the deficiency at the two withdrawal points increased from 1337 mgd to 1463 mgd.

Technical Appendix A has additional drought sensitivity analysis tables for the Delaware River that incorporate meeting the needs of the watersheds identified for further study with Delaware River water.

2.4.1.7 Reservoir Storage in the Delaware River Basin. The analysis showed no additional reservoir storage was necessary for water supply needs. However, 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 Mod. The analysis conducted for this report did not show a need for flow augmentation from FE Walter for water supply, but it should be noted that several factors were not considered in the analysis. First, the analysis was based upon $Q_7$10 and not the drought of the record from the 1960s. $Q_7$10 flows are higher than the flows experienced during the 1960s 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. An examination of FE Walter Mod should be done in this comprehensive basin-wide drought analysis. Also, not conducted as part of this analysis was a drought sensitivity analysis of the other 139 watersheds that were not identified as requiring further study for the year 2030. The analysis was restricted to the eight watersheds identified as being deficient using projections out to the year 2030, and only examined reducing water availability in those eight identified watersheds in the lower portion of the Basin. It would be reasonable to expect that by reducing $Q_7$10 and the 25-yr 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 Mod could be a possible solution to meet those deficits.

Table 2.24
Delaware River Water Supply Conditions in 2030 with Watersheds Identified for Further Study Incorporated

Map ID (1)	Water Use Type (2)	Natural $Q_7 10$ for Year 2030 (mgd) (3)	Adjusted $Q_7 10$ Based Upon Watershed Demands for Year 2030 (mgd) (4)	Projected Cumul. Consumptive Use Above Withdrawal Point Year 2030 (mgd) (5)	Projected Withdrawal at Point Year 2030 (mgd) (6)	Adjacent Watershed Needs for Year 2030 (mgd) (7)	Cumulative Adjacent Watershed Needs for Year 2030 (mgd) (8)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd) (9)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd) (10)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd) (11)
40	GOLF	929.45	929.45	0.00	0.44	0.00	0.00	0.05	0.00	0.00
BRODHEAD CREEK										
3	PWR	1058.36	1058.36	0.39	614.71	0.00	0.00	58.10	0.00	0.00
80	MANUF	1061.85	1061.85	2.97	1.45	0.00	0.00	0.14	0.00	0.00
5	PWR	1104.96	1104.96	3.41	0.00	0.00	0.00	0.00	0.00	0.00
6	PWR	1104.96	1104.96	3.41	15.00	0.00	0.00	1.36	0.00	0.00
23	PWR	1104.96	1104.96	7.39	2.04	0.00	0.00	0.19	0.00	0.00
83	RES. INTAKE	1104.96	1104.96	8.24	0.00	0.00	0.00	0.00	0.00	0.00
41	PWS	1126.12	1126.12	8.24	7.84	0.00	0.00	0.70	0.00	0.00
75	MANUF	1552.17	1552.17	13.39	0.00	0.00	0.00	0.00	0.00	0.00
72	PWR	1552.17	1552.17	13.39	3.11	0.00	0.00	0.20	0.00	0.00
90	AG	1552.17	1552.17	13.96	0.00	0.00	0.00	0.00	0.00	0.00
91	AG	1552.17	1552.17	13.96	0.00	0.00	0.00	0.00	0.00	0.00
34	PWS	1600.56	1419.86	13.96	18.80	0.00	0.00	1.34	0.00	0.00
DEMAND: WATERSHED DB-108 = 1.7 mgd DEMAND: SCHUYLKILL (D/S of Perkiomen) = 100 mgd DEMAND TOTAL = 101.7 mgd UTILIZING PT PLEASANT PUMPING INTAKE NODE #46										

Table 2.24
Delaware River Water Supply Conditions in 2030 with Watersheds Identified for Further Study Incorporated (Continued)

Map ID (1)	Water Use Type (2)	Natural $Q_7 10$ for Year 2030 (mgd) (3)	Adjusted $Q_7 10$ Based Upon Watershed Demands for Year 2030 (mgd) (4)	Projected Cumul. Consumptive Use Above Withdrawal Point Year 2030 (mgd) (5)	Projected Withdrawal at Point Year 2030 (mgd) (6)	Adjacent Watershed Needs for Year 2030 (mgd) (7)	Cumulative Adjacent Watershed Needs for Year 2030 (mgd) (8)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd) (9)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd) (10)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd) (11)
46	PWS	1600.56	1498.86	15.84	24.80	101.70	101.70	1.67	0.00	0.00
DELAWARE & RARITAN CANAL - NODE 82 WITHDRAWAL										
82	PWS	1601.23	1499.53	18.32	100.96	0.00	101.70	6.82	0.00	0.00
42	PWS	1622.61	1520.91	119.28	0.01	0.00	101.70	0.00	0.00	0.00
88	PWS	1644.14	1542.44	119.29	29.69	0.00	101.70	2.09	0.00	0.00
36	PWS	1644.14	1542.44	119.29	3.18	0.00	101.70	0.22	0.00	0.00
USGS GAGE AT TRENTON										
35	PWS	1644.19	1542.49	122.25	3.00	0.00	101.70	0.21	0.00	0.00
ASSUNIPINK CREEK										
1	**PWR**	**1673.60**	**1571.90**	**122.55**	**1364.69**	**0.00**	**101.70**	**94.16**	**379.34**	**0.00**
22	PWR	1714.56	1612.86	130.34	4.30	0.00	101.70	0.29	0.00	0.00
44	COMM	1714.56	1612.86	131.88	43.50	0.00	101.70	2.94	0.00	0.00
14	PWR	1714.76	1613.06	136.23	95.87	0.00	101.70	6.49	0.00	0.00
38	PWS	1714.76	1613.06	137.55	7.93	0.00	101.70	0.54	0.00	0.00
37	PWS	1730.58	1628.88	138.34	5.95	0.00	101.70	0.40	0.00	0.00
87	PWS	1730.59	1628.89	138.93	0.00	0.00	101.70	0.00	0.00	0.00
33	MANUF	1731.40	1629.70	138.93	0.40	0.00	101.70	0.03	0.00	0.00
86	PWS	1743.48	1641.78	138.97	2.18	0.00	101.70	0.15	0.00	0.00

Table 2.24
Delaware River Water Supply Conditions in 2030 with Watersheds Identified for Further Study Incorporated (Continued)

ASSUMPINK CREEK CONTINUED										
73	PWR	1744.42	1642.72	139.19	0.00	0.00	101.70	0.00	0.00	0.00
NESHAMINY CREEK										
39	PWS	1891.44	1789.74	139.19	140.83	0.00	101.70	8.53	0.00	0.00
DEMAND: WATERSHED DB-90 (GW) = 13.9 mgd **DEMAND: WATERSHED DB-92 (GW) = 8.2 mgd** **DEMAND: WATERSHED DB-111 (GW) = 10.1 mgd** **DEMAND: WATERSHED DB-137 (GW) = 77.1 mgd** **DEMAND: WATERSHED DB-117 (SW) = 0.4 mgd**										
DEMAND: WATERSHED DB-118 (SW) = 1.3 mgd										
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
DEMAND TOTAL = 111 mgd **UTILIZING AMERICAN WATER CO'S TRI-COUNTY WATER** **SUPPLY PIPELINE INTAKE NODE #89)**										
89	PWS	1893.41	1680.71	153.27	18.07	111.00	212.70	1.18	0.00	0.00
45	MANUF	1911.60	1698.90	155.08	0.77	0.00	212.70	0.05	0.00	0.00
84	MANUF	1921.94	1709.24	155.08	0.16	0.00	212.70	0.01	0.00	0.00
30	MANUF	1921.94	1709.24	155.10	10.28	0.00	212.70	0.66	0.00	0.00
74	MINING	1931.18	1718.48	156.13	0.00	0.00	212.70	0.00	0.00	0.00
8	PWR	1933.25	1720.55	156.13	0.00	0.00	212.70	0.00	0.00	0.00
18	PWR	1951.40	1738.70	156.13	30.89	0.00	212.70	1.95	0.00	0.00
77	MANUF	1951.41	1738.71	156.29	0.00	0.00	212.70	0.00	0.00	0.00
78	MANUF	1951.42	1738.72	156.29	0.00	0.00	212.70	0.00	0.00	0.00
79	MANUF	1951.42	1738.72	156.29	0.00	0.00	212.70	0.00	0.00	0.00
SCHUYLKILL RIVER										
TOTALS				**156.29**	**2550.83**	**212.70**	**212.70**		**379.34**	**0.00**

Notes:
Column (4) = Column (3) – Column (8)
Column (8) taken from Table 5 for Lower Schuylkill and Table 7 for PA & NJ Watersheds Identified for Further Study

Table 2.25: 50% Reductions in Available Water for Delaware River with Watersheds Identified for Further Study Incorporated

Map ID (1)	Water Use Type (2)	Natural $Q_7$10 for Year 2030 (mgd) (3)	Adjusted $Q_7$10 Based Upon Watershed Demands for Year 2030 (mgd) (4)	Projected Cumul. Consumptive Use Above Withdrawal Point Year 2030 (mgd) (5)	Projected Withdrawal at Point Year 2030 (mgd) (6)	Adjacent Watershed Needs Under 50% Reduction of Avail. Water (mgd) (7)	Cumulative Adjacent Watershed Needs (mgd) (8)	Withdrawal as Percentage of Natural $Q_7$10 (mgd) (9)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd) (10)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd) (11)
40	GOLF	489.18	489.18	0.00	0.44	0.00	0.00	0.09	0.00	0.00
BRODHEAD CREEK										
3	**PWR**	**557.03**	**557.03**	**0.39**	**614.71**	**0.00**	**0.00**	**110.43**	**267.07**	**0.00**
80	MANUF	558.87	558.87	2.97	1.45	0.00	0.00	0.26	0.00	0.00
5	PWR	581.56	581.56	3.41	0.00	0.00	0.00	0.00	0.00	0.00
6	PWR	581.56	581.56	3.41	15.00	0.00	0.00	2.59	0.00	0.00
23	PWR	581.56	581.56	7.39	2.04	0.00	0.00	0.36	0.00	0.00
83	RES. INTAKE	581.56	581.56	8.24	0.00	0.00	0.00	0.00	0.00	0.00
41	PWS	592.70	592.70	8.24	7.84	0.00	0.00	1.34	0.00	0.00
75	MANUF	816.93	816.93	13.39	0.00	0.00	0.00	0.00	0.00	0.00
72	PWR	816.93	816.93	13.39	3.11	0.00	0.00	0.39	0.00	0.00
90	AG	816.93	816.93	13.96	0.00	0.00	0.00	0.00	0.00	0.00
91	AG	816.93	816.93	13.96	0.00	0.00	0.00	0.00	0.00	0.00
34	PWS	842.40	661.70	13.96	18.80	0.00	0.00	2.90	0.00	0.00
DEMAND: WATERSHED DB-108 = 2.4 mgd DEMAND: SCHUYLKILL (D/S of Perkiomen) = 123.4 mgd DEMAND TOTAL = 126 mgd UTILIZING PT PLEASANT PUMPING INTAKE NODE #46										
46	PWS	842.40	716.40	15.84	24.80	126.00	126.00	3.54	0.00	0.00

Map ID	Water Use Type	Natural $Q_7 10$ for Year 2030 (mgd)	Adjusted $Q_7 10$ Based Upon Watershed Demands for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point Year 2030 (mgd)	Projected Withdrawal at Point Year 2030 (mgd)	Adjacent Watershed Needs Under 50% Reduction of Avail. Water (mgd)	Cumulative Adjacent Watershed Needs (mgd)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
DELAWARE & RARITAN CANAL - NODE 82 WITHDRAWAL										
82	PWS	842.75	716.75	18.32	100.96	0.00	126.00	14.46	0.00	0.00
42	PWS	854.01	728.01	119.28	0.01	0.00	126.00	0.00	0.00	0.00
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
88	PWS	865.33	739.33	119.29	29.69	0.00	126.00	4.79	0.00	0.00
36	PWS	865.33	739.33	119.29	3.18	0.00	126.00	0.51	0.00	0.00
USGS GAGE AT TRENTON										
35	PWS	865.36	739.36	122.25	3.00	0.00	126.00	0.49	0.00	0.00
ASSUNIPINK CREEK										
1	**PWR**	**880.84**	**754.84**	**122.55**	**1364.69**	**0.00**	**126.00**	**215.83**	**1196.40**	**0.00**
22	PWR	902.40	776.40	130.34	4.30	0.00	126.00	0.67	0.00	0.00
44	COMM	902.40	776.40	131.88	43.50	0.00	126.00	6.75	0.00	0.00
14	PWR	902.51	776.51	136.23	95.87	0.00	126.00	14.97	0.00	0.00
38	PWS	902.51	776.51	137.55	7.93	0.00	126.00	1.24	0.00	0.00
37	PWS	910.83	784.83	138.34	5.95	0.00	126.00	0.92	0.00	0.00
87	PWS	910.84	784.84	138.93	0.00	0.00	126.00	0.00	0.00	0.00
33	MANUF	911.26	785.26	138.93	0.40	0.00	126.00	0.06	0.00	0.00
86	PWS	917.62	791.62	138.97	2.18	0.00	126.00	0.33	0.00	0.00
73	PWR	918.11	792.11	139.19	0.00	0.00	126.00	0.00	0.00	0.00
NESHAMINY CREEK										
39	PWS	995.49	869.49	139.19	140.83	0.00	126.00	19.28	0.00	0.00
DEMAND: WATERSHED DB-90 (GW) = 23.9 mgd										
DEMAND: WATERSHED DB-92 (GW) = 17.3 mgd										

Map ID	Water Use Type	Natural $Q_7 10$ for Year 2030 (mgd)	Adjusted $Q_7 10$ Based Upon Watershed Demands for Year 2030 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point Year 2030 (mgd)	Projected Withdrawal at Point Year 2030 (mgd)	Adjacent Watershed Needs Under 50% Reduction of Avail. Water (mgd)	Cumulative Adjacent Watershed Needs (mgd)	Withdrawal as Percentage of Natural $Q_7 10$ (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
DEMAND: WATERSHED DB-111 (GW) = 19.0 mgd DEMAND: WATERSHED DB-137 (GW) = 100.7 mgd DEMAND: WATERSHED DB-117 (SW) = 2.1 mgd										
DEMAND: WATERSHED DB-118 (SW) = 2.8 mgd										
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
DEMAND TOTAL = 166 mgd UTILIZING AMERICAN WATER CO'S TRI-COUNTY WATER SUPPLY PIPELINE INTAKE NODE #89)										
89	PWS	996.53	704.53	153.27	18.07	166.00	292.00	3.28	0.00	0.00
45	MANUF	1006.10	714.10	155.08	0.77	0.00	292.00	0.14	0.00	0.00
84	MANUF	1011.55	719.55	155.08	0.16	0.00	292.00	0.03	0.00	0.00
30	MANUF	1011.55	719.55	155.10	10.28	0.00	292.00	1.82	0.00	0.00
74	MINING	1016.41	724.41	156.13	0.00	0.00	292.00	0.00	0.00	0.00
8	PWR	1017.50	725.50	156.13	0.00	0.00	292.00	0.00	0.00	0.00
18	PWR	1027.05	735.05	156.13	30.89	0.00	292.00	5.34	0.00	0.00
77	MANUF	1027.06	735.06	156.29	0.00	0.00	292.00	0.00	0.00	0.00
78	MANUF	1027.07	735.07	156.29	0.00	0.00	292.00	0.00	0.00	0.00
79	MANUF	1027.07	735.07	156.29	0.00	0.00	292.00	0.00	0.00	0.00
SCHUYLKILL RIVER										
TOTALS				**156.29**	**2550.83**	**292.00**	**292.00**		**1463.47**	**0.00**

Notes:
Column (4) = Column (3) – Column (8)
Column (8) taken from Table 11 for Lower Schuylkill and Table 7 for PA & NJ Watersheds Identified for Further Study

2.4.1.8 Reservoir Storage in the Schuylkill River Basin

A review of reservoir projects proposed in H.D. 522 was done in order to identify potential water source projects that could alleviate the water deficits calculated for the drought sensitivity analysis (Table 11) for the Schuylkill River Basin. H.D. 522 screened 193 potential major dam sites that would satisfy widespread needs for water supply, flood control, recreation, and hydropower. Nineteen major dam projects were selected based upon several screening levels that were done that took into account factors such as worthiness of the project to satisfy multiple needs (flood control, water supply, and recreation) balanced against the cost estimate of the project.

H.D. 522 also screened 386 small dam sites to address uneven stream flows at a local problem reaches in the intermediate upstream areas. These small dam sites were restricted to drainage areas of no more than 20 square miles. Successive screenings of these sites brought the total down to 39 that were recommended in the final plan. These projects were earmarked for local flood control primarily and for recreation, and water supply to the extent warranted by local needs and interest.

The 1984 Delaware River Basin Study conducted by the Corps re-evaluated previously identified sites. Sites from H.D. 522, Madigan-Praeger Report, TAMS Reports, the Basin Electric Utility group (DRBEUG), the DRBC, and the Level "B" Study were compiled. Criteria was established that eliminated all the sites except for Aquashicola in the Lehigh River Basin and Cherry Creek on the Delaware River. The criteria follows:

1. Projects had to be located above Trenton NJ.
2. Projects had to have a minimum 20,000 ac-ft of storage for flood control and a minimum uncontrolled drainage area of 50 sq. miles.
3. Projects could not be located on Federal or State designated scenic rivers, protected areas, nor on the main-stem
4. Projects which were part of the Level "B" Plan and are designated for water supply were considered unavailable to provide protection.
5. Projects could not require extensive relocation of major roads railways or structures.
6. Projects in environmentally and socially sensitive areas would reinforce other negative findings.
7. Projects could not be economically feasible as a single purpose flood control project if they were infeasible as a flood control component of a multipurpose project.

Applying the criteria from the 1984 Report eliminated all sites below Trenton, NJ which includes the entire Schuylkill River Basin. The 1984 Report also evaluated all the projects based primarily on flood control and did not consider in its conclusions projects for water supply. It is for this reason that H.D. 522 was utilized as the basis for identifying potential water supply projects.

Three reservoir projects were identified from H.D 522 for the Schuylkill River Basin as potential projects to consider for water supply flow augmentation in this analysis. They were 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. Locations of these reservoirs as examined in H.D. 522 are shown in Figure 2.38. In addition to these three reservoirs, modifying the existing Blue Marsh Reservoir was considered for water supply flow augmentation for the drought sensitivity analysis.

These three reservoirs along with modification of Blue Marsh Reservoir should be considered only as a few of many possible solutions to the water deficiency issues identified on the Schuylkill. Many structural and non-structural solutions exist within the Schuylkill Basin that were beyond the scope of this analysis and therefore not examined. The review of H.D. 522 and the subsequent inclusion of Maiden Creek, French Creek, Evansburg Reservoirs along with modification of Blue Marsh into the river analysis by no means should be interpreted as the only solutions to the water supply issues identified in this report. The intent of this analysis was to identify some potential water supply issues and to examine some possible solutions to them. A further detailed investigation should be done to identify the specific magnitude of the water supply issues and applicability of these reservoir projects along with others. Other structural and non-structural projects should be part of the detailed investigation as well.

As previously stated in the report, the deficiencies attributable to the power sector in year 2030 were not incorporated into the solution provided by these three reservoirs. The three reservoirs embedded into the analysis were only used to alleviate the deficits attributable to all other sectors besides power. Since the 2030 analysis showed (Table 2.16) no deficits attributable to sectors other than power, these reservoirs were incorporated into the drought sensitivity analysis for the Schuylkill River. The following sections describing Maiden Creek, French Creek, and Evansburg were taken from H.D. 522.

2.4.1.8.1 Maiden Creek. The Maiden Creek Project was originally proposed for multiple-purpose development to provide supplies of water, flood control and recreation. The Maiden Creek dam site is located on Maiden Creek about 1/3 mile upstream from the mouth of Moselem Creek and about 12 miles north of Reading, PA. The drainage area above this site is 161 square miles. The original dam design as stated in H.D. 522 was 2,600 feet long and rising 110 feet above the bed of Maiden Creek. It would be of earth and rock fill construction. It was also reported that the spillway would be 71.0 feet wide and would be cut through a rock ridge about 400 feet east of the dam. Storage allocations for the Maiden Creek Project as indicated in H.D. 522, were 2,000 acre-feet of inactive long-term storage to elevation 323 ft.; 74,000 acre-feet of active long-term storage for supplies of water and recreation to elevation 381 ft.; and 38,000 acre-feet of short-term storage for flood control to elevation 394 ft. It was proposed that the reservoir would extend about 10 miles up Maiden Creek and relocation of a railroad line, numerous roads, and the communities of Lenhartsville, Virginville and a part of Moselem would be required according to H.D. 522. An updated site investigation was not done as part of this analysis. It was also reported in H.D. 522 that a total of 8,450 acres of land would have to be acquired for the complete development. It was also reported that in addition to the 2,850 acres required for the construction of the project, 2,255 acres would be required for directly related recreation and 3,345 acres for indirectly related recreation. H.D 522 documented that the use of

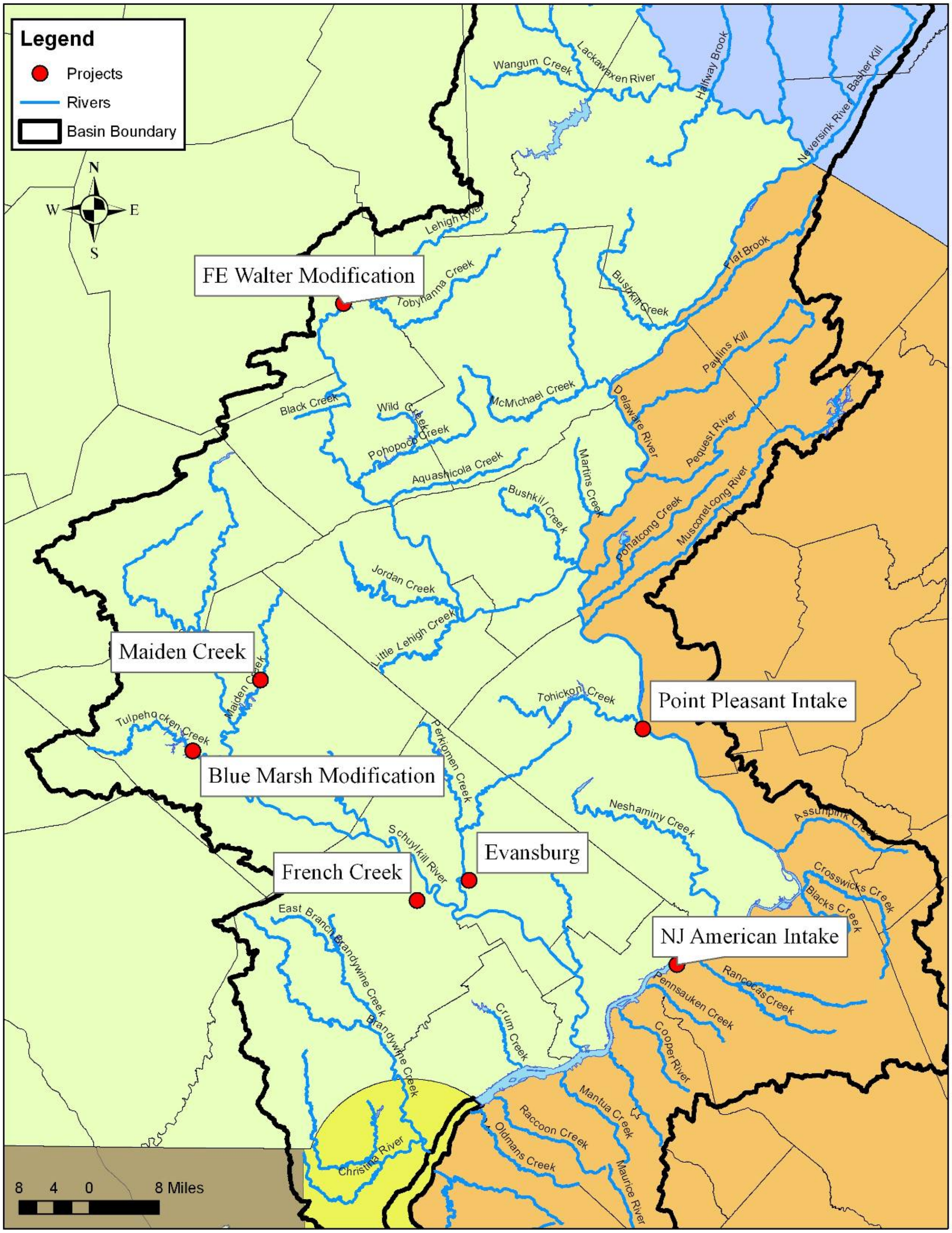


Figure 2.38: Location of Projects

the 74,000 acre-feet of active long-term storage at Maiden Creek Project would provide a net yield of 134 cfs (87 MGD). The report also foresaw that flow augmentation from Maiden Creek would contribute to the satisfaction of the needs of the Pottstown-Reading area as well as to the Philadelphia area.

2.4.1.8.2 French Creek. The French Creek Project as described in H.D. 522 was to be fully developed in two stages and would be a multiple-purpose project to provide supplies of water and recreation. The project site is located about 9.5 miles above the mouth of French Creek and 8 miles west of Phoenixville, Pennsylvania. The drainage area upstream from the dam site is 47 square miles. It was reported that the suggested storage allocations for ultimate development was 1,300 acre- feet of inactive long-term storage to elevation 240 and 25,700 acre-feet of active long-term storage for supplies of water and recreation to elevation 289. H.D. 522 also stated that the reservoir at elevation 289 would extend 8 miles upstream from the dam and provide a reservoir area of 1,250 acres. Total lands, including the eventual reservoir area desirable for the initial stage of development would include 4,270 acres. When fully developed French Creek the 25,700 acre-feet of active long-term storage in the French Creek Project would provide a net yield of 33 cfs (21 MGD).

2.4.1.8.3 Evansburg. The Evansburg Project was projected to be developed in two stages and would be a multiple-purpose project to provide supplies of water and recreation. The project site is located on Skippack Creek about a mile above its confluence with Perkiomen Creek and about two miles southeast of Collegeville, Pennsylvania. The drainage area above the dam site is 54 square miles. H.D. 522 reported that the suggested storage allocations for ultimate development were 1,500 acre-feet of inactive long-term storage to elevation 125 and 23,500 acre-feet of active long-term storage for supplies of water and recreation to elevation 166. The reservoir at elevation 166 would extend about eight miles upstream from the dam and provide a reservoir area of 1,120 acres. It was also reported that the total lands, including the eventual reservoir area would be 4,654 acres. When fully developed, use of the 23,500 acre-feet of active long-term storage in the Evansburg Project would provide a net yield of 36 cfs (23 MGD). The old study also foresaw that flow augmentation from Evansburg would contribute to the satisfaction of the water needs after the year 2010.

The 120 day average yield was used for each potential reservoir: The yield value is defined as the sustained constant draft which completely utilizes all of the active long-term storage in a drought similar to the 1930s. Values were taken directly from H.D. 522 (see previous section) Table M-31a except for Blue Marsh Mod which was not considered at the time and with one minor adjustment to the other reservoirs. The adjustment was a 5% reduction in the yield values in order to account for climate variability as previously mentioned in this report. All yield values used are shown below:

Table 2.26
Reservoir Yields

Project	Basin	Mean Monthly Yield in 2003 (mgd)	Projected Mean Monthly Yield in 2030 (mgd)
Maiden Creek	Schuylkill	114	108
Blue Marsh Mod	Schuylkill	71	68
French Creek	Schuylkill	28	26
Evansburg	Schuylkill	30	29
FE Walter Mod	Lehigh	173	164

The 120-day average yield for a modified Blue Marsh project was determined by calculating the necessary quantity of water needed to alleviate deficits from all sectors other than from the power sector for the drought sensitivity analysis that reduced available flows by 50%. It was back-calculated using the storage-elevation curve for Blue Marsh that in order to provide the additional 173 MGD, the pool elevation would have to be raised by 20 feet.

A detailed site investigation as to the practicality of modifying Blue Marsh was not done as part of this analysis. As with the other reservoirs incorporated into this analysis, it is recommended that further investigation be done.

Table 2.27 summarizes the drought sensitivity analysis on the Schuylkill River when available water is reduced by 50% along with the additional storage Maiden Creek, French Creek, and Evansburg could provide to the Basin. Comparing Table 2.27 with Table 2.22 shows that the 139 mgd deficit due to all sectors other than power has been eliminated and the 957 mgd deficit due to the power sector withdrawals has been reduced to 497 mgd. Only one withdrawal point remains in deficit on the Schuylkill River; that is a reduction of seven withdrawal points from the ones identified in Table 2.22. Additional Schuylkill River tables summarizing other percentages used in the drought sensitivity analysis along with the effects of augmenting flow from a modified Blue Marsh Reservoir are shown in Technical Appendix A.

Table 2.27

50% Reductions in Available Water for Schuylkill River with Potential Reservoir Projects Incorporated

Map ID (1)	Water Use Type (2)	50% Reduction in Natural $Q_7 10$ (mgd) (3)	Adjusted $Q_7 10$ (mgd) (4)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd) (5)	Projected Withdrawal at Point for Year 2030 (mgd) (6)	Projected Yield from Potential Projects (mgd) (7)	Withdrawal as Percentage of Adjusted $Q_7 10$ (mgd) (8)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd) (9)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd) (10)
54	AG	30.47	30.47	0.00	0.00	0.00	0.00	0.00	0.00
68	MANUF	30.51	30.51	0.00	0.00	0.00	0.00	0.00	0.00
PROJECT: MAIDEN CREEK (108 mgd Added Flow)									
63	MANUF	46.59	154.59	0.00	0.34	108.00	0.22	0.00	0.00
4	PWR	48.37	156.37	0.03	33.82	108.00	21.63	0.00	0.00
TULPEHOCKEN CREEK									
USGS GAGE AT READING									
67	PWS	76.30	184.30	2.94	4.78	108.00	2.64	0.00	0.00
MANATAWNY CREEK									
USGS GAGE AT POTTSTOWN									
55	MANUF	83.64	191.64	3.42	0.12	108.00	0.06	0.00	0.00
11	PWR	84.99	192.99	3.43	84.41	108.00	44.53	0.00	0.00
64	PWS	86.48	194.48	70.01	2.71	108.00	2.18	0.00	0.00
58	PWS	87.99	195.99	70.28	3.67	108.00	2.92	0.00	0.00
7	**PWR**	**88.01**	**196.01**	**70.65**	**384.20**	**108.00**	**306.47**	**497.46**	**0.00**
PROJECT: FRENCH CREEK (26 mgd Added Flow)									
62	PWS	94.07	228.07	72.76	27.28	134.00	17.56	0.00	0.00
PERKIOMEN CREEK									
PROJECT: EVANSBURG (29 mgd Added Flow)									

Map ID	Water Use Type	50% Reduction in Natural $Q_7$10 (mgd)	Adjusted $Q_7$10 (mgd)	Projected Cumul. Consumptive Use Above Withdrawal Point for Year 2030 (mgd)	Projected Withdrawal at Point for Year 2030 (mgd)	Projected Yield from Potential Projects (mgd)	Withdrawal as Percentage of Adjusted $Q_7$10 (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Power Sector (mgd)	Additional Flow Needed to Lower Utilization Below 75% for Other Sectors (mgd)
60	PWS	128.70	291.70	75.48	11.87	163.00	5.49	0.00	0.00
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
USGS GAGE AT NORRISTOWN									
61	MANUF	129.42	292.42	76.67	0.27	163.00	0.12	0.00	0.00
56	MANUF	136.10	299.10	76.70	6.31	163.00	2.84	0.00	0.00
WISSAHICKON CREEK									
65	PWS	137.29	300.29	76.77	76.09	163.00	34.04	0.00	0.00
66	PWS	137.48	300.48	152.86	49.67	163.00	33.65	0.00	0.00
USGS GAGE AT PHILADELPHIA									
20	PWR	137.97	300.97	202.53	71.28	163.00	72.42	0.00	0.00
69	PWR	137.97	300.97	202.64	11.18	163.00	11.37	0.00	0.00
10	PWR	137.97	300.97	203.36	91.64	163.00	93.88	0.00	0.00
59	MANUF	138.73	301.73	203.66	2.08	163.00	2.12	0.00	0.00
57	MANUF	138.79	301.79	204.25	8.25	163.00	8.46	0.00	0.00
DELAWARE RIVER									
TOTALS				**204.25**	**869.98**			**497.46**	**0.00**

Notes:
Column (4) = Column (3) + Column (7)

2.4.2 Approaches to Curtail Demand

2.4.2.1 Improved Water Accountability with Reduced Infrastructure Losses: The DRBC continues to promote best practice in water conservation and continues to have to implement regulations that reflect current best practice. One such area is in advancing the issue of *Water Accountability* for public water suppliers. The water accountability issue focuses on how water is managed within the distribution system by the water supplier and has a specific focus on minimizing water loss from the distributions system. This provides a different focus from many traditional end-user oriented water conservation programs. It is estimated that 150 million gallons of treated and pressurized water is physically lost from public water supply distribution systems in the Delaware River Basin each day and current methods to account for, track and reduce these losses are inadequate.

Traditionally, this issue has been addressed using the concept of "unaccounted for water"; however, this approach has several flaws, such as a lack of standardized terminology and lack of a rigid water audit structure. A new approach has evolved from within the water industry and has been promoted by the American Water Works Association (AWWA). The Delaware River Basin Commission believes that by requiring water suppliers to implement the new AWWA water audit methodology, the following benefits are likely to be realized:

- utility managers (especially those operating smaller systems) will better understand their systems.
- the use of a more rational water audit structure will help identify water losses and target efforts to improve water supply system efficiency.
- more meaningful performance indicators will help identify systems with the greatest losses.

In addition to the large volume of potential savings that can be made by reducing and minimizing water losses in the distribution system, the fact that the lost water serves no beneficial use provides added incentive to control losses. In contrast to many traditional water conservation programs, savings realized from water loss control will not impact end-users in any way.

The Water Accountability Audit Approach:

The traditional approach of tracking "unaccounted for water" relied on a very simplistic modeling of the distribution system and utilized performance indicators that were not technically robust. The AWWA water audit approach has well-defined terminology and requires system operators to examine the complete spectrum of how water may be lost in the distribution system. The audit approach covers both physical losses of water and also apparent losses which take the form of paper losses and may impact the revenue collected by the water supplier. Examples of apparent losses include meter error, billing error and theft. A schematic representation of the AWWA water audit approach is shown in Figure 2.39.

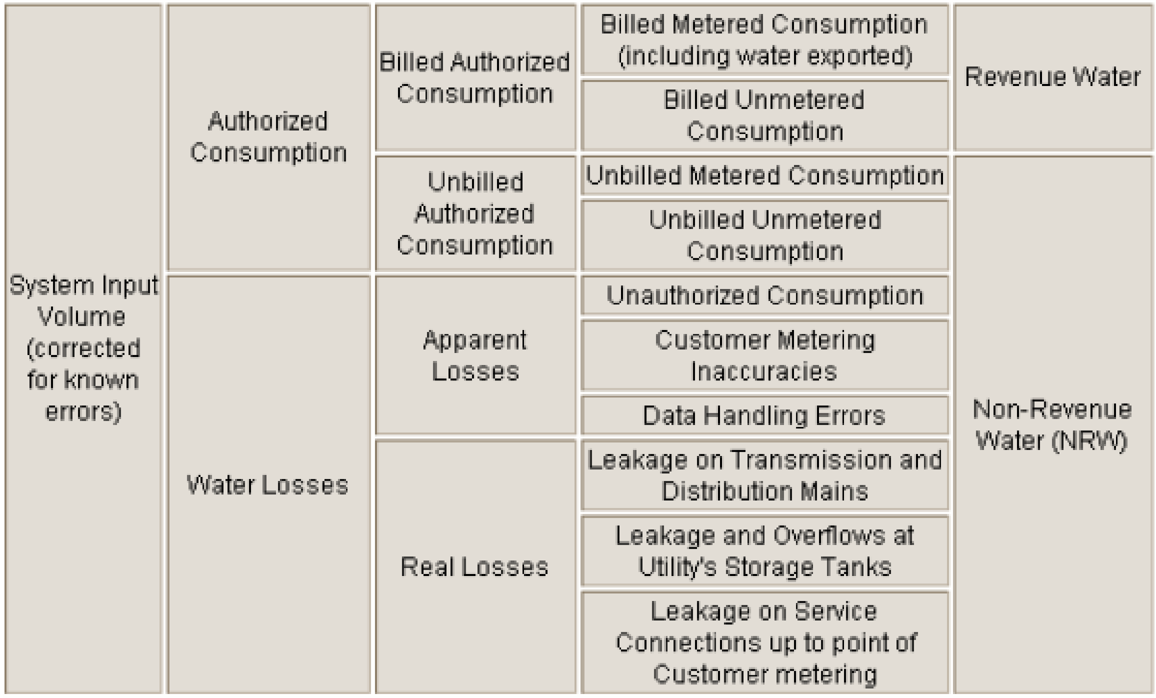


Figure 2.39 AWWA Water Accountability Water Audit Structure

Estimating the potential savings in water demand due to the identification and remediation of water losses is a complex challenge. Traditional measures of water loss indicate that the majority of systems physically lose between 5% and 35% of the water that enters the distribution system; however the accuracy of these estimates is questionable due to the problems identified above with the method of estimation. Older systems are likely to experience the highest losses due to the age of the infrastructure.

Rural systems may also experience high losses due to the greater likelihood of a significant leak going undetected. In general, small systems (<35,000 customers) are also likely to have large losses as many of these systems will not have the resources or expertise on staff to conduct regular water audits and carry out leak detection and repair activities.

In the Delaware River Basin, the largest water purveyor is the Philadelphia Water Department (PWD), with an average daily water demand of approximately 235 million gallons per day (mgd). The PWD system has a history of significant water losses due to aging infrastructure (the system is among the oldest in the U.S.) and a declining population, which means a declining customer base from which to obtain revenue and fund repairs. Recognizing these challenges, the PWD system has been studied extensively and the AWWA water audit approach has been implemented to identify the extent and nature of the water losses throughout the system. Based on 2006 data, estimated physical losses in the distribution system were approximately 60mgd (or 25% of distribution system input). According to the AWWA water audit approach, the unavoidable real losses for the system are approximately 6mgd (this represents less than

3% of system input). This is the level that is technically achievable by applying the best available technology and an aggressive level of leakage control.

An approximation of the reduction that may be possible by addressing water loss issues in the Delaware River Basin can be calculated using data from the PWD example. Although the exact extent of water loss from infrastructure failings in the Basin is unknown a likely range can be estimated. Table 2.28 below shows a range of potential existing levels of water loss and a range of potential target levels of loss, along with the estimated savings achievable by moving from an existing loss level to a target loss level (the intersection of the rows and columns). As an example, if, on average, the existing level of water loss for PWS systems is estimated at 15% and a target of 5% is achievable, then the potential savings are 95.3 million gallons per day. The likely range of savings is highlighted and ranges from 76.3mgd to 143mgd, as a basin-wide total.

Table 2.28
Range of potential savings from addressing water loss issues within PWS

	Target level of losses (as % of system input)			
Current level of losses (as % of system input)	**3%**	**5%**	**7%**	**10%**
10%	66.7	47.7	28.6	0.0
15%	114.4	95.3	76.3	47.7
20%	162.0	143.0	123.9	95.3
25%	209.7	190.6	171.6	143.0

Values of potential savings expressed as million gallons per day (mgd).

Additional water supply alternatives, ranging from conjunctive use practices, aquifer-storage-recovery (ASR), pumping from other water-bearing aquifers, water reclamation and reuse (wastewater, desalination) and mine discharges were evaluated in a literature review and were found not to be viable on a regional scale. However, they may be practical at a local level and should be considered in future water supply studies. However, they should not be considered “new found” water but as water being used at a different location in the water cycle.

2.4.2.2 Additional Conservation: Conservation assumptions were embedded into the water supply analysis presented in this report. The assumptions were based upon projecting current conservation practices into the future for each given sector. Assuming additional water conservation scenarios above and beyond current practices would curtail demand and lower the projected water deficits. Potential impacts of implementing these scenarios should be investigated further as part of a comprehensive drought analysis study for the Basin.

2.4.2.3 Change Water Allocations/New Regulations: Demand could also be curtailed by lowering water allocations given to purveyors along with implementing stricter water supply regulations that protect water sources in critical areas where demand exceeds supply. A comprehensive review of existing long-standing allocations given to purveyors along with current water supply regulations in critical areas within the Basin should be investigated as part of a comprehensive drought analysis study

2.4.2.5 Improved Irrigation Techniques: Drip irrigation is a conservation measure that allows for the slow, even application of low pressure water to soil and plants using plastic tubing placed directly at the plants root zone. A well-designed drip irrigation system loses practically no water to runoff, deep percolation, or evaporation and curtails demand. Drip irrigation reduces water contact with crop leaves, stems, and fruit. In areas of the Basin where water demand is high due to the irrigation sectors, the potential quantifiable benefits in curtailing demand by implementing an improved technique such as drip irrigation should be investigated in further detail for practicability and cost effectiveness.

2.5 CONCLUSIONS AND RECOMMENDATIONS

The findings of the Long Term Sufficiency Study include the following:

Based on the screening processes used in this study to identify watersheds with the greatest likelihood of potential future issues, those with the greatest level of water use relative to water availability, eight watersheds were selected for further investigation (DB-90, DB-92, DB-108, DB-111, DB-117, DB-118, DB-127 and DB-137). Many of these watersheds are located within two previously identified special management areas; the Southeastern Pennsylvania Ground Water Protected Area (GWPA) and New Jersey's Water Supply Critical Area 2.

For those watersheds selected for further investigation, a more detailed study of water use should be performed in conjunction with the relevant state agency and local watershed partners. A more detailed analysis would include verification of water use, tracking water imports and exports across watershed boundaries and the effects of any mitigation efforts (reservoir releases, pass-by flow requirements) that were not modeled in this Basin-wide effort. A better understanding of agricultural water demand is also needed in order to plan and manage water resources to accommodate all demands.

An assessment of water availability was performed for surface water intakes on the Delaware, Schuylkill and Lehigh rivers. The analysis concluded that, based on 2003 water demand, water availability under low flow conditions was adequate in most locations. In the base year, only one location, a power generation facility on the Schuylkill River, was identified as having a potential supply deficit. Based on projected water use for the year 2030, additional water demands for power generation may add further stress to the Schuylkill River and could potentially create stress in other parts of the Basin. A study of the potential growth in water demand for the thermoelectric sector is recommended due to the impact that a large power generating facility may have on the Basin's water resources.

An assessment of additional storage in the Schuylkill River Basin should also be evaluated further, particularly for drought conditions.

3.0 FLOOD RISK MANAGEMENT

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. Most recently, 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. 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 3.1 Lambertville-New Hope Bridge

Figure 3.2 Lambertville

Due to the sudden onslaught of storm events in the past three 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 include 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 and (5) potential solution matrix for priority communities. The data collected 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, Livingston Manor Feasibility Study. The updated stage frequency curves and skew analysis will also be used by the Corps and USGS for future studies.

3.1 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 together to update the discharge-frequency analysis for eight gaging stations on the Delaware River. These stations are identified in Table 3.1.

Table 3.1
Updated Delaware River Gaging Stations

USGS Station Number	Station name	Drainage area, (mi^2)	Period of record, in water years[1]
01427410	Delaware River near Callicoon, N.Y.[2]	1,708	1968-1975
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
01462000	Delaware River at Lambertville, N.J.[3]	6,680	1898-1907
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.

Procedures prescribed from both the Water Resources Council “Guidelines for Determining Flood Flow Frequency” (commonly referred as Bulletin 17B) and EM 1110-2-1415, “Hydrologic Frequency Analysis” were used to calculate the frequency discharges. The computer program HEC-SSP was used for the flood frequency analysis on both regulated and unregulated annual peak discharges at each of the gage locations.

The USGS and Corps agreed to use the station skew in the analysis for all gages rather than a generalized skew because the drainage areas to these gages are large, the regional skew coefficients previously developed for the Basin were outdated, and the fact that the period of record on most of the gages was greater than 50 years.

However, 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 were completed for a discharge-frequency analysis both at gages sites and at ungaged sites.

As previously mentioned, the one notable difference with the Corps' and USGS' analysis procedures was how the Corps accounted for upstream regulation at the gage locations. Numerous reservoirs exist within the Delaware River Basin which have affected peak flows since the early 1900s down to the city of Trenton.

The procedure used for determining the effects of reservoirs on downstream discharge-frequencies is to adjust the frequency curve so as to reflect the reduction of peak flows due to operation of the reservoirs. Prior to calculating frequencies, the effects of the reservoirs on the downstream annual peak discharges have to be quantified in an analysis and the discharges need to be converted from regulated to unregulated conditions. The frequency analysis is done on the unregulated peak discharges and then re-adjusted from unregulated to regulated conditions.

Three rainfall-runoff hydraulic models previously developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC) for the calculation of the Standard Project Flood (SPF) for the Delaware River Basin were used in this analysis. The three models were divided up by major basins. The Upper Delaware Basin model went from the headwaters to the USGS gage at Montague. The Lower Delaware Basin model went from the Montague to Trenton gage, and the third model was for the Lehigh River Basin. Refer to SPM 82-9 from HEC entitled Standard Project Flood Development, Delaware River Basin for a full description.

The models were modified from their original state to simulate multiple storms, and reservoirs coded in the input files of these three models were removed in order to simulate unregulated or natural flow conditions. The year when storage started was obtained for each reservoir in the model and a new simulation was done as each individual reservoir started to store water. Summaries of the reservoirs used are shown in Table 3.2.

Table 3.2
Reservoirs Simulated in Rainfall-Runoff Models

Reservoir	Model	State	Storage Start Water Year
Hopatcong	Lower Delaware	NJ	1825
Wallenpaupack	Upper Delaware	PA	1926
Rio	Upper Delaware	NY	1926
Toronto	Upper Delaware	NY	1926
Swinging Bridge	Upper Delaware	NY	1930
Neversink	Upper Delaware	NY	1953
Pepacton	Upper Delaware	NY	1954
Wild Creek[1]	Lehigh	PA	1959
Penn Forest[1]	Lehigh	PA	1959
Jadwin	Upper Delaware	PA	1960
Prompton	Upper Delaware	PA	1960
FE Walter	Upper Delaware	PA	1961
Cannonsville	Upper Delaware	NY	1963
Beltzville	Lehigh	PA	1971
Nockamixon	Lower Delaware	PA	1974

[1]Penn Forest & Wild Creek are combined in Models as one reservoir

Simulations were conducted with and without the reservoirs in place in order to develop a relationship between regulated and unregulated annual peak discharges. It was assumed for this analysis that the reservoirs were full at the beginning of each storm. Model results were graphed and a linear regression analysis was done in order to develop a mathematical equation to apply to the regulated annual peak discharges obtained from the USGS.

Results of the regression analysis were compared to the similar regression analysis summarized in the 1984 Report. The comparison showed that the updated analysis agreed very closely with the original analysis done for the 1984 Report. It would be expected that there would be some differences between the regression equations developed between the two analyses because of the longer period of record incorporated in the updated analysis.

As previously mentioned, the computer program HEC-SSP was used to calculate the unregulated frequency-discharge curve. Once this curve was developed at each gage location, the curve was re-adjusted back to a regulated condition. The re-adjusted curve at each gage location for the regulated discharge analysis was compared to the USGS analysis at each gage location. The differences between the Corps and the USGS generally were within five percent of each other and can generally be contributed to the conversion of the regulated annual peaks to an unregulated condition and then readjusted back to a regulated condition at the end. The Corps also did an independent analysis in which upstream regulation was not accounted for. This independent analysis basically followed the USGS' analysis procedures using the same exact annual peak discharges with the only difference between the two being the computer programs used. The USGS used the program PEAKFQ (Flynn and others, 2006) and the Corps used the program HEC-SSP. The results of the Corps' analysis agreed with the USGS' results. Therefore, the minor differences between the two are directly related to the linear regression analysis of converting regulated annual peaks to unregulated annual peaks and not related to the computer program being used. Given the nature of a linear regression analysis and the assumptions that went into the HEC-1 simulations, the five percent difference between the two agencies would be expected.

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, the Commonwealth of Pennsylvania, and New Jersey Highlands Council. The Committee agreed to adopt the proposed flood frequency figures developed by USGS for use in on-going flood insurance studies and Corps' flood studies. The adopted flood frequency is summarized in Table 3.3.

Table 3.4 compares the updated flood frequency against the flood frequencies published in the 1984 COE Report. There are no values for Callicoon from 1984 because the 1984 COE Report did not include Callicoon in its study area. As Table 3.4 shows, the discharges increased for all gages for the 2- to the 50-year events from the previously published values in the 1984 COE Report except for the 50-yr event at Barryville which decreased slightly by 1,000 cfs. Discharges from the 100-yr up to the 500-yr decreased at the Trenton, Riegelsville, and Barryville gages, but increased at the Port Jervis, Montague, and Delaware Water Gap gages. These increased discharges will produce higher damages than those reported in 1984 and will therefore assist in potentially providing greater potential benefits from flood damage reduction efforts.

Table 3.5 summarizes the peak discharges at each gage location associated with historical flood events including the August 1955 flood of record, and the recent events of September 2004, April 2005, and June 2006. Utilizing the updated flood frequency shows that the September 2004 flood ranged from a 20- to 35-year event, the April 2005 flood ranged from a 40- to 70-year event, and the June 2006 flood ranged from a 70- to 100-year event along the Delaware River.

Table 3.3.
Adopted Regulated Discharge Frequency Values for the Delaware River[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 2008-1203.

Table 3.4.
Comparison of Adopted Flood Frequencies Against 1984 Flood Frequencies

USGS Station Number	Station Name	Date of Analysis	Recurrence Interval (cfs)								
			2-year	5-year	10-year	20-year	25-year	50-year	100-year	200-year	500-year
1427510	Callicoon, NY	1984									
		2008	40,100	62,300	78,600		101,000	118,000	137,000		185,000
1428500	Barryville, NY	1984	42,000	62,000	78,000	97,000		125,000	150,000	180,000	230,000
		2008	44,100	67,100	83,600		106,000	124,000	142,000		188,000
1434000	Port Jervis, NY	1984	49,000	71,000	88,000	110,000		140,000	170,000	205,000	270,000
		2008	59,500	91,000	114,000		147,000	173,000	201,000		273,000
1438500	Montague, NJ	1984	53,000	76,000	95,000	118,000		150,000	183,000	220,000	290,000
		2008	65,200	101,000	127,000		164,000	194,000	226,000		308,000
1440200	Del. Water Gap, PA	1984	57,000	83,000	103,000	127,000		165,000	200,000	240,000	310,000
		2008	71,800	110,000	139,000		178,000	210,000	244,000		332,000
1446500	Belvidere, NJ	1984	64,000	94,000	118,000	145,000		190,000	230,000	275,000	350,000
		2008	76,900	116,000	145,000		184,000	215,000	248,000		334,000
1457500	Riegelsville, NJ	1984	73,000	110,000	137,000	175,000		230,000	278,000	330,000	410,000
		2008	92,300	136,000	167,000		208,000	241,000	274,000		358,000
1463500	Trenton, NJ	1984	76,000	117,000	145,000	183,000		238,000	288,000	340,000	420,000
		2008	94,900	138,000	169,000		211,000	245,000	280,000		372,000

Table 3.5
Peak Discharges from Historical and Recent Flood Events on the Delaware River

USGS Station Number	Station Name	Drainage Area (sq. mi)	Oct 1903 (cfs)	Mar 1936 (cfs)	Aug. 1955 (cfs)	Sept. 2004 (cfs)	Apr. 2005 (cfs)	Jun. 2006 (cfs)
1427510	Callicoon, NY	1,820				107,000	112,000	144,000
1428500	Barryville, NY	2,020			130,000	112,000	118,000	151,000
1434000	Port Jervis, NY	3,070	205,000	137,000	233,000	151,000	166,000	180,000
1438500	Montague, NJ	3,480	217,000	164,500	250,000	168,000	206,000	212,000
1440200	Del. Water Gap, PA	3,850			260,000	176,000	215,000	225,000
1446500	Belvidere, NJ	4,535	250,000	179,000	273,000	184,000	226,000	225,000
1457500	Riegelsville, NJ	6,238	275,000	237,000	340,000	216,000	262,000	254,000
1463500	Trenton, NJ	6,780	295,000	227,000	329,000	201,000	242,000	237,000

3.2 SKEW ANALYSIS

As part of this study, the Philadelphia District contracted with the Hydrologic Engineering Center (HEC) to conduct a generalized skew study for the Delaware River Basin. 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.

The following paragraphs were taken from the Executive Summary of the "Delaware River Basin Regional Skew Analysis Report" from HEC. At the present time, the report is still in draft form and is being reviewed by Philadelphia District personnel. Upon final review, the report will be shared with all four USGS District Offices within the Basin and can be provided upon request to other interested parties.

The purpose of the report was to recommend, and describe methods for estimating, regional skew values required by Bulletin 17B to develop frequency curve estimates. As suggested in Bulletin 17B, candidate regional skew estimates are calculated by applying area averaging, isoline mapping, and regression methods to skew estimates from gages within a defined region, and the regional skew estimate with the smallest mean square error (MSE) selected. The District's analysis will include development of frequency curves and flow quantities at a given location. Bulletin 17B states that a weighted skew value should be used in the log-Pearson III frequency distribution fitting parameters used to develop frequency functions of annual peak flows. Weighted skew is computed by weighting regional skew and station (gage) skew values inversely proportional to their mean square errors of estimation.

Regional skew analysis methods use data from independent streamgage sites in a region to estimate regional skew values. Use of multiple streamgage sites approximates an analysis based on a much longer period of record. The approach exchanges space for time, reducing time-based sampling error in the skew estimate, while introducing a lesser spatial sampling error.

The current regional skew values for the Delaware River Basin are considered out of date. HEC originally completed a regional skew study in 1983 entitled "Generalized Skew Study of the Delaware River Basin" (USACE 1983). In the twenty-five years since that study's completion, more annual peak flows have been recorded and the methods for determining regional skew values have been updated. The purpose of this study is to update the regional skew values for the Delaware River Basin.

HEC was tasked with gathering streamgage data for the greater Delaware River Basin, and completing a regional skew analysis using three methods:

- *Method 1: Region area-average skew. (This method was implemented three ways: Method 1a - average skew of the entire basin; Method 1b - average skews of* *homogeneous regions (defined geographically and verified with L-moment analysis); Method 1c – Generalized Least Squares (GLS) consistent regression defined geographically using L-moment analysis.)*

- *Method 2: Skew isoline map.*
- *Method 3: Predictive equations using GLS regression.*

To complete the regional skew study of the Delaware River Basin, HEC did the following tasks:

- *Updated annual peak records for 215 streamgage records. These streamgages were considered in the previous regional skew study of the Delaware River Basin (USACE 1983). This task included collecting streamgage data from 1983 through the 2006 water year and verifying seven watershed parameters: drainage area, ten to eighty-five percent slope, basin length, mean basin elevation, percent lake storage, percent forested area, and mean annual precipitation (MAP).*
- *Gathered annual peak data - recorded through the 2006 water year - for an additional 477 streamgages in and around the Delaware River Basin. These gages were not included in the original 1983 study because they either did not exist at that time, or failed to meet the criteria specified in the 1983 study.*
- *Analyzed these 692 records to ensure data quality and homogeneous records, and eliminated 444 streamgages because of tidal or anthropogenic effects. This was done by noting USGS codes in the peak flow record, and comparing mean, standard deviation, and skew to drainage area for remaining gages. The slope and R^2 values from a linear regression of annual peak flows to water year were also examined.*
- *Calculated sample statistics, including station skew values, for the remaining 248 streamgages considered in this study using Bulletin 17B procedures. Special attention was given to records with historical information, as peaks that are historically weighted can have a significant impact on station statistics.*
- *Narrowed the list to 163 streamgages using the following criteria: absence of anthropogenic effects (regulation, urbanization, and so on); minimum of twenty-five years of systematic record length; the streamgage is located within the Delaware River Basin, or has a majority of its watershed within twenty-five miles of the basin; less than ten percent of the watershed is urbanized; and the gage is absent of tidal effects.*
- *Verified, and in some cased determined, watershed parameters for the 163 streamgages.*
- *Calculated regional average skew and MSE for these 163 streamgages (Method 1a).*
- *Determined eleven plausibly homogeneous regions of average skew using river subbasins (Method 1b and Method 1c). Region heterogeneity and streamgage discordance statistics were calculated to find acceptably homogeneous regions. Computed average and weighted average skew for those regions.*
- *Developed, and calculated MSE for, a regional skew contour map using inverse distance weighting, modified using engineering judgment based on basin physiography and hydrology (Method 2).*
- *Calculated regional skew coefficients and their average prediction errors using a GLS procedure (Method 1c and Method 3). The GLS procedure used gages for which watershed parameters were available.*

HEC used 163 streamgages - 115 of the gages used in the 1983 study and an additional forty-eight gages - in completing this study. Each streamgage has at least twenty-five years of unregulated annual peak flows whose records are considered absent of both tidal and anthropogenic effects per Bulletin 17B guidelines.

Averaging all 163 station skews into a single region resulted in a regional average skew of 0.184, and MSE of 0.142. This Bulletin 17B recommendation for estimating MSE assumes that all gage skew values are perfectly estimated. An estimate of MSE equal to 0.241 was obtained using Monte Carlo simulation to include the sampling error of gage skew estimates (Method 1a).

For the homogeneous regions HEC verified using L-moment analysis (Hosking and Wallis, 1997) the weighted-average skew (weighted by the number of gages in a region) for all gages was 0.181, the MSE was 0.133, and the simulated MSE (including time-sampling error) was 0.232. The weighted-average skew for gages within the Delaware River Basin was 0.221, the MSE was 0.146, and the simulated MSE was 0.251 (Method 1b).

HEC completed a GLS regression of the regions using only a constant, effectively obtaining regional average skew values. The constant provides a direct comparison with the regional average obtained using standard methods outlined above, while also accounting for inter-gage correlation and differences in gage record length. In this approach, average variance of prediction (AVP) is used as a measure of prediction error in place of MSE and simulated MSE. The GLS-consistent region area-average approach results in a weighted-average constant (based on the number of gages in a region) of 0.151, which would be used as the regional skew value. The method has a weighted-average AVP of 0.044 (Method 1c).

A skew isoline map was developed by calculating skew isolines using an inverse distance squared interpolation. The isolines were then modified using engineering judgment based on consideration of region physiography and hydrology. The MSE for this skew isoline map was 0.147 (Method 2).

GLS regression of all gages in the Delaware River Basin resulted in no regression model prediction error, with all error attributed to limited record length. This was felt to be an unreasonable result because no model error implies a perfect regression model prediction if the gage skew values were perfectly estimated i.e., no sampling error. This is unlikely to occur in skew prediction. More significant results were achieved, however, by dividing the basin into northern and southern regions. A regression using only mean elevation identified a regression model error and had an AVP equal to 0.027 for the northern region. A regression using mean annual precipitation resulted in an AVP of 0.019 for the southern region, but no regression model error could be defined (Method 3).

Recommendation

For determining a regional skew for the Delaware River basin, HEC recommends the results of Method 1c (see page 2). This method (based on homogeneous regions verified by L-moment analysis) yields region skew values that average to GLS regression constant of 0.151. This has a corresponding AVP of 0.044. The GLS-consistent method is recommended because:

- *The simplicity of using only a constant and the comparably small AVP makes this method preferable to the GLS regression equations or skew contour map.*
- *The method produces improvements to the recommendations of Bulletin 17B, as presented in this report.*
- *The minimum error of the method, AVP, will promote the greatest consistency in the application of the Bulletin 17B guidelines.*

3.3 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. Table 2.2 lists the basins with their major streams.

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 3.6-3.7 summarize the highest ranked basins for repetitive losses and severely repetitive losses respectively. Figures 3.3-3.4 graphically show the highest ranked basins for each database.

Table 3.6
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 3.7
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

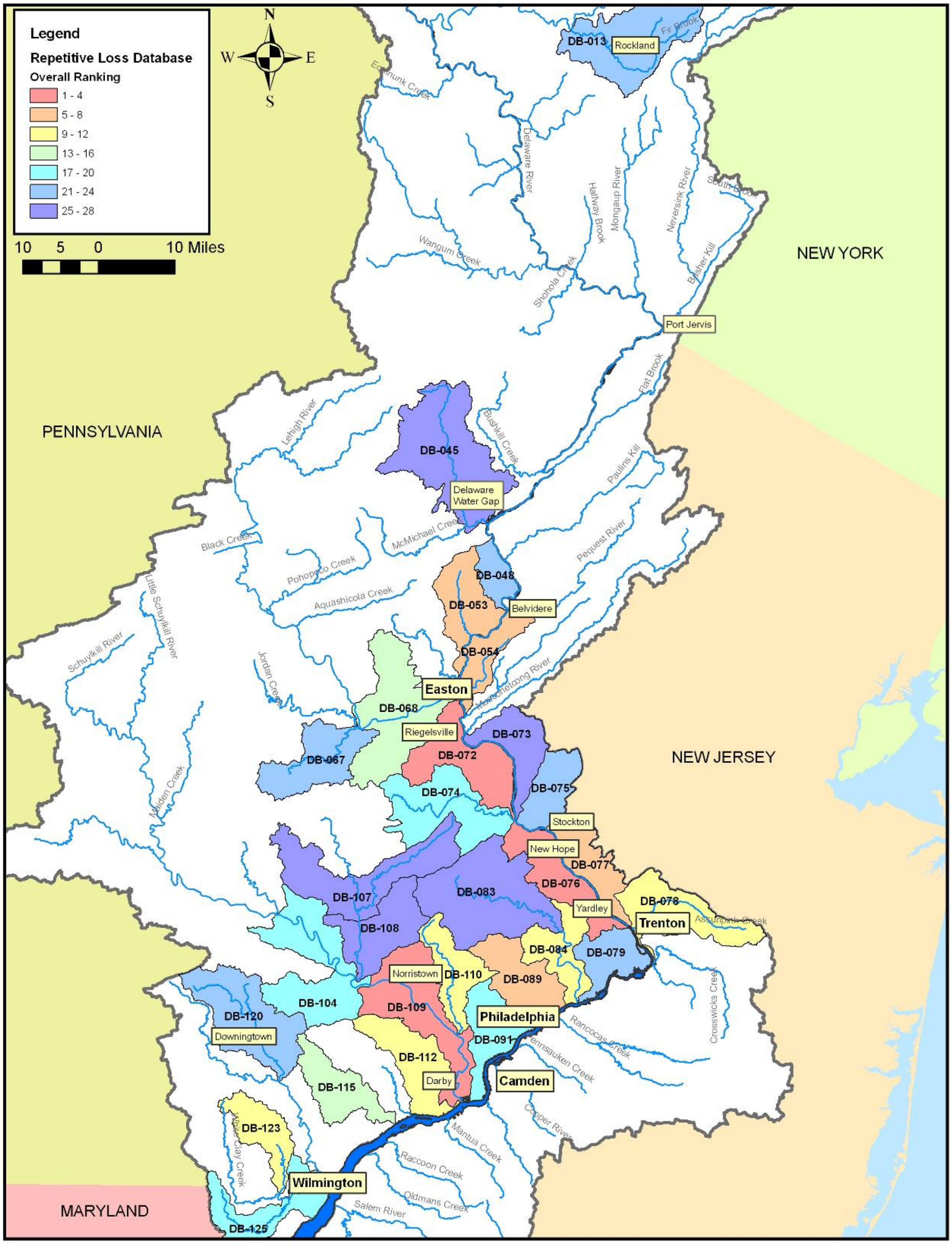


Figure 3.3 Highest Repetitive Loss Rankings by Basin

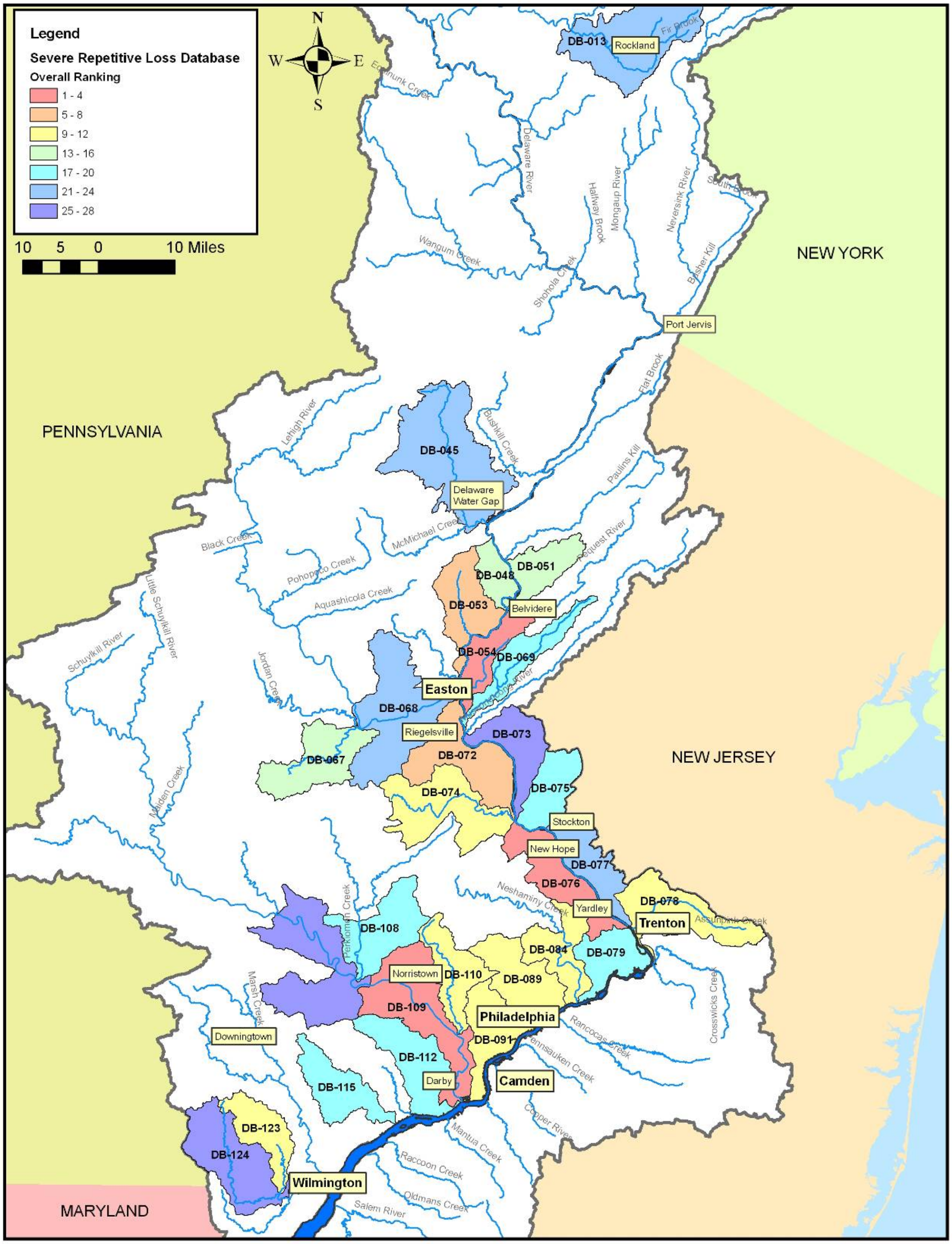


Figure 3.4 Highest Severe Repetitive Loss Rankings by Basin

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 3.8 shows a breakout of the top ten municipalities in the basin with the highest number of designated loss properties.

Table 3.8

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 3.5.

Figure 3.5 Key Flood Prone Areas used for Structure Inventories and Solution Matrix

3.4 STRUCTURE INVENTORY FOR 10 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 for advancing the efforts of three other studies and assisting locals in the evaluation of potential projects.

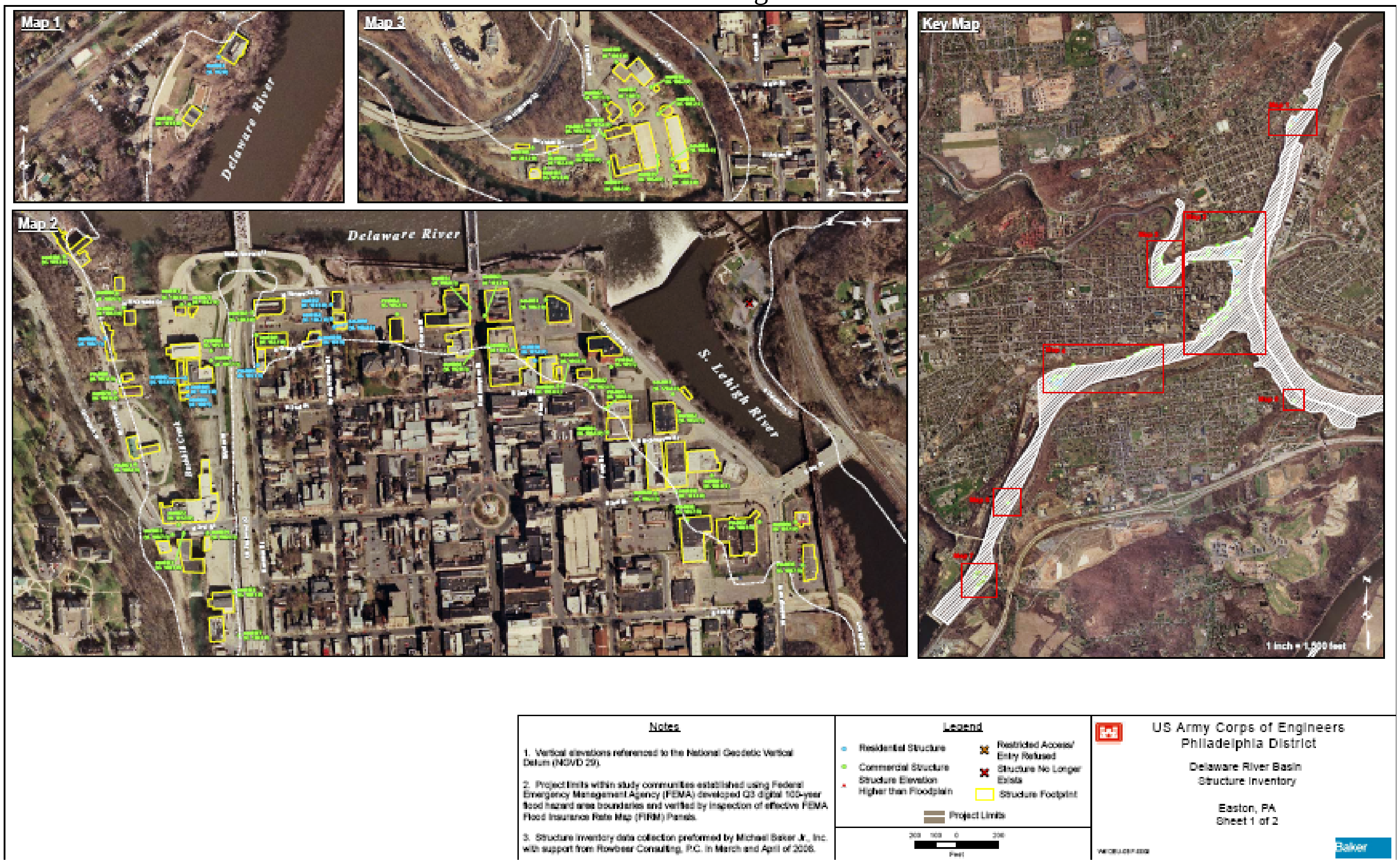
The inventory was conducted for all residential, commercial and industrial structures within the 100-year floodplain for the ten priority communities, totaling approximately 1,900 structures. Table 3.6 shows a breakdown of the number of structures per community.

Table 3.6
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 3.6. 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 3.6


Map 1
Delaware River
Map 3
Key Map
Map 2
Delaware River
S. Lehigh River
Bushkill Creek
1 inch = 1,500 feet
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 Rowbear Consulting, P.C. in March and April of 2006.
Legend
Residential Structure
Commercial Structure
Structure Elevation Higher than Floodplain
Restricted Access/ Entry Refused
Structure No Longer Exists
Structure Footprint
Project Limits
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 generic depth-damage curves. 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 3.10 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 3.10
Sample Depth Damage Curve

Residential Structures S03 (2 story, no basement)		Residential Contents (S04)	
Depth (in Feet)	Damage to structure	Depth (in Feet)	Damage to contents
-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 used in the Delaware River Basin Comprehensive, New Jersey Study, which is being cost-shared with the New Jersey Department of Environmental Protection; the Upper Delaware Watershed, Livingston Manor Feasibility Study; and the Delaware River Basin, Watershed Flood Management Plan. 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 study-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.

3.5 SOLUTION MATRIX

In addition to the structure inventory, the team moved forward with problem identification and the development of a solution matrix for the ten priority communities. Problem identification began with a review of previous studies, coordination with locals and a review of flood mitigation plans (where available). Potential alternatives were evaluated for each of the ten communities and a reconnaissance level screening was conducted. Potential alternatives for these communities are outlined in Table 3.11, which provides a brief description of structural and non-structural alternatives along with a definition of each alternative and a list of pros and cons which should be considered in evaluating the alternative.

Table 3.12 then goes on to provide solutions which should be given further consideration in future studies. The matrix (Table 3.12) provides the names of each water body within the community along with potential structural and non-structural alternatives. These alternatives were developed through a literature review, discussions with local municipalities, states and other Federal agencies, engineering judgment and a review of proposed flood mitigation plans being developed for FEMA. These are just a few alternatives which should be considered.

Table 3.11
Descriptions of Possible Alternatives

STRUCTURAL METHODS: Modify flooding to keep water away from specific developments and/or populated areas or to reduce flooding in such areas by constructing flood control works such as dams and reservoirs, levees and floodwalls, channel alterations, seawalls, and diversion channels

Measure	Description	PRO	CON	Conclusions (1984 Basin Study)
Channel Modifications and Diversions	Channel modification involves widening, deepening or straightening of existing channels and the modification of highway and railroad bridges that constrict the channel.	1.) Flood levels could be reduced through channel modifications 2.) For most of the river, the effect of existing bridges on flood flows is minimal	1.) The Delaware River through the study area maintains a very mild slope throughout most of its length, limiting the effective flow carrying capacities of any channel modifications. 2.) Significant reduction to flood levels would require extensive excavation, relocations, and acquisition of additional lands, all at high costs 3.) Channelizing only portions of the river would move flood waters more rapidly downstream, thereby accentuating problems in affected areas. 4.) The proximity of developed property to the stream bank would require the acquisition of some of that property considered for protection. Adverse environmental effect of extensive channel modifications on fish and wildlife	Channel modifications and diversions were not considered further.
Flood or High Flow Skimming Impoundments	A flood control impoundment or lake is that area behind a dam used to collect and store flood waters thus preventing them from reaching the areas to be protected. The stored flood waters are later released at reduced (nondamaging) flow rates.	1.) For the entire Delaware River Basin, a total of 386 small and 193 major dam and reservoir sites were identified. Of those, 70 sites met minimum storage criteria of 20,000 acre-feet. Work since 1962 has resulted in the identification of 37 more project variations or sites increasing the total to 107.	1) Difficult to develop enough control to significantly lower stages on the Delaware River 2) Limited availability of land for the size of impoundment needed in order to significantly reduce flows 3) Flood skimming could adversely impact smaller streams and adjacent wetlands; need to maintain a minimum conservation flow. 4) Expensive alternative when compared to others.	All 107 sites were once again considered.

Table 3.4
Descriptions of Possible Alternatives (Continued)

Measure	Description	PRO	CON	Conclusions (1984 Basin Study)
Levees and Floodwalls with Interior Drainage System	A levee (an earth embankment) or floodwall (a concrete wall) is constructed along the banks of a stream. They contain flood waters within the stream channel and protect the adjacent community.	1.) They eliminate flood damages from storms that do not cause stream levels to rise above their design height. 2.) Typically, levees and floodwalls are designed against rare flood events, thereby providing a high degree of protection.	1.) Floodwalls and levees often conflict with community plans (plans for open space, conservation, park, or recreational development of portions of flood plain lands) 2.) Existing or potential riverfront resources could be reduced or eliminated by levees and floodwalls which preclude visual or physical access to the river 3.) Levee/floodwall systems have been difficult to justify because of the natural and man-made characteristics of the study area 4.) High Zero Damage Elevations (ZDE), steep banks, and the level and complexity of the infrastructure of communities being protected has resulted in high project costs with respect to potential benefits 5.) Potential levee/floodwall alignments often contain buildings, utilities and other structures. 6.) The interior protected areas have no room for ponding stormwater drainage, have antiquated storm drainage systems and require large-volume interior drainage systems.1.) Floodwalls and levees often conflict with community plans (plans for open space, conservation, park, or recreational development of portions of flood plain lands)	An investigation of the economic feasibility of levees and floodwalls was conducted for all applicable damage centers.

Table 3.4
Descriptions of Possible Alternatives (Continued)

NONSTRUCTURAL METHODS: Floodplain management measures that (1) modify the impact of flooding such as flood insurance or (2) modify susceptibility to flooding, such as warning/preparedness systems, floodplain regulations, floodproofing, and relocation.

Measure	Description	PRO	CON	Conclusions (1984 Basin Study)
Flood Insurance	Flood insurance offers property owners a means of avoiding catastrophic losses due to floods. It provides for reimbursement of possible financial losses with the payment of a regular premium.	1.) In addition to financial protection, the flood insurance program encourages wise use of flood hazard lands through required flood plain zoning and building codes. These reduce future flood losses. 2.) The payment of the flood insurance premium brings the degree of flood risk to property owners' attention in one of the most direct ways short of a flood. Presumably this easily recognizable cost encourages a modified use and eventual abandonment of hazardous areas.	1.) Flood insurance does not eliminate the flood hazard. 2.) It is limited in the amount of financial loss that may be covered by policy. 3.) It does not eliminate associated costs such as cleanup required after a flood. 4.) Because the flood hazard remains, the threat to public safety and loss of life is still present. 5.) The availability of insurance and avoidance of catastrophic loss may actually encourage continued occupancy and reinvestment in the flood plain because it reduces the true risk.	From a national perspective, flood insurance is justified on the basis of proper management of flood plain lands for the future and on its social benefits. Flood insurance would be an inherent part of any plans for the study area that address residual damages.
Flood Forecasting, Warning and Preparedness Planning	Flood forecasting, flood warning, and preparedness planning are each individual components of an overall measure. Flood forecasting and flood warning have existed as part of the regular program of the National Weather Service (NWS). Flood preparedness plans should be fully documented and practiced.	1.) Flood recognition (forecast) and flood warning systems function well and are completely adequate to meet the needs of main stem Delaware River communities.	1.) The weaknesses in providing a complete system lie primarily in preparedness planning and program maintenance. 2.) Local preparedness plans are often inadequate and public concern tends to wane with time.	There are opportunities to improve existing flood recognition and flood warning arrangements from an efficiency and factor-of-safety standpoint.
Flood Plain Management	Proper management of flood plains by local communities is a delicate composition of regulatory, taxing and policy measures tailored to the specific flooding problem within a framework of total needs and desires of a community.	1.) Alternative development concepts or plans would be more rational if the consequences of future flooding were correctly incorporated in those decisions and plans.	1.) These management measures do not reduce or prevent damages to existing development but are meant to reduce or eliminate flood damages to future development.	General flood plain management requirements by local communities should be incorporated with any "basic" flood control plan being recommended.

Table 3.4
Descriptions of Possible Alternatives (Continued)

Measure	Description	PRO	CON	Conclusions (1984 Basin Study)
Flood Proofing	Flood proofing is designed to protect damageable property from floodwaters by preventing the water from entering a structure. Flood proofing is performed by either raising the structure; providing perimeter protection (levee or floodwall) around the structure; sealing the structure; or reducing the degree of potential damage even if the structure were to be flooded.	1.) Flood problem areas throughout the study area do exist which have high zero damage elevations (ZDE) and development characteristics suitable for flood proofing. 2.) Raising is more applicable to frame construction; perimeter protection to multi-building installations or small groups of buildings; sealing to heavily constructed masonry or concrete structures; and water damage reduction techniques to almost all units.	1.) All exterior losses such as damage to grounds, utilities, roads, crops, etc. would be fully sustained. 2.) Flood Proofing is not applicable for every situation. 3.) As little as 15 percent of the existing structures in a flood plain lend themselves to a flood proofing solution (Madigan-Praeger Report).	Flood proofing was considered for all structures.
Permanent Flood Plain Evacuation	The objective of permanent evacuation is to remove people and damageable property from the flood hazard area.	1.) With the removal of flood-susceptible buildings, an opportunity exists for increasing open space, park, and recreational development; for promoting natural and conservation areas; and for advancing compatible utilization such as parking, transient storage or pedestrian malls for commercial development. 2.) Permanent evacuation, if not part of a more comprehensive community plan, can have a positive impact on a community.	1.) The removal of property can upset a neighborhood; decrease the communities' tax base; and, in general, have adverse social and economic effects.	Flood plain evacuation was investigated but solely from the perspective of flood control project investment; not as a secondary purpose.

Table 3.12
Solution Matrix for Top 10 Priority Communities

Community	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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

Community	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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
BELVIDERE, NJ				
	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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
YARDLEY, PA (Continued)	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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

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	0.67	(1) Temporary floodwall coupled with a permanent base and some permanent floodwalls should be investigated.
		5% of structures in 25 year floodplain needed floodproofing or floodwalls	1.95 to 1	(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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

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	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
	Houghs & Jericho Creeks			Erosion, not flooding appears to be larger problem than flooding

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

Community	Flooding Issues	Solutions Previously Evaluated	Benefit to Cost Ratio from Previous Evaluations	Potential Alternatives to be Re-examined
COLCHESTER, NY				
	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

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

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.

Table 3.5
Solution Matrix for Top 10 Priority Communities (Continued)

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.

3.6 FLOOD RISK MANAGEMENT RECOMMENDATIONS

Below is a summary of potential future efforts which should be evaluated further.

3.6.1 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. This would not only assist in safe evacuations but also assist in assessment of post event damages

3.6.2 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 detailed studies, these sites should be re-evaluated using the potential recommendations provided in the solution matrix as part of collaborative, multipurpose planning efforts. Communities should prepare flood mitigation plans in coordination with State Emergency Management Agencies.

3.6.3 Detailed Feasibility Studies for Additional Flood Prone Communities.

Detailed studies should be conducted for the ten priority communities as they have the greatest damages and the most urgent needs. Additional flood prone communities beyond the ten priority communities identified in this report should also be evaluated to address and help mitigate their damages from flooding. This study limited its 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.

4.0 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.

Salinity intrusion is such a concern to the local habitat and water supply that the DRBC's drought plans are triggered by the movement of the "salt front". The salt front is defined as 7-day average location of the 250mg/L chloride concentration in the Delaware Estuary. As the salt front moves upriver it increases corrosion control costs for surface water users, particularly industry, and has the potential of raising sodium levels in a large aquifer underlying southern New Jersey which is used for municipal water supply. The tidal Delaware River also provides drinking water for approximately 1.5 million people in the Philadelphia metropolitan area, primarily through surface water intakes on the Delaware River and its tributaries. In recent years, the salt front has migrated into streams and creeks in Delaware, threatening water supplies in northern New Castle County.

Tidal freshwater of Delaware River is maintained by carefully monitoring flows in the non-tidal river and location of the salt front to support drinking water use purposes. During periods of low flow, additional fresh water is released from up basin reservoirs to keep the salt front well below the water intakes in the tidal fresh water portion of the river. Complex operational rules are applied for New York City's Delaware Basin reservoirs for their diversions and releases based on amount of reservoir storage and salt front. These complex reservoir operation rules have been continuously modified to optimize the use of limited water resources. These reservoir operation rules are evaluated through the use of three stand-alone 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").

Through this study the team linked these models enabling engineers to better evaluate the reservoir operating policies of the effects of reservoir operating program alternatives on salinity concentrations within the estuary and thus enhancing 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 to provide the Commission with the support that it has recently requested for the development of flood mitigation operating plans for existing reservoirs as modifications to operations of reservoirs. Therefore, the tool developed as part of this effort will enable DRBC and other basin stakeholders to better incorporate the effect any proposed changes in the basin would have on salinity or the location of the salt front. This is a valuable investment for the future of the Basin.

Appendix C provides more detail on the development of these model linkages.

5.0 RE-EVALUATE APPROACH TO USER SUPPLY COSTS TO SUPPORT FLOW MANAGEMENT AND EQUITABLE ALLOCATION GOALS

5.1 Financing Water Supply Storage. 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, Blue Marsh and Beltzville. Storage consists of 9.2 billion gallons in Beltzville and 2.6 billion gallons in Blue Marsh Reservoir. This storage is financed through a surface water charging program established in 1971.

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

5.2 Determining Water Supply Costs through 2030. 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/upgrades costs
- Current replacement costs for both dams and facilities
- Projected costs to meet increased demand

The costs for the above, with the exception of the current replacement costs, were projected to fiscal year 2030. The DRBC cost share for each project is 31.01% for Beltzville Lake and 12.698% for Blue Marsh Lake.

5.2.1 Estimated Annual Operation, Maintenance and Administrative Costs. The estimated joint use annual operation, maintenance, and administrative cost were projected from the actual costs of $207,150 for Beltzville Lake billed in fiscal year 2006 and $64,995 for Blue Marsh Lake billed in Fiscal Year 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. The projected joint use costs are presented in Table 5.1. It is anticipated that there will not be a major increase in these general operations and maintenance costs, however there is no guarantee of future budget levels or required costs.

Table 5.1
Estimated Annual Operation and Maintenance
Joint Use Costs

FY	Beltzville Lake			Blue Marsh Lake		
	O&M Projected	O&M Actual	Total	Projected	O&M	Total
2006		**$207,150**	**$207,150**			
2007	$213,737	N/A			**$64,995**	**$64,995**
2008	$220,534	N/A	$220,534	$67,062	N/A	$67,062
2009	$227,547	N/A	$227,547	$69,194	N/A	$69,194
2010	$234,783	N/A	$234,783	$71,395	N/A	$71,395
2011	$242,249	N/A	$242,249	$73,665	N/A	$73,665
2012	$249,953	N/A	$249,953	$76,008	N/A	$76,008
2013	$257,901	N/A	$257,901	$78,425	N/A	$78,425
2014	$266,103	N/A	$266,103	$80,919	N/A	$80,919
2015	$274,565	N/A	$274,565	$83,492	N/A	$83,492
2016	$283,296	N/A	$283,296	$86,147	N/A	$86,147
2017	$292,305	N/A	$292,305	$88,886	N/A	$88,886
2018	$301,600	N/A	$301,600	$91,713	N/A	$91,713
2019	$311,191	N/A	$311,191	$94,629	N/A	$94,629
2020	$321,087	N/A	$321,087	$97,639	N/A	$97,639
2021	$331,297	N/A	$331,297	$100,744	N/A	$100,744
2022	$341,832	N/A	$341,832	$103,947	N/A	$103,947
2023	$352,703	N/A	$352,703	$107,253	N/A	$107,253
2024	$363,919	N/A	$363,919	$110,663	N/A	$110,663
2025	$375,491	N/A	$375,491	$114,182	N/A	$114,182
2026	$387,432	N/A	$387,432	$117,813	N/A	$117,813
2027	$399,752	N/A	$399,752	$121,560	N/A	$121,560
2028	$412,464	N/A	$412,464	$125,426	N/A	$125,426
2029	$425,581	N/A	$425,581	$129,414	N/A	$129,414
2030	$439,114	N/A	$439,114	$133,529	N/A	$133,529

* Annualized rate of construction cost inflation for last 10 years applied:
3.18% per annum rate of inflation

Source: Engineering News-Record's Construction Cost Index

5.2.2 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 certain components or systems to have a major repair or upgrade. 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.

These cost were then escalated from fiscal year 2007 to the appropriate fiscal year based on a compounded escalation factor of 3.18%, which was based on a per annum rate of inflation as detailed in the above paragraph. The cost to DRBC was then calculated based on the cost share percentage for the respective project. The estimated major repairs/upgrades for Beltzville and Blue Marsh Lakes are presented in Tables 5.2 and 5.3 respectively. It should be noted that the items presented are based on a prediction of service life and repair history and is subject to change. Items budgeted for certain fiscal years may be deferred or expedited based on budget constraints or the immediate need for repair or upgrade.

Table 5.2 Beltzville Lake					
Estimated Major Repairs/Upgrades					
FY	**Description**	**FY07 Est. Cost**	**Escalate to FY Cost**	**Cost Share %**	**DRBC Est. Cost**
2008	Lead Paint Remediation (Tower)	$180,000	$185,724	31.01%	$57,593
2008	Replace Operations Building HVAC	$30,000	$30,954	31.01%	$9,599
2008	Upgrade Water Control Platform	$22,000	$22,700	31.01%	$7,039
2008	Replace Standby Generator	$50,000	$51,590	31.01%	$15,998
2008	Repair Outlet Structure/Conduit	$655,000	$675,829	31.01%	$209,575
2009	Upgrade Operation Building Potable Water System	$25,000	$26,615	31.01%	$8,253
2009	New Dehumidification System	$38,000	$40,455	31.01%	$12,545
2010	Positional Survey: Dams & Structures	$52,000	$57,120	31.01%	$17,713
2010	Elevator Upgrade	$500,000	$549,233	31.01%	$170,317
2010	Replace Sump Pit 4" Backwater Valve	$50,000	$54,923	31.01%	$17,032
2010	Repair Emergency Spillway Chute	$473,000	$519,574	31.01%	$161,120
2010	Rehabilitate Flood Control Gate	$1,000,000	$1,098,466	31.01%	$340,634
2010	Replace gear box & limit torque motor on water quality gate	$50,000	$54,923	31.01%	$17,032
2011	A-E Study on Tower Concrete	$80,000	$90,672	31.01%	$28,117
2011	Paint Tower Spillway Bridge	$544,000	$616,568	31.01%	$191,198
2012	Plug/Grout Piezometer/H20 Sampling Piping Terminals	$341,000	$398,779	31.01%	$123,661
2012	Electrical upgrade @ elevations 548, 530 & 519	$50,000	$58,472	31.01%	$18,132
2013	Discharge Channel-Right Bank Stabilization	$595,000	$717,943	31.01%	$222,634
2013	Replace Hydraulic fluid tank, pumps (2), motors (2)	$250,000	$301,657	31.01%	$93,544
2013	Upgrade Sump Pumps (2)	$50,000	$60,331	31.01%	$18,709
2014	Automated Geotechnical Data Acquisition System	$215,000	$267,675	31.01%	$83,006
2014	Install AAR Remedial Lining @ Intake Tower	$1,500,000	$1,867,497	31.01%	$579,111
2015	Tower Mechanical Repairs (Intake/Exhaust Fans/Heater)	$40,000	$51,384	31.01%	$15,934
2015	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$66,799	31.01%	$20,714
2020	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$78,117	31.01%	$24,224
2025	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$91,353	31.01%	$28,329
2030	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$106,832	31.01%	$33,129

FY	Description	FY07 Est. Cost	Esc. to FY Cost	Cost Share %	DRBC Est. Cost
	Table 5.3 **Blue Marsh Lake** **Estimated Major Repairs/Upgrades**				
2008	Repair Hydraulic Seals on Service Gates	$55,000	$56,749	12.698%	$7,206
2008	Upgrade Water Control Data Platform	$22,000	$22,700	12.698%	$2,882
2010	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$57,120	12.698%	$7,253
2010	Evaluate Reservoir Bank Erosion	$58,000	$63,711	12.698%	$8,090
2010	Upgrade Operations Building Potable Water System	$25,000	$27,462	12.698%	$3,487
2011	Rehabilitate Flood Control Gate	$291,000	$329,819	12.698%	$41,880
2011	Replace Leaf Gate on Service Gate #1 Motor	$300,000	$340,019	12.698%	$43,176
2012	Concrete Repairs in Stilling Basin	$230,000	$268,971	12.698%	$34,154
2013	Lead Paint Remediation - Service Bridge	$290,000	$349,922	12.698%	$44,433
2013	Replace Operations Building HVAC	$30,000	$36,199	12.698%	$4,597
2014	Automated Geotechnical Data Acquisition System	$244,000	$303,780	12.698%	$38,574
2014	Rehab Water Quality Gate	$600,000	$746,999	12.698%	$94,854
2015	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$66,799	12.698%	$8,482
2016	Replace Operations Building Roof	$50,000	$66,272	12.698%	$8,415
2016	Rehabilitate Flood Control Gate	$1,000,000	$1,325,439	12.698%	$168,304
2020	Replace Tower Heater	$20,000	$30,045	12.698%	$3,815
2020	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$68,923	12.698%	$8,752
2020	Water Quality Control Selective Withdraw System	$1,500,000	$2,253,373	12.698%	$286,133
2025	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$91,353	12.698%	$11,600
2030	Positional Survey: Dams & Structures (every 5 yrs)	$52,000	$106,832	12.698%	$13,565
	Bernville Protective Works				
2011	Upgrade Pumping Station Float Switch System	$50,000	$56,670	12.698%	$7,196
2012	Replace Roof on Pumping Station	$30,000	$35,083	12.698%	$4,455
2015	Upgrade Pumping Station Control System	$600,000	$770,753	12.698%	$97,870
2025	Rehabilitate Pumping Station Pumps	$1,500,000	$2,635,182	12.698%	$334,615

5.2.3 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 when using the $Q_7 10$ flows for 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.

For sensitivity analyses, the team also investigated the impact of reducing the Schuylkill $Q_7 10$ flow by 50 percent. As a result of this decrease, the water deficiency increased to139 mgd not including the power sector demands.

Under this scenario, the construction of three new reservoirs in the Schuylkill basin could make up the 139 mgd non-power deficiency. However, the potential power sector deficiency of 518 mgd could not be met with these reservoirs. The total project cost of constructing three new reservoirs, Maiden Creek, French Creek and Evansburg, was estimated to be 746 million dollars. If flood damage reduction were one of the authorized uses in addition to water supply, the water supply related costs would be less. The costs for these three reservoirs were escalated from the 1959 Section 522 study up to 2008.

The cost of providing the additional water supply depends on which one or all of the suggested projects would be built. To illustrate the significance of the financing endeavor to construct one of the reservoirs, it is useful to consider financing a hypothetical 300 million dollar reservoir as well as some of the policy considerations that the DRBC would have to evaluate in order to fund the project through its water charging program.

The example reservoir would be similar in cost to the 1986 proposed water supply modification of F.E. Walter Reservoir, located on the upper Lehigh River, and would portray the difficulty in funding large, expensive water supply projects by the DRBC. The DRBC proposed to modify F.E. Walter Reservoir to supply 23 billion gallons (bg). The estimated water supply related cost at that time was about 160 million dollars. This cost today adjusted for inflation would be 100 percent higher or approximately 320 million dollars. This amount of money would probably only be sufficient to build one of the three new reservoirs being considered to meet the 139 mgd non-power sector water deficiency, assuming that the DRBC would have to fund the entire project without any federal support.

Currently, the DRBC's charging system brings in revenue of about 2.7 million dollars annually to pay for the water supply portion of Blue Marsh and Beltzville Reservoirs. This revenue covers the debt service, operation and maintenance and administrative costs. The water supply portion of these two reservoirs cost about 15 million dollars when they were built.

The methodology that the DRBC used to determine the current water charging rates is based on the calculated safe yield of the two water supply reservoirs, namely Blue Marsh and Beltzville. The safe yields of these two reservoirs were 30.8 mgd and 28.7 mgd, respectively, using the 1960's drought as the record drought. In 1978 the DRBC last increased the consumptive surface water charging rate to $60 from $40 per million gallons to include the cost of Blue Marsh Reservoir. The safe yield of the modified F.E. Walter Reservoir is approximated by dividing 23 bg storage by 122 days, the time duration between June and September. This results in a safe yield of 188 mgd.

To illustrate the significantly large increase in funding needed to fund a large reservoir project, one of the suggested reservoirs would most likely cost 300 million dollars. To borrow this amount for 30 years at an interest rate of 5 percent tax exempt bonds the debt repayment would be 19.33 million dollars annually exclusive of operation and maintenance. Using the pooled water concept which combines the safe yield of the hypothetical reservoir and of Blue Marsh and Beltzvillle, the revised consumptive use water rate would be $226.7 per mg compared to the current consumptive use water rate of

$60 per mg., an increase of 3.78 times. Factoring in this increase to the current revenue of 2.7 million dollars, the annual revenue would increase to 10.2 million dollars. This is approximately 10 million dollars less than what would be required to pay the revised annual repayment. This would indicate that the methodology of calculating water rates would have to be modified if an additional reservoir were built.

The proposed modification of F.E. Walter Reservoir in 1986 indicated the potential problems that would ensue should the DRBC fund such a project. The DRBC realized that the use of its existing water charging program to fund 160 million dollars would have significantly increased the cost burden of the then approximately 200 post-Compact (1961) surface water users. In order to spread the impact of this rate increase, the DRBC proposed changing its policy of exempting from charge pre-Compact and ground water users. This would have distributed the costs among many more users. The proposed new policy and resulting charging schedule was met with great opposition from many pre-compact large water users that held water entitlements and from farmers that primarily used ground water for irrigation. The proposed F.E. Walter modification did not proceed because of the basin community's opposition to the increased water charges and the lack of Congressional support to change the DRBC Compact to charge pre-Compact water users.

Changes in federal government funding policies have put the burden of funding reservoir projects directly on the sponsor compared to the 1970s and 1980's when Federal financing of up to 70 percent of the project cost was available.

The problems associated with funding larger amounts of capital would again arise if another large reservoir project was proposed. Fundamental policies of charging the basin water users would have to be examined once more by the DRBC. Also, if a proposed reservoir's water supply benefit a specific area such as the Schuylkill basin, the question of which users to charge would need to be answered.

If additional water supply is needed to supply future in-basin power generating facilities, as shown previously, there is not enough existing water supply storage in the basin to compensate for this added demand. Instead of building additional storage capacity it is possible to have the utilities allocate the remaining storage of approximately eight billion gallons in the Merrill Creek Reservoir. This storage, under present DRBC regulations, is released to make up the utilities' generating facilities consumptive use only when the basin is in drought warning or drought conditions. However, these releases would not add to the $Q_7 10$ minimum flows of the stream or river.

5.3 Debt Repayment. As part of the investigation regarding the setting of DRBC water user charges, the DRBC requested the Corps to provide estimates until the year 2030 of the cost of future capital replacement and operation and maintenance costs for Blue Marsh and Beltzville Reservoirs. The DRBC owns water supply storage in these two reservoirs and is responsible for paying the Federal Government a portion of future capital replacement costs as well as operation and maintenance costs. The percentage of cost obligation depends on whether or not they are water supply related or joint replacement costs. The DRBC's portion of joint costs for Blue Marsh and Beltzvillle Reservoirs are 12 percent and 31 percent, respectively.

The estimated costs for both reservoirs from 2008 to 2030 are displayed in Tbles 5.2 and 5.3.   Also included in these tables are costs for principal and interest, depreciation, in accordance with the type of accounting the Commission utilizes for the reservoirs. The total costs over the 23 years to 2030 total $40.236 million dollars, not including DRBC administrative expenditures. The current indebtedness for Beltzville is scheduled to be paid by 2021 and that for Blue Marsh by 2030. As those debts are retired, there would be a basis for reducing water charging rates.

DRBC estimated revenues and expenditures for the same time period up to 2030. This includes water supply related salaries and fringe benefits, administrative and special project costs, transfers to the general fund, water sales revenue, and investment income. The revenue stream from surface water charges was assumed to increase at a rate one percent annually. This resulted in estimated total revenues of $90.140 million dollars compared to estimated total cost of 80.216 million dollars. This would result in a $9.923 million dollars surplus by 2030. The funding of any capital replacements would have to be authorized by Congress prior to their construction by the Corps.

5.4 Alternative Charge Schedules. While capital and repair and replacement costs were updated, the team reviewed alternative charge schedules that could be used to help meet potential increased needs. Technical Appendix D provides an overview of the 1987 Black and Veatch Report to be used as a reference for researching and developing alternative charge schedules.

5.5 Determining Need to Update Surface Water Rates for Basin Users. At this time it does not appear necessary to update surface water rates to basin users based on the information gathered in this report. However, additional water supply needs should be re-evaluated under a thorough drought analysis.

6.0 PUBLIC ACCESS TO INFORMATION

The Public Access component of this study requires that all data gathered for this study be made available to anyone wishing to use it. This information will be placed on an internet site and will include water supply/flood damages/demographics/revised stage-frequency curves/results of skew analysis and other such data so agencies can use similar methodology for conducting studies within the Basin.

7.0 CONTINUATION OF EFFORTS

Whereas most USACE reports end with final recommendations regarding possible future construction opportunities, this study is much different. The focus of this study was to use limited Federal funds in order to bring together key stakeholders from all levels of government and interest groups to form cooperative partnerships in order to more effectively identify and address water resources needs in the region. Through this study the Corps has worked with several 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.

Over the 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 passages.

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 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 and opportunities exist, 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.

Appendix A
Water Supply

1. Ground and Surface Water Availability Estimates.

The following tables of ground-water availability and surface water availability contain alternative availability measures for each of the 147 watersheds of the Delaware River Basin. These estimates have been derived using the methods described in the main report. The numbers in the tables are expressed in both million gallons per square mile per day ($MG/mi^2/d$) and million gallons per day (MG/d), for each watershed.

Table A1.1: Ground-Water Availability

Basin identification number	(MGD/mi2)			(MGD)		
	10-yr RI	25-yr RI	50-yr RI	10-yr RI	25-yr RI	50-yr RI
DB-001	0.492	0.403	0.373	70.812	57.975	53.695
DB-002	0.492	0.403	0.373	25.738	21.072	19.517
DB-003	0.492	0.403	0.373	40.802	33.405	30.940
DB-004	0.492	0.403	0.373	26.143	21.403	19.824
DB-005	0.501	0.412	0.384	61.452	50.562	47.090
DB-006	0.495	0.406	0.376	19.418	15.915	14.766
DB-007	0.503	0.415	0.387	34.063	28.109	26.255
DB-008	0.542	0.456	0.434	23.003	19.336	18.439
DB-009	0.620	0.537	0.468	38.500	33.315	29.053
DB-010	0.497	0.408	0.380	104.389	85.730	79.779
DB-011	0.498	0.410	0.382	80.354	66.110	61.620
DB-012	0.524	0.446	0.429	50.846	43.342	41.665
DB-013	0.515	0.442	0.427	68.221	58.493	56.522
DB-014	0.514	0.426	0.401	47.030	38.994	36.667
DB-015	0.477	0.414	0.400	33.347	28.947	28.007
DB-016	0.513	0.439	0.422	40.225	34.425	33.144
DB-017	0.394	0.356	0.349	32.470	29.341	28.787
DB-018	0.635	0.550	0.471	79.447	68.870	58.954
DB-019	0.347	0.318	0.311	12.358	11.331	11.092
DB-020	0.444	0.396	0.390	33.865	30.208	29.696
DB-021	0.336	0.309	0.302	8.667	7.973	7.799
DB-022	0.639	0.553	0.473	51.172	44.328	37.908
DB-023	0.340	0.312	0.306	20.152	18.504	18.106
DB-024	0.639	0.554	0.473	25.211	21.842	18.662
DB-025	0.640	0.554	0.474	59.058	51.089	43.740
DB-026	0.639	0.554	0.473	44.765	38.783	33.137
DB-027	0.648	0.555	0.483	53.252	45.633	39.752
DB-028	0.640	0.554	0.474	80.656	69.825	59.721
DB-029	0.504	0.423	0.400	44.811	37.563	35.559
DB-030	0.651	0.555	0.488	43.954	37.503	32.933
DB-031	0.647	0.555	0.483	103.418	88.688	77.180
DB-032	0.640	0.554	0.474	59.247	51.291	43.869
DB-033	0.502	0.415	0.388	39.124	32.354	30.259
DB-034	0.497	0.408	0.380	20.060	16.478	15.316
DB-035	0.507	0.420	0.394	56.122	46.459	43.538

Basin identification number	(MGD/mi2)			(MGD)		
	10-yr RI	25-yr RI	50-yr RI	10-yr RI	25-yr RI	50-yr RI
DB-036	0.624	0.537	0.477	50.064	43.093	38.279
DB-037	0.516	0.430	0.407	47.772	39.855	37.675
DB-038	0.514	0.427	0.393	101.457	84.311	77.585
DB-039	0.531	0.445	0.408	38.478	32.285	29.571
DB-040	0.617	0.530	0.479	54.682	46.943	42.393
DB-041	0.610	0.522	0.480	10.965	9.386	8.636
DB-042	0.530	0.459	0.408	35.133	30.427	27.025
DB-043	0.635	0.549	0.475	99.967	86.432	74.786
DB-044	0.499	0.431	0.374	15.309	13.216	11.478
DB-045	0.634	0.546	0.477	110.217	95.020	82.913
DB-046	0.626	0.539	0.478	71.257	61.312	54.427
DB-047	0.547	0.472	0.423	19.025	16.436	14.716
DB-048	0.415	0.358	0.278	12.543	10.817	8.410
DB-049	0.426	0.354	0.286	45.672	37.906	30.654
DB-050	0.424	0.351	0.284	29.632	24.503	19.810
DB-051	0.425	0.352	0.284	20.831	17.234	13.895
DB-052	0.454	0.361	0.308	54.629	43.530	37.113
DB-053	0.421	0.356	0.283	31.603	26.672	21.201
DB-054	0.452	0.349	0.304	21.685	16.777	14.587
DB-055	0.423	0.346	0.282	33.828	27.653	22.513
DB-056	0.651	0.557	0.489	60.646	51.925	45.529
DB-057	0.650	0.555	0.487	83.928	71.602	62.869
DB-058	0.650	0.574	0.499	59.261	52.264	45.485
DB-059	0.650	0.583	0.505	32.101	28.782	24.941
DB-060	0.650	0.575	0.500	97.035	85.792	74.620
DB-061	0.636	0.555	0.492	74.601	65.142	57.654
DB-062	0.629	0.541	0.479	69.812	60.014	53.091
DB-063	0.516	0.447	0.381	58.280	50.473	43.046
DB-064	0.590	0.508	0.453	46.190	39.801	35.479
DB-065	0.421	0.347	0.280	38.683	31.810	25.730
DB-066	0.419	0.348	0.277	44.385	36.851	29.420
DB-067	0.451	0.348	0.303	37.796	29.151	25.372
DB-068	0.436	0.339	0.292	64.882	50.464	43.397
DB-069	0.464	0.372	0.318	26.982	21.647	18.518
DB-070	0.485	0.413	0.345	39.585	33.706	28.141
DB-071	0.459	0.373	0.315	33.924	27.572	23.278
DB-072	0.303	0.251	0.215	29.389	24.312	20.866
DB-073	0.254	0.213	0.181	15.933	13.347	11.363
DB-074	0.211	0.175	0.150	23.633	19.650	16.850
DB-075	0.246	0.207	0.176	13.407	11.290	9.565
DB-076	0.300	0.253	0.217	23.193	19.588	16.837
DB-077	0.240	0.202	0.172	15.055	12.651	10.758
DB-078	0.822	0.671	0.640	78.636	64.191	61.225
DB-079	0.331	0.290	0.274	17.886	15.657	14.802
DB-080	0.379	0.327	0.306	54.683	47.181	44.151
DB-081	0.379	0.327	0.306	19.833	17.112	16.013

Basin identification number	(MGD/mi2)			(MGD)		
	10-yr RI	25-yr RI	50-yr RI	10-yr RI	25-yr RI	50-yr RI
DB-082	0.558	0.504	0.467	29.633	26.765	24.801
DB-083	0.298	0.252	0.212	50.090	42.496	35.628
DB-084	0.359	0.312	0.273	23.358	20.298	17.768
DB-085	0.558	0.504	0.467	61.566	55.608	51.526
DB-086	0.558	0.504	0.467	38.295	34.589	32.050
DB-087	0.558	0.504	0.467	42.435	38.329	35.515
DB-088	0.558	0.504	0.467	53.474	48.299	44.754
DB-089	0.348	0.303	0.277	27.964	24.343	22.225
DB-090	0.443	0.393	0.390	24.898	22.088	21.920
DB-091	0.330	0.289	0.274	21.701	18.988	17.979
DB-092	0.443	0.393	0.390	22.724	20.159	20.005
DB-093	0.443	0.393	0.390	43.826	38.880	38.583
DB-094	0.615	0.543	0.475	84.167	74.311	65.047
DB-095	0.650	0.584	0.505	43.463	39.033	33.801
DB-096	0.610	0.534	0.474	84.428	73.866	65.629
DB-097	0.424	0.360	0.286	45.569	38.661	30.723
DB-098	0.419	0.367	0.284	38.030	33.282	25.789
DB-099	0.431	0.349	0.288	53.985	43.814	36.050
DB-100	0.427	0.344	0.284	55.953	45.077	37.218
DB-101	0.427	0.355	0.288	37.743	31.339	25.402
DB-102	0.356	0.297	0.249	60.395	50.370	42.301
DB-103	0.425	0.351	0.297	38.926	32.116	27.152
DB-104	0.299	0.250	0.222	41.703	34.865	30.976
DB-105	0.346	0.300	0.266	24.287	21.087	18.695
DB-106	0.300	0.253	0.213	43.193	36.479	30.733
DB-107	0.231	0.193	0.165	30.979	25.838	22.110
DB-108	0.219	0.183	0.156	18.420	15.357	13.140
DB-109	0.357	0.302	0.272	46.114	39.039	35.129
DB-110	0.349	0.292	0.256	22.254	18.616	16.324
DB-111	0.443	0.393	0.390	22.220	19.712	19.562
DB-112	0.331	0.289	0.274	26.975	23.608	22.355
DB-113	0.780	0.688	0.670	32.000	28.225	27.487
DB-114	0.330	0.289	0.274	25.492	22.306	21.120
DB-115	0.331	0.289	0.274	21.946	19.207	18.187
DB-116	0.325	0.284	0.269	13.295	11.626	11.017
DB-117	0.353	0.344	0.265	17.553	17.105	13.177
DB-118	0.353	0.344	0.265	15.546	15.150	11.671
DB-119	0.780	0.688	0.670	56.128	49.508	48.213
DB-120	0.343	0.292	0.275	42.279	36.062	33.930
DB-121	0.336	0.290	0.275	45.289	39.198	37.060
DB-122	0.331	0.289	0.274	21.564	18.872	17.840
DB-123	0.336	0.291	0.275	18.860	16.304	15.389
DB-124	0.337	0.291	0.275	35.044	30.252	28.554
DB-125	0.328	0.287	0.272	27.851	24.385	23.080
DB-126	0.780	0.688	0.670	53.684	47.352	46.113
DB-127	0.633	0.532	0.515	19.940	16.759	16.223

Basin identification number	(MGD/mi2)			(MGD)		
	10-yr RI	25-yr RI	50-yr RI	10-yr RI	25-yr RI	50-yr RI
DB-128	0.340	0.278	0.267	11.004	8.997	8.641
DB-129	0.780	0.688	0.670	60.625	53.474	52.075
DB-130	0.309	0.234	0.178	28.149	21.317	16.215
DB-131	0.540	0.482	0.443	29.830	26.626	24.471
DB-132	0.340	0.278	0.267	33.901	27.719	26.623
DB-133	0.560	0.509	0.470	60.004	54.539	50.361
DB-134	0.540	0.482	0.443	59.971	53.530	49.199
DB-135	0.309	0.234	0.178	31.041	23.507	17.881
DB-136	0.511	0.458	0.431	38.808	34.783	32.733
DB-137	0.511	0.458	0.431	58.612	52.533	49.436
DB-138	0.511	0.458	0.431	35.599	31.907	30.026
DB-139	0.511	0.458	0.431	38.540	34.542	32.506
DB-140	0.780	0.688	0.670	38.176	33.673	32.792
DB-141	0.780	0.688	0.670	67.484	59.524	57.967
DB-142	0.780	0.688	0.670	35.270	31.110	30.296
DB-143	0.309	0.234	0.178	27.288	20.665	15.720
DB-144	0.309	0.234	0.178	32.185	24.373	18.540
DB-145	0.309	0.234	0.178	23.108	17.499	13.311
DB-146	0.309	0.234	0.178	25.732	19.486	14.823
DB-147	0.340	0.278	0.267	28.392	23.215	22.296

Table A1.2: Surface Water Availability

Basin identification number	$MG/mi^2/d$			MG/d		
	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$
DB-001	0.027	0.058	0.115	3.940	8.312	16.589
DB-002	0.027	0.058	0.116	1.436	3.029	6.043
DB-003	0.027	0.058	0.116	2.274	4.798	9.574
DB-004	0.027	0.058	0.115	1.456	3.072	6.131
DB-005	0.031	0.064	0.122	3.854	7.889	14.974
DB-006	0.028	0.060	0.117	1.118	2.337	4.599
DB-007	0.033	0.067	0.125	2.250	4.551	8.464
DB-008	0.050	0.095	0.153	2.139	4.029	6.508
DB-009	0.045	0.096	0.181	2.780	5.989	11.238
DB-010	0.030	0.062	0.119	6.272	12.971	25.065
DB-011	0.031	0.064	0.121	5.003	10.266	19.575
DB-012	0.053	0.099	0.157	5.166	9.631	15.222
DB-013	0.054	0.101	0.158	7.211	13.386	20.967
DB-014	0.038	0.075	0.133	3.468	6.840	12.142
DB-015	0.051	0.095	0.151	3.580	6.679	10.598
DB-016	0.053	0.098	0.155	4.131	7.704	12.195
DB-017	0.046	0.087	0.140	3.818	7.160	11.548

Basin identification number	MG/mi²/d			MG/d		
	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$
DB-018	0.042	0.094	0.183	5.229	11.728	22.960
DB-019	0.038	0.074	0.126	1.369	2.631	4.481
DB-020	0.056	0.102	0.157	4.237	7.784	11.947
DB-021	0.036	0.070	0.122	0.938	1.817	3.150
DB-022	0.041	0.094	0.184	3.321	7.494	14.749
DB-023	0.037	0.072	0.124	2.207	4.258	7.322
DB-024	0.042	0.094	0.184	1.636	3.693	7.269
DB-025	0.045	0.098	0.186	4.140	9.046	17.193
DB-026	0.041	0.094	0.184	2.904	6.558	12.913
DB-027	0.078	0.141	0.206	6.438	11.625	16.950
DB-028	0.043	0.096	0.185	5.452	12.097	23.379
DB-029	0.041	0.079	0.137	3.636	7.059	12.166
DB-030	0.094	0.161	0.215	6.318	10.879	14.517
DB-031	0.077	0.140	0.206	12.354	22.388	32.849
DB-032	0.043	0.095	0.185	3.948	8.811	17.137
DB-033	0.034	0.068	0.126	2.618	5.283	9.781
DB-034	0.030	0.061	0.119	1.196	2.479	4.809
DB-035	0.037	0.073	0.130	4.075	8.042	14.429
DB-036	0.093	0.159	0.231	7.426	12.786	18.543
DB-037	0.041	0.079	0.137	3.778	7.347	12.694
DB-038	0.050	0.092	0.143	9.890	18.078	28.247
DB-039	0.067	0.116	0.164	4.831	8.412	11.879
DB-040	0.115	0.188	0.251	10.154	16.637	22.277
DB-041	0.138	0.219	0.273	2.489	3.928	4.913
DB-042	0.080	0.141	0.155	5.272	9.327	10.243
DB-043	0.059	0.116	0.200	9.221	18.215	31.491
DB-044	0.074	0.130	0.145	2.260	3.982	4.440
DB-045	0.071	0.131	0.209	12.307	22.856	36.376
DB-046	0.094	0.161	0.231	10.679	18.336	26.267
DB-047	0.092	0.157	0.179	3.189	5.455	6.226
DB-048	0.061	0.107	0.157	1.842	3.230	4.753
DB-049	0.106	0.153	0.175	11.408	16.378	18.786
DB-050	0.104	0.149	0.173	7.230	10.378	12.085
DB-051	0.111	0.158	0.178	5.443	7.722	8.738
DB-052	0.183	0.235	0.211	21.992	28.356	25.371
DB-053	0.084	0.130	0.166	6.305	9.753	12.444
DB-054	0.206	0.256	0.219	9.880	12.295	10.502
DB-055	0.117	0.161	0.179	9.313	12.869	14.279
DB-056	0.102	0.171	0.217	9.526	15.948	20.263
DB-057	0.094	0.162	0.215	12.176	20.920	27.801
DB-058	0.183	0.264	0.240	16.691	24.088	21.832
DB-059	0.230	0.318	0.252	11.351	15.709	12.465
DB-060	0.192	0.275	0.242	28.696	41.021	36.148
DB-061	0.159	0.238	0.248	18.623	27.870	29.034
DB-062	0.091	0.157	0.227	10.084	17.448	25.128
DB-063	0.075	0.134	0.187	8.501	15.149	21.092

Basin identification number	MG/mi²/d			MG/d		
	$Q_7$10	95% Exceedence	Sept. Med minus $Q_7$10	$Q_7$10	95% Exceedence	Sept. Med minus $Q_7$10
DB-064	0.092	0.159	0.208	7.234	12.415	16.316
DB-065	0.109	0.153	0.176	9.987	14.074	16.132
DB-066	0.099	0.143	0.172	10.471	15.197	18.273
DB-067	0.207	0.256	0.219	17.314	21.478	18.331
DB-068	0.183	0.229	0.205	27.165	34.043	30.452
DB-069	0.190	0.247	0.216	11.078	14.363	12.553
DB-070	0.161	0.228	0.209	13.129	18.621	17.054
DB-071	0.171	0.227	0.207	12.677	16.786	15.322
DB-072	0.069	0.110	0.124	6.705	10.691	12.038
DB-073	0.042	0.082	0.104	2.607	5.113	6.500
DB-074	0.019	0.054	0.084	2.154	6.059	9.424
DB-075	0.021	0.053	0.087	1.123	2.907	4.738
DB-076	0.037	0.070	0.102	2.865	5.424	7.880
DB-077	0.021	0.054	0.087	1.286	3.370	5.425
DB-078	0.429	0.635	0.492	41.051	60.740	47.022
DB-079	0.098	0.191	0.196	5.302	10.339	10.565
DB-080	0.154	0.246	0.236	22.156	35.506	33.984
DB-081	0.148	0.236	0.226	7.720	12.371	11.841
DB-082	0.253	0.357	0.280	13.437	18.963	14.843
DB-083	0.028	0.059	0.096	4.791	10.011	16.117
DB-084	0.051	0.099	0.133	3.306	6.466	8.628
DB-085	0.254	0.359	0.281	28.061	39.600	30.997
DB-086	0.255	0.359	0.281	17.482	24.672	19.312
DB-087	0.255	0.360	0.281	19.375	27.343	21.402
DB-088	0.253	0.357	0.279	24.247	34.219	26.784
DB-089	0.082	0.157	0.173	6.568	12.631	13.864
DB-090	0.184	0.282	0.240	10.333	15.872	13.475
DB-091	0.101	0.197	0.199	6.633	12.938	13.096
DB-092	0.176	0.271	0.230	9.034	13.876	11.781
DB-093	0.180	0.276	0.234	17.787	27.321	23.195
DB-094	0.168	0.246	0.225	22.997	33.658	30.804
DB-095	0.234	0.323	0.254	15.662	21.610	16.966
DB-096	0.156	0.234	0.237	21.629	32.423	32.849
DB-097	0.084	0.131	0.167	9.005	14.093	17.912
DB-098	0.045	0.093	0.150	4.128	8.407	13.634
DB-099	0.134	0.181	0.188	16.785	22.666	23.552
DB-100	0.132	0.176	0.185	17.292	23.112	24.175
DB-101	0.113	0.160	0.178	9.956	14.172	15.761
DB-102	0.070	0.105	0.127	11.877	17.912	21.589
DB-103	0.146	0.201	0.188	13.326	18.413	17.189
DB-104	0.070	0.123	0.138	9.743	17.203	19.344
DB-105	0.065	0.127	0.151	4.555	8.928	10.569
DB-106	0.058	0.101	0.119	8.322	14.517	17.170
DB-107	0.030	0.067	0.093	3.950	8.908	12.471
DB-108	0.020	0.054	0.085	1.643	4.528	7.123
DB-109	0.093	0.154	0.165	12.070	19.886	21.359

Basin identification number	MG/mi²/d			MG/d		
	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$	$Q_7 10$	95% Exceedence	Sept. Med minus $Q_7 10$
DB-110	0.082	0.132	0.148	5.193	8.399	9.415
DB-111	0.187	0.287	0.244	9.375	14.401	12.226
DB-112	0.101	0.198	0.200	8.270	16.132	16.328
DB-113	0.440	0.538	0.291	18.066	22.090	11.932
DB-114	0.101	0.198	0.200	7.825	15.264	15.451
DB-115	0.101	0.198	0.200	6.729	13.126	13.286
DB-116	0.099	0.194	0.196	4.064	7.928	8.025
DB-117	0.073	0.160	0.214	3.649	7.963	10.652
DB-118	0.075	0.164	0.220	3.317	7.239	9.684
DB-119	0.186	0.299	0.298	13.390	21.498	21.449
DB-120	0.116	0.206	0.203	14.353	25.447	25.034
DB-121	0.108	0.201	0.201	14.537	27.178	27.175
DB-122	0.102	0.198	0.200	6.637	12.905	13.050
DB-123	0.109	0.202	0.202	6.106	11.327	11.300
DB-124	0.110	0.203	0.202	11.442	21.080	20.987
DB-125	0.101	0.196	0.198	8.538	16.656	16.859
DB-126	0.468	0.573	0.309	32.227	39.406	21.286
DB-127	0.303	0.454	0.362	9.555	14.301	11.403
DB-128	0.007	0.034	0.090	0.240	1.108	2.920
DB-129	0.522	0.639	0.345	40.598	49.640	26.815
DB-130	0.066	0.125	0.149	5.972	11.358	13.571
DB-131	0.241	0.343	0.264	13.320	18.925	14.578
DB-132	0.007	0.034	0.089	0.731	3.368	8.874
DB-133	0.175	0.349	0.468	18.784	37.365	50.198
DB-134	0.245	0.349	0.269	27.263	38.734	29.836
DB-135	0.065	0.124	0.148	6.554	12.464	14.892
DB-136	0.202	0.310	0.244	15.332	23.555	18.540
DB-137	0.202	0.311	0.245	23.201	35.645	28.055
DB-138	0.201	0.308	0.243	13.972	21.466	16.895
DB-139	0.202	0.310	0.244	15.217	23.379	18.401
DB-140	0.483	0.591	0.319	23.649	28.916	15.620
DB-141	0.525	0.641	0.346	45.387	55.497	29.978
DB-142	0.522	0.639	0.345	23.622	28.883	15.602
DB-143	0.066	0.125	0.150	5.819	11.066	13.222
DB-144	0.066	0.125	0.149	6.839	13.005	15.539
DB-145	0.065	0.124	0.148	4.882	9.285	11.093
DB-146	0.065	0.124	0.148	5.422	10.311	12.320
DB-147	0.007	0.034	0.091	0.624	2.876	7.577

2. A Review of Population Projections Conducted within the Delaware River Basin

Population growth is a key driver of demand for public water supply. This makes it an integral component when projecting future water demand. The boundary of the Delaware River Basin contains portions of Delaware, New Jersey, New York and Pennsylvania. Numerous population projections by state agencies and research organizations within the Basin were reviewed for use in this study. As each agency or research publication pertained to a particular state, uniformity of projection methods across the entire basin was not possible. The best available projection figures were selected based on the needs of this project.

The most applicable population figures were allocated to the 147 watersheds using GIS. To minimize the assumptions that arise when allocating figures across a geographic boundary, the finest geographic boundaries available were selected. Population projections for New Jersey and Pennsylvania were found at the municipal level. Delaware had county level population projections which also included figures for major cities, three of which are found within the basin. Projections for the New York portion of the DRB were only available at the county level. However, due to the lack of major cities and the overall distribution of the population in this region of the basin, these figures are believed adequate for the purposes of this study.

In the state of Delaware all population studies are conducted by the Delaware Population Consortium (DPC). The DPC is a cooperative organization that consists of representatives from state, county and local governments. It was formed to provide uniform projections of population and households in the state of Delaware. The DPC provides projections for all counties and major cities. Major cities within the Basin include Dover, Newark, and Wilmington. The DPC uses mortality, fertility, and labor force data to develop their projections, which are updated each year. These are annual projections spanning a range from 2000 through 2030.

In the state of New Jersey two sources of population projections were found. Population projections were made by the New Jersey Department of Labor and Workforce Development (NJLWD), as well as by Metropolitan Planning Organizations (MPO), which deal with transportation issues within their jurisdictions. The projections provided by each MPO were at the municipal level and had a range that was more applicable to the needs of this project than the projections provided by the NJLWD.

The North Jersey Transportation Planning Authority, Inc. (NJTPA) serves the 13 county region of northern New Jersey. They have created a spreadsheet model that calculates projections of both population and employment at the municipal level. Their figures are provided in five year increments beginning in 2000 and continuing through 2030. Their model factors in historical information regarding base year population, fertility, mortality and migration.

The South Jersey Transportation Planning Organization (SJTPO) is the MPO that serves the southern region of New Jersey. They provide projected population figures by municipality every five years from 2000 through 2025.

The Delaware Valley Regional Planning Commission (DVRPC) is an interstate MPO that serves the central portion of New Jersey and the greater Philadelphia region in Pennsylavania. They produced population projections at the municipal level every five years from 2000 through 2030.

The best available population projection figures for the State of New York were provided by the New York Statistical Information System (NYsis). NYsis is a component of the Program on Applied Demographics (PAD) at the Cornell Institute for Social and Economic Research (CISER). CISER is a research organization established to provide research support to the social science program at Cornell University. NYsis provides population projections by county in five year increments from 2000 through 2030.

Projections for the State of Pennsylvania were provided by the Pennsylvania Department of Environmental Protection (PADEP). The PADEP provided figures at the municipal level in ten year increments beginning in 2000 and continuing through 2030. To produce their population projections, the PADEP used an Ordinary Least Squares trending function that incorporated historical population figures from three previous decades of Federal Census data.

Table A2: Population Projections

BASIN ID	2000 BASE	2005 PROJ	2010 PROJ	2015 PROJ	2020 PROJ	2025 PROJ	2030 PROJ
DB-001	6,875	6,895	6,877	6,833	6,758	6,644	6,492
DB-002	1,210	1,214	1,211	1,203	1,190	1,171	1,144
DB-003	2,993	3,003	2,996	2,977	2,945	2,896	2,830
DB-004	3,362	3,373	3,365	3,345	3,308	3,253	3,179
DB-005	2,986	2,996	2,989	2,970	2,938	2,889	2,823
DB-006	1,520	1,525	1,523	1,518	1,507	1,488	1,462
DB-007	2,038	2,042	2,050	2,062	2,075	2,082	2,083
DB-008	1,004	1,008	1,005	999	988	972	950
DB-009	1,052	1,072	1,091	1,124	1,157	1,157	1,155
DB-010	6,200	6,232	6,230	6,206	6,154	6,068	5,947
DB-011	2,181	2,190	2,188	2,178	2,157	2,125	2,081
DB-012	1,074	1,102	1,130	1,157	1,184	1,206	1,226
DB-013	5,458	5,659	5,868	6,090	6,310	6,520	6,721
DB-014	1,668	1,673	1,669	1,659	1,641	1,613	1,577
DB-015	1,034	1,049	1,060	1,069	1,075	1,076	1,073
DB-016	1,651	1,657	1,653	1,643	1,625	1,598	1,561
DB-017	2,006	2,053	2,096	2,140	2,179	2,212	2,238
DB-018	2,998	3,129	3,260	3,437	3,614	3,627	3,639
DB-019	1,500	1,556	1,613	1,674	1,735	1,792	1,848
DB-020	4,898	5,078	5,266	5,465	5,663	5,851	6,032
DB-021	994	1,030	1,068	1,109	1,149	1,187	1,224
DB-022	3,844	4,162	4,479	4,815	5,151	5,209	5,266
DB-023	1,765	1,830	1,897	1,969	2,040	2,108	2,174
DB-024	2,183	2,486	2,788	3,139	3,489	3,786	4,082
DB-025	6,722	7,048	7,373	7,709	8,044	8,043	8,041
DB-026	3,687	3,848	4,010	4,179	4,348	4,347	4,346

BASIN ID	2000 BASE	2005 PROJ	2010 PROJ	2015 PROJ	2020 PROJ	2025 PROJ	2030 PROJ
DB-027	6,697	7,200	7,704	8,321	8,938	8,922	8,906
DB-028	11,032	11,979	12,926	13,940	14,954	15,910	16,866
DB-029	3,765	3,904	4,048	4,201	4,353	4,498	4,637
DB-030	7,093	7,602	8,111	8,635	9,159	9,157	9,155
DB-031	14,574	16,721	18,867	21,429	23,991	25,688	27,385
DB-032	6,262	7,970	9,678	11,285	12,893	14,754	16,616
DB-033	10,934	11,337	11,756	12,199	12,641	13,062	13,466
DB-034	4,501	4,667	4,839	5,022	5,204	5,377	5,543
DB-035	10,650	11,080	11,524	11,991	12,456	12,896	13,310
DB-036	9,334	11,199	13,064	15,233	17,401	19,911	22,420
DB-037	1,247	1,292	1,339	1,389	1,438	1,485	1,528
DB-038	28,479	29,668	30,895	32,250	33,594	34,836	36,079
DB-039	7,389	7,672	7,967	8,277	8,586	8,880	9,159
DB-040	11,934	15,618	19,302	22,508	25,714	29,426	33,138
DB-041	922	984	1,051	1,134	1,217	1,315	1,435
DB-042	2,388	2,505	2,636	2,793	2,953	3,204	3,510
DB-043	13,705	17,162	20,620	23,923	27,226	30,895	34,564
DB-044	1,950	2,129	2,195	2,273	2,338	2,418	2,472
DB-045	46,346	52,221	58,096	63,886	69,676	75,473	81,271
DB-046	37,101	41,912	46,722	51,522	56,322	61,122	65,922
DB-047	5,334	5,917	6,501	7,082	7,664	8,245	8,827
DB-048	4,445	4,829	5,212	5,584	5,956	6,167	6,377
DB-049	28,406	29,879	31,344	32,799	34,267	35,887	37,518
DB-050	7,505	7,978	8,162	8,475	8,744	9,081	9,314
DB-051	5,869	6,310	6,515	6,783	7,002	7,284	7,485
DB-052	28,840	31,174	34,013	35,973	37,820	39,399	40,539
DB-053	29,410	30,770	32,129	33,540	34,951	35,641	36,331
DB-054	29,032	32,297	34,674	35,913	36,567	37,470	38,078
DB-055	59,932	63,084	66,236	69,812	73,389	75,780	78,171
DB-056	6,550	7,617	8,684	9,756	10,827	11,597	12,367
DB-057	16,880	20,858	24,836	28,761	32,686	36,576	40,465
DB-058	3,807	3,702	3,597	3,535	3,473	3,467	3,461
DB-059	5,629	5,431	5,234	5,107	4,980	4,970	4,960
DB-060	23,227	23,480	23,733	24,164	24,595	24,942	25,289
DB-061	24,279	24,362	24,445	24,375	24,305	24,327	24,349
DB-062	22,100	25,522	28,945	32,386	35,827	38,488	41,148
DB-063	27,337	28,512	29,686	30,748	31,809	31,995	32,181
DB-064	15,614	16,898	18,182	19,323	20,465	21,418	22,371
DB-065	58,201	60,869	63,537	66,012	68,488	69,190	69,892
DB-066	83,450	86,155	88,861	91,330	93,799	94,051	94,302
DB-067	118,051	121,704	125,357	129,186	133,015	133,940	134,866
DB-068	199,042	204,565	210,088	216,245	222,402	223,191	223,981
DB-069	20,661	22,521	24,439	25,413	26,229	27,169	27,828
DB-070	60,573	62,829	64,340	65,289	66,103	66,910	68,784
DB-071	24,121	25,471	26,701	27,099	27,618	28,147	28,869
DB-072	16,558	17,835	19,112	20,449	21,789	22,622	23,455
DB-073	12,496	13,189	13,532	13,946	14,485	15,031	15,606
DB-074	39,245	42,530	45,816	49,578	53,340	56,199	59,058

BASIN ID	2000 BASE	2005 PROJ	2010 PROJ	2015 PROJ	2020 PROJ	2025 PROJ	2030 PROJ
DB-075	6,437	6,845	6,972	7,215	7,664	8,110	8,588
DB-076	47,370	50,377	53,383	56,645	59,906	61,934	63,962
DB-077	40,108	41,205	42,041	42,654	43,921	45,087	46,291
DB-078	184,558	189,156	195,099	198,441	201,755	204,852	208,252
DB-079	126,147	128,837	131,527	133,731	135,935	134,428	132,922
DB-080	82,989	86,859	91,438	94,443	97,426	100,793	104,333
DB-081	25,172	28,992	31,994	33,226	34,300	37,057	39,280
DB-082	41,478	45,303	47,096	48,673	50,117	52,568	55,179
DB-083	185,122	196,439	207,756	219,481	231,206	237,833	244,460
DB-084	146,125	150,707	155,290	159,444	163,597	163,381	163,164
DB-085	28,809	29,609	30,699	31,107	32,016	32,465	33,155
DB-086	12,273	13,244	13,609	14,073	14,915	15,784	16,440
DB-087	64,617	70,167	72,394	74,726	76,729	79,239	81,904
DB-088	120,215	127,729	134,014	138,689	143,355	148,111	153,229
DB-089	338,555	338,166	337,777	341,390	345,002	338,874	332,745
DB-090	131,734	136,973	137,015	138,052	140,553	142,202	144,923
DB-091	848,992	840,422	831,853	839,499	847,145	827,707	808,269
DB-092	189,241	188,341	187,121	186,214	186,166	184,274	183,904
DB-093	295,985	298,296	299,963	299,713	300,349	299,847	300,826
DB-094	24,150	23,783	23,416	22,972	22,528	22,539	22,550
DB-095	27,557	26,288	25,019	23,896	22,773	22,752	22,731
DB-096	37,054	37,077	37,101	37,254	37,407	37,389	37,370
DB-097	52,298	53,863	55,428	57,620	59,812	59,723	59,633
DB-098	6,289	6,709	7,130	7,553	7,977	8,166	8,356
DB-099	35,847	38,033	40,219	42,677	45,134	45,132	45,130
DB-100	25,762	27,093	28,423	29,496	30,568	30,681	30,794
DB-101	39,988	42,362	44,735	47,470	50,206	50,162	50,118
DB-102	182,995	188,088	193,181	198,811	204,442	204,270	204,098
DB-103	31,598	32,785	33,973	35,391	36,810	36,749	36,688
DB-104	120,828	127,620	134,411	141,265	148,118	151,478	154,838
DB-105	24,317	25,431	26,545	27,334	28,124	28,539	28,954
DB-106	44,024	47,207	50,390	53,453	56,516	58,819	61,123
DB-107	88,613	95,413	102,212	108,743	115,273	120,076	124,879
DB-108	100,939	107,084	113,229	118,248	123,267	124,965	126,663
DB-109	556,678	556,205	555,732	561,729	567,726	557,187	546,648
DB-110	161,552	162,832	164,111	165,581	167,052	164,302	161,552
DB-111	82,788	85,859	89,007	92,053	95,850	98,482	101,712
DB-112	457,638	452,925	448,212	447,057	445,903	442,854	439,805
DB-113	12,290	12,654	13,309	14,105	14,952	15,664	16,491
DB-114	133,222	133,862	134,502	134,967	135,431	135,396	135,361
DB-115	104,497	108,154	111,811	115,396	118,982	119,375	119,769
DB-116	118,490	122,258	125,794	129,419	132,713	134,918	136,684
DB-117	15,934	17,949	20,350	23,014	25,648	29,695	32,344
DB-118	7,110	8,020	9,008	10,393	11,539	12,651	13,897
DB-119	21,920	21,951	22,081	22,321	22,476	22,519	22,692
DB-120	94,602	100,649	106,695	111,742	116,789	119,054	121,319
DB-121	55,477	58,416	61,356	63,761	66,166	67,356	68,546
DB-122	69,793	72,032	74,219	76,456	78,531	79,180	79,818

BASIN ID	2000 BASE	2005 PROJ	2010 PROJ	2015 PROJ	2020 PROJ	2025 PROJ	2030 PROJ
DB-123	41,218	44,011	46,725	49,118	51,402	52,903	54,250
DB-124	116,533	124,214	131,421	137,700	143,472	147,702	151,335
DB-125	188,524	196,229	203,218	209,523	214,910	219,478	223,142
DB-126	19,755	19,751	19,640	19,415	19,275	19,251	19,083
DB-127	32,356	34,060	35,652	37,154	38,503	39,605	40,492
DB-128	8,859	9,325	9,761	10,172	10,541	10,843	11,086
DB-129	5,501	5,522	5,613	5,781	5,891	5,921	6,042
DB-130	15,609	16,431	17,199	17,924	18,574	19,106	19,534
DB-131	3,387	3,467	3,573	3,757	3,886	3,985	4,119
DB-132	12,920	14,283	15,281	16,171	17,010	17,727	18,333
DB-133	39,375	40,803	42,191	44,519	46,239	47,951	49,665
DB-134	6,290	6,541	6,785	7,194	7,497	7,797	8,098
DB-135	20,129	22,318	23,761	25,104	26,382	27,512	28,487
DB-136	35,079	36,951	39,336	41,751	44,493	47,084	49,574
DB-137	57,562	59,494	61,710	65,405	68,108	70,433	73,185
DB-138	30,472	31,717	32,927	34,954	36,452	37,946	39,438
DB-139	21,897	22,711	23,503	24,776	25,735	26,693	27,652
DB-140	3,614	3,760	3,902	4,141	4,317	4,492	4,668
DB-141	11,147	11,643	12,133	12,750	13,286	13,815	14,350
DB-142	25,391	26,513	27,634	28,684	29,732	30,754	31,870
DB-143	53,866	59,058	62,340	65,540	68,577	71,312	73,685
DB-144	18,585	21,005	22,685	24,161	25,570	26,788	27,829
DB-145	13,981	15,699	17,143	18,478	19,716	20,800	21,749
DB-146	8,280	9,248	10,190	11,090	11,909	12,633	13,275
DB-147	15,932	17,793	19,606	21,338	22,914	24,306	25,542
DRB-Total	**7,742,242**	**7,978,836**	**8,196,574**	**8,433,737**	**8,669,240**	**8,770,787**	**8,873,315**

3. Water Conservation Program in the Delaware River Basin

The Delaware River Basin Commission has a well-established and comprehensive water conservation program which has for many years provided water resources protection and improved drought preparedness and response. Water conservation has become an integral component of the Commission's strategy to manage water supplies throughout the Basin and includes both regulatory and educational initiatives

It is the policy of the Commission to require maximum feasible efficiency in the use of water on the part of water users throughout the Basin. The Commission works towards this through its regulatory program. Under Section 3.8 entitled 'Referral and Review' of the Delaware River Basin Compact, the Commission is charged with reviewing and approving all projects having a substantial effect on the water resources of the Delaware River Basin. The Commission's regulatory program covers the following general areas which discussed in more detail below:

- Source and Service metering

- Water loss, leak detection and repair
- Water conservation performance standards for plumbing fixtures and fittings
- Conservation oriented pricing structures; and
- Requirements for water conservation plans and water user education.

The Commission continually works to ensure its regulations reflect the latest thinking in the field of water conservation. It is currently working to update its regulations regarding water loss in drinking water supply distribution systems and is considering adoption of the American Water Works Association (AWWA) Water Audit Methodology.

Source and Service Metering

In the mid-1980's the Commission passed resolutions requiring source (Resolution No. 86-12) and service (Resolution No. 87-7) metering for users withdrawing greater than an average of 100,000gpd. Metering at the source level is essential to enable water users to monitor and report their withdrawals. The source metering resolution requires the use of an automated continuous recording device or flow meter, accurate to within five percent. Exception to the five percent performance standard, but no greater than ten percent, may be granted for surface water withdrawals if maintenance of the five percent performance standard is not technically feasible or economically practicable. Meters or other methods of measurement are subject to approval and inspection regarding type, method, installation, maintenance, calibration, reading, and accuracy. The following water users are exempt from the source metering requirements:

- agricultural irrigation;
- snowmaking;
- dewatering incidental to mining and quarrying; and
- dewatering incidental to construction

These exempt users are however required to estimate withdrawals based on pumping rates and durations.

Owners of water supply systems serving the public that withdraw more than 100,000gpd are required to install water meters at the customer connection. Metering at the customer level is important for tracking efficient operation of the distribution system and for providing information and incentives to the customer to reduce water use. The Commission further requires that water charges collected by purveyors shall be based in part on metered usage.

Requirements for Water Purveyors

<u>Water loss, leak detection and repair</u>
The Commission is currently in the process of revising its regulations regarding the measurement and tracking of water loss. The existing resolution (Resolution 87-6 Rev 1)

promotes the concept of “unaccounted for water” which is no longer considered best practice by the water industry. Recent efforts by the AWWA have resulted in a new approach to track water loss which relies on a more rigid audit structure and well-defined definitions. It is estimated that over 150 mgd is physically lost from distribution systems throughout the basin and that the new audit approach will help the Commission, State Agencies and utility managers target efforts to improve water supply planning and efficiency thereby reducing water withdrawals that have no beneficial end use. AWWA hosts a water audit software tool on its website which is available as a free download for use by water purveyors. The software design was led by Commission staff, demonstrating DRBC’s continued leadership in the field of water conservation.

Water conservation performance standards for plumbing fixtures and fittings

In 1988 the DRBC implemented Resolution 88-2 (Rev 2) which established water conservation performance standards for plumbing fixtures and fittings. The performance standards, which were consistent with federal regulations, stipulate that all performance standards or plumbing codes adopted by the four states or political subdivisions shall comply with certain minimum standards. By January 1, 1992, the states of Delaware, New Jersey and New York had adopted statewide conservation requirements that met DRBC standards. In Pennsylvania, attempts to adopt a statewide plumbing code failed in the Legislature and DRBC notified the 505 Pennsylvania municipalities in the Basin that they were required to enact local ordinances to meet DRBC standards. The standards described apply to plumbing fixtures and fittings installed in new construction and, under certain conditions, to existing structures undergoing renovations involving replacement of such fixtures and fittings. In 2004, by Act of the General Assembly, the Uniform Construction Code (UCC) went into effect in the Commonwealth of Pennsylvania. Resolution 88-2 still remains in the DRBC Water Code, however the adoption of the UCC by Pennsylvania means that the municipal ordinances are no longer required by DRBC.

Conservation oriented pricing structures

Resolution No. 92-2 makes it the policy of the Delaware River Basin Commission to promote and support retail water pricing that encourages conservation. A water conserving pricing structure is an important demand management tool that provides incentives to consumers to reduce average or peak water use, or both. Conservation pricing reflects the fact that water is a precious resource that should be used in an efficient manner. Such pricing can be characterized by one or more of the following components:

- Rates in which the unit price of water per class of customer (residential, industrial, etc.) is constant within each class regardless of the quantity of water used (uniform rates) or increases as the quantity of water used increases (increasing block rates);
- Seasonal rates or excess-use surcharges to reduce peak water demands during summer months; or
- Rates based on the long-run marginal cost or the cost of adding the next unit of water supply to the system.

All purveyors are encouraged to evaluate alternative pricing structures with the objective of adopting a water conserving pricing structure. A purveyor seeking approval under Section 3.8 of the Compact for a new or expanded water withdrawal and whose proposed total withdrawal equals or exceeds an average of one million gallons of water per day must include in its water conservation plan, submitted as part of the application, an evaluation of the feasibility of implementing a water conserving pricing structure and billing program. A purveyor may limit the evaluation to less than its entire system upon application and a determination that a review of its entire system is not necessary.

Requirements for water conservation plans and water user education

Owners of water supply systems serving the public (purveyors) seeking approval under section 3.8 of the Compact for a new or expanded water withdrawal must develop a water conservation plan. The plan must, at a minimum, describe the implementation of the programs described above. All applications for a new or expanded water withdrawal that results in a total withdrawal equaling or exceeding an average of one million gallons of water per day shall include a plan for provision of information on the availability of water conserving devices and procedures (Resolution No. 81-9). In addition, a Drought Contingency Plan describing use priorities and emergency conservation measures to be instituted in the event of a drought or other water shortage condition is required. Contingency plans of public authorities or private water works corporations shall be prepared in cooperation with all municipalities in the area affected by the contingency plan, and shall be coordinated with any applicable statewide water shortage contingency plans.

Requirements for Non Water Purveyors

The Commission requires that applications for approval of new industrial or commercial water withdrawals from surface or ground water sources in excess of an average of one million gallons per day contain a report of the water-conserving procedures and technology considered by the applicant and the extent to which they will be applied in the development of the project. In addition, a contingency plan must be developed which includes emergency conservation measures to be instituted in the event of a drought or other water shortage. The report and contingency plan must estimate the impact of the water conservation measures upon consumptive and non-consumptive water use by the applicant.

Applications for approval of new agricultural irrigation water withdrawals from surface or ground water sources in excess of one million gallons per day shall include a statement of the operating procedure or equipment to be used by the applicant to achieve the most efficient method of application of water and to avoid waste.

4. Water Use Estimates and Projections

The table below contains a summary of current and future water use, aggregated to the watershed scale. All figures are peak demand using the month of July (Million gallons/per day), and are listed by source type, ground water (GW) and surface water (SW). Assumptions regarding water conservation are included in these estimates.

Table 4.1 Total Withdrawals: Peak MGD (July)

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-001	GW	0.790	0.787	0.771	0.752	0.732	0.709	0.684
DB-001	SW	0.070	0.068	0.065	0.061	0.058	0.056	0.053
DB-002	GW	0.194	0.193	0.188	0.183	0.177	0.172	0.165
DB-002	SW	0.025	0.024	0.023	0.022	0.021	0.020	0.019
DB-003	GW	1.427	1.427	1.406	1.370	1.330	1.284	1.233
DB-003	SW	0.039	0.038	0.037	0.035	0.033	0.031	0.030
DB-004	GW	0.312	0.311	0.305	0.298	0.290	0.281	0.271
DB-004	SW	0.025	0.025	0.023	0.022	0.021	0.020	0.019
DB-005	GW	0.619	0.617	0.604	0.588	0.572	0.555	0.535
DB-005	SW	0.058	0.057	0.054	0.051	0.049	0.046	0.044
DB-006	GW	0.264	0.263	0.258	0.253	0.247	0.241	0.233
DB-006	SW	0.019	0.019	0.018	0.017	0.016	0.015	0.015
DB-007	GW	0.486	0.485	0.478	0.472	0.467	0.461	0.454
DB-007	SW	0.035	0.035	0.033	0.031	0.030	0.029	0.027
DB-008	GW	0.187	0.186	0.182	0.177	0.172	0.167	0.161
DB-008	SW	0.020	0.020	0.019	0.018	0.017	0.016	0.015
DB-009	GW	0.428	0.429	0.429	0.432	0.436	0.429	0.422
DB-009	SW	0.043	0.042	0.041	0.039	0.037	0.035	0.034
DB-010	GW	1.060	1.057	1.038	1.012	0.986	0.958	0.927
DB-010	SW	0.125	0.123	0.118	0.112	0.107	0.102	0.098
DB-011	GW	0.672	0.669	0.655	0.637	0.619	0.600	0.579
DB-011	SW	0.088	0.086	0.083	0.078	0.074	0.071	0.068
DB-012	GW	0.505	0.507	0.506	0.503	0.500	0.497	0.495
DB-012	SW	0.087	0.086	0.083	0.080	0.076	0.073	0.071
DB-013	GW	0.931	0.942	0.960	0.979	0.997	1.015	1.032
DB-013	SW	0.057	0.057	0.055	0.053	0.052	0.050	0.049
DB-014	GW	0.486	0.484	0.474	0.462	0.450	0.436	0.421
DB-014	SW	0.043	0.042	0.040	0.038	0.036	0.035	0.033
DB-015	GW	0.434	0.435	0.431	0.426	0.421	0.415	0.408
DB-015	SW	0.032	0.031	0.030	0.028	0.027	0.026	0.024
DB-016	GW	0.346	0.344	0.337	0.327	0.318	0.308	0.297
DB-016	SW	0.037	0.036	0.035	0.033	0.031	0.030	0.028
DB-017	GW	0.486	0.488	0.489	0.489	0.490	0.489	0.487
DB-017	SW	0.034	0.033	0.032	0.030	0.029	0.028	0.027
DB-018	GW	0.986	0.998	1.018	1.049	1.081	1.069	1.057
DB-018	SW	0.088	0.087	0.084	0.079	0.076	0.072	0.070

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-019	GW	0.447	0.453	0.463	0.474	0.485	0.496	0.505
DB-019	SW	0.011	0.011	0.011	0.011	0.010	0.010	0.010
DB-020	GW	0.858	0.869	0.889	0.910	0.931	0.950	0.968
DB-020	SW	0.024	0.024	0.024	0.023	0.022	0.022	0.022
DB-021	GW	0.282	0.286	0.292	0.299	0.306	0.312	0.318
DB-021	SW	0.008	0.008	0.008	0.008	0.008	0.007	0.007
DB-022	GW	0.759	0.778	0.819	0.862	0.904	0.901	0.899
DB-022	SW	0.053	0.052	0.050	0.048	0.045	0.043	0.042
DB-023	GW	0.554	0.561	0.574	0.587	0.600	0.612	0.624
DB-023	SW	0.019	0.019	0.018	0.018	0.017	0.017	0.017
DB-024	GW	0.784	0.827	0.927	1.038	1.147	1.247	1.344
DB-024	SW	0.015	0.015	0.014	0.013	0.013	0.012	0.012
DB-025	GW	1.309	1.330	1.370	1.411	1.452	1.442	1.433
DB-025	SW	0.064	0.063	0.061	0.058	0.055	0.053	0.051
DB-026	GW	0.533	0.540	0.550	0.561	0.573	0.565	0.557
DB-026	SW	0.049	0.048	0.046	0.044	0.042	0.040	0.038
DB-027	GW	1.424	1.458	1.532	1.621	1.711	1.709	1.709
DB-027	SW	0.069	0.069	0.067	0.065	0.064	0.061	0.059
DB-028	GW	2.282	2.350	2.495	2.647	2.799	2.949	3.099
DB-028	SW	0.096	0.097	0.099	0.101	0.102	0.104	0.105
DB-029	GW	0.681	0.689	0.704	0.719	0.735	0.749	0.763
DB-029	SW	0.028	0.028	0.028	0.027	0.026	0.025	0.025
DB-030	GW	1.252	1.283	1.346	1.410	1.473	1.457	1.441
DB-030	SW	0.048	0.048	0.046	0.044	0.042	0.040	0.038
DB-031	GW	2.625	2.749	3.029	3.367	3.699	3.856	4.010
DB-031	SW	0.125	0.128	0.134	0.140	0.146	0.148	0.150
DB-032	GW	1.652	1.800	2.148	2.473	2.791	3.155	3.513
DB-032	SW	0.006	0.006	0.006	0.006	0.006	0.005	0.005
DB-033	GW	0.922	0.934	0.956	0.979	1.002	1.022	1.042
DB-033	SW	0.025	0.025	0.024	0.023	0.023	0.022	0.022
DB-034	GW	0.911	0.923	0.946	0.970	0.994	1.016	1.036
DB-034	SW	0.013	0.013	0.013	0.012	0.012	0.012	0.011
DB-035	GW	1.651	1.672	1.711	1.748	1.786	1.821	1.853
DB-035	SW	0.092	0.091	0.088	0.085	0.081	0.079	0.077
DB-036	GW	1.963	2.090	2.384	2.739	3.087	3.486	3.878
DB-036	SW	0.006	0.006	0.006	0.005	0.005	0.005	0.005
DB-037	GW	0.594	0.599	0.604	0.607	0.610	0.614	0.618
DB-037	SW	0.098	0.098	0.095	0.091	0.087	0.084	0.082
DB-038	GW	3.346	3.397	3.495	3.602	3.706	3.795	3.885
DB-038	SW	0.400	0.398	0.390	0.377	0.364	0.354	0.347
DB-039	GW	1.830	1.855	1.902	1.947	1.992	2.032	2.068
DB-039	SW	0.042	0.042	0.041	0.039	0.038	0.037	0.036
DB-040	GW	2.086	2.301	2.812	3.245	3.669	4.156	4.632

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DB-040	SW	0.006	0.006	0.006	0.006	0.006	0.005	0.005
DB-041	GW	0.403	0.412	0.435	0.462	0.489	0.522	0.562
DB-041	SW	0.049	0.049	0.048	0.046	0.044	0.042	0.041
DB-042	GW	0.582	0.591	0.611	0.634	0.658	0.701	0.754
DB-042	SW	0.186	0.185	0.180	0.172	0.164	0.159	0.154
DB-043	GW	1.988	2.143	2.510	2.852	3.191	3.566	3.937
DB-043	SW	0.242	0.261	0.303	0.342	0.377	0.415	0.448
DB-044	GW	0.601	0.616	0.622	0.629	0.632	0.641	0.644
DB-044	SW	0.548	0.545	0.531	0.508	0.485	0.468	0.457
DB-045	GW	3.811	3.961	4.297	4.619	4.941	5.263	5.584
DB-045	SW	3.257	3.357	3.578	3.787	3.991	4.198	4.401
DB-046	GW	1.932	2.016	2.207	2.393	2.575	2.754	2.929
DB-046	SW	0.087	0.089	0.093	0.097	0.100	0.103	0.105
DB-047	GW	1.018	1.059	1.150	1.238	1.326	1.414	1.501
DB-047	SW	0.130	0.134	0.144	0.153	0.160	0.167	0.174
DB-048	GW	0.237	0.243	0.256	0.267	0.279	0.284	0.289
DB-048	SW	0.057	0.056	0.055	0.052	0.050	0.048	0.047
DB-049	GW	3.629	3.699	3.837	3.963	4.085	4.211	4.329
DB-049	SW	0.386	0.386	0.381	0.372	0.362	0.355	0.350
DB-050	GW	1.916	1.952	1.965	1.998	2.023	2.063	2.084
DB-050	SW	1.284	1.279	1.250	1.199	1.151	1.115	1.092
DB-051	GW	2.484	2.520	2.528	2.540	2.542	2.561	2.564
DB-051	SW	1.003	0.998	0.973	0.930	0.889	0.858	0.837
DB-052	GW	5.032	5.166	5.615	5.891	6.149	6.347	6.481
DB-052	SW	1.861	1.854	1.816	1.745	1.676	1.622	1.583
DB-053	GW	1.700	1.717	1.742	1.765	1.788	1.783	1.779
DB-053	SW	1.054	1.067	1.091	1.110	1.128	1.129	1.130
DB-054	GW	7.982	8.124	8.262	8.340	8.296	8.302	8.264
DB-054	SW	1.077	1.075	1.056	1.016	0.975	0.945	0.923
DB-055	GW	3.955	3.972	3.993	4.016	4.040	4.041	4.043
DB-055	SW	2.856	2.827	2.729	2.612	2.500	2.395	2.296
DB-056	GW	0.631	0.664	0.739	0.813	0.885	0.934	0.981
DB-056	SW	0.059	0.058	0.057	0.054	0.051	0.050	0.048
DB-057	GW	2.280	2.432	2.783	3.118	3.448	3.773	4.093
DB-057	SW	0.392	0.420	0.486	0.549	0.605	0.658	0.709
DB-058	GW	0.505	0.497	0.471	0.455	0.439	0.432	0.426
DB-058	SW	0.101	0.100	0.098	0.093	0.089	0.086	0.084
DB-059	GW	0.587	0.577	0.547	0.525	0.504	0.495	0.487
DB-059	SW	0.047	0.046	0.045	0.043	0.041	0.040	0.039
DB-060	GW	0.616	0.614	0.606	0.602	0.598	0.597	0.598
DB-060	SW	5.584	5.504	5.254	5.021	4.793	4.722	4.655
DB-061	GW	8.341	8.464	8.759	9.052	9.367	9.746	10.147
DB-061	SW	2.783	2.579	2.697	2.800	2.920	3.084	3.269

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-062	GW	0.892	0.941	1.053	1.162	1.265	1.344	1.416
DB-062	SW	18.190	18.355	18.594	18.811	19.040	19.043	19.064
DB-063	GW	4.923	4.915	4.872	4.830	4.798	4.702	4.614
DB-063	SW	0.283	0.282	0.275	0.263	0.253	0.244	0.239
DB-064	GW	0.840	0.851	0.873	0.892	0.911	0.931	0.951
DB-064	SW	4.023	4.083	4.194	4.302	4.413	4.469	4.530
DB-065	GW	6.591	6.644	6.731	6.793	6.858	6.835	6.815
DB-065	SW	1.326	1.333	1.339	1.340	1.341	1.325	1.312
DB-066	GW	10.284	10.368	10.479	10.533	10.599	10.568	10.549
DB-066	SW	0.651	0.653	0.651	0.641	0.629	0.613	0.597
DB-067	GW	19.052	19.189	19.353	19.469	19.602	19.489	19.398
DB-067	SW	5.128	5.147	5.145	5.126	5.114	5.048	4.993
DB-068	GW	10.094	10.140	10.203	10.274	10.341	10.279	10.217
DB-068	SW	0.793	0.795	0.792	0.784	0.774	0.758	0.743
DB-069	GW	3.334	3.398	3.536	3.588	3.621	3.667	3.685
DB-069	SW	1.222	1.217	1.189	1.139	1.090	1.054	1.029
DB-070	GW	6.210	6.298	6.375	6.388	6.400	6.405	6.464
DB-070	SW	1.273	1.281	1.280	1.257	1.226	1.192	1.166
DB-071	GW	7.021	7.100	7.175	7.114	7.076	7.047	7.030
DB-071	SW	2.229	2.231	2.211	2.160	2.109	2.069	2.038
DB-072	GW	1.732	1.778	1.875	1.975	2.074	2.133	2.191
DB-072	SW	0.259	0.257	0.251	0.239	0.229	0.221	0.215
DB-073	GW	1.954	1.991	2.016	2.046	2.088	2.132	2.177
DB-073	SW	0.419	0.419	0.412	0.399	0.386	0.377	0.371
DB-074	GW	5.517	5.658	5.953	6.278	6.599	6.815	7.028
DB-074	SW	0.481	0.481	0.475	0.463	0.452	0.440	0.432
DB-075	GW	1.388	1.416	1.425	1.450	1.507	1.563	1.623
DB-075	SW	0.305	0.304	0.297	0.285	0.273	0.265	0.259
DB-076	GW	6.342	6.484	6.816	7.166	7.525	7.826	8.139
DB-076	SW	0.309	0.310	0.309	0.305	0.300	0.295	0.290
DB-077	GW	1.597	1.611	1.627	1.633	1.658	1.681	1.705
DB-077	SW	0.861	0.862	0.853	0.829	0.808	0.787	0.768
DB-078	GW	7.089	7.184	7.362	7.406	7.453	7.483	7.528
DB-078	SW	1.480	1.476	1.451	1.401	1.349	1.311	1.282
DB-079	GW	2.526	2.553	2.595	2.625	2.656	2.644	2.634
DB-079	SW	1.058	1.060	1.056	1.040	1.025	1.012	1.000
DB-080	GW	9.220	9.477	9.870	10.141	10.401	10.681	10.967
DB-080	SW	4.487	4.501	4.496	4.407	4.305	4.238	4.197
DB-081	GW	5.280	5.461	5.735	5.895	6.039	6.230	6.420
DB-081	SW	2.113	2.116	2.091	2.017	1.942	1.899	1.869
DB-082	GW	10.347	10.558	10.631	10.637	10.626	10.698	10.749
DB-082	SW	1.961	1.953	1.907	1.825	1.746	1.688	1.648
DB-083	GW	17.691	18.057	18.832	19.590	20.351	20.830	21.320

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-083	SW	18.616	18.931	19.529	19.834	20.132	20.098	20.069
DB-084	GW	4.241	4.310	4.440	4.557	4.670	4.677	4.685
DB-084	SW	11.102	11.234	11.460	11.618	11.785	11.919	12.067
DB-085	GW	3.655	3.689	3.757	3.741	3.783	3.778	3.797
DB-085	SW	9.699	9.725	9.752	9.703	9.667	9.647	9.662
DB-086	GW	2.690	2.751	2.774	2.800	2.880	2.975	3.036
DB-086	SW	2.937	2.925	2.864	2.758	2.655	2.579	2.526
DB-087	GW	6.575	6.797	6.923	7.036	7.094	7.218	7.350
DB-087	SW	3.504	3.518	3.470	3.374	3.268	3.194	3.140
DB-088	GW	9.237	9.348	9.567	9.698	9.793	9.890	9.979
DB-088	SW	3.963	3.958	3.892	3.757	3.620	3.520	3.449
DB-089	GW	3.294	3.331	3.390	3.443	3.498	3.512	3.529
DB-089	SW	0.344	0.343	0.337	0.333	0.327	0.315	0.301
DB-090	GW	27.198	27.435	27.167	26.923	26.811	26.452	26.192
DB-090	SW	2.110	2.104	2.055	1.973	1.895	1.834	1.792
DB-091	GW	0.247	0.251	0.258	0.264	0.271	0.278	0.285
DB-091	SW	0.106	0.106	0.103	0.102	0.100	0.096	0.092
DB-092	GW	24.380	24.302	23.823	23.266	22.818	22.237	21.771
DB-092	SW	1.891	1.879	1.827	1.749	1.674	1.611	1.560
DB-093	GW	27.958	28.012	27.840	27.380	26.981	26.532	26.473
DB-093	SW	4.756	4.735	4.626	4.434	4.247	4.105	4.004
DB-094	GW	13.968	13.359	12.013	10.815	9.757	8.841	8.035
DB-094	SW	2.535	2.504	2.406	2.297	2.193	2.135	2.084
DB-095	GW	6.465	6.221	5.703	5.254	4.880	4.582	4.348
DB-095	SW	10.813	10.685	10.264	9.846	9.444	9.271	9.110
DB-096	GW	2.473	2.489	2.505	2.527	2.551	2.523	2.497
DB-096	SW	2.812	2.774	2.650	2.524	2.401	2.358	2.320
DB-097	GW	7.963	8.012	8.061	8.145	8.237	8.156	8.082
DB-097	SW	0.555	0.552	0.540	0.520	0.504	0.492	0.484
DB-098	GW	1.546	1.571	1.621	1.669	1.719	1.734	1.750
DB-098	SW	0.809	0.805	0.787	0.763	0.741	0.721	0.705
DB-099	GW	12.452	12.704	13.297	13.935	14.602	15.033	15.497
DB-099	SW	14.690	14.823	15.027	15.209	15.411	15.544	15.702
DB-100	GW	4.270	4.399	4.559	4.681	4.820	4.873	4.940
DB-100	SW	1.154	1.151	1.135	1.104	1.076	1.054	1.038
DB-101	GW	6.031	6.147	6.378	6.631	6.884	6.861	6.841
DB-101	SW	0.601	0.599	0.588	0.569	0.553	0.539	0.529
DB-102	GW	7.715	7.825	8.046	8.287	8.540	8.593	8.656
DB-102	SW	1.525	1.537	1.557	1.563	1.574	1.553	1.540
DB-103	GW	2.037	2.059	2.098	2.144	2.193	2.173	2.155
DB-103	SW	1.074	1.076	1.071	1.059	1.049	1.040	1.036
DB-104	GW	13.156	13.548	14.517	15.540	16.653	17.766	18.990
DB-104	SW	4.855	4.909	4.997	5.053	5.107	5.140	5.178

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DB-105	GW	1.671	1.698	1.753	1.789	1.825	1.848	1.872
DB-105	SW	0.501	0.501	0.497	0.485	0.473	0.462	0.453
DB-106	GW	5.007	5.115	5.338	5.538	5.737	5.870	6.002
DB-106	SW	0.658	0.658	0.653	0.639	0.626	0.614	0.605
DB-107	GW	8.422	8.624	9.047	9.446	9.839	10.109	10.378
DB-107	SW	0.776	0.784	0.795	0.799	0.800	0.797	0.793
DB-108	GW	7.179	7.308	7.558	7.723	7.886	7.892	7.899
DB-108	SW	19.704	19.943	20.359	20.652	20.961	21.203	21.465
DB-109	GW	11.673	11.803	12.041	12.229	12.427	12.569	12.722
DB-109	SW	0.666	0.665	0.655	0.647	0.635	0.611	0.585
DB-110	GW	9.192	9.305	9.501	9.630	9.761	9.786	9.815
DB-110	SW	0.486	0.487	0.483	0.479	0.471	0.454	0.435
DB-111	GW	19.796	20.023	20.409	20.692	21.013	21.178	21.645
DB-111	SW	4.131	4.117	4.033	3.878	3.728	3.616	3.540
DB-112	GW	0.237	0.236	0.231	0.227	0.223	0.219	0.215
DB-112	SW	0.348	0.346	0.339	0.332	0.324	0.314	0.304
DB-113	GW	4.986	5.012	5.069	5.091	5.118	5.125	5.162
DB-113	SW	4.094	4.091	4.044	3.937	3.831	3.754	3.709
DB-114	GW	1.031	1.033	1.030	1.023	1.017	1.008	0.998
DB-114	SW	21.731	21.989	22.433	22.746	23.074	23.336	23.619
DB-115	GW	1.124	1.137	1.159	1.178	1.197	1.190	1.184
DB-115	SW	2.637	2.664	2.709	2.738	2.770	2.793	2.819
DB-116	GW	0.421	0.422	0.421	0.416	0.411	0.406	0.401
DB-116	SW	0.041	0.041	0.040	0.038	0.037	0.035	0.034
DB-117	GW	4.098	4.228	4.564	4.868	5.139	5.680	5.925
DB-117	SW	3.798	3.783	3.701	3.552	3.407	3.307	3.236
DB-118	GW	3.611	3.705	3.921	4.196	4.400	4.591	4.805
DB-118	SW	4.386	4.368	4.273	4.103	3.936	3.812	3.731
DB-119	GW	9.452	9.436	9.348	9.196	9.051	8.937	8.843
DB-119	SW	20.668	20.602	20.221	19.589	18.955	18.411	17.969
DB-120	GW	8.509	8.661	8.967	9.211	9.469	9.668	9.882
DB-120	SW	6.999	7.083	7.232	7.325	7.425	7.494	7.575
DB-121	GW	5.773	5.889	6.127	6.307	6.493	6.589	6.690
DB-121	SW	6.468	6.608	6.904	7.161	7.438	7.682	7.955
DB-122	GW	1.447	1.462	1.484	1.505	1.523	1.516	1.510
DB-122	SW	19.244	19.326	19.307	19.255	19.122	18.951	18.767
DB-123	GW	2.573	2.629	2.745	2.843	2.938	3.002	3.061
DB-123	SW	1.273	1.240	1.152	1.060	0.976	0.902	0.837
DB-124	GW	5.421	5.517	5.685	5.817	5.930	6.004	6.062
DB-124	SW	21.618	21.984	22.588	23.092	23.478	23.764	23.934
DB-125	GW	6.861	6.958	7.099	7.192	7.251	7.304	7.331
DB-125	SW	2.912	2.959	3.033	3.092	3.136	3.168	3.186
DB-126	GW	3.945	3.935	3.854	3.730	3.621	3.544	3.465

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-126	SW	8.071	8.030	7.833	7.488	7.156	6.908	6.738
DB-127	GW	14.214	14.327	14.453	14.544	14.624	14.689	14.739
DB-127	SW	1.444	1.388	1.246	1.106	0.983	0.874	0.778
DB-128	GW	0.531	0.527	0.511	0.492	0.473	0.457	0.443
DB-128	SW	0.054	0.053	0.052	0.050	0.047	0.046	0.045
DB-129	GW	3.063	3.055	3.015	2.957	2.890	2.826	2.798
DB-129	SW	10.027	9.980	9.753	9.355	8.960	8.650	8.435
DB-130	GW	1.363	1.372	1.377	1.368	1.356	1.346	1.339
DB-130	SW	0.152	0.151	0.147	0.140	0.134	0.129	0.126
DB-131	GW	2.011	2.013	2.003	1.992	1.969	1.948	1.946
DB-131	SW	5.719	5.691	5.551	5.307	5.071	4.895	4.775
DB-132	GW	5.619	5.630	5.571	5.443	5.317	5.217	5.141
DB-132	SW	0.768	0.763	0.744	0.711	0.679	0.656	0.639
DB-133	GW	11.796	11.844	11.843	11.965	11.953	11.959	11.981
DB-133	SW	10.388	10.315	10.014	9.547	9.097	8.750	8.498
DB-134	GW	2.537	2.541	2.523	2.485	2.434	2.402	2.387
DB-134	SW	9.540	9.495	9.270	8.877	8.498	8.215	8.022
DB-135	GW	7.325	7.370	7.331	7.187	7.044	6.945	6.884
DB-135	SW	1.254	1.247	1.216	1.162	1.110	1.071	1.044
DB-136	GW	11.251	11.440	11.803	11.980	12.248	12.519	13.089
DB-136	SW	6.470	6.446	6.315	6.071	5.835	5.660	5.543
DB-137	GW	83.778	84.795	86.772	90.618	92.340	93.583	95.229
DB-137	SW	11.856	11.799	11.515	11.018	10.536	10.176	9.930
DB-138	GW	7.676	7.758	7.875	8.126	8.259	8.399	8.545
DB-138	SW	5.781	5.752	5.611	5.365	5.126	4.949	4.827
DB-139	GW	3.284	3.305	3.321	3.353	3.355	3.367	3.389
DB-139	SW	5.918	5.891	5.753	5.510	5.274	5.098	4.978
DB-140	GW	1.628	1.635	1.634	1.637	1.629	1.628	1.635
DB-140	SW	7.196	7.176	7.077	6.903	6.736	6.611	6.526
DB-141	GW	2.575	2.613	2.679	2.744	2.799	2.860	2.928
DB-141	SW	3.119	3.103	3.027	2.894	2.765	2.670	2.604
DB-142	GW	8.388	8.505	8.708	8.892	9.069	9.234	9.416
DB-142	SW	0.618	0.615	0.600	0.574	0.548	0.529	0.516
DB-143	GW	12.997	13.164	13.206	13.185	13.143	13.124	13.108
DB-143	SW	1.103	1.097	1.069	1.022	0.976	0.942	0.918
DB-144	GW	7.900	7.977	7.994	7.884	7.771	7.693	7.646
DB-144	SW	1.298	1.291	1.259	1.203	1.149	1.109	1.081
DB-145	GW	8.300	8.422	8.538	8.546	8.549	8.574	8.619
DB-145	SW	1.164	1.162	1.144	1.106	1.072	1.050	1.039
DB-146	GW	6.812	6.804	6.716	6.512	6.331	6.220	6.176
DB-146	SW	1.664	1.665	1.654	1.616	1.585	1.572	1.574
DB-147	GW	10.893	11.000	11.152	11.154	11.166	11.231	11.351
DB-147	SW	1.674	1.675	1.664	1.626	1.595	1.581	1.584

The table below contains a summary of current and future water use, aggregated to the watershed scale. All figures are peak consumptive use, using the month of July (Million gallons/per day), and are listed by source type, ground water (GW) and surface water (SW). Assumptions regarding water conservation are included in these estimates.

Table 4.2: Consumptive Use: Peak MGD (July)

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-001	GW	0.222	0.219	0.210	0.201	0.192	0.184	0.177
DB-001	SW	0.063	0.061	0.059	0.055	0.052	0.050	0.048
DB-002	GW	0.070	0.069	0.066	0.063	0.060	0.058	0.055
DB-002	SW	0.022	0.022	0.021	0.020	0.019	0.018	0.017
DB-003	GW	0.223	0.222	0.216	0.208	0.201	0.193	0.185
DB-003	SW	0.035	0.035	0.033	0.031	0.030	0.028	0.027
DB-004	GW	0.083	0.082	0.079	0.075	0.072	0.069	0.066
DB-004	SW	0.023	0.022	0.021	0.020	0.019	0.018	0.017
DB-005	GW	0.181	0.179	0.172	0.164	0.157	0.151	0.144
DB-005	SW	0.052	0.051	0.049	0.046	0.044	0.042	0.040
DB-006	GW	0.066	0.065	0.062	0.060	0.058	0.055	0.053
DB-006	SW	0.017	0.017	0.016	0.015	0.014	0.014	0.013
DB-007	GW	0.120	0.119	0.115	0.111	0.107	0.104	0.101
DB-007	SW	0.032	0.031	0.030	0.028	0.027	0.026	0.025
DB-008	GW	0.060	0.059	0.057	0.054	0.052	0.050	0.047
DB-008	SW	0.018	0.018	0.017	0.016	0.015	0.014	0.014
DB-009	GW	0.100	0.099	0.096	0.094	0.092	0.089	0.086
DB-009	SW	0.039	0.038	0.037	0.035	0.033	0.032	0.030
DB-010	GW	0.340	0.336	0.324	0.310	0.298	0.286	0.275
DB-010	SW	0.112	0.111	0.106	0.101	0.096	0.092	0.088
DB-011	GW	0.239	0.236	0.227	0.216	0.207	0.199	0.190
DB-011	SW	0.079	0.078	0.074	0.070	0.067	0.064	0.061
DB-012	GW	0.196	0.195	0.190	0.184	0.178	0.173	0.169
DB-012	SW	0.078	0.077	0.075	0.072	0.068	0.066	0.064
DB-013	GW	0.195	0.195	0.195	0.193	0.192	0.192	0.192
DB-013	SW	0.051	0.051	0.050	0.048	0.046	0.045	0.044
DB-014	GW	0.138	0.136	0.131	0.125	0.120	0.115	0.110
DB-014	SW	0.039	0.038	0.036	0.034	0.033	0.031	0.030
DB-015	GW	0.108	0.107	0.104	0.100	0.097	0.094	0.091
DB-015	SW	0.029	0.028	0.027	0.025	0.024	0.023	0.022
DB-016	GW	0.111	0.109	0.105	0.100	0.096	0.092	0.088
DB-016	SW	0.033	0.033	0.031	0.029	0.028	0.027	0.025
DB-017	GW	0.116	0.115	0.113	0.110	0.107	0.105	0.103
DB-017	SW	0.030	0.030	0.029	0.027	0.026	0.025	0.024
DB-018	GW	0.211	0.210	0.207	0.204	0.202	0.197	0.191
DB-018	SW	0.079	0.078	0.075	0.071	0.068	0.065	0.063
DB-019	GW	0.066	0.067	0.067	0.068	0.068	0.069	0.070
DB-019	SW	0.010	0.010	0.010	0.010	0.009	0.009	0.009
DB-020	GW	0.132	0.133	0.134	0.135	0.136	0.137	0.138
DB-020	SW	0.022	0.022	0.021	0.021	0.020	0.020	0.019
DB-021	GW	0.044	0.044	0.045	0.045	0.045	0.045	0.046

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-021	SW	0.007	0.007	0.007	0.007	0.007	0.007	0.007
DB-022	GW	0.145	0.145	0.146	0.147	0.148	0.145	0.142
DB-022	SW	0.048	0.047	0.045	0.043	0.041	0.039	0.038
DB-023	GW	0.092	0.092	0.092	0.093	0.093	0.094	0.095
DB-023	SW	0.017	0.017	0.017	0.016	0.016	0.015	0.015
DB-024	GW	0.104	0.108	0.118	0.129	0.140	0.150	0.160
DB-024	SW	0.013	0.013	0.013	0.012	0.011	0.011	0.010
DB-025	GW	0.215	0.215	0.215	0.215	0.215	0.211	0.207
DB-025	SW	0.058	0.057	0.055	0.052	0.050	0.047	0.046
DB-026	GW	0.117	0.116	0.114	0.112	0.110	0.107	0.104
DB-026	SW	0.044	0.043	0.042	0.039	0.038	0.036	0.035
DB-027	GW	0.239	0.242	0.247	0.254	0.261	0.259	0.258
DB-027	SW	0.062	0.062	0.060	0.059	0.057	0.055	0.053
DB-028	GW	0.278	0.284	0.296	0.309	0.322	0.335	0.348
DB-028	SW	0.086	0.087	0.089	0.091	0.092	0.093	0.094
DB-029	GW	0.122	0.123	0.123	0.123	0.123	0.124	0.125
DB-029	SW	0.026	0.025	0.025	0.024	0.023	0.023	0.023
DB-030	GW	0.174	0.176	0.180	0.184	0.188	0.185	0.181
DB-030	SW	0.043	0.043	0.041	0.039	0.037	0.036	0.035
DB-031	GW	0.335	0.346	0.370	0.400	0.430	0.443	0.456
DB-031	SW	0.113	0.115	0.120	0.126	0.131	0.133	0.135
DB-032	GW	0.168	0.183	0.218	0.250	0.282	0.318	0.354
DB-032	SW	0.006	0.006	0.006	0.005	0.005	0.005	0.005
DB-033	GW	0.140	0.141	0.142	0.143	0.144	0.145	0.147
DB-033	SW	0.022	0.022	0.022	0.021	0.021	0.020	0.020
DB-034	GW	0.116	0.117	0.119	0.120	0.122	0.124	0.125
DB-034	SW	0.012	0.012	0.011	0.011	0.011	0.010	0.010
DB-035	GW	0.322	0.323	0.323	0.320	0.318	0.317	0.317
DB-035	SW	0.082	0.082	0.080	0.076	0.073	0.071	0.069
DB-036	GW	0.200	0.213	0.242	0.278	0.312	0.352	0.391
DB-036	SW	0.005	0.005	0.005	0.005	0.005	0.004	0.004
DB-037	GW	0.218	0.217	0.214	0.208	0.202	0.198	0.195
DB-037	SW	0.088	0.088	0.086	0.082	0.079	0.076	0.074
DB-038	GW	0.527	0.531	0.538	0.544	0.551	0.557	0.564
DB-038	SW	0.360	0.358	0.351	0.339	0.327	0.319	0.312
DB-039	GW	0.257	0.259	0.262	0.264	0.266	0.268	0.270
DB-039	SW	0.038	0.038	0.037	0.035	0.034	0.033	0.032
DB-040	GW	0.212	0.233	0.284	0.327	0.369	0.418	0.466
DB-040	SW	0.006	0.006	0.006	0.005	0.005	0.005	0.005
DB-041	GW	0.054	0.055	0.057	0.059	0.061	0.064	0.067
DB-041	SW	0.044	0.044	0.043	0.041	0.039	0.038	0.037
DB-042	GW	0.111	0.111	0.111	0.111	0.111	0.114	0.118
DB-042	SW	0.167	0.166	0.162	0.155	0.148	0.143	0.139
DB-043	GW	0.206	0.221	0.258	0.292	0.325	0.362	0.399
DB-043	SW	0.204	0.220	0.258	0.293	0.324	0.358	0.387
DB-044	GW	0.166	0.166	0.164	0.160	0.156	0.153	0.151
DB-044	SW	0.493	0.490	0.478	0.457	0.437	0.421	0.411
DB-045	GW	0.410	0.425	0.460	0.493	0.526	0.559	0.591

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-045	SW	0.861	0.894	0.967	1.036	1.097	1.157	1.208
DB-046	GW	0.231	0.241	0.262	0.283	0.303	0.323	0.342
DB-046	SW	0.078	0.080	0.084	0.087	0.090	0.093	0.095
DB-047	GW	0.106	0.110	0.119	0.128	0.136	0.145	0.153
DB-047	SW	0.117	0.121	0.129	0.138	0.144	0.151	0.157
DB-048	GW	0.048	0.048	0.048	0.048	0.048	0.048	0.048
DB-048	SW	0.051	0.051	0.049	0.047	0.045	0.043	0.042
DB-049	GW	0.508	0.515	0.528	0.539	0.549	0.561	0.571
DB-049	SW	0.347	0.347	0.343	0.335	0.325	0.319	0.315
DB-050	GW	0.432	0.433	0.428	0.420	0.413	0.409	0.405
DB-050	SW	1.125	1.119	1.092	1.044	0.998	0.964	0.940
DB-051	GW	0.440	0.442	0.437	0.429	0.422	0.417	0.413
DB-051	SW	0.903	0.898	0.876	0.837	0.800	0.772	0.753
DB-052	GW	0.869	0.882	0.919	0.931	0.942	0.948	0.948
DB-052	SW	1.579	1.574	1.543	1.483	1.424	1.380	1.348
DB-053	GW	0.242	0.243	0.243	0.243	0.243	0.240	0.238
DB-053	SW	0.360	0.363	0.368	0.370	0.370	0.367	0.362
DB-054	GW	1.017	1.030	1.039	1.038	1.026	1.021	1.012
DB-054	SW	0.955	0.953	0.935	0.899	0.863	0.836	0.816
DB-055	GW	0.664	0.665	0.665	0.664	0.664	0.662	0.660
DB-055	SW	0.268	0.267	0.260	0.251	0.243	0.236	0.230
DB-056	GW	0.093	0.096	0.102	0.108	0.115	0.118	0.122
DB-056	SW	0.053	0.052	0.051	0.049	0.046	0.045	0.043
DB-057	GW	0.243	0.258	0.293	0.326	0.359	0.391	0.423
DB-057	SW	0.352	0.378	0.437	0.494	0.544	0.592	0.639
DB-058	GW	0.074	0.073	0.070	0.067	0.064	0.063	0.061
DB-058	SW	0.091	0.090	0.088	0.084	0.080	0.077	0.075
DB-059	GW	0.070	0.069	0.066	0.063	0.060	0.059	0.058
DB-059	SW	0.042	0.042	0.041	0.039	0.037	0.036	0.035
DB-060	GW	0.097	0.097	0.095	0.094	0.093	0.092	0.091
DB-060	SW	0.620	0.612	0.585	0.559	0.534	0.525	0.517
DB-061	GW	1.456	1.480	1.541	1.604	1.671	1.746	1.826
DB-061	SW	1.455	1.248	1.370	1.487	1.620	1.774	1.949
DB-062	GW	0.373	0.393	0.439	0.485	0.525	0.553	0.575
DB-062	SW	1.850	1.867	1.890	1.910	1.932	1.931	1.933
DB-063	GW	0.821	0.817	0.805	0.792	0.781	0.763	0.745
DB-063	SW	0.254	0.252	0.246	0.236	0.226	0.219	0.214
DB-064	GW	0.097	0.098	0.100	0.102	0.104	0.106	0.108
DB-064	SW	0.424	0.430	0.441	0.451	0.461	0.466	0.471
DB-065	GW	0.943	0.949	0.956	0.960	0.965	0.960	0.955
DB-065	SW	0.304	0.304	0.300	0.292	0.285	0.278	0.273
DB-066	GW	1.105	1.113	1.121	1.124	1.127	1.122	1.118
DB-066	SW	0.586	0.588	0.586	0.577	0.566	0.552	0.537
DB-067	GW	2.096	2.110	2.125	2.135	2.146	2.132	2.120
DB-067	SW	0.761	0.761	0.755	0.743	0.732	0.719	0.709
DB-068	GW	1.806	1.811	1.817	1.823	1.827	1.813	1.797
DB-068	SW	0.592	0.593	0.589	0.581	0.571	0.557	0.542
DB-069	GW	0.561	0.565	0.572	0.567	0.561	0.558	0.555

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-069	SW	1.100	1.095	1.071	1.025	0.981	0.949	0.926
DB-070	GW	0.708	0.716	0.722	0.719	0.717	0.714	0.718
DB-070	SW	0.489	0.488	0.480	0.462	0.445	0.431	0.421
DB-071	GW	0.976	0.984	0.989	0.975	0.963	0.954	0.947
DB-071	SW	1.024	1.020	0.998	0.959	0.921	0.892	0.872
DB-072	GW	0.257	0.261	0.269	0.277	0.286	0.290	0.295
DB-072	SW	0.233	0.232	0.226	0.216	0.206	0.199	0.193
DB-073	GW	0.309	0.313	0.314	0.315	0.317	0.320	0.323
DB-073	SW	0.377	0.377	0.371	0.359	0.348	0.340	0.334
DB-074	GW	0.626	0.639	0.666	0.695	0.724	0.743	0.762
DB-074	SW	0.298	0.296	0.289	0.277	0.266	0.257	0.251
DB-075	GW	0.282	0.286	0.286	0.288	0.295	0.302	0.309
DB-075	SW	0.269	0.267	0.261	0.249	0.238	0.230	0.225
DB-076	GW	1.075	1.097	1.150	1.206	1.264	1.316	1.371
DB-076	SW	0.278	0.279	0.278	0.274	0.270	0.265	0.261
DB-077	GW	0.279	0.280	0.280	0.277	0.276	0.276	0.276
DB-077	SW	0.495	0.493	0.482	0.462	0.443	0.429	0.418
DB-078	GW	0.984	0.993	1.008	1.005	1.002	0.999	0.998
DB-078	SW	1.328	1.324	1.302	1.256	1.210	1.175	1.149
DB-079	GW	0.288	0.291	0.293	0.295	0.296	0.294	0.292
DB-079	SW	0.230	0.230	0.226	0.220	0.214	0.209	0.205
DB-080	GW	1.588	1.615	1.652	1.665	1.675	1.692	1.712
DB-080	SW	4.038	4.051	4.046	3.967	3.874	3.814	3.777
DB-081	GW	0.979	1.004	1.039	1.047	1.051	1.072	1.090
DB-081	SW	1.902	1.904	1.882	1.815	1.748	1.709	1.682
DB-082	GW	1.458	1.482	1.485	1.476	1.463	1.465	1.467
DB-082	SW	1.765	1.757	1.716	1.643	1.572	1.519	1.483
DB-083	GW	2.464	2.513	2.617	2.719	2.821	2.888	2.955
DB-083	SW	2.667	2.707	2.780	2.818	2.850	2.840	2.828
DB-084	GW	0.697	0.707	0.723	0.736	0.747	0.741	0.736
DB-084	SW	1.255	1.267	1.286	1.296	1.306	1.315	1.327
DB-085	GW	0.772	0.773	0.770	0.751	0.738	0.725	0.718
DB-085	SW	4.297	4.297	4.269	4.178	4.096	4.026	3.985
DB-086	GW	0.659	0.663	0.656	0.642	0.634	0.631	0.629
DB-086	SW	2.329	2.318	2.264	2.168	2.076	2.007	1.960
DB-087	GW	1.119	1.140	1.143	1.137	1.126	1.126	1.130
DB-087	SW	3.085	3.094	3.050	2.962	2.867	2.801	2.754
DB-088	GW	1.582	1.593	1.606	1.599	1.587	1.582	1.579
DB-088	SW	3.567	3.562	3.503	3.381	3.258	3.168	3.104
DB-089	GW	0.361	0.365	0.369	0.373	0.377	0.378	0.378
DB-089	SW	0.309	0.309	0.304	0.300	0.294	0.283	0.271
DB-090	GW	3.214	3.239	3.203	3.165	3.142	3.095	3.060
DB-090	SW	1.899	1.893	1.850	1.776	1.705	1.651	1.613
DB-091	GW	0.034	0.034	0.034	0.034	0.035	0.035	0.036
DB-091	SW	0.096	0.095	0.093	0.092	0.090	0.087	0.083
DB-092	GW	2.774	2.766	2.711	2.645	2.590	2.522	2.467
DB-092	SW	1.206	1.200	1.171	1.122	1.075	1.038	1.010
DB-093	GW	3.729	3.731	3.696	3.618	3.546	3.474	3.448

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-093	SW	4.267	4.248	4.150	3.977	3.809	3.680	3.590
DB-094	GW	2.918	2.781	2.533	2.314	2.126	1.968	1.835
DB-094	SW	0.695	0.690	0.671	0.643	0.616	0.599	0.586
DB-095	GW	1.804	1.774	1.749	1.738	1.753	1.794	1.860
DB-095	SW	1.303	1.289	1.242	1.191	1.143	1.120	1.100
DB-096	GW	0.412	0.413	0.413	0.413	0.415	0.412	0.411
DB-096	SW	0.743	0.737	0.714	0.684	0.655	0.638	0.626
DB-097	GW	1.220	1.222	1.221	1.220	1.226	1.215	1.207
DB-097	SW	0.500	0.497	0.486	0.468	0.453	0.443	0.436
DB-098	GW	0.380	0.381	0.382	0.381	0.383	0.383	0.383
DB-098	SW	0.396	0.394	0.385	0.371	0.358	0.348	0.342
DB-099	GW	2.415	2.453	2.545	2.641	2.748	2.836	2.931
DB-099	SW	2.045	2.058	2.070	2.074	2.081	2.082	2.088
DB-100	GW	1.543	1.623	1.686	1.739	1.810	1.881	1.965
DB-100	SW	1.036	1.034	1.019	0.991	0.967	0.946	0.932
DB-101	GW	1.130	1.143	1.169	1.195	1.224	1.216	1.208
DB-101	SW	0.463	0.461	0.452	0.438	0.426	0.416	0.409
DB-102	GW	1.590	1.600	1.621	1.639	1.667	1.677	1.691
DB-102	SW	0.886	0.883	0.871	0.848	0.828	0.810	0.799
DB-103	GW	0.598	0.599	0.599	0.598	0.600	0.595	0.591
DB-103	SW	0.471	0.469	0.461	0.447	0.435	0.426	0.420
DB-104	GW	2.454	2.520	2.690	2.870	3.069	3.274	3.500
DB-104	SW	1.356	1.367	1.382	1.387	1.388	1.379	1.371
DB-105	GW	0.526	0.529	0.533	0.532	0.532	0.528	0.525
DB-105	SW	0.451	0.451	0.447	0.437	0.426	0.416	0.407
DB-106	GW	0.758	0.769	0.791	0.808	0.828	0.840	0.853
DB-106	SW	0.468	0.468	0.462	0.450	0.439	0.429	0.422
DB-107	GW	1.202	1.226	1.279	1.327	1.374	1.406	1.439
DB-107	SW	0.589	0.596	0.606	0.610	0.612	0.610	0.607
DB-108	GW	0.794	0.807	0.831	0.845	0.860	0.859	0.857
DB-108	SW	2.248	2.275	2.321	2.351	2.381	2.400	2.421
DB-109	GW	1.637	1.652	1.677	1.699	1.722	1.733	1.745
DB-109	SW	0.600	0.598	0.589	0.582	0.571	0.550	0.527
DB-110	GW	1.180	1.191	1.209	1.220	1.229	1.222	1.214
DB-110	SW	0.438	0.438	0.435	0.431	0.424	0.408	0.391
DB-111	GW	8.191	8.292	8.466	8.609	8.740	8.780	8.889
DB-111	SW	3.486	3.471	3.391	3.248	3.111	3.008	2.937
DB-112	GW	0.058	0.058	0.056	0.055	0.053	0.052	0.051
DB-112	SW	0.313	0.312	0.305	0.299	0.291	0.283	0.273
DB-113	GW	0.981	0.981	0.975	0.956	0.940	0.925	0.919
DB-113	SW	3.127	3.117	3.064	2.961	2.861	2.786	2.740
DB-114	GW	0.297	0.297	0.293	0.288	0.283	0.278	0.272
DB-114	SW	2.551	2.576	2.615	2.639	2.663	2.680	2.699
DB-115	GW	0.173	0.174	0.174	0.173	0.173	0.171	0.169
DB-115	SW	0.439	0.442	0.445	0.445	0.445	0.443	0.442
DB-116	GW	0.180	0.179	0.176	0.169	0.163	0.158	0.155
DB-116	SW	0.037	0.037	0.036	0.034	0.033	0.032	0.031
DB-117	GW	1.087	1.101	1.132	1.151	1.165	1.220	1.242

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-117	SW	3.418	3.404	3.331	3.197	3.066	2.976	2.913
DB-118	GW	1.100	1.109	1.121	1.129	1.129	1.133	1.147
DB-118	SW	3.947	3.931	3.846	3.693	3.542	3.431	3.358
DB-119	GW	2.989	2.980	2.929	2.850	2.764	2.691	2.636
DB-119	SW	10.241	10.200	9.987	9.629	9.263	8.973	8.769
DB-120	GW	1.193	1.203	1.223	1.233	1.248	1.259	1.273
DB-120	SW	1.424	1.434	1.448	1.445	1.443	1.435	1.430
DB-121	GW	1.054	1.062	1.075	1.079	1.088	1.088	1.089
DB-121	SW	1.213	1.223	1.237	1.239	1.246	1.254	1.269
DB-122	GW	0.290	0.291	0.290	0.288	0.286	0.282	0.278
DB-122	SW	2.796	2.810	2.813	2.809	2.789	2.756	2.718
DB-123	GW	0.531	0.540	0.555	0.567	0.578	0.582	0.585
DB-123	SW	0.474	0.471	0.460	0.443	0.426	0.412	0.399
DB-124	GW	1.130	1.136	1.139	1.130	1.121	1.112	1.106
DB-124	SW	2.537	2.578	2.645	2.697	2.736	2.762	2.774
DB-125	GW	1.134	1.142	1.145	1.137	1.125	1.117	1.110
DB-125	SW	0.457	0.462	0.469	0.472	0.472	0.472	0.471
DB-126	GW	1.674	1.666	1.626	1.558	1.495	1.447	1.412
DB-126	SW	7.263	7.227	7.050	6.739	6.440	6.217	6.064
DB-127	GW	1.460	1.476	1.498	1.512	1.525	1.537	1.547
DB-127	SW	0.186	0.180	0.165	0.149	0.135	0.123	0.112
DB-128	GW	0.264	0.263	0.259	0.250	0.241	0.235	0.229
DB-128	SW	0.048	0.048	0.047	0.045	0.043	0.041	0.040
DB-129	GW	1.811	1.801	1.760	1.690	1.621	1.568	1.533
DB-129	SW	8.602	8.560	8.352	7.990	7.639	7.375	7.194
DB-130	GW	0.641	0.639	0.626	0.604	0.582	0.565	0.553
DB-130	SW	0.136	0.136	0.132	0.126	0.121	0.116	0.113
DB-131	GW	1.147	1.143	1.121	1.083	1.045	1.015	0.996
DB-131	SW	5.147	5.122	4.996	4.776	4.564	4.406	4.298
DB-132	GW	3.218	3.205	3.133	3.006	2.884	2.792	2.728
DB-132	SW	0.691	0.687	0.670	0.640	0.611	0.590	0.575
DB-133	GW	4.441	4.472	4.501	4.561	4.554	4.559	4.577
DB-133	SW	8.546	8.505	8.299	7.945	7.599	7.341	7.164
DB-134	GW	2.103	2.103	2.079	2.037	1.983	1.946	1.923
DB-134	SW	8.349	8.308	8.106	7.752	7.411	7.157	6.983
DB-135	GW	5.088	5.070	4.959	4.759	4.566	4.422	4.324
DB-135	SW	1.128	1.122	1.094	1.045	0.999	0.964	0.940
DB-136	GW	2.279	2.297	2.320	2.307	2.304	2.309	2.353
DB-136	SW	5.823	5.802	5.683	5.464	5.251	5.094	4.989
DB-137	GW	63.057	63.844	65.435	68.448	69.727	70.586	71.802
DB-137	SW	10.671	10.619	10.363	9.916	9.482	9.158	8.937
DB-138	GW	2.550	2.568	2.583	2.617	2.616	2.622	2.637
DB-138	SW	5.203	5.177	5.050	4.828	4.614	4.454	4.345
DB-139	GW	1.598	1.601	1.590	1.571	1.542	1.522	1.511
DB-139	SW	5.326	5.302	5.177	4.959	4.746	4.588	4.480
DB-140	GW	0.795	0.793	0.777	0.751	0.724	0.705	0.693
DB-140	SW	4.282	4.264	4.175	4.019	3.868	3.756	3.679
DB-141	GW	0.815	0.818	0.815	0.804	0.792	0.785	0.783

Basin_ID	SourceType	2003	2005	2010	2015	2020	2025	2030
DB-141	SW	2.807	2.793	2.724	2.604	2.489	2.403	2.344
DB-142	GW	0.949	0.960	0.979	0.993	1.007	1.021	1.038
DB-142	SW	0.556	0.553	0.540	0.516	0.493	0.476	0.465
DB-143	GW	5.121	5.118	5.027	4.861	4.699	4.579	4.496
DB-143	SW	0.993	0.987	0.962	0.920	0.879	0.848	0.827
DB-144	GW	5.287	5.272	5.162	4.958	4.761	4.614	4.514
DB-144	SW	1.168	1.162	1.133	1.082	1.034	0.998	0.973
DB-145	GW	4.748	4.748	4.686	4.545	4.413	4.324	4.274
DB-145	SW	1.048	1.046	1.030	0.995	0.965	0.945	0.935
DB-146	GW	6.131	6.124	6.044	5.861	5.698	5.598	5.559
DB-146	SW	1.497	1.499	1.489	1.454	1.427	1.415	1.417
DB-147	GW	6.512	6.515	6.457	6.291	6.145	6.061	6.035
DB-147	SW	1.506	1.508	1.498	1.463	1.435	1.423	1.425

APPENDIX B

Lambertville, New Jersey

BACKGROUND

Lambertville is a City in Hunterdon County, New Jersey, United States. As of the United States 2000 Census, the city population was 3,868. Lambertville is located at 40°22′4″N, 74°56′34″W (40.367881, -74.942860). The city borders Delaware Township and West Amwell Township. The city has a total area of 1.2 square miles (3.2 km²), of which, 1.1 square miles (2.9 km²) of it is land and 0.1 square miles (0.3 km²) of it (9.60%) is water.

Lambertville is located on the Delaware River in the southwestern portion of Hunterdon County. Since the 1800s, Lambertville, due to its proximity to the canal and the (now defunct) railroad, became a factory town. However, today the factories are closed and the town has maintained some of its 18th and 19th century flavor remains -- particularly in its houses, many of which have been restored. The town has become a tourist destination, with many shops, galleries, restaurants, and B&Bs.

The City of Lambertville has highly developed the area in the river's floodplain with 20% of the Town's property value situated in the 100-year floodplain, totaling $147M. Swan Creek flows northwest as it enters the city and joins the Swan Creek Tributary about 1,000 feet inside the city limits then flows west into the Delaware River. Swan Creek drains the southern part of the city. Both portions of these streams have steep channels with high velocities. The Alexauken Creek has its headwaters in the central part of West Amwell Township and flows generally west along the northern border of Lambertville to the Delaware River. From its mouth upstream to a Conrail bridge, 1,200 feet, the creek forms the boundary between the City of Lambertville and Delaware Township.

PROBLEM IDENTIFICATION

Riverine flooding occurs along the Delaware River west of the Delaware and Raritan Canal. The Canal is elevated over the normal level of the river and is adjacent to a railroad track. The canal and railroad acts as a levee through the City, so from the treatment plant to Alexauken Creek there isn't overtopping from the Delaware River until waters rise higher than the100-year flood. There exist two areas where these earthworks passes over creeks. Backup in water from the Delaware River prevents the creek waters from flowing out of the City resulting in backwater flooding along the Swan Creek (+3 mi^2 drainage area) and Alexauken Creek (15 mi^2 drainage area). A 1999 flood event, from Hurrican Floyd, was a Swan Creek only event, the Delaware River did not cause a problem. Nearby, Ely Creek, (0.7 mi^2 drainage area) flows between Alexauken and Swan Creeks, and goes behind businesses and homes, also floods.

The municipality experienced major flooding events in September 2004, April 2005 and June 2006, resulting in millions of dollars of damage. The flooding of 2005 was 6" higher than the other two flooding events. The highest event in 2005 was estimated to be a 75 year flood event by the town's municipal engineer, but elsewhere was close to a 100 year event.

Flash flooding has occurred in the vicinity of the Elementary School along North Main Street. Additionally, flash flooding has been associated with hillside runoff. In both instances the hazards, vulnerability and potential mitigation measures have been studied by the City and selected mitigation measures have been funded or are scheduled in the next year or two. In the past the area of the School has received additional drainage structures that has mitigated the problem to a great extent, but has not eliminated it. Flooding in this area has an impact to the school and the adjacent roadway that impairs commerce and limits accessibility of the fire company equipment during times of flooding.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D, provided flood information from prior storm events. Lambertville damages for the 1955 event were $131,000 residential, $465,000 commercial, $295,000 industrial, $194,000 emergency costs, when coupled with other damages totaled $1,165,000,000 (1955 dollars) and would be between nine and ten times that amount in current dollars.

A partial file was recovered providing some information from a small flood control study done by the Corps in 1976-77. The information was principally hydraulic/hydrologic in nature involving tributary streams rather than the Delaware River itself. No report was found and the study was thought to have been terminated due to limited flood damages reported from a 1970 storm event and a termination of national program funding in 1978-79 by Congress.

The August 1984 Delaware River Basin Report listed 360 residences, 70 commercial properties, 7 industries and 13 other structures in the 500 year floodplain (also referred to a the Standard Project Flood SPF). There were 133 structures in the 100-year floodplain and 235 in the 1955 flood of record floodplain. That report provided information on the damages expected based on the level of development in 1983 from different flooding events: $1,000 for the 10-year event, $3,557,000 for the 50-year event, $10,168,000 for the 100-year event, $16,214,000 for a repeat of the 1955 flood of record, and $27,956 for the 500-year event. A consolidated Average Annual Damages was estimated at $285,000 in March 1983 dollars.

The August 1984 Delaware River Basin Report evaluated some flood reduction measures available to the City. Two new levees were evaluated, one on each side of Swan Creek. The total linear footage was 5,000 feet and would have had an initial cost of $10,140,000 in March 1983 dollars. Average annual costs were $918,000 and average annual benefits were $275,000 with a BCR of 0.30 to 1. Flood proofing was also evaluated. Of the 450 structures in the floodplain 45% needed no protection, 194 needed flood proofing, 10 needed individual floodwalls, 39 needed elevation, and 4 buyouts. The Benefit cost ratio for this low stage flood reduction as 0.65 to 1.

The National Park Service prepared in 1999 a National Wild and Scenic Study Report for the Lower Delaware River. That plan recommended that several river segments, including Segments G and H be designated as recreational within the Wild and Scenic River System. There is a 2,750 foot gap between these two designated segments which includes a portion of Lambertville 1000 feet north and 1,750 feet south of the Route 202 Bridge of the Delaware River. The Lower Delaware River Wild and Scenic River was made law in October 2000. Section 7(a) of the Wild and Scenic Rivers Act prohibits federal authorization of any water resources project or assistance by loan, grant, license or construction of any water resource project that would have an adverse impact on the values for which the river is designated. The boundary of this designation extends one-quarter mile inland from the ordinary high water mark. The 2,750 foot gap is not totally exclusionary in nature since the Wild and Scenic Designation also requires an evaluation of construction outside a wild and scenic designated river segment which could adversely affect a portion within a designated segment.

"Recreational" river areas -- Those rivers or sections of rivers that are readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past. Regardless of classification, each designated river is administered with the goal of nondegradation and enhancement of the values which caused it to be designated.

An October 2004 *Technical Report of the Interagency Wild and Scenic Rivers Coordinating Council titled Wild* & Scenic Rivers Act: Section 7 provides additional guidance. A determination is required when a project is proposed by a federal agency or it requires some type of federal assistance such as a permit, license, grant or loan. Unlike new FERC-licensed projects, which are prohibited if they are "on or directly affecting" a designated river, other proposed federally assisted water resources projects are prohibited only if they would have a "direct and adverse effect" on the values for which a river was added to the National System. Examples of projects that would likely be subject to this standard include, but are not limited to: dams; water diversion projects; fisheries habitat and watershed restoration/enhancement projects; bridge and other roadway construction /reconstruction projects; bank stabilization projects; channelization projects; levee construction; recreation facilities such as boat ramps and fishing piers; and, activities that require a Section 404 permit from the Army Corps of Engineers. The determination is made in consultation with state and federal agencies as part of the environmental assessment/impact statement process. Depending on the nature of the proposed construction and the degree of effect on the river's values and defined in the original study and management plan, the proposal can be approved, modified, conditioned, or denied.

The Hazard Mitigation Plan for the City of Lambertville, New Jersey (July 2006 draft) was the result of a collaborative effort and represents comprehensive disaster mitigation planning through evaluation and understanding of potential hazard risks, vulnerabilities to those risks, capabilities to manage those risk and selection of actions to achieve Lambertville's goals of a safer, sustainable community. This plan has been constructed to address the three highest vulnerability that the Community has to natural hazards, with flooding being the highest. The low lying, relatively flat topography and poor drainage characteristics of the majority of the land within the city boundaries combine to expose the City of Lambertville to a high potential to be flooded. When heavy rainfall and a high river discharge combine, low lying areas adjacent to streams and rivers become inundated. However, flood risks also arises from one or more of the following: sewer backup; drainage system backup; dam breaches; and storm water runoff problems. There are three significant drainage areas in City of Lambertville. These include the Swan and Alexauken Creeks and the Delaware River that forms the western boundary of the City. In the City of Lambertville several types of flooding have been observed to occur and include overbank flooding as a result of excessive water levels in the Delaware River inundating areas normally dry; backwater flooding where the higher level of the water in the Delaware causes backup or reverse flow in small streams and drainage piping structures; and backwater flooding due to high main-stem levels prohibiting discharge of the small creeks and drainage piping structures. As part of hazard mitigation, Lambertville wants to ensure that existing structures specifically targeting repetitive loss structures that are in the floodplain are resistant to flood related damage. To do this it would consider:

- Voluntary Acquisition or relocation for structures that are repetitively flooded or have high flood depths;
- Dry floodproofing for buildings on sound slab foundations that are subject to less than 27" of flooding.
- Elevating a building when flood depths are less than 10 feet and have low velocity (less than 5ft/sec).
- Conduct an assessment of all structures (60+/- structures in 100-year floodplain in City) in the 100-year floodplain and obtain flood depths, foundation type, historic nature of property, etc. to determine the best flood protection measure that will keep the character of the structure intact. Project costs and benefits will be considered when projects are prioritized.
- Protect critical facilities in the 100-year flood plain.

A field inspection was conducted on 23 January 2007 by Corps of Engineers staff and local representatives. There are approximately 42 homes and businesses which have repetitive losses when the flooding occurs, with two having severe repetitive losses. Overflow of Swan Creek occurs on the city side and floods approx. 60 properties, coming into basements and 1st floors. When Alexauken creek floods it backflows through the storm drainage system thus flooding area homes (primarily basements) and a commercial business (CVS). The houses on Lambert Lane are flooded by the River and have water coming into the basements and 1st floor; there are historic homes in this area ranging from $500-$600K, with a total value of $10-15M. Other impacted properties in the area range from $279K-$429K. During storm event of 2006 there were 400-500 evacuees; one death occurred when a person got too close to Swan Creek and was sucked in.

Lambertville is looking at all alternatives to try to better the situation, though the town does not want to force people to have their homes bought out. The city now has its own gauge with USGS doing maintenance; National Weather Service does the forecasting.

Municipal officials are looking at means to notify the public, possibly a reverse 911(comparable to what the county has now) and an AM radio station with a 30 mile radius area for coverage to warn people. They're working with residents to get homes raised (2 property owners have/are already raised theirs). Owners along the River would probably sell, but location makes selling price unacceptable.

According to DRBC, based upon a comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 64 repetitive loss properties (payments totaling $3,348,860) with 2 severe repetitive losses (payments totaling $$171,728) . This does not include damages from noninsured properties. These are clustered at 3 locations.
NRCS has completed a Preliminary Flood Damage and Mitigation Report on Swan Creek. Considerable information was developed on flood damages and structures damaged by flooding. A preliminary evaluation was done for the following alternatives:

- Modification of Water Supply Reservoir for Flood Control
- Floodwall
- Flood Gate and Pump (lift) Station
- Nonstructural Measures
- Combined Flood Gate and Pump (lift) Station and Nonstructural Measures

The study recommended further study with the combined plan favored.

Lambertville is thinking about pursuing the floodgate and lift (pumping) station so the creek could be closed before Delaware River flood waters come down from the north. The pumping station would have to handle both Swan Creek flood waters and canal overflow. Calculation of the downstream impact of keeping the Swan Creek backflow in the Delaware River is not part of the project, nor was there a price estimate. This project would not protect from a 100 year event and the FIRM maps would need to stay the same and people would still need to buy flood insurance.

The municipality is trying to obtain State funding for Ely Creek and for the storm sewer backflooding on the Alexauken. The municipality is thinking about putting a slide gate and small pump on Ely Creek. They are considering treating Alexauken Creek the same as Swan Creek, but the watershed is much larger (estimated as 15 square miles by the town officials), so the approach may not work. As with Swan Creek, neither of these projects would be designed for the 100 year flood.

<u>ALTERNATIVE EVALUATION</u>

<u>DELAWARE RIVER</u>

- <u>STRUCTURAL AND NON-STRUCTURAL FLOOD CONTROL MEASURES</u>
  With the overtopping of the banks of the Delaware River not occurring until greater than a 100 year flood, neither structural nor non-structural flood protection measures are justified. Stream backup will be evaluated separately under each specific waterbody.

SWAN CREEK

- STRUCTURAL FLOOD CONTROL MEASURES

  - A new levee-floodwall system is not possible due to the high real estate and construction costs. The proposal by NRCS which would construct a Flood Gate and Pump (lift) Station appear viable and should be pursued.

  - A full Channel Modification as such is not viable; deepening or widening Swan Creek would at most cause only a few feet of flood stage reduction at high fiscal and ecological cost. An updating of the stream hydraulics will determine if limited modifications could result in measurable stage differences. There has been no report of debris being a problem.

The construction of any structural plan must take into consideration the potential for an adverse determination which will be strongly influenced by the exact nature and specific design. While the Delaware River in the vicinity of Swan Creek is not designated as Wild and Scenic, construction could adversely impact the recreational condition of the river segments either up or downstream. Early coordination with the National Park Service should be initiated as soon as possible.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

  - The prior 1984 evaluation of nonstructural flood control measures demonstrate sufficient viability of non-structural measures to be considered. For structures where raising or buyout are not obviously feasible, other floodproofing measures need to be given greater emphasis.

  - Lambertville desires improved mapping in order to know what the river elevation reading means for the municipality in terms of area flooded (the modeling being done for the Susquehenna River is the kind they are interested in). The City has stated its desire for a "reverse" 911 type system. There exists an existing company named, reverse 911, which can utilize GIS flood mapping such as the Corps is developing coupled with a river forecast, as operated by the Weather Service and USGS, as the basis for such a system. They would also like to have an AM radio station that could be updated from a cell phone.

ALEXAUKEN CREEK

  - STRUCTURAL AND NON-STRUCTURAL FLOOD CONTROL MEASURES The prior evaluation for Swan Creek is also appropriate here.

ELY CREEK

- STRUCTURAL AND NON-STRUCTURAL FLOOD CONTROL MEASURES With a drainage area of about half the 1.5 square mile minimum for Corps participation, there can be no Federal flood project, as such. The placement of a flap gate and pump appears to be the most practical solution. The time and cost of project evaluation for a Federal project, even if the drainage criteria were not an issue, would likely be prohibitive.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D,
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
Lambertville Flood Insurance Study, April 1988
The National Park Service 1999 National Wild and Scenic Study Report for the Lower Delaware River.
Hazard Mitigation Plan, City of Lambertville, July 2006
Swan Creek Watershed, Preliminary Flood Damage and Mitigation Report USDA Natural Resources Conservation Service January 2007.
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, 2006

Stockton, New Jersey

BACKGROUND

Stockton is a Borough in Hunterdon County, New Jersey. Stockton is located at 40°24′24″N, 74°58′39″W (40.406701, -74.977546). According to the United States Census Bureau, the borough has a total area of 1.6 km² (0.6 mi²). 1.4 km² (0.6 mi²) of it is land and 0.2 km² (0.1 mi²) of it (10.00%) is water. The Borough population was 560 in 2000 census, and there were 246 households, and 148 families residing in the borough. There were 258 housing units. Stockton doesn't have an historic district, per se. However, everything within 300' of the 170 year old D&R Canal is affected by its historic designation (essentially, from Route 29 to the Delaware River).

Besides the Delaware River, there are two streams in Stockton; Brookville Creek and Wickecheoke Creek. Brookville Creek begins in the southwestern part of the Township of Delaware and flows generally southwest to its confluence with the D&R Canal. The last 2,500 feet of the stream forms the southeastern corporate limits between the Borough of Stockton and the Township of Delaware. Wickecheoke Creek has its headwaters in the Township of Raritan and flows generally southwest. Approximately the last 2,000 feet of the Creek forms the northwestern corporate limits between the Borough of Stockton and the Township of Delaware.

PROBLEM IDENTIFICATION

Flooding in 2004 was minimal while flooding in 2005 and 2006 were much more significant. These flooding events were caused by rain events, especially in New York State. Approximately two days after New York State was hit with torrential rain, flooding occurred in Stockton. Flooding occurs traditionally along Mill Street, and along Route 29 in the communities of Brookville and Prallsville Mill. Flooding of the Delaware River also leads to flooding of the canal, which in turn, floods the adjacent portion of the Boro. The September 2004 flood only affected one residence in Stockton. However, during the April 2005 flood, the canal wall breached south of Mill Street and north of town (just south of the Prallsville Mill). The canal wall was also breached during the June 2006 at the south end of Mill Street and during the 1955 flood event.

Although the levee can adequately hold in the canal water, the outer wall tends to fail against pressure from the Delaware River. This occurred during the 2005 and 2006 storms. The canal has been repaired, since the recent storm events, to the pre-existing wall elevations.

Flooding that occurs near the mouths of Wickecheoke Creek and Brookville Creek is primarily the result of backwater from the Delaware River.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from the storm of record. Stockton had 69 residential, 12 commercial, 5 service and 1 public properties damaged by the 1955 event. Damages for the 1955 event were $84,000 physical residential, $157,000 other damages (business, utilities, crops), and $11,000 emergency/highway costs for a total of $257,000 (1955 dollars) which would equate to nearly ten times that amount in current dollars.

The August 1984 Delaware River Basin Report listed 108 residences, 22 commercial properties, 1 service property, 2 public and 1 historic property in the 500 year floodplain (also referred to a the Standard Project Flood SPF). There were 64 structures in the 100-year floodplain. That report provided information on the damages expected based on the level of development in 1983 from different flooding events: $24,000 for the 10-year event, $559,000 for the 50-year event, $1,270,000 for the 100-year event, $2,240,000 for a repeat of the 1955 flood of record, and $2,991,000 for the 500-year event. Consolidated Average Annual Damages were estimated at $55,800 in March 1983 dollars.

In the August 1984 Delaware River Basin Report a 2,900 foot levee was designed; it had an initial cost of over $6,600,000 in 1983 dollars (double in 2007 dollars) and a benefit to cost ratio of 0.07 to 1 making it highly uneconomical. Flood proofing was also evaluated and found even less economically viable with 54 structures susceptible to flooding from a 500 year event. The Benefit to Cost ratio for flooding was 0.02 to 1 (or 2¢ reduction in flood damages for every $1 spent).

According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 12 repetitive loss properties (payments totaling $775,042) with 1 severe repetitive loss (payments totaling $154,507) . This does not include damages from noninsured properties. These repetitive losses were clustered at Mill along the Delaware River and 8 individual locations.

A field inspection was conducted on 23 January 2007 by Corps of Engineers staff and local representatives. The NJ Water Supply Authority is responsible for maintenance of the canal, including repair of breaches. This portion of the D&R Canal is a feeder branch to the main canal, which NJWSA uses to supply water to other parts of New Jersey. Stockton OEM notifies those residents in danger of flooding by going door-to-door. During the 2005 and 2006 events 37 basements were pumped out, approximately 77 homes (121 people) were evacuated, and flooding filled basements and affected some first floors. The April 2005 flood caused foundation damage to four properties and required structural evaluations. Thirty seven properties experience repetitive flooding. The sanitary sewer system was inundated in 2005 and 2006; the pumping station succumbed. (Sewage is normally pumped to Lambertville for treatment.). Emergency services located on Mill Street have gotten flooded. The historic value of properties and blocks could preclude structure elevation.

NJWSA has repaired both the 2005 and 2006 canal wall breaches to pre-existing heights. Each repair cost NJWSA about $500K, of which the 2006 repairs were partially reimbursed by FEMA.

NJWSA has contracted with French & Parello Associates to prepare an overall assessment report for the canal embankment in Stockton. This August 1996 Visual Inspection Report on the Delaware and Raritan Feeder Canal Western Embankment evaluated the condition of the canal between the Prallsville Lock (Station 155+00) to Railroad Crossing (Station 280+00) a distance of 5300 feet which is generally in Stockton. It found that the Western Embankment (that between the Delaware River and the canal) was generally found to be in poor overall condition and in need of significant repair. A review of plan drawings from that report shows that the Western Embankment is marginally overtopped by the 50 year flood event at many locations while at others the 50 year flood is barely contained. The left bank canal wall (that away from the river) is several feet lower in some locations, not even the height of the 10-year flood event.

<u>ALTERNATIVE EVALUATION</u>

- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>
  - A full Channel Modification of the Delaware River as such is not viable; deepening the Delaware River would at most cause only a few feet of flood stage reduction at high fiscal and ecological cost.
  - A separate levee-floodwall was evaluated in 1984 with an extremely low benefit to cost ratio. A comparison of past and present site conditions would indicate this would remain a poor choice, primarily due to the high cost of real estate and construction.
  - The use of the canal structure as a levee is a major problem because of the structural instability of the canal in this area. Until improvements to the canal can be made, consideration of this option is not practical.
  - Additional waste gates for canal overflow need to be considered. Construction of several wastegates north of the Borough could provide some measurable flood reduction potential in the near term without great expense.
  - The relatively high structure density along Mill Street may justify some structural solution. Construction of a 3’ ringwall system around repetitive damaged structures needs to be evaluated. The clustering of several repetitive claims along Mill and Bridge Streets would make an evaluation of a ring levee/floodwall of a few feet in height around each cluster something to consider. A similar ringwall-levee or floodproofing of the sewer pumping station should also be evaluated.

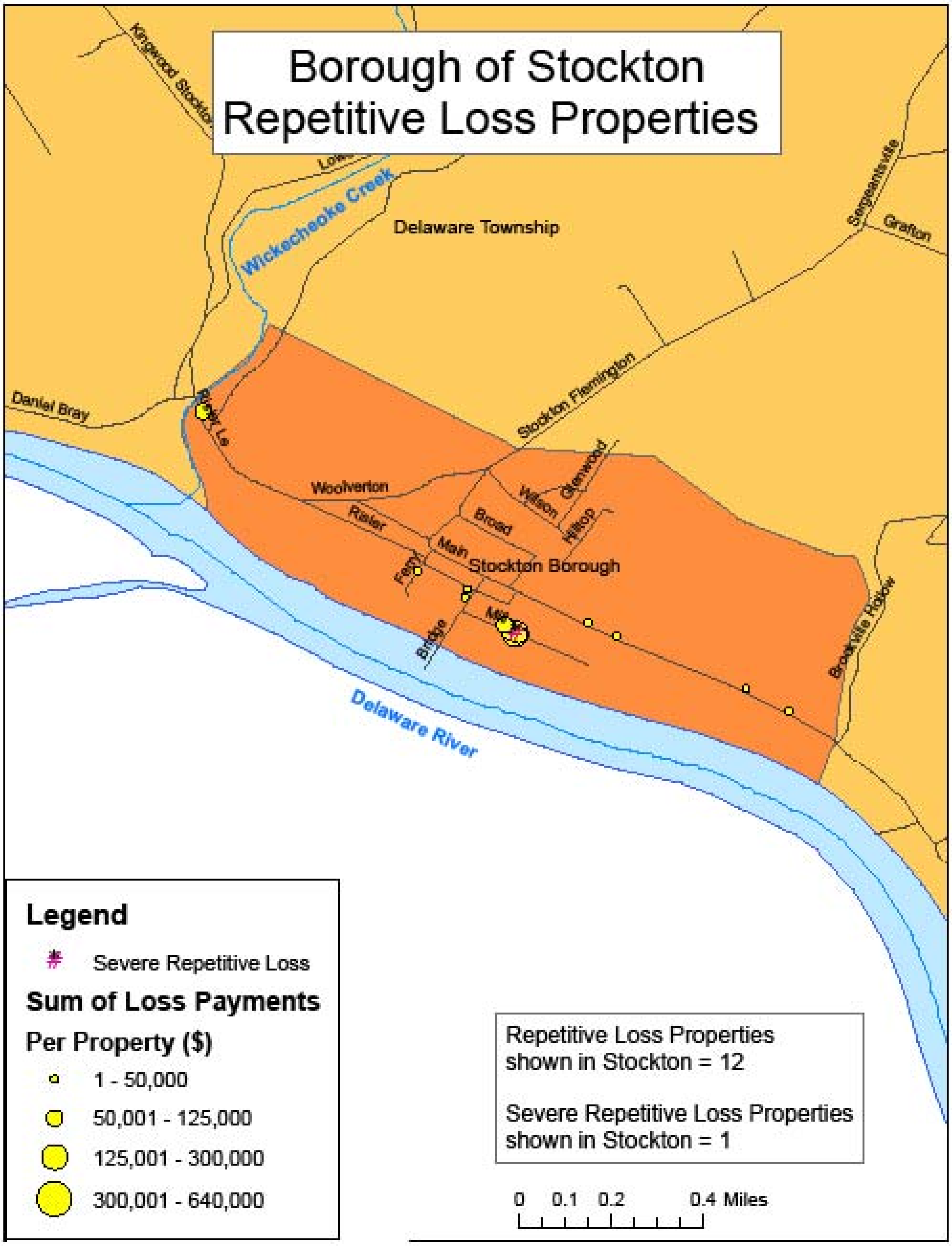
- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>

    - An improved flood warning (whether reverse 911, etc.) might be a significant non-structural measure; the current method of OEM having to go door-to-door has its limits, especially if a flooding event from a levee breach occurs during the night (as has happened historically and fortunately did not result in a loss of life).

    - The prior 1984 evaluation of nonstructural flood control measures makes the likelihood of large scale non-structural measures unlikely. The raising of two structures by their private owners shows that at a minimum an individual structural evaluation of the 13 repetitive damaged properties needs to be conducted. Floodproofing of the Emergency Services Building on Mill Street should be a priority; it will likely be included as a priority in the upcoming County Hazard Mitigation Plan and as such may get some priority in receiving a Hazard Mitigation grant from FEMA

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
August 1996 Visual Inspection Report on the Delaware and Raritan Feeder Canal Western Embankment by French & Parello Associates



Source: Federal Emergency Management Agency (FEMA). A property is considered a repetitive loss property 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. Losses from 01/01/1978 - 08/31/06 that are closed are considered.

Prepared by Delaware River Basin Commission Staff, October 2006. Draft, subject to change.

BELVIDERE, NEW JERSEY

BACKGROUND

Belvidere is a town in west-central Warren County, New Jersey. The town borders Oxford Township to the north, south and east and the Delaware River to its west. It is the county seat of Warren County. Belvidere is located at 40°49′42″N, 75°4′35″W (40.828299, -75.076496). The town has a total area of 3.5 km² (1.4 mi²). 3.4 km² (1.3 mi²) of it is land and 0.1 km² (0.04 mi²) of it (1.48%) is water. As of the 2000 Census there were 2,771 people, 1,088 households, and 716 families residing in the town. While portions of the Delaware are designated as Wild and Scenic, no portion of the Delaware River at Belvidere is so designated.

PROBLEM IDENTIFICATION

Belvidere has been subjected to flooding from all three of its water bodies. Flooding on the Delaware River also causes backwater along the Pequest River and Pophandusing Creek. Most of the Pequest floodplain is developed by residential and commercial structures. The Pophandusing Creek is located in the southern portion of town and is more reactive to shorter duration, high intensity events.

Flooding in Belvidere is of varied origin and may be experienced any time of year. Flooding during the winter is less frequent, but flooding compounded by snowmelt and ice has occurred.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from prior storm events. Belvidere had 58 residential, 20 commercial and 0 industrial properties inundated during the 1955 flood event. Damages in 1958 dollars at Belvidere from this event were $167,000 for the Delaware River and $215,000 on the Pequest. Damages from earlier events were not able to be broken down. In today's dollars this would be between nine and ten times that amount.

The October 1966 Report titled Extent and Frequency of Floods on Delaware River in the Vicinity of Belvidere, NJ by George M. Farlekas of the USGS developed information relative to the extent, depth, and frequency of flooding. The estimated reoccurrence of the 1955 was over 150 years, while the 1942 was a 5 year event. The areal extent of flooding from both was delineated. The flooding from the Delaware River from the 1942 event only extended to the lower dam, while the 1955 event flooded not only up the Pequest for an additional 1,500 feet but also flooded inland along virtually all of DePue Street. There was no documentation on the level of damages or the cause of flooding except in general terms.

A Reconnaissance Report on the Flood Control Problem, Town of Belvidere, Warren County, New Jersey was completed by the Corps of Engineers in October 1971. It recommended further study based on a cursory evaluation (7 pages of text) determining that a plan to protect residents from Pequest flooding was economically justified with a BCR of 1.6 to 1. The October 1971 study referenced a 1963 study by McCrosby-Seelye, Associated Consultants, which included a plan to protect the town from flooding as part of urban renewal. This plan called for:

- Channel excavation, removal of two check dams, and the construction of dikes but concluded that the cost of dikes was too expensive to be economical.

The April 1973 Flood Control and the Delaware River by Laurie Burt and Leo M. Eisel, PH.D. evaluated 8 flood damage centers along the Delaware River including Belvidere. Its purpose was to provide updated flood damage data and evaluate flood reduction strategies. It estimated that a maximum of 104 residences and 20 commercial structures were at that time potentially located within the 150 year floodplain representing the 1955 flood of record. Of these residential structures 54 were not reported flooded by the 1955 event; this could have been the result of topographic inaccuracies, or structures built elevated above the natural ground by even a foot or two. This document reported that a winter 1970 storm on the Pequest alone caused flooding damage to 75-85 homes and 25 businesses, about the same as the 1955 flood of record.

The September 1983 Floodplain Management Study Pequest River Watershed by the Soil Conservation Service identified and delineated flood hazard areas along the stream corridors of the Pequest. Within Belvidere, it was reported that a seven-foot-high dam downstream of the railroad bridge near the mouth of the Pequest River (which still exists) creates a backwater about 5’ at the 10-year event and 2’ at the 100-year flood. A second dam upstream of Market Street (also still exists) creates a backwater about 4’ at the 10-year event and 2’ at the 100-year flood. Belvidere’s flooding is a result of three factors: one, there is a high concentration of residential and commercial dwellings along the river; two, Beaver Brook (located 2 1/3 miles upstream) substantially increases the peak flow rate which when combined with one causes the water to flow out of bank onto Water Street near Howell; and three, the lower section of the town is subject to flooding from the Delaware River (which can extend all the way up the Pequest to the second dam in the vicinity of Market Street (1/3 mile from the mouth).

A Pre-Authorization Planning Report and Plan of Work, titled “Lower Pequest River Watershed, Warren County, New Jersey” was completed by the United States Department of Agriculture, Soil Conservation Service (now known as the Natural Resource Conservation Service (NRCS)) in April 1985. This report was prepared in part to evaluate various methods to reduce flooding along the Lower Pequest River, specifically in the Town of Belvidere. Two of the alternatives pertain to the removal of one or more of the existing dams mentioned above and were both determined to be economically justified at that time. A subsequent April 1987 evaluation done by SCS/NRCS found that as a result of a more detailed hydraulic analysis, the flood stages (elevation associated with a given flood event) were somewhat lower than earlier computed and that groundwater induced flooding of basements was not reduced to the degree assumed. In addition, a detailed structure by structure economic inventory found that, in large part to property owner's initiative, basement flooding was less than half of that assumed in using nationwide standard damage curves developed by the National Flood Insurance Administration. As a result of these two refinements, removal of one or both dams recommended in the 1985 report could no longer be economically justified.

The August 1984 Delaware River Basin Report listed 151 residences, 38 commercial properties, and 2 services in the 500 year floodplain (also referred to a the Standard Project Flood SPF) and 75 structures in the 100-year floodplain. That report provided information on the damages expected based on the level of development in 1983 from different flooding events. Those damages are as follows: $0 damages for the 10-year event, $150,000 for the 50-year event, $782,000 for the 100-year event, $2,112,000 for a repeat of the 1955 flood of record, and $6,406,000 for the 500-year event. Consolidated Average Annual Damages were estimated at $40,000 in March 1983.

The August 1984 Delaware River Basin Report evaluated flooding along the Delaware River including the Pequest.

- At Belvidere it evaluated two levees, on either side of the Pequest. This alternative produced $31,000 Average Annual Benefits vs. Average Annual Costs of $770,00) for a Benefit to Cost ratio of 0.04 to 1.
- Belvidere was also evaluated for nonstructural flood measures. 191 structures were located within the floodplain, with 83 percent requiring protection. The Benefit to Cost ratio of providing this level of protection was 0.13 to 1 (AAB $24,000 to AAC $180,00 at 1984 price levels).

Results of a field inspection conducted on 24 January 2007 by Corps of Engineers staff and local representatives. When the Delaware reaches 16', it backs up into the Pequest River. Water in the Pequest then goes up storm drains and causes flooding. Later, the water also overtops the Pequest and causes additional flooding. The Delaware River has not overtopped its banks in this area since 1955. The Pequest floods parts of Wall Street, Water Street, Front Street and DePue Street. On the southern side of the Pequest, water from the Delaware River also comes up a municipal boat ramp and further contributes to the flooding.

There are two existing run of river type dams within Belvidere on the Pequest River. The lower dam was recently purchased by the State of New Jersey with Green Acres funding and is currently operated by the NJDEP, Division of Fish & Wildlife. Local residents report siltation within the Pequest, notably behind and downstream of the lower Dam. Local residents also report a rise in the Delaware River bed at the confluence of the Pequest and Delaware River. Since the first of the three floods, an island has begun forming on the south side of the Water Street bridge.

On the southern edge of Belvidere the Delaware River floodwaters back up the Pophandusing Brook, and also scour out the river bank. Flooding occurs on DePue Street and Mansfield Road. Just upstream from the confluence of the river and the brook, the Pophandusing flows in an "S" shaped meander that is constrained by a culvert thru a railroad embankment and by the end of DePue Street. The brook shows signs of attempting to realign itself; there is significant erosion along its banks. Some local residents have deposited boulders on portions of the embankment in an attempt to keep the brook's alignment from encroaching on DePue Street. Portions of one driveway have already been lost due to bank erosion. Some basements in Belvidere have dirt floors and experience inundation by ground water.

Belvidere uses reverse 911 to warn people about impending flooding. They then go door-to-door to try to get people to evacuate. The majority of the residents don't want to evacuate, especially those who get only basement flooding. With adequate warning of an imminent flood, many people move exposed contents to higher locations in the structures (see prior NRCS evaluation). Municipal representatives have encouraged residents to raise their utilities above flood levels, evacuate when instructed to do so, and seal basements from groundwater.

Municipal Officials have stated that during a major storm event, approximately 55 homes have been flooded, 22 get flooded about 3'-5' in the first floor, the rest get flooded only in the basements. Property values of the homes are approximately $250K-$350K. Impacted owners are interested in relocating and several "for sale" signs were visible during the site visit. Two houses that incurred 1st floor damage have been sold. Town officials report that the market value of homes has dropped since the recent set of storm events. The damage for each event was approximately $50K-$75K for 1st floor flooding. No deaths have occurred as a result of flooding.

According to FEMA, based upon **a** comparative analysis of the National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 31 repetitive loss properties (payments totaling $1,411,393) with 3 severe repetitive losses (payments totaling $440,229) . This does not include damages from noninsured properties. These losses are primarily clustered along the Pequest in the vicinity of the Market Street Dam (Water and South Water Streets) or along DePue Street.

ALTERNATIVE EVALUATION

PEQUEST

- STRUCTURAL FLOOD CONTROL MEASURES

The Municipality would like the following measures evaluated: (1)dredging the Pequest- if dredging could be designed to direct floodwaters onto the undeveloped State property on the south side of the river, rather than the developed properties on the north side. (2) removal of the downstream dam on the Pequest to help with the backwater problem they seem to experience from the Delaware River by helping the Pequest carry floodwater more efficiently, thereby reducing property damage. (3) Channelization to make the Pequest wider and/or deeper. (4) Flap gates on the storm drains that are carrying floodwaters in the wrong direction. (5)Local officials would prefer not to have buyouts of flooded properties because there would be a loss of tax ratables. (6) Some homeowners are interested in elevation of their homes.

  - A levee-floodwall system was considered previously.
  - Channel Modification as such is not viable. No constrictions exist whose removal would likely measurably reduce flood stages. Debris blockage has not been reported as a problem in prior reports nor in correspondence with local officials.
  - Local Detention is not viable since no vacant land is available & minimal stage reduction could result. Upstream dams were investigated in the past but economic viability is highly unlikely. Offline detention basins should be reviewed.
  - FlapGates/Stormwater Outlets are definitely needed and would be effective both for Delaware Backup as well as fluvial flooding from the Pequest.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

  - Basement floodproofing/sealants, raising/protection of utilities, dry floodproofing/individual levees are all measures that could be viable.

POPHANDUSING CREEK

- STRUCTURAL FLOOD CONTROL MEASURES
  - FlapGates/Stormwater Outlets are definitely needed and would be effective both for Delaware Backup as well as fluvial flooding from the Pophandusing Creek. A flapgate on the railroad embankment may also be warranted.
  - No other structural solutions are viable based on the relatively low level of damages.

- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - A review of nonstructural flood control measures is warranted.

MAINSTEM DELAWARE RIVER

- STRUCTURAL FLOOD CONTROL MEASURES
  - With river flooding not occurring until a flood exceeds the 100 year event, no structural solution is economically justified.

- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - No nonstructural solution is economically justified but any nonstructural plan for either the Pequest or the Pophandusing Creek would have the added benefit of protecting from Delaware River Flooding.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D, 1962
Report titled Extent and Frequency of Floods on Delaware River in the Vicinity of Belvidere, NJ by George M. Farlekas of the USGS October 1966
Flood Control and the Delaware River by Laurie Burt and Leo M. Eisel, PH.D. April 1973
A Reconnaissance Report on the Flood Control Problem, Town of Belvidere, Warren County, New Jersey, Corps of Engineers in October 1971
The September 1983 Floodplain Management Study Pequest River Watershed by the Soil Conservation Service
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
A Pre-Authorization Planning Report and Plan of Work, titled "Lower Pequest River Watershed, Warren County, New Jersey", USDA SCS (now NRCS) April 1985.
Design Manual fro Retrofitting Flood-prone Residential Structures FEMA 114, Sep 1986

YARDLEY, PENNSYLVANIA

BACKGROUND

The small community of Yardley Borough is bordered by the Delaware River and Trenton, NJ on the east and by Lower Makefield Township on the north, west, and south. Yardley is located at 40°14′29″N, 74°50′11″W (40.241508, -74.836325). The population was 2,498 at the 2000 census. Surrounding Lower Makefield Township (often colloquially paired with Yardley) had a population of 32,681. According to the United States Census Bureau, the borough has a total area of 2.6 km² (1.0 mi²). 2.4 km² (0.9 mi²) of it is land and 0.3 km² (0.1 mi²) of it (9.90%) is water. While portions of the Delaware are designated as Wild and Scenic, no portion of the Delaware River at Yardley is so designated.

As of the census of 2000, there were 2,498 people, 1,170 households, and 649 families residing in the borough. The population density was 1,048.4/km² (2,729.0/mi²) and there were 1,209 housing units. The Borough's population has remained stable, while growth in surrounding Lower Makefield Township has nearly doubled the Township's population's size since 1980.

PROBLEM IDENTIFICATION

Yardley has been subjected to flooding from four sources. Flooding from the Delaware River can come from fluvial flood stages or as occurred in 1996 from ice jams. Floodwaters also enter the Borough from the Delaware Canal which parallels the Delaware River with the distance between the canal and the river varying from 650 to 1,500 feet. Flooding from the Delaware Canal was considered a major problem in the 1955 flood and resulted in the addition of an overflow weir where the Delaware Canal crosses over Brock Creek.

The Delaware Canal just below lock 8 at New Hope is only a few feet above the banks of the Delaware River and even minor flooding, such as occurred on April 1-2, 1993, can cause river waters flowing into the Canal. Heavy local rainfall also causes runoff into the canal; runoff from I-95 just North of Yardley has also been reported as a problem. The West Trenton Railroad embankment restricts flows in the lower portion of the Borough and even minor river stages (above 17') at the Trenton USGS Gauge causes water to backup culverts under River Road and flood homes nearby.

Two tributary streams have also been a source of flooding. In June 12, 1996 over 9 inches of rain from a local thunderstorm fell in 4 hours overflowing the banks of local streams, Silver Creek (also called Bock Creek) begins south of Yardley and flows through a 10 acre lake and flows into the Delaware Canal. Brock Creeks originates west of Yardley and has a 6.01 square mile drainage area (including 2.38 sq. mile Buck Creek) and flows under the Delaware Canal. A concrete aqueduct carries the canal over this creek and any excess flows in the canal are designed to overtop a weir and spill into Brock Creek.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from earlier storm events. Yardley had 223 residential, 26 commercial and no industrial properties inundated in the 1955 storm of record. Damages in 1955 dollars at Yardley from this event were estimated at $3,200,000. In today's dollars damages would nine or ten times the 1955 reported amount.

The 1955 flood event at Yardley was compounded by debris buildup at the Yarley-Wilburtha Bridge causing as much as a 2-3 foot higher crest before the bridge was swept downstream. It was not rebuilt.

The April 1973 Flood Control and the Delaware River Report by Laurie Burt and Leo M. Eisel, PH.D. evaluated 8 flood damage centers along the Delaware River including Yardley. Its purpose was to provide updated flood damage data and evaluate flood reduction strategies in opposition to Tocks Island. At Yardley it reported that estimated damages from a return of the 1955 in 1972 would involve estimated residential damages of $444,000, commercial damages of $641,000, and industrial damages of $319,000, for a total of $1,403,000 which would convert to $5,600,000 in 2007 dollars.

The July 1983 State Water Plan, prepared by PADER (now PADEP) includes combined flood information on Yardley, Lower and Upper Makefield Townships. Average Annual Damages (AAD) of $198,700 (1976 price level) were reported which converts to an AAD of $ 630,000 (2007 price level) for all three municipalities. It was determined that structural projects were not feasible due to scattered damages. However, PADER did recommend nonstructural measures including Flood Plain Regulation, Flood Insurance, Flood Proofing and Flood Forecasting.

The August 1984 Delaware River Basin Report evaluated flooding along the Delaware River including Bock and Brock Creeks and the Delaware Canal.

- A comparison of structures damaged in 1955 and potentially damaged in 1981 for a repeat of that storm showed an increase in number of structures. Residential Structures increased from 223 in 1955 to 272 in 1981 and Commercial Structures increased from 26 in 1955 to 27 in 1981. The Amount of damages from a single event was also reported as follows.

March 1983 Dollars and Conditions ($000)

10 yr	50 yr	10 yr	1955	500 yr
156	3,942	8,308	11,509	15,696

- The report evaluated two levees above and below Brock Creek ($379,000 Average Annual Benefits vs. Average Annual Costs of $2,668,000) for a Benefit to Cost ratio of 0.14 to 1.
- Yardley was also evaluated for nonstructural flood measures. Of the 328 structures in the floodplain, 63% required no protection from the 35 year flood event, 24% needed floodproofing or floodwalls, 12% needed elevating and 1% required buyouts. The Benefit to Cost ratio of providing this level of protection was 0.66 to 1 (AAB $97,400 to AAC $148,300 at 1984 price levels). Floodproofing to a higher level of protection would have much higher costs and a lower amount of benefits.

A Preliminary Investigation, Flood Control Study (Section 205) Report was completed by the Corps of Engineers in July 1999. That study followed the June 1996 storm. An initial screening for several locations was conducted but neither costs nor benefits were quantified:

- <u>North Main Street Bridge at Brock Creek</u> Brock Creek overflowed its banks from the storm of June 1996 and flooded the Friends Meetinghouse and several residences downstream. The bridge was not thought to be a cause of flooding; channel capacity and the affect of the aqueduct backwater were likely causes of the limited flooding. A structural solution was not recommended due to the limited dollar damages.
- <u>Yardleyville Square Shopping Center</u> Located adjacent to Brock Creek near the confluence with Buck Creek, floodwaters did not reach the shops but were limited to the parking lot. A structural solution was not recommended.
- <u>Brock Creek at Delaware Canal</u> A concrete aqueduct carries the Delaware Canal over Brock Creek with the June 1996 flood. The size of the opening is inadequate for a 100+ year flood. When the aqueduct is eventually replaced, the opening should be enlarged.
- <u>Silver Creek at Delaware Canal</u> This stream discharges directly into the Delaware Canal and has caused towpath failure due to the stormwaters' velocity. An overflow pipe to divert excess water to the Delaware River plus strengthening the canal by construction of a wall to prevent a repeat of the scour should both be considered further.

- Non-Structural Measures were recommended for further consideration.

Flooding from the Delaware River was not evaluated at that time. Further investigation was not undertaken since the Borough of Yardley was unable to fund its share of the continuing portion of study.

A study by PADEP, Bureau of Waterways Engineering, completed in May 2001, a Hydraulic Study of Silver Creek, Brock Creek, and the Delaware Canal in the Borough of Yardley. It computed peak discharges comparing 7 hydrologic methods.

Two Hazard Mitigation Grant Program Joint State –Federal Applications were prepared for Yardley in late 2006. The first was for construction of two additional 48-inch diameter relief gates at the Delaware Canal-Brock Creek Aqueduct. Costing $1,500,000, it would add the single existing relief gate and was to relieve a 100-year localized storm event. The second is a stormsewer relief project along Lechworth Ave. at an estimated cost of $415,000 which would collect runoff at low points protecting the 100 adjacent property owners.

Flood Control Measure Report for The Township of Lower Makefield, Bucks County, PA prepared by Schoor Depalma in October 13, 2007 provides some information concerning flooding in the vicinity of the Conrail railroad embankment. This embankment acts as a dam and lets only water through the Delaware Canal and towpath opening.

According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 143 repetitive loss properties (payments totaling $13,967,309) with 29 severe repetitive losses (payments totaling $5,495,912). This does not include damages from noninsured properties.

ALTERNATIVE EVALUATION

BUCK AND BROCK CREEKS

- STRUCTURAL FLOOD CONTROL MEASURES
    - Local Detention was re-evaluated by Lower Makefield Township and the Borough of Yardley after the June 1996 storm. Nearly half the detention basins did not retain stormwater as anticipated from a greater-than a 100-year storm event. Outlet controls have been modified to insure adequate retention from subsequent storms.
    - Brock Creek Streambed modification was proposed for evaluation in the 1999 Corps Flood Evaluation. Removal of debris (clearing & snagging) that has accumulated in the streambed in the vicinity of the aqueduct (upstream, downstream, and under aqueduct) should become a regular part of Borough maintenance activities. Deepening of the streambed to

increase flow capacity for Brock Creek under the Canal may be a viable short term solution but deepening alone may be inadequate to handle excess flow in Brock Creek because (1) silting would occur over time, (2) rock exists in the streambed, limiting the degree of channel deepening.

- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - Flood Proofing. Need to investigate the feasibility of utilizing flood proofing techniques for residential properties in the vicinity of Brock Creek at the Canal. Focus on properties that were affected by past flooding.

DELAWARE CANAL

- STRUCTURAL FLOOD CONTROL MEASURES
  - Repair Aqueduct: Some repair needs to be made to existing aqueduct structure. Remove spalled concrete and repair cracked sections as necessary. Increase capacity of overflow from Canal into Brock Creek, as the Borough has proposed in its Hazard Mitigation Grant Application. Remove excess silt & debris from creek bed in vicinity of aqueduct, especially upstream side—to provide unobstructed flow of Brock Creek under canal.
  - Replace Aqueduct: Minimal flood control benefits are thought to occur from removal of old aqueduct and replacement with new structure. Should consider increasing the width of opening for flow of Brock Creek under Canal when aqueduct eventually replaced.
  - Increase Number of Wastegates: The Borough's request for additional relief gates at the canal aqueduct over Brock Creek needs to be implemented since higher river flows do enter the canal upstream just below New Hope and historic gates within the canal to restrict high flows from traveling down the canal have been removed long ago. Additional weirs or overflows need to be considered as well both upstream of Yardley and in the vicinity of Lock 5.
  - During the recent floods, the Delaware Canal overtopped the towpath in several places, contributing to the flooding in Yardley and Lower Makefield. Raising the grade and stability of the towpath in low areas would reduce the amount of water gathering in the drainage ditch that runs parallel to the canal and reduce the likelihood of canal breaching or overflowing at improper locations.
  - Delaware Canal at Silver Creek. Stabilize the Canal bank opposite Silver Creek. Determine the most appropriate material/method or combination (rip-rap, geotextile, gabion, etc.). Past dredging project has provided a reconstructed bank but without any stabilization.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

- Flood proofing techniques used to protect the residential properties from Delaware River floodwater will have coincidental benefits from flows overtopping the Canal.

<u>MAINSTEM DELAWARE RIVER</u>

- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>

    - A levee-floodwall system along the Delaware River was previously found to be a poor economical investment. The area between River Road and the banks of the Delaware River has sufficient area for construction of a levee/floodwall. A temporary floodwall, typically 3-4 foot high could be (if placed upon a 2 foot high permanent base) a 4 foot high levee with a 2 foot freeboard. With River Road beginning to flood at elevation 20'+/- this would provide protection against a 50-60 year flood event. The need to provide over a mile of temporary floodwall in about 24-30 hours, even with the structures bought and stored nearby, would probably be beyond the ability of the Borough's personnel to fully put in place. This could be rectified by utilizing a combination of permanent and temporary floodwalls. While this levee variation may not be economically justified, sufficient viability exists to warrant further investigation. Stacking of the temporary floodwalls may increase the level of protection but construction within a 24 hour period is unlikely.
    - Channel Modification is not viable. No constrictions exist whose removal would likely reduce flood stages. There would be limited stage reduction with high economic & environmental cost from deepening river channel. There are no dams on Delaware River in vicinity of Yardley whose removal could alter stage flows.
    - Local Detention for River caused flooding is not viable. No sizable vacant land is available & minimal stage reduction could result.
    - FlapGates/Stormwater Outlets are a critical component of any flood control project. The community between the Canal and the Delaware River centering on College and Lechworth Avenues is especially low-lying with river flooding known to occur before River Road is overtopped. In addition to flap gates a series of pumps for interior drainage would be needed.
    - Conrail Railroad Embankment- The embankment restricts flows and ways to reduce this impediment needs to be studied. One option being discussed is a bypass either to a channel directly into the Delaware River or into a detention basin created at Macclesfield Park in Lower Makefield.

- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>

    - The 1984 Corps evaluation of floodproofing found sufficient economic viability (BCR = 0.66) that these series of options needed to be re-evaluated in more detail. Flood proofing techniques include levees, flood walls, elevation, relocation, closures & sealants. Flood proofing functions fall into three general categories: (1) construction of barriers to prevent floodwater from entering the property, (2) elevation or relocation of the structure above the flood hazard, (3) alteration of the structure and relocation of the contents to minimize flood damage. The ability for staged implementation is a significant positive factor.

- Flood warning should also be re-evaluated.
- Wetland/ Floodplain Restoration is not viable in itself with limited unoccupied former floodplain.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, 1962, Appendix D, 1962
April 1973 Flood Control and the Delaware River Report (Environmental Defense Fund) by Laurie Burt and Leo M. Eisel, PH.D
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
July 1983 State Water Plan, prepared by PADER
A Preliminary Investigation, Flood Control Study (Section 205) Report was completed by the Corps of Engineers in July 1999.
A Hydraulic Study of Silver Creek, Brock Creek, and the Delaware Canal by PADER, Bureau of Waterways Engineering May 2001
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, October 2006
Flood Control Measure Report for The Township of Lower Makefield, Bucks County, PA prepared by Schoor Depalma October 13,2007.

NEW HOPE, PENNSYLVANIA

BACKGROUND

New Hope, formerly Coryell's Ferry, is a borough in Bucks County, Pennsylvania, and is located at 40°21′37″N, 74°57′26″W (40.360312, -74.957203).
According to the United States Census Bureau, the borough has a total area of 1.4 square miles (3.7 km²), of which, 1.3 square miles (3.3 km²) of it is land and 0.2 square miles (0.4 km²) of it (11.19%) is water. Much of this is the Delaware River. The population was 2,252 at the 2000 census.

The borough is located at the confluence of the Delaware River and Ingham Creek sometimes called Aquetong Creek, which begins in Solebury Township at Ingham Springs, the most productive spring in Southeastern Pennsylvania, about two miles from its mouth. The name "Aquetong" comes from a local Indian word meaning "place of the pine trees," a reference to the pine forest that the creek runs through at the beginning of its route. Near its end, the creek forms a scenic millpond and waterfall near the Bucks County Playhouse, a former mill powered by the flow of water. The Delaware River Joint Toll Bridge Commission operates two bridges over the Delaware River between New Hope, Pennsylvania and Lambertville, New Jersey. One is a free, two-lane bridge between the two towns, the other, which carries U.S. Highway 202, is a modern toll bridge.

The primary industry of New Hope is tourism. On weekends the streets are crowded with tourists visiting the many restaurants, antique shops and art galleries, or just strolling along the river and the Delaware Division of the Pennsylvania Canal.

PROBLEM IDENTIFICATION

Of the three water bodies within the boundaries of New Hope; the Delaware River, the Aquetong Creek and the Delaware Canal, it appears that the Delaware River is the primary source of flooding and has been a continual problem since settlement of the area. Although the worst flooding generally results from excessive rainfall alone, flooding in the Delaware River in early spring can be even more severe because of moving ice and snowmelt.

Based on a comparison of flood maps and aerial photos it does not appear that the last mile of Aquetong Creek, which lies within the boundaries of New Hope Borough, is a significant threat to the residents of New Hope due to the limited structural occupation along the creek's floodplains.

The Delaware Canal also does not appear to cause a separate flooding problem but rather is affected directly by overbank floodwaters from the Delaware River.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from earlier storm events. New Hope had 146 residential, few commercial and industrial properties inundated in the 1955 storm of record. Damages in 1955 dollars from this event were estimated at $1,500,000. In today's dollars damages would be nine or ten times the 1955 amount.

The April 1973 Flood Control and the Delaware River Report by Laurie Burt and Leo M. Eisel, PH.D. evaluated 8 flood damage centers along the Delaware River including New Hope. Its purpose was to provide updated flood damage data and evaluate flood reduction strategies in opposition to Tocks Island. At New Hope it reported that estimated damages from the 1955 storm of record were as follows: residential damages of $444,000 to 146 residential structures, commercial damages of $641,000, and industrial of $319,000, for a total of $1,403,000 which would convert to $6 million in 2007 dollars. In 1972 that report estimated a total of 117 structures remained in the floodplain valued at $3.1 million.

The July 1983 State Water Plan, prepared by PADER (now PADEP), includes flood information on New Hope. In their analysis, PADEP analyzes a levee and estimates Total Average Annual Damages (AAD) of $54,300 (1976 price level), Average Annual Costs (AAC) of $46,000 and Average Annual Benefits (AAB) of $31,000 for a BCR of .67 Recommended alternatives were nonstructural measures including Flood Plain Regulation, Flood Insurance, Flood Proofing and Flood Forecasting.

The August 1984 Delaware River Basin Report evaluated flooding along the Delaware River and developed a comparison of structures damaged in 1955 and structures potentially damaged in 1981 for a repeat of that storm. The report showed a decrease in the number of residential and an increase in commercial structures. residential structures decreased from 146 in 1955 to 105 in 1981 while commercial structures increased from 0 in 1955 to 109 in 1981. The Amount of damages from a single event was also reported as follows.

March 1983 Dollars and Conditions ($000)

10 yr	50 yr	100yr	1955	500 yr
67	2,589	5,929	10,932	18,424

The report evaluated two levees/floodwalls above and below Aquetong Creek totaling 6,600 feet with a first cost of $11,400,000. The report estimated $214,000 Average Annual Benefits vs. Average Annual Costs of $1,018,000 for a Benefit to Cost ratio of 0.20 to 1.

New Hope was also evaluated for nonstructural flood measures. Of the 278 structures in the 22 year floodplain, 93% required no protection from that 22 year flood event, 5% needed floodproofing or floodwalls, 2% needed elevating and none required buyouts. The Benefit to Cost ratio of providing this level of protection was 1.95 to 1 (AAB $66,200 to

AAC $33.89 at 1984 price levels). Floodproofing to a higher level of protection would have much higher costs and a lesser amount of relative benefits.

Aquetong Creek Coldwater Heritage Plan Jan 2007, done by F. X. Browne for Trout Unlimited reported that Solebury Township, within which most of the 7.5 square mile watershed is located, has a stringent stormwater ordinances. It now requires no net increase in discharge into streams which is more restrictive than NPDES Phase 2 stormwater regulations in Pennsylvania.

According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 88 repetitive loss properties (payments totaling $3,895,035). This does not include damages from noninsured properties.

ALTERNATIVE EVALUATION

AQUETONG CREEK

- STRUCTURAL FLOOD CONTROL MEASURES

    - Local Detention criteria has been strengthened by Solebury Township which restricts new development from any increase in offsite drainage flow increase and is inspecting all existing detention basins to insure proper operation and maintenance. Further action for New Hope is not required.

- NONSTRUCTURAL FLOOD CONTROL MEASURES
    - Flood Proofing. Need to investigate the feasibility of utilizing flood proofing techniques for residential properties along the stream.

DELAWARE CANAL

- STRUCTURAL FLOOD CONTROL MEASURES
    - No improvements are envisioned that could measurably affect flooding in New Hope. A proposed stop gate repair on the canal near Center Bridge, which is included in the 1987 Canal Master Plan may provide limited benefits if locks upcanal of New Hope cannot now completely stop flows.
    - Downstream of Lock 11 there was a former lock that allowed canal boats to enter the Delaware River. The lock mechanism and a canal stop gate are reported as not functional and this may be contributing to downriver canal storm flows and subsequent flooding.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

    - No separate action appears viable.

MAINSTEM DELAWARE RIVER

- STRUCTURAL FLOOD CONTROL MEASURES

    - A levee-floodwall system along the Delaware River was previously found to be a poor economical investment. The area south of Aquetong Creek had a sufficient BCR of 0.66 to 1 to justify a reanalysis. Rather than a permanent levee/floodwall which would isolate the community, a temporary floodwall coupled with a permanent base and some permanent floodwalls should be investigated. The amount of permanent vs. temporary would to a large degree be determined by the type of temporary structure chosen and the time the Borough could erect the temporary floodwall.
    - Channel Modification is not viable. No constrictions exist whose removal would likely reduce flood stages. There would be limited stage reduction with high economic & environmental cost from deepening river channel. The one dam on Delaware River in vicinity of New Hope would at most affect the flood stage by 1 or 2 feet.
    - Local Detention for River caused flooding is not viable. No sizable vacant land is available & minimal stage reduction could result.
    - FlapGates/Stormwater Outlets are a critical component of any flood control project and several pipe extensions need to be implemented. A review of recent flooding should be undertaken to determine if backup of the stormwater system which appears to be a major contribution for minor flood events would benefit from the addition of either permanent or temporary pumping stations.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

    - The 1984 Corps evaluation of floodproofing found sufficient economic viability (BCR = 1.95) even for a relatively low level of protection (22-year event) that these series of options needed to be re-evaluated in more detail. Flood proofing techniques include levees, flood walls, elevation, relocation, closures & sealants. Flood proofing functions fall into three general categories: (1) construction of barriers to prevent floodwater from entering the property, (2) elevation or relocation of the structure above the flood hazard, (3) alteration of the structure and relocation of the contents to minimize flood damage. The ability for staged implementation is a significant positive factor.
    - Flood warning should also be re-evaluated. An emergency telephone system in Bucks County is currently operational.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, 1962, Appendix D, 1962
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
April 1973 Flood Control and the Delaware River Report (Environmental Defense Fund) by Laurie Burt and Leo M. Eisel, PH.D
July 1983 State Water Plan, prepared by PADER
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, October 2006.
Aquetong Creek Coldwater Heritage Plan Jan 2007, F. X. Browne for Trout Unlimited

EASTON, PENNSYLVANIA

BACKGROUND

Easton is a city in Northampton County, in the eastern region of Pennsylvania. It is also the county seat of Northampton County. The population was 26,263 at the 2000 census. The city is split up into four primary sections: Historic Downtown, the West Ward, the South Side and College Hill. Historic Downtown is a low-lying area surrounded by hills, lying south of the Bushkill Creek, north of the Lehigh River, to the west of the Delaware River and continues west to Sixth Street. The West Ward lies between Sixth and Fifteenth Streets; the South Side lies south of the Lehigh River; and College Hill is home of Lafayette College.

Easton is located at 40°41′18″N, 75°12′59″W (40.688248, -75.216458).
According to the United States Census Bureau, the city has a total area of 12.0 km² (4.7 mi²). 11.0 km² (4.3 mi²) of it is land and 1.0 km² (0.4 mi²) of it (8.39%) is water including Bushkill Creek and the Lehigh and Delaware Rivers. While portions of the Delaware are designated as Wild and Scenic, no portion of the Delaware River at Easton is so designated.

PROBLEM IDENTIFICATION

Easton has been the subjected to flooding from all three of its water bodies. Flooding from high Delaware River flood stages also causes backup into the Bushkill and Lehigh.

For the Lehigh River, a majority of flood damage has been eliminated by the cooperation of two Corps of Engineers' reservoirs (F. E. Walter and Beltzville). Backup from high Delaware River flows can still be expected to cause significant damages.

For Bushkill Creek more than half the flooding is a result of Delaware River backup but one can not ignore flooding from rainfall upstream overflowing the Bushkill.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from earlier storm events. Easton had 237 residential, 119 commercial and 12 industrial properties inundated in the 1955 storm of record. Damages in 1955 dollars at Easton from this event were estimated at $5,000,000 for the Delaware River, $300,000 for the Lehigh, and $35,000 on the Bushkill. Damages from earlier events were not able to be broken down. In today's dollars damages would be nine or ten times the 1955 amount.

The April 1973 Flood Control and the Delaware River Report by Laurie Burt and Leo M. Eisel, PH.D. evaluated 8 flood damage centers along the Delaware River including Easton. Its purpose was to provide updated flood damage data and evaluate flood reduction strategies in opposition to Tocks Island. At Easton it reported the elimination of over 150 residences, nearly 100 commercial properties, and 9 industrial properties as part of the Riverside Drive Redevelopment Project which created Scott Park in Easton. Non-structural measures (floodproofing and floodwarning) were proposed strategies for damage reduction for the remaining structures.   It also reported a PADER proposed dam along the Bushkill, 14 miles north of Easton which would have reduced flood damage along the Bushkill; it was however, never built. See discussion Belfast/Jacobsberg Reservoir that follows.

The Bushkill was also investigated in October/November 1967 in response to a request by Congressman Rooney. Bushkill Park was visited and flood damage information obtained. According to local interests, the primary cause of damages was debris blockage from an old bridge on the Bushkill. Information was provided to local interests on the Corps' Continuing Authority Program but a request for a study was never received. As part of that investigation, PA Department of Forests and Waters, (PADEP Predecessor) was contacted concerning a Jacobsburg Project. That recreation reservoir was first reported in the Comprehensive Study of the Delaware River Basin H.D. 522 as Belfast Dam (Wg-5), one of 39 small flood control projects but was not pursued further due to a lack of local interest. This 523 acre reservoir would have reduced average annual flood damages from $86,800 in 1955 dollars ($800,000 today) to $52,800 (also 1955 dollars which can be updated to a current $500,000 dollars). This Belfast/Jacobsberg Reservoir had in 1955 a computed BCR of 2.6 to 1 based primarily on recreation. This reservoir site was subsequently acquired by Pennsylvania and was developed as a State Park without a Reservoir due to local opposition to a reservoir. The Pennsylvania staffer contacted as part of the October/November 1967 Coordination also mentioned that the Soil Conservation Service was investigating the Bushkill for flood control reservoirs at that time but locations were too expensive to implement. NRCS (SCS's new nane) was contacted as part of this flood evaluation and had no documentation other than a database which indicated insufficient economic benefits were found to justify its constructing a reservoir on the Bushkill.

The July 1983 State Water Plan, prepared by PADER (now PADEP) includes combined flood information on Easton and West Easton. This damage center includes flooding from both the Lehigh and Delaware River (and presumably Bushkill Creek) reporting a 77% reduction in Natural Annual Damages Due to Existing Projects (F.E. Walter and Beltzville) with residual Average Annual Damages (AAD) of $241,600 (1976 price level) which converts to an AAD of $770,000 (2007 price level).

- Flood Damage Reduction Solution Alternatives listed a levee (AAD Prevented $140,100 at a Average Annual Cost (AAC) of $182,900 making the project not Economically Justified. (Location details absent).
- Recommended were nonstructural measures including Flood Plain Regulation, Flood Insurance, Flood Proofing and Flood Forecasting.

The August 1984 Delaware River Basin Report evaluated flooding along the Delaware River including the Bushkill.

- At Easton it evaluated a levee ($129,600 Average Annual Benefits vs. Average Annual Costs of $2,100,000) for a Benefit to Cost ratio of 0.06 to 1.

- Easton was also evaluated for nonstructural flood measures. Of the 260 structures in the floodplain, 78% required no protection from the 50 year flood event, 12% needed floodproofing or floodwalls, 10% needed elevating and none required buyouts. The Benefit to Cost ratio of providing this level of protection was 0.64 to 1 (AAB $98,700 to AAC $152,900 at 1984 price levels).

The May 1990 Lehigh River Flood Warning Study proposed a separate flood warning/preparedness system for the Lehigh Basin as an interim flood control measure. It was never implemented in large part due to the inability of a non-Federal sponsor to guarantee operation and maintenance of additional stream gauges. Economics were based upon surveys conducted for the F.E. Walter Modification General Design Memorandum. Benefits were to come from a reduction in content damages.

The December 1992 Lehigh River Basin, Reconnaissance Study evaluated flooding on the Lehigh River and Tributaries. AAD in Easton from Lehigh River damages was reported as $55,000 and $123,000 in West Easton ($87,000 and $195,000 in current dollars) based on detailed economic surveys from the F.E. Walter Modification General Design Memorandum. Flood damage reduction started at the ten year event and peaked in the 50-80 year flood range. Damages were primarily commercial with some industrial and little residential.

- A fifteen foot sheetpile wall of 3,450 feet along the Lehigh was evaluated. It would not have provided any flood protection to Downtown Easton since it tied into high ground 4000 feet upstream of the Third Street Bridge.

Easton was also included in the Lehigh Valley Hazard Mitigation Plan, July 2006. This report lists flooding as the number one disaster of Lehigh and Northampton Counties. Of the 21 declared disasters since 1955 in these two counties, 14 were from flooding. Easton had the highest number of both claims and payments from flood insurance in the Lehigh Valley from the September 2004, the April 2005, and the June 2006 storms. This Hazard Mitigation Plan lists 176 parcels with structures and 173 parcels without structures within the outline of the 100 year floodplain. This does not mean all these structures get flooded since structure specific elevations were lacking. Of the 176 parcels with structures, 76 were residential, 31 commercial, 26 industrial, 15 office, 7 utility, and 20 public. Total market value was estimated at $336,112,000. There were 4 public utilities and 1 school within the floodplain with an estimated market value of $140,320,000. There were 10 Hazard Mitigation Flooding Projects listed for Easton.

Proposed Hazard Mitigation Projects – City of Easton

BUSHKILL CREEK

- Relocate City Services Center - currently in Bushkill Creek flood area (currently) City Services Center - 500 Bushkill Drive
- Flooding from confluence of Bushkill Creek and Delaware River 100 block of Bushkill Drive

- Homes, businesses flood from Bushkill Creek and Delaware River North Delaware Drive at Bushkill Drive
- Structural enhancements/design modification to floodproof bridge Pearl and Bushkill St.

LEHIGH RIVER
- Properties impacted by Lehigh River Buttonwood between Raspberry and 14th St.
- Properties impacted by Lehigh River Winter St. in area of Raspberry and 14th.
- Relocate/elevate homes located in flood area 14th Street at Lehigh Drive
- Relocate/elevate homes located in flood area Lynn St.
- Relocate/elevate homes located in flood area Raspberry St. at Lehigh Drive area.

DELAWARE RIVER
- Park floods from Delaware River Eddyside Park - North Delaware Drive SR611

According to FEMA, based upon **a** comparative analysis of the National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 30 repetitive loss properties with total payments of $4,793,574 with 1 severe repetitive loss with a payment of $83,848. This does not include damages from noninsured properties.

<u>ALTERNATIVE EVALUATION</u>

<u>BUSHKILL CREEK</u>

- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>

  - A levee-floodwall system is possible for protecting Delaware River flows from backing up the Bushkill. A roadway over the creek 0.1 miles above the mouth could, with a Flapgate added, provide about a 50 year level of protection. NJ Barriers placed along the bridge shoulder and approaches could also possibly increase the level of protection but would still have less than a 100 year level of protection. Portable pumps need to be investigated as part of this effort.
  - Channel Modification as such is not viable as a stand alone system. No constrictions exist whose removal would likely measurably reduce flood stages. A review of potential debris blockage would be warranted based upon the 1967 field investigation and limited channel modification may be warranted in conjunction with than effort. A debris structure typically consists of a series of piles placed across a stream at an angle at a location where debris could collect, have sufficient open space not to cause upstream flood damages by ponding, and have easy access for heavy equipment to remove the debris after a storm.
  - Local Detention is not viable here. No sizable vacant land is available & minimal stage reduction could result. Upstream dams were investigated in the past but economic viability is highly unlikely.

- FlapGates/Stormwater Outlets may possibly be viable. Limited information available but stormwater backup likely. Need to contact the City of Easton to obtain more details.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

  - Review of River Stage Forecast Map (1990) would appear to indicate majority of 57 structures within 50 year floodplain are within Bushkill Creek. Based on 1984 Basin Study sufficient benefits (57 structures with BCR of 0.64 to evaluate further. Of these none required buyouts, 31 benefitted from raising and 26 from floodproofing.
  - County Hazard Mitigation Plans list two locations within Bushkill for non-structural measures.
  - Flood warning should also be re-evaluated
  - Wetland/ Floodplain Restoration is not viable in itself with limited unoccupied former floodplain.

Figure 1: Black Mill Apartments on Bushkill Drive in the City of Easton, September 2004. Photograph by City of Easton.

MAINSTEM DELAWARE RIVER

- STRUCTURAL FLOOD CONTROL MEASURES

  - A levee-floodwall system along the Delaware River was previously found to be a poor economical investment and should not be evaluated further.
  - Channel Modification is not viable. No constrictions exist whose removal would likely reduce flood stages. There would be limited stage reduction with high economic & environmental cost from deepening river channel. There are no dams on Delaware River in vicinity of Easton whose removal could alter stage flows.
  - Local Detention is not viable. No sizable vacant land is available & minimal stage reduction could result.
  - FlapGates/Stormwater Outlets may be viable. Limited information available but stormwater backup likely. Need to contact the City of Easton.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

  - Review of River Stage Forecast Map (1990) indicates majority of 57 structures within 50 year floodplain are within Bushkill Creek. As part of an evaluation of Bushkill Creek those structures affronting the Delaware should be concurrently evaluated.
  - Flood warning should also be re-evaluated.
  - Wetland/ Floodplain Restoration is not viable in itself with limited unoccupied former floodplain.

Flooding at the junction of the Delaware and Lehigh Rivers

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, 1962, Appendix D
April 1973 Flood Control and the Delaware River Report (Environmental Defense Fund) by Laurie Burt and Leo M. Eisel, PH.D
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
May 1990 Lehigh River Flood Warning Study
December 1992 Lehigh River Basin, Reconnaissance Study
River Stage Forecast Map Delaware River – Reach 4 Sheet 24 Northampton & Warren Counties 1993
Easton Intermodal Transportation Center/Riverwalk Project Environmental Assessment
Lehigh Valley Hazard Mitigation Plan, July 2006.
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, October 2006

UPPER MAKEFIELD, PENNSYLVANIA

BACKGROUND

Upper Makefield Township is a township in Bucks County, Pennsylvania. According to the United States Census Bureau, the township has a total area of 21.5 square miles (55.8 km^2), of which, 20.9 square miles (54.2 km^2) of it is land and 0.6 square miles (1.6 km^2) of it (2.88%) is water. As of the census of 2000, there were 7,180 people, 2,512 households, and 2,105 families residing in the township. There were 2,598 housing units. The average household size was 2.86 and the average family size was 3.13. The median income for a household in the township was $102,759, and the median income for a family was $114,064.

PROBLEM IDENTIFICATION

Flooding has been a continual problem along the Delaware River here since settlement of the area. Although the worst flooding generally results from excessive rainfall alone, flooding in the Delaware River in early spring can be even more severe because of moving ice and snowmelt. The Delaware Canal does not appear to cause a separate flooding problem but rather is affected directly by overbank floodwaters from the Delaware River.

Stormwater management has also become an issue in the township. Within the township, Hough's Creek (5.9 sh. Mi) and Jericho Creek (9.63 sq. Mi.) have repeatedly flooded and caused major impact to properties along their banks, primarily erosional in nature.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D provided flood information from earlier storm events. Damages in 1955 dollars from this event were estimated at $394,000 residential, $50,000 commercial, $35,000 public and $85,000 highway, for a total, including miscellaneous of $590,000. In today's dollars damages would be nine or ten times the 1955 amount.

The July 1983 State Water Plan, prepared by PADER (now PADEP) did not include separate damages for Upper Makefield but consolidated damages with Yardley and Lower Makefield. Damages were reported as scattered and local flood protection was not feasible.

The August 1984 Delaware River Basin Report evaluated flooding along the Delaware River and developed a comparison of damages and number of structures for different storm levels.

March 1983 Dollars and Conditions ($000)
And number of structures

	10 yr	50 yr	100yr	1955	500 yr
$ Damages	260	1,702	3,728	8,134	15,565
# Structures	1/	1/	116	246	304

1/ Not listed

At Upper Makefield, local protection (i.e levees/floodwalls) were not evaluated. Upper Makefield was evaluated for nonstructural flood measures. Of the 304 structures in the 22 year floodplain, 91% required no protection from that 22 year flood event, 7% needed floodproofing or floodwalls, 2% needed elevating and none required buyouts. The Benefit to Cost ratio of providing this level of protection was 0.87 to 1 (AAB $29,800 to AAC $34,200 at 1984 price levels). Floodproofing to a higher level of protection would have much higher costs and a lesser amount of relative benefits.

A Plan to Preserve Upper Makefield Township's Farmland & Open Space report dated June 1998 provides some description of watersheds in the Township but limited information on flooding.

The National Park Service prepared, in 1999, a National Wild and Scenic Study Report for the Lower Delaware River. That plan recommended that several river segments, including Segment I containing Upper Makefield, above Washington's Crossing, be designated as recreational within the Wild and Scenic River System. It was made law in October 2000. Section 7(a) of the Wild and Scenic Rivers Act prohibits federal authorization of any water resources project or assistance by loan, grant, license or construction of any water resource project that would have an adverse impact on the values for which the river is designated. The boundary of this designation extends one-quarter mile inland from the ordinary high water mark.

"Recreational" river areas -- Those rivers or sections of rivers that are readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past. Regardless of classification, each designated river is administered with the goal of nondegradation and enhancement of the values which caused it to be designated.

Section 7 of an October 2004 Technical Report of the Interagency Wild and Scenic Rivers Coordinating Council titled Wild & Scenic Rivers Act provides additional guidance. A determination is required when a project is proposed by a federal agency or it requires some type of federal assistance such as a permit, license, grant or loan. Unlike new FERC-licensed projects, which are prohibited if they are "on or directly affecting" a designated river, other proposed federally assisted water resources projects are prohibited only if they would have a "direct and adverse effect" on the values for which a river was added to the National System. Examples of projects that would likely be subject to this standard include, but are not limited to: dams; water diversion projects; fisheries habitat and watershed restoration/enhancement projects; bridge and other roadway construction /reconstruction projects; bank stabilization projects; channelization projects; levee construction; recreation facilities such as boat ramps and fishing piers; and, activities that require a Section 404 permit from the Army Corps of Engineers. The determination is made in consultation with state and federal agencies as part of the environmental assessment/impact statement process. Depending on the nature of the proposed construction and the degree of effect on the river's values and defined in the original study and management plan, the proposal can be approved, modified, conditioned, or denied.

According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 58 repetitive loss properties (payments totaling $8,701,479) which was the 6th highest municipality in the basin and 17 severe repetitive losses (payments totaling $4,504,390) which was third highest in the basin. This does not include damages from noninsured properties.

Upper Makefield Township prepared a binder titled Delaware River Flooding Data and Effects on Upper Makefield Township dated June 15, 2007.

- Chapter 1 provides general information including a map of the 100 year flood area. That map shows 6 flood damage clusters with 2 above Washington Crossing (30 and 21 damaged homes) with a 6 home cluster at Washington Crossing and 3 clusters south of Washington Crossing with 6, 17, and 4 homes damaged respectively). Also included is a fact sheet that states that flood stage in this area begins when the Trenton gauge shows 20'. Flooding begins to have a major impact at 21' while Delaware Canal begins to fill with water at 18" flood stage. Route 32 is completely impassible at the 18ft level north of Route 532. It also indicates that 17 homes have been elevated and a FEMA grant for 13 more has been applied for.
- Chapter 2 provides information that the Township requires elevation to be 1.5 feet above the 100 foot flood elevation and hydraulic information on flood stage elevation. There is considerable information concerning the Delaware Shores Community which had the largest number of residences flooded in the township. Of the 31 properties, 16 get flooded by the 25 year event and all would be flooded by the flood of record. The April 2005 flood damaged 21 homes (even with 4 being floodproofed) at the 100 year flood level.

- Chapter 3 includes information on the number of homes flooded June 29, 2006 (74).

ALTERNATIVE EVALUATION

HOUGH'S CREEK

- STRUCTURAL FLOOD CONTROL MEASURES
  - Based on the limited data available, erosion rather than flooding appears to be the primary problem from storm events. A DEP Stream Improvements Program grant appears to be the best option for municipal assistance.
- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - Need to investigate the feasibility of utilizing flood proofing techniques for residential properties along the stream.

JERICHO CREEK

- STRUCTURAL FLOOD CONTROL MEASURES
  - Based on the limited data available, erosion rather than flooding appears to be the primary problem from storm events. A DEP Stream Improvements Program grant appears to be the best option for municipal assistance.
- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - Need to investigate the feasibility of utilizing flood proofing techniques for residential properties along the stream.

DELAWARE CANAL

- STRUCTURAL FLOOD CONTROL MEASURES
  - Downstream of Lock 11 in Upper Makefield there was a former lock that allowed canal boats to enter the Delaware River. The lock mechanism and a canal stop gate are reported as not functional and this may be contributing to downriver canal storm flows and subsequent flooding. While no report of canal induced flooding in Upper Makefield has been noted, replacement of the stopgate may at least help flooding in Lower Makefield and Yardley.
- NONSTRUCTURAL FLOOD CONTROL MEASURES
  - No separate action appears viable.

MAINSTEM DELAWARE RIVER

- STRUCTURAL FLOOD CONTROL MEASURES

  - A levee-floodwall system along the Delaware River was not previously investigated. With the damages clustered at 6 locations the use of ring levees around these damage locations needs to be evaluated. Rather than a permanent levee/floodwall which would isolate the community and be determined contrary (at least north of Washing Crossing) to the federal Wild and Scenic River Designation, a temporary floodwall coupled with a permanent base and some permanent floodwalls should be investigated. The amount of permanent vs. temporary would to a large degree be determined by the type of temporary structure chosen and the time the municipality could erect the temporary floodwall. How acceptable even a temporary floodwall would be to the Wild and Recreational designation is unknown.
  - Channel Modification is not viable. No constrictions exist whose removal would likely reduce flood stages. There would be limited stage reduction with high economic & environmental cost from deepening river channel.
  - Local Detention for River caused flooding is not viable. No sizable vacant land is available & minimal stage reduction could result.
  - FlapGates/Stormwater Outlets are a critical component of any flood control project and several pipe extensions need to be implemented. A review of recent flooding should be undertaken to determine if backup of the stormwater system which appears to be a major contribution for minor flood events would benefit from the addition of either permanent or temporary pumping stations.
  - The construction of any structural plan must take into consideration the potential for an adverse determination which will be strongly influenced by the exact nature and specific design. Early coordination with the National Park Service should be initiated as soon as possible.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

  - The 1984 Corps' evaluation of floodproofing found sufficient economic viability (BCR = 0.87) that these series of options need to be re-evaluated in more detail. Flood proofing techniques include: levees, flood walls, elevation, relocation, closures & sealants. Flood proofing functions fall into three general categories: (1) construction of barriers to prevent floodwater from entering the property, (2) elevation or relocation of the structure above the flood hazard, (3) alteration of the structure and relocation of the contents to minimize flood damage. The ability for staged implementation is a significant positive factor.
  - Flood warning should also be re-evaluated. An emergency telephone system in Bucks County is currently operational.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, 1962, Appendix D, 1962
Delaware River Basin Study Final Report and Technical Appendices 1984 (2 volumes)
July 1983 State Water Plan, prepared by PADER
Plan to Preserve e Upper Makefield Township's Farmland & Open Space June 1998
The National Park Service 1999 National Wild and Scenic Study Report for the Lower Delaware River. 1999
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, October 2006.
Delaware River Flooding Data & Effects on Upper Makefield Twp. June 15, 2007

COLCHESTER, NEW YORK

BACKGROUND

Colchester is a township in the State of New York. It is approximately 137.4 square miles with a population of 2,042 in the 2000 Census. It has 1,587 houses (837 occupied: 670 owner occupied, 167 renter occupied). Estimated median house/condo value in 2005: $92,900 (it was $73,500 in 2000). The town includes the village of Downsville and the hamlet of Corbett and Shinoppe on the East Branch Delaware River and the hamlets of Cook Falls, and Horton on the Beaverkill.

There are two major waterway systems in the Township. The Beaverkill is a 48 mile stream with the lower 14 miles in Delaware County. There are two clusters of damage centers on the Beaverkill with the lower one in Colchester at the Horton-Cooks Falls Area. They are residential communities where the mouths of small streams enter the Beaverkill. For Horton, its Horton Brook while for Cooks Falls its Cooks Brook. For the East Branch Delaware River, the New York City Pepacton Reservoir is dominant, with this 15 mile long reservoir located just upstream of Downsville. It is also where Downs Brook and Wilson Hollow Brook flow into the East Branch.

PROBLEM IDENTIFICATION

The following description of historic flooding of Downsville comes from a summary of a 1975 interview of the Colchester Town Supervisor. On May 21, 1942 Downsville saw major flooding with the Downs Brook destroyed and major flooding of Main Street. Downs Brook also flooded in August 1952 with water overflowing its banks below the bridge and flooding lower Main Street. In 1952 the Pepacton Dam spillway overflowed with houses on River Street flooded. Ice jams on the East Branch caused flooding in 1964 and again in 1965. The 1973 storm caused Downs Brook to overflow into Main Street.

There is record form the Corps' Cold Region Research Lab of several ice jams occurring at Cooks Falls along the Beaverkill.

Flooding at Horton-Cooks Falls area is caused by a combination of factors. Besides the tributary streams of Horton Brook, Russell Brook, Horse Brook, and Cooks Brook overflowing, the Beaverkill leaves it banks.

Besides Hurricanes and Tropical Storms, localized summer storms in the region are especially damaging as was the case with the June 19-20 2006 event, just the latest of events. The flash flood occurred June 19-20 after this area, along the Delaware and Sullivan counties border, received 6-8 inches of torrential rain in a matter of hours. During the flash flooding which ensued, one bridge was destroyed and several others sustained significant damage. A seven-mile stretch of Holiday Brook Road was also washed away. Dozens of homes were ripped from their foundations, 14 were inaccessible, and an additional 160 were without utilities.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D, provided little flood information from prior storm events. Damages from the 1955 storm was only provided for the East Branch and Beaverkill Watersheds and not individual communities.

The April 1981 Survey Feasibility Report, Flood Control and Flood Plain Management for the Tributaries to the Delaware River New York and its backup evaluated Colchester in detail. It identified flood damage locations and developed detailed evaluations of 10 locations including one at Downsville. Information on flood damages at locations in Colchester are as follows:

SUMMARY OF DAMAGE SURVEY INFORMATION

Damage Center	Sub-Basin	Flood of Event	Total Damages (Nov 80 $)	Total Damages (2007 $)
Cooks Falls	Beaver Kill	31 March 51	$23,200	$55,000
Horton	Beaver Kill	29 June 1973	$12,100	$29,000
Shinhoppe	East Branch	26 Nov 50	$66,500	$158,000
Downsville	East Branch	29 June 73	$209,000	$496,000
Corbert	East Branch	26 Nov 50	$25,800	$61,000

- For Downsville a 4 foot high levee (3 foot freeboard) and floodwall (including closure structure for Main Street) along Downs Brook was evaluated to protect residential and commercial property to the 100-year elevation. The initial cost was $1,080,000, with the AAC of $85,300 and AAB of $18,000 providing a BRC of 0.2.
- Backup can be found in a June 1980 Downsville Flood Control Analysis Summary. That report provides details on the design of the levee and floodwall as well as hydraulic computations. Based on the amount of historic flooding noted (4-6' of flood stage from the flood of record) coupled with the absence of damages computed at the 25 year flood event, the stage-damage curve and the levee-floodwall height need to be revisited. Use of a sheet pile wall rather than a traditional levee-floodwall would also reduce costs.

The Delaware River Basin Ice Jams Study of 1985 did not indicate that within Colchester Township there were major problem areas for ice jams.

The 1996 Upper Delaware River Watershed, New York Expedited Reconnaissance Study did not mention Colchester. The Plan of Study did include Downsville as one flood damage location to be studied in detail. A survey of flooding damages of residential and commercial buildings and infrastructure was to be conducted along roughly 4,200' of Downs Brook, 1,000' of the East Branch Delaware River, 3,000' of Wilson Hollow Brook, and 1,000' of Tub Mill Brook

The 2006 Delaware County Hazard Mitigation Plan (Draft) provides more current levels of flood damages. Colchester was reported as having 108 buildings (106 residences) exposed to the 100 year flood event with a total value of $19.7 million and expected damages of $2.6 million ($1.6 Building Structure and $1.0 Building Contents). For the residential properties this translates to $15,400 structural damages per structure and $9,600 contents damage per structure. With an average value of $92,900, this means a 16% structural damage per event converts to, on average, a first floor flooding of about 1-2 foot. For a 500 year event, the number of structures exposed only increases to 117 (115 residential) with projected damages of $2.3 million building structure and 1.2 million contents. It should be noted that these damages are based on FEMA damage curves that show somewhat lower structural damages and higher content damages. Two hundred of the 2,042 citizens live within the 100 year flood zone and and 250 live within the 500 year flood flood zone areas. No specific project proposals were included in that draft document.

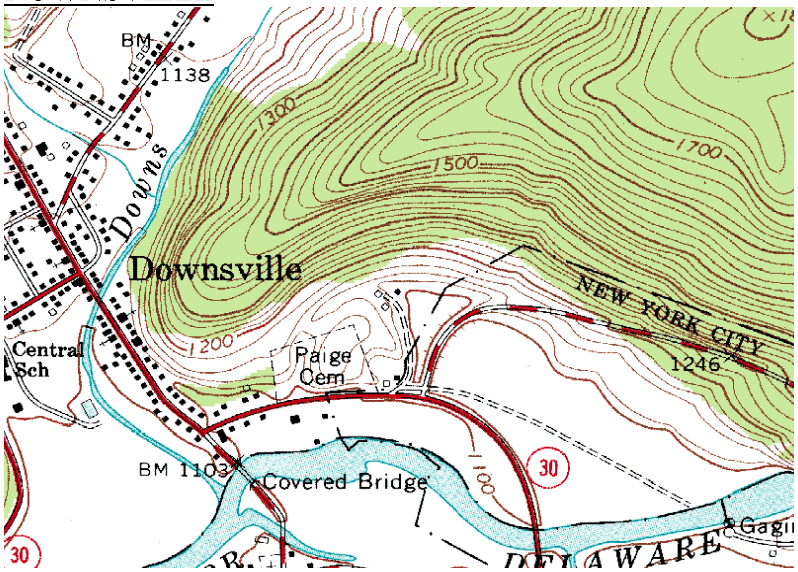
According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 22 repetitive loss properties (payments totaling $931,265) with no severe repetitive losses. This does not include damages from noninsured properties.

The September 2007 East Branch Delaware River Stream Corridor Management Plan recommends a need for an early flood warning system along the East Branch in Colchester.

A May 3, 2007 Press Release by Senator Clinton reports a Hazard Mitigation Project for the voluntary acquisition and demolition of a total of thirty-three (33) residential properties in the Towns of Hancock, Walton, Middletown and Colchester and the Villages of Walton, Sidney, and Deposit. The majority of these properties are located within designated Special Flood Hazard Areas of the Delaware or Susquehanna Rivers and tributaries. Each property identified in the application has incurred substantial damages or was destroyed as a result of flooding that occurred during the last week of June 2006. The number of properties in Colchester were not specified but were located in the Hamlet of Shinoppe on Island Road.

ALTERNATIVE EVALUATION

DOWNSVILLE



Historic Flooding Village of Downsville

0 0.1 0.2 0.3 0.4 0.5 mi

Flooding along Downs Brook was historically caused by constriction of flow at the Main Street Bridge and by inadequate channel capacity along the brook downstream of Main Street. Flooding on the East Branch Delaware River is now generally controlled by the upstream Pepacton Reservoir. The historic flood of record on June 1973 caused approximately $20,000 at that time ($80,000 in 2007 dollars). Structural solutions for this level of damage could not be economically justified. Teleford Hollow causes some minor residential flooding on the outskirts of Downsville. A June 1973 (historic flood of record) was less than a foot out of banks. No Federal project appears warranted.

STRUCTURAL FLOOD CONTROL MEASURES

- Downsville was previously analyzed in the 1970’s by the Corps for a levee/floodwall with minor channel widening along Downs Brook paralleling Main Street The 1,400 earthen levee having a height of 4 feet above the streambed and a top width of 6 feet would prevent damages to the 100 year storm event. The cost was estimated at $1,010,000 (January 1980 dollars) which can be adjusted to a current cost of about $2,600,000 (2007 dollars). One home would need to be relocated. The average benefits in 1970’s were $15,800 with a benefit-to-cost ratio of 0.3. A re-evaluation based upon updated flood stage computations plus a possible switch from a standard levee-floodwall to a sheet pile one needs to be evaluated

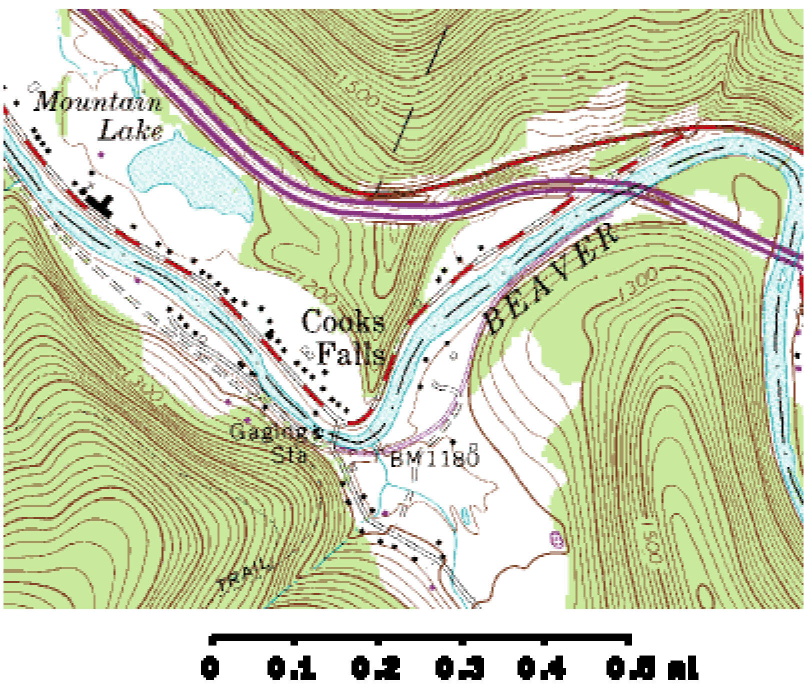
- A moderate channel modification of Downs Brook might be justified. High flow diversion might also be possible. The 1970’s Corps levee-floodwall design noted above included channel modification and an evaluation should be conducted to evaluate the possibility of isolated shoaling or a channel restriction being the prime flooding issue. Also stream/bank ecosystem restoration could restore the natural channel thereby improving stream flow capacity and should be investigated.

- Detention basins in the Downs Brook Watershed would not be economically justified based on the combined high construction and mitigation costs coupled with the need for multiple structures from the several tributaries just upstream.

NONSTRUCTURAL FLOOD CONTROL MEASURES

- Nonstructural measures appear to be the most viable alternative but a detailed analysis would depend on the specific structural considerations of each home as well as updated flood stages. Structural raising as well as dry floodproofing would be likely options. Benefits would occur from a reduction in damages from all three sources of flooding.

HAMLET OF COOKS FALLS



The previous flood of record at Cooks Falls occurred in March 31, 1951 as a result of the Beaver Kill overflowing its banks by less than a foot. Damage to homes was reportedly limited to basement flooding coupled with road damages. The historic flood of record caused approximately $15,000 in 1973 dollars ($ 63,000 in 2007 dollars). A few ice jam events were also found in a Cold Regions Research Lab database without details.

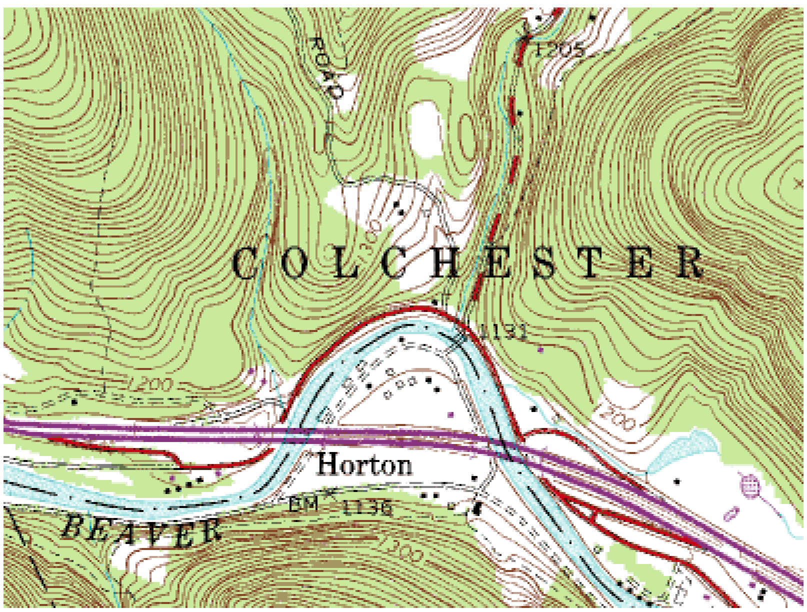
- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>

  The level of damages precludes finding a structural measure from being economically justified.

- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>

. Dry floodproofing, ring levees or grading by homeowners may be warranted especially since it would prevent damages from the two causes of flooding (fluvial and ice jams) .

<u>HAMLET OF HORTON</u>



Flooding in Horton was historically caused by overtopping of the banks of both Horton Brook and Dry Brook which join to become Horton Brook before entering the Beaver Kill. The Beaver Kill caused no historic problems and actual damages from the tributaries have historically been minimal. A review of current aerial photos found no significant recent development.

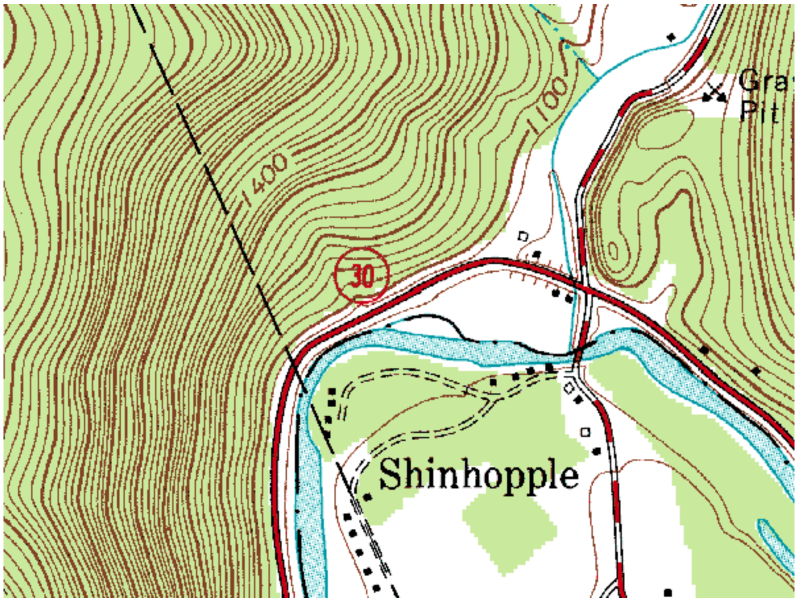
- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>

  The level of damages precludes structural measures from being economically justified.

- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>

. Dry floodproofing, ring levees or grading by homeowners may be warranted.

HAMLET OF SHINOPPLE



Hamlet of Shinopple

0 0.1 0.2 0.3 0.4 0.5 mi

There is no record of historic flood damage at the Hamlet of Shinopple. The 2006 flood caused considerable residential flooding and several homes were reported to be part of a County Hazard Mitigation Project (Buyout).

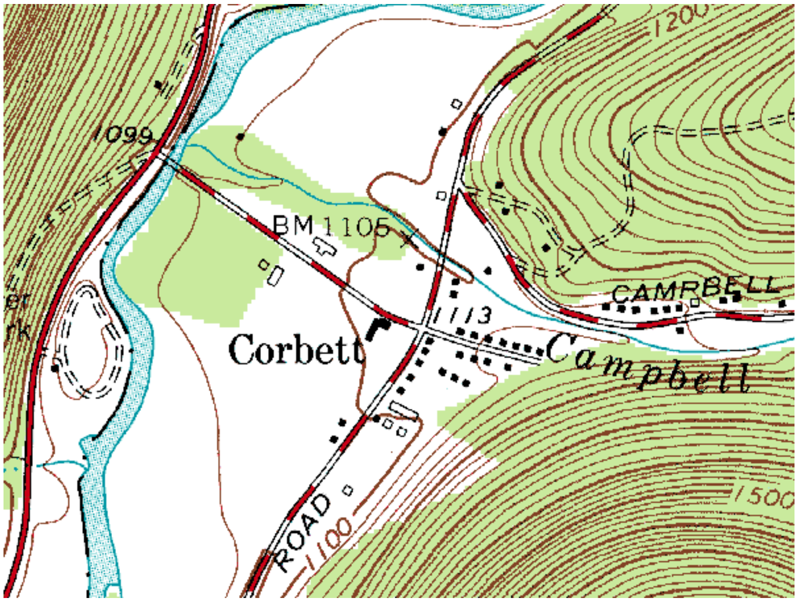
- STRUCTURAL FLOOD CONTROL MEASURES

  The level of damages precludes structural measures from being economically justified.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

. Dry floodproofing, ring levees or grading by homeowners may be warranted. Evaluation of buyouts should be considered.

<u>HAMLET OF CORBETT</u>



Hamlet of Corbett

0 0.1 0.2 0.3 0.4 0.5 mi

The previous historic flood of record at Corbertt occurred in 1950 as a result of Campbell Brook overflowing its banks by about 3 feet. Damage to homes was reported as being limited to lawns and basement flooding coupled with road damages. This flood caused approximately $16,000 in 1973 dollars ($66,000 in 2007 dollars).

- <u>STRUCTURAL FLOOD CONTROL MEASURES</u>

  The level of damages precludes structural measures from being economically justified.

- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>

. Dry floodproofing, ring levees or grading by homeowners may be warranted.

1/ PUBLISHED REFERENCES

Comprehensive Study of the Delaware River Basin H.D. 522, 1962
April 1981 Survey Feasibility Report, Flood Control and Flood Plain Management for the Tributaries to the Delaware River New York
Delaware River Basin Ice Jams Study 1985
Flood Insurance Study, Town of Colchester, New York 1987
Upper Delaware River Watershed, New York Expedited Reconnaissance 1996
Analysis of Repetitive and Severe Loss Properties in the Delaware River Basin, DRBC, October 2006
Delaware County, NY Hazard Mitigation Plan
East Branch Delaware River Stream Corridor Management Plan, Sept 2007

ROCKLAND, NEW YORK

BACKGROUND

Rockland is a township in New York with a total area of 95.2 sq mi, 94.3 sq mi. of it is land and 1.0 sq mi. of it is water. Population in year 2000 was 3,913. Estimated population in July 2006: was 3,940. There were 2,475 houses (1,560 occupied: 1,097 owner occupied, 463 renter occupied). There are 12 hamlets of varying sizes within Rockland, with Livingston Manor being the largest with 3.1 square miles and a population of 1,355 in the year 2000. The three hamlets of Livingston Manor, Lew Beach and Roscoe form the "Golden Triangle of Fly Fishing" and encompass the world famous Beaverkill and Willowemoc Rivers.

PROBLEM IDENTIFICATION

The 1993 FEMA Flood Insurance Study describes the Willowemoc Creek as the major source of flooding in the Township. The areas most frequently flooded are located in Livingston Manor. During the winter and spring months, ice jams occasionally cause basement flooding along the Little Beaver Kill, immediately upstream of Livingston Manor, and along Pleasant Street. The most notable location of ice jams are at the Main Street Bridge over the Little Beaver Kill in Livingston Manor. The hamlets of Roscoe and Rockland are subject to periodic flooding due to overbank flooding of Willowemoc Creek and the Beaver Kill. Ice jams are also the cause of occasional flooding on Yorktown Road along the Willowemoc near Roscoe.

The town has indicated the belief that flooding in Livingston Manor can not be completely prevented. The town does not want a structural flood damage reduction project that adversely impacts the natural values of the area, citing the concrete channels and floodwalls of a nearby project as an example.

PRIOR REPORTS

The Comprehensive Study of the Delaware River Basin H.D. 522, Appendix D, dated 1960 provided flood information from prior storm events. The November 1950 flood event, which was the prior storm of record for this location caused the following number of properties to be inundated:

Major Damage Centers November 1950 Storm

	No. of Properties Inundated		
	Residential	Commercial	Industrial
Rockland	30	0	0
Roscoe	12	17	3
Livingston Manor	69	30	1

A September 1967 Corps of Engineers Report (20 pages) titled Beaver Kill, Rockland New York evaluated a Flood Skimming Project. It evaluated flood control benefits to the villages of Rockland and Roscoe from construction of a flood skimming project (dam) proposed by the Board of Water Supply, City of New York. The benefits from flood reduction to about 1/3rd of the Township of Rockland would occur by New York City constructing a structure which would transfer all greater than normal flows into City reservoirs. Basement flooding from seepage was reported at the 2 year event even when flood flows remained within streambanks.

Based on the large floodplain, most out of bank flooding was limited at a 15 year event or greater to a foot or two depth. Damages at a 5 year event were only $3,500 while those for a 10 year were $9,500, with a 20 year event escalating to $120,000.

A USGS Open File Report done in 1969 on the Flood of July 27-28, 1969 in Southeastern New York by Bernard Dunn and F. Luman Robinson stated that this flood, which exceeded all stream flows since the gauge was established in 1937, was greater than a 100-year event and damaged about 20 residences, campgrounds, the sewage treatment plant and a motel in Livingston Manor.

An August 1970 Reconnaissance Report of the Flood Control Problem, Livingston Manor and Roscoe – Rockland, Rockland Town, Sullivan County, N.Y. looked at flooding from the Willowemoc Creek from its confluence with the BeaverKill at Roscoe to a point two miles upstream of Livingston Manor as well as portions of the hamlets of Rockland and Roscoe lying adjacent to the BeaverKill. That report listed damages as:

Flood Damages Town of Rockland

Community	Damages 1969 Flood	Average Annual Damages
Livingston Manor	$509,000	$104,000
Roscoe-Rockland	$37,000	$4,4000

The preliminary plan of improvement for Livingston Manor which had a first cost of $1,460,000 included a system of levees, channel relocation and a flume and wall structure. It would have reduced minor flooding to once every twenty years. BCR =1.3 to 1. No other plans or locations were detailed.

A December 1975 COE Plan of Study from the Tributaries of the Delaware River in New York State identified 25 residences, a school, and almost 30 businesses damaged in the July 1969 flood at Livingston Manor. For Roscoe, flooding due to overbank flooding of both the Willowemoc Creek and Beaverkill affected 20 homes, the municipal garage, and a motel. In Rockland flooding damaged about 10 residences bordering the Beaverkill.

A 1976 Economic Damage Assessment by the Justin & Courtney, Inc, for the COE identified four major damage areas in the Township. A description of each follows:

- <u>Lewbeack</u> – Historic flooding of the BeaverKill has caused agricultural flooding as well as some basement flooding. Shin Creek backs up at its only bridge crossing and causes primarily commercial damages. Stage damage curve showed a 1.5' flood stage above the top of bank for the flood of record from both streams.

- Livingston Manor– Historic flooding of the Little Beaver Kill caused a majority of the flooding, affecting both residential and commercial districts. A major cause of flooding is backup from the Main Street Bridge during heavy rains. Flooding further upstream was caused by ice jams. Stage damage curve showed a 5.5' flood stage above the top of bank/floodwall for the flood of record. During very heavy storms the Willowemoc comes out of the bank, usually only affecting the basement level of some commercial properties, but with the July 28, 1969 flood water came up to the 1st floor in some cases; the Stage damage curve showed a 2.5' flood stage above the top of bank/floodwall for the Willowemoc flood of record.
- Rockland – Darby Brook and an Un-Named Tributary were reported to have caused damages (basement flooding) from the July 28, 1969. The Stage damage curve showed a 0.5' flood stage above the top of bank for the Darby Brook flood of record. Flooding of some farm fields and basements from the rising Beaver Kill; the Stage damage curve showed a 1' flood stage above the top of bank
- Roscoe - The main flooding problem occurs at "Junction Pool, the confluence of the Willowemoc Creek and the BeaverKill. Sediment carried down both streams had built up creating a large gravel bar forcing the flow to the sides. The Stage damage curve for Junction Pool showed a 1' flood stage above the top of bank for the 1989 event. Some residential flooding occurs from a small tributary, Stewarts Brook; the Stage damage curve also showed a 1' flood stage above the top of bank for the 1989 event.

A September 1979 Reconnaissance Report by the Corps of Engineers for Livingston Manor, Town of Rockland reported minor flooding, about once every 2 years, and major flooding occurring an average of once every 10 to 25 years. In that report a summary of flooding was provided based upon the 1976 damage survey. A series of upstream reservoirs, and major stream relocation and dredging of the Willowemoc Creek were dismissed as uneconomical and environmentally detrimental. The recommended plan of improvement was divided into multiple features:

- A levee around the Willowemoc Hotel – First Cost of $162,000
- Modifying the Rock Avenue Bridge along the Willowemoc – First Cost of $74,000
- A levee along the North Side of Willowemoc Creek -First Cost of $420,000
- Levees & Floodwalls along the South Side of Willowemoc Creek – First Cost of $461,000
- A levee around the Sewage Treatment Plant – First Cost of $229,000
- Stream relocation & widening along the Little Beaver Kill – First Cost of $2,375,000
- Internal Drainage including 2 pumping stations and a retention pond for the levees – First Cost of $1,073,000
- Contingencies, Design, Supervision and Administration – First Cost of $2,399,000

Due to the unfavorable benefit/cost ratio (0.29 to 1) it was concluded that further studies were not warranted at that time.

The April 1981 Survey Feasibility Report, Flood Control and Flood Plain Management for the Tributaries to the Delaware River New York and its backup evaluated Rockland in detail.

SUMMARY OF DAMAGE SURVEY INFORMATION

Damage Center	Sub-Basin	Flood of Event	Total Damages (Nov 80 $)	Total Damages (2007 $)
Lewbeach	BeaverKill/ Shin Creek	July 28, 1969	$36,500	$87,000
Livingston Manor	Little BeaverKill/ Willowemoc Creek	July 28, 1969	$1,620,010	$3,864,000
Rockland	Darby Brook/ BeaverKill	July 28, 1969	$2,500	$6,000
Roscoe	Willowemoc/ BeaverKill	July 28, 1969	$17,200	$41,000

- For Lewbeach, the Beaverkill flood of record had a 1.5’ flood stage and $1,930 in damages, while the Shin Creek tributary had the same flood stage and $21,000 in actual damages (not updated).
- For Livingston Manor, the Beaverkill flood of record had a 6’ flood stage and $516,200 in damages, while the Willowemoc Creek had a 2.5’ flood stage and $497,800 in actual damages (not updated).
- For Rockland, the Darby Brook and un-Named Trib had a 0.5‘flood stage and $500 in damages while the Beaverkill had a 1’ flood stage and $1,050 in damages. For Roscoe, Junction Pool (confluence of Willowemoc Creek and the Beaverkill had $5,750 in damages with 1’ of water, and Stewart’s Brook had $5,100 in damages from 0.5’.

Eight flood control plans were analyzed in detail. The one at Livingston Manor would have provided a 100 year level of protection. The plan involved channel relocation, levees and floodwalls on Willowemoc Creek and Little Beaver Kill and levees along Cattail Brook. The Initial cost was $7,720,000 with Average Annual Costs of $611,000 and Average Annual Benefits of $175,000 and a BCR of 0.3

The 1993 FEMA Flood Insurance Study describes the Willowemoc Creek as the major source of flooding. Local interests with state and Works Progress Administration (WPA) aid constructed approximately 1,600 feet of masonry wall and 1,400 feet of low levee along the banks of Willowemoc Creek in Livingston Manor with the wall built in front of the high school on the right bank and the levee downstream of the wall. In 1951, with state aid, approximately 1,000 feet of levee was constructed on the left bank below the confluence with the Cattail Brook. While these local protection works provide some protection they do not protect against rare events such as the 100-year event.

The 1997 Upper Delaware River Watershed, New York Expedited Reconnaissance Study stated that the January 1996 flood caused damage to 232 houses, 20 mobile homes, 27 businesses, 3 apartment buildings, and the water and sewer plants of the town. No specifics on exact location were provided nor proposals for further study at this location.

A May 2003 Draft Preliminary Restoration Plan for the Little Beaverkill Trout Habitat Restoration Project was prepared by the Bioengineering Group for the Corps of Engineers under its Section 206, Continuing Authority Ecosystem Restoration Authority. Thermal degradation of trout habitat is caused by borrow pits adjacent to the Little Beaverkill channel. Prior restoration measures to resolve the thermal degradation focused unsuccessfully on realigning the stream into its historic channel. Features of the proposed project included channel re-alignment of approximately 2,600 feet of the Little Beaverkill and bank stabilization, creation of floodplain wetlands, filling of the borrow pits, and establishment of a forested riparian buffer zone. Costs to implement included $200,000 for a Feasibility Study, $200,000 for Plans and Specifications, and $2,000,000 for construction.

A 12 page memorandum prepared by LU Engineers for NYSDOT evaluated the Livingston Manor Airport site for Mitigation purposes as part of the Conversion of Route 17 to I-86. It presented a conceptual framework for a restoration of about 800 yards of the Little Beaver Kill and creation of wetlands adjacent to the existing ponds. Its goals were to reduce thermal impacts on trout habitat, improve riparian habitat, and create additional wetlands to mitigate impacts to wetlands affected by highway construction. That evaluation concluded that the project as proposed would not result in significant flood reduction benefits.

In November 2005 FEMA Pre-Disaster Mitigation Grant for $1,450,000 (75% of the cost) was received for the Voluntary Acquisition and removal of 15 properties identified with major repetitive flood damages. This effort is ongoing.

A December 2005 Feasibility Analysis Report was prepared by the Firm of McFarland-Johnson. Inc, for the Town of Rockland to evaluate a flood control concept to protect Livingston Manor from Little Beaver Kill flooding. A Hydrologic and Hydraulic Analysis were conducted and Environmental Considerations evaluated. It concluded that a plan is feasible but would require some adjustments. A dry lake would need to have a storage volume of about 700 acre-feet for a 100 year level of protection which could be placed within 50 acres with a max depth of twelve feet assuming a levee system were placed around the entire storage area. A downstream levee would still be necessary.

The 2006 public draft update New York State Hazard Mitigation Plan does not mention county specific problems or plans.

Town of Rockland, contracted with the engineering firm of McFarland-Johnson who prepared a 3 page Flood Mitigation/Ecorestoration Feasibility Study, Potential Study Concepts package dated March 30, 2006 for Livingston Manor as part of a public coordination process. Streams in the area have been modified extensively. A combination of measures would be required to achieve the desired flood mitigation benefits. The concepts are described briefly below.

- *Fulton Plan or Variation* - is intended to provide floodwater storage upstream of the hamlet in the old airfield area, through a combination of berm construction and excavation. The original Fulton Plan did not include a stream restoration component, but did wetland creation. There are variations including stream restoration, wetland creation, and one without a berm.
- *Flood Wall/Setback Levee* - construct a flood wall or setback levee along Pearl St. to prevent inundation of the hamlet center and would require at least some channel relocation/stream restoration due to width restrictions.
- *Little Beaverkill Stream Restoration* - The Little Beaverkill channel has been modified/relocated with several gravel pits through with the stream now flows. The stream warms substantially as it flows through the pits degrading trout habitat, and the effect of the pits may create a thermal barrier to trout passage. Restoration would provide significant benefits for the trout fishery and a stream restoration could be coupled with floodplain forest/wetland creation. This can be considered a standalone ecorestoration project but with some bearing on flood mitigation.
- *Create Floodplain Storage at the Poultry Plant Site along Willowemoc Creek* -. Considerable floodwater storage could be created by removing fill material and lowering ground elevations with a floodplain forest and wetland habitat created. This could be a standalone ecorestoration project, with the possibly for flood mitigation.
- *Longer Bridge Span/Larger Waterway Opening at Main Street* - The existing Main St. bridge over the Little Beaverkill is very short and the waterway opening small. Stream banks are steep, and there is no floodplain at the bridge location. With other measures (upstream flood wall or levee), replacing this bridge with a longer span could eliminate a major impediment to flow and reduce flooding. Construction of a longer-span bridge would require acquisition and demolition of some structures.
- *Levee Removal at the Central School* - There is a stone wall in front of the school to provide flood protection which transitions to a low levee downstream, in order to protect athletic fields from floodwaters. It is not necessary to protect the athletic fields from flooding. Removal, or partial removal, of the levee may be desirable to increase flood storage. A gap near the Route 178 bridge should also be evaluated.
- *Evaluate Additional Culverts under NYS Route 17* - A backwater occurs at the NYS Route 17 bridge below Livingston Manor, just downstream of the hamlet's sewage treatment plant. There is only one small culvert in the roadway segment located west of the bridge which contributes to flooding.
- *Upstream Detention/Floodwater Storage* - The potential exists for some floodwater storage in existing impoundments in the Little Beaverkill watershed upstream of the hamlet. Effort has focused on the Town-owned Lake Matawah. With the small drainage area of this single lake, it would not have a significant effect on flood discharges. However, modification of the outlet and lowering of the lake level to create wetlands and provide a modest amount of detention might be possible. This might be considered a standalone ecorestoration project.

An Initial Appraisal Report was completed in June 2006 by the Corps of Engineers for Livingston Manor, Town of Rockland. As the first step in a flood study under the Corps Small Flood Control Program it determined Federal interest and recommended further study. The Town of Rockland experienced over $1.9 million in flood damages in September 2004 and April 2005. A Feasibility study was recommended to consider both structural and non-structural solutions to the flooding problems. Structural solutions could include channel improvements, possible bypass of floodwaters before they enter the Manor, and modification of existing upstream detention basins. Non-structural solutions could include flood proofing, raising structures, buyouts, floodplain restoration and wetlands creation.

Another report, a Technical Support for a Feasibility Study of Livingston Manor in the Town of Rockland, New York, was prepared by McFarland-Johnson, Inc. in December 2007 for the Corps of Engineers. Its purpose was to assemble existing data on stream channel cross-sections and recommend a stability analysis and hydrologic and hydraulic analysis as part of a future feasibility study.

According to DRBC, based upon **a** comparative analysis of FEMA's National Flood Insurance Program (NFIP) closed claims in the Delaware River Basin there were 40 repetitive loss properties (payments totaling $2,291436) with 5 severe repetitive losses (payments totaling $1,2999,321). This does not include damages from noninsured properties and includes the 15 properties from the Pre-Disaster Mitigation Grant mentioned above.

<u>ALTERNATIVE EVALUATION</u>

<u>HAMLET OF LIVINGSTON MANOR</u>

- <u>STRUCTURAL FLOOD CONTROL MEASURES</u> A single solution is unlikely due to the extent of floodplain alteration. The McFarland-Johnson, a 3 page Flood Mitigation/Ecorestoration Potential Study Concepts package, dated March 30, 2006 needs to be evaluated in detail. The components, which need to be individually evaluated and justified, can be implemented as determined viable. These components are:
    - *Fulton Plan or Variation* Floodwater storage
    - *Flood Wall/Setback Levee Little Beaverkill Stream*
    - *Create Floodplain Storage at the Poultry Plant Site along Willowemoc Creek*
    - *Longer Bridge Span/Larger Waterway Opening at Main Street*
    - *Levee Removal at the Central School.*
    - *Evaluate Additional Culverts under NYS Route 17*
    - *Upstream Detention/Floodwater Storage* in the Little Beaverkill

- <u>NONSTRUCTURAL FLOOD CONTROL MEASURES</u>
  The potential for additional non-structural measures should not be ignored. The 2005 FEMA Hazard Mitigation Grant should be considered only an initial phase and not a complete action in itself. While additional mitigation will

have the potential to reduce flood benefits and potentially affect economic justification of structural solutions, the time required to design and implement these structural solutions is such that a concurrent non-structural solution should not be ignored.

HAMLET OF ROCKLAND

For Rockland, Darby Brook and the Beaverkill had a 1' flood stage or less in 1969 and $2,500 in damages, in today's dollars that equates to under $10,000.

- STRUCTURAL FLOOD CONTROL MEASURES

The level of damages precludes structural measures from being economically justified.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

. Dry floodproofing, ring levees or grading by homeowners may be warranted.

HAMLET OF ROSCOE

The Willowemoc Creek, the BeaverKill and Stewarts Brook all had a 1' flood stage in 1969 and $17,200 in damages, in today's dollars that equates to under $50,000.

- STRUCTURAL FLOOD CONTROL MEASURES

The level of damages precludes structural measures from being economically justified.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

. Dry floodproofing, ring levees or grading by homeowners may be warranted.

HAMLET OF LEWBEACH

For Lewbeach, the Beaverkill flood of record in 1968 had a 1.5' flood stage and $1,930 in damages, while the Shin Creek tributary had the same flood stage and $21,000 in actual damages, in today's dollars that equates to under $90,000.

- STRUCTURAL FLOOD CONTROL MEASURES

The level of damages precludes structural measures from being economically justified.

- NONSTRUCTURAL FLOOD CONTROL MEASURES

. Dry floodproofing, ring levees or grading by homeowners may be warranted.

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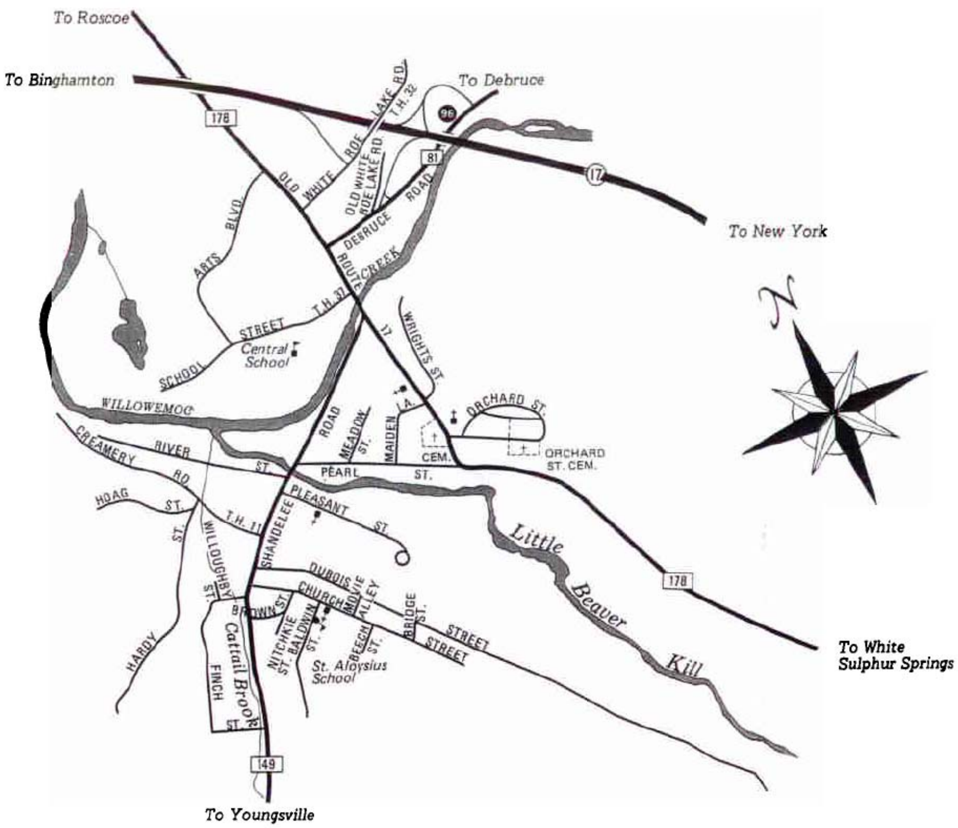
LIVINGSTON MANOR STREETS
NO. 58 (TOWN OF ROCKLAND)
1 Inch equals approx. 1340 Feet



APPENDIX C
ESTUARY INFLOW EVALUATION

Integrated Delaware River Basin Model: OASIS, DYNHYD5 and TOXI5

Documentation of Model Integration

January 2008

Introduction

Up to this point several standalone computer models have been used to simulate flow and solute transport in the lower reaches of the Delaware River and its estuary. Among these are the Delaware River Basin OASIS Flow Model, DYNHYD5, and TOXI5. It was realized that some of the regulatory applications of these models could be conducted more efficiently if these models were run in parallel, with a feedback loop to pass information back and forth between them. The models require feedback because the management of water (simulated in the OASIS model) affects the salt front in the Delaware River estuary (simulated by DYNHYD5/TOXI5). In turn, the management of water can be affected by the salt front.

Through this study we've integrated the existing DYNHYD5/TOXI5 model of the Delaware River estuary with the existing OASIS model of the Delaware River Basin. Both DYNHYD5 and TOXI5 were modified to run as *external modules* for OASIS. The external-module system allows other types of simulation models to exchange data with an OASIS model in each simulation time step.

The external modules are designed to be very flexible. The modeler should not have to change the source code to reconfigure the model. This document describes how the modules can be reconfigured. It also describes how the source code of the module can be changed if the current module design does not meet future modeling needs.

Models that were Integrated

OASIS
The Delaware River Basin OASIS Model (Delaware OASIS) is a reservoir operations and flow routing model of the Delaware River and its main tributaries. Users of Delaware OASIS can modify the physical configuration of the system and operating rules through data entered in input tables or in the Operations Control Language (OCL) input. Standalone simulations typically cover the whole period of record (currently about 70 years). The time-step size is one day. An important feature of any OASIS application, including Delaware OASIS, is that other computer programs in DLLs, known as *external modules*, can exchange data with the OASIS model.

DYNHYD5 and TOXI5
DYNHYD5 simulates the hydrodynamics and TOXI5 simulates the chloride transport in the tidal Delaware River and Bay, from Trenton to the mouth of the Delaware Bay. Standalone simulations typically cover one to three years. TOXI5 has a time-step size of 15 minutes; DYNHYD5 can accommodate time steps as small as 30 seconds. Prior to the model integration described by this document, DYNHYD5 and TOXI5 were run in series. First DYNHYD5 must be run. Then, TOXI5 uses the DYNHYD5 output for flow input. In this relationship, TOXI5 is completely dependent on DYNHYD5 output.

Overlap between OASIS and DYNHYD5/TOXI5
Each model represents a one-dimensional network of nodes, and they overlap geographically in their coverage of the tidal portion of the Delaware River. DYNHYD5/TOXI5 represents the estuary in much finer detail than OASIS. However, OASIS dynamically determines flow that results from the operating rules that are described in OASIS input. DYNHYD5 determines flow only from the input boundary conditions and the physics of flow. In the original version of DYNHYD5, management decisions would be implicit in the boundary conditions. Any change to management must be pre-processed into the time-series input that DYNHYD5 reads. In the OASIS-module

version of DYNHYD5, OASIS specifies the dynamically-determined upstream boundary conditions to DYNHYD5.

Information about DYNHYD5/TOXI5

The linked DYNHYD5/TOXI5 models were calibrated for water surface elevations, current velocities, and chloride concentrations throughout the Delaware estuary for the 19-month period from 2001 to 2003. Detailed calibrations results can be found from the DRBC's technical report, which can be obtained from http://www.state.nj.us/drbc/TMDL/HydroModelRptDec2003.pdf. Downstream boundary tidal conditions and constant inflows from point source discharges and minor tributaries have been modified for this linkage. More detailed description of this work can be obtained from DRBC staff at http://www.state.nj.us/drbc.

Design of the DYNHYD5/TOXI5 modules

Source-code changes

When creating the DYNHYD5 and TOXI5 modules, the goal was to interfere with the existing source code as little as possible. The source code of the external modules differs from the standalone versions in the following ways:

- **Flow of processing.** The protocol for an OASIS external module requires that the module be divided into three distinct phases of processing: 1) initialization, 2) time-step loop, and 3) shutdown. This is necessary because OASIS must call the module at least once for every OASIS time step. In general, it is necessary that the module respond by simulating a period of time equal to one OASIS time step. Thus, there are three subroutines in the module which OASIS can call:

    - ***MODULE_INIT:*** This routine is called only once, while OASIS is initializing.
    - ***MODULE_STEP:*** This routine is called every time OASIS evaluates a *Run_module* command. Thus, this routine is called at least once every OASIS time step.
    - ***MODULE_SHUT:*** This routine is called only once, when OASIS is shutting down.

  The existing code in DYNHYD5 and TOXI5 had to be divided so that it fit into these three phases. This was not extremely difficult, since the flow of both programs already generally followed the progression of the three phases. Some change was necessary, because in the original source code the three phases were not perfectly isolated from each other.

- **Routines for the interface.** New subroutines had to be added to the module which did not exist in the original source of the standalone programs. These routines include the callable routines *MODULE_INIT*, *MODULE_STEP*, and *MODULE_SHUTDOWN* described above. There are a few new subroutines that are only called from the three callable routines. Also, there are error-handling subroutines described below.

  The routines that are new to the module version (not found in the standalone version) are found in the following Fortran and C++ source-code files. None of the source code in these files is found in the original DYNHYD5 or TOXI5.

In DYNHYD5:	**In TOXI5:**
_DynHyd5_init.f90	_Toxi5_init.f90
_DynHyd5_shut.f90	_Toxi5_shut.f90
_DynHyd5_step.f90	_Toxi5_step.f90
_OASIS_mod_init.f90	_OASIS_mod_init.f90
_OASIS_module.f90	_OASIS_module.f90
mod_oasis.f90	mod_oasis.f90
mod_shutdown.f90	mod_shutdown.f90
_OASIS_mod_initC.cpp	_OASIS_mod_initC.cpp

The new routines have some effects on the way DYNHYD5 and TOXI5 run. The new routines manage the current working directory so that DYNHYD5 and TOXI5 execute in a folder specified by the OCL *:MODULE:* command. The new routines override input parameters in DYNHYD5/TOXI5 that specify the length of the run, so that the modules run as long as OASIS is running. The new routines also override variable-flow input from the DYNHYD5 input file, applying flow values from the OCL *Run_module* command instead. No entirely new subroutines were added to the original DYNHYD5/TOXI5 source-code files. However, some modifications were done to the original files for error handling and the use of scratch files as described below.

- **Error-handling.** In the standalone programs, error handling generally included use of the Fortran *STOP* command. This is not acceptable for an external module because OASIS should process the error and write final output files before terminating. Therefore, the use of the *STOP* command was replaced by a call to the new subroutine *FORTRAN_MOD_ERR_SHUTDOWN*. This subroutine flags an error and passes the error message back to OASIS. Furthermore, the error message is constructed by subroutine *ADD_LINE_TO_MESSAGE*. This subroutine is used to build a long error message that OASIS can display, which is otherwise very difficult in Fortran.
- **Reading and writing scratch files.** Whereas the original versions of DYNHYD5 and TOXI5 were run in series, the module versions run in parallel, and it is necessary for DYNHYD5 to pass data to TOXI5 once per 24-hour cycle (one OASIS time step). In order to make the least interference with the existing source code of DYNHYD5 and TOXI5, HydroLogics designed a scratch file that is based on the output file that DYNHYD5 was already writing. This file is named *scratch.HYD*, and contains all the information that DYNHYD5 calculated for a single simulated day. The nature of the scratch file is described in more detail below.

Any part of the original Fortran source-code files that was modified by HydroLogics for the creation of the external modules is marked with the comment:

```
! %% OASIS
```

DYNHYD5 and TOXI5 input and output

The DYNHYD5 module reads the same input files, does the same calculations, and writes the same output files a the standalone version. However, after the DYNHYD5 module reads the input file, *temp.INP*, all of the variable-inflow values are discarded. Instead the module assigns the variable-inflow values that are passed from OASIS each time step. The DYNHYD5 module still requires that the input file contain data for each of these inflows, and the formatting has to be consistent with the original DYNHYD5 input file requirements. However, the actual values entered do not matter. The current input file has 20 days worth of dummy values, all set to -.005.

DYNHYD5/TOXI5 modules create the same output files, in their entirety, as the original standalone programs. A modeler can thus do the same analysis of these files as with the standalone version.

However, if the optional parameter *Large_Output=0* is specified in the *:MODULE:* command, then DYNHYD5's original output files are not written by the module. This can save significant disk space, and the files are not needed by OASIS or the module version of TOXI5.

Additionally, the DYNHYD5 module creates a block of information stored in the file *varblock.TMP*, which can be pasted into the DYNHYD5 file *temp.INP* in the variable-inflow section. Thus, after a run with the integrated OASIS/DYNHYD5/TOXI5 models is finished, the modeler can run the standalone DYNHYD5 model with the same data that was used in the integrated model.

The original standalone DYNHYD5 writes data twice per simulated day to a file named *temp.HYD*. This file is rather large (approximately 100 MB per simulated day) due to the small time step that has been used in the Delaware estuary model. In the standalone versions of the estuary models, this becomes an input file for TOXI5.

HydroLogics added source code to the DYNHYD5 module that writes every single day's worth of data to a scratch file designated *scratch.HYD*. The file *scratch.HYD* contains all of the same data, in the exact same format, as in *temp.HYD*. However, whereas *temp.HYD* contains all the output data for the entire DYNHYD5 run, *scratch.HYD* contains only one simulated day's worth of data. The data in *scratch.HYD* is overwritten every simulated day. The module version of TOXI5 reads input data from *scratch.HYD* instead of from *temp.HYD*. The TOXI5 module still reads the original input file *tempwq.INP*. The module version of TOXI5 also uses an entirely new file, *segmile.tbl,* to correlate TOXI5 segments to DRBC river miles. *Segmile.tbl* is described in the implementation section below.

Since DYNHYD5 is not dependent on TOXI5, it is possible to execute the DYNHYD5 module without TOXI5. Note, however, that DYNHYD5 by itself does not pass any information to OASIS. It is not possible to execute the TOXI5 module without the DYHYD5 module running at the same time.

Interface between OASIS and DYNHYD5/TOXI5

General OCL syntax
The Operations Control Language (OCL), is a form of input to OASIS. An OASIS model can be designed with great flexibility due to the language-nature of OCL. In the integrated model, the interface between OASIS, DYNHYD5, and TOXI5 is controlled entirely by OCL commands.

There are two OCL commands that are critical to external modules: *:MODULE:* and *Run_module*.

:MODULE: Command
The *:MODULE:* command is used to *declare* the module. It identifies the file that contains the module, and specifies information about how the module is initialized. The *:MODULE:* command is an OCL *meta command*. This means that it only contains information about how OASIS is initialized. Unlike the *Run_module* command, it does not contain information that is re-evaluated every simulation time step.

Run_module Command
The *Run_module* command is an OCL *simulation command*. This means that it contains information that is re-evaluated every simulation time step. The *Run_module* command contains a list of values that are sent to the external module (the *Input* field). It also contains a list of OCL variables whose values are assigned by the module (the *Output* field).

For a complete description of the syntax of these commands, please refer to the OASIS user manual.

Specific OCL syntax for DYNHYD5 module
The DYNHYD5 external module is programmed to process certain information from the *:MODULE:* and *Run_module* commands.

```
:MODULE: DLL  DynHyd5 = [HomeDir]\DynHyd5_module.dll
    InitParam "Folder=DRBC-DH5 Large_Output=1"
```

The *:MODULE:* command tells OASIS to use a module named *DynHyd5*. The name *DynHyd5* is used to refer to this module in the *Run_module* command. This module is contained in the file *[HomeDir]\DynHyd5_module.dll* (*[HomeDir]* is the folder where *model.exe* is found). The *InitParam* field is used to pass two parameters named *Folder* and *Large_Output*. The module uses the value of the *Folder* parameter (*DRBC-DH5*) as the name of the folder that DYNHYD5 executes in. That is, DYNHYD5 will look for all input files and write all output files in this folder. The value of the parameter *Large_Output* tells the module whether to store the large output files that are created by standalone DYNHYD5. If *Large_Output=1*, the large output files are written. If *Large_Output=0*, the output files are not written. These files are not needed to run DYNHYD5 or TOXI5 with OASIS. However, they may be needed to analyze the output files in the same way as standalone DYNHYD5.

```
Run_Module : DynHyd5
{
   Input: { RunFlag, ParamType, DynHyd5JunctionNumber,
             OasisFlowValue }
   Output : {  }
}
Run_Module : DynHyd5
{
   Input : { RunFlag }
   Output : {  }
}
```

The *Run_module* command for DYNHYD5 is used for two purposes: passing flow values and executing. The different uses are determined by the first parameter, *RunFlag*. In neither case are there any output values that OASIS receives from the module. For the purpose of passing flow values, the module is programmed to receive one flow value per *Run_module* command. Thus, there are generally several *Run_module* commands with *RunFlag=0*, but there must be only one *Run_module* command with *RunFlag=1*. The input parameters of the *Run_module* command are:

RunFlag = [0 or 1].

- If *RunFlag*=0, DYNHYD5 is not executed, but the subsequent input parameters specify a value that OASIS passes to the module.
- If *RunFlag*=1, then the module does not read the parameters *ParamType*, *DynHyd5JunctionNumber*, and *OasisFlowValue* (they should be omitted). DYNHYD5 is executed for 24 simulated hours. *RunFlag* should equal 1 only in the last *Run_module* command. DHYHYD5 can not be run more than once per simulated OASIS day, so *RunFlag* must not equal 1 in more than one *Run_module* command. It would serve no purpose to follow the *Run_module* command with *RunFlag=1* with another *Run_module* command with *RunFlag=0*.

ParamType = [1]

- This parameter should be used only if *RunFlag=0*. *ParamType* specifies the type of data that is being passed in the *Run_module* command. The only value that is currently recognized is 1, which specifies that the value *OasisFlowValue* is a variable flow. If a future need arises, the module can be programmed to recognize other types of parameters.

DynHyd5JunctionNumber = [Integer]

- This parameter should be used only if *RunFlag=0*. The value should be the integer number of a junction defined for variable flow in the DYNHYD5 input file *temp.INP*.

OasisFlowValue = [Real number (CMS)]

- This parameter should be used only if *RunFlag=0*. This value should be a flow in CMS that OASIS determines for the DYNHYD5 junction number given by *DynHyd5JunctionNumber*. The module overrides the value from DYNHYD5 input file *temp.INP* with *OasisFlowValue*.

Specific OCL syntax for TOXI5 module

The TOXI5 external module is programmed to process certain information from the *:MODULE:* and *Run_module* commands.

```
:MODULE: DLL  Toxi5 = [HomeDir]\Toxi5_module.dll
    InitParam "Folder=DRBC-DH5 Large_Output=1"
```

This command tells OASIS to use a module named *Toxi5*. The name *Toxi5* is used to refer to this module in the *Run_module* command. This module is contained in the file *[HomeDir]\Toxi5_module.dll* (*[HomeDir]* is the folder where *model.exe* is found). The *InitParam* field is used to pass two parameters named *Folder* and *Large_Output*. The module uses the value of the *Folder* parameter (*DRBC-DH5*) as the name of the folder that TOXI5 executes in. That is, TOXI5 will look for all input files and write all output files in this folder. Because the TOXI5 module is dependent on the scratch file generated by the DYNHYD5 module, it would not make sense to specify a TOXI5 *Folder* value different that what is used for DYNHYD5. The value of the parameter *Large_Output* tells the module whether to store the large output files that are created by standalone TOXI5. If *Large_Output=1*, the large output files are written. If *Large_Output=0*, the output files are not written. These files are not needed to run TOXI5 with OASIS. However, they may be needed to analyze the output files in the same way as standalone TOXI5.

```
Run_module : Toxi5
{
   Input: { RunFlag, ParamType, ParamInput }
   Output: { Return_Value }
}
```

The *Run_module* command for TOXI5 is used for two purposes: passing water-quality values and executing. Executing is done only when parameter *RunFlag* is 1. The passing of water quality values occurs whether or not *RunFlag* is 1. The module is programmed to send one water-quality value per *Run_module* command. There are four different types of water-quality information that can be sent by the TOXI5 module. In each *Run_module* command, the type of water quality information to be sent is specified by parameter *ParamInput*. There can be more than one *Run_module* command for TOXI5, but only one of these *Run_module* commands can have *RunFlag=1*, and that command should be the first one. The input and output parameters of the *Run_module* command are:

RunFlag = [0 or 1]

- If *RunFlag*=1, TOXI5 is executed for 24 simulated hours, and send one water-quality value to OASIS. *RunFlag* can equal 1 only in the first *Run_module* command.

- If *RunFlag*=0, TOXI5 is not executed, but one water-quality value from the previous 24-hour execution is sent to OASIS. It would not make sense to apply *RunFlag=0* in a *Run_module* command before the *Run_module* command where *RunFlag=1*.

ParamType = [1, 2, 3, or 4]

- If *ParamType*=1, then *Return_Value* is the river mile of the isochlor of *ParamInput* -- that is, the most upstream River Mile where chloride concentration exceeds *ParamInput*. The module does linear interpolation to find the precise river mile.
- If *ParamType*=2, then *Return_Value* is the TOXI5 segment number of the isochlor of *ParamInput* -- that is, the most upstream segment number where chloride concentration exceeds *ParamInput*.
- If *ParamType*=3, then *Return_Value* is the chloride concentration at river mile equal to *ParamInput*. The module does linear interpolation to find the precise concentration.
- If *ParamType*=4, then *Return_Value* is the chloride concentration at TOXI5 segment number *ParamInput*.

ParamInput = [chloride concentration (mg/L), River Mile, or TOXI5 segment number]

- If *ParamType*=1, *ParamInput* is a chloride concentration in mg/L.
- If *ParamType*=2, *ParamInput* is a chloride concentration in mg/L.
- If *ParamType*=3, *ParamInput* is a river mile
- If *ParamType*=4, *ParamInput* is a TOXI5 segment number.

ReturnValue = [River Mile, TOXI5 segment number, or chloride concentration (mg/L)]

- If *ParamType*=1, *Return_Value* is the river mile of the isochlor of *ParamInput*
- If *ParamType*=2, *Return_Value* is the TOXI5 segment number of the isochlor of *ParamInput*
- If *ParamType*=3, *Return_Value* is the chloride concentration (mg/L) at river mile *ParamInput*.
- If *ParamType*=4, *Return_Value* is the chloride concentration (mg/L) at TOXI5 segment number *ParamInput*

Modifying the source code of the DYNHYD5/TOXI5 modules

The DYNHYD5/TOXI5 modules were designed to be very flexible. However, if the module interface does not provide the necessary control, the source code can be modified.

Initialization Parameters
If new initialization parameters are needed, then the module must be programmed to process them. This is done in subroutine *MODULE_INITIALIZE* in file *_OASIS_mod_initC.cpp*. The comments indicate a section where processing loops through all arguments of the initialization parameters. Within this loop, each parameter should be handled by its own *IF* block. For example, the current parameter *FOLDER* is handled by this *IF* statement:

```
if( strnicmp(temp_string, "FOLDER=", 7)==0 )
```

Parameters passed in the *Run_module* command
If new values are to be passed by the *Run_module* command, then the module must be programmed to send or receive them. This is done in subroutine *MODULE_STEP* in file *_OASIS_module.f90*. The only argument of the subroutine is named *argument*, and it is an array of type *real*4*. That reflects the fact that all parameters of the *Run_module* command are floating-point numbers.

One of the first things that should occur in *MODULE_STEP* is that the elements of the *argument* array should be assigned to local variables. This is how the input values from the *Run_module* command are assigned to variables in *MODULE_STEP*.

One of the last things that should occur in *MODULE_STEP* is that the values of local variables are assigned to elements of the *argument* array. This is how variables in *MODULE_STEP* are assigned to output variables (OCL variables) in the *Run_module* command.

As described above, the DYNHYD5 and TOXI5 modules have been designed so that *Run_module* command can be used as a sort of inquiry command. The second input parameter is a code for which type of data to retrieve, and the succeeding parameters identify for which segment or junction data should be retrieved or assigned. It is suggested that any changes to the module conform to this protocol. That is, a new code can be defined. The module can be programmed to recognize this code and respond appropriately. Additional *Run_module* commands that apply this code can then be added to the OCL input.

Limitations of the DYNHYD5/TOXI5 modules

The DYNHYD5 and TOXI5 modules have limitations that are inherited from the original standalone programs.

1. DYNHYD5 was originally coded to be limited to 700 variable flow time steps. This practically translates to 700 daily variable inflow steps. This was increased to 55,000. Tests indicate that the module runs properly for runs greater than 5 simulated years in length. With 55,000 variable inflow values, the longest possible run should be 150 simulated years.
2. DYNHYD5/TOXI5 output files are very large – combined about 100 Megabytes per month when using the supplied time steps. On Windows computers with hard drives formatted with the FAT32 file system, this will artificially limit the length of runs when a single output files reaches 4 Gigabytes. Computers with hard drives formatted with the NTFS file system

will not have this limitation. However, to run these files with OASIS, the only output that is strictly necessary are the small scratch files. The module versions have been programmed so that the large output files can be turned off using the *Large_output=0* parameter in the *:MODULE:* command.

3. The DYNHYD5/TOXI5 modules have been tested with OASIS for position analysis. The tests indicate that the module will work properly for position analysis. However, it should be noted that not all DYNHYD5/TOXI5 output is saved when doing position analysis. Position analysis is accomplished by running the OASIS model multiple times – once for each position analysis trace. With each trace run, the DYNHYD5/TOXI5 output files are overwritten. This is probably not a problem for the modeler, since the most important results can be stored by OASIS. Anyway, it would be difficult to analyze the large number of DYNHYD5/TOXI5 output files from a position analysis.
4. Examination of the original DYNHYD5 source code indicates that the Restart Function (using file *temp.RST*) contains errors, and should not be used.

Modifications to input files for the integrated model.

DYNHYD5 and TOXI5 input and output

TOXI5 and DYNHYD5 files are placed in the folder specified by the *Folder* parameter in the *:MODULE:* commands. The folder name *DRBC-DH5* was chosen for this folder, although the folder name is easily changed. The folder is assumed to be a subfolder of the OASIS run folder.

segmile.tbl – This is a new file not used by standalone TOXI5. It contains a table of values listing the river mile that corresponds to each TOXI5 segment number. The format is strictly column-based. Each row contains a 3-digit TOXI5 segment number followed by an 8-digit river mile value with up to 2 decimal places. The file starts at the highest river mile (133.3) and continues to the lowest river mile (8.0).

For Example:

```
 76   133.3
 75   132.0
 74   130.6
...
 84    18.6
 85     8.0
```

temp.inp– This file is used by the standalone TOXI5 and DYNHYD5, but the input data was modified slightly for use with the module versions. The variable inflow data was abbreviated, since the module was configured to override variable inflow data from this file (values passed through the OASIS *Run_module* commands are used instead). Each inflow is assigned 20 dummy data points (the number 20 is arbitrary). The value of each data point is unimportant. With each variable inflow, a note was added to identify the corresponding OASIS node number.

For Example:

```
*VARIABLE INFLOW DATA:  negative=inflow; positive=withdrawal ****
   12
       90        20           Del. Riv. at Trenton          [OASIS:365]
     1.  0 0     -.005    2.  0 0     -.005    3.  0 0     -.005    4.  0 0     -.005
     5.  0 0     -.005    6.  0 0     -.005    7.  0 0     -.005    8.  0 0     -.005
     9.  0 0     -.005   10.  0 0     -.005   11.  0 0     -.005   12.  0 0     -.005
    13.  0 0     -.005   14.  0 0     -.005   15.  0 0     -.005   16.  0 0     -.005
    17.  0 0     -.005   18.  0 0     -.005   19.  0 0     -.005   20.  0 0     -.005
```

```
…
        24        20           Inflows                        [OASIS:540]
   1.  0 0     -.005   2.  0 0     -.005   3.  0 0     -.005   4.  0 0     -.005
   5.  0 0     -.005   6.  0 0     -.005   7.  0 0     -.005   8.  0 0     -.005
   9.  0 0     -.005  10.  0 0     -.005  11.  0 0     -.005  12.  0 0     -.005
  13.  0 0     -.005  14.  0 0     -.005  15.  0 0     -.005  16.  0 0     -.005
  17.  0 0     -.005  18.  0 0     -.005  19.  0 0     -.005  20.  0 0     -.005
```

tempwq.inp – This file is used by standalone TOXI5. The module version of TOXI5 uses the file in exactly the same way. This file was not modified in any way from the version that DRBC provided.

Modifications to OASIS model input:
Of the OASIS input files, only OCL files were modified, as described here.

_module_declare.ocl – This is a new file. It contains the *:MODULE:* commands for DYNHYD5 and TOXI5, as described in the syntax section

main.ocl **–** This file existed in the previous model, but contains some modifications for the integration with DYNHYD5 and TOXI5. A new *:SUBSTITUTE:* command sets a flag (*[UseToxi5]*) with which you can specify whether OASIS should use original regression formula or the TOXI5 module to model the salt front. New *:INCLUDE:* commands are also used to apply the new OCL files. The file also contains a new *SOLVE* command. In the previous version of the model, the *SOLVE* command was implicit only. In the integrated model, the *SOLVE* command must be explicitly applied because DYNHYD5 and TOXI5 are called after flow information has been solved in each OASIS time step.

udef_list.ocl **–** This file existed in the previous model, but contains some modifications for the integration with DYNHYD5 and TOXI5. *Udef* commands were added for variables that were used to store information from TOXI5.

For example:

```
...
Udef : _SaltFrontMile_T5 init{[InitSalt] , [InitSalt] , [InitSalt] , [InitSalt] ,
       [InitSalt] , [InitSalt] , [InitSalt] }

Udef : _SaltFrontMovAv_T5 init{[InitSalt] , [InitSalt] , [InitSalt] , [InitSalt] ,
       [InitSalt] , [InitSalt] , [InitSalt] }

/* For DynHyd5 / Toxi5 Module testing and reference */

Udef : _SegNum_T5
Udef : _ConcMile_T5
Udef : _ConcSeg_T5
...
```

dynhyd5.ocl **–** This is a new file. It contains all *Run_module* commands for DYNHYD5. A *Run_Module* command is required for every DYNHYD5 variable flow that is set by the OASIS model. DYNHYD5 is configured to process flow in CMS, so a conversion from MG (the units used by OASIS) is necessary. The final *Run_module* command tells the DYNHYD5 module to simulate one day.

For example:

```
Run_Module : DynHyd5
{
   Input : { 0, 1, 90, Convert_Units{ Flow365.994, MG, CMS} }
   Output : { }
```

```
}
…
/* After all inputs are sent to the DynHyd5 Module, run it.  All output goes
   to Toxi5 through scratch files, so no data transfer is necessary between Oasis
*/

Run_Module : DynHyd5
{
   Input : {1}
   Output : { }
}
```

toxi5.ocl – This is a new file. It contains all *Run_module* commands for TOXI5. The first *Run_module* command tells TOXI5 to simulate one day. Then, a *Run_module* command is required for every value that OASIS retrieves from TOXI5.

For example:

```
Run_Module : Toxi5
{
   Input : { 1, 1, 250 }
   Output : { _SaltFrontMile_T5 }
}
Run_Module : Toxi5
{
   Input : { 0, 2, 250 }
   Output : { _SegNum_T5 }
}
Run_Module : Toxi5
{
   Input : { 0, 3, _SaltFrontMile_T5 }
   Output : { _ConcMile_T5 }
}
Run_Module : Toxi5
{
   Input : { 0, 4, _SegNum_T5 }
   Output : { _ConcSeg_T5 }
}
```

salt_front.ocl – This file existed in the previous model, but contains some modifications for the integration with DYNHYD5 and TOXI5. The *[UseToxi5]* flag, declared in *Main.ocl*, is applied here. If it *[UseToxi5]* equals 1, the model uses the TOXI5 output to create a moving average of the river mile where the salt front is located. If *[UseToxi5]* is not equal to 1, then the model uses the previously existing regression relationship to create a moving average of the river mile where the salt front is located.

For example:

```
/*  If the [UseToxi5] flag is used, it uses the value returned from the Toxi5 Module  */

:IF: { [UseToxi5] = 1 }

   Set : _SaltFrontMile_T5  { Value: _SaltFrontMile(-1) }

   Set : _SaltFrontMovAv_T5
   {
       Condition: Abs_Period <= 7
       Value : _SaltFrontMile_T5

       Condition: default
       Value : accumulate { _SaltFrontMile_T5 , -7 , -1 } / 7
   }

/* Otherwise Use the current approximation method */
//:ELSE:

...
```

Modifications to OASIS GUI input:

***GUI.ini* –** This file (which is always used by the OASIS GUI) contains one important modification for the integrated model. The new parameter *AddnlCopyFiles* is applied such that the GUI will copy the DYNHYD5 and TOXI5 input files whenever the GUI is used to copy a run folder. The new parameter appears as such:

```
AddnlCopyFiles=DRBC-DH5\*.inp;DRBC-DH5\*.tbl
```

Where *DRBC-DH5* is the name chosen for the folder that contains DYNHYD5/TOXI5 input files.

Modifications to OASIS database:

***Statdata.mdb* –** Each run needed to updated to work with the latest version of OASIS. This was accomplished by using Hydrologics' OASISConv.exe program. A double-entry in the lookup table, *Nevers_Rel*, had to be manually deleted in OASIS to get the run to work.

APPENDIX D
USER SUPPLY FEES

In 1987 Black and Veatch conducted a study to develop relative benefit allocations and alternative water charge schedules for Commission sponsored reservoir projects. The water charge schedules would be designed to recover the non-federal costs of these projects which included the existing Blue Marsh and Beltzville water supply reservoirs and the modification of F.E. Walter and Prompton Reservoirs to hold water supply storage. The Commission also desired to determine the financial impact of charging ground water users and the amendment of Section 15.1(b) of the October, 1961 DRBC Compact that would allow charging pre-compact water users.

Black and Veatch sought to develop alternative water charge systems which could be used to recover the costs of the non-federal share of the reservoir projects. These alternative methods studies were based on relative benefits to the users and also on a cost causative methodology. The Commission's Water Project Financing and Water Charges Advisory Committee (Advisory Committee), which worked in tandem with the consultant as the report progressed, eventually recommended that a third charging system using a combination of both relative benefits and cost causative methods be applied.

The relative benefits allocation and water charge alternatives in the Black and Veatch Report were developed after an extensive review process led by the Advisory Committee, as well as DRBC representatives and staff and a final report was submitted April 1987.

The Commission is responsible for financing the nonfederal portion of projects costs, and because state funds were reportedly not available, it was proposed that revenue bonds be issued by DRBC to fund the two modification projects as well as the annual costs for the two existing reservoirs. The annual debt service on these bonds, as well as annual operation, maintenance and administrative expenses, would be recovered through water user charges. Currently, the Commission repays its nonfederal share of reservoir costs by repaying a loan from the federal government. The two project modifications were identified in DRBC's Level B study and in the Good Faith Agreement.

Benefits Allocation Methodology

Part One of the Black and Veatch Report presented the results of the development and implementation of the relative benefits allocation. Generally, the relative benefits allocation was made using a weighting system to assign relative importance units to predetermined benefit categories. These benefit weightings were then allocated across water user categories and to sub-basins. The general theory behind this method is that the total benefits received by each user or sub-basin were based on relative shares of depletive surface or groundwater use within the basin. The more water a user consumed, the greater the benefit that was derived from the reservoir projects. All depletive water use data used in this methodology was developed from DRBC's 1986 Water Use Inventory.

The first step in the benefits allocation methodology involved identifying nine water user groups from the 1986 DRBC water use inventory:

• Municipal
• Rural Domestic and Livestock

• Industrial Self Supplied
• Power Generators
• Golf Sources
• Agricultural Irrigation
• Institutional and Other
• Recreational Use
• Fisheries

In addition to water user groups, 12 designated sub-basins were identified, which were in turn, separated by state portion or area of interest into 21 sub-areas.

After identifying user groups and sub-basins, a weighting system was used to assign relative percent (%) units to each of nine benefit categories. The overall theory was that each benefit category is assumed to have some unknown quantity of basin wide benefits which is designated at 100 percent. Therefore, all of the benefits of each category over all 21 sub-areas are equal to 100 percent.

The weighting of each category was essentially a judgmental assignment of relative importance units based on information available at the time. Weighting was achieved through the development of 12 computer runs used to determine the amount of water supply needed to 1) compensate for current depletive use, 2) provide for new or future depletive use, 3) increase salinity standards at River Mile 98, 4) offset sea level rise through the year 2000. It was determined that a total of 485 cfs would be required to fulfill these goals. The four reservoir projects combined could provide 615 cfs. The additional storage, 130 cfs, would be available for future use.

Benefit categories were weighted according to how much flow would be required in proportion to the total available storage.

TABLE 45
FLOW AUGMENTATION ALLOCATION

	Depletive Use cfs	Salinity Control cfs	Total cfs	Percent %
Water to Compensate for Current Depletive use	135		135	22
Water to provide for Salinity Improvement	200		200	33
Water to Compensate for Future Depletive Use	130		130	21
Water to Fight Sea Level Rise		150	150	24
	465	150	615	100

cfs figures represent June-September drought condition flow requirements at Trenton.

In establishing importance weightings several underlying factors have been considered including:

- The judgmental nature of the weighting assignment.

- The need for flow augmentation and salinity protection relative to project storage capacity as determined from DRBC special flow and salinity computer model runs.

- The potential for realizing drought and salinity related benefits is quite substantial.

- One of the benefit categories (fisheries improvements) is judged to be not allocable with available information and has thus been Liven a weighting of zero.

- Since other plausible weightings can be formulated, sensitivity analysis was used to help judge the ultimate impact of alternative weightings on allocated relative benefits.

`

Benefit categories were weighted as follows:

Benefits Category	***Weight %***
Compensate for Depletive use	43.00
Increased Supply for future Depletive use	20.00
Salinity Control-PRM Protection	19.49
Reduced Risk of Restriction on Essential Depletive use	10.00
Salinity Control-surface water users	4.51
Increased Reliability of Supply-surface water	2.00
Recreation-downstream	1.00
Increased Reliability of Supply-groundwater	0.00
Fisheries improvement and Protection	0.00

Note in the table above that the Downstream Recreation was assigned a weighting of one percent based on some downstream rafting on the Lehigh during low flow or drought conditions. The benefit to Increased Reliability of Supply-groundwater was also assumed to be insignificant and was given a weighting of zero percent. The benefit to Increased Reliability of Supply-surface water was assigned to be two percent.

The combined recreation and reliability benefit was assigned to be three percent. Therefore, 97 percent remained to be allocated to the remaining categories.

As it was assumed that benefits accrue to water users in proportion to their use, weighted benefit percentages were allocated across water user categories and sub-basins based on the proportion of depletive water use in each sub-basin and user category relative to basin-wide depletive use. An example of application of the relative benefit formula is given in *Volume 2, Appendix F* of the Report.

Based on the 1986 Water Use Inventory, the benefit allocation **by state** was determined to be as follows:

State	***% Allocation of Total Benefits from Reservoirs***
Pennsylvania	46.97
New Jersey	50.06
Delaware	2.22
New York	0.7511

The benefit allocation **by user category** was determined to be as follows:

User	***% Allocation of Total Benefits from Reservoirs***
Municipal	50.43
Industrial	19.37
Power	7.33
Golf	3.42

Summaries of the relative benefit allocations for the basin and each state is provided in *Tables 14-18* in the Appendix and on pages 41-45 of the Report.

The relative weightings were calculated using various assumptions. Please refer to *Procedures for Sub-Basin and User category Allocations of Relative Benefits*, pages 25-37 of the Report, for additional information on the basis of the allocations. *Appendix D* in *Volume 2* of the Report contains detailed sub-basin allocations based on the DRBC water use survey.

Alternative Water Charge Schedules

Part Two of the Report developed examples of alternative water charge schedules which could recover DRBC's costs to pay for the four DRBC reservoirs. The aim was to make the schedules as fair and equitable as practical.

Two basic alternative charging methods were developed. One method relies primarily on the allocated benefits as the basis of determining charges and the other method relies primarily on allocations based on cost causative factors. The Commissioners and the Advisory Committee selected the policy options to be considered in developing the charging schedules. A wide range of documents including those relating to the Commission's authority and studies made by the Commission staff were reviewed. These documents provided information concerning public opinion regarding the DRBC imposed water charges and on the basic legal framework that would ultimately control any water charge system adopted by the Commission.

The documents included, in part, the Delaware River Basin Compact, the Good Faith Agreement, the DRBC Water Code, DRBC Resolution 85-35, and Merrill Creek Reservoir DRBC docket, summaries of public comments relating to proposed revision of Compact Section 15.1(b) and the proposed metering requirements.

The policy considerations which were taken into account for alternative charging schedules include:

• Good Faith Recommendation 1 established a more strict salinity objective of 150 mg/l of chlorides compared to 180 mg/l at River Mile 98 for the year 2000.

• Recommendation 2 called for the establishment of a water management system capable of providing a reliable water supply for essential uses during the most severe drought of record, 1961-1967.

• Drought operating formulae for the three Delaware Basin New York City Reservoirs were established in Recommendation 3.

• Recommendations 4, 10, 11 and 12 promoted the objective of reducing overall use of fresh water by fifteen percent.

• Recommendation 13 was to develop a program to balance future depletive use with the availability of storage capacity to meet salinity objectives

• The above program also established a “salinity control area” downstream of the Montague, New Jersey gage and upstream of the C & D Canal in Delaware

• The Merrill Creek Owners Group constructed a pump-storage reservoir in Warren, New Jersey to replace the depletive uses of evaporative losses of cooling water by specific power plants in the Basin. Releases would be made from this reservoir whenever the Delaware River flows at Trenton are less than 3,000 cfs

The Compact addresses three topics related to the study. They are (1) the Commission’s responsibility and authority to provide for planned water use within the Basin, (2) Its powers during drought emergencies, and (3) its powers to establish fees for water use.

Section 3.7 of the Compact provides that the Commission may set rates and charges for the use of Commission owned facilities and for the use of products and services derived from those facilities. However, Section 15.1 (b) states that there will not be imposed any charge for water withdrawals or diversions of they could have been lawfully made without charge on the effective date of the compact, or prior to October, 1961. This provision has been referred to as the “grandfather clause”.

The Commission is further limited by Section 3.5(b) that prohibits it from charging for any water diversion permitted by the U.S. Supreme Court. Accordingly, the Commission does not have the authority to impose charges for diversions made by New York City and New Jersey as provided by the 1954 Supreme Court Decree.

After consideration of the construction costs and higher water charge rates that would be required to pay for the modification of F.E. Walter and Prompton Reservoirs, the Commission decided that the financial burden only on the post-compact water users to pay this new debt would be too large a burden on them. In DRBC Resolution 85-34, it concluded that these water users could not effectively finance the cost of providing a larger supply of safe and secure water. Therefore, the Commission recommended to Congress an amendment of Section 15.1(b) of the Compact which would have required pre-compact water users to also pay water charges that would help finance the modifications to the reservoirs. The charges would include the cost for the annual costs of the Blue Marsh and Beltzville Reservoirs.

Estimated Annual Revenue Requirements

The DRBC intended to cover the cost of building the reservoir modifications and carrying the existing reservoirs annual cost by the sale of tax exempt bonds. The bonds would also have been used to pay the interest costs to cover the short term notes issued during construction. It would also establish a reserve fund equal to one year's bond interest and principal payments, and bond issuance costs.

A summary of the revenue bond requirements are shown in *Table 19 and on* page 55 of the Report. The 1987 total estimate of building the F.E. Walter modification totaled $124 million dollars. The DRBC share of the Prompton modification was $69.5 million dollars if construction began in 1995. However, annual water charge payments for F.E. Walter would reduce the cost for Prompton Reservoir to $52.6 million dollars. With added reserve and interest requirements, the total cost for Prompton would have been $66 million dollars.

TABLE 19
ESTIMATED REVENUE BOND
REQUIREMENTS FOR DRBC RESERVOIRS

	Bond Requirements $
F.E. Walter Reservoir Modification	
Construction Cost	97,100,000
Interest During Construction	12,200,000 (a)
Debt Service Reserve	11,000,000 (b)
Bond Issuance Expense	3,600,000

Total Bond Requirement	123,900,000
Assumed Bond Issue for F. E. Walter	124,000,000
Prompton Reservoir Modification	
Construction Cost	52,600,000 (c)
Interest During Construction	5,500,000 (a)
Debt Service Reserve	5,800,000 (b)

Bond Issuance Expense	1,900,000

Total Bond Requirement	65,800,000
Assumed Bond Issue for Prompton	66,000,000

(a) Estimated interest on short—term notes during three year construction period.

(b) One year's debt service on bonds

(c) Estimated construction cost of $69,500,000 less $16,900,000 of monies accumulated from F. E. Walter debt service coverage requirement.

The annual water charge payment requirement for the two modifications and the current annual cost for the two existing reservoirs totaled $20.6 million dollars. The annual operation, maintenance, and administrative costs for the modified projects were estimated at 20 percent of the bond cost for the projects or a total of about 3.4 million dollars. The annual operation and maintenance cost of the existing reservoirs was estimated to be only $30,000 for 1986. A breakdown of the annual revenue requirement for the four projects is shown in *Table 20 and on* page 57 of the Report.

4.3.5 Water Charge System Principles

The study scope of work required that the proposed alternative charge system be "fair and equitable, as well as practical". The Consultant concluded that the equitability of a water charge system can be measured by the degree that charges differ between users with similar characteristics. An equitable system is one where users with similar characteristics are charged on the same basis. However, the more characteristics there are to consider in determining equability, the more complex the system becomes. Therefore, it concluded that the characteristics must be limited so that the system does not become unwieldy.

4.3.6 Water Charge System Alternatives

Three alternative charging schedules were developed. The relative benefits allocation presented in Part One of the report was referred as Alternative A. Alternative B was developed using the cost causative principles that often applied in the design of utility rate schedules. The Advisory Committee requested that a variation of Alternative A plus Alternative B be developed and this combination was referred to as Alternative C.

The charging schedules were considered as preliminary estimates of charges which would ultimately be required, especially since the cost estimates of construction and operation of the proposed projects were preliminary. Also, the depletive use factors were based on an expanding data base that will change with time.

Policy Considerations
Six policy issues were addressed in the development of the alternative water charge schedules. They include:

- The ratio of charges applicable to post and pre-compact users
- The level of payment associated with the New Jersey diversions
- The practicality of collecting from small users
- The degree of credit that the Merrill Creek Owners Group should receive
- The level of agricultural charges
- The establishment of the location along the Delaware River below which charges are not applicable

1. Charges for Pre-Compact Use
If pre-compact users were allowed to be charged by the Commission, a ratio between the pre-compact and post-compact charges was assumed to be required as part of the water charging schedules.

It was one of the premises of the study that pre and post-Compact users would not pay the same water charge rates because of their different requirements for augmented flows. The consultant calculated a post/pre-compact ratio of 3.3 to 1 in developing the water charge schedule for Alternative B. This was the same ratio that the Commission previously calculated. Because of the limitations of the accuracy of the methods used to develop the ratio, the Commission decided that a post/pre-compact charge ratio of 3 to 1 be used for purposes of this study for all depletive use and withdrawal charges.

2. Charges for New Jersey Diversion
Although the Commission is prohibited by Section 3.5(b) of the Compact from charging for taking water from the New Jersey D&R Canal diversion, this does not prevent New Jersey from agreeing to contribute towards a project that would provide a benefit to the users located there. The Commission directed the consultant to determine charge schedules which assumed New Jersey would contribute at a level equal to the pre-Compact charges applied to 100 percent, 50 percent, 25 percent, and 10 percent of the water diverted by New Jersey.

3. Charging Threshold
Because of the complexity and impracticality of charging small water users such as residential wells, the Commission directed the consultant to use a 100,000 gpd withdrawal exemption for the development of all the water charge schedules options. The policy that would exempt 100,000 gpd from charges for all users, would give each agricultural user “free water” to irrigate about 340 acres with an annual rate of application of four inches of water. This would provide a substantial exemption for small farmers. It was estimated that the exemption policy would reduce the billed units of depletive use by 13 percent and the withdrawal units by 5 percent.

TABLE 20
ESTIMATED ANNUAL REVENUE
REQUIREMENTS FOR DRBC RESERVOIRS

Cost Category	Estimated Annual Revenue Requirements $
Beltzville & Blue Marsh	
Debt Service	864,000 (a)
Operation & Maintenance	30,000 DRBC Background Paper
F. E. Walter	
Debt Service	11,000,000 (b)
Debt Service Coverage and Major Repairs and Replacements	2,200,000 (c)
Operation & Maintenance	100,000 DRBC Background Paper
Interest Earnings on Reserves	(770,000) (d)
Charge Program Administration	406,000 (e)
Subtotal	13,830,000
Prompton	
Debt Service	5,900,000
Debt Service Coverage and Major Repairs and Replacements	1,180,000 (g)
Operation & Maintenance	100,000 Assumed Equal to F.E. Walter
Interest Earnings on Reserves	(410,000)
Subtotal	6,770,000
Total	20,600,000

(a) Scheduled annual capital cost for the period from 1989-2028.
(b) $124,000,000 bond issue (Table 19) with an assumed term of 30 years at an interest rate of 8 percent rounded to the nearest $100,000.
(c) Twenty percent of annual debt service.
(d) Seven percent interest on debt service reserve fund of $11,000,000.
(e) Assumed ten persons plus expenses, adjusted to round total cost to the nearest $100,000.
(f) $66,000,000 bond issue (Table 19) with an assumed term of 30 years at an interest rate of 8 percent rounded to the nearest $100,000.
(g) Twenty percent of annual debt service.
(h) Seven percent interest on debt service reserve fund of $5,900,000.

4. Merrill Creek Owners Group Credit
In considering the credit that the Merrill Creek Owners Group (MCOG) should receive because it constructed its own reservoir which was designed to release flows to make up for depletive use of its associated power plants, the Report recommended that the MCOG receive a five percent credit because the reservoir would release five percent of the days of the 49-year model simulation period. The Commission directed that reduction factors of 52, 75, and 95 percent be applied to the MCOG depletive use when developing the water charge schedules. The Commission has since decided to exempt Merrill Creek from withdrawal charges. Instead, the utilities covered by the Owners Group pay for consumptive use withdrawal unless Merrill Creek is releasing to make up for the generating units depletive use. The utilities pay for nonconsumptive withdrawal regardless of the releases from Merrill Creek.

5. Agricultural Use Charges
Among the public comments after the draft report was published was that the agricultural users felt that water charges could impose severe economic hardships and that agricultural land provides for ground water recharge that is not found in developed areas. The Commission's "Background Paper" stated that "For agricultural users, particularly small farmers, a form of exemption or partial exemption may be considered in light of the groundwater recharge and conservation benefits provided by such users".

Based on these comments by the public and other considerations, the Commission directed that the alternative water charge schedules developed in the study include schedules where agricultural irrigation is charged for: (1) its depletive use which is defined as 90 percent of withdrawals; and for 50 percent of withdrawals. The 50 percent factor was based on the use of a lower depletive use factor, recharge credits, or other conservation credits that may be adopted. The agricultural charges would be billed annually compared to quarterly for most other type of users.

6. Sub-basins Exempt from Charge
Based on salinity computer simulations by the Commission and on the relative benefit studies made in Part One of the report, depletive water use at the extreme downstream end of the Estuary would have minor if any affect on the availability of surface water to other users in the Basin. Also, the water charges to users in the area would be minimal so to make it economically impractical to collect these charges. The Commission directed that no charges be applied to users within Sub-basins 11 and 12, in New Jersey and Delaware, respectively.

Alternative A-Benefits Based Charge
The procedure for the design of the Alternative A water charge schedule is relatively straightforward, is as follows:

- The annual revenue requirement for the four DRBC reservoirs is allocated to each of the benefit categories in proportion to the benefit weight which is used in the relative benefit allocation.

• Determine for each benefit category the total of the users units, such as the annual depletive use or annual water withdrawal, upon which a charge will be applied.

• Divide the revenue requirement allocated to each benefit category by the units of charge recognizing the post/pre-compact charge ratio of 3:1 and the 100,000 gpd charge exemption. This calculation yields the charges to be applied to each benefit category.

The units of charge were basically for either depletive use or non-depletive use withdrawals and may include certain adjustment factors as follows:

• Compensation for Depletive Use, Replacement Factor Applie7d

• Reduced Risk of Restriction of Essential Depletive Use, excluding the New Jersey Diversion and 95 percent of the depletive use for the MCOG

• Increased Supply for Future Depletive Use, excluding depletive use in Sub-basin (above Montague, NJ)

• Salinity Control – The withdrawals of all PRM groundwater and the effective surface withdrawal of all users located between River Mile 118.5 and River Mile 76. There is no differential between pre and post-compact users for salinity control.

• Increased Reliability of Supply – The annual withdrawal of users that withdraw directly from portions of the Delaware and its tributaries that receive flow augmentations.

• Recreation Downstream – No units of charge

The results of this determination are shown in *Table 21* which can be found in the Appendix and on page 71 of the Report.

The schedule of water charges for Alternative A and the formula use for their application are shown in *Table 22* in the Appendix and on page 72 of the Report.

Table 23 shown in the Appendix and on page 73 of the Report shows the projected revenue that would result from each sub-basin and each state by user category.

Table 24 shown in the Appendix and on page 74 of the Report shows examples of the procedures which would be used to calculate the annual charge for two typical users.

Alternative B – Cost Casuative Based Charge
Alternative B focuses on the costs of providing benefits to the users. It utilizes cost causative principles and recovers non-salinity control related costs based on current depletive use and withdrawals, and salinity control related costs by means of the same

salinity control surcharge developed for Alternative A. With this type of charging system, users with identical usage are charged the same regardless of the end use of the water. This method is commonly used in the design of utility rates.

The water and flow release capabilities of the existing and proposed DRBC reservoirs are shown in *Table 25* below, based on computer simulations with the DRBC reservoir model.

Table 25
DRBC RESERVOIR YIELDS

Reservoir	Total Yield, cfs
Blue Marsh	65
Beltzville	130
F.E. Walter (Mod)	290
Prompton (Mod)	130
Total Yield	615 cfs

For cost causative rate purposes water released from the DRBC reservoirs may be regarded as providing for four types of use. They are:

- provision of depletive use compensation for current water users
- Provision of depletive use compensation for pre-Compact users which is not fully met without augmentation by a DRBC reservoir
- Provision of depletive use compensation for future increases in depletive use by with pre or post-compact users; and
- Salinity control

The Commission had not determined the quantity of water that will be available for future use. An assumption was made that the rate of increase of depletive use between 1986 and the year 2000 would be one percent annually. This would require a reservoir yield of about 130 cfs.

Table 26 shown below and on page 78 of the Report summarizes the allocation of reservoir yield to type of use and gives the equations to calculate the basic post/pre-Compact water charge ratio which resulted in a 3.3 to 1 ratio. However, due to the assumptions used and the accuracy of the water use inventory, the DRBC directed the use of a 3 to1 ratio.

Design of Alternative B Water Charge Schedules

The Alternative B type water charge consists of a pre- and post-compact depletive use and withdrawal charges and a salinity control surcharge. The users depletive use is first adjusted to reflect equivalent impact factors and also for the 100,000 gpd threshold.

The Commissioners directed that a withdrawal or non-consumptive use charge, based on a fixed ratio of the depletive use charge, be included in the Alternative B water charge schedules. Such a charge recognizes the value of being able to withdraw water even though the water is not depleted. The Commission's current charging regulations uses a factor of one percent or 1/100 ratio of the water withdrawn.

TABLE 26
CALCULATION OF POST/PRE WATER CHARGE RATIO

<u>DRBC Reservoir Yield Allocation</u>

Current Post Compact Requirement	221 cfs (a)	A
Current Pre Compact Requirement	114 cfs (b)	B
Future Use	130 cfs (c)	C
Salinity Control Requirement	150 cfs (d)	D

Total Yield	615 cfs (e)	E

<u>Current Depletive Water Use</u>

Post Compact Use	147 cfs	F
Pre Compact Use	398 cfs	G

Total Depletive Use	545 cfs	H

<u>Basic Post/Pre Compact Water Charge Ratio</u>

Percentage Responsibility of Post Compact Users = *((*A/E*)* + ((C/E)*(F/H)))*100 =41.6%

Percentage Responsibility of Pre Compact Users = ((B/E) + ((C/E)*(G/H)))*100 = 34.0%

Post/Pre Compact Water Charge Ratio = G*41.6%/F*34.0% = 3.3

(a) Current average annual post compact depletive use (including relative impact factor adjustments) times a storage quantity factor of 1.5.
(b) Total allocated yield for depletive use, 335 cfs, less post compact allocated yield for depletive use.
(c) Allocated yield for future depletive use.
(d) Allocated yield used to offset sea level rise.
(e) DRBC 120—day reservoir yield.

Options of a ratio of 1/50th or 1/100th of the depletive use charge were used in developing the charge schedules. The projected revenue to be recovered by the salinity control surcharge is equal to 24 percent (130/615 cfs) of the total annual revenue requirement. The remainder of the annual revenue requirement must come from the depletive use and withdrawal charge.

Table 27 shown in the Appendix and on page 81 of the Report, presents a schedule of water charges for Alternative B1 with the use of three instead of four reservoirs (excluding Prompton).

Alternative B1 assumed that the New Jersey diversion would be at a one hundred percent depletive use, the 100,000 gpd threshold was in place, the agricultural irrigation depletive use is at 90 percent and the MCOG payment is based on 95 percent. The withdrawal charge for Alternative B1 was set at 1/100th of the depletive use charge.

Alternative B1 can be looked at as the base charge schedule which reflects the policy considerations previously discussed. The charging schedule for this alternative determined that the pre-Compact use would be charged $56 per million gallons of depletive use and that all post-Compact depletive use at three times that rate or $168 per million gallons. Assuming these charge rates and all users are charged a withdrawal charge or non-depletive use of one percent (0.0l) of their depletive use charge, a total of $10.45 million dollars would be received annually. This amount plus the estimated $3.348 million dollars accrued from the salinity surcharge would total $13.78 million dollars. This amount essentially meets the project $13.83 million dollars annual revenue requirement for the two existing reservoirs plus the F.E. Walter modification. These calculations are shown in *Table 28* and on page 82 of the Report. The annual revenue requirement to include the Prompton modification would be about 50 percent higher, to nearly $20 million dollars.

Thirteen water schedule alternatives, selected by the Commissioners, were developed for the Alternative B type of charge. These alternatives are summarized in *Table* 29 in the Appendix and on page 84 of the Report.

Alternative C – Advisory Committee Alternatives

After reviewing the consultant's preliminary report, the Advisory Committee requested that eight additional charging schedules be developed. These schedules are similar in format to the Alternative A benefits based charges, except there was no benefit assignment for future depletive use and users in New York State were exempt from all charges. The Advisory Committee further requested that charges be developed for only three reservoirs, excluding Prompton. For the purposes of determining Alternative C charges, the percentage distribution for the annual revenue requirement to the various benefit categories is in proportion to the Alternative A distribution, excluding the future use benefit category. *Table 30* shown in the Appendix and on page 87 of the Report presents a summary of these alternative charge schedules requested by the Advisory Committee.

System Development Charge
The proposed DRBC reservoir projects were intended to provide sufficient reservoir yield so that water is available for increased depletive water use. A weighting of 20 percent of the total benefits in Part One was given to future depletive use. It recognized that about 20 percent of the yield of four reservoirs could be available to future use compensation. This means that a portion of the charges proposed many of the water charge schedules previously presented represents the cost of providing the capability of increased deplete use with in the basin. Because the current water users would be the only initial source of funding the additional depletive use, new users may receive benefits from projects for which they had not contributed.

A fairer system that is commonly used by utilities is to institute a system charge for new users for at least a portion of the costs the current users have borne. This charge should be structured that it would recover the costs of providing and holding reservoir capacity, but not so high that it would discourage new users from locating within the basin.

A format was suggested in the report to help determine a system charge for the DRBC. The total system development charge could equal the sum of the annual charges, less that portion of the charge that are related to future use, that the user would have paid as if they were a user when the water charge system commenced. Since this charge could be substantial, it was suggested that the DRBC may allow the user to amortize the payments over a period of several years. This policy would lessen the immediate financial impact on new users.

A certain level of usage must be assumed for the new user to implement the system charge. It could be based on the first full year of water use or on the user's water allocation. This type of charge could reduce the future charges to existing users. Because existing users would only be charged a system charge when requesting additional water allocations, the potential impact of this is charge to them is considered to be small.

Evaluation of Alternative Water Charge Schedules
The advantages and disadvantages of each of three basic types of water charge schedules which were presented in the report are evaluated below.

The implementation of any of the water charge alternatives presented in the report would require substantial effort. The effort would include the identification of all the users to be charged, their water withdrawal, depletive use factors, and whether the use is pre- or post-compact. All users below River Mile 92.5 must be assigned a relative impact factor. If all small users were to be included in the charging system, i.e. the 100,000 gpd exemption was not approved, a very large effort would be required to incorporate them into the data base and thus present a major disadvantage for such charging systems.

For Alternative A or C type charges, users withdrawing from the three or four reservoir-augmented streams must be identified. Users within the salinity control area would also need to be identified with any of the alternatives.

The Consultant's report recommended that once a water charge schedule is implemented that it would need to be revised periodically, perhaps annually, so that the annual cost and revenues would remain in balance. This would be to keep the current differences among users that pay different charges to be recognized properly. Because Alternative B charging schedule is based on the allocation of a known quantity of reservoir yield and not on a relative benefit allocation, there may be a small advantage in using this alternative for charging from a view of less complexity.

From an equity point of view, all of the major types of charge systems that were presented in the report were regarded as equitable, even though the user characteristics considered by each system were somewhat different. Alternative B does not give special consideration for increased supply for future use, increased reliability of supply, decreased risk of restrictions on essential use, and improved downstream recreation. The consideration of the different charging systems does result in charges that vary considerably; however, the consultant's opinion was that each water charge schedule is equitable.