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.

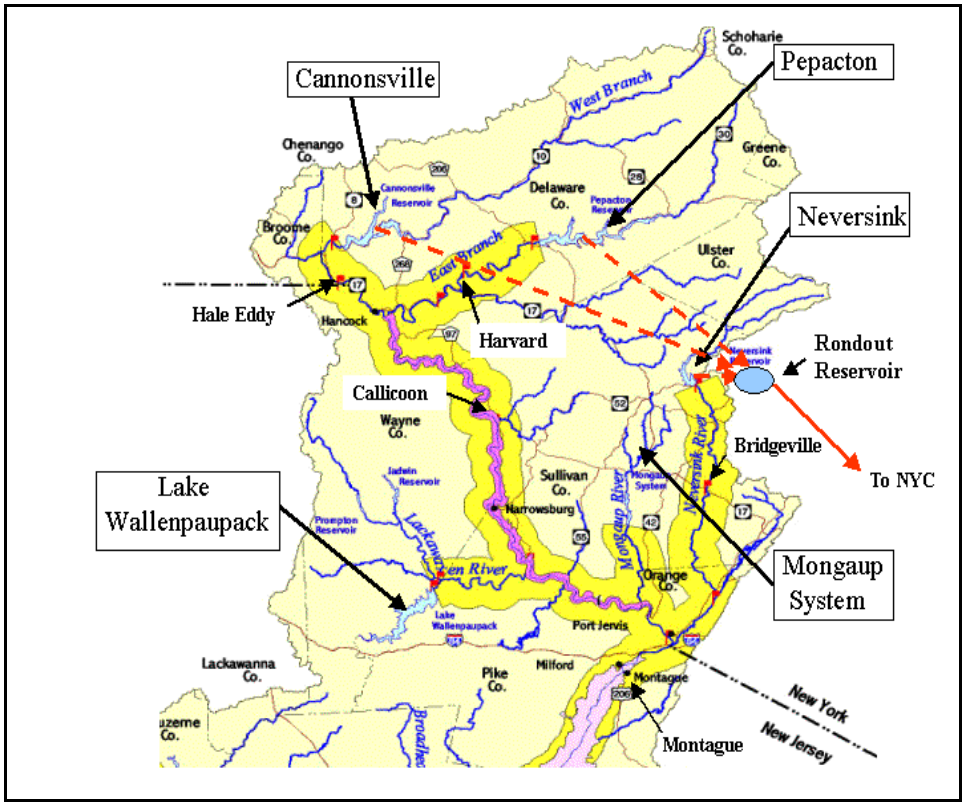

Figure 1: Upper Basin Reservoirs and Stream Segments

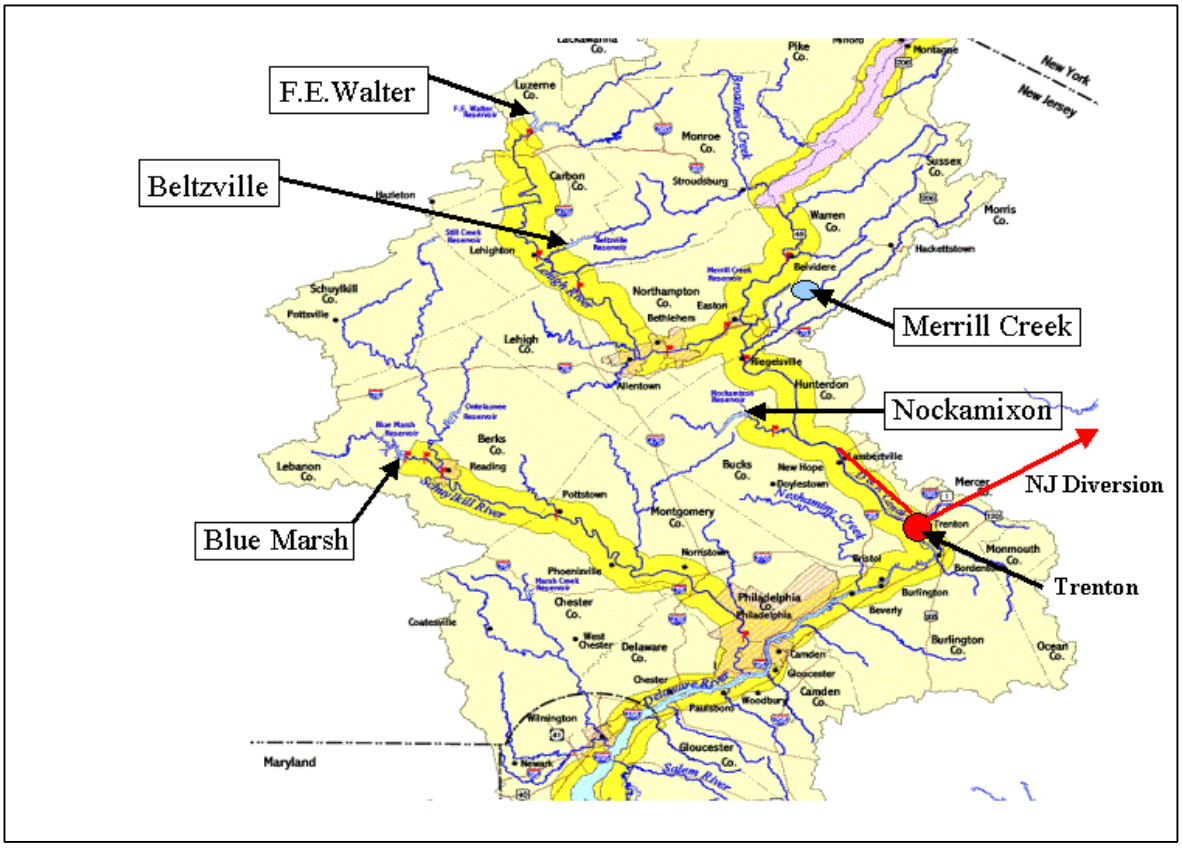

Figure 2: Lower Basin Reservoirs and Stream Segments

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.