Strategy for Resolution of Interstate Flow Management Issues In the Delaware River Basin

HydroLogics, Inc.
in association with
STV, Inc., ATS, Inc.,
the Greeley-Polhemus Group,
and the DRBC staff

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DISCLAIMER

This report by HydroLogics, Inc. summarizes flow management issues in the Delaware River Basin and recommends procedures and technical tools to resolve these types of issues. The report was extensively reviewed by the Commission Staff and the Parties to the 1954 Supreme Court Decree. It is important for the reader to understand that this report does not set flow or reservoir release policy and was not intended to do so. Policy relating to the 1954 Supreme Court Decree can only be modified with the unanimous consent of the Decree Parties. With the assistance of the Commission Staff, Decree Party representatives, and the Office of the Delaware River Master, care has been taken to present information and recommendations in a manner that considers the water rights of each of the Decree Parties, which include the States of Delaware, New Jersey, Pennsylvania, and New York and the City of New York. Due to the lengthy review period required for this report, the status of some issues and conditions presented may have changed from the time of writing. In many cases, the wording of this report summarizes existing policy. This is not a replacement for the wording in the legal documents which establish such policy.

ACKNOWLEDGMENT

Van Dyke Polhemus, a consulting water resources economist who contributed much to the text of this report, passed away in early December, 2003, after a long battle with cancer. Van also contributed to the Commission's Level B planning effort which supported the development of flow management policy in the early 1980s. As an economist, Van provided valuable insight to improving water resources management. Both as a colleague and as a friend, he will be missed.

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EXECUTIVE SUMMARY

Flow management is the set of actions taken to affect streamflow in order to achieve environmental, social, or economic objectives. The goal of flow management is to produce a politically acceptable and economically efficient mix of social and environmental benefits from both streamflow and the storage used to augment flow. The need for flow management results from the stress placed on rivers and streams by human activity and the reliance on reservoir storage for multiple uses, including augmentation of flows during dry periods.

I. Purpose and Scope

The purpose of this report is to present a strategy for resolving interstate flow management issues in the Delaware River Basin. The strategy includes a recommended process for flow management issue resolution as well as recommendations for improving the scientific basis for flow management decision-making in the Basin. The report identifies current flow management issues and is intended to provide better public understanding of flow management in the Basin.

A major focus of flow management activity in the Delaware River Basin is flow augmentation from the system of reservoirs included in the Delaware River Basin Commission's (DRBC) basinwide drought operating plan. These include the three New York City (NYC) Delaware Basin reservoirs: Cannonsville, Pepacton, and Neversink; two hydroelectric projects: Lake Wallenpaupack and the Mongaup system (consisting of several reservoirs); three U.S. Army Corps of Engineers reservoirs; Blue Marsh, Beltzville, and Francis E. Walter; Nockamixon Reservoir, owned by the State of Pennsylvania; and Merrill Creek Reservoir, which is owned by a consortium of electric utilities. The reservoirs are shown in Figures 1 and 2. Lake Hopatcong, located in the Musconetcong River watershed near Hackettstown, New Jersey, is included in the DRBC Lower Basin drought operating plan but it is a privately owned non-utility lake that would only be considered in Basin operations during drought emergencies in the Lower Basin. Because of its very limited role in interstate flow augmentation, Lake Hopatcong was not included in the scope of this study.

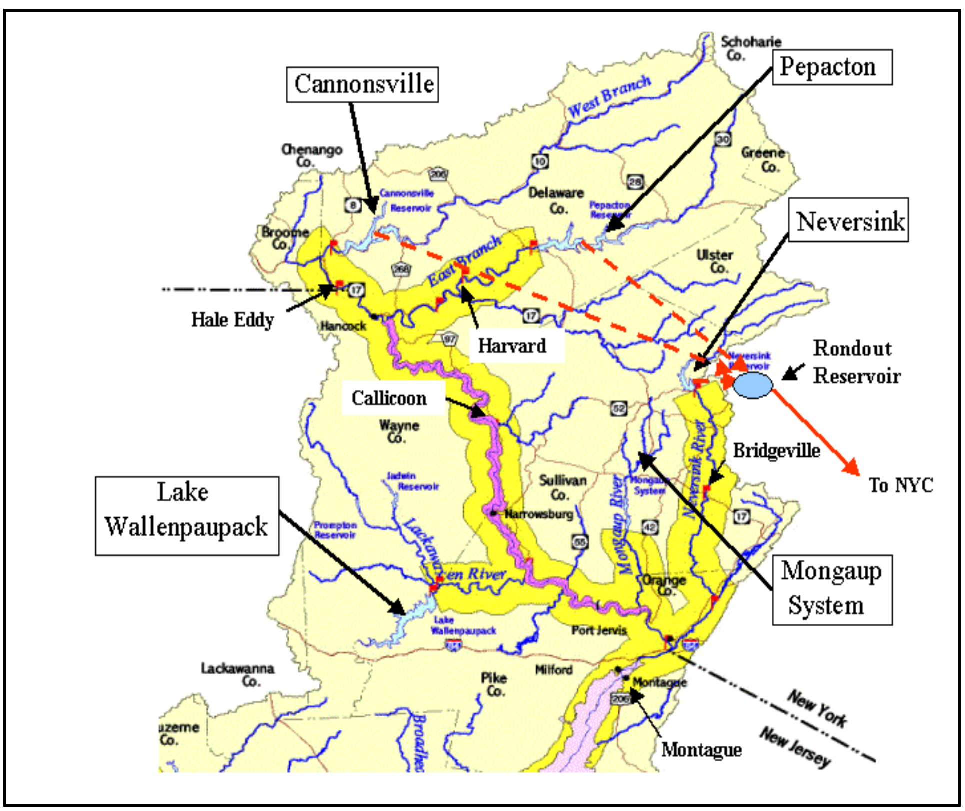


Figure 1: Upper Basin Reservoirs and Stream Segments

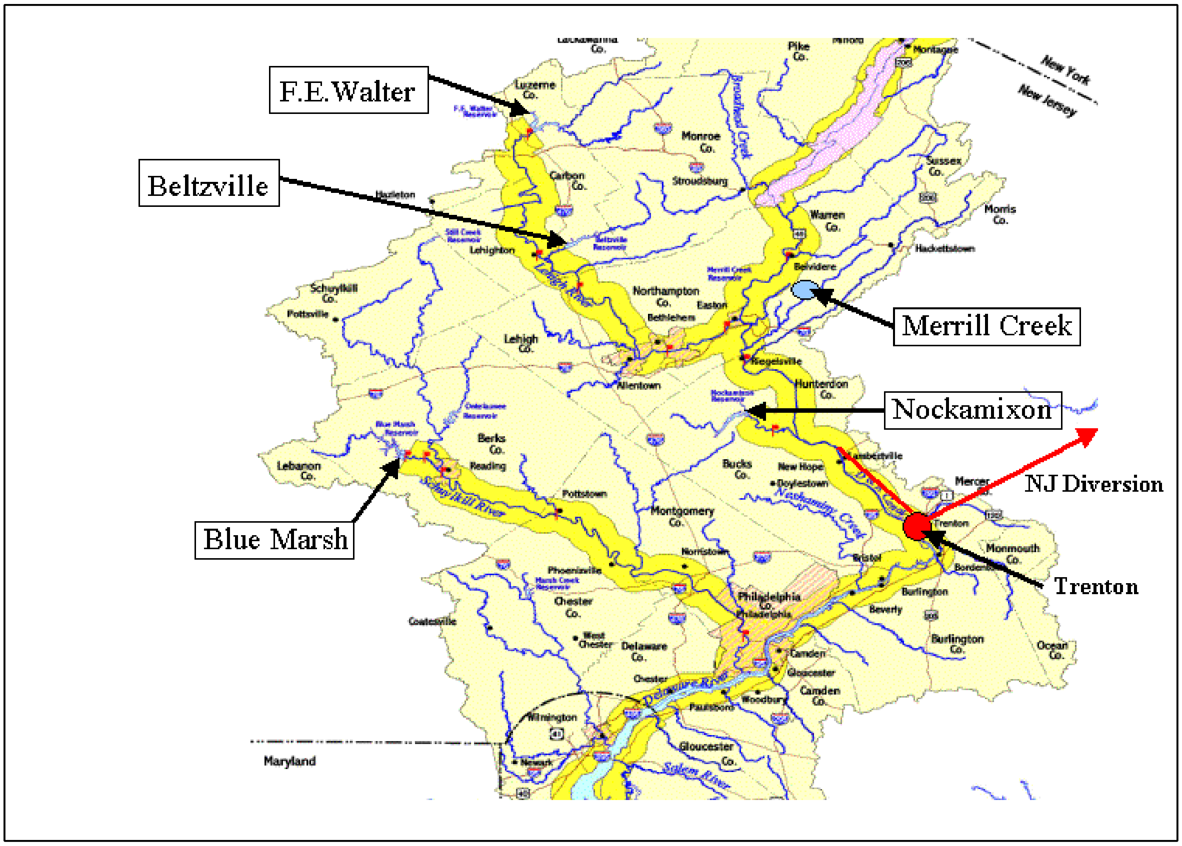


Figure 2: Lower Basin Reservoirs and Stream Segments

The 12 stream segments included within the scope of this report are located downstream from the reservoirs from which flow releases are currently managed in accordance with the DRBC's drought operating plans and as agreed to by the Decree Parties. These stream segments are shown in Figures 1 and 2, and listed below.

Segment	**Length in Miles**
1. East Branch Delaware River from Pepacton Dam to Junction with West Branch	33
2. West Branch Delaware River from Cannonsville Dam to Junction with East Branch	18
3. Neversink River from Neversink Dam to Mouth	42
4. Main Stem Delaware River from Hancock, NY to Trenton, NJ	197
5. Lackawaxen River from Lake Wallenpaupack Hydropower Generating Station to Mouth	13
6. Mongaup River from Swinging Bridge Reservoir to Mouth	18
7. Lehigh River from F.E. Walter Dam to Mouth	78
8. Pohopoco Creek from Beltzville Dam to Mouth	5
9. Tohickon Creek from Nockamixon Dam to Mouth	11
10. Delaware Estuary and Bay from Trenton to Mouth	134
11. Tulpehocken Creek from Blue Marsh Dam to Mouth	7
12. Schuylkill River from Confluence with Tulpehocken Creek to Mouth	77

This report is intended to help the Delaware River Basin community establish priorities for improving the science to support flow management decisions and to help different water users communicate their goals in more objective terms. While funding availability may constrain the ability to carry out all the suggested technical work, the process for identifying user goals in explicit, quantitative terms can proceed independently and is useful when flow management decisions and the associated tradeoffs among uses are made.

While this report presents recommendations of HydroLogics, Inc., it does not set flow management policy. Flow management policy decisions related to the DRBC drought operating plans are made by the Parties to the 1954 Supreme Court Amended Decree and the Delaware River Basin Commission under the terms of the DRBC Compact. The Decree Parties are the City of New York, and the States of Delaware, New Jersey, New York, and Pennsylvania. The DRBC consists of a federal representative appointed by the President and the Governors of Delaware, New Jersey, New York, and Pennsylvania.

In addition to the legal constraints imposed by the 1954 Decree, flow management options are subject to DRBC water quality regulations such as those for Special Protection Waters and the Delaware Estuary. Most importantly, constraints are imposed by the combination of current drought operating plans and the ownership and physical limits of storage. For example, under the existing rules of operation, modeling shows that the New York City Delaware Basin reservoirs would be reduced to extremely low levels during a recurrence of the 1960's drought of record. Accordingly, the proposed use of storage from these reservoirs for additional flow augmentation for downstream purposes must be balanced against potential harm to the City's water supply capabilities.

II. Background and Institutional Setting (Sections 1 and 2)

The Delaware River is an exceptional scenic and recreational resource and supports the water supply needs of millions of people. Reservoirs in the river's Catskill Mountain headwaters provide approximately half of the water supply needs of New York City. The main stem is undammed, and most of the river upstream from Washington's Crossing, New Jersey has been included in the National Wild and Scenic Rivers Program. In addition, sections of the Lehigh and Schuylkill Rivers have been designated as state scenic rivers. The Upper Delaware main stem and three tributaries, (the East and West Branches of the Delaware, and the Neversink River) as well as the Mongaup and Lackawaxen Rivers, support trout fisheries. Further, most of the upper and middle portions of the main stem, from the Delaware Water Gap northward, have been classified under the DRBC water quality regulations as Special Protection Waters, meaning that measurable degradation of the existing generally excellent water quality is prohibited. In the Delaware Estuary, improved dissolved oxygen levels since the 1960s have improved habitat for resident and diadromous fish. The Estuary serves the water supply needs of the highly developed Philadelphia metropolitan area and supports fishing and boating recreation. All of these stream reaches are downstream from the reservoirs included in the DRBC drought operating plans.

Interstate flow management disputes have a long history in the Delaware River Basin, stretching back to the early 1900s. In 1931 the Supreme Court issued a Decree allocating the Delaware's waters between the Basin states. In 1954, the Decree was amended as New York City developed the Upper Delaware for water supply exports. The process leading to those decrees was long and arduous and used the best data and analytical methods available at the time. The 1954 Amended Decree defined the allocation of water in terms of enforcing operating restrictions on the City of New York, primarily a limit on diversions to a running average of 800 million gallons per day (mgd) at any time in the 12-month period after June 1. As compensation for this diversion, the Decree also included a requirement that releases be made from the City's reservoirs to support a minimum daily mean flow of 1,750 cubic feet per second (cfs) at Montague, New Jersey.

In 1961, the Delaware River Basin Commission was formed to better manage the river. Under the auspices of the DRBC and with the unanimous consent of the Decree Parties, modifications during drought conditions have been made to the diversions and releases specified under the 1954 Amended Court Decree to better manage fisheries in the Upper Delaware, coordinate the management of Upper and Lower Basin reservoirs, manage salinity in the Estuary, and deal with droughts more severe than those considered in the development of the 1954 Decree, particularly the drought of the mid 1960s. Nearly all of these revisions are based on a 1982 agreement by the Decree Parties known as the "Good Faith Recommendations."

III. Identified Flow Management Issues (Section 4)

The issues identified for each of the stream segments are described in detail in Section 4 and summarized below. They were identified through a review of literature and through interviews with state, federal, and non-profit representatives as well as with businesses and private citizens. Many viewpoints were sought, and no attempt was made to screen or weight issues based on their source. A preliminary Issues Paper was prepared and made available for comments by all parties in January, 2001. It is understood that no list of issues is "final," and some issues may have been missed in this process.

The effect of flow regulation on trout habitat is the dominant issue for the East and West Branch of the Delaware River, the Neversink River, and the upper reaches of the main stem Delaware River. Trout habitat as a function of flow is also an issue for the Lackawaxen River, the Mongaup River, the Lehigh River, and Tulpehocken Creek below Blue Marsh Dam. Shad and smallmouth bass habitat are issues for the East Branch Delaware and main stem Delaware, respectively.

The effect of flow on recreational boating (either canoeing or whitewater rafting) is an issue for the main stem Delaware River, the Lackawaxen River, the Mongaup River, the Lehigh River, Tohickon Creek, and the Schuylkill River.

Water quality of the Special Protection Waters of the Upper Delaware could potentially be influenced by significant changes in flow regulation and is an issue because DRBC regulations require that the existing high water quality be maintained. Water quality during low flow conditions is the major concern in the heavily populated and industrial Delaware Estuary, where inflow can affect salinity intrusion, waste assimilation, and the quality of surface water supplies. Taste and odor problems at public supply intakes and their relationship to reservoir releases during low flow periods are an issue, along with turbidity, in the West Branch and Upper Delaware.

Other issues include the effect of freshwater inflow to the Estuary on wetlands habitat; continued concern over reservoir operations policy and oyster habitat; the potential for increased power generation to diminish streamflows; impacts of low flows at water supply intakes such as the D&R Canal; and the relationship between ice formation and flow in Upper Delaware reservoir tailwaters.

IV. The Strategy For Resolving Flow Management Issues (Sections 3 and 4)

The recommended strategy for resolving the flow management issues includes both *process* and *technical* components. The process recommendations are aimed at integrating flow relationships with user goals through the use of the OASIS flow model. The technical recommendations focus on the development of flow relationships and modeling capabilities. No recommendations for additional work are made in cases where flow relationships are sufficiently known or where no issues were identified.

A. Process Recommendations (Section 3)

Section 3 presents a planning and dispute resolution process. HydroLogics believes that the single most important recommendation of this report is for the DRBC to implement this six-step process. The steps of this process are as follows:

1) Identify issues and index displays (also called performance measures) for each stakeholder. This must be done as an inclusive activity involving all stakeholders.
2) Based on the issues and index displays, identify the data and scientific methods needed to evaluate alternative management policies in terms of the displays, and obtain a stakeholder consensus on using those data and methods to develop the necessary flow relationships.
3) Obtain the necessary data and tools to develop flow relationships, as well as tools capable of evaluating the costs and benefits of alternatives.
4) Develop a representative set of alternatives to be evaluated.
5) Provide all stakeholders access to the flow relationships and analytical tools.
6) Use the tools to focus negotiations on alternatives.

It is recommended that this process be kept current through periodic reviews of the adequacy of the performance measures and analytical tools. In addition, monitoring programs and forecasting tools can help develop an adaptive management strategy to implement the proposed six-step process.

B. Technical Recommendations (Section 4)

The following technical recommendations are proposed to address the second and third process recommendations. They are directed at improving the scientific basis for decision-making.

1) Recommendations Specific to Stream Segments: Technical recommendations specific to each of the stream segments are listed in detail and in priority order in Section 4. The recommendations fall within the following categories:

a) Water quality modeling for the Delaware Estuary including linking an improved salinity model to the OASIS model (considered a top priority).
b) Updated analysis of Estuary chloride levels versus cost to water users.
c) The development of thermal models for reservoirs and stream segments (high priority for Cannonsville and Blue Marsh reservoirs).
d) Data assembly and water quality analysis related to downstream taste and odor problems at treatment facilities.
e) Defining the relationship between turbidity and reservoir releases.
f) Determination of the impact of flow on compliance with the Special Protection Waters regulations.
g) Development or refinement of the relationships between streamflow and fish habitat.
h) Analysis of reservoir releases versus ice formation.

2) General Recommendations: Additional recommendations are made in Section 4 based on overall needs of the managed flow system. Some of these recommendations extend beyond the development of flow relationships to more general water management concepts. These are assigned a priority of "High" or "Medium."

High Priority:

a) Extend, test, and improve the daily inflow file used to drive the DRBC version of the OASIS model.
b) Develop toxic spill modeling capability for the Basin.
c) Evaluate forecasting tools for use in adaptive management.
d) Investigate water banking and conjunctive use of ground and surface water to improve efficiency in regional water management.
e) Develop habitat models through the creation of an environmental modeling oversight committee and link the habitat models to the OASIS model.
f) Develop reservoir water quality models for major Basin reservoirs.
g) Maintain and refine water quality and quantity monitoring capabilities.

Medium Priority:

a) Distribute modeled consumptive use demands in the Basin with more precision to better represent tributary flow impacts.
b) Develop more comprehensive, up-to-date demand data and forecasting techniques for the Basin, with special attention to the growing demand of the electric power sector.
c) Develop watershed-based water quality models for the Basin.
d) Improve understanding of surface/ground water interactions through modeling.
e) Investigate strategies for enhancing boating recreation, either through establishment of a new DRBC committee or the use of an existing committee.
f) Conduct a DRBC-sponsored colloquium to develop a coordinated research agenda for information needed to manage freshwater inflows to the Estuary.
g) Consider the feasibility of combining the Delaware River Basin Commission and New York City versions of the OASIS model

V. Case Studies (Section 5)

Five case studies were performed in order to demonstrate how the OASIS daily flow model, developed as a part of this study, could be applied to the recommended process for resolving issues. The case studies and their results are described fully in Section 5 and listed below. These case studies are experiments to demonstrate model use and do not represent DRBC policy.

A. Evaluation of the Trout Unlimited Minimum Flow Proposal for the Upper Basin

This case study was based on a 2001 proposal by Trout Unlimited (Parasiewicz, 2001.) It involved modeling a minimum release schedule for the NYC reservoirs that substantially exceeded current requirements, in lieu of meeting the Montague target. The study showed that this particular proposal would increase the percentage of time that the Basin is in drought from 11 percent to 45 percent. Although the proposal would result in higher minimum flows from the three NYC reservoirs, the reservoirs would spill in only 10 percent of the years, compared to 70 percent of the years under the present operating rules.

B. NYC Reservoirs Operated to Meet the Trenton Target

This case study tested rules that eliminated the Montague flow target. Releases in excess of minimum reservoir releases were targeted at meeting the existing flow targets at Trenton. Greater use of the storage in the Lower Basin reservoirs was made to meet the Trenton target only during the fall so that a full recreation season was always provided in the downstream reservoirs. Due to the increased use of Lower Basin storage, this case study showed that such an operating policy would result in substantially higher reservoir levels in the New York City Delaware Basin reservoirs and substantial reductions in the need to call for water use restrictions throughout the Basin. Such an operational change would represent a departure from the requirements of the 1954 Amended Decree, which places the burden of maintaining downstream flows on the City's reservoirs. The construction of the downbasin reservoirs in the 1970s represented an effort by the DRBC to provide augmentation of downbasin flows over and above what was being provided by the NYC reservoirs, rather than as substitutes for the NYC releases. In addition, the potential impacts on the Delaware River of reduced flows at Montague would need to be examined.

C. NYC Reservoir Balancing

This case study implemented NYC's current reservoir balancing rules in the OASIS model. It evaluated the changes in streamflows in the West Branch, East Branch, and Neversink compared to earlier modeling in which the three reservoirs were drawn down proportionally. Flows in the West Branch were higher and flows in the Neversink were substantially lower than in the previous evaluations. The reservoir balancing rules are now incorporated in DRBC's OASIS model.

D. Rafting Releases at Beltzville

The Beltzville case study examined the impacts of instituting a summer rafting release below the reservoir on Pohopoco Creek. This would provide a predictable release schedule that would enhance the recreational rafting industry in the area. The releases were scheduled at 235 cfs for six hours, with ramp-up and ramp-down, on weekends May through October, as long as the entire Basin was under normal conditions with regard to water supply. The study showed such an operation would likely have a minimal impact on other water uses in the Basin.

E. Temperature Control Below Blue Marsh Reservoir

The final case study showed how increasing minimum flows from Blue Marsh Reservoir on hot days might be used to control temperatures downstream. The objective of such operations would be to improve temperature management to improve the cold water fishery below the dam. Because there is no data on the relationship between temperature and flow downstream of the reservoir, a hypothetical relationship was postulated with a maximum additional release of 100 cfs. As in the previous case study, these additional releases would stop when conditions in the Upper Basin fall to *drought watch* or conditions in the Lower Basin fall to *drought warning*. This represents a substantial amount of water and would likely be able to maintain a limited stretch of year-round cold water, except during droughts. The study showed that it is likely that some degree of instream temperature control below Blue Marsh could be obtained with minimal impacts on other uses in the Basin.

VI. Additional Products Completed for This Project

Additional products were furnished as a part of this project. These are tools designed to support the process for resolving flow management disputes. A hydrologic model of the Delaware River Basin (DRBC OASIS) has been prepared and delivered to the DRBC and is available to the Basin states and Parties to the 1954 Amended Decree. This model is capable of evaluating alternative management strategies when used in combination with flow relationships and associated index displays (graphics showing the degree of attainment of user goals). The model is being used to facilitate negotiations concerning reservoir releases to enhance fisheries in the Upper Delaware River. An extensive set of GIS overlays was also produced to provide a framework for organizing data. The overlays will be integrated with DRBC's existing GIS system.

1.0 INTRODUCTION

This report identifies interstate flow management issues in the Delaware River Basin and recommends a strategy for resolving these and future issues. The report provides background on flow management so that readers may better understand and participate in the issue resolution process.

Section 1 summarizes the water resources features of the Delaware River Basin, outlines the role of the Delaware River Basin Commission in flow management, discusses the need for additional data and decision-making tools, presents the study goal, describes the study area, and lists the limitations of the study.

Section 2 describes the current state of the Basin's flow management and provides background on how the current policies have evolved. The policy background is considered crucial to formulating practical alternatives for resolving the issues.

Section 3 presents the recommended process for issue resolution. The process includes steps to build the scientific basis for developing flow relationships, as well as steps to use the flow relationships along with analytical tools to resolve the flow management issues.

Section 4 describes the current flow management issues for each of the study area stream segments. Recommended index displays (performance measures) describing the relationship between flows and stream uses are presented. Section 4 includes both stream-specific and general recommendations for developing the information necessary for defining flow relationships and other index displays. Section 4 also recommends development of toxic spill modeling, and suggests evaluation of water banking and conjunctive use alternatives as potential means of improving water management efficiency.

Section 5 of the report presents the results of several case studies carried out using the DRBC OASIS model, developed by HydroLogics, Inc. as part of this project, to illustrate the capabilities of the tools in the dispute resolution process.

1.1 <u>Water Resources of the Delaware River Basin</u>

The Delaware River and its tributaries flow from forested Appalachian highlands in upstate New York, northeastern Pennsylvania, and northwestern New Jersey, through the Piedmont region of eastern Pennsylvania and western New Jersey, to the New Jersey, Pennsylvania and Delaware coastal plain, and, ultimately, to the Delaware Bay and Atlantic Ocean. A map of the Delaware River Basin is shown in Figure 1.1.

The Delaware River is an exceptional scenic and recreational resource and supports the water supply needs of millions of people. The main stem is undammed and most of the river upstream from Trenton, New Jersey has been included in the National Wild and Scenic Rivers Program. In addition, sections of the Lehigh and Schuylkill Rivers have been designated as state scenic rivers. The Upper Delaware main stem and three tributaries - the East and West Branches of the Delaware, and the Neversink River, support outstanding trout fisheries. Further, most of the upper and middle portions of the main stem, from the Delaware Water Gap northward, have been classified under DRBC water quality regulations as Special Protection Waters, meaning that measurable degradation of the existing generally excellent water quality is prohibited. As water quality has improved with better waste treatment, recreational use of the Delaware Estuary has increased. All of these stream reaches are downstream from large reservoirs located on tributary streams, and all of the reaches are affected to varying degrees by releases from these reservoirs.

Relative to other major river basins, the Delaware River Basin is small – its 13,500 square mile area is about 0.4 percent of the land area of the 48 contiguous United States. Sixty U.S. river basins are larger. Yet, in spite of its small size, about five percent of the U.S. population (15 million people including the City of New York) depends on the Basin's resources for water supply. The Basin has a population greater than 40 of the 50 states. The largest and fifth largest U.S. cities, New York City and Philadelphia, obtain water from the Delaware River and its tributaries. The Delaware River is renowned as the longest undammed river east of the Mississippi. While there are no dams on the main stem, permanent storage capacity in tributary reservoirs totals over 400 billion gallons. Accordingly, flows in the largest tributaries and the main stem Delaware River are affected by reservoir releases. In addition to water supply, the reservoir storage and releases are used for flood control, water quality management, hydropower generation, replacement of consumptive water use, support of aquatic habitat, and recreational fishing and boating.

The reservoirs, consumptive water use, and out-of-Basin diversions have altered the natural flow regime in the tributaries and main stem. The reservoirs fill by skimming high streamflows and reducing the number of high flow events. Conversely, during some dry periods, up to 90 percent of the flow of the Delaware River at Port Jervis, New York, and half of the flow at Trenton, New Jersey, consists of releases from major reservoirs.

The Basin has been a focus of interstate water management programs. The most severe basinwide drought in the Delaware River Basin occurred during the 1960s, and drought plans designed for basinwide reservoir operation during a repetition of the 1960's drought have been implemented. Water quality of the Estuary, once so polluted that it blocked the passage of migratory fish, is greatly improved due to the concerted efforts of federal, state and local governments, industry, watershed organizations, and individuals.

The Basin's reservoirs provide storage for fisheries habitat, recreation, electricity generation, water supply, water quality maintenance and other uses of the water in the Basin. The Delaware River Basin's history has been marked by competition for its waters, and increasingly by competition for the use of reservoir storage.

1.2 Delaware River Basin Commission's Role in Flow Management

Figure 1.1 Delaware River Basin

The Delaware River Basin Commission (DRBC, Commission) was created in 1961 by an interstate Compact among the four states that share the Delaware Basin – Delaware, New Jersey, New York, and Pennsylvania – and the federal government. The Commission members are the Governors of the four Basin States and a federal representative appointed by the President. Prior to the signing of the Compact, conflict over water diversions from the Basin had resulted in two United States Supreme Court decisions: a 1931 Decree and an Amended Decree in 1954. The 1954 Amended Decree granted an increased out-of-Basin water allocation to New York City and mandated compensating releases from New York City reservoirs to maintain a flow target at Montague, New Jersey. The Amended Decree also granted an out-of-Basin water allocation to the State of New Jersey.

The DRBC Compact, and its relationship to the 1954 Amended Decree, involves the Commission and the Decree Parties (the four Basin states and New York City) in any future modification of the formulae for diversions to

New York City and New Jersey as well as downstream releases from the New York City Delaware Basin Reservoirs. Subsequent agreements by the Decree Parties - the most significant of these being the Good Faith Recommendations of 1982[1] - were adopted by the Commission, resulting in drought operating plans for a system of reservoirs which includes the three New York City Delaware Basin Reservoirs. The reservoirs covered by this study support basinwide drought operations and contain a total permanent storage capacity of 394 billion gallons. They include the three New York City reservoirs (Cannonsville, Pepacton, and Neversink); two privately-owned hydroelectric reservoirs (Lake Wallenpaupack and the Mongaup system); the privately-owned Merrill Creek pumped storage reservoir; Blue Marsh, Beltzville, Francis E. Walter, owned by the U.S. Army Corps of Engineers; and the State of Pennsylvania's Nockamixon Reservoirs. The Good Faith Recommendations also resulted in the Commission's adoption of operating plans for fisheries protection in the New York City reservoir tailwaters.

During *drought emergency* conditions **only**, the Compact gives the Commission, with the unanimous consent of the Commission members, the authority to temporarily adjust the releases and diversions of the 1954 Decree. During all other conditions, the Compact requires that any adjustments to releases and diversions specified in the 1954 Decree receive unanimous approval of the Decree Parties and subsequent approval by the DRBC. This concept is essential for understanding flow management in the Delaware River Basin. The Compact forbids any signatory state or its political subdivisions from applying for a modification of the Decree, but does give the states, acting together through the Commission and under the terms of the DRBC Compact**,** the authority to adjust the Decree formulae if there is unanimous consent of the five Decree Parties. This allows the Decree Parties to negotiate and use the Commission's Compact provisions to avoid litigation over the interstate allocation of the waters in the Basin.

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

The Commission provides a forum for comprehensive water resources planning and has broad regulatory power. In matters relating to the 1954 Amended Decree, the Compact provides explicit limits to the Commission's authority. The Commission's activities related to the Amended Decree and DRBC drought operating plans are generally referred to as "flow management" and are conducted through the DRBC Flow Management Technical Advisory Committee (FMTAC), which consists of Decree Party and Commission representatives.

1.3 Study Background and Authorization

Discussions leading to this study began in 1996, when U.S. Geological Survey (USGS) findings on the relationship between Delaware Estuary chloride levels and chloride concentrations in nearby water supply wells in the Camden, New Jersey area were presented to the FMTAC. The findings, which were based on particle track modeling, showed that the effect of estuary chlorides on these wells was less than had previously been determined in the absence of such modeling.

One of the bases of the Commission's flow management policy is the repulsion of estuary chloride intrusion to protect the wells in the vicinity of Camden. This is implemented by making reservoir releases to maintain a flow target at Trenton, New Jersey, located at the head of tide for the Delaware Estuary. In light of the USGS findings, the need to continue the current level of protection using the existing set of flow targets was questioned. Given the multiple uses of managed flows in the Delaware; the complex legal and policy history of interstate water apportioning and flow management; and the continued need for the Trenton flow target to protect other estuary uses, developing a better understanding of the relationships between flow and multiple water uses, as well as the ability to integrate these in decision-making, became a priority for the FMTAC. Subsequently, the FMTAC recommended that this study be undertaken to provide a plan, or strategy, for increasing the technical bases for flow management decision-making and incorporating these in the decision process. The study was authorized and funded by the Commission in June of 1999.

[1] officially the "Interstate Water Management Recommendations of the Parties to the U.S. Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Resolution 78-20"

1.4 The Need for Additional Tools for Flow Management Decision-making

The starting point and a major effort in this study was an assessment of flow management issues for the stream segments downstream of the reservoirs included in the Commission's drought operating plans. This involved working with state and federal agencies, public utilities, businesses, interest groups, and individuals throughout the Basin to identify flow management issues and to quantify, to the extent possible with existing information, the relationships between the quality of use and streamflow. This effort to define flow relationships revealed that for most of the stream reaches, more data and analysis are needed to establish the relationships between flow and stream use.

Over the past several decades, recreational water use has increased within the Delaware River Basin. Recreational use is linked to water quality, scenic attributes, boating opportunities, and aquatic habitat.

An understanding of the relationships between flow and stream uses such as these is needed to support flow management decision-making. The following are examples of questions which require such an understanding:

1) Can the existing flow augmentation program be more efficient?
2) How much flow augmentation is required for downstream water supply?
3) How much flow augmentation should support water quality?
4) How much flow augmentation should be provided for stream channel maintenance and the protection of fisheries and other natural resources?
5) How much money does the Commission save water purveyors and industry by its program of flow augmentation for salinity control?
6) How much flow augmentation is required to support recreation?
7) How much, if any, flood control storage should be reallocated for flow augmentation?
8) Are flow objectives that more closely replicate the variability of natural flows better than fixed flow objectives?
9) Should freshwater flows to the Delaware Estuary be increased and, if so, at what cost?[2]
10) What indices can be used to measure progress toward flow management objectives?

To answer these questions, knowledge of the relationships between flow and habitat, recreation, water quality, and water supply capability is required. These flow relationships can be used to develop performance measures which will assist different user groups in evaluating how well their objectives are attained by a particular flow regime. In many cases, these relationships are not currently known for the regulated stream segments within the scope of study. There is a need to understand, as scientifically and as quantitatively as possible, the relationship between the range of streamflows and the various stream uses.

Flow models can be used to evaluate the impact on flows and storage of alternative reservoir operating plans. For this reason, a daily flow model, known as the DRBC OASIS model, was developed by HydroLogics, Inc. as a part of this study. Flow relationships link flow model results to the performance of various release alternatives.

In addition to the use of analytical tools, flow management decision-making must consider the policy background and policy constraints surrounding the apportioning of water and the use of storage. This is an especially important matter given the interstate setting and water management history of the Delaware River Basin.

The development of flow relationships and performance measures, the use of analytical models, and the recognition of water supply and policy constraints are included in the issue resolution process recommended in this report.

[2] Action item W-6 of the Delaware Estuary Program specifies: "Support efforts to ensure freshwater flows to the Estuary to meet water supply needs to the year 2020." One of the "Measures of Success" for this item is "...increased freshwater flows."

1.5 Study Goal

The goal of this study is to develop a strategy for resolving interstate flow management issues for the stream segments downstream of the reservoirs included in the DRBC drought operating plans. This strategy is a recommended set of steps necessary to improve the scientific basis and the process for flow management decision-making. This study recommends steps to determine additional flow relationships and to incorporate them in a recommended issue resolution process.

1.6 Study Area Description

The 12 stream segments included in this study are downstream from the large reservoirs included in DRBC's drought operating plans. They are listed in Table 1.1, and shown in Figures 1.2 and 1.3.

Table 1.1 – Stream Segments Included in this Study

Segment	Length in Miles
1. East Branch Delaware River from Pepacton Dam to junction with West Branch	33
2. West Branch Delaware River from Cannonsville Dam to junction with East Branch	18
3. Neversink River from Neversink Dam to mouth	42
4. Main Stem Delaware River from Hancock, NY to Trenton, NJ	197
5. Lackawaxen River from Lake Wallenpaupack hydropower generating station to mouth	13
6. Mongaup River from Swinging Bridge Reservoir to mouth	18
7. Lehigh River from F.E. Walter Dam to mouth	78
8. Pohopoco Creek from Beltzville Dam to mouth	5
9. Tohickon Creek from Nockamixon Dam to mouth	11
10. Delaware Estuary and Bay from Trenton to mouth	134
11. Tulpehocken Creek from Blue Marsh Dam to mouth	7
12. Schuylkill River from confluence with Tulpehocken Creek to mouth	77

A range of stream uses – including recreational and commercial fishing, recreational boating, swimming, sightseeing, water supply, waste assimilation, navigation, and recreation – take place within the study segments. The specific objectives of flow augmentation vary between stream segments and among different groups of water users.

1.7 Study Limitations

This report does not provide a plan to manage flows in the Delaware River Basin. It does not present a specific operating policy or propose new facilities or conservation measures as a prescription to remedy problems or to enhance one or more uses. Rather, this report presents the recommended steps for a process to improve the basis for flow management decision-making. Changes in flow management policy relating to the Commission's drought operating plans can only be implemented with the unanimous consent of the Decree Parties and the approval of the DRBC.

Issues presented in this report were identified by reviewing available reports, meeting with resource agency personnel, and interviewing many individuals with expert knowledge of the river segments and their users. The process involved over six months of gathering information from data sources and interviews. The issues were presented in a preliminary issues report, and the report was distributed in January of 2001 with a two-month comment period provided.

The major limitation of the study was the lack of available information with which to quantify new flow relationships. The process of identifying instream flow issues and relationships is complicated because augmented flows are only one part of the dynamic river system that supports natural resources and human needs in the Basin. Reservoir flow augmentation, for example, provides a volume of water that will vary in its physical and chemical characteristics. Changes in flows affect the depth, temperature, dissolved oxygen levels, chemical concentrations, wetted perimeter, and velocity at a specific location. Most of the recent research on the Delaware River has focused not on flow changes and their impacts, but on other characteristics of water resources at specific locations. The effect of this is that most reports, such as the extensive Delaware Estuary Study, do not directly address flow rates and their impacts.

Previous fisheries work by the New York Department of Environmental Conservation and the Pennsylvania Fish and Boat Commission has produced useful flow versus habitat relationships for the Upper Delaware tailwaters and the Tulpehocken Creek below Blue Marsh Dam, respectively. The Federal Energy Regulatory Commission (FERC) relicensing process has also produced such relationships for the Mongaup and Lackawaxen Rivers. Previous work by the U.S. Army Corps of Engineers and the DRBC has quantified the relationship between flow and chloride intrusion in the Delaware Estuary. Additional work to quantify flow relationships with habitat (channel maintenance), water quality, and recreation suitability has yet to be undertaken. The scope of this study did not include conducting the original research needed to define these relationships. HydroLogics, Inc. believes that the recommended process in Section 3 and the technical work recommended in Section 4 would help to produce these tools.

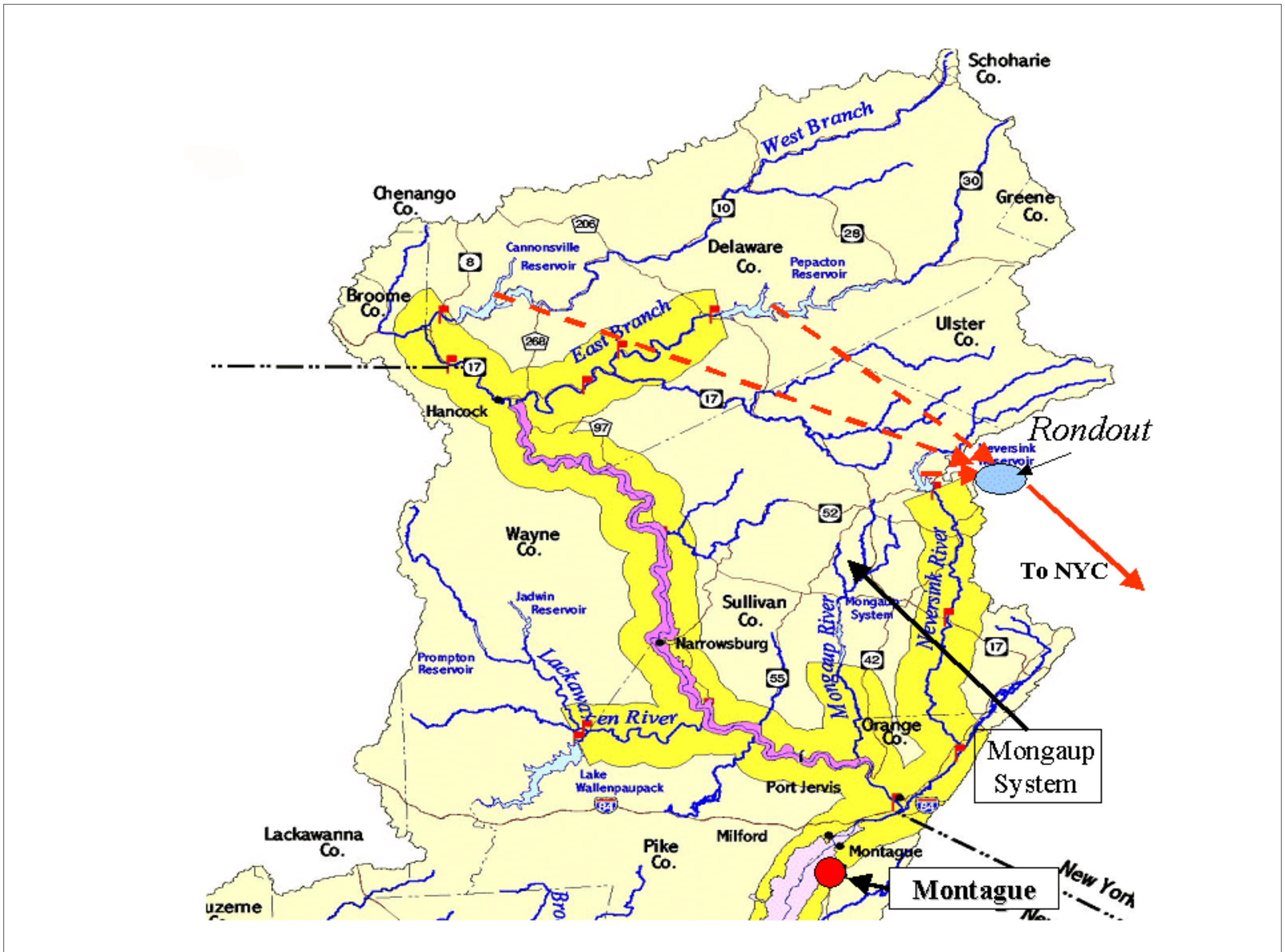


Figure 1.2 Upper Basin Stream Reaches

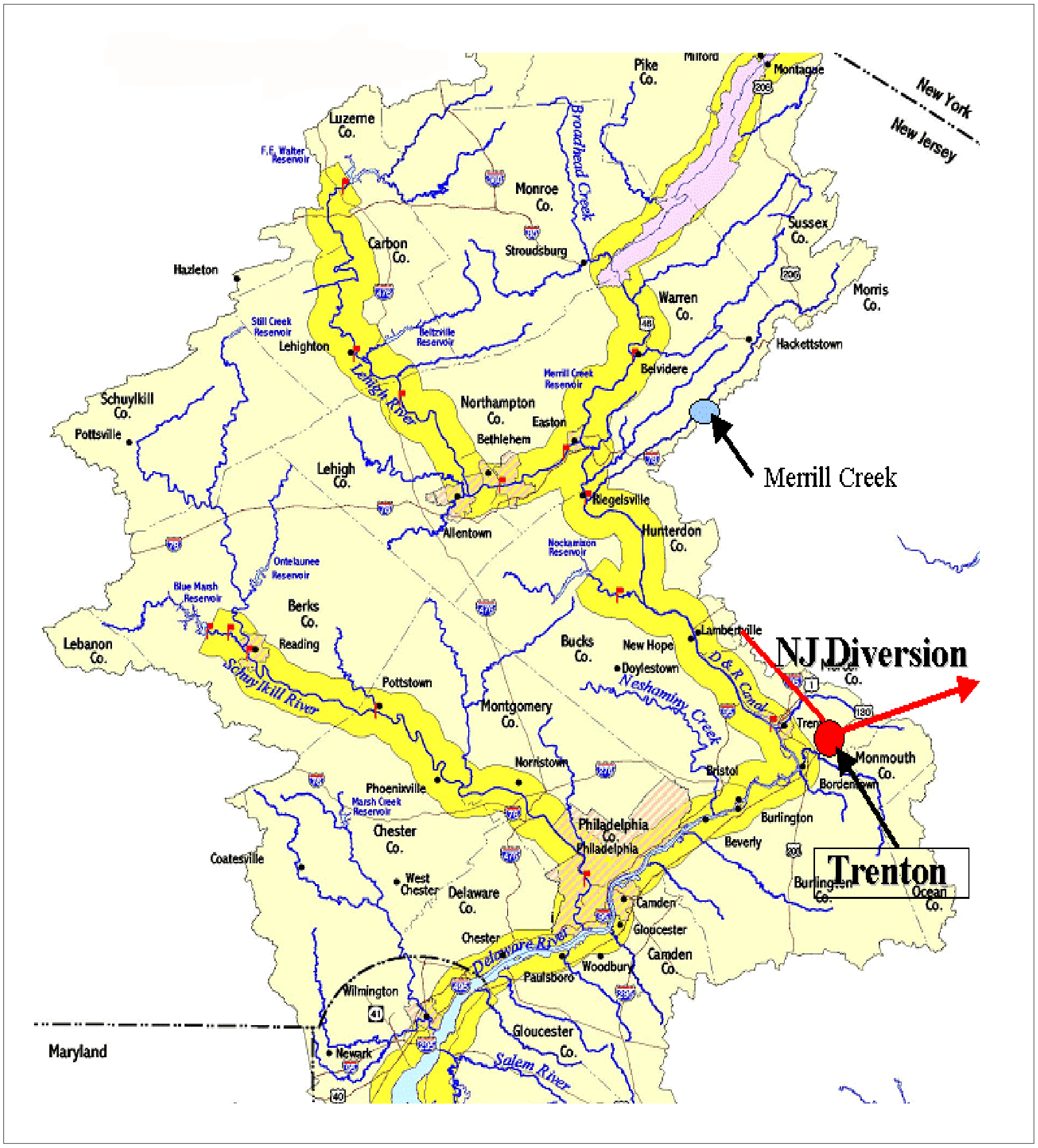


Figure 1.3 Lower Basin Stream Reaches

2.0 UNDERSTANDING FLOW MANAGEMENT IN THE DELAWARE RIVER BASIN

2.1 What is Flow Management?

Flow management is the collection of actions taken to affect flow in order to achieve environmental, social, or economic objectives. Three examples of flow management are:

- Coordinated releases from reservoirs to meet instream flow targets
- A coordinated program of water conservation practices or demand restrictions, both drought-related and during normal periods, to improve the reliability of long term supply
- A program for coordinated use of ground water and surface water designed to increase base flow in a stream or increase the reliability of supply

The goal of flow management is to produce a politically acceptable and economically efficient mix of social and environmental benefits. Two keys to effective flow management are 1) setting flow targets that achieve user objectives, and 2) achieving multiple benefits from releases of stored water wherever possible. Section 6 sets forth the steps believed necessary to establish the flow relationships needed to determine the benefits of a particular flow regime. Daily flow models such as that developed as part of this project provide a means for evaluating potential flow targets and for developing operating strategies that realize multiple benefits from release of stored water. The process for resolving disputes is designed to help achieve consensus on the mix of benefits.

There is a wide range of objectives for flow management. Objectives include increasing the reliability of current and future water supplies, improving instream water quality, providing or enhancing recreational boating and fishing opportunities, and protecting aquatic habitat and natural resources. Flow is often managed by setting a flow target to achieve such objectives, and that target is normally expressed as a pattern of flows (that may vary according to time or some other condition) at a particular point on the river.

River flow targets in the Delaware River Basin have been established for the Delaware River at Montague and Trenton, New Jersey. These targets were established to maintain equity in interstate water allocation and to provide control of salinity and protection of water quality. Flow management is also accomplished through minimum reservoir releases (usually referred to as conservation releases) for protecting and improving natural resources and stream channels and through releases for the control of water temperature to protect cold water fisheries. Significant efforts have been devoted to the evaluation of potential flow targets in the East and West Branches of the Delaware River, and the Neversink River.

Other, less direct means of flow management in the Delaware River Basin include:

- Conjunctive use of ground and surface water
- Minimum stream passby flow requirements as conditions for surface water withdrawals
- Ground water withdrawal limits in the Southeastern Pennsylvania Ground Water Protected Area
- A basinwide water conservation program which includes water saving fixtures and water pricing requirements

All of these measures serve to protect streamflow during dry periods.

Flow targets may serve single or multiple purposes. The Montague flow target does not relate directly to any use, but is used as a means of providing equity to the downbasin community which relinquished future use of 800 mgd of water exported to New York City. The minimum flow thus provides a quantity of water to the downstream community for instream uses as well as for meeting and protecting current and projected water supply needs. The U.S. Supreme Court, which set the Montague target and the 800 mgd export limit which necessitated the target, based its 1954 Amended Decree on the best available information at the time, and also on the practical limitations of then-available water supply and flow management techniques.

2.2 Water Uses

Water is used in the Basin in many ways. It is useful to distinguish between traditional, out-of-stream water uses and uses that depend on the water being in streams, lakes, or reservoirs. All projections in this section come from "Preliminary Consumptive Water Use Estimates for the Delaware River Basin for 1996 Including Projections for 2020 and 2040" (DRBC, November 2000).

2.2.1 Withdrawals and Consumptive Water Use

New York City and New Jersey export water from the Delaware River Basin for municipal and industrial uses. Under the Supreme Court Decree, New York City is entitled to a total diversion of 800 mgd from its three reservoirs and New Jersey is entitled to 100 mgd, which is now taken through the Delaware and Raritan Canal near Trenton.

In-basin consumptive use is the portion of the water withdrawn by users within the Basin that is not returned to the Basin. DRBC staff has categorized withdrawals and estimated consumptive use for each of 22 major subbasins in the Basin. Table 2.1 shows the average annual in-basin consumptive use by use category and the portion of the total withdrawal that is used consumptively.

2.2.2 Instream Water Uses

The demand for instream water uses, particularly cold water fishing and recreational boating, has grown substantially over the past several decades. The enhancement of cold water fisheries below the NYC reservoirs, as well as the growth of boating liveries, particularly in the upper part of the Basin, have resulted in increased public appreciation of the value of instream flow as a resource.

2.2.2.1 Fishing

Fisheries for cold water, warm water, and diadromous (migratory) species are present in the study stream segments and produce both recreational and economic benefits. The demand for fishing contributes to local economies, particularly since anglers often spend considerable sums on gear, guides, and accommodations. The annual value of cold water fishing to the economy in the Upper Delaware region is approximately $30 million, according to a 1998 report entitled *"The Economic Impact of Trout Fishing on the Delaware River Tailwaters in New York,"* (American Sportfishing Association and Trout Unlimited, 1998). Flow management provides water to support fish survival during low flow or high temperature conditions and may also improve fishing conditions by providing suitable depth and velocities for floating or wading and the proper stream velocities for casting flies.

Fishery experts with the New York State Department of Environmental Conservation (NYSDEC) note that the Delaware River watershed includes many high quality trout streams. One such example is the Beaverkill River. However, the original baseline fishery surveys, conducted in 1935, prior to construction of the three NYC Delaware Basin reservoirs, indicate that trout populations in most of the lower East and West Branches and all of the main stem were "poor or limited in scope." Trout were present in patches near springs or the mouths of cold tributaries. The 1935 study recommended that the lower 21 miles of the East Branch and lower 47 miles of the West Branch be managed as smallmouth and walleye waters. Only the lower 12 miles of the Neversink were viewed as non-trout waters. At that time, the section of the Neversink managed for trout extended 25 miles below what is now the site of Neversink Dam.

A description of the impact of the cold water reservoir releases on the fishery environment in the East Branch is provided in the unpublished report entitled, "*A History of Fishery Resources in the Upper Delaware Tailwaters from 1800-1983*" (NYSDEC, 1990). Following construction and filling of Pepacton Reservoir in 1955, cold water releases had substantial impact on downstream aquatic resources. Summer cold water releases in 1956 created a thermal environment unsuitable for warm water species historically present in the river. Largemouth and smallmouth bass and other fishes were reduced to remnant levels. A brown trout stocking program begun in 1956, wild trout recruitment from tributary streams, and substantial reservoir release to meet the Montague flow target (Cannonsville had yet to be constructed) resulted in flourishing trout populations until the summer of 1960. The onset of the 1960's drought in the summer of 1960 caused releases to be reduced to conservation release levels (19 cfs) and resulted in unsuitable

Table 2.1 Summary of In-Basin Consumptive Water Use
(See notes below table)

Use Category	Annual Consumptive Use - 1996	Percent Increase in Dry Year	Percent of Basin's Total Consumptive Use	Percent of Withdrawal Used Consumptively
Public Water Supply (1)(2)	91.8 mgd	20	29.5	10
Commercial/Institutional	1.3	20	< 1	10
Snowmaking	0.25		< 1	22
Domestic Self-Supply (3)	19.8	20	6.4	10
Industrial (4)	71.0	N/A	22.8	10
Non-Agricultural Irrigation (5)	5.5	70	1.8	90
Agricultural Irrigation (6)	30.3	80	9.7	90
Energy Production (7)	92.5	N/A	29.7	1.5

(1) Public Water Supply is defined as water withdrawn from streams or aquifers and distributed by a public water supply utility. Consumptive use for public water supply is about 10 percent of the total withdrawal on an average annual basis, but that percentage may be as much as three times higher in the summer than it is in the winter.

(2) Ground water accounts for about 30 percent of the total public water supply use in the Basin (DRBC, 1996). Because ground water flows to the river vary over time and are highest in non-drought periods, and because ground water pumping during droughts results in substantial flows through sewage treatment plants, it is likely that the use of ground water for public water supply provides a substantial supplement to surface water flow during critical droughts. Without further study, it is not possible to provide a quantitative estimate of this effect, but it probably serves to offset some of the impact of ground water and surface water withdrawals during low flows.

(3) Domestic self-supplied use is mainly ground water and occurs throughout the Basin.

(4) Industrial use is assumed to be independent of wet or dry years.

(5) Non-agricultural irrigation in the Basin consists mainly of golf courses.

(6) There is substantial agricultural irrigation in the Basin. While it is estimated that average consumptive use was about 30 mgd in 1996, the summer peak can be as high as 65 mgd.

(7) Based on an analysis of power generation in the Basin, consumptive use for energy production is estimated at .013 mgd per MW of installed capacity in the peak month, which is assumed to be August regardless of the cooling process used. Consumptive use is at a minimum in February, at about 81 percent of the peak. The overall average consumptive use is 1.5 percent because once-through cooling uses such a large volume of water relative to the fraction of water evaporated.

conditions for trout. A rotenone sample survey in July 1961 produced only one-tenth as many trout as did a July 1960 survey. Similar conditions continued through most of the 1960s. Rainbow trout populations in the main stem below Hancock most likely benefitted from the substantial cold water releases in the late 1950s. Warm water species continued to reside in the main stem during this period.

Cold water releases from Pepacton and Cannonsville reservoirs have enhanced and expanded cold water fisheries on the East and West Branches and the main stem Delaware. According to the NYSDEC, the upper main stem Delaware, the entire West Branch, and the Mongaup River below Rio Reservoir support wild trout. The East Branch and Neversink tailwaters contain wild trout populations that are supplemented by "put, grow, and take" stocking. The NYSDEC notes that absent cold water releases during the summer, trout fisheries below the NYC reservoirs would be much reduced. Other tailwater reaches which support trout include Tulpehocken Creek below Blue Marsh Dam, Pohopoco Creek below Beltzville Dam, the Lackawaxen River below Lake Wallenpaupack, and the reaches of the Mongaup River and its tributaries below the Mongaup system reservoirs. The trout fishery in the Lehigh River is enhanced by stocking programs, but has not been strongly influenced by cold water reservoir releases.

The Delaware, its tributaries and the Delaware Estuary support warm water species such as smallmouth and largemouth bass. These species are not as directly affected by reservoir releases as are cold water fish in the tailwater reaches. They are more tolerant of changes in dissolved oxygen and water temperature, but can be adversely affected by reduced stream habitat due to large changes in flow.

Diadromous fish species such as the American shad, striped bass and herring, as well as catadromous species such as the American eel are present in the regulated river system. Their migration takes them through the Delaware Estuary. The number of migrating shad and striped bass have increased with improved treatment of wastewater and the subsequent improvement of Estuary water quality since the 1960s. Recreational fishing for shad, herring, and striped bass is popular and commercial fishing for American eel takes place in the upper main stem of the Delaware.

2.2.2.2 Boating

Recreational boating in the Delaware River and its tributaries depends on sufficient flow and is affected by flow management. While spring flows are usually sufficient, adequate flow through the summer and fall is not guaranteed. Existing flow management has produced benefits for boating. Releases for whitewater recreation are made from F.E. Walter, Nockamixon, and the Mongaup system reservoirs. Boating releases for the Lackawaxen River have also been evaluated in the FERC relicensing process for Lake Wallenpaupack, currently underway. Boating in the main stem Delaware and its tributaries benefits from reservoir releases for the Montague and Trenton flow targets, but special releases for boating are not made. Sudden changes in releases impact boating quality, but advance scheduling of releases makes the boating conditions more predictable and adds to the value of flow management for boating.

2.2.2.3 Waste Assimilation

Discharge permits are issued based on the assimilative capacity of the stream at a given flow and temperature, usually the 7Q10 coupled with a water temperature typical of summer low flow. (The 7Q10 is the minimum running average flow over seven consecutive days, which would be expected to occur, on average, once every 10 years.) If flows fall below the 7Q10, where it has been used to set waste allocations, then there is a risk that water quality will not meet minimum standards. Flows other than the 7Q10 can also be used for this purpose. For example, waste load allocations for aquatic life protection in the Delaware Estuary have been established assuming a target flow of 2500 cfs for the Delaware River at Trenton. Reservoir releases are required to meet this flow target during most years. This flow target is approximately 138 percent of the 7Q10 (1810 cfs) computed for the post-regulation period of record (1954-1989).

2.2.2.4 Chloride Control

The upper portions of the Delaware Estuary are classified for use as a public water supply. In times of drought, when inflows are low, diluted seawater can extend far up into the Estuary, increasing the level of chloride and lowering the quality of municipal and industrial water supply. Mathematical models are used to evaluate the impact of alternative flow management programs on chloride concentrations in the Estuary. A flow target for the Delaware River at Trenton, New Jersey is used to control chloride intrusion in the upper Estuary, and reservoir releases are required to maintain this flow target.

2.2.2.5 Special Protection Waters

Several reaches of the Delaware are designated as Special Protection Waters because of their unique environmental value. Flow management can assist in maintaining the ecological integrity of these areas and support their use for recreational purposes.

2.2.3 Trends in Water Use

Table 2.2 shows projected trends in consumptive water use (DRBC, November 2000). The greatest projected increase, by far, is the use for cooling electrical generation facilities. This projection is driven by the assumption that electrical demand will continue to increase and that the resulting power plants will be located in the Basin, proximate to the load. In 2004, the DRBC staff initiated a study to update the demand projections for the Basin.

Public water supply is projected to increase about 15 percent by 2040. Domestic self supply (i.e., ground water) is expected to increase by 35 percent, but the absolute magnitude of the increase is just over half that for public supply. No growth is projected in industrial use, and agricultural use is expected to decrease, largely due to development of agricultural land. The other categories of use are small enough to be inconsequential on a basinwide basis, but they may be very important locally.

Table 2.2
Trends in Consumptive Water Use by Category (mgd)

Type of Use	1996	2020	2040
Public Supply	92	99	105
Commercial/Industrial	1	1	2
Ski Areas Snow Generation	<1	<1	<1
Domestic Self Supply	20	24	27
Industrial Supply	71	71	71
Agricultural Supply	30	24	21
Non-Agricultural Irrigation (primarily golf courses)	5.5	12.5	16.9
Electrical Generation	93	162	230

New York City water use has decreased over the past decade due to conservation measures, but the New York City Department of Environmental Protection (NYCDEP) expects demands to increase in the future. Eventually, NYCDEP expects that the City may approach the maximum diversion allowable under the Supreme Court Decree.

As shown in Table 2.2, the projected increase in consumptive use for public water supply, based on projected population change, is relatively small. Yet the reliability of flows for current and future water supply in the downbasin states is a concern. Analysis of the present reservoir system, under the rules of the DRBC drought operating plans, shows that the New York City Delaware Basin reservoirs would become severely depleted during a repeat of the drought of record and would be unable to sustain the Montague flow target during some periods. In such cases, the Lower Basin reservoirs would be required to make up shortfalls to maintain the Trenton flow target. Although the ability to physically withdraw water is generally not a concern in the Lower Basin, the ability to maintain the Trenton flow target, and that target's relationship to estuary water quality, have been and continue to be major concerns to Estuary water users and the Lower Basin states.

Demand for instream uses is expected to continue to increase. Given the financial and environmental obstacles facing the development of new storage projects, the competition for the limited storage available for flow augmentation is expected to become greater over time.

Data provided by the National Ocean Service (Lyles, et al., 1988) indicate that sea level has been increasing at the mouth of the Delaware Estuary (Lewes, Delaware) at a rate of 3.1 mm per year over the last several decades. Additional increases have been projected by the US EPA (Titus and Narayanan, 1995). Both the historical and the additional sea level rise have the potential to increase salinity levels in the Delaware Estuary. Increased costs to water users posed by salinity increases and potential changes in wetland and oyster habitat are concerns.

The U.S. Geological Survey has found that the impact of climate change on river flow is impossible to predict with any certainty at this time. Projections of changes in rainfall and temperature vary much too widely between studies to provide useful management information.

Waste load allocations based on Total Maximum Daily Loads (TMDLs) for watersheds and the use of non-degradation policies such as those for Special Protection Waters are expected to further constrain flow management in the future.

2.3 History and Current Policy

Current Delaware River Basin flow management policy requires reservoir releases to meet minimum flow targets on the main stem Delaware River at Montague and Trenton, New Jersey. At present, these targets are 1750 cfs (0.50 cfsm) at Montague and 3000 cfs (0.44 cfsm) at Trenton under normal conditions and as low as 1100 cfs (0.32 cfsm) at Montague and 2500 cfs (0.37 cfsm) at Trenton under drought conditions. During dry periods, reservoir releases are required to meet these flow targets. At times (for example, several days in August, 1999), reservoir releases have comprised more than 90 percent of the flow in the Delaware River at Montague, New Jersey, and over 50 percent of the Delaware River flow at Trenton, New Jersey. (USGS, Reports of the River Master of the Delaware River).

In addition to releases to maintain flow targets at Montague and Trenton, policies aimed at protecting fisheries in reservoir tailwaters prescribe minimum or "conservation" releases from reservoirs. Reservoir operating policies have been negotiated whereby diversions, target releases, and conservation releases are based on reservoir operating rule curves that relate reservoir levels to instream flow targets exist for both basinwide and Lower Basin (downstream of Montague, NJ) operations.

A major component of the river's flow management policy has centered on ocean salinity intrusion in the Delaware Estuary. During drought conditions, flow targets at Montague and Trenton vary in accordance with the location of the 7-day average 250 mg/l isochlor or "salt front." Flow targets increase as salinity intrusion increases, but decrease as available storage decreases. The Commission's policy is to maintain the 7-day average chloride level below the established 250 mg/l standard at Delaware River Mile 95, the downstream end of Zone 3 of the Estuary. Zone 3 is used as a water supply source by both the City of Philadelphia, Pennsylvania and the Camden, New Jersey, metropolitan areas.

The rest of this section provides information about how current interstate flow management policy developed, and the legal aspects of flows, releases, and diversions, focusing particularly on drought (low flow) conditions. The information in this section was taken from the following references: Damming the Delaware (Albert, 1987), the doctoral dissertation of Jeffrey Featherstone (Featherstone, August 1999), "New York City's Delaware Basin Supply - A Study in Interstate Cooperation" (Conway and Hurwitz, 1990), personal communications with Raphael Hurwitz, in January 2001, and "The Delaware River Drought Emergency" (Hogarty, 1970). It traces the history of current policy beginning with the conflict among the Basin States that resulted in the 1931 Supreme Court Decree, through the 1954 Amended Decree, to the Delaware River Basin Compact and the formation of the DRBC in 1961. This section also describes the issues and events, such as the 1960's drought, that led to negotiations by the Decree Parties and to unanimous agreement on strategies for long-term flow management. It concludes with a discussion of the resulting flow management policy governing the Basin.

2.3.1 The U.S. Supreme Court Decree of 1931 and the Amended Decree of 1954

In the early 1920s, major cities sought new water supply sources to meet increasing demand and to replace local supply sources of poor quality. Allocation of the water resources of the Upper Delaware River Basin was the focus of debate among New Jersey, New York and Pennsylvania. After two failed attempts by these states to form a three-state Compact agency, the New York City Board of Water Supply developed a three-stage reservoir development plan for the Upper Basin that was based on the principle of equitable apportionment, an approach recognized by the Supreme Court in other cases. This plan was approved by the New York State Water Power and Control Commission. New

Jersey subsequently filed suit against New York State and New York City in the U.S. Supreme Court; Pennsylvania joined the suit as an intervenor.

The Supreme Court's 1931 decision was based on the principle of equitable apportionment. Under the ruling, New York State was entitled to its share of the water and was permitted to divert that share out of the Delaware River Basin. The Court limited the diversion to 440 mgd, the amount corresponding to the first two phases of New York City's plan. The City was required to make compensating releases from its reservoirs of up to 61 cfs when the flow at Trenton, NJ or Port Jervis, NY fell below 0.5 cfsm (approximately 3400 cfs at Trenton and 1540 cfs at Port Jervis). The City was also required to correct the water quality problems caused by releases of sewage from Port Jervis, NY. Neversink Reservoir, the first Delaware Basin project, was completed in 1950.

In 1952, the City of New York petitioned the U.S. Supreme Court to re-open the 1931 case. New York City sought to build the Cannonsville Reservoir (the third stage in the plan) and increase its allowable diversion to 800 mgd. New York State joined the New York City petition, New Jersey and Pennsylvania responded, and the State of Delaware was later granted intervenor status. The five parties negotiated an agreement, which the Court-appointed Special Master then submitted to the U.S. Supreme Court.

To adjudicate the dispute, a determination had to be made as to the compensation to which the downbasin community was entitled in return for the loss of the 800 mgd which was to be impounded in the headwaters of the Delaware Basin and exported to the most downstream point of the Hudson River Basin, for use by New York City and neighboring communities in southeastern New York State. The compensation took the form of requirements that New York City make releases from its impoundments "in quantities designed to maintain a basic minimum rate of flow." While different minimum flows and measurement points were provided as New York City progressed in its reservoir construction phases, when all three Delaware River Basin reservoirs were completed, the 1954 Amended Decree specified a design flow of 1,750 cfs at Montague, NJ (approximately 0.5 cfs per square mile of drainage area upstream of Montague). This flow rate was exceeded approximately 80 percent of the time. In other words, the minimum flow that New York City was required to maintain at Montague had been exceeded on the average four out of every five days prior to the construction of the reservoirs. The 1750 cfs minimum flow at Montague was the quantity determined by the Supreme Court as the required compensation for the downstream community. To administer the Amended Decree, the Court established the position of River Master, drawn from the staff of the USGS.

The 1954 Amended Decree allowed New York City to increase its diversion from 440 mgd to 800 mgd in steps that coincided with the completion of Pepacton and Cannonsville Reservoirs. In addition, New Jersey was permitted to divert 100 mgd from the Basin and was granted the right to future expansion of its out-of-basin diversion, so long as it provided compensating releases.

The Lower Basin states agreed to facilitate the development of a main stem dam at Wallpack Bend on the Delaware River (this was later replaced by a proposal for a dam at Tock's Island), which was to have added an additional 1,800 cfs of reliable flow at Trenton, New Jersey. The release requirements in the Amended Decree were based on the drought of the 1930s, the drought of record at the time.

As compensation for the 800 mgd exportation of water, the releases from the City's reservoirs were to be designed to maintain a basic rate of flow of 1,750 cubic feet per second (cfs) at Montague upon the completion of Cannonsville Reservoir (the Montague Formula). In addition, a volume of water designated the "excess quantity," defined as 83 percent of the difference between the safe yield of the reservoirs and anticipated annual consumption, was to be released to the downbasin states in a controlled manner. The excess releases were to be made during the summer and fall months in order to provide additional low-flow augmentation using water that otherwise would be likely to spill during the following spring. This "excess quantity" release was to be reduced as New York City's consumption approached the safe yield of its entire water supply system (including the Croton and Catskill supplies) obtainable without pumping.

The 1954 Amended Decree contained the following diversion allowances and release requirements:

Neversink Only:

- Diversion allowance: 440 mgd maximum
- Release requirements: releases of 61 cfs required when flow at Montague dropped below 1,740 cfs, or flow at Trenton, NJ dropped below 3,400 cfs

Neversink and Pepacton:

- Diversion allowance: 490 mgd maximum
- Release requirements: releases required to meet a target of 1,525 cfs at Montague

Neversink, Pepacton, and Cannonsville:

- Diversion allowance: 800 mgd maximum
- Release requirements: releases required to meet a target of 1,750 cfs at Montague
- Excess releases (described below)

The 1954 Amended Decree did not provide for minimum conservation releases from the three reservoirs. They were subsequently negotiated by New York State and New York City. Minimums for Neversink were 5 cfs in winter and 15 cfs in summer; for Pepacton, 6 cfs in winter and 19 cfs in summer; and for Cannonsville, 8 cfs in winter and 23 cfs in summer.

2.3.2 The Delaware River Basin Compact

On October 27, 1961, the Delaware River Basin Compact created the Delaware River Basin Commission (DRBC). The Compact was enacted jointly by Delaware, New Jersey, New York, Pennsylvania and the federal government. It was the first time in U.S. history that the federal government and a group of states had joined together as equal partners in a river basin planning, development, and regulatory agency. The duration of the Compact covers an initial period of 100 years. It automatically continues for successive 100-year periods if none of the signatory states gives notice of intent to terminate. The U.S. may withdraw at any time.

The members of the Commission are the governors of the four Basin states (Pennsylvania, Delaware, New York, and New Jersey) and a federal member appointed by the President of the United States. Although the federal member was initially the U.S. Secretary of the Interior, it is presently the Chief of the U.S. Army Corps of Engineers. The President also appoints an alternate Commissioner, as do each of the four governors. These alternates are usually high-ranking officials in the four state environmental regulatory agencies and the Corps of Engineers. The Compact specified the mayor of the City of New York as an official advisor to the State of New York on Commission matters.

At the time the Commission was founded, powers and duties within the watershed were exercised by some 43 state agencies, 14 interstate agencies, and 19 federal agencies. The Compact consolidated this arrangement by creating a regional body with the legal authority to coordinate the development and control of the river system.

During the drafting of the Compact, its relationship to the 1954 Amended Decree was a topic of debate. Although the Compact gives the Commission power over new diversions and flow releases unrelated to the Decree, it strictly limits the Commission in Decree-related matters. The Compact gives the Commission authority to make adjustments to the Decree formula if there is unanimous consent of the five Decree Parties (the four Basin States and New York City). During a declared emergency not limited to drought, the formula may be temporarily modified with the unanimous consent of the Commissioners. This structure allows the Decree Parties to negotiate through the Commission to avoid further litigation over the use of the Basin's waters.

2.3.3 New York City Delaware System Operations

The three New York City Delaware Basin Reservoirs control a total drainage area of 917 square miles, or approximately one-quarter of the drainage area upstream of Montague, New Jersey. Neversink Reservoir, on the Neversink River, was the first reservoir built with a total usable storage of 34.9 billion gallons. Pepacton Reservoir, on the East Branch of the Delaware River, has 140.2 billion gallons of usable storage. Cannonsville Reservoir, on the West Branch, has 95.7 billion gallons of usable storage. Storage of water began at Neversink Reservoir on June 2, 1953, at Pepacton Reservoir on September 15, 1954, and at Cannonsville Reservoir on September 30, 1963. However, New York City records the official start of operations as the date when each reservoir began to supply drinking water to the City: Neversink Reservoir on December 3, 1953 (first diversion), Pepacton Reservoir on January 6, 1955 (first diversion), and Cannonsville Reservoir on March 31, 1967 (when storage reached 50 billion gallons above lowest diversion structure and release outlet, as required by the Supreme Court Amended Decree). Note that although storage at Cannonsville began in 1963, it filled for the first time only in 1967, after the end of the multi-year drought of record.

Pursuant to the 1954 Amended Decree, these reservoirs are operated as a system. The Decree authorized New York City to divert up to 800 mgd (as a running average), but required as compensation that a minimum flow of 1,750 cfs be maintained at Montague, New Jersey by supplemental releases from the reservoirs. The Decree also authorized the State of New Jersey to divert an average of 100 mgd of uncompensated water from the Delaware River. Subsequent adjustments to the 1954 Decree formula resulted from the Good Faith Recommendations of 1982, which were negotiated through the unanimous consent of the Decree Parties. Adoption and implementation of these recommendations by the DRBC has resulted in a reservoir operating plan with phased reductions in diversions and Montague flow targets based on drought severity. The Delaware River Master, established by the Supreme Court, specifies the releases to be made in order to meet the flow target, monitors the City's reservoir operations, and monitors the New Jersey diversion. In addition, New York State Department of Environmental Conservation Reservoir Releases Regulations (Title 6, Part 671) require conservation and thermal releases from the reservoirs for fisheries protection to maintain minimum flows and prevent excessive water temperatures. These conservation release requirements are also included in the DRBC Comprehensive Plan and reflected in Docket D-77-20 CP (Revised).

During most of the year, natural flows are sufficient to meet or exceed the Montague requirements without any directed releases from City reservoirs. During the summer and fall, however, directed reservoir releases are generally necessary. The City operates the system so as to have the reservoirs full after the spring runoff (June 1). Because the quality of water in Pepacton and Neversink Reservoirs is better than that in Cannonsville Reservoir, the City prefers to divert water for drinking from these two reservoirs. As a result, about 80 percent of the releases to meet the Montague flow target are made from Cannonsville.

Diversions to New York City from the three reservoirs travel through tunnels into Rondout Reservoir, located just outside of the Delaware River Basin. Diversions from all three reservoirs are normally passed through the hydroelectric plants located at each tunnel outlet. When diversion rates outside the operational ranges of the hydroelectric plants are required, bypass control valves may be used. Bypass control valves are also used to allow flow for diversion through the tunnels when the hydroelectric facilities are out of service for maintenance or repair work. The generating capacities of the Neversink, Pepacton, and Cannonsville facilities are 25 MW, 20 MW, and 8 MW, respectively.

Excess Releases: In addition to requiring those releases needed to meet the 1,750 cfs flow target at Montague, the 1954 Amended Decree also required excess releases. Each year, during normal hydrologic conditions, the so-called "excess quantity" is released, primarily to supplement the Montague target to support fisheries and habitat needs. This quantity is calculated based on the difference between the City's estimated annual water consumption and the pre-1960's estimate of safe yield (1,665 mgd). The Decree defines the excess quantity as "a quantity of water equal to 83 percent of the amount by which the estimated consumption for each calendar year is less than the City's estimate of the continuous safe yield during such year of all its sources obtainable without pumping." Thus, the excess release is expected to be reduced over time as the City's water use increases. The conditions for release of the excess quantity also have been temporarily modified through unanimous agreements of the Decree Parties.

Conservation Releases: New York State and DRBC regulations require the City to make minimum releases from each reservoir for conservation purposes, primarily to meet fisheries habitat needs. The 1954 Amended Decree did not provide for minimum conservation releases from the reservoirs. A gentlemen's agreement between New York City and New York State allowed for such releases from Neversink and Pepacton reservoirs. Conservation releases from Cannonsville Reservoir were a requirement stipulated in New York City's permit from New York State for that facility. The conservation releases for all three reservoirs were eventually incorporated into a Stipulation resolving litigation between New York State and New York City regarding claims for riparian damage on the Delaware tributaries below the reservoirs. Subsequently, an augmented conservation releases program was negotiated by New York State, New York City, and the other Parties to the Supreme Court Decree, and several experimental release programs and temporary extensions of these programs have been employed. The "basic" (pre-1977), augmented, and experimental conservation release requirements as of April 1999 are shown in Table 2.3. On November 30, 1983, after unanimous consent of the Decree Parties, Docket D-77-20 CP (Revised) established a permanent program of augmented conservation releases during periods of normal reservoir operation. Temporary experimental programs for conservation releases have been established through a series of later revisions to Docket D-77-20 CP.

Table 2.3
Reservoir Minimum Release Rates
D-77-20 CP (Revision No. 4 – April 28, 1999)

Reservoir and Operative Dates	Basic Conservation Release	Augmented Conservation Release	Experimental Augmented Conservation Release
Pepacton			
1/1 - 3/31	6 cfs	50 cfs	45 cfs
4/1 - 4/7	6	70	45
4/8 - 4/30	19	70	45
5/1 - 5/31	19	70	70
6/1 - 8/31	19	70	95
9/1 - 9/30	19	70	70
10/1 - 10/31	19	70	45
11/1 - 12/31	6	50	45
Neversink			
1/1 - 3/31	5cfs	25 cfs	25 cfs
4/1 - 4/7	5	45	25
4/8 - 4/30	15	45	25
5/1 - 9/30	15	45	53
10/1 - 10/31	15	45	25
11/1 - 12/31	5	25	25
Cannonsville			
1/1 - 3/31	8 cfs	33 cfs	45 cfs
4/1 - 4/15	8	45	4/1 - 5/31: 45 cfs
4/16 - 6/14	23	45	
6/15 - 8/15	23	325	6/1 - 9/15: 160 cfs
8/16 - 10/31	23	45	
11/1 - 11/30	23	33	
12/1 - 12/31	8	33	9/16 - 3/31: 45 cfs

NOTE: On July 17, 2002, DRBC Resolution No. 2002-21 (DRBC Docket D-77-20 CP Revision 5 Amended) temporarily modified this release program to include a flow target for the West Branch Delaware River at Hale Eddy, a minimum experimental release from Cannonsville Reservoir of 45 cfs, and a habitat bank comprised of the 9,200 cfs-day thermal stress bank and 5,700 cfs-days from the excess release quantity. The Docket was extended for one year on March 19, 2003 with the provisions that the excess release portion of the habitat bank be reduced by 20 percent and the NYSDEC submit a longer term proposal for tailwaters fishery protection by September 30, 2003. In April of 2004, the program was revised on an interim basis to include flow targets at Hale Eddy, Harvard and Bridgeville.

Special Thermal Stress Releases: DRBC Docket D-77-20 CP and its revisions direct additional releases to relieve thermal stress conditions, which pose a threat to fisheries. The Docket established a thermal bank of 6,000 cfs-days (drawn from all reservoirs) from which NYSDEC can direct releases whenever the maximum water temperature in designated downstream reaches is projected to exceed either a maximum temperature of 75º F or a 72º F daily average. The designated downstream reaches include:

- The East Branch of the Delaware between Pepacton Dam and the confluence of the East Branch and the Beaver Kill
- The West Branch of the Delaware River between Cannonsville Dam and Hancock
- The Delaware River between Hancock and Callicoon
- The Neversink River between Neversink Dam and Bridgeville

If the thermal bank is not used by October 31 of any year, it does not carry over into the subsequent year. No thermal releases are made between November 1 and April 30 of any year, and the releases are suspended altogether during *drought warning* and drought conditions. The original 6,000 cfs-day bank was later temporarily increased to 9,200 cfs-days by revision of DRBC Docket D-77-20 CP. Table 2.3 provides a summary of the current conservation release requirements from the three New York City reservoirs. Experience with temperature management has shown that the existing thermal bank is insufficient for management of the 75-degree criterion to Callicoon. The bank provides for management to Hankins in most years.

Flows in the major tributaries (West Branch Delaware River, East Branch Delaware River, and Neversink River) and the Upper Delaware River are greatly affected by both directed releases for the Montague target and conservation releases from the reservoirs. This raises a number of flow management issues related to the quantity, timing, temperature, and quality of water released from reservoirs.

2.3.4 Drought of the 1960s

Between 1961 and 1967, the northeastern United States experienced the most severe drought in its recorded history. The USGS estimated the recurrence interval in some parts of the Basin to be 500 years. This drought revealed that the New York City reservoir storage capacity in the Delaware River Basin was insufficient to meet both the 800 mgd diversion to New York City and the 1,750 cfs flow requirement at Montague. The record low 7-day average flow of 565 cfs was recorded at Montague in July of 1965. At Trenton, July of 1965 produced the minimum monthly mean flow of record (1,548 cfs). The mean monthly flows for June, July, and August of 1965 are each the lowest on record for those months. During the drought of the 1960s, the 7-day average 250 mg/l isochlor in the Delaware Estuary reached its maximum extent upstream, reaching River Mile 101, approximately 20 miles upstream of its normal October/November location. In addition, several Camden, NJ-area wells withdrawing from the Potomac-Raritan-Magothy (P-R-M) aquifer yielded water with increased chloride levels.

On June 1, 1965, storage in the Neversink and Pepacton Reservoirs was only 68 billion gallons (38 percent of capacity). At this time, Cannonsville Reservoir was only partially complete and had only 15 billion gallons of available storage. On June 14, 1965, New York City decided to reduce downstream releases from Neversink and Pepacton to the approximate amount of the inflow to those reservoirs, despite the requirements of the Amended Decree. The City's action created a crisis in water management and represented the newly-formed DRBC's first major challenge.

At the time of the crisis, the four Basin governors had two options: they could either return to the Supreme Court for enforcement or suspend the Decree administratively under the Compact's emergency provisions. The governors chose the latter course of action. In July 1965, at the request of DRBC Chairman Richard Hughes (Governor of New Jersey), the DRBC members evaluated a number of ad hoc schemes developed by DRBC staff to temporarily apportion the waters of the Basin. Following a July 7, 1965, public hearing, the DRBC formally declared a *drought emergency* in the Basin. Among its other effects, the drought declaration lowered the Montague, NJ, flow objective from 1,525 cfs to 1,200 cfs and reduced New York City's diversion from 490 mgd to a 30-day average of 335 mgd.

Also as a result of its July 7, 1965 *drought emergency* declaration, the DRBC enacted Conservation Order No. 1, which directed owners of Lake Wallenpaupack and the Mongaup Reservoirs to make releases from their reservoirs in accordance with a schedule furnished by the DRBC. Releases of 200 mgd (309 cfs) from Lake Wallenpaupack and 66 mgd (102 cfs) from Rio Reservoir were directed.

On August 18, 1965, the DRBC Commissioners met again to negotiate a series of technical proposals, including a "water bank" plan proposed by Stewart Udall, then Secretary of Interior and the DRBC Federal Commissioner. Such a bank would allow the DRBC some flexibility in addressing the drought crisis. Depending upon the greatest need, the DRBC could release water from the bank either to New York City or to the Lower Basin. Furthermore, the Delaware River Basin and service area were declared a federal drought disaster area in August of 1965, which provided federal disaster funds for the construction of various drought-related projects, including a proposal (not implemented) to relocate Philadelphia's Torresdale water intake farther upstream.

The water crisis abated somewhat with the improvement of hydrologic conditions in December 1965. While drought conditions persisted into 1966, a long, wet fall and winter in 1966-1967 completely ended the crisis. In March 1967, the DRBC terminated its *drought emergency* declaration. At the same time, Cannonsville Reservoir became fully operational, which allowed the City to increase its average daily diversion from the Basin to 800 mgd in accordance with the Amended Decree. The Montague flow target was concurrently returned to 1,750 cfs.

The drought of the 1960s highlighted the flaw in basing fixed water allocations on the flow during the 1930's drought (the drought of record at the time). Safe yield estimates based on the drought of the 1960s were 40 percent lower than those based on the 1930's drought. The 1930's drought was the basis for the Amended Decree. The 1960's drought pointed out the need for a more flexible approach to allocation, one that could adapt to future and potentially more severe droughts.

2.3.5 1982 Good Faith Recommendations

The drought of the 1960s made it clear that it would not be possible to meet the 800 mgd diversion to New York City and the 1,750 cfs flow target at Montague simultaneously during extreme droughts. It also provided additional support for the then-proposed Tocks Island project, which would have added 133 billion gallons (bg) of additional storage for water supply, recreation, and power generation. Despite the water supply shortages experienced during the mid-1960s and initial basinwide support for the project, local opposition to Tocks Island gradually intensified in the early 1970s. Propelled by the increasing national support for environmental protection, by 1975 both New Jersey and New York had withdrawn their earlier political support for the project. Over the vigorous opposition of Pennsylvania, the DRBC voted to recommend against congressional appropriations to construct the project. In 1978, Congress designated a portion of the Delaware River, which would have been flooded by the Tocks Island project, as part of the National Wild and Scenic Rivers System. Such a designation precludes construction of any dam in the designated area.

A new plan for flow management was needed. In 1976, with funding from the U.S. Water Resources Council, DRBC initiated a new comprehensive water resources study known as the Level B Study (DRBC, 1981). Completed in 1981, the Level B Study supported a scaled-back program for reservoir construction and placed more emphasis on non-structural and regulatory alternatives such as conservation. The Level B study also substantially lowered earlier projections of population growth and water use. In December 1978, the DRBC unanimously approved a motion, championed by Pennsylvania member Dr. Maurice Goddard, calling upon the Parties to the 1954 Amended Decree to "…enter into good faith discussions to establish the arrangements, procedures, and criteria for management of the waters of the Delaware River Basin, consistent with the Compact" (Albert, 1987). The Level B Study served as the technical support for the "good faith negotiations" that would ensue.

After intense discussions over the course of three years, the good faith negotiators drafted a set of fourteen recommendations that were then signed by the four Basin state governors and the mayor of New York City. The final agreement, presented to the DRBC in November of 1982, was entitled "Interstate Water Management Recommendations of the Parties to the U.S. Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Resolution No. 78-20" and is commonly referred to as the Good Faith Recommendations.

Since 1982, interstate flow management policy in the Delaware River Basin has been driven by the Good Faith Recommendations. The control of salinity intrusion was the basis for many of the 14 recommendations, which also included interstate drought management based on staged water conservation, increased reservoir storage, and fisheries protection downstream of the New York City reservoirs. Each of the parties pledged to support all of the recommendations. Using the Compact authority to adjust the Amended Decree with the unanimous consent of the Decree Parties, the Commission adopted the following 10 of the 14 recommendations in 1985. (The wording of the recommendation is taken directly from or paraphrased from Albert, 1987)

1. Revisions to the salinity standard for the Estuary.

Changes to DRBC's 1967 salinity standards were recommended because the existing and anticipated Delaware River Basin reservoirs lacked sufficient capacity to maintain the old chloride standards during drought. The recommendations also proposed a new reference point for the standards in order to provide protection to the Camden well fields. A standard for sodium was recommended as well.

2. Adoption of the drought of record (1961-1967) as the basis for water supply planning.

A drought equal in magnitude to the 1960's drought was recommended as the basis for all future water supply planning in the Delaware River Basin. By using the 1960's drought, the recommendation declared, the Basin would protect itself from any future such event, even if the risk of such a drought was very low.

3. Adoption of a schedule of phased reductions in diversions, releases, and flow objectives for drought management.

The 1980-81 drought demonstrated the value of a formula for reducing reservoir releases and water diversions when drought conditions appeared in the Basin. The recommendation included criteria developed by the Drought Task Group that out-of-Basin water diversions be reduced by as much as 35 percent and that the amount of water flowing down the Delaware River also be decreased by reducing both the Montague flow requirement and the Trenton flow objective.

4. Adoption of a Lower Basin drought operating plan for defining Lower Basin drought conditions.

This recommendation assumed that the DRBC would direct releases from federal, state, and power company reservoirs during a drought, as it had done twice in the past. A plan was proposed for coordinating the operation of the New York City reservoirs with the other reservoirs in the Delaware River Basin during drought periods.

5. Completion of a study to examine potential solutions to the over-pumping of the Potomac-Raritan-Magothy aquifer in southern New Jersey.

By 1985, the State of New Jersey was to develop a plan for solving the ground water problems of the Camden metropolitan area, to be implemented by 1990. The purpose of this recommendation was to reduce the region's reliance on the vulnerable Potomac-Raritan-Magothy aquifer.

6. Amendment of the Comprehensive Plan to update the status of Tocks Island Dam to place it in reserve for development, if needed for water supply after the year 2000.

Tocks Island Dam was not to be de-authorized, but held in reserve for development after the year 2000 if the additional water supply was needed. The project's description in the DRBC Comprehensive Plan was to be modified to reflect its change in status. The project has since been de-authorized by Congress.

7. Adoption of a drought trigger policy for mandatory conservation measures based upon storage conditions in the three New York City Delaware Basin reservoirs.

The amount of water in New York City's Delaware River Basin reservoirs was to be the principal basis for declaring and suspending drought emergencies. The recommendation established as policy the criteria proposed in Recommendation 3.

8. Adoption of a policy to reduce freshwater consumptive use during drought periods by 15 percent.

A goal of reducing depletive water use by 15 percent was recommended for adoption as a DRBC policy. The 15 percent figure had been derived from the Level B study, and reductions in water use during the 1980-81 drought had verified that a 15 percent reduction was attainable.

9. Preparation of state drought contingency plans to achieve the 15 percent reduction in consumptive use.

Each state was to develop a drought contingency plan describing how it would achieve the desired reduction stated in Recommendation 11.

10. Authorization of augmented conservation releases from the New York City Delaware Basin reservoirs on a permanent basis.

Experimental studies had demonstrated that such a program had a beneficial impact on the cold water fishery. (In addition to the augmented releases, a number of subsequent experimental programs for conservation releases have been approved by the Decree Parties and the Commission.)

Four of the Good Faith Recommendations either have not been adopted or have been only partially adopted. They are:

11. Construction of Merrill Creek Reservoir and modification of two flood control reservoirs-F.E. Walter and Prompton Reservoirs–to add permanent water supply storage.

Merrill Creek Reservoir, a pumped storage reservoir located on a small tributary of the Delaware River, was completed in 1988 by a consortium of electric utility companies for the purpose of replacing the freshwater equivalent consumptive use of water evaporated by electric power generation units during low flow periods, per DRBC requirements. The project is managed by the Merrill Creek Owners Group and has approximately 15.7 bg of usable storage. The yield for the facility is estimated at approximately 160 cfs during extreme drought conditions. The combined freshwater equivalent consumptive use of the presently operating electric generating units is approximately 80 cfs.

The F.E. Walter flood-control reservoir, located on the upper Lehigh River and owned and operated by the U.S. Army Corps of Engineers, was to have been enlarged by the Corps for water supply storage by 1990. The proposed enlargement would have provided a permanent storage pool of approximately 23 billion gallons with a flow augmentation potential of 285 cfs during extreme drought while retaining the current flood storage capacity of 35.1 bg (DRBC Annual Report, 1985, DRBC Water Management of the DRB, 1975). The Corps of Engineers performed a preliminary design and complete environmental assessment for the project. The DRBC pursued funding for the project by seeking both state and federal appropriations and modification of its water charging program under Section 15.1(b) of the Compact. The Commission supported the funding requests with a draft revised drought operating plan that would have significantly reduced the frequency of drought declarations based on reservoir operating criteria in the Delaware River Basin. Funding was not obtained, and the modification was not constructed (Greeley-Polhemus Group, 1993).

Prompton Reservoir, located on the upper Lackawaxen River, is also owned and operated by the U.S. Army Corps of Engineers. It includes a 1.15 bg permanent storage pool for recreation and an authorized flood storage capacity of 6.6 bg. The recommended modification of the Prompton dam would have provided 10.4 bg for the permanent storage pool for water supply and would have maintained the authorized flood storage capacity. The permanent water supply storage pool would have had a flow augmentation capability of 130 cfs during extreme drought conditions (DRBC Annual Report, 1985, DRBC Water Management of the DRB, 1975). Again, the Corps of Engineers performed preliminary design and environmental assessment for the project, but local support was lacking and funding was not obtained to construct the modification.

12. Enlargement of Cannonsville Reservoir, if practicable, based on feasibility and environmental studies.

The enlargement of New York City's Cannonsville Reservoir was also recommended. The enlargement was to be completed by the State of New York by 1990 and would have resulted in an additional storage pool of 13 bg for flow management and water supply in the West Branch and Upper Basin. In 1985, a consultant to New York State determined the project to be "technically and environmentally feasible," but found a marginal benefit/cost ratio (1.1 to 1). New York State officials abandoned the project in 1987 (Featherstone, 1999).

13. Evaluation of pumping glacial alluvium to supplement flow during droughts.

Ground water located in alluvial deposits in the Upper Basin was to be examined as a potential emergency source of water for use after the year 2000. This recommendation, which was highly controversial, was based on the idea that ground water could be used to augment river flows during drought. Pumping the ground water into the river would make it available for downstream users and instream flows. This proposal was strongly opposed by local interests in upstate New York, where the demonstration project was proposed. In a meeting conducted by the DRBC in late November 1982 in Port Jervis, New York, several hundred citizens and local officials voiced their displeasure with the proposed pumping scheme. Given such local opposition, the project never materialized (Albert, 1987; Featherstone, 1999).

14. Implementation of a regulatory program to limit consumptive water use based on a budget which would balance future consumptive water uses with available storage capacity designed to meet salinity objectives.

DRBC was to develop a program to regulate new consumptive water uses. Increased consumptive water use could offset any gains in water storage brought about by the agreement. This was a very important recommendation, since it recognized that the amount of reservoir storage that can be built is limited. Due to its controversial nature, however, this program has not been implemented (Albert, 1987; Featherstone, 1999).

2.3.6 Drought Operating Plans

This section presents a historical analysis derived from Albert, 1987 and Featherstone, 1999, and summarizes the current DRBC drought operating plans. (DRBC Resolution 88-22 (revised), 1988 - Amendment to the Comprehensive Plan Relating to Criteria and Operations Formulae)

The next major drought after that of the 1960s occurred in 1980-81. The drought began in the summer of 1980, when precipitation deficits and water use demands diminished storage in the three New York City reservoirs to 40 percent of capacity by December. By the second week of January 1981, storage in the three reservoirs had dropped to 33 percent of capacity. On January 15, 1981, the then-DRBC Chairman, Governor Brendan Byrne of New Jersey, called the DRBC into a special session, whose attendees included the four Basin governors and the mayors of New York City and Philadelphia. During the session, the DRBC formally declared its second *drought emergency*.

In contrast to the drought of the 1960s when there were no emergency plans in place, the DRBC now had drafted proposed drought operating criteria as a result of the "good faith" negotiations initiated in 1978. Utilizing these proposed criteria, the DRBC took several actions. Once again, the DRBC administratively adjusted the provisions of the 1954 Amended Decree and simultaneously reduced the diversions to both New York City and New Jersey and the Montague flow objective. In addition, the DRBC exercised jurisdiction over reservoirs owned by the Federal government, the Commonwealth of Pennsylvania, and two electric utility companies to help maintain flows in the river. The DRBC also recommended a series of non-essential-use bans that were adopted and enforced by the four states.

The 1980-1981 drought was relatively short-lived. Although storage in the New York City reservoirs had dropped to 25 percent of capacity by early February 1981, a dramatic increase in precipitation together with snow melt in late February and March added 100 billion gallons of water. This inflow allowed for full restoration of the New York City and New Jersey out-of-Basin diversions in May of 1981. Storage remained adequate for the remainder of 1981, and the *drought emergency* declaration was terminated by the DRBC early in 1982.

Through the adoption of several "good-faith" recommendations in 1983, the DRBC had formalized its drought operating procedures so as to equitably share water between upstream and downstream users during periods of shortage. The two most important provisions were (1) a rule curve for determining *drought warning*s and emergencies based upon the

combined storage in the three New York City reservoirs and (2) a schedule of phased reductions in diversions, releases, flow objectives, and salinity control.

The current drought operating plan is intended to provide reliable water supplies for essential uses during a drought equal in severity to the 1960's drought of record while sustaining river flows to meet the Estuary's salinity standard. Response to a drought more severe than that of the 1960s would be negotiated separately, depending upon its severity. Under normal conditions, provisions of the 1954 Amended Decree apply. During the different stages of drought, the rules in the following table apply.

Table 2.4
Interstate Operation Formula for Reductions In Diversions, Releases and Flow Objectives During Periods of Drought
Table Reflects Temporary Operations as of March 2003 based on Docket D-77-20 CP and its Revisions

NYC Storage Condition	NYC Diversion (mgd)	NJ Diversion (mgd)	Montague Flow Objective (cfs)	Trenton Flow Objective (cfs)
Normal	800	100	1,750	3,000
Drought Watch	680	100	1,655	2,700
Drought Warning	560	70	1,550	2,700
Drought	520	65	1100 - 1,650*	2,500 - 2,900*

Severe Drought (to be negotiated based upon conditions).
*Varies with time of year and location of salt front in Delaware Estuary.

The drought operating procedures have been employed eleven times since their adoption in 1983. While the Basin has only experienced two additional drought emergencies (in 1985 and 2001), DRBC has periodically declared *drought warnings*. In all instances, *drought warning* or *emergency* declarations were terminated by the DRBC once conditions returned to normal, as specified in the rule curve and operating procedures.

In addition to the above "Basinwide" operating plan, which is triggered by New York City Delaware Basin reservoir storage, the DRBC adopted a "Lower Basin" operating plan in 1988. This plan is triggered by storage levels in Beltzville, Blue Marsh, and Nockamixon reservoirs and controls the Trenton flow target and the New Jersey diversion. If both plans are triggered simultaneously, the plan producing the most stringent conditions for the Trenton target and New Jersey diversion applies.

2.3.7 River Master (Daily Operations)

The 1954 Amended Decree established the position of Delaware River Master to administer the Decree. The U.S. Geological Survey was chosen because it is a neutral federal agency. The Supreme Court carefully specified the River Master's duties, which are to:

- Administer the provisions of the Decree relating to yields, diversions, and releases so as to have the provisions of this Decree carried out with the greatest possible accuracy.
- Conserve the waters of the river, its tributaries and in any reservoirs maintained in the Delaware River Watershed by the City of New York or any which may hereafter be developed by any of the other parties.
- Compile and correlate all available data on the water needs of the Parties to the Decree.
- Check and correlate the pertinent streamflow gagings on the Delaware River and its tributaries.
- Observe, record, and study the effects of developments on the Delaware River, and its tributaries on water supply and other necessary, proper and desirable uses.
- Make periodic reports to the Supreme Court, not less frequently than annually, and send copies to the governors of the four Basin States, and the Mayor of New York City.

Thus, the primary duty of the River Master, in cooperation with the City of New York, is to monitor and adjust daily water releases to maintain the flow of the river at Montague in accordance with the provisions of the Decree. The River Master does not direct conservation or thermal releases, which are made in accordance with a fishery protection program approved by the Decree Parties and the DRBC.

The River Master considers several factors when planning to meet the Montague flow target:

- Present conditions in the Basin (water in the streams and on the ground),
- Forecasts by power companies of releases from power plants (based on forecasted power needs), and
- Precipitation forecasts. (The travel time of water from Pepacton Reservoir to the Montague gage is 60 hours, so releases must take place at least that far in advance.)

Because the flow releases from the NYC reservoirs generally take between 33 and 60 hours to reach Montague (depending upon which facility the water is released from), they must be based on forecasts. As a result of errors in the forecasts, the releases are sometimes too large, resulting in flows higher than the target, or too low. The Delaware River Master keeps track of the actual flows at Montague and determines, day-by-day, if the releases made in previous days turned out to be too large or too small due to flow forecasting errors. For example, if the River Master had called for releases of 300 cfs two days previous in order to meet today's 1750 cfs flow target, and the actual flow turned out to be 1760 cfs, then the over release for today would have been 10 cfs. If today's flow was 2500 cfs, due to an unexpected storm, then the over-release would be 300 cfs less the minimum required conservation release from each of the individual dams. If today's flow were 1720 cfs, then the under-release would be 30 cfs.

A balancing adjustment is made based on the cumulative difference since June 1 between the directed releases and the amount that would have been required if the forecasts had been exact. Each day the cumulative difference (over-release minus under-release) is divided by ten and added to or subtracted from the directed release for the following day. The division by ten is performed in order to smooth out the correction of the forecast-induced errors over a period of many days and to avoid large fluctuations in directed releases. In the end, the releases are adjusted over the summer, fall, and winter so that approximately the same amount of water is released from the NYC reservoirs as would have been released if there were no errors in the forecasts. Major consideration is given to balancing the reservoirs to maximize the "probability of refill" for the entire reservoir system by June 1 (the beginning of the maximum consumption period by users of the water supplied by NYCDEP).

As indicated previously in Section 2.3.3, the Decree also specified that because New York City had an excess of capacity over demand, part of that excess capacity must be released downstream.

2.4 Current Delaware River Basin Operations

The Delaware River Basin Water Code prescribes the operations of major diversions and reservoirs within the Basin; it is summarized in this section. For ease of discussion, the section first discusses the operation of the NYC reservoirs, then describes the operation of Lake Wallenpaupack, the Mongaup system, and the Merrill Creek project. Finally, the section describes the operation of Beltzville, Blue Marsh, and Nockamixon reservoirs, the Trenton flow target, and the D&R Canal Diversion.

2.4.1 NYC Reservoir Operations and the Montague Target

Diversions from the NYC reservoirs to Rondout Reservoir are limited by the 1954 Amended Decree and adjustments resulting from the implementation of the Good Faith Recommendations. The allowable diversions vary from a running average of 800 mgd when basinwide conditions are normal to a running average of 520 mgd during basinwide drought (See Table 2.4). In times of plentiful runoff, the total diversion varies with the New York City demand and with the amount of available storage in the City's Catskill and Croton systems. When drought threatens, the City generally increases its Delaware Basin diversion to enhance the reliability of its overall supply. Diversions are taken preferentially from Neversink, Pepacton, and Cannonsville Reservoirs, in that order, to maximize water quality. Consideration is given to balancing the reservoirs to minimize the possibility of spill and the probability of depleting storage in any one of the reservoirs. NYC operators determine the diversions from each reservoir.

Conservation releases are the minimum downstream releases from each of the three reservoirs. They are scheduled according to the most recent revision of DRBC Docket D-77-20 CP, and depend on basinwide conditions and the time of year. The NYSDEC release manager ensures that the minimum releases are met by NYC operators.

By using forecasts of weather and flow conditions three days in advance, the River Master determines the New York City reservoir releases that are required to meet the Montague target. The target varies based on basinwide conditions and on the additional "excess quantity" release. The River Master adjusts the Montague target to account for past releases that turned out to be either too high or too low, as described above. If the directed release is greater than the sum of the conservation releases, NYC operators will make additional releases to satisfy the Montague requirement. The portion of the directed release that exceeds the conservation releases is normally made from Cannonsville Reservoir. If the refill probability of Cannonsville approaches that of Pepacton, then some of the burden of meeting the directed release will be shifted to Pepacton.

The NYSDEC uses a series of graphical relationships (nomographs based on computer modeling results) and air temperature forecasts to determine the amount of water required to meet temperature targets (75 degrees maximum, 72 degrees daily average) at Hankins, Harvard, and Bridgeville, New York. Although normally made from Cannonsville Reservoir, NYC operators will shift directed releases (over and above conservation releases) in an attempt to meet the thermal release requirements with the same water. If the thermal releases sum is more than the directed release and more than the conservation releases, then the difference is subtracted from the water available in the thermal bank. Limitations in the graphs and the underlying temperature models, as well as in the temperature forecasts, make it likely that temperature targets will sometimes not be met in practice.

When the thermal bank is depleted, available water can be released from the habitat bank. In the event that banks are depleted and only directed releases can be made, the potential for significant harm to the cold water fisheries exists if hot weather does occur. For this reason, as the thermal bank becomes increasingly depleted, NYSDEC may abandon temperature targets at lower stations on the main stem (particularly below Hancock) in order to save water to continue to meet upstream tributary targets.

2.4.2 Lake Wallenpaupack and the Mongaup System

Lake Wallenpaupack and the Mongaup system are normally operated for peak power generation. PPL, the owner of Lake Wallenpaupack, has provided the DRBC with the rule curves that it follows to maintain adequate lake levels for power generation and summer recreation. In general, these rules take the water surface up to an elevation of 1187 on June 1 and then let it gradually fall to elevation 1177.8 on April 1, 10 months later. Monday through Friday, the water entering the reservoir in excess of the amount needed to maintain the rule curve storage is released through the turbines to generate electricity. Generally, no releases are made on weekends unless the inflows cause the lake to rise into the flood pool (elevation 1188), which is evacuated as soon as practicable. No conservation releases from Lake Wallenpaupack are currently required, although they may be as a result of the current FERC relicensing process. PPL applied for a new license in September 2002. The current license expires in September 2004.

In accordance with the DRBC Water Code, the Lake Wallenpaupack rule curve is modified during declared drought emergencies. The high elevation is still 1187 on June 1, but the low is reduced to 1170 on December 1. The storage area between these two elevations totals 29.8 bg. DRBC is authorized to direct release of that storage during drought emergencies. PPL has formally proposed an enhanced drought operations plan that would make additional storage available to DRBC for release during *drought watch*, *drought warning*, and *drought emergency* operations.

The Mongaup system, with approximately 15 bg of storage, is also primarily used to produce power. According to documentation provided by the NYSDEC, the minimum release from Rio Reservoir, the downstream-most reservoir in the system, is driven by inflow to Swinging Bridge Reservoir. The release requirement is 100 cfs when inflow equals or exceeds 100 cfs. Releases decrease with decreasing inflow to 60 cfs and are maintained at 60 cfs regardless of further declines in inflow. Should the DRBC declare *drought emergency* conditions, the minimum release may be lowered further. Releases were lowered to 30 cfs by the DRBC during the *drought emergency* of 2001-2002. As is the case with Lake Wallenpaupack, the DRBC can call for releases from the Mongaup system during drought emergencies. Unlike Lake Wallenpaupack, however, the DRBC Water Code does not specify a drought operating rule curve for the Mongaup system.

The Water Code severely constrains DRBC from effectively utilizing power reservoir storage to augment river flows below Montague. Subsections D(3)(e)(iii) and (iv) of Section 2.5.6, in effect credit NYC with the first 350 cfs of power reservoir releases if needed to meet the Montague flow objective, and thus do not constitute any additional augmentation for points downstream of Montague.

2.4.3 Beltzville, Blue Marsh, Nockamixon and F.E. Walter Reservoirs and the Trenton Flow Target

Beltzville (Corps of Engineers, completed 1971), Blue Marsh (Corps of Engineers, completed 1979), and Nockamixon (Commonwealth of Pennsylvania, completed 1973) Reservoirs are operated to ensure that the Trenton flow target is met. While Beltzville and Blue Marsh may be used for this purpose during normal, *drought watch*, *drought warning*, and drought conditions, Nockamixon may be used only during declared drought emergencies. Blue Marsh releases are counted toward the Trenton target even though they enter the main stem below Trenton. The Trenton flow target depends upon the basinwide or Lower Basin drought condition, which is defined by either storage levels in the New York City Delaware Basin reservoirs or storage levels in Beltzville and Blue Marsh reservoirs. Each reservoir has a minimum release requirement that depends on the time of year and also on the basinwide or Lower Basin drought condition. When the flow at Trenton would otherwise fall below the target, releases in excess of minimum flows are made from the Lower Basin Reservoirs in order to maintain the target. (Because of travel times, the releases are actually scheduled two days in advance based on forecast flows.)

Under normal hydrologic conditions, the Trenton flow target is 3,000 cfs. When the basinwide drought condition falls below normal, the target is reduced to 2,700 cfs. When basinwide conditions reach drought or when the Lower Basin drought condition falls below normal to either warning or drought, the Trenton flow target is dependent on the position of the salt front in the Delaware Estuary. When the salt front is below mile 82.9, the target falls to 2,500 cfs. As the front moves upstream, the target increases – to 2,700 cfs at mile 87 and to 2,900 cfs (May through November) at mile 92.5.

The DRBC Water Code defines the order in which reservoirs are drawn down to meet the Trenton target. Water is released from Beltzville and Blue Marsh Reservoirs during *drought watch* and *drought warning* conditions, and from Nockamixon Reservoir and F.E. Walter Reservoir, when available, during *drought emergency* conditions. Beltzville has approximately 13 bg of usable storage, Blue Marsh has 6.5 bg (summer pool) or 4.7 bg (winter pool) of usable storage, and Nockamixon has 13 bg of usable storage.

F.E. Walter Reservoir (Corps of Engineers, completed 1961) is operated as a flood control reservoir with two very limited exceptions. The first exception stores water for up to five whitewater rafting releases per year, two in June, one in September, and two in October. The amount of water used for these releases is relatively small, but because the reservoir inflows in the summer may be insufficient to provide even this small amount of water as well as the mandated minimum release of 50 cfs, the releases are sometimes canceled.

During some droughts, DRBC has negotiated with the Corps of Engineers to purchase temporary storage in F.E. Walter and Prompton reservoirs from which flow augmentation releases could be made to support downstream flow targets. Because the procedures are not implemented until a drought is in progress, the amount of water in storage is highly dependent on the time of year. When it is available, water stored in F.E. Walter is released before releases are made from Beltzville and Blue Marsh Reservoirs.

2.4.4 D&R Canal Diversion

The State of New Jersey diverts up to 100 mgd (monthly average) of water into the D&R canal. During *drought watch* conditions as defined by New York City Delaware Basin Reservoir storage, under the temporary provisions of revisions to DRBC Docket D-77-20 CP, the allowable diversion remains at 100 mgd. During basinwide or Lower Basin warning conditions, the maximum diversion is reduced to 70 mgd. In the event that either condition reaches drought, the maximum diversion is further reduced to 65 mgd.

2.4.5 Merrill Creek Reservoir and Electrical Generation Cooling Water Use Replacement

Merrill Creek Reservoir is a pumped storage project containing approximately 16 bg of usable storage. It was designed to provide water to offset the consumptive use of post-Compact power plants during *drought warning* and drought events. Merrill Creek makes a small conservation release at all times. When either a Lower Basin or a basinwide *drought watch*, *drought warning*, or drought operating condition exists and flows at Trenton would otherwise fall below 3,000 cfs, Merrill Creek makes an additional release equal to that day's total consumptive use from the power plants owned by the utilities that purchased storage in the reservoir. Because there is surplus storage in the reservoir, the owner companies have thus far made voluntary releases for pre-Compact units as well.

Water is pumped from the Delaware River to refill storage in the reservoir. Pumping is not permitted when additional releases are being made or when the pumping would cause the flows at Trenton to fall below specified levels. These levels depend on the time of year and the position of the salt front in the Delaware Estuary; the farther upstream the salt front encroaches, the less pumping is permitted.

Merrill Creek Reservoir was constructed in 1989 to provide makeup water for current and future power generation facilities located in the Basin. As discussed above, the majority of increases in water use in the Basin over the next 40 years is expected to be associated with new electric generation facilities. Substantial capacity in Merrill Creek is currently unused and is thus available for future purchase as makeup water for new facilities.

2.5 Assessing Flow Management Benefits and Costs

Flow augmentation in the study stream reaches results in higher than natural flows during dry periods. Yet the benefits of these flows have not been fully evaluated. In order for the benefits and costs of flow augmentation policy to be fully assessed, relationships which relate flow rate to stream uses are required. Salinity modeling and Instream Flow Incremental Methodology (IFIM) work in the Upper Delaware tributaries and along Tulpehocken Creek are examples of previous efforts to develop a scientific basis for flow relationships. Much additional work is required and has become a priority in the work of the Decree Parties, the DRBC, and its partner organizations. The following provides a qualitative list of benefits and costs of flow augmentation, and gives an example of how daily flow modeling can be used to help evaluate benefits.

The benefits of flow augmentation in the Delaware may be measured in terms of:

- Improvements in water supply reliability
- Reductions in salinity-related costs in the Upper Delaware Estuary
- Improvements in water quality
- Improvements in aquatic habitat
- Improvements in scheduled and unscheduled recreational opportunities for fishing and boating
- Hydropower production, as measured by the value of electricity produced

The costs of flow management include:

- The costs of building and operating storage facilities
- The costs incurred by users when water use is restricted
- Costs to purveyors and customers who own or rely on reservoirs for water supply
- Costs to those who use the reservoirs that supply the water for flow management (e.g., a loss of boat ramps when the reservoir falls, damage to reservoir fish populations and water quality, and scenic impairment)

Daily flow modeling makes it possible to compare the streamflows, reservoir storage, and drought event frequency that would result from alternative flow augmentation policy. With flow relationships it is possible to translate the basic flow model outputs into attributes such as fish habitat, boating suitability, or salinity intrusion, which has been modeled for many years by the DRBC. To demonstrate the role of daily flow modeling in the assessment of benefits and costs, an example comparing "natural" conditions to those approximating current operations is provided here. The "natural" conditions are estimated by assuming that no reservoirs are in place and that no out-of-Basin diversions are made. Note that this understates the actual impact of flow management because it assumes that no water would be diverted to New York City, which is entitled to divert up to 800 mgd under the 1954 Supreme Court Amended Decree. Because these scenarios are so different, they have a clearly identifiable impact on the high and low end of the flow hydrograph.

Figures 2.1, 2.2, and 2.3 illustrate the differences in minimum monthly flows under the flow augmentation program which approximately represents DRBC Docket D-77-20 CP (Revision 4), absent thermal releases, and flows as if no reservoirs were in place. These graphs plot the minimum daily flow for each month between 1975 and 1984 at Bridgeville, Hale Eddy, and Harvard, New York for both the managed flow and natural flow. In the summer and fall, natural flows at all three sites are less than the managed minimums in most years.

The flow traces produced by these two model scenarios can be compared to the flow rates desired or required for specific stream uses. For example, based on IFIM work by the NYSDEC, flow targets to support cold water fisheries have been proposed for each of the three locations (Bridgeville, Hale Eddy, and Harvard). Using these targets and the flow traces, the number of times that monthly minimum flows, or daily flows using another output format, would not meet the habitat targets could be determined. This is an example of an "index" or measure of relative success of a particular management scenario in meeting a particular stream use objective. While such a measure is not as complete as the assignment of dollar costs for failure to meet a particular objective, such indices, if available for each stream segment, would be useful for flow management decision-making because they enable policy alternatives to be more explicitly quantified. This is necessary for a better understanding of flow management costs and benefits.

2.6 Improving Flow Management within Existing Limitations

The high quality and extensive use of the recreational resources provided by the study stream segments has focused attention on ways to improve flow management for the benefit of both fisheries habitat and recreation. HydroLogics believes that changing flow management policy does not mean that the water equity established by the 1954 Amended Decree must be abandoned. With the strategy proposed in this report, we believe it will be possible to fully evaluate alternatives to the 1954 regime that preserve the equitable allocation of water. Flow modeling provides the means to efficiently test whether a proposed regime is better than the existing management scheme.

HydroLogics believes that the following should be addressed to improve flow management in the Delaware River Basin:

1) *Lack of information to establish flow relationships:* The recommendations section of this report details and prioritizes actions to improve on existing knowledge. A lack of knowledge regarding flow versus use relationships hinders efforts to evaluate flow augmentation policy and to assess the benefits of existing storage or additional storage that might be proposed.

2) *Lack of institutional processes and technology to allow stakeholders to have effective input to flow management decisions:* While stakeholders are welcome to attend and to speak at DRBC Flow Management Technical Advisory Committee and Commission meetings, their lack of access to the technical tools and information needed to analyze flow management alternatives has made it difficult for them to present convincing arguments. The process proposed in Section 3 is aimed at giving stakeholders access to the technical tools they need to evaluate alternatives and to have input to flow management policy decisions. While the actual use of the technical tools may require expertise and training, access to and understanding of the underlying analytical concepts allows for better stakeholder input. Development of the index displays suggested in Section 4 is a first step toward obtaining policy input from stakeholders.

The terms of the 1954 Amended Decree and the legal framework of the DRBC Compact provide the context within which changes in flow management must be approached by the DRBC. Adjustments to the diversion and release formulae cannot be made without the unanimous consent of the Decree Parties. This includes any proposal for banking or adaptive management. In addition to Decree-related matters, all potential policy changes must be evaluated against DRBC water quality regulations, such as those in the Special Protection Waters and Delaware Estuary.

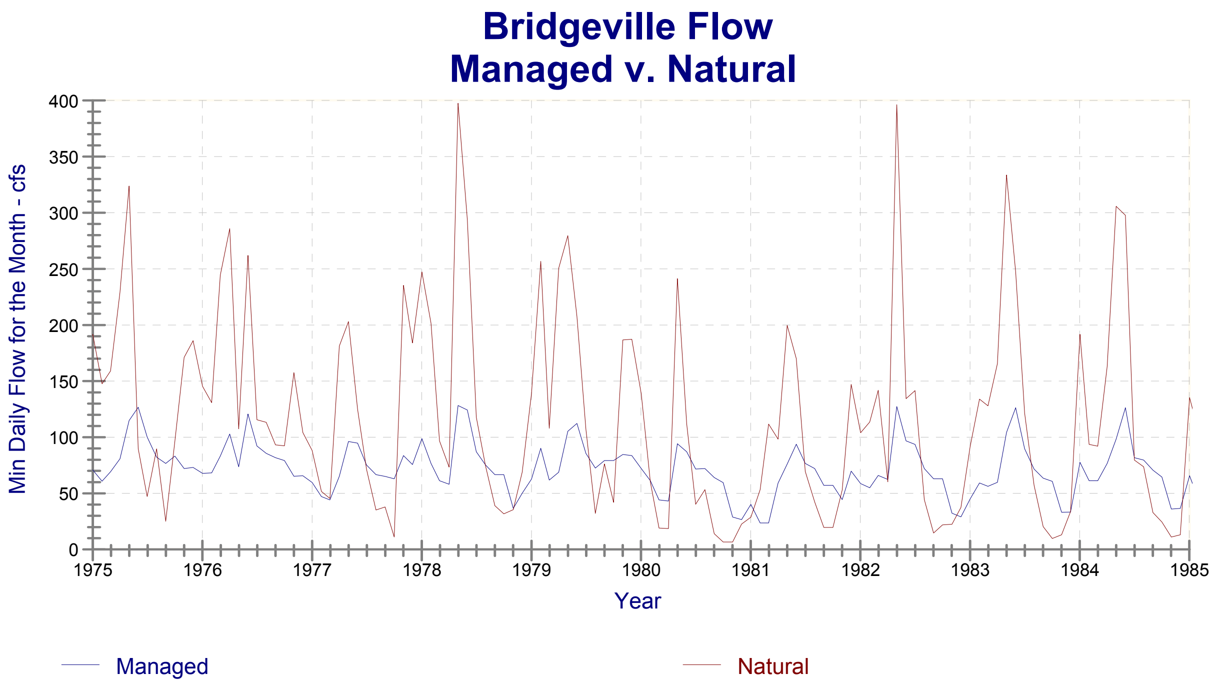


Figure 2.1 Comparison of Flows Below Neversink Reservoir

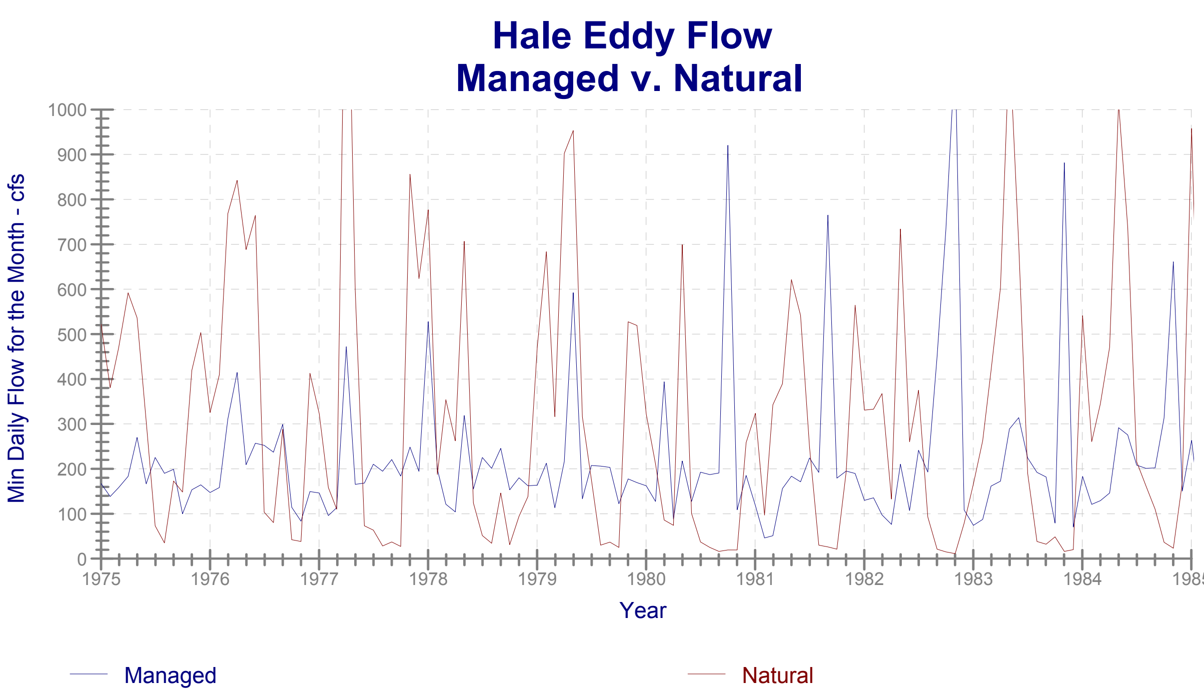


Figure 2.2 Comparison of Flows Below Cannonsville Reservoir

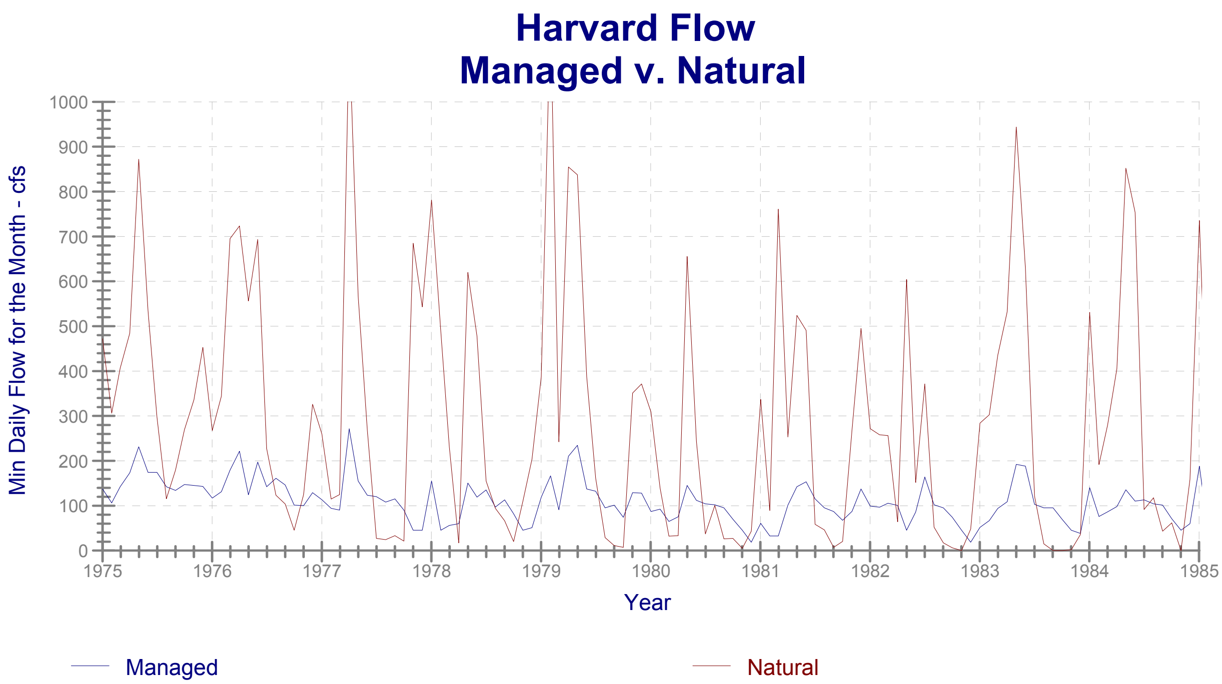


Figure 2.3 Comparison of Flows Below Pepacton Reservoir

3.0 THE RECOMMENDED PROCESS FOR FLOW MANAGEMENT ISSUE RESOLUTION

This section presents the recommended process for resolving interstate flow management issues. HydroLogics considers the adoption of a consensus-building process, using the best available information and analytical tools, to be the critical component of the recommended strategy for resolving flow management issues. For clarity, the process is presented before the specific issues and technical recommendations, which are presented in Section 4. The process and technical components of the strategy are interdependent.

Adoption of an “open” or “transparent” water resources planning process – a procedure followed by the Commission in the development of a new Basin Plan for the Delaware River Basin – is believed necessary in the resolution of flow management issues. A consensus approach is recommended not only for making final decisions but also for developing the means to reach a final decision, including the selection or development of the information and tools. It is HydroLogics’ view that if stakeholders have no say in, for example, planning field studies or developing models, it will be difficult to convince them of the merit of decisions arising from the information gained. Such open approaches are being adopted with increasing frequency in hydroelectric project licensing under the jurisdiction of the Federal Energy Regulatory Commission and in other forums dealing with the allocation of water resources.

In the Delaware River Basin, the DRBC Compact requires unanimous approval of the Decree Parties for flow management policy changes that modify the 1954 Supreme Court Amended Decree. While the Decree Parties consider the inputs of many interests, these interests do not have decision-making authority. Opportunities for outside interest group participation are provided through public meetings of the Flow Management Technical Advisory Committee and the Commission.

3.1 <u>Recommended Process for Resolving Interstate Flow Management Issues</u>

The process proposed below is presented as a means to help resolve water management issues by reaching stakeholder consensus on flow management alternatives, policies, and solutions. It is the framework into which the technical recommendations for the development of flow relationships fit. While adoption of and adherence to the proposed process does not guarantee that every issue will be resolved to the complete satisfaction of all parties, HydroLogics’ experience has shown that similar processes elicit respectful and committed participation from most stakeholders and maximize the chances for success.

That proposed process consists of the following steps:

1) Identify issues and index displays (also called performance measures) that reflect the relationship between flow and user benefits for a given issue. This must be done as an inclusive activity involving all stakeholders.

2) Identify the data and scientific methods needed to evaluate alternative management policies in terms of the displays, and obtain stakeholder consensus on using those data and methods. The analytical tools selected must be capable of evaluating all of the likely alternatives in an efficient and scientifically defensible manner.

3) Obtain the data and analytical tools needed to develop currently unquantified flow relationships as well as tools capable of evaluating the costs and benefits of alternatives.

4) Develop a representative set of alternatives to be evaluated.

5) Provide all stakeholders access to the flow relationships and analytical tools.

6) Use the tools to focus negotiations on promising alternatives.

This study has initiated several of the steps in the above recommended process. For Step 1, issues have been identified and performance measures have been suggested; for Step 2, a new daily flow and reservoir operations model, OASIS, has been developed for the analysis of alternatives and the development of additional models has been recommended; for Step 3, technical recommendations for developing flow relationships have been made and GIS data useful in presenting and evaluating alternatives have been assembled.

HydroLogics recommends that the process, once established, be maintained through the periodic review and revision of performance measures and associated analytical tools and expanded through the use of forecasting tools to support the adaptive management of water resources.

3.1.1 Review and Revise the Tools and Performance Measures on a Periodic Basis

Very few institutional processes can be static and remain relevant over the long term. The following actions are suggested to keep the process current:

1) Review the adequacy of all analytical techniques on a periodic basis.

   The DRBC should schedule regular internal (more frequent) and external (less frequent) reviews of its analytical tools, and upgrade them as stakeholder concerns and political and legal realities dictate, and as funding and time permit.

2) Review performance measures through advisory committees.

   We suggest that the DRBC periodically convene a "State of the River" conference. At the conference, stakeholders would be invited to share their concerns and suggest new issues, index displays, and analytical improvements that would be helpful in assuring that the tools and process remain up to date. Such a conference might alert DRBC to emerging issues so that the tools can be upgraded to deal with those issues.

3.1.2 Develop Monitoring and Forecasting Capabilities to Support Adaptive Management

As used in this report, adaptive management is a process through which management strategies change in response to changes in the state of the water resources system, new scientific understanding of how management actions affect the system, and changes in management objectives. Clearly, implementing an adaptive management strategy requires monitoring and forecasting of the things that might cause the management strategy to change - the state of the system, the progress of related science, and the management objectives. Unfortunately, monitoring is an often overlooked part of the process, even though without monitoring, adaptive management cannot be effective.

Forecasting tools predict the future state of the water resources system, and thus may be an important part of an adaptive management strategy. Using forecasting tools as a part of a management strategy broadens the range of alternatives, and may dramatically improve the ability to manage for important objectives. HydroLogics suggests that DRBC work with the National Weather Service to apply products from the Advanced Hydrologic Prediction System (AHPS) (e.g., the River Forecast System and its Extended Streamflow Prediction component) to flow management.

3.1.3 The Concepts of Flow Relationships, Performance Criteria, and Index Displays

The recommendations of this report are centered on the development and use of flow relationships and the identification of performance criteria so that index displays can be prepared to allow operating alternatives to be evaluated in terms that are as explicit and objective as possible.

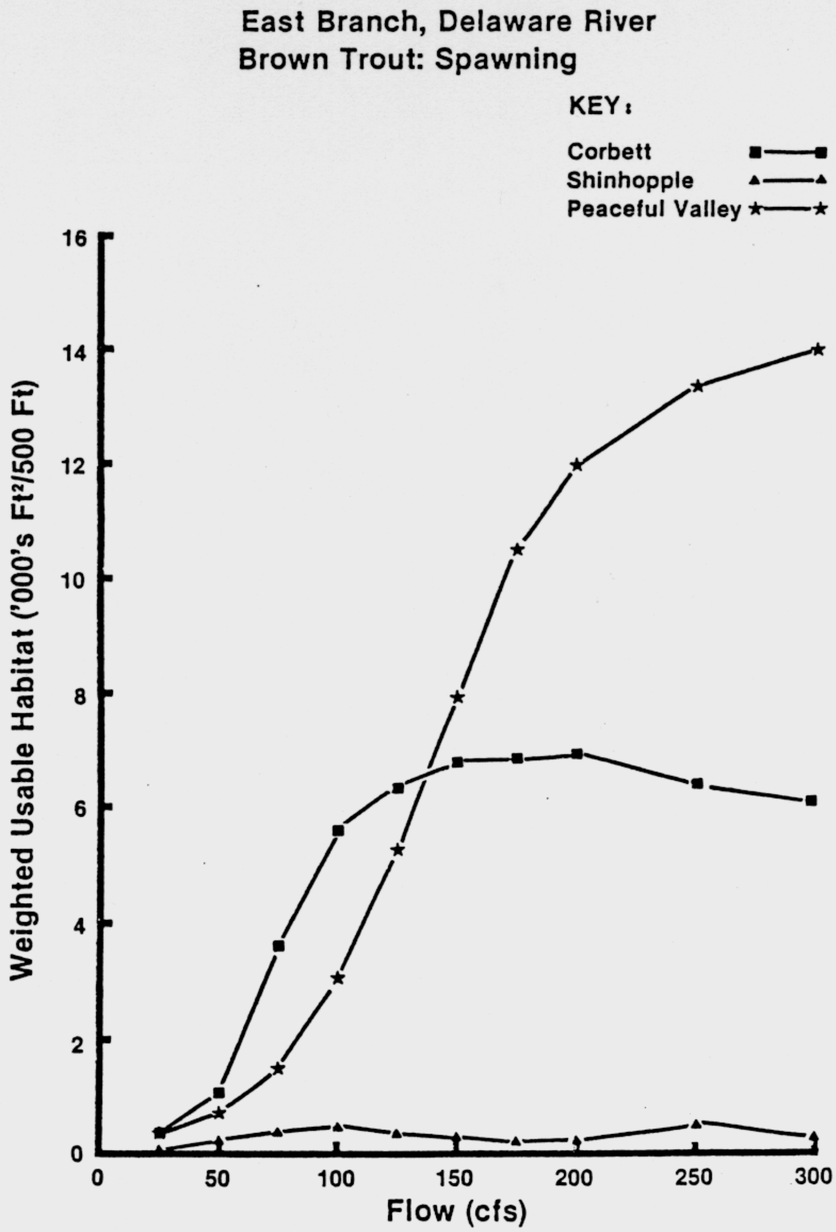
In this report, the term index display refers to a means of gaging the performance of a particular operating scenario against an explicit criterion. An example of such a display might be a flow hydrograph on to which a horizontal line that defines minimum acceptable flows for fish habitat is superimposed. In order to develop such a display, the underlying relationships between flow and fish habitat must be understood, which may require data collection, analysis, and modeling. Once the flow relationship is understood, the flow that is “acceptable” must be defined for the various interest groups participating in the negotiation process. It is likely that not all parties in a negotiation will have the same definition of this condition, so the flow relationship is important to allow tradeoffs that must be made among competing water uses. The more scientifically defensible the flow relationship and the performance criterion are, the more meaning they have as an objective, physical measure of water resources evaluation.

An example of the development of cold water fisheries flow relationships and a recommended performance criterion is provided by NYSDEC Technical Report 83-5 (Sheppard, 1983). A number of the recommended flow criteria continue to be considered (as of May 2003) in negotiations between NYSDEC and NYCDEP over modifications to the existing fisheries release program.

Figures 3.1 thru 3.4 show the set of flow versus habitat curves developed for four life stages of brown trout at several locations along the East Branch of the Delaware. The life stages include spawning, fry, juvenile, and adult. Similar sets of curves were developed for the West Branch of the Delaware and the Neversink. These curves relate to the wetted area and depth of fishery habitat and not to water temperature, which must be considered separately.

After evaluation of these flow relationships for each of the stream segments, the NYSDEC recommended a set of flow criteria for the East Branch at Harvard of 175 cfs during normal conditions, 125 cfs during *drought warning* (there was no *drought watch* stage at that time), and 100 cfs during drought. These recommendations are not to be confused with any more recent recommendations and are presented here for example purposes only.

When this type of scientifically derived information is combined with flow modeling (such as that provided by the DRBC OASIS model), reservoir operating scenarios can be evaluated in terms of index displays which might show the flow hydrograph for a given period and the success of meeting the flow criteria, or graphs or tables showing the number of days above or below the criteria. Again, the value of the flow relationship is that it defines the basis for the flow criteria and the basis for evaluating the impacts of compromises that may be made during the negotiation process.



Changes in weighted usable brown trout spawning habitat with flow at the Corbett (4.6 miles), Shinhopple (8.0 miles) and Peaceful Valley (9.0 miles) study reaches on the East Branch, Delaware River downstream of Pepacton Reservoir.

Figure 3.1 Habitat Curve for Spawning Brown Trout (NYSDEC Technical Report 83-5)

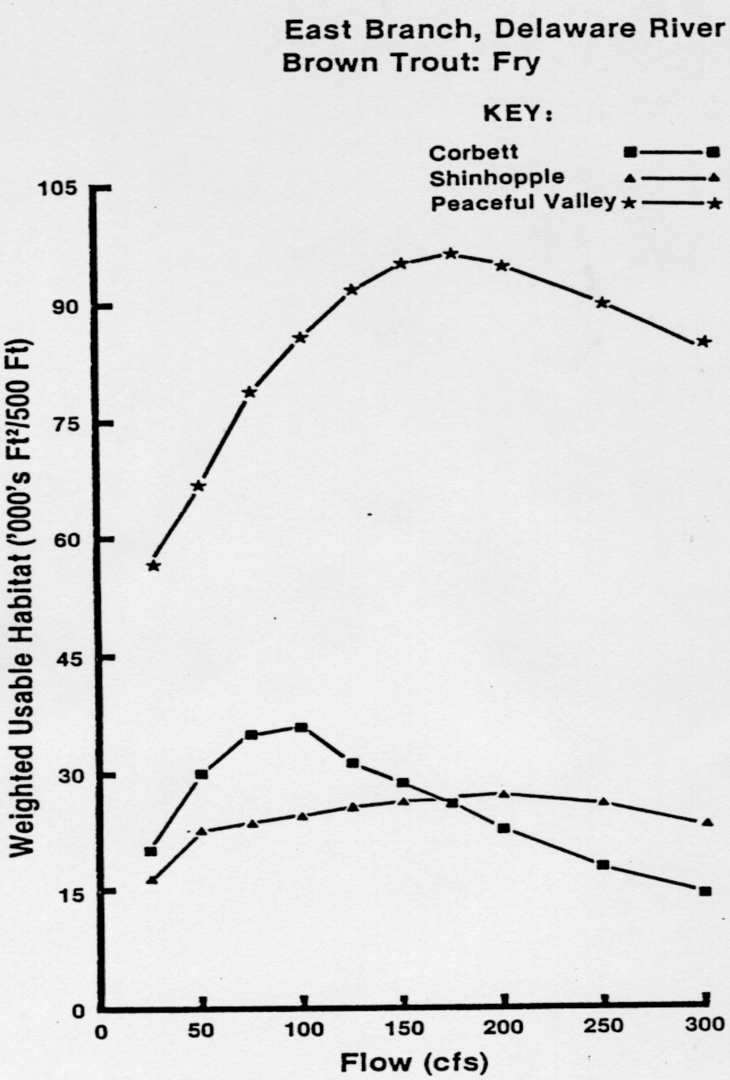


Figure 19. Changes in weighted usable brown trout fry habitat with flow at the Corbett (4.6 miles), Shinhopple (8.0 miles) and Peaceful Valley (9.0 miles) study reaches on the East Branch, Delaware River downstream of Pepacton Reservoir.

Figure 3.2: Habitat Curve for Brown Trout Fry
(Reference, NYSDEC Technical Report 83-5)

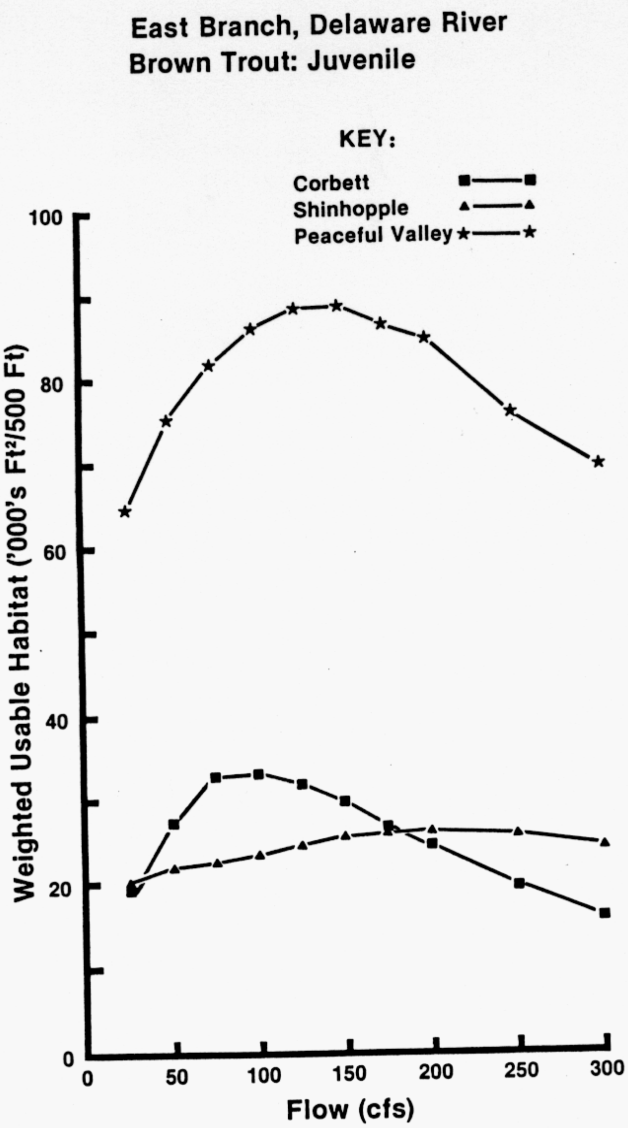


Figure 20. Changes in weighted usable juvenile brown trout habitat with flow at the Corbett (4.6 miles) Shinhopple (8.0 miles) and Peaceful Valley (9.0 miles) study reaches on the East Branch, Delaware River downstream of Pepacton Reservoir.

Figure 3.3: Habitat Curve for Juvenile Brown Trout
(Reference: NYSDEC Technical Report 83-5)

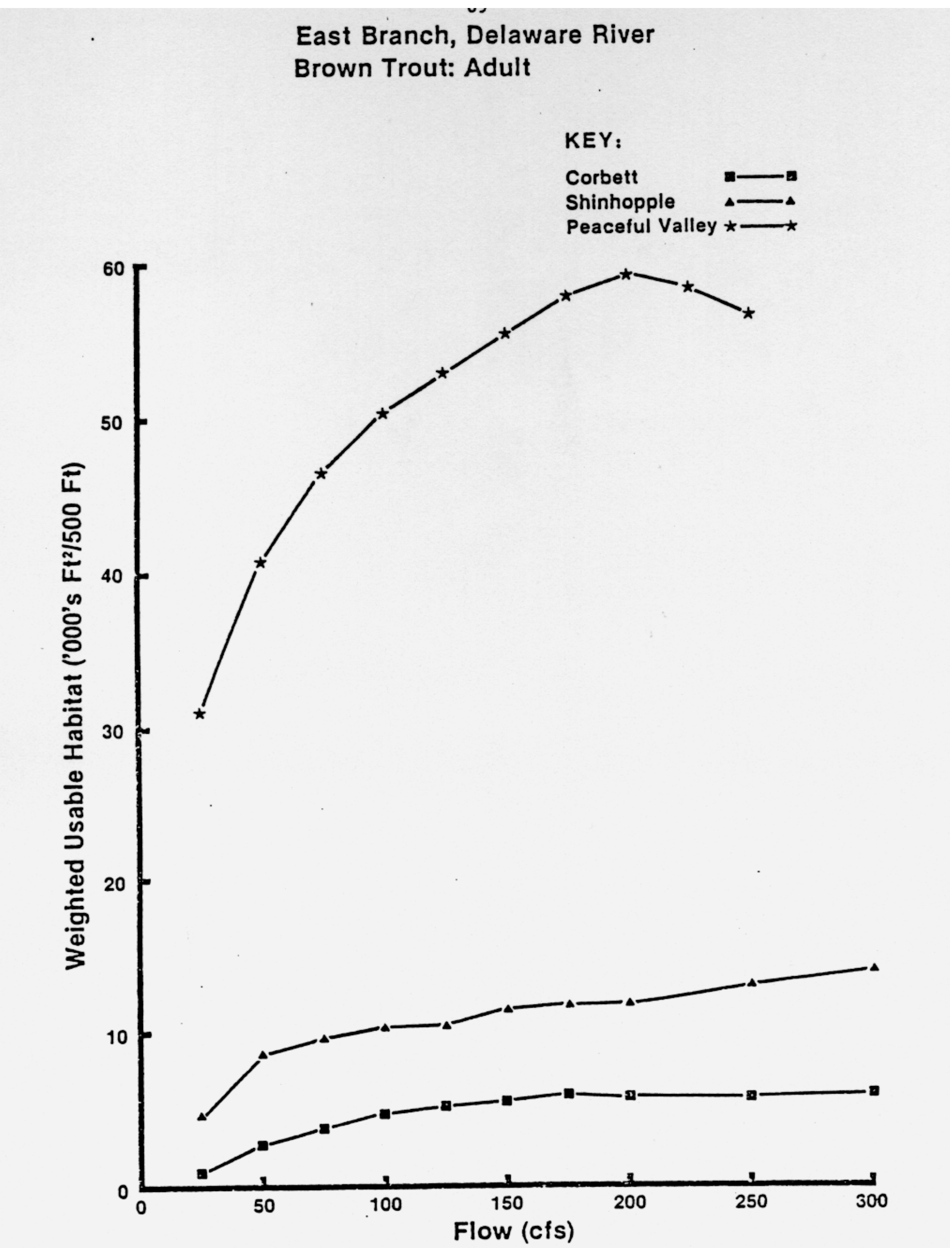


Figure 21. Changes in weighted usable adult brown trout habitat with flow at the Corbett (4.6 miles), Shinhopple (8.0 miles) and Peaceful Valley (9.0 miles) study reaches on the East Branch, Delaware River downstream of Pepacton Reservoir.

Figure 3.4: Habitat Curve for Adult Brown Trout
(Reference: NYSDEC Technical Report 83-5)

4.0 FLOW ISSUES AND TECHNICAL RECOMMENDATIONS

This section provides guidance for implementing Steps 1, 2, and 3 of the issue resolution process presented in Section 3. The section describes each of the 12 stream segments studied and lists the flow management issues identified for each. Potential index displays (performance measures) to evaluate alternative operating policies for various stream segments are described. The stream segment descriptions and segment-specific recommendations are followed by additional general technical recommendations at the end of this section. In order to thoroughly research the flow-related issues, a detailed issues paper was prepared and distributed to all interested parties and a six-month review period was provided during the winter and spring of 2001. Although an effort was made to include all issues for each stream segment, we acknowledge that some issues may have been missed during the literature review and interviews. It is also understood that issues will change as conditions change in the regulated river system.

4.1 East Branch Delaware River from Pepacton Dam to Junction with West Branch

4.1.1 Setting

The East Branch Delaware River segment (Figure 4.1) extends 33 miles from New York City's Pepacton Reservoir to Hancock, New York, where it meets the West Branch and forms the main stem of the Delaware River. Pepacton Reservoir is situated in the middle section of the East Branch watershed and controls slightly less than one-half of the watershed. The Beaver Kill, a major tributary, enters the East Branch approximately midway between the reservoir and Hancock.

The East Branch downstream from Pepacton Reservoir flows through a generally wide, "U"-shaped valley containing farms, woodland, and several small communities. Outside of the valley itself, the land is wooded and sparsely settled. Industry in the basin includes agriculture, forest products, and the quarrying of building stone. Somewhat more than 90 percent of the land adjacent to the stream is privately owned. The area is dotted with motels, campgrounds, bed and breakfasts, restaurants, guide services, fishing tackle stores, gas stations and canoe and boating livery services. The stream is fairly accessible due in part to New York Routes 30 and 17, which parallel the course of the stream between Downsville and Hancock.

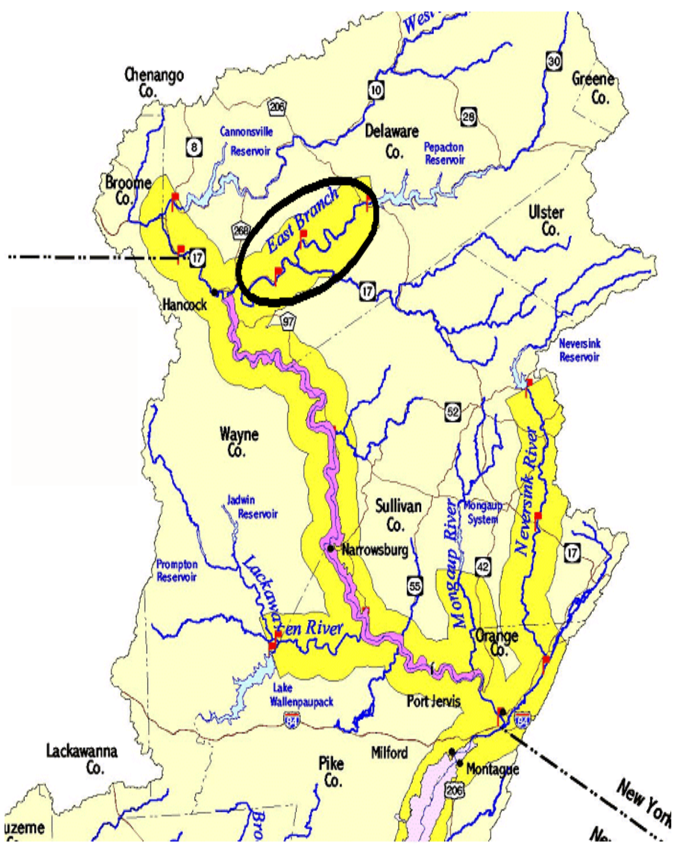


Figure 4.1
East Branch, Delaware River

The construction of Pepacton Reservoir fundamentally changed the hydrology of the East Branch. As a result of New York City's diversions for water supply, total annual flow immediately downstream from the reservoir is approximately 30 percent of the pre-reservoir flow. (This figure results from comparing the average annual flow at the USGS gaging station at Downsville, New York, before [1942-1953] and after [1955-2001] Pepacton Reservoir started operations). Median monthly flows for all months are also lower than their pre-reservoir rates. The magnitude and frequency of high flows, including flood events, have been reduced, and stream temperatures during late spring, summer, and early fall are typically cooler than those recorded prior to the reservoir's construction.

Some reaches of the East Branch downstream of the Pepacton Dam at Downsville supported seasonal cold water fisheries prior to construction of the dam. The cold water fishery has been extended and enhanced by releases from the reservoir. The East Branch has a wild trout population that is augmented by put, grow, and take stocking. Prior to reservoir construction, the lower 21 miles of the East Branch were managed as smallmouth bass and walleye waters. Currently the NYSDEC classifies the entire East Branch as Class C(TS), which designates the river as suitable for fish propagation and survival, particularly trout spawning (TS). All streams designated as C(T), C(TS), B, or A are subject to the stream protection provisions of the NYSDEC Protection of Waters regulatory program. (The denominations C, B, or A correspond to the water's best use - fishing, primary contact recreation, or drinking water supply, respectively). Upstream from the confluence with the Beaver Kill, streamflow conditions are closely related to the quantity and character of the release water. During hot weather, the water temperature in the Beaver Kill, which is unregulated and has no large reservoirs making cold water releases, is affected by solar radiation and air temperature, making it substantially warmer than the water released to the East Branch of the Delaware from Pepacton Reservoir. Below the confluence with the Beaver Kill, water temperatures in the East Branch are influenced by the relative magnitude and temperature of the water added by the Beaver Kill.

American shad continued to use the East Branch all the way to Downsville following the construction of Pepacton Reservoir. According to the NYSDEC, Cemetary Pool on the East Branch continues to be a popular fishing spot.

Both the East and West Branches of the Delaware River are in Delaware County, New York. In 1992, 1,182 business establishments in Delaware County produced nearly $2 billion in annual revenues (1992 U.S. Census of Businesses) and supported nearly 12,400 employees. Nearly half of the economy (47%) is supported by manufacturing, which employs over 4,100 people. Fishing-related businesses are included in the Services and Retail Trade sectors. Services and Retail Trade represent 18 percent and 14 percent, respectively, of the county economy and account for over 6,000 employees. In their 1998 report on the importance of the trout fishing business in Delaware County, (Economic Impact of Trout Fishing on the Delaware River Tailwaters in New York, 1998), the American Sportfishing Association and Trout Unlimited reported that trout fishing generates a total of $29.9 million a year (about 1.5 percent of Delaware County's total annual revenues), and 348 local resident jobs.

Water quality in the Upper Delaware is very good and is improving further as a result of New York City's program to control point and non-point source pollution. The City's program was initiated to protect and improve the water quality of the three City reservoirs as a means of avoiding the expense of water filtration. Its intensive efforts with regard to land acquisition, wastewater treatment plant upgrades, and non-point source controls in the headwaters benefit both the reservoirs and other users of the East and West Branches and the Neversink River.

4.1.2 Issues and Analysis

Flow management issues on the East Branch stem from the use of Pepacton Reservoir for out-of-Basin water supply and releases from that reservoir for in-channel habitat protection. Releases are also made in support of the Montague flow target, although less frequently than from Cannonsville Reservoir. The following flow management issues were identified:

- Section 4.1.2.1 Trout Fishing Conditions/Trout Habitat
- Section 4.1.2.2 American Shad Habitat

The NYSDEC has recommended that additional diadromous fisheries such as river herring, channel maintenance, and assessment of annual spillage be considered as flow management issues for the East Branch. Channel maintenance was also cited by NYSDEC as a general concern applicable to all study reaches.

The desired flows for these various purposes are not necessarily the same, and the desired flows for the same purpose may be different among different interest groups. Nevertheless, the groups are able, albeit with poor precision, to identify the flows that satisfy their particular objectives. The identified flow objectives serve as the basis for potential index displays, which are described in the following sections.

4.1.2.1 Trout Fishing Conditions/Trout Habitat

Much work has been done by the NYSDEC to establish minimum releases for habitat needs in the Upper Delaware River and tributaries. This work has been documented in several NYSDEC reports listed with the references. These include NYSDEC reports 80-1, 83-5, and the 1992 Fishery Management Plan for the Upper Delaware Tailwaters. The work has been the technical basis for NYSDEC in its negotiations with the City of New York concerning minimum reservoir releases. This work, the resulting negotiations between the City and NYSDEC and the Decree Parties, and the information provided by anglers that relate the quality of the fishery to flow and flow patterns have resulted in substantial improvements in the cold water fishery since reservoir construction. Support for further examination of the ecology of the Upper Delaware has recently been provided through the efforts of The Nature Conservancy and Trout Unlimited. The results of the NYSDEC research are continuing to be used by NYSDEC to support additional increases in releases over those now in place. These additional releases, in the form of flow targets in each of the three tailwaters, were under negotiation as of mid-2003.

The following are potential index displays and supporting technical recommendations for addressing this issue:

a) Spawning habitat - acres, by year.

Successful trout spawning depends on having the right combination of substrate (gravel), depth of flow, and instream velocity for the entire spawning season. The Instream Flow Incremental Methodology (IFIM) can be used to assess the area of suitable habitat as a function of flow, but in the case of the East Branch, temperature is critical as well. Producing an estimate of the acres of suitable habitat thus requires both temperature and IFIM models as well as a time series of flows. Although IFIM modeling has been completed for the East Branch by the NYSDEC, development of an improved temperature model is recommended. Daily flow models, such as the DRBC OASIS model developed as part of this study, can be used to produce a time series of flows for comparing management alternatives.

b) Water temperature at Harvard, number of days temperature exceeds criteria, by year.

DRBC Docket D-77-20 CP (and revisions) permit the use of thermal stress releases whenever the maximum water temperature at Harvard, Hale Eddy, Woodbourne, or Callicoon is projected to exceed a maximum of 75° F or a 72° F daily average (Sheppard). The number of such "thermal stress days" and the number of violations of thermal criteria serve as good indicators for evaluating operating scenarios. Existing temperature models are quite crude and need to be upgraded to improve the precision of the displays. In particular, existing models predict only maximum temperature. It may be helpful to add a weighting factor for successive days of violations, but determining the additional effect of longer term warm water episodes will require further scientific investigation.

c) Water temperature at Harvard, daily average and daily maximum.

This display should be useful to fisheries biologists for generating overall assessments of temperature-related conditions. Again, note that the existing temperature models estimate only the maximum temperature. The precision of these estimates could also be substantially improved by employing a better temperature model.

d) Daily Flow at Harvard, number of days below threshold, by year.

The NYSDEC tailwater fishery study (Fishery Management Plan for the Upper Delaware Tailwaters, 1992) recommended, for example, a threshold daily average flow for trout habitat at Harvard of 175 cfs. IFIM studies performed for the reach showed that below this value the habitat for mature trout quickly diminishes as flows diminish. Thus, it may be useful to plot the number of days per year that flows fall below 175 cfs, or other flow rates that are determined to be critical for fishery protection. Using single number flow thresholds, however, can be problematic, since it fails to incorporate the effects that time of year, temperature, and other factors have on the species. More comprehensive displays would consider flow requirements that vary over both the course of the year and also as water temperature changes. The NYSDEC (Sheppard) has indicated that there should be sufficient physical habitat simulation (PHABSIM) stations on the East Branch between Downsville and Harvard to assess seasonal ecosystem base flow requirements for use with daily flow modeling.

e) Area of trout habitat damaged by ice, by year.

During cold weather, ice can form on the bottom of river beds, thereby altering fish and insect habitat. At present, however, it is impossible to evaluate this problem because of insufficient scientific knowledge concerning ice formation and the lack of detailed mapping of vulnerable habitat. Until the requisite scientific work has been done, it will be impossible to evaluate these impacts except through the use of anecdotal evidence.

4.1.2.2 American Shad Habitat

Based on HydroLogics' conversations with fisheries research personnel and fishermen, there did not appear to be a well-defined relationship between low flows and upstream shad migration. Shad migrate upstream in the spring, probably in response to solar angle and water temperature, which is normally not influenced by cold water reservoir releases at that time of year.

A NYSDEC fisheries expert (Elliot, personal communication) confirmed that shad are spawning in the East Branch, for the most part in the segment downstream from the Beaver Kill, where cold water releases from Pepacton have less influence. Some years' runs are better than others, but this is true throughout the Delaware. It was suggested that there may be some threshold of flow at the mouth of the East Branch below which shad may choose not to swim upstream. Thus, in those spring seasons with floods below this threshold (whatever that threshold is), there could be a benefit of timing a release pattern that would put streamflow in the desirable range, so long as the water does not become too cold. According to a second NYSDEC source, a Delaware River Fisheries Cooperative study in the late 1970s determined that the experimental releases program on the East Branch was not having a detrimental effect on American shad.

Young shad migrate downstream when flows are generally lower than during the upstream migration of the adults. Low flows are not considered an impediment to their migration, but survival rates may be lower during low flow periods. The young migrating shad swim downstream at night and rest (and hide) during the day in very shallow water out of the reach of predators (such as bass). Since river levels that expose large portions of the riverbed reduce the potential hiding areas for the young fish, lower flows may increase the mortality of the young of the year, which in turn reduces the number of spawning fish two or three years later.

IFIM study results could provide information on the habitat available at various flows for downstream migration as well as upstream migration and spawning. Daily flow model output for a given operations alternative could then be used to determine the number of days when habitat conditions were acceptable. Existing IFIM data should be evaluated to determine if it provides adequate information to assess migration habitat for shad.

4.1.3 Additional Information and Study Needs - East Branch Delaware River

These steps are suggested, in priority order, for acquiring the information necessary to establish additional flow relationships and support the index displays listed for the East Branch Delaware River. Several of the information needs for the East Branch are common to the West Branch and the Neversink River as well. They are listed separately for clarity but could be combined into a single research effort.

1) Assemble data with which to correlate shad and herring reproduction/migration with releases from Pepacton Reservoir, seasonal precipitation, and temperature.

2) Improve flow forecasting and thermal modeling for the East Branch, in combination with the NYCDEP thermal model of Pepacton Reservoir. The instream temperature model should address the impacts of releases from all three reservoirs as well as local runoff.

   Together, these models would allow better quantification of the cold water available and more effective utilization of releases targeted at maintaining instream temperatures. The Delaware River Master has made a similar recommendation.

3) Assemble data with which to correlate Pepacton Reservoir releases and air temperature with river ice formation downstream of the reservoir. Assemble data for the correlation of heavy ice formation with fish survival. The U.S. Army Corps of Engineers' Cold Regions Research Laboratories may provide valuable information in this effort. Analytical approaches to address ice issues include research concerning historical, pre-reservoir ice conditions and the development of analytical models of ice formation and ablation in the stream as a function of flow, source of flow, and air temperature.

4) Incorporate existing research results and consult with the NYSDEC Bureau of Fisheries and others to verify the adequacy of existing IFIM information for establishing ecological flow requirements and channel maintenance. Also assemble data relating observed fishing conditions to flow, and determine the usefulness of existing IFIM data for analysis of flow versus shad and herring migration.

5) Conduct an assessment of annual spills from Pepacton Reservoir and their impacts on downstream ecology.

4.2 West Branch Delaware River from Cannonsville Dam to Junction with East Branch

4.2.1 Setting

The West Branch Delaware River project segment (Figure 4.2) extends 18 miles from New York City's Cannonsville Reservoir to Hancock, New York, where it meets the East Branch of the Delaware and forms the main stem Delaware River. Steep, forested hills and the "U"-shaped valley dominate the landscape. Concentrated residential development is largely limited to a few small villages, the largest of which is Hancock; the remaining land is sparsely settled. Close to 99 percent of the land along the stream is privately owned, making public access to the stream extremely limited. Commercial activities in the area outside of Hancock are largely related to outdoor recreation.

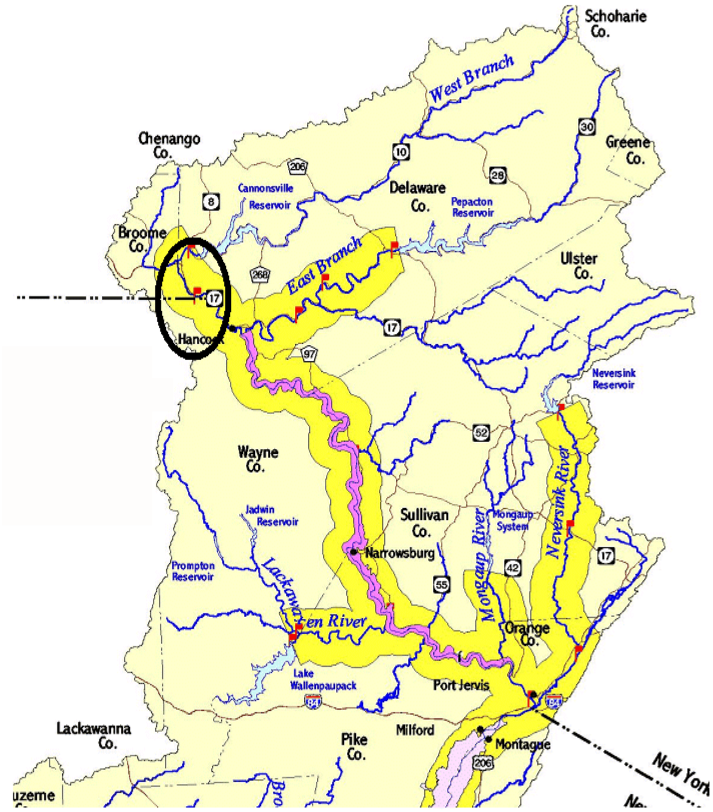


Figure 4.2
West Branch, Delaware River

The construction and operation of the Cannonsville Reservoir changed the hydrology of the West Branch in three ways. First, due to water supply diversions, the observed total annual flow downstream from the reservoir is now approximately 80 percent of that under pre-reservoir conditions. (This figure results from comparing the average annual flow at the USGS gaging station at Stilesville, New York before [1953-1962] and after [1964-2001] Cannonsville Reservoir started operations.) Second, the natural flow regime has been altered. In most years, average summer flows are higher than before while fall, winter, and spring flows are lower than prior to the dam's construction. Both the magnitude and frequency of high flow events, including floods, have been reduced. Due to the small drainage area contributing to the West Branch downstream of the reservoir, Cannonsville releases during dry conditions often represent nearly all the water in the stream down to the confluence with the East Branch. Third, due to reservoir releases, stream temperatures during summer and early fall are almost always substantially cooler than those recorded prior to the reservoir's construction.

Cannonsville Reservoir makes the bulk of the releases required to meet the Montague flow target during dry weather conditions. Since the late 1960s, these cold water releases have improved what was originally a very limited trout fishery in the West Branch. The entire reach of the West Branch downstream of Cannonsville Reservoir now supports wild trout. The quality of the wild trout fishing makes the West Branch a popular destination for wading and guided float fishing for trout. The West Branch is within a three-hour drive of nearly 30 million people. Trout fishermen from the Middle Atlantic states and beyond come to the West Branch to fish. The recreational industry they support includes fishing resorts, campgrounds, guides, and tackle shops. Local construction, retailers, and other businesses are directly and indirectly supported by the recreational industry.

Between Cannonsville Reservoir and the New York-Pennsylvania border, NYSDEC classifies the West Branch as Class B (TS); they classify the stream as A (TS) from that point to the confluence with the East Branch.

The NYSDEC's 'A' and 'B' designations specify that the waters are suitable for both contact recreation and fish propagation and survival. 'A' waters are also suitable for potable water supply. The 'TS' designation applies this classification specifically to trout (TS stands for trout spawning). Pennsylvania Department of Environmental Protection (PADEP) classifies this same section of the West Branch as CWF, MF. PADEP's 'CWF' indicates that the stream is suitable for maintenance and/or propagation of trout as well as additional flora and fauna indigenous to a cold water habitat. 'MF' designates the segment as suitable for passage, maintenance, and propagation of anadromous and catadromous fishes as well as other fishes which ascend to flowing waters to complete their life cycle. Such fishes include the Atlantic shad and the American eel. All the above stream designations allow these stream segments to be protected under existing state regulations.

4.2.2 Issues and Analysis

Flow management issues on the West Branch stem from the use of the Cannonsville Reservoir for out-of-Basin water supply and in-channel uses (within both the West Branch and the main stem Delaware).

The following flow management issues were identified:

- Section 4.2.2.1 Recreational Trout Fishing
- Section 4.2.2.2 Trout Habitat Conditions
- Section 4.2.2.3 Irregular and Uncertain Releases Stress West Branch and Upper Delaware Fishery
- Section 4.2.2.4 Temperature Stress Release Bank
- Section 4.2.2.5 Water Quality

The NYSDEC also cited channel maintenance as a flow management issue on the West Branch.

Potential index displays for these issues are described in the following sections.

4.2.2.1 Recreational Trout Fishing

Because downstream releases from Cannonsville Reservoir are generally larger than those from Pepacton or Neversink, the West Branch supports the most significant recreational fishery in the Upper Basin. It is therefore appropriate to include some measure of the quality and quantity of the resource available. One such potential measure is discussed below.

a) Recreational fishing index

Excellent recreational fishing days occur when a) the streamflow is right for either wading or drifting, and b) the water temperature change over the course of the day induces mayfly and other larvae to hatch. It may be possible to determine which days in a simulation fit all the criteria for excellent fishing for a number of sites along the West Branch. These days could be weighted by day of week with the weight based on the ratio of anglers on different days of the week, or using other factors such as time of year and weather conditions. The details of this display would need to be developed in collaboration with the fishing community.

4.2.2.2 Trout Habitat Conditions

The measures indexing trout habitat conditions would be identical to those identified for the East Branch, except that the displays would be focused on conditions at Hale Eddy instead of Harvard. The scientific and data concerns regarding the indices are also very similar. Although IFIM modeling has been completed for the West Branch by the NYSDEC, development of an improved temperature model is recommended. Daily flow models, such as the DRBC OASIS model, can be used to produce time series of flows for comparing management alternatives. The issue of ice damage to trout habitat also applies to the West Branch.

4.2.2.3 Irregular and Uncertain Releases

One of the impediments to recreation and to ecological balance in the Upper Delaware Basin, particularly in the West Branch, is the unnatural variation in flow caused by releases to meet the Montague target. This variation is further exacerbated by the adjustments made to compensate for releases made from Lake Wallenpaupack and the Mongaup system to generate on-peak energy. To the extent that this variation can be controlled and/or forecasted, it would become possible to advertise times when conditions are expected to be good and thus increase the benefits gained in terms of environmental improvements, visitor days, and the quality of the recreational experience. Much of the current forecast error is due to last minute changes in power generation schedules and changes in weather conditions. Using one- to five-day forecasts of energy prices, temperature, rainfall, flow, and temperature conditions may make it possible to improve the predictions. Ramping of releases for the Montague flow target could also be considered. A potential index display for improved forecasting capability is suggested below.

a) Number of excellent fishing days forecast with at least 3-day lead time, by year

Producing this display would require prior development of the recreational fishing index discussed in 4.2.2.1 in order to establish which days should be classified as "excellent." This classification would be combined with a forecast methodology for predicting three days in advance when such days would occur. The number of correctly forecast excellent days could then be counted and displayed on an annual basis. Weekend days might be given additional weight in the displays.

4.2.2.4 Temperature Stress Release Bank

As with the extreme drawdown of water supply reservoirs, the extreme drawdown of the water available for environmental quality control puts vital resources at risk. The frequency with which supplies reach a critical state provides one measure of system performance. Such an index display would characterize the frequency of critical drawdown of the Thermal Stress Bank, as described below.

a) Frequency of Critical Drawdown of the Thermal Stress Bank

The number of times that the thermal bank empties or reaches a critical level can be tracked using daily flow and thermal release modeling. The time at which the bank empties is also important since depletion by mid-summer would produce a longer period of temperature stress for the fishery. The daily flow and temperature modeling capabilities of the DRBC OASIS model can be used for producing this index display, but improved temperature modeling is recommended for more accurately representing the West Branch temperature profile.

4.2.2.5 Water Quality

Water quality in the West Branch is generally good, with the exception of occasional turbidity problems. The cause of the turbidity is not clear. Some NYSDEC biologists (Elliot, 2003) believe that most of the turbidity comes from dead phyto- and zoo-plankton in the Cannonsville releases. It typically develops "...in the late summer or fall in years when high releases have exhausted the hypolimnion." Turbidity indicates the presence of suspended solids, which may fill the interstitial spaces in the gravel in spawning beds, thereby reducing oxygen levels and the likelihood of successful trout spawning. However, inorganic particles remaining in suspension after passage through a reservoir are likely to be very fine and therefore unlikely to settle in a dynamic river environment. It would be advisable to conduct a preliminary assessment of the extent of the problem by measuring turbidity on a daily basis at a few stations in the West Branch. This data could be used in conjunction with reservoir release and precipitation data to determine the correlation between releases and instream turbidity. Watershed and instream water quality models and a reservoir water quality model may be necessary to accurately predict turbidity as a function of releases. The daily time step now used for daily flow modeling may be too long for turbidity modeling. A potential index display would be hourly turbidity measured at Hale Eddy.

The Philadelphia Water Department has traced a cucumber-like odor to algae in Cannonsville Reservoir and has reported that other water systems are also affected. This may not be a flow management issue in the traditional sense because at least part of the problem is associated with uncontrolled winter spills from the reservoir. Rather, to the extent that amelioration is possible, it has more to do with the elevations from which water is released and operations that might reduce the frequency of winter spills.

4.2.3 Additional Information and Study Needs - West Branch Delaware River

The following steps are suggested, in priority order, for acquiring the information necessary to establish additional flow relationships and support the index displays listed for the West Branch Delaware River. Several of the information needs for the West Branch are common to the East Branch and the Neversink River as well. They are listed separately for clarity but could be combined into a single research effort.

1) Assemble a data set of all known occurrences of downstream taste and odor problems and correlate it with data on Cannonsville releases, and flow above the water supply intakes. In addition, identify the species of algae causing the taste and odor problems and determine whether that species exists in Cannonsville Reservoir. Finally, determine the additional treatment costs associated with control of taste and odor from algae and the extent to which reservoir releases affect those costs.

2) Monitor turbidity on the West Branch and determine the correlation with reservoir releases. A reservoir water quality model that predicts turbidity levels in the reservoir as a function of inflow, outflow, and storage, and a watershed model that predicts the impacts of best management practices and land use changes on reservoir water quality could be required to address this issue.

3) Improve flow forecasting and thermal modeling for the West Branch of the Delaware River.

4) Assemble data with which to correlate Cannonsville Reservoir releases and air temperature with river ice formation downstream of the reservoir. Assemble data for the correlation of heavy ice formation with fish survival.

5) Incorporate existing research results and consult with the NYSDEC Bureau of Fisheries and others to verify the adequacy of existing IFIM information for establishing ecological flow requirements and channel maintenance. Also assemble data which relates observed fishing conditions to flow.

6) Consult with NYSDEC concerning the issue of channel maintenance and additional required work to define flow requirements for channel maintenance vs. those now defined for fisheries management.

7) Conduct an assessment of spills from Cannonsville Reservoir and their impacts on downstream ecology.

4.3 Neversink River from Neversink Dam To Mouth

4.3.1 Setting

The Neversink River segment (Figure 4.3) extends 42 miles from New York City's Neversink Reservoir to Port Jervis, New York, where it enters the Delaware River seven miles upstream of the Montague gaging station. The Neversink Reservoir is in the headwaters of the watershed. More than 70 percent of the Neversink Rivers contributing drainage basin lies downstream of the reservoir.

From the dam downstream to Bridgeville, the stream flows through a gently sloping valley occupied by farms, the town of Monticello, and several small villages. Much of the land is wooded and is home to a large resort industry that includes hotels, summer camps, and vacation cottages. Other industries include sand and gravel mining and forestry. Downstream from Bridgeville, the creek cascades through a steep-sided, heavily forested, seven-mile long gorge that lies primarily within state-owned parkland until it reaches the more moderately sloped Oakland Valley. From there, the stream valley continues to broaden and decrease in slope until, downstream of Godeffroy, the stream flows through a broad, largely rural, "U"-shaped valley with wooded hillsides. Port Jervis, the largest community in the Upper Basin, occupies the last few miles of the river's course and includes a mix of residential, commercial, and industrial land uses.

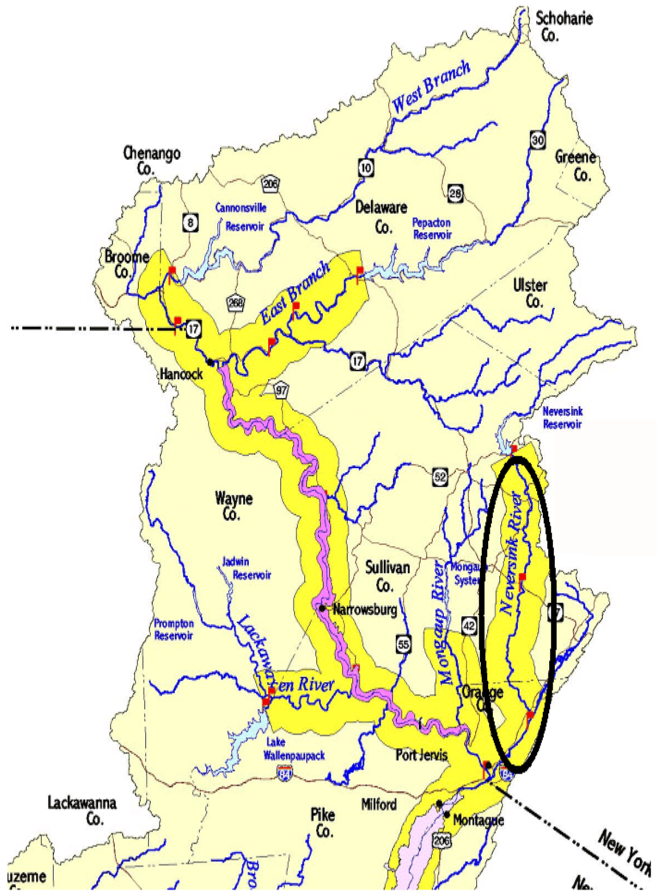


Figure 4.10
Neversink River

The construction and operation of the Neversink Reservoir fundamentally changed the hydrology of the Neversink River downstream of the dam. Total annual streamflow immediately downstream of the reservoir is approximately 20 percent of the pre-reservoir flow, as a result of diversion for water supply. (This figure results from comparing the average annual flow at the USGS gaging station at Neversink, New York, before [1942-1952] and after [1954-2001] Neversink Reservoir started operations.) Median monthly flows for all months are lower than their pre-reservoir rates. The magnitude and frequency of high flows, including flood events, have been reduced. Stream temperatures during late spring, summer, and early fall are cooler than prior to the reservoir, although the change is diminished further downstream as uncontrolled tributaries enter the river.

Year-round cold water releases from Neversink Reservoir help maintain a cold water trout fishery throughout much of the Neversink's course, though the reach of the Neversink extending to 25 miles below the dam was suitable for trout propagation and survival prior to construction of the reservoir. NYSDEC classifies the Neversink from the dam to Godeffroy as Class B(TS) and from Godeffroy to the mouth as Class B. The B(TS) classification specifies that the stream is suitable for trout propagation and survival, in addition to primary contact recreation (B). The 'TS' applies to trout; its absence indicates the stream is suitable for warm water fishes, such as smallmouth bass. The whole Neversink River segment - from the dam to the mouth - is protected under the NYSDEC Protection of Waters regulatory program because of its designation as Class B waters.

4.3.2 Issues and Analysis

The following flow management issue was identified based on HydroLogics' research of the Neversink River:

- Section 4.3.2.1 Recreational Trout Fishing

The NYSDEC also cited channel maintenance as a flow management issue on the Neversink.

The primary issue identified for the Neversink River is the quality of recreational trout fishing. There has also been interest by The Nature Conservancy in altering the pattern of releases from Neversink Reservoir to promote increased survival of freshwater mussels. There are several rare or threatened species of freshwater mussels in the Neversink River including the dwarf wedgemussel. Habitat for these species may become an issue in the future. Ice damage to fish habitat has also been cited as an issue for the Neversink River tailwaters.

4.3.2.1 Measures Associated with Recreational Trout Fishing

Index displays similar to those recommended for the East and West Branches of the Delaware, including acres of spawning habitat and number of days meeting habitat flow or temperature targets, could also be used to evaluate operating alternatives for the Neversink River.

4.3.3 Additional Information and Study Needs - Neversink River

The following steps are suggested, in priority order, for acquiring the information necessary to establish additional flow relationships and support index displays for the Neversink River. Some of these items could be combined with those for the East and West Branches into a single research effort.

The following steps are suggested, in priority order, for establishing additional flow relationships:

1) Improve flow forecasting and thermal modeling for the Neversink River. This same recommendation was made for the East Branch. See Section 4.1.3 for a more complete discussion.

2) Assemble data for correlating Neversink Reservoir releases and air temperature with river ice formation downstream of the reservoir. Assemble data for the correlation of heavy ice formation with fish survival.

3) Coordinate with The Nature Conservancy to assemble data for correlating mussel survival/reproduction with flow patterns downstream of Neversink Reservoir. Other factors affecting survival such as temperature and water quality should also be investigated.

4) Incorporate existing research results and consult with the NYSDEC Bureau of Fisheries and others to verify the adequacy of existing IFIM information for establishing ecological flow requirements and channel maintenance. Also assemble data which relates observed fishing conditions to flow.

5) Consult with NYSDEC concerning the issue of channel maintenance and additional required work to define flow requirements for channel maintenance versus those now defined for fisheries management.

6) Conduct an assessment of spills from Neversink Reservoir and their impacts on downstream ecology.

4.4 Main Stem Delaware River from Hancock to Trenton

4.4.1 Setting

The non-tidal main stem of the Delaware River extends 200 miles, from Hancock, New York, to Trenton, New Jersey. The Delaware is one of the last major U.S. rivers without a dam on the main stem. From Hancock to Port Jervis, New York, the river serves as the border between New York and Pennsylvania; from Port Jervis to Trenton it is the border between Pennsylvania and New Jersey.

The main stem can be divided into three parts: (1) the Upper Delaware -- the 73.4-mile reach between Hancock, New York and Sparrow Bush, New York, designated a National Scenic River; (2) the Middle Delaware -- the 38-mile segment from Milford, Pennsylvania to Stroudsburg, Pennsylvania that comprises the Delaware Water Gap National Recreational Area & Scenic and Recreational River; and (3) the Lower Non-tidal Main Stem -- the segment covering the approximately 80 river miles from the Delaware Water Gap to Trenton, New Jersey, which is also protected as a scenic and recreational river from the Delaware Water Gap to Washington Crossing (upstream of Trenton).

UPPER DELAWARE

The 73.4-mile segment of the river extending from the confluence of the East and West Branches near Hancock downstream to the railroad bridge below Cherry Island near Sparrow Bush, New York (Figure 4.4) was designated a component of the National Scenic Rivers System by the National Parks and Recreation Act of 1978. Approximately two-thirds of this segment is classified as recreational while the remaining third is classified as scenic under the national system.

A River Management Plan was prepared and adopted in 1986 to provide for the conservation and enhancement of the major valley resources within the 56,095-acre area. These resources include the sport fishery, water quality, and scenic, cultural, economic, and recreational qualities. The Upper Delaware Council, composed of local, state, and federal representatives, was established to implement the Plan. The Plan recommended that the National Park Service (NPS) acquire only 130 acres for the support of visitor management responsibilities. The rest of the land was to remain in private ownership.

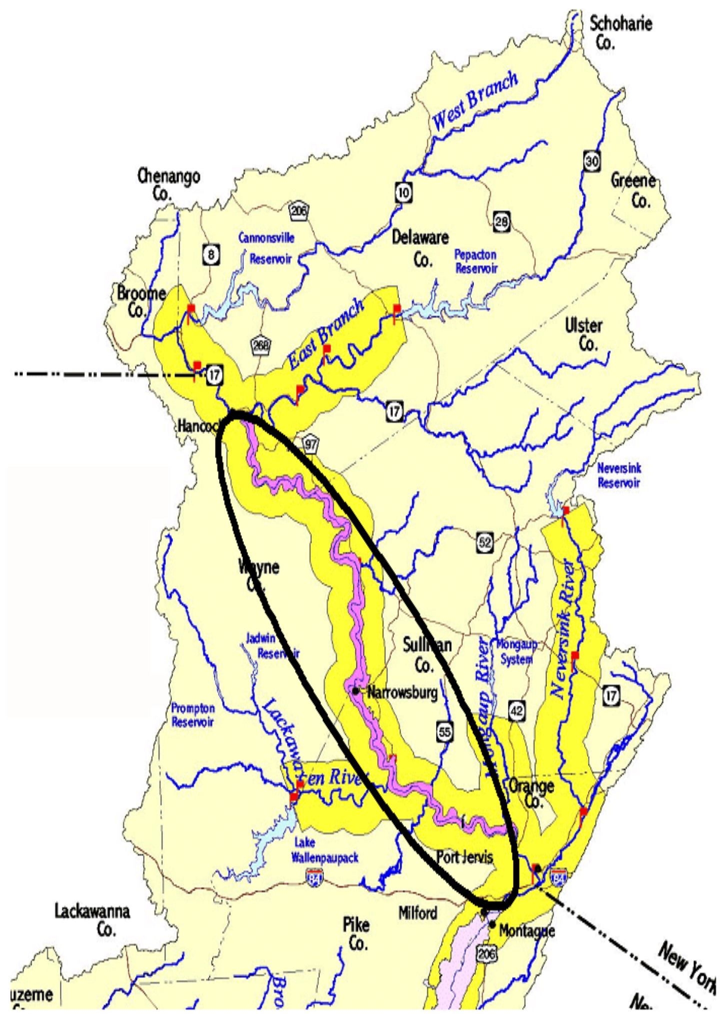


Figure 4.4
Upper Delaware River

This segment exhibits a variety of geomorphological forms. The headwaters portion ends at Narrowsburg, New York, where the river narrows and deepens, forming a pool over 113 feet deep. In the 36 miles between

Narrowsburg and Port Jervis, the average gradient is eight feet per mile. This segment contains over 30 Class I rapids, defined as having moving water with a few riffles and small waves. In addition, the stretch contains six Class II rapids--Ten Mile Falls, Westcolang Rapid, Narrow Falls Rift, Big Cedar Rapid, Shohola Falls, and Mongaup Rift. These rapids are fast flowing, but have waves of less than three feet, and the passages are wide and clear. The Delaware River does not have any Classes III to VI rapids.

Recreational opportunities are abundant in the Upper Delaware. The mountainous, rural setting, the clear, clean water, and numerous small rapids provide an outstanding canoeing environment. Most of this river segment is between 300 and 500 feet wide, with pools or eddies located in between long stretches of riffle. In some 2-mile stretches the gradient ranges from 13 to 30 feet per mile, creating whitewater during periods of medium to high water levels. The most heavily boated sections extend from Narrowsburg, New York to Cherry Island, New York (five miles upstream of Port Jervis).

The proximity of the Upper Delaware to the New York City and Philadelphia metropolitan areas has contributed to the establishment of a significant recreational boating industry. For the purposes of this section, the term 'boating' includes canoeing, kayaking, and rafting.

The northern 25-mile segment of the river between Hancock and Callicoon supports an excellent cold water fishery due to the large volumes of cold water releases from the Cannonsville Reservoir on the West Branch. This stretch supports abundant self-sustaining populations of rainbow and brown trout and is considered by many anglers to be one of the finest trout fishing destinations in the Northeast (Schultz, 1998). Almost all of the tributaries provide important trout spawning and nursery areas. Below Callicoon, the river is well known for its warm water sport fishing opportunities. Anglers (both in boats and along the shoreline) fish for smallmouth bass, sunfish, walleye, and fallfish.

Because the main stem of the Delaware River is free flowing, undammed, and uncontrolled from Hancock all the way to the Atlantic Ocean, the entire length of the Upper Delaware provides key spawning and nursery habitat for the anadromous American shad, an important recreational fishing species in the Delaware. Shad range in weight from two to five pounds and are a very popular sport fish. Since the late 1970s, water quality improvements and state and federal programs to support the species have resulted in a resurgence of this species and related recreational fishing in the Delaware River from the Bay all the way up to the East Branch. The NYSDEC (Sheppard, January 2003) reports that American shad continued to use the East Branch all the way to Downsville Dam following the construction of Pepacton Reservoir, and notes that Cemetery Pool on the East Branch continues to be a popular fishing spot. In contrast, the West Branch shad fishery declined dramatically with the construction and operation of Cannonsville Dam.

River temperature, flow, and solar angle are thought to be critical environmental triggers for up-river shad migration and spawning. Migration occurs in springtime when the water temperature is cool and flows are generally ample. High flows, not low flows, are considered impediments to upstream migration. After the spring spawning, the young of the year begin their migration to the ocean in the fall when they are just a few inches in length. Low flows are not considered an impediment to their migration, but survival rates may be lower during low flow periods. The young migrating shad swim downstream at night and rest (and hide) during the day in very shallow water out of the reach of predators (such as bass). Since river levels that expose large portions of the riverbed reduce the potential hiding areas for the young fish, lower flows may increase the mortality of the young of the year, which in turn reduces the number of spawning fish two or three years later.

The most important shad nursery areas are located in the deep pools between Belvedere and Hancock and up into the East Branch. It is estimated that populations of up to 500,000 shad migrate annually to the upper reaches of the Delaware. The peak of the spawning period usually occurs in June, when large numbers of anglers follow the spawning "run" up the river.

The NYSDEC (Elliot, March 2003) reports that striped bass have substantially increased in numbers and range as far upstream as Hancock. The 1935 fisheries survey, which included seine net catches and interviews with local anglers, did not list striped bass as being present in the Upper Delaware at that time. In the section of the report about shad, there is a discussion about pollution in the Estuary impacting shad migration. It is probable that the pollution would similarly inhibit striped bass from migrating upstream. Also, striped bass feed on young shad, which were diminished in number by the 1930s.

One NYSDEC source (Sheppard, January 2003) commented that shortnose sturgeon have reappeared upstream of Port Jervis. None were reported in the 1935 fisheries survey. This is a federally protected species.

According to NYSDEC (Elliot, March 2003), blueback herring and gizzard shad have returned to the Upper Delaware and East Branch in the last 10 to 15 years. Neither are sport fish, but they are food for other fish, eagles, etc. Again, they were not observed in the 1935 fishery survey.

Commercial trapping for the American eel, a catadromous species, continues in this reach of the main stem Delaware.

Total visitation, including land- and water-based activities, at the Upper Delaware National Recreation Area in 1999 and 2000 was 356,486 and 278,308 people, respectively. Since a large part of the visitation is river-related, the fluctuations in numbers may be related to weekend/holiday weather and flow conditions.

MIDDLE DELAWARE

The 1978 National Parks and Recreation Act designated the 38-mile segment between Milford, Pennsylvania, and the Delaware Water Gap (the Middle Delaware River, Figure 4.5) as a component of the National Scenic Rivers System. This segment, which starts about eight miles downstream of the southern boundary of the Upper Delaware, is protected through extensive Federal land acquisition and as a national park.

Both the Upper and Middle Delaware River segments are used heavily for sightseeing, canoeing, fishing, hiking, and hunting. In addition, the Middle Delaware segment has five environmental education centers, a crafts village, a restored farmstead, and a crossroads village.

Figure 4.5
Middle Delaware River

From Port Jervis to Stroudsburg, Pennsylvania, the water flows calmly in a wide channel, most of which lies within the boundaries of the Delaware Water Gap National Recreation Area. Of the 20 islands that dot this stretch of the river, Tocks Island (the site of the de-authorized Tocks Island Dam), is one of the largest. One unique physical feature of this section of the river is the Wallpack Bend where, in a major loop, or S-turn, the river completely reverses its direction within three miles. The water at Wallpack Bend reaches a depth of 25 feet, one of the deepest parts of this segment. As the river is forced around the bends, it produces a high current, resulting in eddy whirlpools.

In this area, the Delaware River cuts through a narrow valley of farmland and woodland that contains swift-flowing streams and waterfalls, significant geologic features, a variety of plants and wildlife, and a wealth of cultural resources. The Middle Delaware is even closer than the Upper Delaware to the large concentrations of people in New York City and Philadelphia, and its variety of recreational opportunities has been widely used by vacationers since the mid-19th century. Approximately 30 million people currently live within 100 miles of the river. Given, the access provided by routes such as I-84, I-80, I-78, and the Northeast Extension of the Pennsylvania Turnpike, these people are within 2-1/2 hours driving time of the Middle Delaware.

Recreation in the Delaware Water Gap National Recreation Area is managed by the NPS. The National Parks and Recreation Act of 1978 transferred all federal lands that were part of the proposed Tocks Island Reservoir Project, as well as land acquisition authority within the boundary of the National Recreation Area, to the NPS. This Act also designated the section of the Middle Delaware within the National Recreation Area as a scenic and recreational river under the National Wild and Scenic Rivers System. The river segment from the northern boundary to the Shawnee area is classified as scenic. The remainder of the segment is classified as recreational.

The recreational objectives differ little from those of the Upper Delaware, but the means by which they are to be achieved are extremely different. Of the 69,629 acres included in the National Recreation Area boundary, the federal government (NPS) currently owns and manages approximately 52,700 acres. The NPS has sole responsibility for interpreting, managing, protecting the natural and cultural values and processes, and for providing appropriate recreational opportunities and public facilities.

The most popular form of boating in the Middle Delaware is canoeing. Rapids are less prevalent and less challenging in the Middle Delaware and canoeing in the National Recreation Area (NRA) does not require as much skill as it would on the Upper Delaware. The NPS owns and operates seven major river access sites located every eight to ten miles. Other boating uses include tubes, rafts, powerboats, and fishing boats.

Flows in the Middle Delaware River are influenced by (1) natural base flows, (2) releases from the New York City water supply reservoirs, (3) hydroelectric power generation releases from a series of five reservoirs on the Mongaup River, and (4) releases from two reservoirs on the Lackawaxen River (Lake Wallenpaupack for hydropower and Prompton Reservoir for flood control).

LOWER NON-TIDAL DELAWARE

At Stroudsburg, Pennsylvania, the Delaware River breaks through the Kittatinny Mountains to form the Delaware Water Gap. At this point, the river flows through a narrow gorge with cliffs rising to a height of over 1,000 feet on either side. South of the Water Gap are long stretches of calm water interrupted by strong rapids only at Foul Rift.

From the mouth of the Lehigh River at Easton, Pennsylvania to the fall line at Trenton, the river has a modest gradient. Although the river has many small riffles in this section, it has only one major rapid, Wells Falls (below the Lambertville Wing Dam). Three wingwall dams in this section, located downstream of Washington's Crossing at Lumberville, Lambertville, and Scudders Falls, create artificial pools in the river.

In October 2000, federal legislation was signed extending the "Wild and Scenic" portions of the Delaware River from the Delaware Water Gap down to Washington Crossing (upstream of Trenton, New Jersey). The extension provides protection for the Delaware River water corridor (for about 1,000 feet on either side), which passes through 30 municipalities in Pennsylvania and New Jersey. The corridor also includes Tohickon Creek (Section 3.9) Twenty-four participating communities have priority for federal grants to protect the environment and must commit to the goals of preserving water quality, protecting natural and historic resources, encouraging low-impact recreational use, and preserving open space. Several industrialized areas, including Easton and New Hope in Bucks County are exempted. Six communities elected not to join the corridor: Durham, Upper Mount Bethel, and Williams Townships in Pennsylvania, and Pohatcong, White, and Alexandria Townships in New Jersey. The legislation prohibits the federal government from spending money on public works projects in the River and commits the NPS to developing and administering a management plan.

In the lower part of the non-tidal main stem, the river is still heavily used for recreation, but other uses become important as well. The region is much more densely populated. Industry and urbanization increase the demands on the River for both water supply and for assimilative capacity for industrial and municipal wastewater discharges.

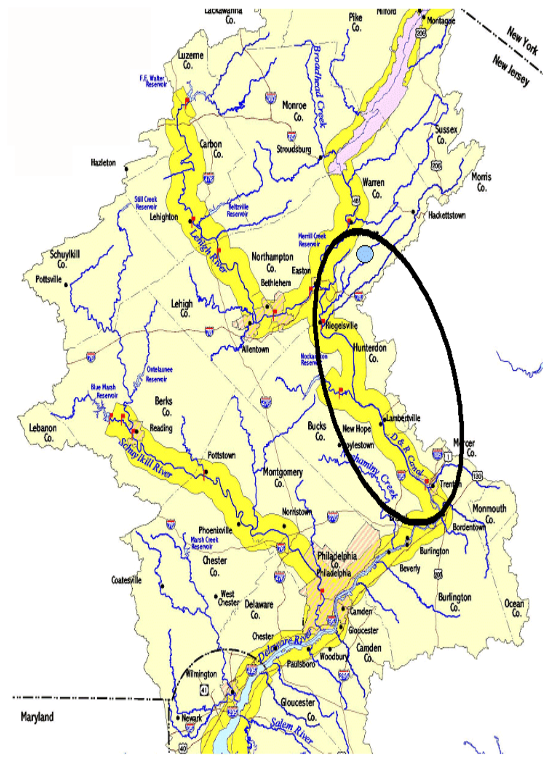


Figure 4.6
Lower Delaware River

4.4.2 Issues and Analysis

Several flow management issues in the Upper Delaware River are the same as issues in the West Branch of and potential index displays for these issues were previously discussed in the sections indicated below:

- Section 4.2.2.3 Irregular and Uncertain Releases
- Section 4.2.2.4 Thermal Release Bank
- Section 4.2.2.5 Water Quality

The following additional flow management issues were identified for the Upper**,** Middle, and Lower Delaware River:

- Section 4.4.2.1 Flows for Recreational Boating
- Section 4.4.2.2 Drought Declarations and Lower Flow Targets
- Section 4.4.2.3 New Jersey's Delaware and Raritan Canal Diversion
- Section 4.4.2.4 Downstream Water Supply Treatment
- Section 4.4.2.5 Improved Design of Reservoir Releases
- Section 4.4.2.6 Habitat Flow Requirements and Channel Maintenance
- Section 4.4.2.7 Special Protection Waters
- Section 4.4.2.8 Flow Target Locations

Potential index displays for these issues are described in the following sections.

4.4.2.1 Flows for Recreational Boating

a) Flow Traces at Barryville and Trenton

Flows at these points are critical to boating interests. The stage (water level) of the river can make the difference between an enjoyable day floating down the river and a miserable day of dragging canoes and rafts across the rocky riverbed. Flow traces (hydrographs*)* at these two points indicate the range of conditions that recreationists may encounter, the duration of those conditions, and their frequency of occurrence. Since commercial liveries usually refer to flow at Barryville in terms of river stage, the flow trace should be related to river stage to interpret boating suitability. Relationships showing river stage at Barryville versus boating quality, and showing Trenton flow versus boating quality, are shown in Tables 4.1 and 4.2.

b) Number of good or excellent boating days, by season and by year

Interviews with boating livery owners indicated a fairly consistent grading of Upper Delaware boating conditions based on the river stage at Barryville and Lower Delaware boating conditions based on the flow at Trenton. The gradings are given in Tables 4.1 and 4.2, respectively. Per these tables, a river stage of between 3.2 and 8.0 feet at Barryville ranks from good to excellent, and a flow of 3500 cfs or better at Trenton is rated good to excellent. Given these criteria, it is easy to count the number of good or better canoeing and/or rafting days by season and by year in a simulation and display them in a bar chart. Weekend days are more important for boating interests than weekdays, and could be displayed separately. This will highlight the boating benefits induced by release schedules which target maintaining boating flows on weekends. Likewise, late spring, summer, and early fall days are more important than winter days.

c) Number of correctly forecast good boating days, by year

As is the case with fisheries, forecasts may afford boaters some assurance that their experience will be a good one. Accurate forecasting may encourage more boaters overall and will certainly decrease disappointments. Flow forecasts for boaters can be made based on expected releases, antecedent flows, and projected rainfall, and should be reasonably accurate. Good forecasting will involve coordination between the National Weather Service (which makes and publicizes flow forecasts) and the agencies responsible for short term planning for reservoir releases. The National Weather Service has recently introduced graphical river stage forecast products which are available on-line through the Mid-Atlantic River Forecast Center. Text products listing river stage forecasts are also available on-line. The U.S. Geological Survey provides on-line flow and stage hydrographs of near real-time stream conditions. While not flow forecasts, these hydrographs provide usesful information about the types of flow or stage fluctuations that may be caused by diversions or hydropower releases.

Table 4.1, Flow vs. Quality of Canoeing/ Rafting Experience, Upper Delaware River

Stage (feet) at Barryville	Flow (cfs)	Quality of Experience	Comment
<2.5	<737	Extremely poor	Most liveries will not rent boats at this condition
2.5	737	Very poor	Most boaters will be unhappy due to excessive grounding, portaging, and risks of stumbling
2.7	880	Poor	
3.0	1131	Fair	
3.2	1327	Good	
3.5	1779	Good	
4.0	2761	Very good	Excellent for nonexpert canoer
5.0	4887	Excellent	Excellent for experienced canoers, fair to poor for non-experts
6.0	7611	Excellent	Excellent for rafting, excellent for highly skilled kayakers
7.0	10,930	Excellent	Same
8.0	14,930	Excellent	Perfect for rafting
>8.0	>14,930	Variable	Waves flatten

Table 4.2, Flow vs. Quality of Canoeing/ Rafting Experience, Delaware River below Montague

Flow at Trenton (cfs)	Quality of Experience
<2000	too low to operate
2000	poor
2500-3000	fair
3500	good
5000	excellent
9000	ideal

Note: Rainfall events can affect the reliability of Table 4.2 as an indicator of boating quality for this large section of the main stem. Boaters should always check rainfall and river stage forecasts when planning boating activity**.**

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4.4.2.2 Drought Operations and Lower Flow Targets

The Delaware River Basin Commission Water Code spells out the conditions for drought operations, which are based on reservoir storage and include reductions in out-of-Basin diversions and associated flow target reductions. It is critical to the effective management of the Delaware's water resources that these reductions in exports and releases be implemented in a timely manner. If they are not, the risks to water supply increase dramatically. New York City's reservoirs are by far the largest source of storage in the Delaware Basin; their storage levels are the triggers for reductions in flow targets at Montague and Trenton, and in exports to the City of New York and the State of New Jersey. Flow targets are also governed by the river mile location of the salt front in the Delaware Estuary. The salt front is defined as the seven-day running average chloride concentration of 250 mg/l. Storage levels in Lower Basin reservoirs (Beltzville and Blue Marsh) may also trigger reductions to the Trenton flow target and the export to New Jersey during Lower Basin droughts.

The following displays have been used in flow management since the development of the existing DRBC Daily Flow Model in the early 1980s and are therefore both well established and well understood.

a) Number of days in *Drought Watch*, Warning, and *Emergency* conditions

This display is a three-entry table recording the number of days in each condition as counted from a simulation run.

b) Number of *Watch, Warning,* and *Emergency* events

This display is also a three-entry table that reports the total number of times each threshold was crossed.

c) Number of days below flow or storage thresholds

This display includes one entry (the number of days) for each threshold desired.

d) Minimum storage in all reservoirs

This display includes a single entry (the minimum storage) for each desired reservoir.

4.4.2.3 Delaware and Raritan Canal Diversion

The Delaware and Raritan Canal diversion conveys New Jersey's allocation of Delaware water eastward for use in northern New Jersey. It has been reported that a low river stage hydraulically restricts the rate of withdrawal at the D&R Canal intake, but this impact has not been well documented. Index displays could include:

a) the number of days of withdrawal restrictions at each level of drought declaration, or

b) the number of days that the River stage falls below the stage at which withdrawal problems occur.

4.4.2.4 Water Supply Treatment-related Displays

In general, the analytical tools needed to create water supply treatment-related displays have not been developed. Water supplies such as Philadelphia's do experience taste and odor problems, but the causes are hard to pinpoint. It is highly likely that they are caused in part by non-point source pollution, but they may also be related to releases from upstream reservoirs with poor quality water. The first step in developing these displays will be to identify the dissolved and suspended pollutants that cause the problems. The causative agents will then need to be traced back to sources, and models will have to be developed for both the generation and transport of the pollutants. Modeling the generation of these pollutants is likely to require watershed models for critical watersheds, and perhaps for the entire Basin. Such modeling will require very sophisticated reservoir water quality models. Index displays could include the following:

a) Concentrations of taste- and odor-causing chemicals at water supply intakes

b) Number of days with taste and odor problems

c) Time series trace of treatment costs

d) Total treatment costs

4.4.2.5 Measures Relating to the Precision in Meeting Flow Targets

Because of the high visibility of Delaware Basin issues, citizens observe and note when flow targets are and are not met, particularly at Montague. While it is desirable to meet the targets as closely as possible, it is not possible to meet them exactly. The Delaware River Master compensates for days when the target is not met by raising and lowering releases on subsequent days in order to achieve the appropriate balance in the long run. Statistics on daily deviations between the water actually released from the reservoirs and that needed to exactly meet the prevailing flow target can provide a performance measure of the overall operating system and methods. Due to the uncertainty of both precipitation and hydroelectric power generation forecasts, only limited control over these daily deviations is possible. The Office of the Delaware River Master (Paulachok) reports that the office receives only a few, occasional inquiries concerning the balancing adjustment used to compensate for under- or over-releases, and that it has had no instances where critics have been dissatisfied with the application of the balancing adjustment procedure.

a) Deviations from target flows

This index display is a table similar to Table 4.3 showing the number of positive deviations, the number of negative deviations, the average overall deviation, average positive and average negative deviations, maximum positive deviation, maximum negative deviation, and median positive and negative deviations from all target flows of interest when (and only when) releases are being made (or should have been made) to meet target flows. These deviations represent the difference between the water actually released from the reservoirs and that needed to exactly meet the prevailing flow target. The negative deviation is simply the difference between the target flow and the actual flow. If the flow is higher than the target, no negative deviation is recorded. The positive deviation is equal to the minimum of the release made to meet the target and the difference between the actual flow and the target flow. If the flow is lower than the target or if no release is made, then no positive deviation is recorded. The example in Table 4.3 is a hypothetical example of a display of deviation statistics for potential flow targets at Bridgeville and Hale Eddy, and the flow target at Montague. This type of comparison should be based on observed data and operating procedures. The existing daily flow and OASIS models for the Basin represent operating rules and historic hydrology and are useful for comparison of operating rule alternatives, but they do not replicate the decisions of the Delaware River Master's office in the day-to-day incorporation of precipitation and power generation forecasts in the design of reservoir releases.

Table 4.3, Deviation Statistics for Meeting Target Flows

Station	Tot Dev	Avg Dev	Pos Dev	Pos Avg	Pos Med	Pos Max	Neg Dev	Neg Avg	Neg Med	Neg Max
Bridgeville	3.2	50	1.7	67	60	400	1.5	32	24	40
Hale Eddy	5.7	75	3.4	82	74	627	2.3	63	52	42
Montague	8.9	120	5.2	145	120	850	3.7	75	60	250

4.4.2.6 Habitat Flow Requirements and Channel Maintenance

Smallmouth bass habitat and the recent observation of a significant population of dwarf wedgemussels in the main stem Delaware are examples of additional issues requiring better definition of flow and channel maintenance needs. Future flow management decisions will be dependent upon flow relationships established through monitoring, modeling, and ecological assessment. Such efforts are in progress for the dwarf wedgemussel.

4.4.2.7 Special Protection Waters

DRBC's Water Quality Regulations designate portions of the Delaware River as Special Protection Waters. The Commission's policy is to prohibit degradation of Special Protection Waters by any point or non-point source of pollution, regardless of class.

To date, the Commission has including the following Delaware River reaches in the program under two classifications.

Outstanding Basin Waters:
- Upper Delaware River (RM 330.7 to RM 258.4),
- Tributaries within the boundary of the Upper Delaware River corridor,
- Middle Delaware River (RM 250.1 to RM 209.5), and
- Tributaries within the boundary of the Delaware Water Gap National Recreation Area.

· Significant Resource Waters:
- Delaware River (RM 258.4 to RM 250.1) between the Upper Delaware River and the Middle Delaware River as designated in the National Wild and Scenic Rivers System.

The Commission is considering including the Lower Delaware River in the special protection waters program. The Commission has been monitoring water quality in the Lower Delaware for several years in order to obtain the requisite background data to establish the water quality standards to be maintained.

The Special Protection Waters regulations do not specify a means to achieve the non-degradation objectives of the special protection designation. Flow prescription might be a component of the strategy, but the analyses needed to define the relationship between water quality and changes in flow due to flow augmentation policies have not been performed. This relationship would have to be defined to determine whether flow augmentation programs in the main stem violate the prohibition on water quality degradation.

4.4.2.8 Location of Flow Targets

As better information defines flow relationships for various habitat or recreational objectives, establishing additional flow targets on the main stem, particularly at Callicoon, has become an issue. Additional habitat assessment and flow modeling are needed to establish flow objectives and their management implications for existing or new reservoir storage. This is a particularly important issue with respect to the dwarf wedgemussel.

4.4.3 Additional Information and Study Needs - Main Stem Delaware River from Hancock to Trenton

The following steps are suggested, in priority order, for acquiring the information necessary to establish additional flow relationships and support index displays for the Main Stem Delaware River from Hancock to Trenton:

1) Review main stem water quality modeling results and monitoring data to determine the correlation of critical water quality parameters to changes in low flow rates. Determine low flow rates which would result in violation of water quality standards, assuming existing and projected rates of effluent discharge.

2) Obtain additional data concerning rates of the diversion from the Delaware and Raritan Canal and low flows in the Delaware River at Riegelsville, NJ. Determine the rate of flow at which the allocated diversions cannot be made.

   The New Jersey Water Supply Authority claims to have had difficulty making the needed diversions under some conditions of low flow. Additional information is needed before the necessary flow relationship and potential ameliorative action can be identified.

3) Assemble a data set of occurrences of downstream taste and odor problems and correlate it with data on reservoir releases and flow above the water supply intakes. In addition, identify the algae or other parameters causing the taste and odor problems and determine whether that species exists in Cannonsville Reservoir. Assess the need for additional water quality modeling to define taste and odor relationships to reservoir releases. Finally, determine the additional treatment costs associated with control of taste and odor and the extent to which reservoir releases affect those costs.

4) Perform a screening level habitat assessment to identify those reaches that are most vulnerable to or which benefit from low flows and flow fluctuations due to reservoir releases. Based on this screening, select reaches for possible IFIM analysis to establish critical flow rates.

4.5 Lackawaxen River from Wallenpaupack Creek to Mouth

4.5.1 Setting

The Lackawaxen River segment (Figure 4.7) extends 13 miles from PPL Generation's Lake Wallenpaupack hydropower generating plant outfall (2.5 miles east of Hawley, Pennsylvania) to the river's junction with the Delaware River at Lackawaxen, Pennsylvania. Land bordering this segment is steeply sloping, heavily forested, and sparsely developed. Vacation homes and small villages occupy portions of the narrow valley, much of which is state game land. A state road runs parallel to the Lackawaxen River, which is used for recreational fishing and boating.

Upstream from the PPL generating station, the watershed area is a mix of forest and small farms. Two Corps of Engineers single-purpose flood control reservoirs (Jadwin and Prompton) lie in this portion of the Basin. These have little impact on daily streamflows except during and immediately after large precipitation events.

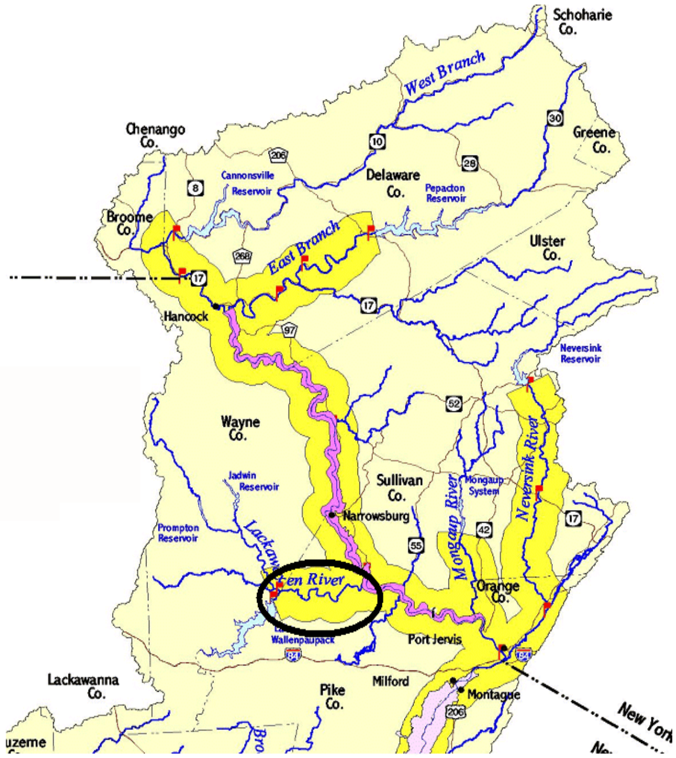

Figure 4.7
Lackawaxen River

Flow in the Lackawaxen River study segment is substantially affected by the rate and timing of releases from Lake Wallenpaupack to the hydropower generating plant. There are currently no required minimum conservation releases from the lake to Wallenpaupack Creek. Summer releases are generally timed to coincide with peak electric energy needs in the northeastern United States and are typically 10-12 hours in duration. Station output is dictated by the regional demand for electricity, and plant discharge varies from a minimum of 125 cfs to a maximum of 1750 cfs. Releases generally are not made on weekends unless lake levels are higher than desired.

Lake Wallenpaupack is also managed for recreation. A large number of vacation homes border the lake, which is extensively used for recreational boating and fishing. Upstream of the lake, the watershed area is a mix of forest and vacation resort development.

PADEP classifies the entire Lackawaxen River segment as Class HQ-TSF, MF. The "HQ" designation indicates high quality streams and watersheds that have excellent quality waters as well as environmental or other features that require special water quality protection. TSF designates a stream that is suitable for maintenance of stocked trout from February 15 to July 31 (additional stocking is performed in the fall) and that is home to additional flora and fauna indigenous to warm water habitat. (Trout are not known to successfully reproduce in the lower Lackawaxen River.) The MF designation is for migratory fish such as American shad.

During drought conditions, the DRBC has the authority to direct releases from Lake Wallenpaupack for maintaining the Montague flow target, and under certain conditions, the Trenton flow target.

4.5.2 Issues and Analysis

Flow in the Lackawaxen is substantially affected by the rate and timing of hydropower releases from Lake Wallenpaupack. PPL is in the process of applying for a renewal of its Federal Energy Regulatory Commission (FERC) license for the facility. As part of this process, PPL has worked with a group of stakeholders to identify resource issues related to management of flows into the Lackawaxen River.

The following flow management issues have been identified:

4.5.2.1 Trout Habitat
4.5.2.2 Recreational Fishing
4.5.2.3 Recreational Boating
4.5.2.4 Use of Lake Wallenpaupack in Drought Management

As a result of boating- and fishing-related surveys and its work with stakeholders, PPL has developed a FERC relicensing application which includes an operating plan to address the listed issues. Peripheral issues, including the effect of changed Lake Wallenpaupack release patterns on New York City release requirements for meeting the Montague target and downstream water quality, have been raised, and continued analysis and negotiations are in progress. OASIS flow modeling was used extensively by PPL to analyze and present the flow- and storage-related impacts of its FERC application on the Delaware River Basin reservoir system. In addition, a revised Lake Wallenpaupack drought operating proposal by PPL is under consideration by the DRBC, and was analyzed by PPL using OASIS.

4.5.2.1 Trout Habitat

Trout are stocked in the Lackawaxen River, but trout spawning is limited in the study reach. IFIM studies are available for the lower Lackawaxen. Consideration of temperature releases to improve summer thermal conditions for trout has been included in the FERC relicensing process for Lake Wallenpaupack.

4.5.2.2 Recreational Fishing

Reports developed by PPL during the FERC relicensing process indicate that anglers prefer flows in the range below 600 cfs and are unhappy with flows in excess of 850 cfs. Combining this information with the modeled hydrographs for reservoir operating alternatives would provide an index display for the number of days of preferred fishing conditions under a particular operating plan.

4.5.2.3 Recreational Boating

Boating condition survey information collected by PPL during the FERC relicensing process indicates that boaters considered flows of 700 cfs to be "good," but that the quality of the boating experience rose rapidly as flows increased from 900 to 1200 cfs. During the summer, these flows occur when the Lake Wallenpaupack station is generating. Modeled flow hydrographs for reservoir operating alternatives, when combined with this boater survey information, would provide an index display of the success of specific alternatives in achieving preferred boating conditions.

4.5.2.4 Use of Lake Wallenpaupack in Drought Management

In conjunction with its FERC relicensing process, PPL has proposed modification of the drought operating plan for Lake Wallenpaupack. This would expand DRBC's ability to direct releases from the lake beyond drought emergencies to both *drought watch* and *drought warning* conditions. Because of the interplay between releases from Lake Wallenpaupack and the directed releases from the NYC reservoirs for meeting the Montague flow target, there has been concern that additional releases from Lake Wallenpaupack during these periods would significantly lessen release requirements from the NYC reservoirs to the detriment of tailwater fisheries. PPL has performed extensive flow modeling using the OASIS model and these results have been used to evaluate the impacts of the proposed change in drought operations. The DRBC has approved the proposed drought operating plan conditioned on the mitigation of adverse impacts it may have on the NYSDEC fishery management program for the NYC reservoir tailwaters. The mitigation measures are currently under negotiation.

The dwarf wedgemussel, classified as endangered under the federal Endangered Species Act, has recently been identified in the Upper Delaware River, in the vicinity of Calicoon, Hankins, and Equinunk. There is concern that changes in Lake Wallenpaupack operation could affect the species. The flow relationship for the dwarf wedgemussel is not yet defined and studies to develop this information are in the planning stage as of late 2003. Findings would be applicable to flow management policy as adopted by the Decree Parties and DRBC. Such policy affects all Upper Basin reservoirs, and primarily affects the management of the three New York City Delaware Basin reservoirs.

4.5.3 Additional Information and Study Needs - Lackawaxen River from Wallenpaupack Creek to Mouth

Flow-related issues on the Lackawaxen stream segment are being addressed in the current FERC relicensing of the Lake Wallenpaupack hydropower project. A substantial amount of work has been done relating flow to benefits. These include fisheries management, re-watering Wallenpaupack Creek directly below the reservoir, fishing conditions, and recreational boating both on the lake and in the river. Significant detail on Lake Wallenpaupack has already been included in the DRBC OASIS model through independent work by PPL. In order to avoid conflicts with determinations that may result from the FERC re-licensing process, which involves numerous regulatory agencies, recommendations for additional study on the Lackawaxen River have not been included in this report.

4.6 Mongaup River from Swinging Bridge Reservoir to Mouth

4.6.1 Setting

The Mongaup River segment (Figure 4.8) extends 17 miles from the Swinging Bridge Reservoir outlet structure (seven miles southwest of Monticello, New York) to the confluence with the Delaware River. Swinging Bridge Reservoir and two downstream reservoirs, Mongaup Falls Reservoir and Rio Reservoir, generate hydropower. Two other reservoirs on Black Lake Creek (a Mongaup River tributary), Toronto Reservoir and Cliff Lake Reservoir, provide additional storage for the Mongaup system upstream of Swinging Bridge Reservoir.

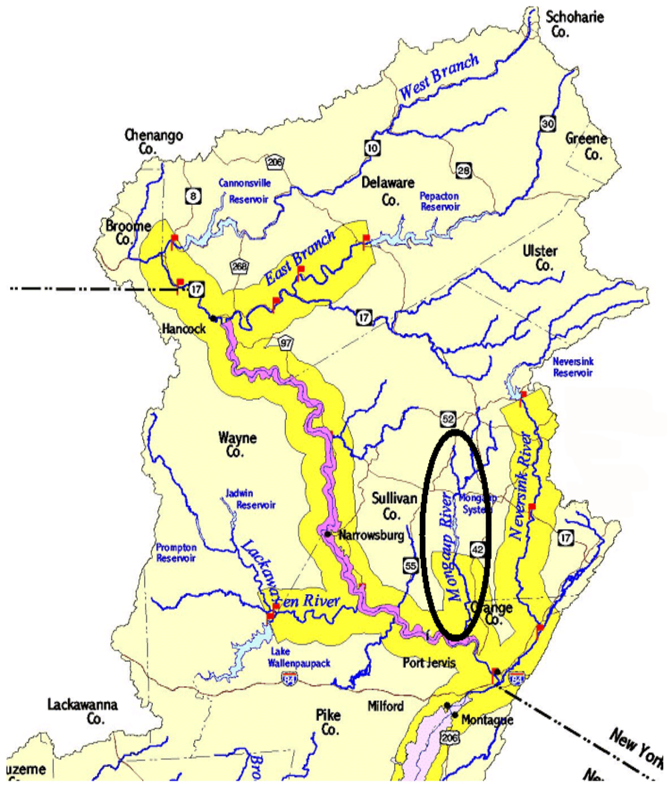

Figure 4.8
Mongaup River

The Mongaup reservoirs are owned and operated by Mirant New York, Inc. as peak electric-generating facilities, and occupy 10.5 miles of this segment. The short, free-flowing reaches downstream of the Swinging Bridge Reservoir reach occupy narrow, heavily wooded valleys. The reach downstream from Rio Reservoir is wilderness-like in appearance. For most of the run, the floodplain and valley walls are state-owned, the river has a steep gradient, and there are no roads close to the channel.

Summer hydropower releases are generally limited to several hours per day, Monday through Friday, to coincide with peak electrical energy demands in the northeastern United States. Hydropower releases from Rio Reservoir are generally 435 cfs (one turbine) or 870 cfs (two turbines).

Coincident with the FERC relicensing process (application made Sept 9, 1988; license granted April 14, 1992), a Memorandum of Understanding (MOU) between Orange & Rockland Utilities, Inc. (O&R, the prior owner) and the NYSDEC established minimum conservation releases to the Mongaup River. The minimum conservation release rates under normal conditions are 100 cfs from Swinging Bridge and Rio Reservoirs and 70 cfs from Mongaup Falls Reservoir. The NYSDEC classifies the free-flowing portions of the Mongaup River downstream from each reservoir as B(T) – suitable for trout propagation and survival. The new FERC license also requires scheduled weekend releases for boating purposes. During drought emergencies, the DRBC has the authority to reduce conservation releases and curtail power releases in order to refill the Mongaup Reservoir system by June 1.

From Rio Reservoir to the river's mouth 4.5 miles downstream, the river contains wild (propagating) brown trout and is considered an outstanding trout fishery. Power generation releases from Rio enter the river 1.5 miles downstream of the dam, and most recreational boating occurs in the last three miles of the river.

4.6.2 Issues

Flow in the Mongaup River depends on both the conservation releases and hydropower releases from the Swinging Bridge, Mongaup Falls, and Rio Reservoirs, and thus is highly variable. The following issues were identified for this segment:

- Section 4.6.2.1 Fish habitat/water quality
- Section 4.6.2.2 Recreational boating

The water quality issue relates to dissolved oxygen (DO) levels in reservoir releases. Studies conducted for the relicensing process found low DO levels in the hypolimnetic zone of the reservoirs. Consequently release water entering the free-flowing portions of the Mongaup River at times was lower than the Class B(T) water minimum criterion (5.0 mg/l). The FERC license required a study to determine means to modify releases so as not to violate the NYSDEC Class B(T) waters DO criteria. Based on the FERC relicensing docket materials and project interviews, there appears to be a general (but not universal) consensus that the habitat and recreational releases mandated in the 1992 FERC license and in the related MOU provide satisfactory trout habitat, fishing, and boating conditions in the free-flowing portions of the Mongaup River. The NYSDEC has expressed concern that the *drought emergency* releases called for in the DRBC Water Code could jeopardize fish habitat, however. Potential index displays are described below:

4.6.2.1 Trout Habitat

a) Trout Habitat

IFIM studies were conducted as a part of the FERC relicensing process, and minimum flow requirements have been established in the reservoir tailwaters. The IFIM results could be used to establish the loss of trout habitat caused by drought operations and the associated reductions in reservoir releases. The IFIM results could be combined with flow modeling results to determine the reductions or increases in habitat under alternative operating plans.

4.6.2.2 Recreational Boating

a) Recreational Boating Days/ Weekend Boating Days

Flows of 435 and 870 cfs (the releases with one and two turbines in operation, respectively) provide excellent whitewater boating opportunities. As mentioned above, weekend releases are scheduled once every two weeks. Flow modeling results can be used to determine the success of operating alternatives in achieving preferred boating conditions. Also, improved power generation forecasts would provide more lead time for boating during weekday periods, and displays similar to those discussed in Section 4.4.2 for the Upper Delaware could be used.

4.6.3 Additional Information and Study Needs - Mongaup River from Swinging Bridge to Mouth

All of the issues identified on the Mongaup River stream segment were investigated during the FERC re-licensing of Mirant New York, Inc., hydropower operations. Thus, good flow-benefit relationships generally exist for this reach. However, the DRBC OASIS model currently lacks the ability to model this system. Very recent work for the City of New York has produced an OASIS-based model of the system. Suggested actions for improving the ability to analyze Mongaup system alternatives include:

1) Add the Mongaup system reservoirs and their operations to the DRBC OASIS model.

2) Re-establish the USGS stream gage below Rio Reservoir as a means of providing flow data downstream of the reservoir.

4.7 Lehigh River from F.E. Walter Dam to Mouth

4.7.1 Setting

The Lehigh River segment (Figure 4.9) extends 77 miles from the Corps of Engineers-operated F.E. Walter Dam near White Haven, Pennsylvania to the river's confluence with the Delaware River at Easton, Pennsylvania. Along this course the river traverses portions of four Pennsylvania counties (Luzerne, Carbon, Lehigh, and Northampton) and three physiographic provinces (the Appalachian Plateau, Valley and Ridge, and the Piedmont). The reach between the dam and Jim Thorpe, Pennsylvania is primarily used as state game lands. River access is limited because there are no roads paralleling the river and few roads that cross it. Through much of this section the river flows through a narrow, steep-sided valley. In the 14 river miles between Jim Thorpe and Lehigh Gap, creeks draining lands once heavily mined for coal and zinc enter the river. The river is accessible at several locations along this reach. The Pohopoco Creek stream segment joins the Lehigh in this reach but does not drain any mined land. South and east of Lehigh Gap, the river gradient decreases as the river traverses rolling farm land before passing through a growing metropolitan area comprised of three moderate-sized cities – Allentown, Bethlehem, and Easton. The river is very accessible within this section.

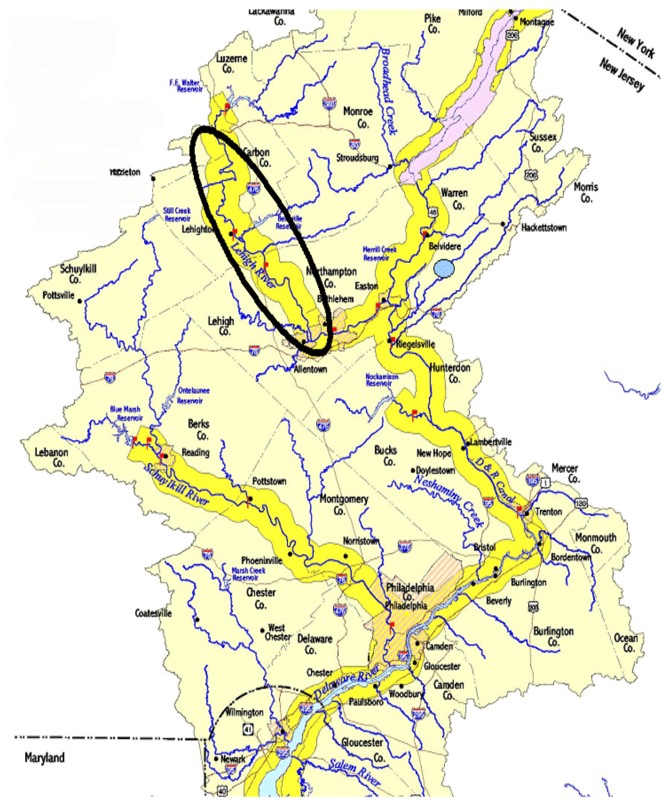

Figure 4.9
Lehigh River

The F.E. Walter Reservoir, a federal flood control facility completed in 1961, is operated by the Philadelphia District of the U.S. Army Corps of Engineers. In 1962, Congress authorized the Corps of Engineers to raise the dam to provide 23 billion gallons of additional storage for water supply while preserving the flood control storage. The water storage capacity could be used to meet downstream flow targets, replace consumptive uses and maintain critical low flows. The modification (a key issue addressed in the Good Faith Recommendations) has not yet been undertaken because funding has not been secured.

The reservoir has a current storage capacity of 35 bg and is operated to reduce flood stages on the Lehigh River at Lehighton, Walnutport, Allentown, and Bethlehem. A conservation pool currently estimated at 0.58 bg is available for maintaining a minimum release specified in the DRBC Water Code at 50 cfs. The Water Code specifies that this minimum release be reduced to 43 cfs under *drought warning* and *emergency* conditions. During the drought of 2001-2002, the Corps of Engineers provided temporary storage in F.E. Walter Reservoir while maintaining a minimum release from the reservoir of 156 cfs, if it was supported by inflow. Both warm and cold water fisheries exist in the Lehigh River. Brown and rainbow trout are stocked.

Public Law 100-676 (November 17, 1988) made recreation an authorized purpose of the project. Recreation was authorized on the lands associated with the project and on the lake itself, as well as downstream of the reservoir where whitewater recreation depends on upstream operations.

4.7.2 Issues

The following flow management issues were identified on the Lehigh River:

- Section 4.7.2.1 Use of F.E. Walter Reservoir for Flow Augmentation
- Section 4.7.2.2 Whitewater Rafting
- Section 4.7.2.3 Water Quality
- Section 4.7.2.4 Rapid Expansion of Small Independent Electric Generating Facilities
- Section 4.7.2.5 Drought Storage in F.E. Walter Reservoir

Because F.E. Walter is operated almost exclusively as a flood control reservoir, there is little downstream flow control. Regular supply of cold water to support a trout fishery has not been available. Up to five scheduled whitewater releases are made each year and there is a provision for emergency storage of water in the reservoir in advance of drought as mentioned above. Changes in F.E. Walter operating policies could provide flow augmentation benefits for whitewater rafting, establishment of a naturally reproducing trout fishery, and other purposes. Benefits would have to be weighed against any losses in flood storage volume and associated reduction in downstream flood control.

4.7.2.1 Flow Augmentation/Emergency Storage

The authorized purposes for F.E. Walter Reservoir are flood control and recreation. Minimum releases are maintained to the tailwaters, but there is no dedicated permanent pool of water available for support of the Trenton flow target or other downstream flow targets that could potentially be considered on the Lehigh River. The use of storage for such releases would require an assessment of the existing authority for operation of the reservoir as well as any spare flood storage capacity.

Flow augmentation at F.E. Walter would involve periodically raising the pool level. This would have important effects both downstream (as discussed above) and in the reservoir. In particular, some habitat surrounding the lake, including some wetlands, would be regularly flooded, and as a result, new habitat would develop along the new shoreline. Any boat ramps into the lake would be affected as well. Potential index displays include the following:

a) Storage at F.E.Walter

The impacts of operational changes on the storage in the reservoir are important from the standpoint of increased risk of downstream flooding, lake-related impacts (discussed above), and the amount of augmentation storage available for other purposes. This display should be a simple time series trace of simulated storage available for augmentation.

b) Downstream flood risk

Unless the dam was to be raised, the current flood storage capacity in F.E. Walter would be reduced if the flow augmentation storage pool were increased. One way to quantify the flood risk is to look at the simulated flood storage available at the start of historical floods. This display would consist of a table listing historical floods and the simulated flood storage available at the start of each flood.

c) Flows at targeted augmentation points

If F.E. Walter is used for flow augmentation, downstream targets will need to be met. Daily deviations from flow targets as described in Section 4.4.2.5 are a potential display related to meeting such targets.

d) Drought Management impacts

The use of flow augmentation from F.E. Walter to meet the Trenton flow target would reduce the frequency and duration of Lower Basin drought events by preserving storage in other Basin reservoirs. Displays for this issue include the number of days in *drought watch*, warning, and drought and minimum reservoir storage as discussed in Section 4.4.2.2

4.7.2.2 Whitewater Rafting

a) Whitewater rafting days

If F.E. Walter is used for additional flow augmentation, some additional whitewater rafting, canoeing, and kayaking benefits can be expected. The U.S. Army Corps of Engineers administers the whitewater release program for the reservoir and has data relating whitewater conditions to flow. This could be used with flow hydrographs produced by daily flow modeling to determine the number of days of preferred boating conditions for alternative operating plans.

4.7.2.3 Water Quality

a) Traces of water quality parameters and number of days values exceed criteria

Fishing and conservation organizations along the Lehigh River have supported the use of releases from F.E. Walter Reservoir to improve water quality in the river. The Lehigh River Watch has collected water quality information at several locations along the middle Lehigh. The Commonwealth of Pennsylvania, the DRBC, and the U.S. Army Corps of Engineers recently completed a water quality monitoring study of the Lehigh River, which constitutes the first step in developing a water quality model that can be used to relate water quality conditions to flow in the river. Comprehensive water quality modeling of the river might also require the development of water quality models for Beltzville and F.E. Walter Reservoirs. The combination of water quality and daily flow modeling could be used to determine the frequency of exceedance of water quality criteria for alternative reservoir operating plans. The correlation of reservoir release data with water quality observations would be a first step in determining the extent of modeling necessary to establish flow versus water quality relationships.

4.7.2.4 Increased Water Demand

a) Demand and shortage plots and tabular summaries

Time series plots of demands along the river and shortages (the extent to which the demand cannot be met) would be the primary index displays. Tabular summaries should include the total number of shortages, the number of days of shortages, and the number of shortage events. To more precisely model water demand, the DRBC OASIS daily flow model should be modified to distribute consumptive use throughout the tributary watersheds.

4.7.2.5 Drought Storage in F.E. Walter Reservoir

The issue of drought storage in F.E. Walter Reservoir is a subset of the issue of flow augmentation storage. During past drought emergencies, the Corps of Engineers has provided temporary storage at the request of the DRBC, but a permanent agreement to provide this storage is not in place. Modeled flows at White Haven, Lehighton, Walnutport, and Bethlehem could be used as an index to compare alternative drought flow augmentation programs for the reservoir.

4.7.3 Additional Information and Study Needs - Lehigh River

With the exception of the expansion of small independent electric generating stations, which will be addressed below, all of the identified issues on the Lehigh River stream segment are associated with the use of F.E. Walter Reservoir to regulate/augment flows for particular purposes, namely water quality, recreational boating, drought management, and maintenance of aquatic habitat. While the DRBC OASIS model can be used to assess the adequacy and impact on reservoir storage of any prescribed flow schedule, at this time our knowledge of the flow relationships is inadequate. The following steps are suggested, in priority order, for establishing additional flow relationships:

1) Evaluate the increased risk of downstream flooding associated with re-allocating a portion of the flood storage pool in F.E. Walter Reservoir to conservation storage. This would make more storage available for other flow management purposes.

2) Conduct a biological assessment of the Lehigh River below F.E. Walter Reservoir. In particular, the relationships between flow and water quality and flow and the maintenance of aquatic habitat are not well known.

   DRBC and the Corps of Engineers recently conducted a water quality study for the Lehigh. The data generated by this study, if used in conjunction with water quality modeling, should contribute to a better understanding the flow and water quality relationship. In particular, the relationship between releases from Beltzville Reservoir and water quality should be addressed. Additional information is needed about the current condition of the aquatic habitat and the extent to which flow management could improve conditions.

3) Document flow versus boating conditions based on available data.

4) Distribute projected increases in consumptive use with more precision in the DRBC version of the OASIS model.

5) Evaluate the need for reservoir water quality models for Beltzville and Blue Marsh Reservoirs.

4.8 Pohopoco Creek from Beltzville Dam to Mouth

4.8.1 Setting

The Pohopoco Creek segment (Figure 4.10) extends five miles from Beltzville Reservoir down to the Lehigh River. Beltzville Reservoir, located near Lehighton in Carbon County, is managed by the Corps of Engineers for flood control, recreation, water quality, and water supply.

The area is rural, primarily forested, and has very little urban development. Carbon County is on the periphery of the northeastern Pennsylvania counties that are growing rapidly.

The drainage area above the dam is 96 square miles. The permanent storage pool of the reservoir is 13 bg; an additional 8.8 bg is available for flood control. The DRBC owns about 70 percent of the permanent storage (9.1 bg), which is used for maintaining the Trenton flow target. The remaining 3.9 bg is federally owned and allocated for downstream water quality control and flow augmentation.

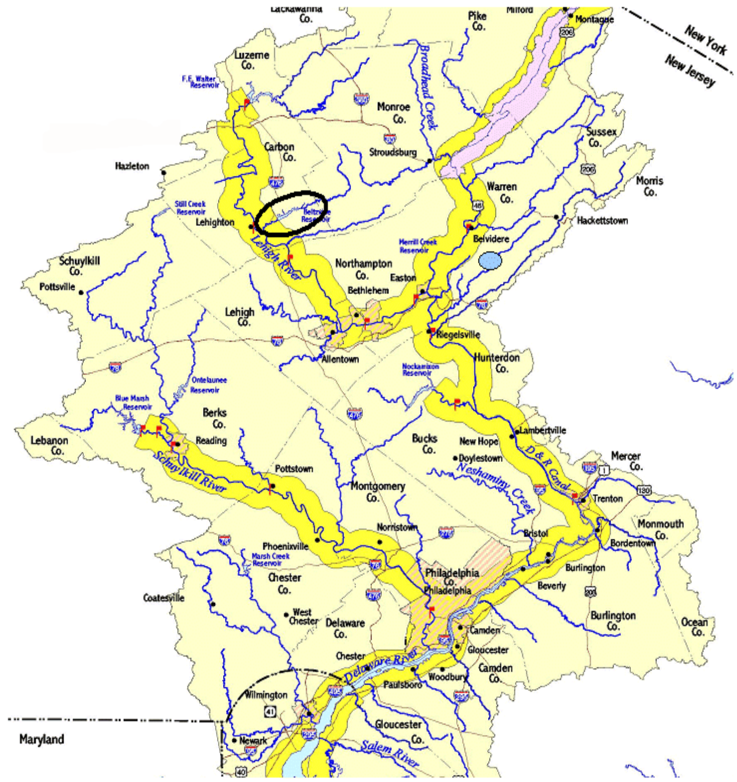

Figure 4.10
Pohopoco Creek

The stream is classified by the PADEP as a cold water fishery (CWF) suitable for the propagation and management of trout. There is a cold water conservation release from the reservoir. Under normal conditions, this release is 35 cfs, but it is reduced to 15 cfs during drought conditions.

Brown and rainbow trout are stocked in Pohopoco Creek downstream from the Beltzville Dam. Fingerling trout have been observed in the creek, but it is uncertain whether they were hatched from eggs spawned in the creek or were released from the reservoir. (Fingerlings are stocked in the reservoir.) Stream channel water temperature remains cold throughout the summer. The releases may even be colder than optimal through much of the spring and summer and productivity may be impacted. No IFIM or other fisheries studies have been performed in this section of Pohopoco Creek.

4.8.2 Issues

No specific instream flow management issues could be identified in Pohopoco Creek. There is a trout fishery in the creek, mainly from annual stocking of fish, but the current reservoir releases support this fishery adequately. Boating was not identified as an issue on Pohopoco Creek.

No recommendations for additional technical work have been made since no flow management issues were identified.

4.9 Tohickon Creek from Nockamixon Dam to Mouth

4.9.1 Setting

The Tohickon Creek stream segment (Figure 4.11) extends in a southeasterly direction from the Nockamixon Reservoir dam to the Delaware River at Point Pleasant, Pennsylvania. The stream flows through a largely rural and agricultural section of Bucks County, approximately eight miles north of Doylestown and just 30 miles north of center city Philadelphia. It is within a one-hour drive of more than two million people.

The portion of Tohickon Creek below the reservoir is classified as a cold water fishery. Although the Pennsylvania Fish & Boat Commission (PAF&BC) stocks trout, they report that few, if any, survive the summer's warm temperatures. The lower portion of the segment lies within Ralph Stover State Park and Bucks County parkland. Outside of the parkland, access to the creek is relatively limited.

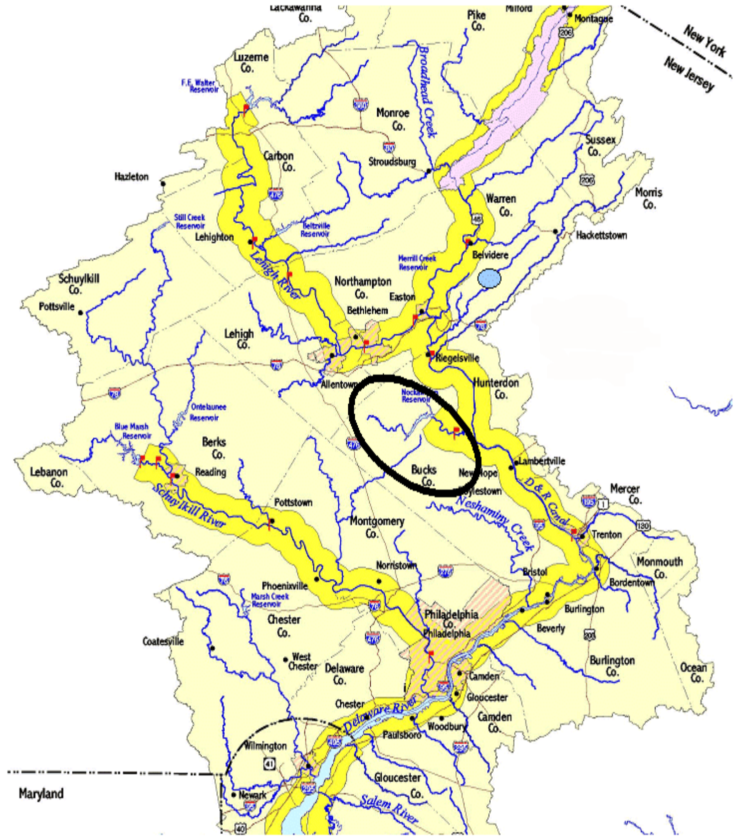

Figure 4.11
Tohickon Creek

Nockamixon Reservoir is owned and operated by the State of Pennsylvania as a recreational lake and is part of Nockamixon State Park. The dam's cold water conservation release was designed to be 12 cfs, but the actual release is on the order of 6 cfs. According to a PAF&BC representative, the reservoir lacks sufficient inflow to both maintain the recreational pool and meet the conservation release flow. The DRBC Water Code authorizes the Commission to direct releases from the reservoir to maintain the Trenton flow target during drought emergencies.

4.9.2 Issues and Analysis

The following flow management issue was identified for Tohickon Creek:

- Section 4.9.2.1 Recreational Boating

Below Nockamixon Dam, the Tohickon Creek is stocked with trout each spring, but the trout do not survive the warm summer. During the two annually scheduled releases from the dam, the stream becomes a world class kayaking venue. Since inflow is limited, additional releases for fisheries or kayaking would impact lake levels and reduce lake recreation benefits. Lake Nockamixon is also a valuable recreational resource with a large marina area for sailboats and motorboats of less than 10 horsepower.

4.9.2.1 <u>Recreational Boating</u>

a) Days of scheduled kayaking releases

Releases of about 760 cfs produce world class whitewater for kayaking downstream of Nockamixon Dam. Two such releases are currently scheduled each year. Inflow forecasts might make it possible to schedule additional releases in the spring of wet years without jeopardizing summer lake levels. The index display would indicate the number of actual kayaking events over a simulation run. The National Weather Service is expanding its deployment of Advanced Hydrologic Prediction Services (AHPS) products, which include 30-day inflow forecasts for major reservoirs. If developed for Nockamixon Reservoir, this would improve forecasting capabilities for potential additional whitewater releases.

4.9.3 <u>Additional Information and Study Needs - Tohickon Creek</u>

The only issue identified in this stream segment was the lack of water to fully meet three demands on the resource: conservation releases, whitewater releases for the two scheduled events per year, and the maintenance of lake levels for recreation. All of these uses are ultimately under the jurisdiction of the State of Pennsylvania, and enough is known about the flow requirements and the storage available in Nockamixon Reservoir for this issue to be evaluated. Both the local and Basinwide implications of such changes can be evaluated using existing information and the DRBC version of the OASIS model.

4.10 Delaware Estuary and Bay from Trenton to Mouth

4.10.1 Setting

The Delaware Estuary segment (Figure 4.12) includes the Delaware Bay and the tidal portion of the Delaware River. The drainage area extends from Trenton, New Jersey and Morrisville, Pennsylvania to the mouth of the Delaware Bay at Cape Henlopen, Delaware and Cape May Point, New Jersey. The Estuary is 135 miles long and has a drainage area of 5,985 square miles (including the entire Schuylkill watershed), or approximately 47 percent of the Delaware River Basin.

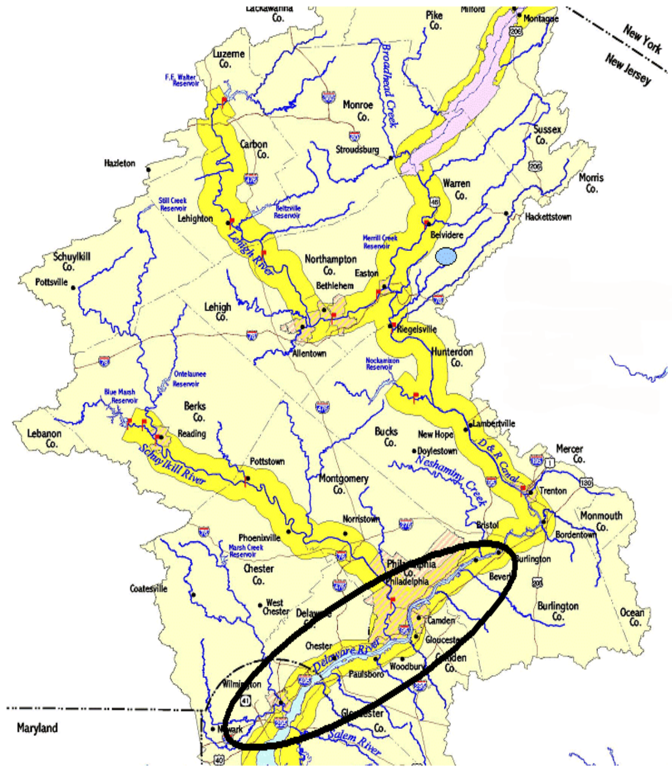

Figure 4.12
Delaware Estuary

The region is a major industrial center, and the Delaware Estuary serves as a navigation link to world markets. The Estuary also provides an expanding recreational resource for boating and fishing, serves the water supply needs for major population centers, and supports an area of unique and abundant biodiversity.

Over five million people reside in the 13 counties of Pennsylvania, New Jersey and Delaware that border the Estuary. Major urban areas include Trenton and Camden, New Jersey; Philadelphia, Pennsylvania; and Wilmington, Delaware. Heavy industry is concentrated along the water and is supported by a 40-foot dredged navigation channel that is authorized to be deepened to 45 feet. The Estuary includes access channels to the Ports of Philadelphia (a major U.S. port), Wilmington, Camden, and Trenton, as well as to the Chesapeake and Delaware Canal, which connects the region to the Port of Baltimore.

The estimated 1999 population of the region was 5,120,000 -- two percent of the total United States population and about 25 percent of the total combined population of the States of Delaware, New Jersey, and Pennsylvania. The population for the region has increased only 2.2 percent since 1970, but population shifts within the region have been dramatic. The area has been affected by heavy out-migration from the City of Philadelphia and other urban centers to the suburbs.

The Estuary has a history of water quality problems, which peaked during World War II, when the pollution was "…so bad that sailors and dock workers were often nauseated by the river's odor." (Majumdar, S.K. editor, et al., 1988; Albert, R.C, 1987; Delaware Estuary Program, April 1996.) Following the adoption of DRBC's more stringent water quality standards and massive investments in wastewater treatment, water quality has improved substantially. Some water quality standards are still not met in the Philadelphia metropolitan area, however.

A major resource for this study was The Scientific Characterization of the Delaware Estuary, (Sutton, C.C., O'Herron, II, J.C., and Zappalorti, R.T., April 1996). The goal of this report was "to integrate and synthesize historic, recent, and ongoing research and information for the purpose of defining priority problems (and their causes) in the Estuary." The Characterization report lists the goals and objectives of the Estuary Program. Some of the specific objectives relevant to flow management were to:

1. Restore population levels of harvestable species of finfish and invertebrate species to levels that will support sustainable recreational and commercial fisheries;
2. Restore or maintain populations of estuarine-dependent amphibians, reptiles, and mammals;
3. Maintain or restore an assemblage of organisms and their habitat throughout the Delaware Estuary and tidal wetlands that contribute to the ecological diversity, stability, productivity, and aesthetic appeal of the region;
4. Ensure an adequate supply of freshwater to the Estuary to maintain habitats, distribution of salinity, and human population in 2020;
5. Develop programs and actions that will be mutually beneficial to both the economy and environment of the Estuary, by forging a partnership with industry, commerce, and local governments.

Because freshwater mixes with the ocean saltwater to create the salinity patterns in the Estuary, and because waste assimilation in the Estuary is affected by freshwater flows, estuary inflow affects the ability to achieve each of these objectives.

Inflow to the Estuary is affected by upstream reservoirs in the Delaware River Basin, which have a combined storage capacity of approximately 500 billion gallons and control approximately 30 percent of the total drainage area. The reservoirs reduce flood peaks and increase low flows over what would naturally occur. In relative terms, the affects on low flows are the most pronounced. During the severe mid-Basin drought of 1999, as much as 50 percent of the measured flow at Trenton was made up of reservoir releases.

According to the Characterization report, over the past 50 years, "upstream intrusion of saline waters from the Estuary has also increased…." While this may apply to lower portions of the Bay and Estuary, analysis of chloride data by the DRBC staff shows no trend toward increasing salinity intrusion at Chester, Pennsylvania, over that time. In the upper Estuary, increased storage capacity since the 1960s and increased flow augmentation from the reservoirs above that which occurred in the 1960's drought has compensated for the effects of increased consumptive use, channel deepening, and sea level rise. Over time, assuming that the existing flow targets remain in place, additional channel deepening, increased consumptive use, and expected continued sea level rise, can be expected to increase salinity intrusion. Any proposals to modify releases from the NYC and other reservoirs should be evaluated in terms of the impact of associated changes in estuary inflow and concerns by Lower Basin states that the benefits of the existing release program not be jeopardized.

4.10.2 Issues and Analysis

The following flow management issues were identified for the Delaware Estuary and Bay:

- Section 4.10.2.1 Potable Water Supply Protection
- Section 4.10.2.2 Industrial and Municipal Impacts From Salinity
- Section 4.10.2.3 Base Flows, Permits and TMDLs, Waste Load Allocation
- Section 4.10.2.4 Freshwater Wetlands (Habitat), Fish Habitat
- Section 4.10.2.5 Oysters and Salinity Intrusion

The potential five-foot deepening of the Delaware River navigation channel has also been an issue in the Estuary. Table 5-1 of the Delaware River Main Channel Deepening Project - Supplemental Environmental Impact Statement, shows results of chloride modeling performed by the U.S. Army Corps of Engineers which indicates that the deepening would increase the 30-day average chloride levels by approximately 45 mg/l (channel bottom) at river mile 98 in the Camden/Philadelphia area during extreme drought conditions. Additional chloride modeling to examine the combined effects of channel deepening, and projected sea level rise has been requested by the DRBC. The models are in place for the Corps to conduct this analysis.

An additional related concern is future public water supply withdrawals from the Delaware. Although in-basin demand projections do not indicate major growth in this sector during the next 30 years, the Supreme Court Decree gives the State of New Jersey the right to export water from the Basin if the State builds additional storage and provides compensating releases. For this reason, the New Jersey Department for Environmental Protection (NJDEP) is concerned about the impacts of any proposals that would diminish releases past the Montague gage or inflows to the Estuary.

Potential index displays to evaluate the impact of alternative management strategies for these issues are described in the following sections.

4.10.2.1 Potable Water Supply Protection

a) Daily trace of chloride concentrations

This index display can be based on the results of a salinity model run in conjunction with (preferably in parallel with) an OASIS run. The DRBC salinity model used for estuary chloride analysis during the past 20 years does deal accurately with potential channel modifications. A regression derived from DRBC salinity model results relating estuary inflow to salinity intrusion is included in the DRBC version of the OASIS model. Improvements to salinity modeling capabilities are needed to account for changes in channel geometry when flow management policy alternatives are considered.

b) Estimated extent of chloride intrusion in the P-R-M Aquifer

The Camden Aquifer provides an important source of drinking water for southern New Jersey. Increased levels of salinity in the Estuary, in conjunction with sea level rise and induced infiltration caused by ground water withdrawals, may increase the extent of salt intrusion in the aquifer. The U.S. Geological Survey has developed a particle tracking model that predicts aquifer chloride concentrations based on pumping rates and assumed levels of estuary chlorides. If coupled with output flow hydrographs from the DRBC OASIS model, the effects of alternative operating policies on P-R-M chloride concentrations could be predicted. The USGS modeling has shown that estuary chloride concentrations required to render P-R-M supplies non-potable exceeds the existing chloride standard of 250 mg/l for protection of surface water uses in Zone 3 of the Estuary.

4.10.2.2 Economic Impact of Salinity on Industrial Water Users

a) Cost of chloride intrusion

The Corps of Engineers has investigated the treatment and increased process costs associated with salinity levels in the Estuary, but the work is 20 years old and portions of the work should be updated. A potential index display for this particular issue would present the sum of the treatment and process costs associated with the salinity traces produced by a long-term run of the salinity model under a particular management alternative. Upgrading salinity modeling capabilities and salinity cost data are required for this work.

4.10.2.3 Waste Load Allocations and TMDL-related Issues

Waste load allocations for the Estuary have been developed based on the minimum Trenton flow targets specified in the DRBC drought operating plan. It is essential that the impacts of any changes in the low flow regime on water quality and waste load allocations be quantified for flow-related policy changes to be considered. This applies to biological oxygen demand (BOD) loadings as well as allocations that may be developed for toxic substances. The impact of inflow changes at Trenton on the thermal loading in the vicinity of Duck Island has been raised as a concern by the NJDEP.

All of the displays in this section will require water quality modeling of the Estuary. In addition, GIS mapping of the relevant physical features will be required to produce the graphics in the potential displays.

a) Animated Displays of Concentrations of Critical Pollutants

BOD, dichloroethane (DCE), and tetrachloroethane (TCE), are currently subject to Waste Load Allocations (WLA) in the Delaware Estuary. WLA determine how much treatment is required for water dischargers and can have significant financial implications. Because of the nature of the methods used to compute Total Maximum Daily Loads (TMDL), which form the basis for WLA, alternative flow management strategies may impact WLA. Inflows affect both the concentrations of pollutants in Estuary inflows and the circulation patterns in the Estuary. Both of these affect the final concentration of pollutants, which is the starting point for computing both TMDLs and WLAs.

Because estuary dynamics are so complex, it is difficult to determine a critical condition for setting TMDL and WLA for an estuary. An animated display of the concentration of critical pollutants in the Estuary offers an approach to evaluating whether or not standards are met. Developing an animated display involves feeding the results of an Estuary water quality model into a GIS-based display system. Inputs to the water quality model would include inflow hydrographs generated by the DRBC OASIS model or an assumed minimum inflow condition. The DRBC has had an Estuary water quality model developed which includes salinity modeling capabilities. The model is presently being evaluated by the DRBC modeling and monitoring staff.

b) Maps of maximum concentration and percent of time criteria are exceeded for critical pollutants

Such maps would allow the user to establish whether or not standards are met and would be derived from flow and water quality modeling.

4.10.2.4 Freshwater Wetlands Habitat, Fish Habitat

Information related to potential and established relationships between flow management and the health of biological systems within the Bay and Estuary were sought out in interviews with staff of the Academy of Natural Sciences, DNREC, NJDEP, and by literature review. With the possible exception of the oyster/predator relationship, no such relationships were found. (For upstream migrating species, migration success is controlled by environmental factors or triggers other than flow. For downstream migration of young in the fluvial sections of the tributaries (not the Estuary), flow may be a factor in predation of young.)

The NJDEP (Miri) notes that the upper Estuary has recently hosted fishing tournaments for largemouth bass, and that striped bass as large as 50 lbs. have been caught in this area. This fishery is dependent on water quality, which is related to Estuary inflow.

Wetlands are influenced by the patterns of salinity intrusion over time. This pattern is affected by Estuary inflow, and would be further affected by sea level rise and deepening of the shipping channel.

a) Animated displays of salinity and important pollutants with a wetlands overlay

The exact nature of the influence of salinity on the viability of wetland ecosystems is poorly understood. Thus, the best displays for evaluating impacts are likely to be animations of predicted salinity for long periods. This would allow biologists to understand the range of salinities and the frequency of extreme events in more concrete terms than with simple tables and charts. This type of display would also use an improved salinity model in conjunction with the DRBC OASIS model.

4.10.2.5 Oysters and Salinity Intrusion

The ecology of oysters in the Delaware Bay, in particular the decline of oyster populations due to predators and disease, has been the topic of much research, much of it conducted by Haskins and Ford. Several references to this work are included in the publication entitled “The Scientific Characterization of the Delaware Estuary,” published by the Delaware Estuary Program, (Sutton, C.C., et.al, 1996, Chapter 7: Living Resources and Their Habitat.) This report summarizes the factors known or suspected to have contributed to the decline of oyster populations and commercial harvesting in the Bay. Researchers attribute the spread of MSX, a protozoan parasite that preys on seed oysters, at least in part to drought and resulting higher salinities. In addition, they attribute reductions in this predator to relatively low salinities in the Bay following tropical storm Agnes in 1972. The drought of 1985 is cited as causing higher salinities and more MSX. In 1990, another parasite, Dermo, entered the Bay and became a new cause of oyster damage. The reference does not discuss a relationship between Dermo and salinity, but does note that Dermo was probably introduced from the Chesapeake Bay, where it has decimated oyster stocks since the 1950s.

a) Animated displays of salinity and important pollutants with a wetlands overlay

These displays would overlay the model results for salinity or other parameters with maps of oyster habitat. Maps of oyster habitat have been developed in the course of the Corps of Engineers' channel deepening project. These types of overlays should help ecologists determine overall impacts of physical changes to the Estuary and changes in flow management.

b) Trace of the position of the 15 ppt isohaline

Work in the Level B Study (DRBC, 1981) demonstrated that the flow management afforded by Basin reservoirs affected chloride levels over the oyster beds, but that the impact was only one-tenth of the annual variation in chloride levels. There is some knowledge concerning the benefits of periodic episodes of lower (<15 ppt) salinity in reducing the impact of oyster parasites. It is not clear, however, that flow management by way of reservoir releases during low flows can have a significant impact on controlling the natural variations in the 15 ppt isohaline.

MSX and Dermo have difficulty surviving when salinity falls below 15 ppt. Thus, oyster bars in areas where salinity falls below this level for a significant part of the year tend to be protected from these parasites. This display will be informative to those familiar with occurrence and health of oysters in the Estuary. This display will also require incorporation of an improved salinity modeling capability with the DRBC OASIS model. The ability to predict the movement of the 15 ppt line will be useful in the implementation of oyster enhancement efforts now being proposed for the Delaware Bay.

4.10.3 Additional Information and Study Needs - Delaware Estuary and Bay

Conditions in the Delaware Bay are influenced by factors other than flow, most notably the point and non-point source pollution that occurs throughout the Basin. The following steps are suggested, in priority order, for establishing additional flow relationships:

1) Incorporate a new salinity versus flow relationship in the DRBC OASIS model. This salinity relationship should be capable of reflecting changes in the geometry of the Delaware ship channel, which might be accomplished by developing a separate relationship for each geometry. The new relationship should be based on the Corps of Engineers' new three-dimensional model of the Estuary or on the new water quality model recently developed for the DRBC's Monitoring and Modeling Branch. (The previously used DRBC salinity model is a two-dimensional (length and depth) model that cannot deal accurately with channel modifications.)

   Currently the DRBC OASIS model uses a regression fit to the current DRBC salinity model. It was adjusted "by eye" to achieve a reasonable model-to-model fit for the purposes of this study. The current regression fit is extremely crude and in need of upgrade. Either of the new models developed for the Corps of Engineers or the DRBC could provide the basis for improved representation of salinity in the DRBC OASIS model. A regression or neural network fit to these models, calibrated for low flows, would be much more appropriate. It is also appropriate to directly link DRBC OASIS and one of these models for detailed confirmation of selected runs made using the regression or neural network fit. The problem with using the direct linkage to the Corps' model for all runs is simply one of computational burden.

   In addition, the work previously completed by the Corps of Engineers to develop salinity versus cost functions for Estuary water users should be evaluated and updated to reflect newer information.

2) Evaluate and update the salinity intrusion versus industrial and public water supply cost information originally developed by the Corps of Engineers in the early 1980s. This information is needed to

evaluate the relationship between Estuary inflow and salinity-related costs to water users.

3) Pursue final peer review and publication of the USGS particle tracking study to document the relationship between Estuary chlorides and P-R-M salinity and evaluate whether the coupling of an Estuary salinity model with this particle tracking model is necessary or feasible. (Note: This recommendation has been included at the request of the DRBC staff.)

4) Develop and fund studies to better understand the ecology of the Estuary and the impacts of changes in the freshwater inflow regime during droughts.

   The research concerning the role of freshwater in the ecology of the Delaware Bay is sparse, perhaps because there were other causes, such as pollution, that were hypothesized to have a greater and more immediate adverse impact. The out-of-Basin diversions and the releases from the reservoirs have changed the volume and timing of inflow to the Estuary. The effect of regulation by the reservoirs in the Basin on the amount of freshwater entering the Bay is most pronounced during periods of prolonged drought. During these periods, flows are maintained at a higher level than would have occurred in an unregulated system. During normal and high flow periods, less inflow enters the Estuary due to out-of-Basin diversions (up to 800 mgd to New York City and 100 mgd to the State of New Jersey) and flow skimming by the reservoirs. Considerably more research is needed to establish impacts of the rate and timing of freshwater inputs from the current system or any alterations that may be proposed.

5) Use water quality models to evaluate the relationship between freshwater inflow and water quality in the Estuary. DRBC has developed such a model for the upper Estuary. This needs to be used to better understand the relationships on a large scale. The existing modeling capabilities for the Estuary should be evaluated in terms of the additional work needed to analyze such processes as eutrophication, sediment interactions, and biomass transport and their relationship to inflow. Relationships between water quality parameters and ecological indicator species should be incorporated with the water quality modeling.

4.11 Tulpehocken Creek from Blue Marsh Dam to Mouth

4.11.1 Setting

The 6.7 mile study segment of Tulpehocken Creek (Figure 4.13) is downstream of the U.S. Army Corps of Engineers' Blue Marsh Reservoir and upstream from the Schuylkill River. The drainage area of the creek above the dam is 175 square miles of mostly gently sloping farm and woodland in Berks and Lebanon Counties, Pennsylvania. Downstream from the dam, the creek is highly accessible to the public as it flows entirely through state, county, and city parks to the Schuylkill. Tulpehocken Creek has become a highly regarded cold water trout fishery because of the releases from Blue Marsh Reservoir. The dam has a multiport outlet works that permits control over the temperature of the release by allowing water to be taken from varying depths in the reservoir.

Figure 4.13
Tulpehocken Creek

Blue Marsh Dam is within six miles of Reading, Pennsylvania, a metropolitan area of over 213,000 people, about 65 miles from Philadelphia. The region supports many major industries, including primary metals, electrical and non-electrical machinery, equipment and supplies, food processing, and fabricated metals products. Reading is also a destination for tourists and discount retailing. Agriculture and forestry are the primary land uses, as only about 20 percent of Berks County is urbanized.

Put into operation in 1978, Blue Marsh Reservoir provides flood control storage (10.6 bg winter, and 8.8 bg summer), DRBC-owned storage for maintaining Estuary inflow (2.6 bg), water quality protection storage (2.2 bg), and recreation. The recreational uses of the park site and the creek below the dam include picnicking, swimming, boating, and fishing. Point and non-point sources of pollution in the headwaters of the lake cause water quality problems and sometimes curtail recreational activities. In general, however, releases are of high quality. The minimum release requirement during non-drought conditions is 50 cfs. Nine cfs can be withdrawn from the creek by the Western Berks Water Authority (WBWA) at a point 1.2 miles downstream from the dam for public water supply. During DRBC Lower Basin *drought warning* or drought conditions, the conservation release can be reduced to 30 cfs (including the 9 cfs for the WBWA), but releases to help meet flow targets at Trenton frequently keep releases higher. Flows have exceeded 50 cfs 96 percent of the time and 30 cfs 99.5 percent of the time, which approximates the frequency prior to the dam's construction.

Reservoir water levels are typically raised from winter to summer pool during a two-week period beginning on or about April 1 of each year. To accomplish this increase, the discharge is typically held at 175 cfs below inflow for the two-week period. (175 cfs for two weeks is enough water to raise the pool from winter to summer storage levels.) Drawdown from the summer to the winter pool typically occurs during a two-week period beginning on October 1.

4.11.2 Issues and Analysis

The following flow management issues were identified for Tulpehocken Creek:

- Section 4.11.2.1 Trout Habitat and Recreational Fishing
- Section 4.11.2.2 Use of Blue Marsh Releases to Meet Trenton Flow Target

4.11.2.1 Trout Habitat and Recreational Fishing

Releases from Blue Marsh Reservoir have made it possible to establish a trout fishery below the dam. The river is stocked with both adults and fingerlings. Recent reports indicate that the wetted area available to insect larvae that provide food for the fish is limited by the releases made during the spring refill period. In particular, flows below 70 cfs seem to create a significant reduction in wetted area, which is a concern given that typical flows during the refill period may be as low as 50 cfs. In recent years, the timing of spring releases has been adjusted with this in mind. Alternative refill strategies, particularly those based on forecast inflows, may further improve this situation.

a) Trout habitat acres by year

The acres of habitat suitable for trout feeding (caddis fly development) can be determined from the minimum spring flow from an OASIS model run and the IFIM study done by the Corps of Engineers and the PAF&BC. The index display can be a bar graph indicating the annual value for the minimum area.

4.11.2.2 Use of Blue Marsh Releases to Meet Trenton Flow Target

This issue was cited by the Philadelphia District of the U.S. Army Corps of Engineers. It has been the practice of the DRBC, which owns some of the storage in Blue Marsh Reservoir, to count directed releases from Blue Marsh Reservoir toward the total directed release needed to meet the Trenton flow target. The rationale has been based on modeling which shows that the salinity control benefits are the same whether freshwater enters the Estuary near Trenton or at the mouth of the Schuylkill River. This rationale may not apply to other purposes for maintaining freshwater inflow, such as Estuary habitat, wasteload allocation, or maintenance of any Schuylkill River flow targets, if they are considered. Additional study of instream and Estuary parameters versus inflow is needed to support the development of release policy and operations for purposes other than salinity control.

4.11.3 Additional Information and Study Needs - Tulpehocken Creek

The only issue identified in this stream segment was the improvement of trout habitat and, coincidentally, recreational fishing. The maintenance of a healthy trout fishery in this segment is dependent upon the release of adequate cold water from Blue Marsh Reservoir. The ability of Blue Marsh Reservoir to maintain sufficient cold water for downstream temperature has been marginal during some years based on Corps of Engineers data. The following is recommended:

1) Develop a thermal model for Blue Marsh Reservoir.

2) Develop an instream thermal model for Tulpehocken Creek below the reservoir. Together, these models would allow better quantification of the cold water available and more effective utilization of releases targeted at maintaining both habitat and instream temperatures.

4.12 Schuylkill River from Confluence with Tulpehocken Creek to Mouth

4.12.1 Setting

The project's Schuylkill River segment (Figure 4.14) extends 77 miles from the river's junction with Tulpehocken Creek at Reading, Pennsylvania, to the river's mouth in Philadelphia where it enters the Delaware River Estuary. The river is characterized by generally modest gradients, a few very modest rapids, and several low dams constructed during the 19th century to support river and canal transportation and industrial water power. The Fairmount Dam in Philadelphia is the head of tide. Between Reading and Fairmount Dam, the river passes through rural, suburban, and urban portions of Berks, Chester, and Montgomery Counties and the Fairmount Park section of Philadelphia. Over three million people live in the area.

River access is relatively limited except within Philadelphia, where access is excellent. There are increasing miles of bike trails not far from the river's edge and increased interest in recreational uses of the river. Downstream of Fairmount Dam, recreational uses have been restricted due to limited access and water quality concerns. Water quality throughout the Schuylkill River has dramatically improved during the past 30 years due to the implementation of the Federal Clean Water Act and the attendant improvement in wastewater treatment.

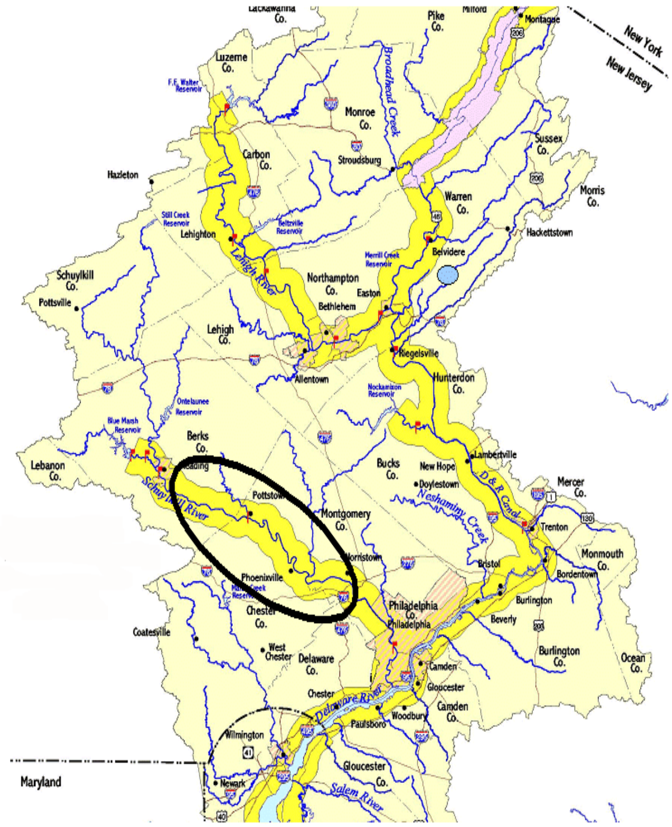

Figure 4.14
Schuylkill River

Water resources demands in the region are high due to the density of development in the area. The Schuylkill watershed leads all of the major tributaries in consumptive water use. During the summer months, the Point Pleasant diversion project replaces a portion of this consumptive use with water diverted from the Delaware River. The City of Philadelphia obtains approximately 50 percent of its water supply from the Schuylkill River. Much of the supply to areas outside of Philadelphia is from ground water. To address problems with ground water protection, the DRBC adopted Resolution No. 80-18 (effective date January 1, 1981), delineating a ground water protection area in southeastern Pennsylvania. The resolution was revised in 1999 to increase ground water protection in portions of Berks, Bucks, Chester, Lehigh Counties and all of Montgomery County. The resolution imposes limits on ground water withdrawals in order to avoid depletion of natural streamflows (ground water eventually seeps into streams) and to protect ground water quality.

4.12.2 Issues and Analysis

The issue of potential growth of water demand for power generation was identified as an issue for this stream segment based on the interviews conducted by HydroLogics. The DRBC staff cited several other areas of concern.

4.12.2.1 Increased power generation

Interviews revealed concern over the potential for large scale increases in consumptive use for power generation along the Schuylkill. Such increases could significantly lower flows in the river and, by extension, affect downstream water users (e.g., the Philadelphia water supply). The index displays needed to evaluate these issues are the same as those discussed for the Lehigh River (see section 4.7.2.4), and would show instream flows, and water demands and shortages.

4.12.3 Additional Information and Study Needs - Schuylkill River

The DRBC staff suggested the following information needs for the Schuylkill:

1) Obtain data relating boating quality and flow rates. The Schuylkill is a Pennsylvania-designated Scenic River, and data relating flow and boating quality should be assembled and correlated. An opportunity to collect such data could be provided through the annual Schuylkill River Sojourn.

2) Document the relationship between Blue Marsh releases and downstream improvement in dissolved oxygen (DO) levels. DO levels have historically been problematic in the Schuylkill. Additional work is needed to correlate releases from Blue Marsh Reservoir with increases in downstream DO conditions.

3) Determine the minimum flow requirements to maintain intake withdrawal capability at major Schuylkill River water supply intakes. At least five entities hold PADEP water allocation permits to withdraw water from the river below Reading for public water supply. The largest allocation is 258 mgd (400 cfs) to the City of Philadelphia. (The allocation was increased to 258 mgd from 200 mgd in 1957.) This flow is not always available. The minimum daily flow of record at Pottstown is 175 cfs (September 1932) and the minimum monthly low flow is 279 cfs (September 1964). To protect the City's supply, the water allocation permits held by the Borough of Phoenixville (7.0 mgd) and the Philadelphia Suburban Water Company (20 mgd) prohibit withdrawal when the flow in the river at Philadelphia is below 258 mgd. The permits held by the Pottstown Borough Authority (8.0 mgd) and the Pennsylvania-American Water Company (formerly Keystone Water Company and, prior to that, the Norristown Water Company) (17.5 mgd) are unrestricted.

4) Evaluate the potential growth of water demand for power generation. The DRBC staff cited the potential for large scale increases in consumptive use for power generation in the Delaware Basin. The geology of the Schuylkill makes it prone to low flows during drought periods and there is no established flow target for the stream. Significant increases in consumptive use could lower flows in the river and, by extension, potentially affect downstream water users (e.g., the Philadelphia water supply).

4.13 General Recommendations To Improve Analysis Capabilities and Promote Management Flexibility

HydroLogics recommends the following activities, applicable to multiple stream segments, in order to better understand the relationships between flow and benefits from a Basinwide perspective, and to increase flexibility in water resources management. The recommendations are grouped according to whether they are considered by HydroLogics to be either high or medium priority activities. It should be noted that a number of the recommendations call for development or refinement of modeling tools. Inherent in this recommendation is the need to evaluate the data collection networks required to support the modeling.

4.13.1 High Priority Recommendations

4.13.1.1 Extend and Improve the Inflow File Used as Input to the DRBC OASIS Model

DRBC is currently involved in a cooperative effort with the Corps of Engineers to extend the existing 60-year inflow file and determine a means of controlling modeled flow fluctuations at nodes where the fluctuations appear unrealistically high. The reasons this work is needed are the unrealistic variations in daily flows, particularly at low flows, output by the DRBC OASIS model, and the need to extend the inflow file from 1986 to 2000. The work includes extension of the inflow file data set, modification of the inflow file as necessary to reduce flow fluctuations, and inclusion of the reservoir operations of the Mongaup system in the DRBC OASIS model.

If the effort to control flow fluctuations is not successful, it is recommended that DRBC develop a new set of inflows using a methodology different than that used previously. The new methodology would involve first estimating local inflows on a monthly basis based on differences between gages and best estimates of historical consumptive use, even if these estimates are extrapolations at best. If the time of travel between gages is more than approximately one-half day, then the differences should be based on appropriately staggered records. The local monthly flows then need to be disaggregated to daily inflows based on local, unregulated, headwater gages. Given the gages and local inflows, the parameters of a Muskingum or lag-type routing equation can be estimated using regression. This equation could then be used to estimate time of travel. This would require modifying the "traveltimes.ocl" file in the DRBC OASIS model.

4.13.1.2 Improve Water Demand Forecasting Techniques for the Basin

The DRBC needs to be able to analyze impacts of water shortages in order to develop effective conservation and supply plans. In order to do this, it needs a more comprehensive method for forecasting demands than is currently available. The DRBC also needs updated water use data in order to evaluate trends. Developing the tools required for more sophisticated demand forecasts is, therefore, a high priority.

The DRBC staff and Basin states are in the process of updating the database to provide for an improved set of water demand projections. From a Basinwide perspective, the emphasis in assessing water demand has been on consumptive water use (water used but not returned to the Basin). Consumptive use impacts the amount of freshwater inflow to the Estuary, as well as losses of base flow in individual watersheds. The daily flow modeling database used with the DRBC OASIS model incorporates observed streamflow to generate historic inflow. All historic inflows, evaporation, and ground and surface withdrawals are included in these observations of streamflow. Modeling of future proposed operations relies on consumptive use forecasts to determine the additional loss of water over and above the historic conditions.

The techniques that have been used to forecast water demands in the Delaware Basin have not incorporated economically-based demand forecasting models. Such models account for growth in various economic sectors, seasonal and weather-related variations, and conservation practices and are readily available (e.g., IWR MAIN). These models can also estimate the economic benefits of water use and the costs of water shortages and, thus, improve the ability to define flow management versus benefit relationships.

4.13.1.3 Develop Toxic Spill Modeling Capability for the Delaware River and Major Tributaries

Many kinds of toxic material are regularly transported across and within the Basin. Given the dependence of the Basin on surface water, it is critical that the Commission have the means to predict the instream transport and fate of toxics when spills occur. This should include both the advection, dispersion, and degradation of toxics in the stream, and should become the basis for emergency response plans and exercises. This capability would allow the Commission to develop action plans and test them using exercises. The modeling required to track spills is different from the modeling needed to track flows, since flow modeling is based on the time of travel of hydraulic waves, and spill tracking requires modeling the movement of physical particles of water and pollutant. Spill tracking also requires knowledge of the fate of the pollutant in the environment, knowledge that may be lacking for some pollutants. Developing the models and other tools required is a very high priority. The DRBC is participating in the development of an early warning monitoring and tracking system financed by the City of Philadelphia.

4.13.1.4 Evaluate Forecasting Tools to Enable the Evaluation and Possible Implementation of Adaptive Management

Adaptive management is a process in which management strategies change in response to changes in the state of the water resources system, new scientific understanding of how management actions affect the system, and changes in management objectives. Implementing an adaptive management strategy requires monitoring of the things that might cause the management strategy to change - the state of the system, the progress of related science, and the management objectives. Without monitoring, adaptive management cannot be effective.

Forecasting tools predict the future state of the water resources system, and thus may be an important part of an adaptive management strategy. Using forecasting tools as a part of a management strategy broadens the range of alternatives and may dramatically improve the ability to manage for important objectives. We suggest that DRBC work with the National Weather Service (NWS) to apply products from the Advanced Hydrologic Prediction System (AHPS) to flow management. The NWS has available rainfall-runoff-based models that could be implemented for the entire Basin. These would provide medium-term probabilistic forecasts of inflow in Extended Streamflow Prediction (ESP) format. These forecasts may be useful in anticipating potential droughts, setting seasonal targets for maintaining cold water fisheries below reservoirs, and better indicating when it is appropriate to issue drought "watch," "warning," and "*emergency*" declarations. The DRBC OASIS model is set up to handle ESP outputs and can test the efficacy of forecast-based operating rules.

4.13.1.5 Investigation of Water Banking and Conjunctive Use of Ground and Surface Water

Based on the information obtained and issues identified during the course of this study, HydroLogics suggests that the concepts of water banking and conjunctive use of surface and ground water be investigated as a means to increase flexibility in flow management.

In the recent past, temporary adjustments to the Decree, approved by all the parties, have set up "banks" of water in the NYC Delaware River Basin reservoirs in order to provide flexibility in meeting the needs of fisheries. These banks differ from fixed minimum flow targets because they allow the flexibility to use water when it is needed most. Banks can be established through the designation of a seasonal fixed quantity of water for a specific purpose, or banks can be "earned" by reductions in flow targets during periods when the targets can be reduced without adverse downstream impacts. Both types of banks have been used in the management of the Upper Delaware tailwater fishery. Because there are multiple objectives for the use of storage for flow augmentation and because the existing operating rules stem from court decisions on interstate water rights, water banking proposals are negotiated among the representatives of the Decree Parties and must receive the unanimous consent of the Parties prior to approval by the DRBC. Banking nevertheless represents a potential means of improving efficiency in the use of storage when it can be implemented without adversely affecting any one of the Parties.

The USGS and other agencies have conducted extensive investigations of the ground water resources of the Delaware River Basin. Some ground water models have been developed, but models which represent the interaction between ground and surface water have not been configured for water management operations. Ground water and surface water conjunctive use could substitute surface water for ground water when surface water is plentiful, thus preserving ground water for use during periods of low flow. This kind of conjunctive use might provide increased reliability for the ground water supplies while minimizing low flow impacts on streams. This type of management might be most feasible for large confined aquifers which have a delayed response to dry conditions. For fractured rock aquifers, which are affected by drought much more quickly, the practice has been to use large surface water sources to supplement ground water when well yields fall off during dry weather. The use of wells is generally cheaper than surface water due to treatment costs. A conjunctive use scheme which preserved ground water for drought periods might be useful in preventing over-drafting of aquifers and might help preserve streamflow during drought conditions. Modeling of surface and ground water interactions is recommended as a means of evaluating this concept. One of the primary purposes of this modeling is understanding the impacts of changes in the aquifer water table on streamflow. Any proposal to rely more heavily on ground water during drought would require evaluation of impacts on base flow via lowered ground water levels.

Conjunctive use with out-of-Basin supplies could work in a similar fashion. For such schemes to provide benefits to all parties, the total diversion (over time) would need to be greater (this provides the benefits to the out-of-Basin users), but the diversions would be significantly reduced below existing levels during drought (this provides benefits to the Delaware Basin. The chances of success of such a scheme would greatly depend on available out-of-basin storage.

4.13.1.6 <u>Habitat Model Development</u>

Attempting to assess the impacts of flows on habitat – be it trout habitat, riparian vegetation, or other – is at least as much art as science. Still, such habitat estimates are typically the only reasonable surrogate for deciding how much water to commit to preserve and enhance environmental and recreational values. Habitat models are needed wherever flow management is used to enhance ecosystem values or promote the success of individual species (e.g., trout). Several IFIM studies have attempted to quantify flow effects on trout habitat at selected locations in the Basin. Much work has been done to establish minimum releases for cold water habitat needs on the East and West Branches of the Delaware, the Neversink River, and Tulpehocken Creek, as well as the Mongaup and Lackawaxen Rivers through FERC relicensing processes. According to the NYSDEC (Sheppard), their work has focused on the base flow requirements for the life stages of aquatic species, and the results give a clear indication of the order of magnitude of the seasonal base flow requirements for the ecosystem components in general. While re-establishment of natural flow conditions is extremely unlikely, the results can be used to more closely replicate natural flow variation. The results of this work have not been presented here, but have been documented in several references (such as NYSDEC Technical Report 83-5, which recommended flow targets now being considered in negotiations by NYC and NYSDEC) and can readily be used in combination with flow modeling in flow management negotiations.

Habitat models generally should be seen as establishing trade-offs rather than thresholds. Natural flows vary considerably and most species are adapted to that variation. More flow may be better (or worse) depending on the time of year and other factors. Judicious use of habitat models can provide useful information to guide decisions about flow management, but generally are not appropriate for prescribing absolute minimum or maximum flows.

In order to enhance the credibility of habitat models and to reduce interstate disputes over evaluation methods, we recommend that DRBC create an environmental modeling oversight committee to review and standardize such efforts within the Basin. This committee should have representation (although perhaps non-voting representation) from stakeholder groups as well.

4.13.1.7 <u>Development of Reservoir Water Quality Models</u>

The need for reservoir water quality models has been raised in the sections above that deal with individual stream segments. Some general comments, however, are in order. Eutrophication is or may become a problem in many Basin reservoirs. Evaluating alternatives to correct such problems will require reservoir water quality models in addition to the watershed models described below. While watershed models may include reservoir and lake quality routines, they may be too crude for effective use on some of the Delaware River Basin reservoirs. Where temperature is important (most major reservoirs in the Basin), these models should include a temperature component. Temperature modeling is generally not included in the watershed models. The watershed and reservoir modeling work performed by the NYCDEP for the three NYC Delaware Basin Reservoirs could provide guidance in the development of models for other reservoirs.

Water quality problems below reservoirs may require both reservoir water quality modeling (similar to or complementing the temperature models discussed above) and instream water quality modeling. While a wide range of competent instream water quality models exists, including such models as QUAL II, the functions of water quality models are also available through the watershed models.

4.13.1.8 Maintain and Refine Monitoring Networks

The development of the information and tools recommended in this report is dependent on the data provided by the Basin's monitoring networks for water quality and quantity. For example, the USGS stream gaging network is the backbone of the inflow data set used to drive flow modeling for the Basin. Loss of monitoring capability would compromise the ability to assess trends and to model operating scenarios.

4.13.1.9 Develop More Representative Distribution of Modeled Water Demand

The projected rapid growth in the construction of gas-fired turbines to meet peak regional electrical demand is potentially an issue anywhere in the Basin. Although each case is unique, the major factors involved in siting these facilities are proximity to natural gas, electrical transmission lines, and water. DRBC's policy requires that these facilities replace the consumptive losses to the system, but current regulations do not specify where the makeup water for these facilities must be delivered.

The current DRBC OASIS model lumps consumptive use increases together at Trenton. This is satisfactory for addressing the impacts of flow management policy on Estuary salinity but is unsatisfactory for assessing impacts on tributary streams. It is recommended that DRBC's demand data be disaggregated and modeled in a more physically realistic manner. The DRBC OASIS model will easily support this disaggregation.

4.13.1.10 Development of Watershed Water Quality Models

This would include developing non-point water quality models where they do not already exist for reservoir watersheds and evaluating the feasibility of developing a non-point water quality modeling capability for the entire Delaware River Basin. These models are necessary to estimate future loadings of pollutants to reservoirs, streams, and the Estuary based on projected land use change and practices. The results can be used with reservoir, instream, or Estuary water quality models and flow modeling to understand the water quality impacts of flow management alternatives.

Watershed models predict nutrient and other pollutant loads based on land use and best management practices (BMPs). It should be possible to develop an initial, crude, Basinwide capability at low cost using EPA's BASINS system and watershed models such as SWAT. The newest versions of SWAT include OCL, which makes it possible to evaluate alternatives based on conditional operating policies. SWAT has also been partially linked to OASIS. Watershed models also include sophisticated instream water quality models, which should be used as the framework for instream water quality modeling.

4.13.2 Medium Priority Recommendations

4.13.2.1 Improve Ground Water Modeling for the Basin

Much of the water supply for the Delaware Basin comes from well fields. The USGS and other agencies have conducted extensive investigations of the ground water resources of the Delaware River Basin. Some ground water models have been developed, but models which represent the interaction between ground and surface water have not been configured for water management operations.

The DRBC, through its comprehensive planning process, expects to coordinate a Basinwide assessment of base flow characteristics. In addition, the USGS is currently developing for the DRBC a detailed ground water model of the French Creek watershed in southeastern Pennsylvania. It is recommended that the DRBC continue to pursue modeling which incorporates surface/ground water interactions as a means of investigating alternatives for flow management.

4.13.2.2 Investigate Strategies for Improving Boating Recreation

This study devoted much effort to investigating relationships between flow and the quality of the recreational boating experience. But managing flow to enhance boating involves more than a simple flow/quality of experience relationship. The timing of releases is also very important, e.g., more people will enjoy optimal recreation flows on a Saturday than will on a Tuesday. Many other types of releases (e.g., total releases for salinity repulsion) could be modified to also serve most effectively to enhance recreation. We recommend that the DRBC convene a committee to investigate strategies for using existing releases to enhance boating recreation or assign this task to an existing committee.

4.13.2.3 Develop a Coordinated Research Agenda to Identify Estuary Inflow Needs

The Trenton flow target was developed in part based on the desire to protect the Camden P-R-M aquifer from saltwater intrusion. A recent study by the USGS (Navoy, et al., 1999) indicates that the aquifer is less susceptible to salinity intrusion than previously thought. This study would seem to indicate a need to rethink the pattern of flow augmentation at Trenton and the criteria used to determine Lower Basin drought conditions in order to ensure the most effective use of stored water. We rate this as a moderate priority item because it is not clear that flow management can have a substantial effect on estuarine resources.

The specific scientific relationship between freshwater inflow and the protection of ecological resources in the Delaware Estuary should be investigated further and should include consideration of seasonal flow rates necessary to support natural resources for seasonal or migratory use. We recommend that the DRBC sponsor a colloquium to develop a coordinated research agenda for the Lower Basin focused on developing information useful for managing freshwater inflows to the Estuary and then support that research as appropriate.

Evaluating water quality impacts and changes in the Estuary will require watershed-based models for the entire Basin, as discussed above. A water quality model specific to the Estuary is also needed. Developing this model will be extremely complex and will likely involve extending the salinity model previously discussed in section 4.10.3. It will need to include salinity, BOD, DO, forms of nitrogen and phosphorus, sediment interactions, phytoplankton biomass, and chlorophyll. It may also need to include an ecological component if impacts on commercially valuable or endangered species are to be considered. DRBC already has a model for the Upper Estuary for some parameters, but developing the science base for a full model is likely to be a long term effort.

4.13.2.4 Combine NYC/DRB Versions of OASIS Model

OASIS models exist for both the Delaware River Basin and the New York City System. They overlap, but are not identical, from the NYC reservoirs down to Montague. Care was taken in developing these models to ensure that corresponding nodes had identical node numbers. Combining the two models would entail a moderate level of effort.

Currently, the DRBC OASIS model must make assumptions concerning the level of demand for NYC. Most runs are made assuming that the City takes its full allocation of 800 mgd during normal conditions, according to an annual pattern, with reductions under Watch, Warning, and Normal conditions per the Good Faith Recommendations and DRBC drought operating plans. Other runs assume lesser withdrawals during normal conditions. None of the runs reflect the changes in NYC withdrawals that result from changes in NYC's Croton or Catskill systems, nor do they reflect the withdrawals that occur at current levels of NYC demands.

Without a truly realistic estimate of NYC's current demands on the reservoirs, it is impossible for DRBC to accurately assess the impacts of changes in release strategies on conditions in the Upper Delaware Basin. In particular, the probability of occurrence of impacts cannot be estimated. Likewise, to the extent that Lower Basin conditions impact NYC reservoir releases, NYC cannot accurately assess the impacts of alternative policies on its water supplies. A combined Delaware River Basin - New York City System Model would overcome these difficulties, and would promote a fuller understanding of the impacts of changes in operating policies for all parties.

4.13.2.5 <u>Perform a Reconnaissance Study of Potential Flow Augmentation Projects</u>

It is likely that as new flow objectives are identified, additional storage would be needed to support these objectives. Accordingly, the feasibility of potential flow augmentation projects should be investigated. Priority should be given to expansion of existing facilities, and particularly to projects identified in Good Faith Recommendations 5 and 6 (F.E. Walter, Prompton, and Cannonsville Reservoirs).

5.0 CASE STUDIES

Five case studies were evaluated using the OASIS modeling system adapted to the Delaware River Basin. These are not comprehensive studies, but are examples of OASIS model runs and performance measures to demonstrate how operating alternatives that address specific issues can be evaluated. The case studies do not reflect any policy or proposals by the DRBC.

Three of the case studies were for the Upper Basin, defined as the watershed above Montague and including the NYC reservoirs. The remaining two are in the Lower Basin – one on Tulpehocken Creek (Blue Marsh Reservoir) and the other on the Pohopoco Creek (Beltzville Reservoir). Originally, a case study on the Lackawaxen River was envisioned instead of one on the Lehigh. But during the course of the project, HydroLogics was contracted by PPL to develop a much more detailed model of Lake Wallenpaupack, which would have been the focus of the case study. A large number of case studies were performed by HydroLogics and by PPL independently, and the results were presented to the DRBC Flow Management Technical Advisory Committee in October of 2001. Given that operations on the Lackawaxen are currently a matter of discussion between DRBC and PPL (both HydroLogics' clients) and that a significant number of studies had already been done, a case study concerning Pohopoco Creek below Beltzville Reservoir was deemed more appropriate.

The Upper Basin case studies were prepared for use in the sample Computer Aided Negotiation (CAN) session conducted by HydroLogics at the DRBC on June 5, 2001. At that time, DRBC's PP460 run of the Daily Flow Model represented the base case for modeling purposes. That is, it was the best available representation of the system as currently operated. The Upper Basin studies were copied from and ultimately compared to this run (draft_base_run). Since June 2001, the base case run (final_base_run) has been updated to include modifications for Wallenpaupack operations and a new routine for balancing the NYC reservoirs. The Tulpehocken Creek, Pohopoco Creek case studies were both based on this new version of the base run, but the Upper Basin case studies were run with the original model.

5.1 Upper Basin Case Studies

5.1.1 Case Study 1 - Trout Unlimited Proposal

The first of the Upper Basin case studies (Trout_Unlimited_Proposal) modeled a proposal from Trout Unlimited that called for much higher minimum releases from the NYC reservoirs. Fisheries releases from the NYC reservoirs have been a long-standing issue, and DRBC has adopted several revisions to the "Good Faith Recommendations" designed to enhance trout fisheries. NYSDEC has developed Instream Flow Incremental Methodology (IFIM) models to determine available trout habitat in the streams and also developed models that predict water temperatures at several points as a function of reservoir release and maximum and minimum daily air temperatures. The latter model is currently used to determine minimum desirable flows on a daily basis.

The objective of the Trout Unlimited proposal is to improve cold water fisheries conditions in the West Branch, East Branch, and Neversink by substantially increasing minimum flows. The following is a brief description of the proposal. Under "normal" or "watch" conditions, the Trout Unlimited minimum releases range from 600 cfs (summer) to 300 cfs (winter) from Cannonsville, 500 cfs to 150 cfs from Pepacton, and 228 cfs to 70 cfs from Neversink (see Table 5.1). These flows are more than four times higher than the minimum releases under current operating policies. (Because the minimum releases are so much higher, they are assumed to substitute for directed releases made to meet the Montague target. Consequently, no directed releases are made in the Trout Unlimited proposal run.) The Trout Unlimited proposal reduced the minimum releases by half during drought "warning" and "drought" conditions. This compares to a 15 percent reduction during "warning" and an approximately 80 percent reduction during "drought" under current operating policies. (This comparison is somewhat skewed because the normal minimums in the base run are much lower than those proposed by Trout Unlimited.)

Table 5.1, Minimum Releases Used for the Trout_Unlimited_Proposal Case Study

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pepacton	250	200	200	300	400	500	500	500	400	150	200	250
Neversink	150	150	200	228	200	150	100	100	100	70	100	150
Cannonsville	300	300	300	300	425	600	600	600	450	300	300	300

The performance measures used to evaluate this run included flows in each of the individual streams, storage in the NYC reservoirs, storage in Lower Basin reservoirs, and the location of the Delaware Estuary salt front. These are displayed in time series plots in Figures 5.1 through 5.6, below. Note that the salt front model used in these runs is a linear regression-based approximation of the two-dimensional hydrodynamic models currently used by DRBC. The regression model was developed by students at Cornell University, then modified by HydroLogics to get a better "eyeball fit." It is quite crude and is not sensitive to potential changes in channel geometry. It is used here only for the purposes of comparing model runs.

Even with no directed releases, the impact of the proposal on other water users in the Basin is striking. Filling of the NYC reservoirs becomes a rare event. Using the current rules that define drought status, the Basin is in drought almost 45-percent of the time as compared to 11-percent of the time under the existing operating policies. Average NYC diversions are reduced by about 21-percent or almost 160 mgd. Figure 5.1 compares the simulated storage in the NYC reservoirs between the base case and the Trout Unlimited proposal.

In contrast to the effects on the NYC reservoirs, the impact on Lower Basin storage is modest. Additional drawdown does occur, however, because releases to meet the Trout Unlimited targets are smaller and more poorly timed than the directed releases which would have been made. The impact on the Lower Basin occurs primarily because the lower storage in the NYC reservoirs results in minimal releases from those reservoirs at precisely the time water is needed to repel salinity in the Delaware Estuary. This, in turn, results in higher releases from the Lower Basin reservoirs to maintain required flows at Trenton. Figure 5.2 shows the impact of the proposal on simulated Lower Basin storage using hydrology of the 1950s, which includes two serious drought events.

Figure 5.3 shows that the Trout Unlimited proposal has a positive, but generally very small impact on the position of the salt front in the Estuary. The larger releases from the New York City reservoirs do move the front slightly downstream, but they are not timed very well for salinity repulsion.

Figures 5.4, 5.5, and 5.6 show how, during a typical period (1954 and 1955), the Trout Unlimited proposal achieves the objective of maintaining higher minimum flows in the Upper Delaware tributaries below the NYC reservoirs. It is important to note that the NYC reservoirs rarely fill under the Trout Unlimited rules. Uncontrolled spills and the resulting high flows in the river reaches downstream of the reservoirs are also rare events. (In contrast, under current operating policies, Cannonsville and Pepacton spill every few years and Neversink somewhat less frequently.)

In summary, this case study shows that the implementation of the minimum flows proposed by Trout Unlimited would have substantial impacts on other water users in the Delaware Basin and on New York City because drought conditions would be triggered more frequently. The case study also illustrates that the demands on the system are such that it is important to target releases as closely as possible to meet the most critical needs with the minimum amount of water. Large, continuous minimum flows that greatly exceed natural flows during low flow periods have the most significant impact on storage for water supply. In contrast, rules that seek to maintain more natural habitat levels at low flows would have less of an impact. Additional information is still needed to quantify the fisheries benefits of the Trout Unlimited proposal with those of the existing operating rules.

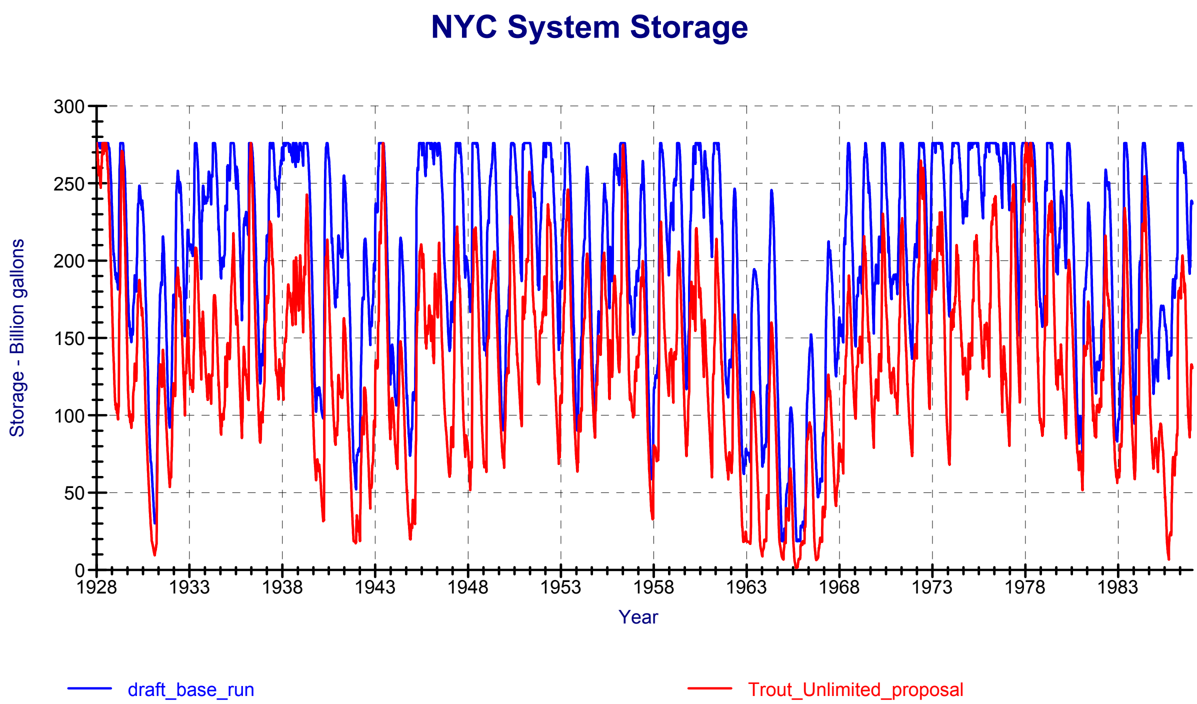

Figure 5.1

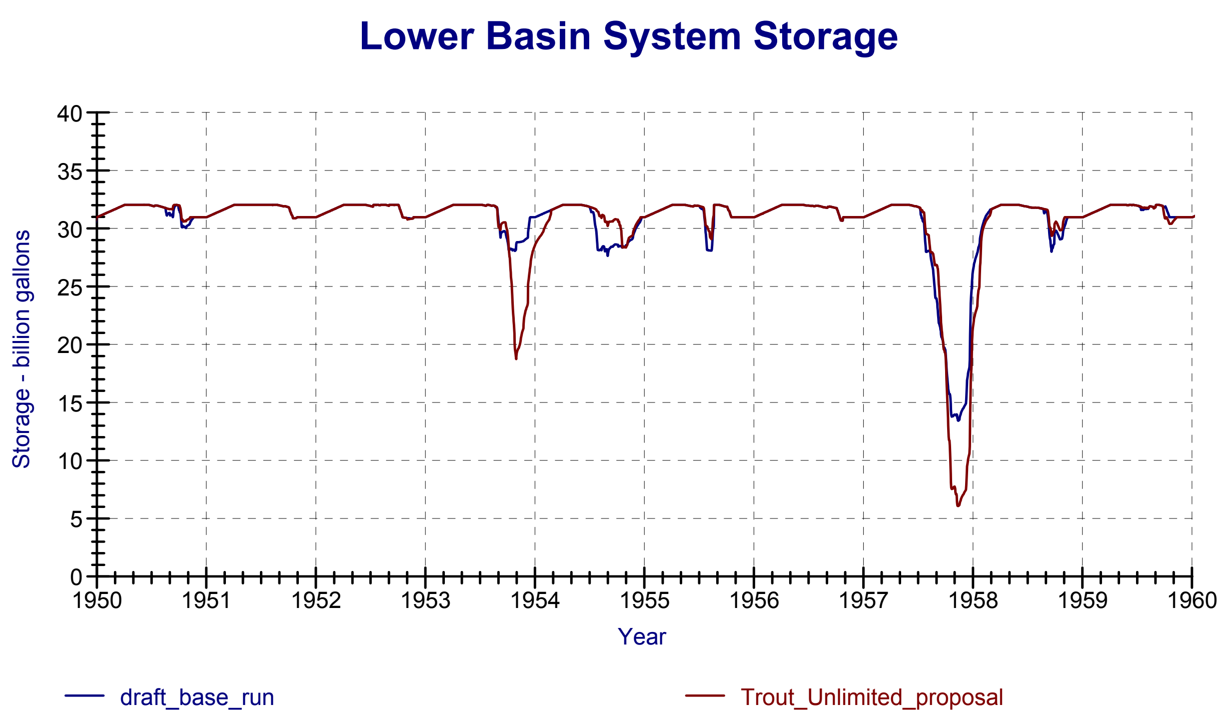

Figure 5.2

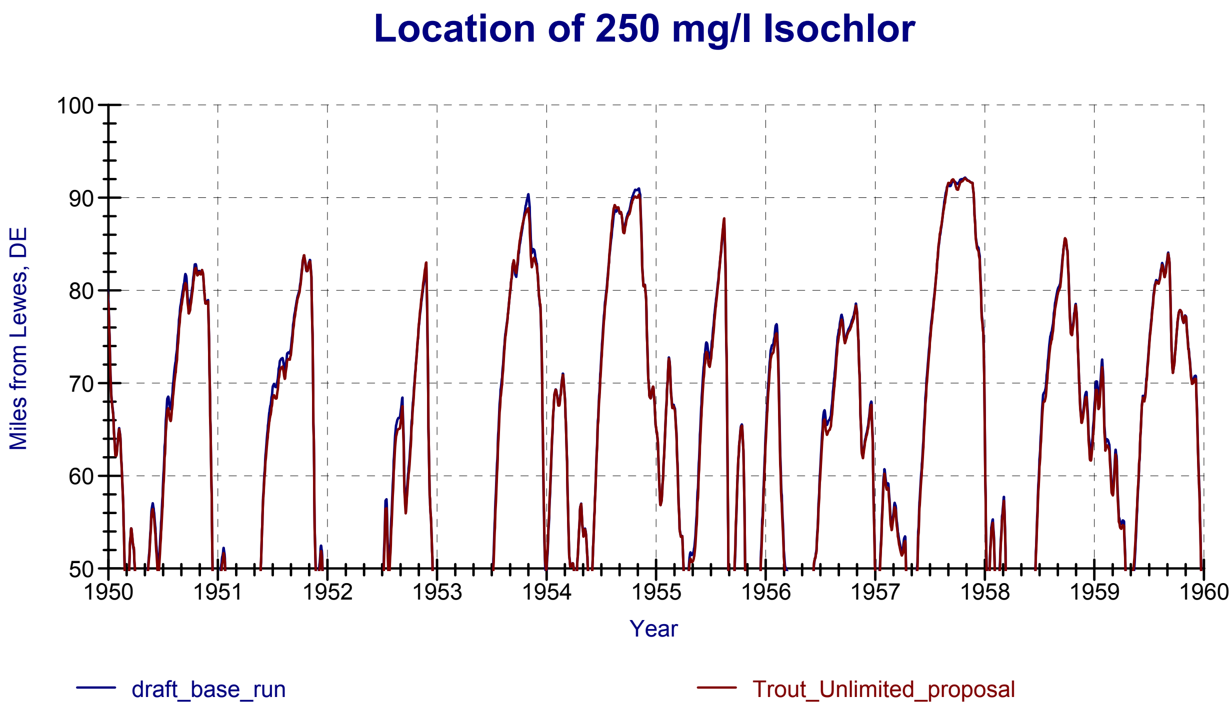

Figure 5.3

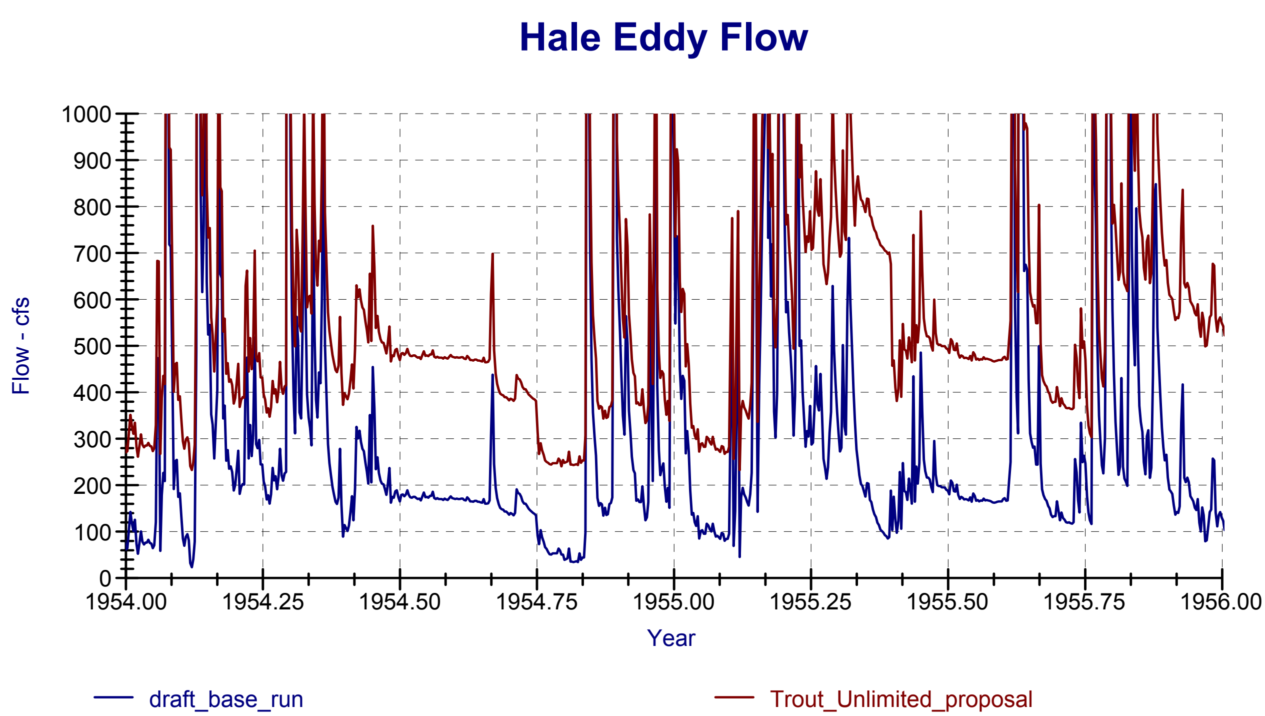

Figure 5.4

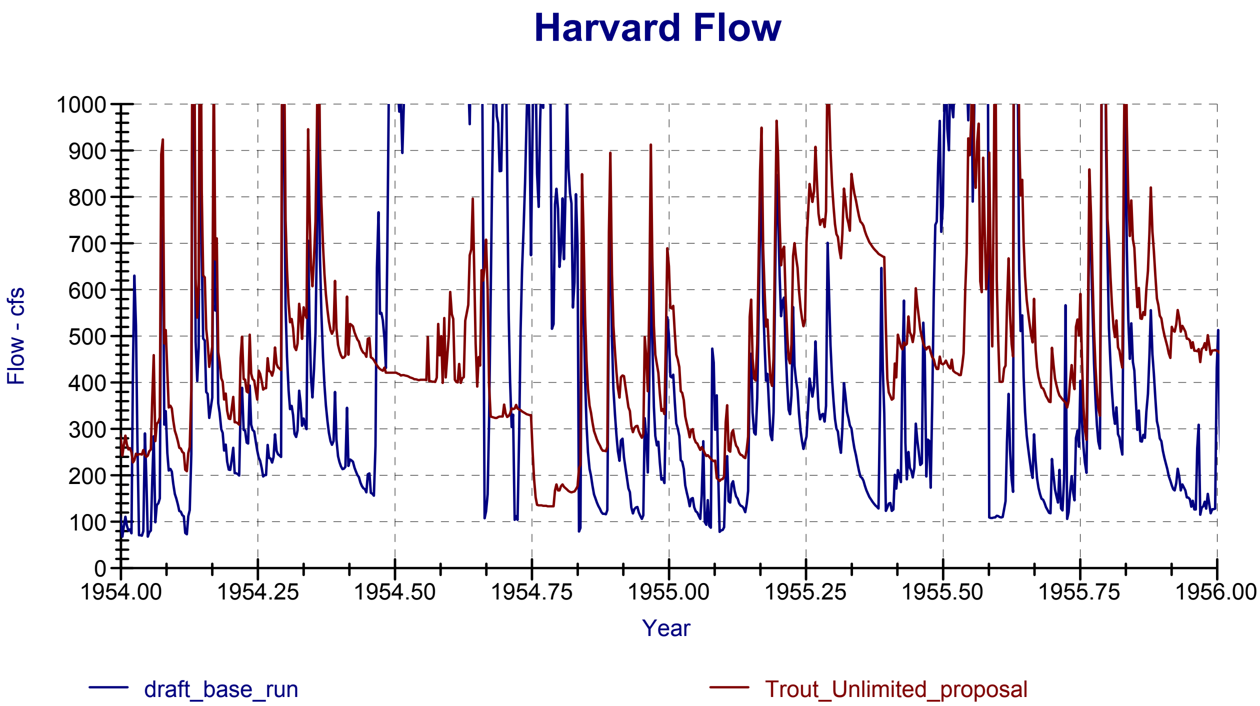

Figure 5.5

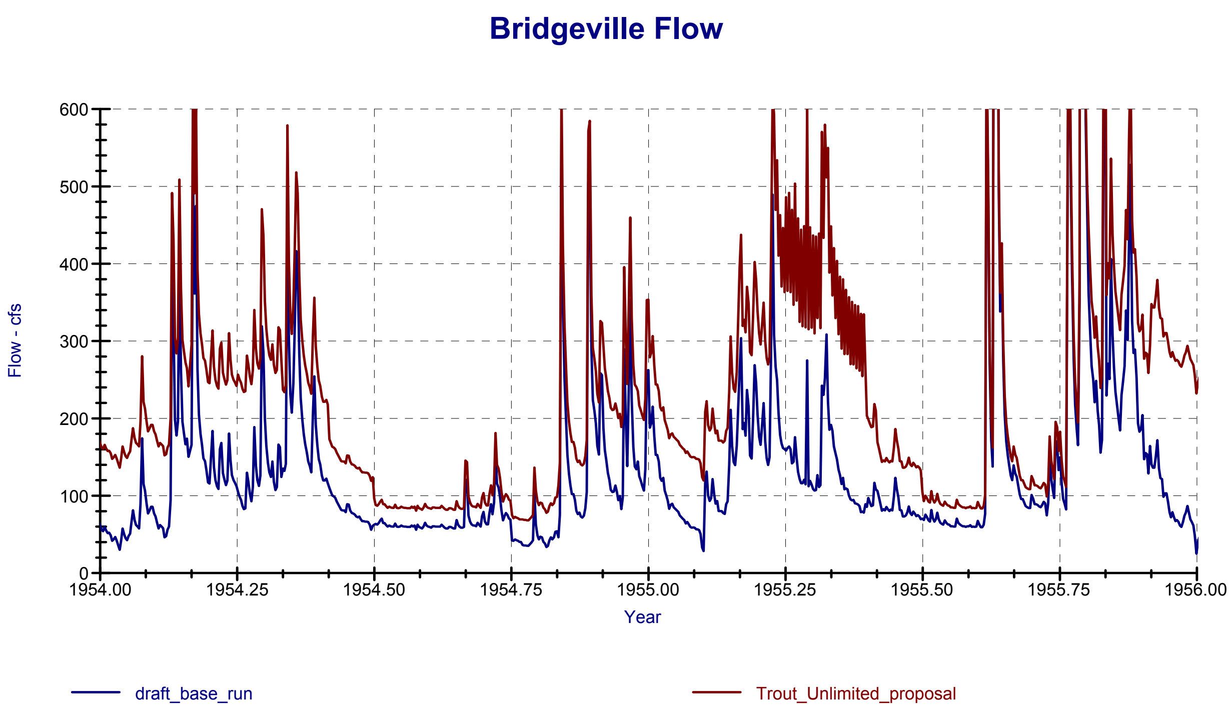

Figure 5.6

5.1.2 Case Study 2 - NYC Reservoirs Operated to meet Trenton Target

The Montague flow target was specified in the 1954 Supreme Court Amended Decree in order to maintain an "equitable apportionment" of the waters of the Delaware River. The second of the Upper Basin case studies (Trenton_Target_only) was aimed at illustrating the improvements in water supply reliability that could be obtained by changing the focus of releases from meeting fixed flow targets at Montague and Trenton to meeting salinity-based flow targets at Trenton alone. This case study replaced the Montague target with a requirement that the NYC reservoirs be used in conjunction with Lower Basin reservoirs to meet the Trenton target.

The rules (operating assumptions) tested in this case study call on the NYC reservoirs to make releases of 70 percent of the water required to meet Trenton flow targets in the late spring and summer (May through August) or when the Lower Basin reservoirs fall to low levels. This has the effect of postponing the drawdown of the Lower Basin reservoirs until after the recreation season. In the fall and winter, the Lower Basin reservoirs are utilized to meet all of the Trenton target, until they are at minimal levels. The rules utilize the water in the Lower Basin reservoirs in this way because the probability that they will refill and spill in the spring is much higher than for the NYC reservoirs. By utilizing water that is likely to be spilled in the spring, these rules maximize the total combined storage available in the Upper and Lower Basins during droughts.

Such an operational change would represent a departure from the requirements of the 1954 Amended Decree which places the burden of maintaining downstream flows on the New York City reservoirs. The construction of the downstream reservoirs in the 1970s represented an effort by the DRBC to provide augmentation of downbasin flows over and above what was being provided by the NYC reservoirs, rather than as substitutes for the NYC reservoir releases. In addition, the potential impacts on the river of reduced flows at Montague resulting from this hypothetical operation would need to be examined.

The rules for this case study also change the way in which the Trenton target is calculated. Current rules vary the required flow based on storage. They are replaced with the rules that determine flow requirements based on the position of the salt front and the time of year. Thus, releases from both the NYC and Lower Basin reservoirs are substantially reduced when the salt front is further down the Estuary and increased as it progresses upstream toward Trenton, even during what would now be considered normal operating conditions. This has the effect of lowering the flow target at Trenton much of the time, but, since uncontrolled inflow at Trenton is normally much more than 3,000 cfs, the effect of reducing the target on actual flows is not often apparent.

The performance measures used to evaluate the results of this case study were storage in the NYC Reservoirs, minimum flows below the NYC reservoirs, storage in the Lower Basin reservoirs, the frequency and duration of "watch," "warning," and "drought" conditions, and the position of the salt front in the Delaware Estuary.

The effectiveness of these rules at preserving storage while meeting the Trenton target is quite clear. Figure 5.7 compares the storage in the NYC reservoirs with the storage in the base run over the period of record. Figure 5.8 shows the same differences for the simulated decade of the 1950s. With the exception of the drought of the 1960s, when storage is simply inadequate to meet all instream flow requirements and water supply demands in both runs, the minimum storage in the reservoirs is typically 25 to 50 billion gallons higher at the worst point in the drought. By comparison, the capacity of all of the Lower Basin reservoirs combined is about 30 billion gallons. Because the Lower Basin reservoirs refill every year, this means that much additional water is available in the later years of a multi-year drought. As a result of the increased storage, the frequency and duration of various basinwide drought alert conditions are substantially reduced. "Watch" days are reduced by 15 percent, "warnings" by 40 percent, and "droughts" by 43 percent. The reduction in "watches," "warnings," and "droughts" allows New York City to divert an additional 34 mgd on average over the course of the simulation. Likewise, diversions to New Jersey are also increased.

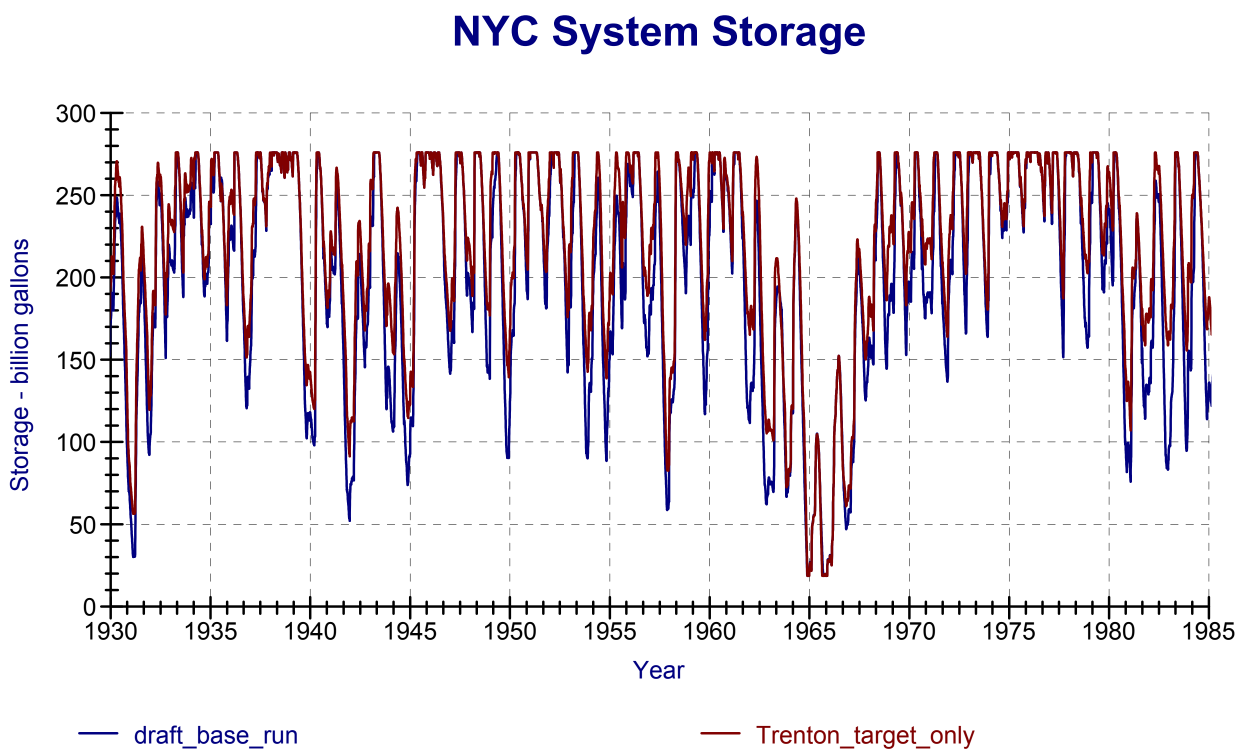

Figure 5.7

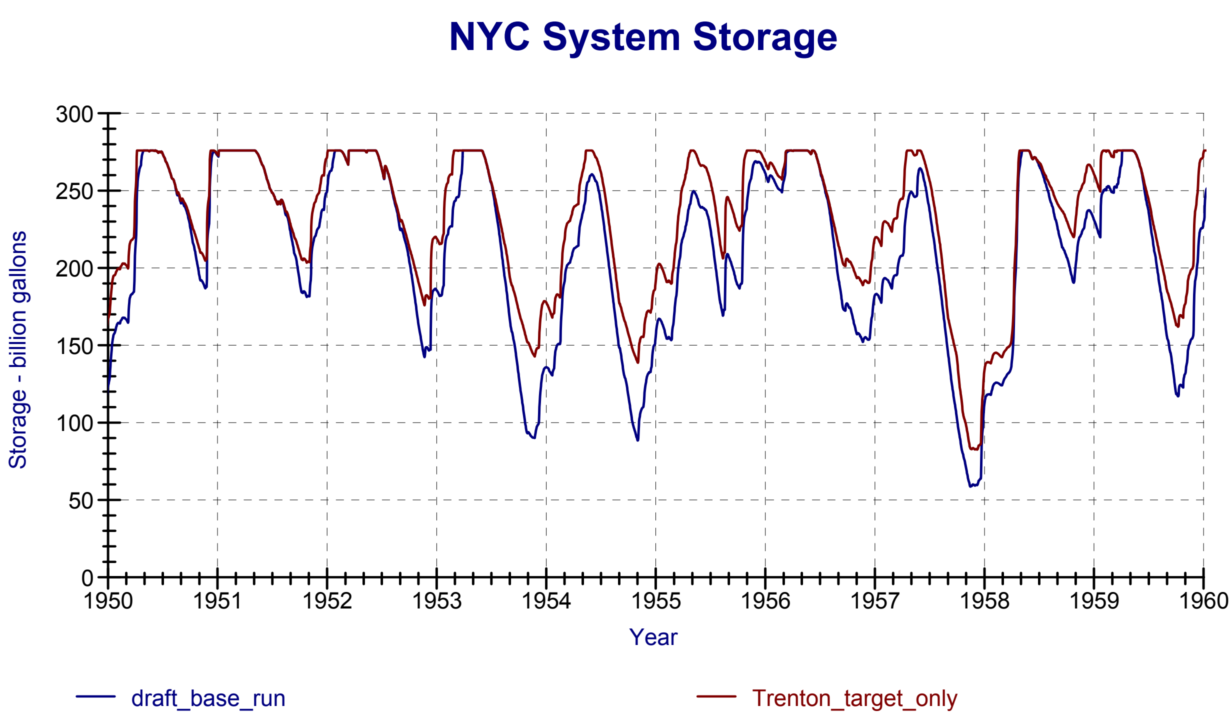

Figure 5.8

Figure 5.9 shows typical impacts on the Lower Basin reservoirs through the decade of the 1950s. In many years, there is little or no impact on Lower Basin storage, but during droughts, the winter drawdowns are substantial. But, as stated previously, this provides significant reliability benefits for the entire system. The change in operations generally raises the minimum flows in the river reaches below the NYC reservoirs. Figure 5.10 shows this for Hale Eddy over a short portion of the 1950s. Figure 5.11 illustrates how the operating policies tested in this case study tend to move the salt front downstream in severe droughts but allow it to come slightly further upstream under more normal conditions. Overall, this case study demonstrates that there may be potential for improving the performance of the system as a whole.

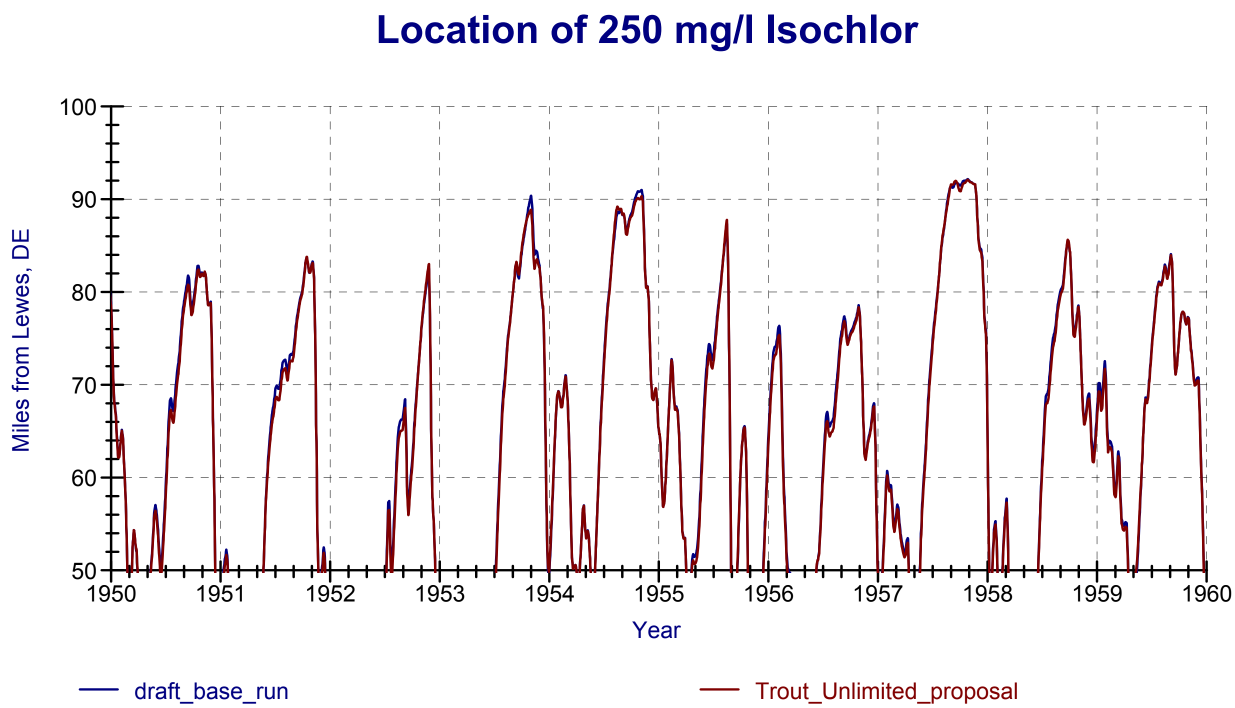

Figure 5.9

Upper Basin instream flow impacts are critical in evaluating these kind of operating rules. Impacts on temperature and spawning habitat for trout are particularly important, as are recreational flows. These have not been fully evaluated here and would need to be evaluated as a part of a complete investigation of any proposed operating rules. It is important to note that the amount of additional storage made available by using rules that follow the same principles as the rules tested in this case study could be used to improve fisheries and recreation conditions as well as to increase the reliability of supply.

5.1.3 <u>Case Study 3 - NYC Reservoir Balancing</u>

This case study (NYC_balancing) illustrated the impacts that current NYC operating policies have on the relative flows in the West Branch, East Branch, and Neversink Rivers. The base run for the Upper Basin attempts to balance storage in the upstream reservoirs on a percent-full basis. It does not specify, beyond the minimum releases, which reservoirs are to be used to meet NYC demands or directed releases to meet the Montague target. In reality, the quality of water in Neversink Reservoir is best, followed by Pepacton, and then Cannonsville. NYC naturally tries to divert the highest quality water for domestic supply.

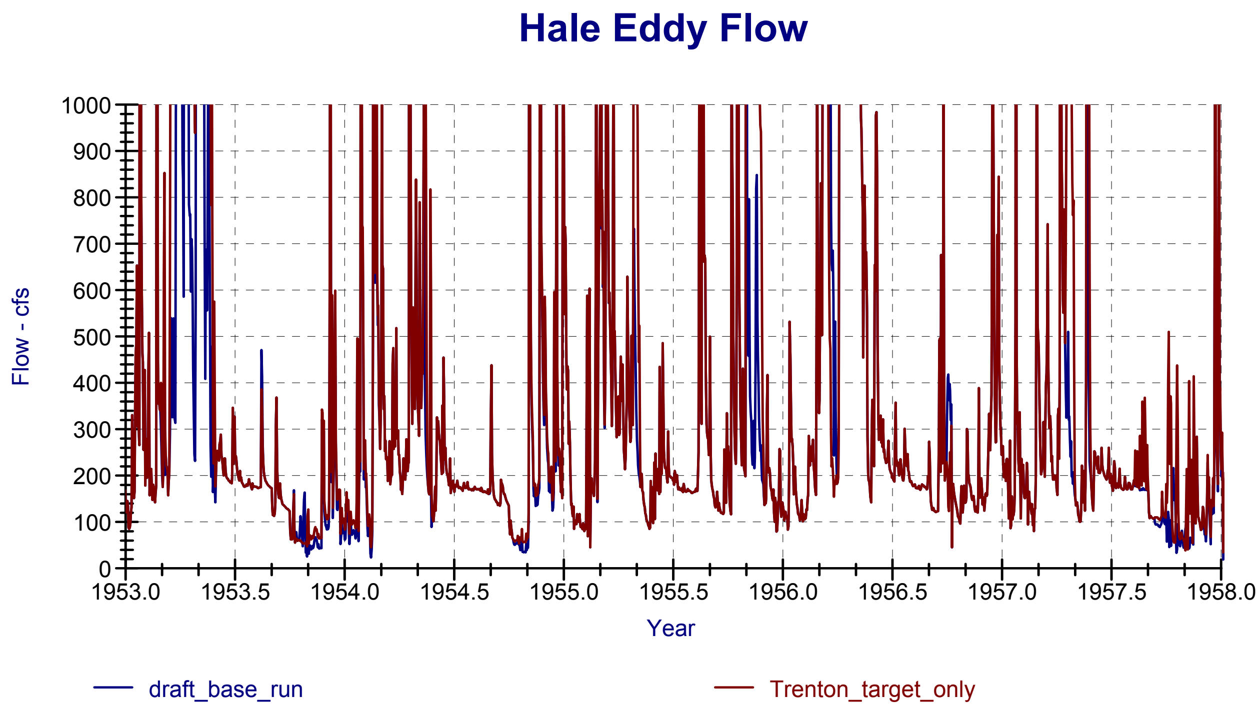

Figure 5.10

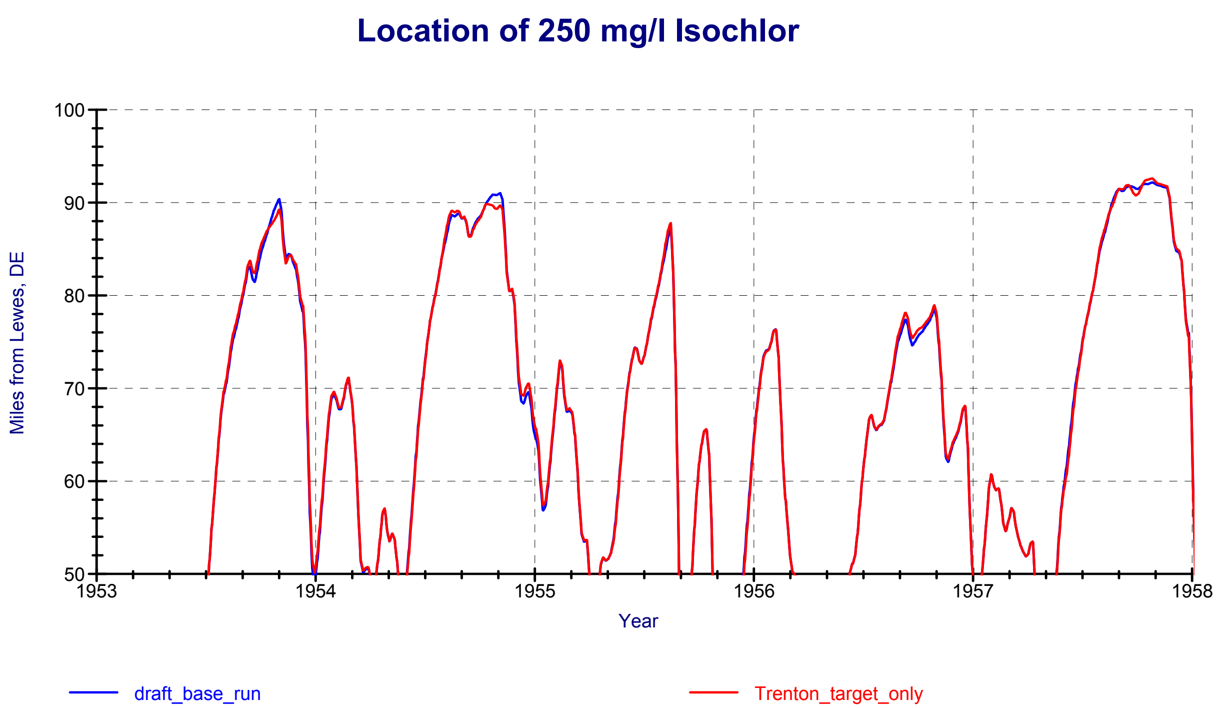

Figure 5.11

The rules tested (operating assumptions) in this case study changed the balancing procedures to maximize NYC diversions from Neversink Reservoir, then Pepacton Reservoir in a way that closely resembles NYC's current operations. This was done by creating a small zone at the top of Neversink Reservoir. Any water in this zone is given first priority for diversion to NYC. In effect, this minimizes spills from Neversink. In addition, a small penalty is applied to downstream releases in excess of minimums from Pepacton and Neversink Reservoirs. This has the effect of forcing most releases to meet the Montague target to be taken from Cannonsville Reservoir.

The performance measures used in this case study are the diversions from each reservoir to NYC and the relative flows in the West Branch, East Branch, and Neversink Rivers.

The new rules are very effective at changing the relative diversions to NYC from the three reservoirs. Cannonsville diversions go from an average of 380 mgd in the base run to 246 mgd in the case study run. Pepacton and Neversink diversions to NYC increase from 235 and 133 mgd to 364 and 136 mgd, respectively. Changes in instream flows are most noticeable on the West and East Branches because of the large shift in diversions from Cannonsville (West Branch) to Pepacton (East Branch) between the runs. These are illustrated in Figures 5.12 and 5.13.

5.2 Lower Basin Case Studies

5.2.1 Case Study 4 - Rafting Releases at Beltzville

This case study examined the impacts of instituting a summer rafting release from Beltzville Reservoir. Whitewater rafting currently does not take place on Pohopoco Creek downstream of Beltzville Dam.

For the purposes of this case study the release was set to 235 cfs for six hours, with two hours of ramping (gradual changes from and back to minimum flows) on each side of the rafting release, which equates to a daily average flow of 105 cfs. The relationship between flow and rafting quality is not known so this is an arbitrary, but large, flow for Pohopoco Creek. The releases**,** as modeled, would be made on both Saturday and Sunday on all weekends from May through September, as long as both Upper Basin and Lower Basin conditions are normal. The releases stop when conditions in the Upper Basin fall to "watch" or conditions in the Lower Basin fall to "warning ."

Performance measures selected for this case example are the flows below Beltzville dam, NYC reservoir storage, and Lower Basin storage.

Figure 5.14 illustrates the hypothetical release pattern for a typical year. Figures 5.15 and 5.16 show the impact on Beltzville and Lower Basin storage. Those impacts are negligible. Changes in minimum flows in the Lower Basin have the potential to affect releases from the Upper Basin reservoirs, but these impacts are also negligible. Based only on these indicators, a program to develop a recreational resource below Beltzville might be accommodated with minimal impact on other Basin activities. There may be impacts on other local uses, such as temporary reduction in fishing access or even minor flooding, and it would be important to consider these potential impacts further. Although the impact on Lower Basin storage appears small, a 60-year analysis of Lower Basin drought frequency and any potential impacts on Merrill Creek operation would be required to more fully evaluate such an alternative. There would be a need to establish the commercial viability of rafting on Pohopoco Creek, where it has not previously been done. Furthermore, both the DRBC and the Corps of Engineers own storage in Beltzville Reservoir. A determination would have to be made concerning which storage would be used to support whitewater rafting.

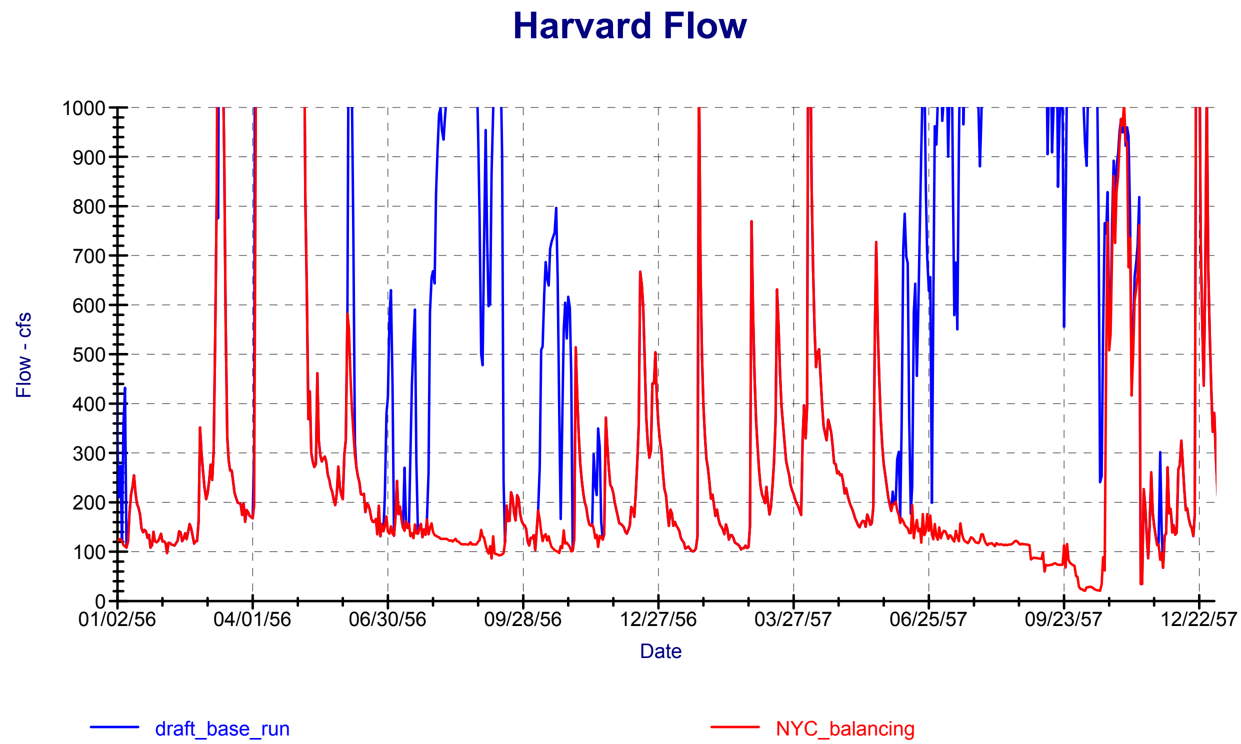

Figure 5.12

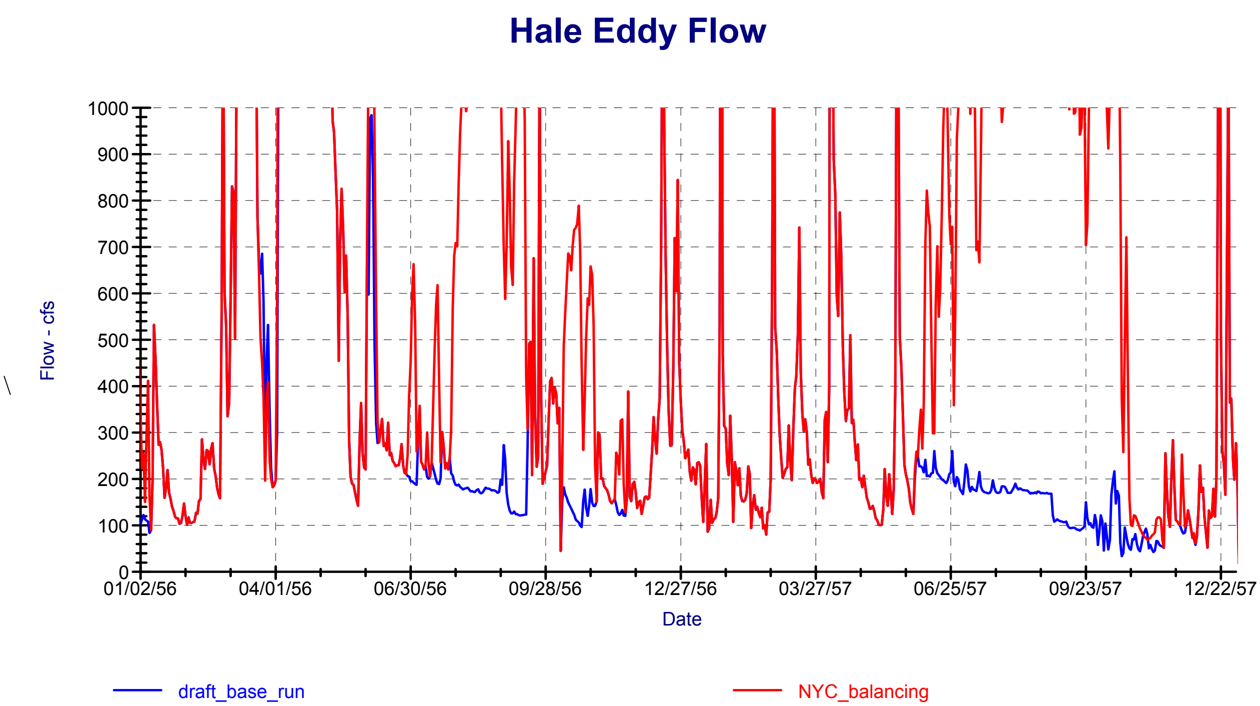

Figure 5.13

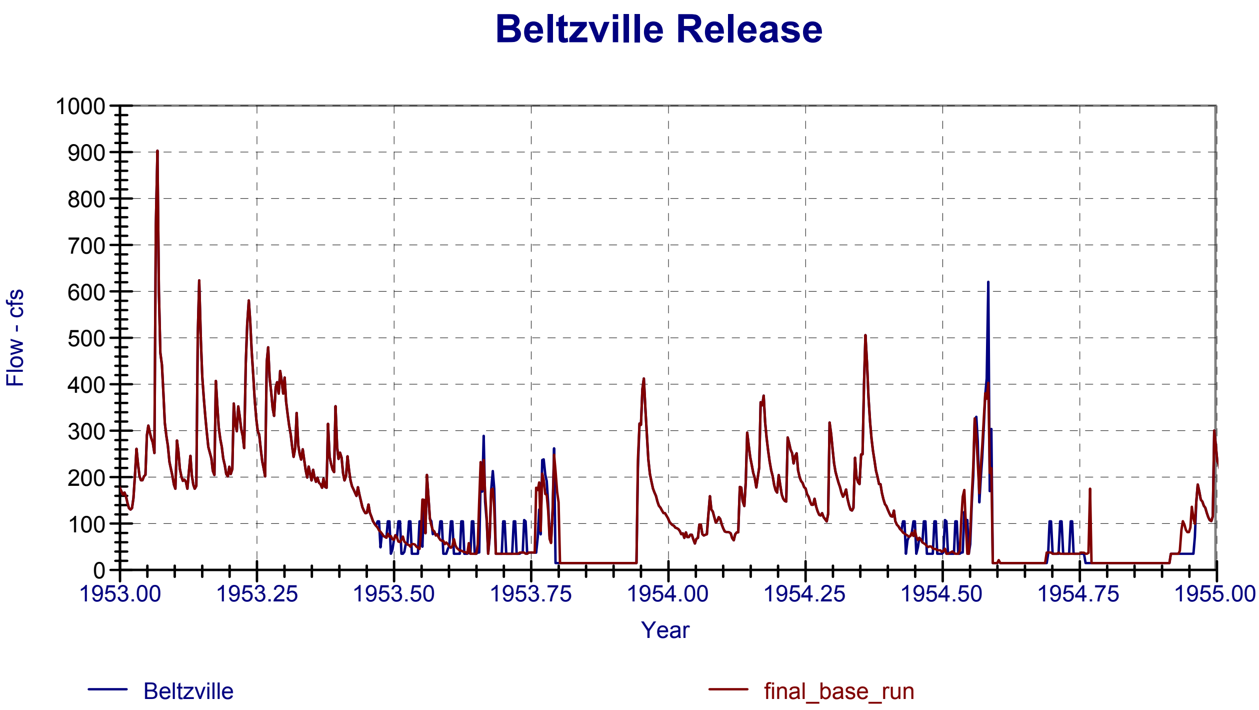

Figure 5.14

5.2.2 Case Study 5 - Temperature Control Below Blue Marsh Reservoir

The final case study (Blue_Marsh) considered how increasing minimum flows from Blue Marsh Reservoir on hot days might be used to control temperatures downstream on Tulpehocken Creek. The objective of such operations would be to enhance the cold water fishery below the dam.

Because there is no data on the relationship between temperature and flow downstream of this particular reservoir, a hypothetical relationship was postulated. That relationship assumes that the release necessary to maintain adequate water temperatures increased linearly with the daily maximum air temperature. For every one degree Fahrenheit that the daily maximum air temperature at a nearby temperature gage (in this case Libertyville, since data was readily available) exceeded 75 degrees, an additional 5 cfs of release from the dam was required. This release was in addition to the current minimum flow requirements. The maximum additional release was set to 100 cfs. As in Case Study 4, these additional releases stop when conditions in the Upper Basin fall to "watch" or conditions in the Lower Basin fall to "warning." The modeled flows relate to temperature control only and are not the same as the flow rates recommended in Leroy Young's study based on IFIM analysis (Young, 1999). Additional model runs could examine the effects of the habitat related flows recommended in Young's study considering temperature control, provided that models for Blue Marsh Reservoir and Tulpehocken Creek temperature are developed. The U.S. Army Corps of Engineers data indicates that Blue Marsh has run out of cold water during the summer. Further analysis of a potential cold water release program would require analysis of this data to estimate the volume of cold water available for release.

Figure 5.17 shows the very modest impact that the example temperature release program would have on Blue Marsh storage. Note, particularly, the small drawdown in simulated storage in 1959. The impacts on total Lower Basin storage are almost identical to the impacts on Blue Marsh itself. The impacts on storage in the NYC reservoirs are very small as well. Figure 5.18 shows how the releases might be made in a hot year (1959), compared to the current release policy.

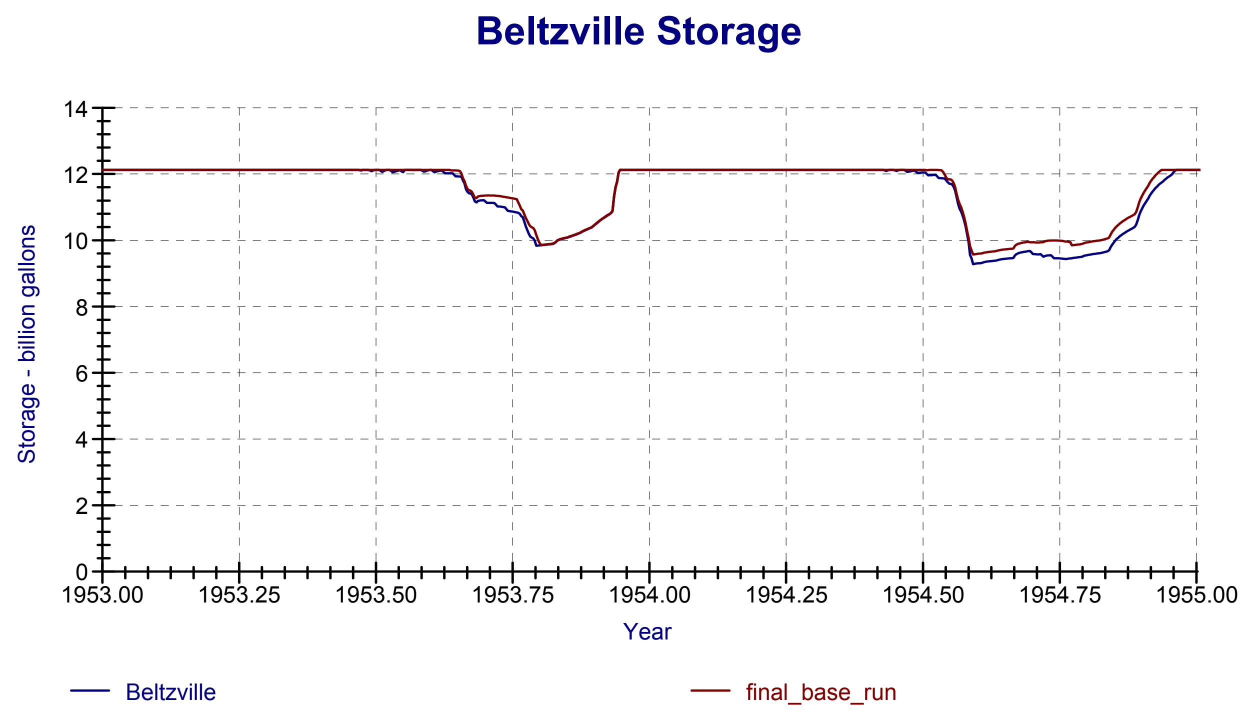

Figure 5.15

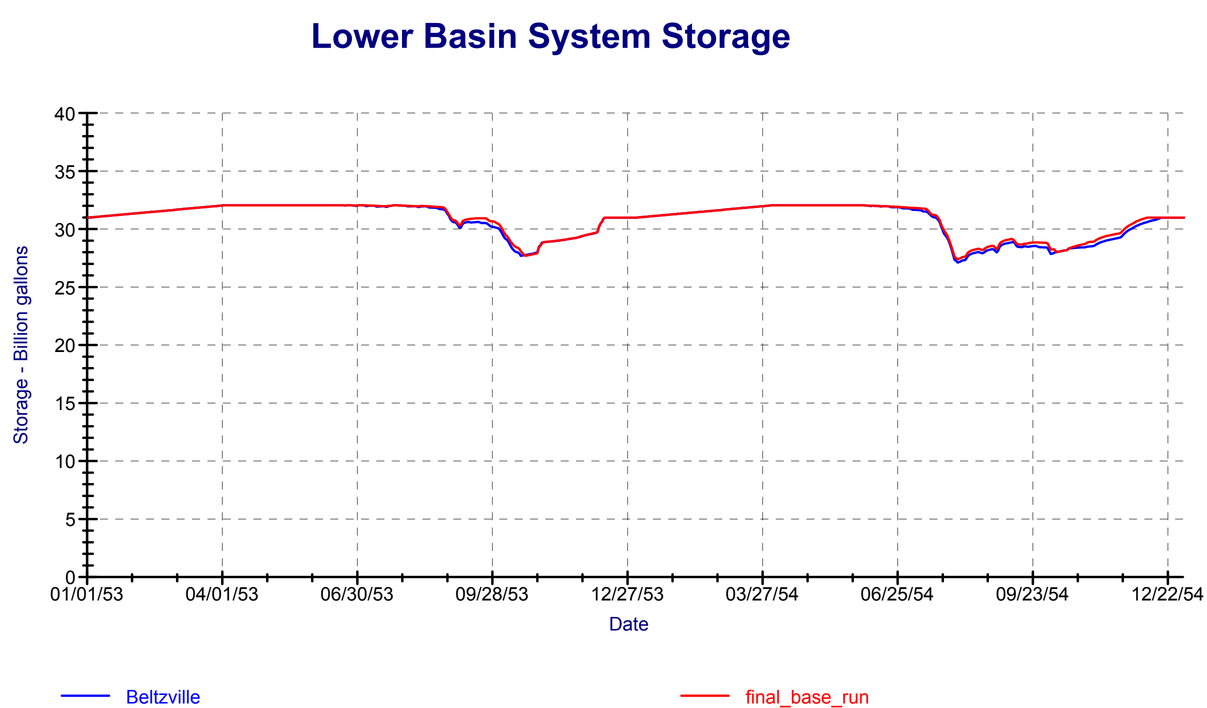

Figure 5.16

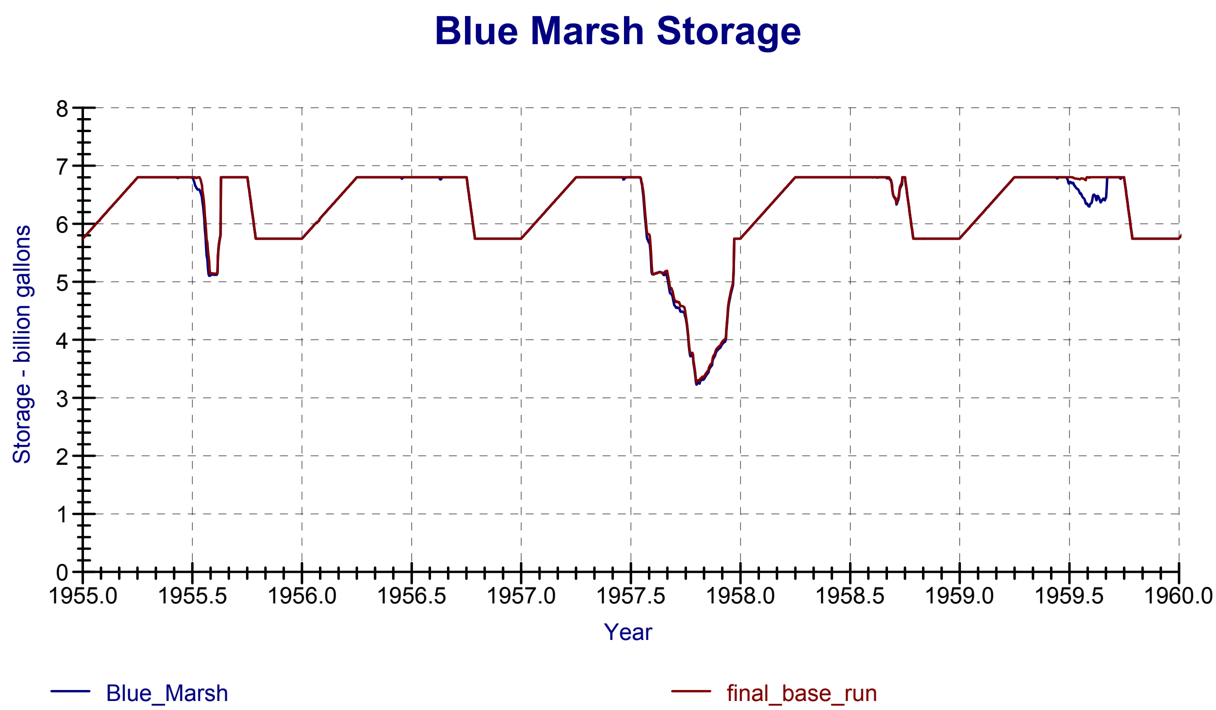

Figure 5.17

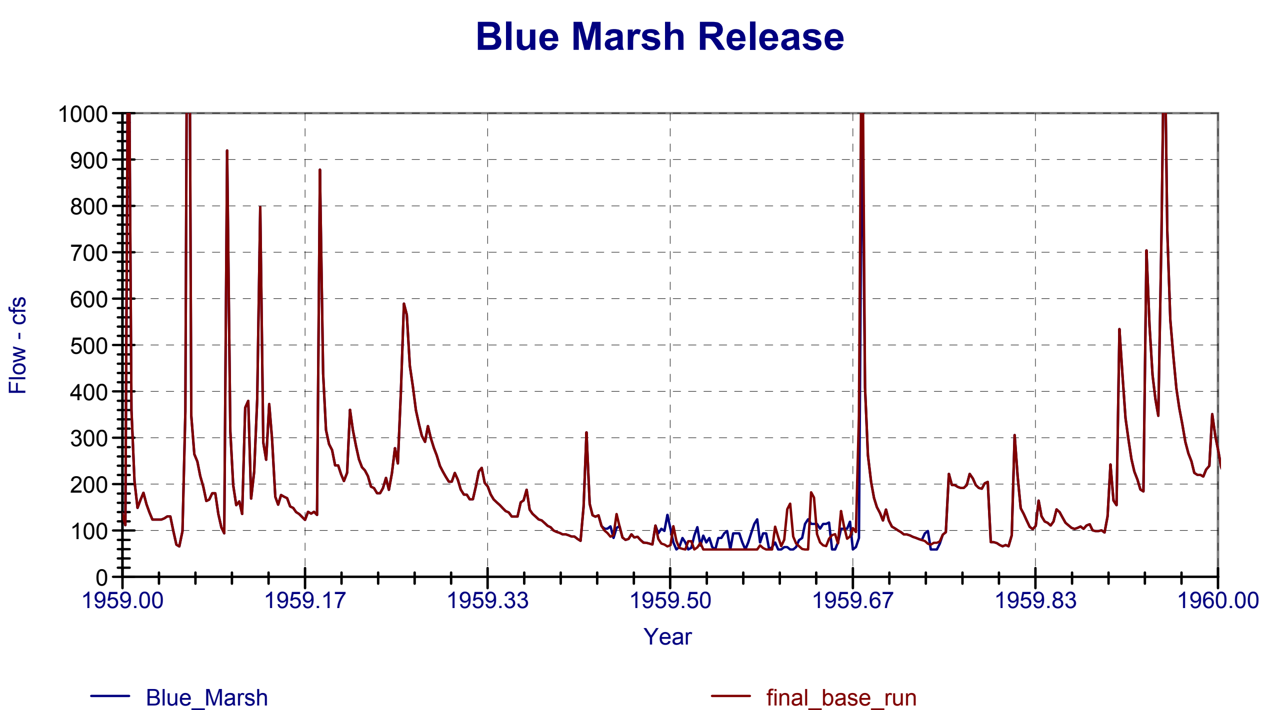

Figure 5.18

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