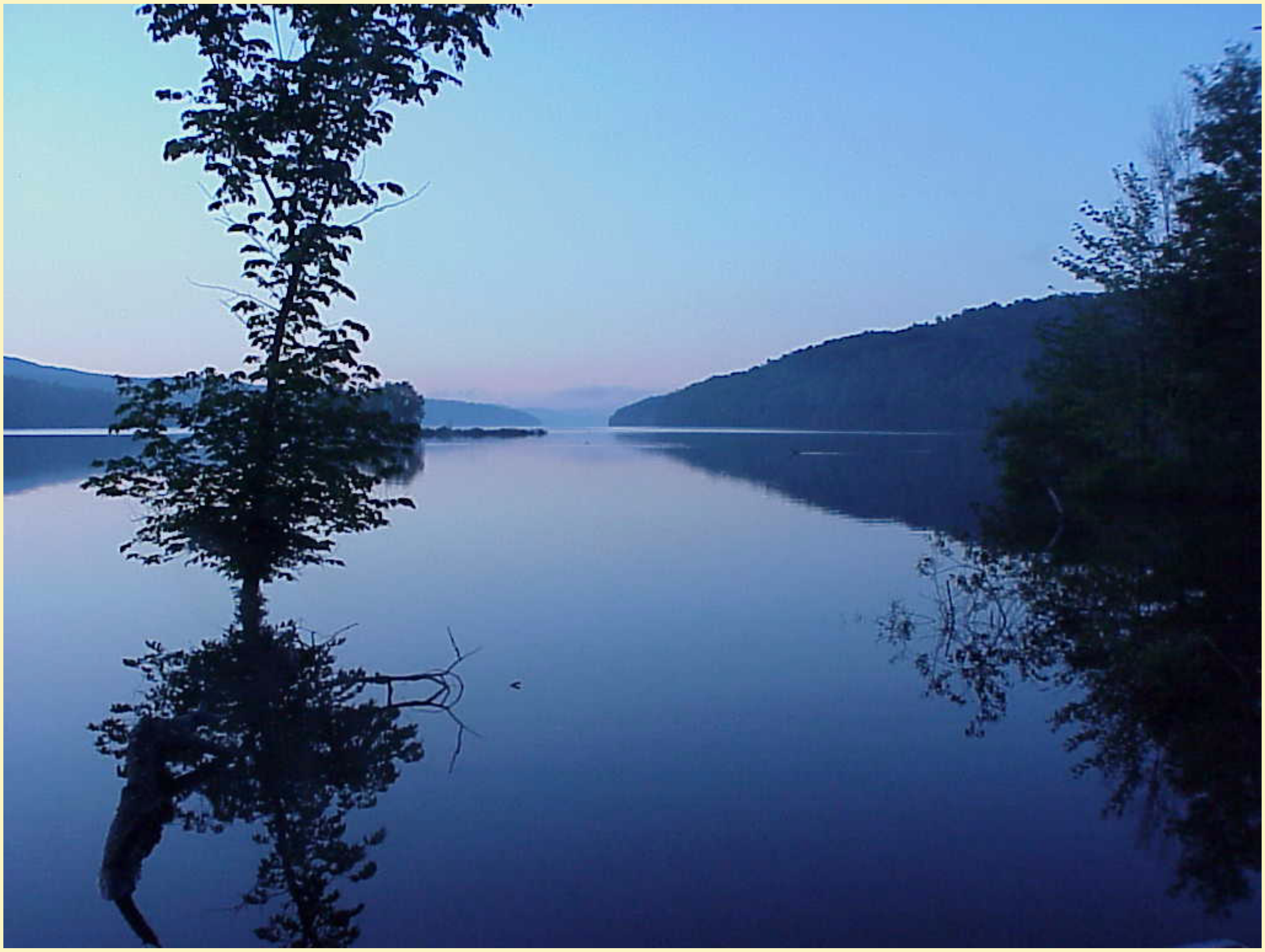
New York City
Department of Environmental Protection

2005 Watershed Water Quality Annual Report



Prepared by the Division of Drinking Water Quality Control

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Acknowledgments

The production of this report required the scientific expertise, creativity, and cooperation of the many staff members of the Division of Drinking Water Quality Control (DWQC). All deserve special recognition and thanks for their willing participation in the many facets of the Division's work ranging from sample collection and analysis to data interpretation and report production. This report would not exist without the extensive field work, laboratory analysis, and administrative work needed to keep the Division operating. Therefore, thanks are due to all the field and laboratory staff who collected and analyzed the thousands of samples emanating from the watershed monitoring programs and the administrative, health and safety, and quality assurance staff who support them. It is only through the collective dedication of these many individuals that the mission of the Division can be accomplished; the scope and content of the information contained here attests to the special efforts and perseverance of the staff.

General guidance in the activities of the Division was provided by Dr. Michael Principe, Deputy Commissioner of the Bureau of Water Supply in 2005, Mr. Steven Schindler, Director of DWQC, and Dr. Lorraine Janus, Chief of Watershed Operations, who also provided editorial guidance. Ms. Lori Emery and Mr. Andrew Bader were responsible for management of the Division's Upstate Laboratory and Field Operation sections, respectively.

The report was compiled and edited by Dr. David Smith with the able assistance of Ms. Patricia Girard, who was responsible for the consolidation and formatting of the many text and graphics files.

Leading roles in authorship and editing were taken by Ms. Lori Emery, Mr. Andrew Bader, Mr. James Mayfield, Mr. Gerard Marzec, Mr. Richard Van Dreason, Ms. Kerri Alderisio, Dr. Kimberley Kane, Mr. Michael Usai, Dr. Elliot Schneiderman, and Dr. Donald Pierson. Special mention of sub-section authors goes to Ms. Salome Freud, Mr. Bryce McCann, Mr. Mark Zion, Mr. Gerald Pratt, Mr. Thomas Baudanza, Ms. Laurie Machung, Ms. Deborah Layton, Dr. James Porter, Ms. Sharon Neuman, and staff of Upstate Freshwater Institute (UFI).

1. Introduction

1.1 What is the purpose and scope of this report?

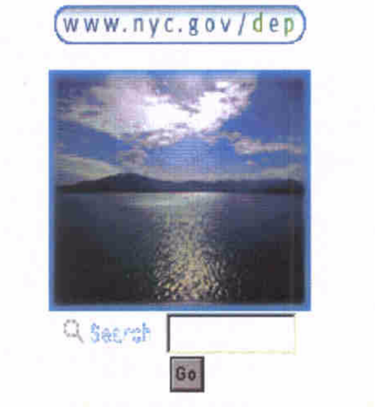


Figure 1.1 DEP website.

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of the City's drinking water. It is an annual report that provides the public with a general overview of the City's water resources, their condition during 2005, and compliance with regulatory standards or guidelines during this period. It is complementary to another report entitled "NYC Drinking Water Supply and Quality Report" that is distributed to consumers annually to provide information about the quality of the City's tap water. However, the focus of this report is different in that it addresses how the City protects its drinking water sources upstream of the distribution system. The report also describes the efforts of the New York City Department of Environmental Protection (DEP) to evaluate the effectiveness of watershed protection and remediation programs, and to develop and use predictive models. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through our website at http://www.nyc.gov/dep (Figure 1.1).

1.2 What role does each Division in the Bureau of Water Supply play in the operation of the NYC water supply?

The Bureau of Water Supply (BWS) is responsible for operating, maintaining, and protecting New York City's upstate water supply system to ensure delivery of high quality drinking water. BWS is currently comprised of 12 separate Divisions (Figure 1.2), which perform various functions to meet the Bureau's mission. Each of the 12 BWS Divisions and their functions are described below.

West-of-Hudson Operations Division

- Operates and maintains New York City Water Supply and Wastewater Treatment Facilities, and Highways west of the Hudson River to ensure that an adequate, reliable supply of high quality drinking water is delivered to the Catskill and Delaware Aqueducts and to ensure the City's compliance with the provisions of the Supreme Court Decree of 1954 and New York State Stream Release Regulations
- Supplies 90% of New York City's drinking water and has operational responsibility in a 4,000 sq. mile area.
- Operates and/or maintains:

    31 water supply facilities
    100 miles of highway

Bureau of Water Supply

- WEST-of-HUDSON OPERATIONS
- EAST-of-HUDSON OPERATIONS *Capital Planning and Community Supplies*
- DRINKING WATER QUALITY CONTROL
- ENGINEERING
- WASTEWATER TREATMENT PLANT UPGRADE PROGRAM
- INFRASTRUCTURE DESIGN AND CONSTRUCTION
- WATER SYSTEMS PLANNING
- WATERSHED LANDS AND COMMUNITY PLANNING
- DEP ENVIRONMENTAL POLICE
- REGULATORY COMPLIANCE AND FACILITIES REMEDIATION
- MANAGEMENT INFORMATION SYSTEMS
- MANAGEMENT SERVICES AND BUDGET
- *SEQRA COORDINATION & WATERSHED MANAGEMENT PROGRAMS*

Figure 1.2 The individual divisions of the Bureau of Water Supply.

6 Dams
6 Dikes
6 Wastewater Treatment Plants
142 miles of tunnel

East-of-Hudson Operations Division

- Operates and maintains New York City Water Supply and Wastewater Treatment Facilities on the east side of the Hudson River to ensure that an adequate, reliable supply of high quality drinking water is delivered to the Croton, Catskill and Delaware Aqueducts.
- Responsible for the supply and treatment of 100% of New York City's drinking water and has operational and maintenance responsibility in a 360 sq. mile area of watershed.
- Operates and/or maintains:

6 Aqueducts (3 systems)
New Croton Aqueduct (24 miles), 10 Structures
Catskill North & South (>50 miles), 73 Structures
Delaware North, Central & South (>50 miles), 17 Structures
9 Water Treatment Facilities (chlorine, fluoride, alum, sodium hydroxide, sodium bisulfite)
2 Wastewater Treatment Plants
16 Reservoirs and Controlled Lakes
Maintenance of 181 Facilities
16 Bridges
Over 80 community connections
DEC Reservoir Release Program – 12 Reservoirs

- **Capital Projects Coordination & Community Supplies Engineering (Subdivision of EOH Operations)**
    1. Facilitates coordination of planning, design, and construction of major capital projects between DEP Bureau of Environmental Design and Construction and BWS.
    2. Ensures that the design and construction to DEP infrastructure meets requirements including that of backflow prevention to protect City water quality, and release of surge pressure to avoid any damage to the DEP infrastructure.
    3. Assists DEP Legal in negotiating terms of Water Supply agreements and retrieves excess water taking back charges by upstate communities.
    4. Coordinates with local health departments and NYSDEC for interconnections utilizing city water.
    5. Enforces accurate flow metering with approved meters that are calibrated annually.
    6. Transmits monthly meter readings spreadsheet for billing to communities.
    7. Provides engineering support to Office of Land Management for east and west of Hudson land use permits for projects on City property.

Drinking Water Quality Control

- Ensures the quality of New York City's drinking water supply and compliance with all Federal and State drinking water regulations.
- Conducts extensive water quality monitoring programs in the watershed and distribution system.
- Provides water quality information critical to the operation of the water supply upstate and downstate.
- Develops water quality monitoring strategies to assist in the long–term protection of the watershed, including the Filtration Avoidance Determination (FAD) planning and policy development regarding the water supply and public health.

Engineering

- Ensures that new development complies with the Watershed Regulations.
- Enforces Watershed Regulations for new and existing development to maintain protection of water quality.
- Coordinates with local health departments and Catskill Watershed Corporation on various onsite wastewater treatment programs.
- Inspects all wastewater treatment plants in the watershed to ensure proper operation.
- Provides engineering support to other BWS units, including Wastewater Treatment Plant Upgrade Program.
- Conducts stream restoration and management projects in East-of-Hudson watershed, and coordinates practices and strategy with Land Management and Community Planning for related programs in West-of-Hudson watershed.
- Develops, designs, constructs, and maintains stormwater management practices to reduce fecal coliform bacteria, turbidity, and various pollutants in the Catskill/Delaware system
- **State Environmental Quality Review Act (SEQRA) Coordination and Watershed Management Programs (Section reporting to First Deputy Director - BWS)**

  Ensures the timely, thorough, and consistent application of SEQRA in the watershed and serves as the primary BWS contact for City sponsored, and funded, projects subject to SEQRA

Wastewater Treatment Plant Upgrade Program

- Manages the program funded in accordance with the Memorandum of Agreement (MOA) to upgrade privately–owned wastewater treatment plants to tertiary treatment standards, and supports operation and maintenance of upgraded plants by the owners.

Infrastructure Design and Construction

- Responsible for managing consulting engineer activities with respect to the design and construction of facilities throughout the BWS to meet operating infrastructure needs of BWS Divisions such as operations, water quality, and coordination with projects underway by the Bureau of Engineering Design and Construction.
- Provides overall construction management services including full resident inspection services on selected projects.

- Prepares budget estimates on BWS projects consisting of engineering and construction costs for incorporation into BWS capital and expense budget plans.

Water Systems Planning

- Performs long–term planning and analysis to identify capital funding levels needed for projects and programs of water quality protection, water quality management and water supply operations
- Prepares budget requests to secure funds in DEP Capital Budget to execute plans coordinated with other DEP Bureaus through Needs Assessment and Risk Management procedures.

Watershed Lands and Community Planning

- Assists in community planning and environmental infrastructure through the Catskill Watershed Corporation (CWC), Westchester/Putnam Counties, and the NYS Environmental Facilities Corporation.
- Evaluates and designs appropriate farm and forest activities in cooperation with the Watershed Agricultural Council (WAC).
- Acquires new lands through fee and conservation easement acquisition and partnerships with WAC, land trusts, counties, and New York State.
- Manages City-owned land for watershed protection purposes, providing appropriate public access and recreation, forestry activities, land use permits and agreements and reservoir and watershed lands patrol.
- Manages streams through stream management plans, stream restorations, research and public education.
- Oversees development and implementation of the Kensico Water Quality Control Program.

DEP Environmental Police

- Maintains 24/7 surveillance of the water supply
- Responds to suspicious, unusual or dangerous activities
- Operates the 24 hour Communications Center
- Detects and prevents environmental threats from pollution, crime, and terrorism.
- Protects DEP employees and facilities from malevolent acts.
- Monitors development within the watershed to ensure compliance with City, State, and local regulations.
- Maintains liaison with federal, state and local law enforcement agencies to provide maximum protection and comprehensive information sharing.
- Investigates intentional and unintentional acts which threaten the water supply, facilities, infrastructure, or employees.
- Develops protective design systems and emergency response protocols

Regulatory Compliance and Facilities Remediation

- Ensures compliance with all applicable Federal, State and local environmental, health and safety rules and regulations, and DEP procedures implemented to address them.

- Provides guidance and assistance to other BWS Divisions with environmental, health and safety rules and regulations and in relations with Agency Management, other DEP Bureaus and outside regulatory agencies.
- Provides emergency spill response and remediation of hazardous materials throughout the Upstate Watershed.
- Provides supervision of contractors utilized for emergency spill response, hazardous waste/ materials remediation and disposal.
- Provides environmental, health and safety training to BWS personnel.
- Coordinates the Bureau's Legacy Assessment Program responsible for identifying and addressing contaminants of concern.

Management Information Systems

- Responsible for the installation and maintenance of computers and computer related systems; the operation of server facilities; the hosting of enterprise applications; and the supervision of system health and security.
- Supports and maintains communication infrastructure, wide area networks, local office networks, internet services and help desk functions.
- Advises Bureau Divisions in the use and selection of commercial and consultant built software programs, plans technical expansion of information management systems and develops custom applications.
- Manages the BWS web site and enterprise database systems.

Management Services and Budget

- Responsible for the Bureau's overtime, capital, expense and personnel services budgets.
- Handles all purchasing, contract management, and personnel services.
- Manages vehicle coordination, facilities/space needs, and special projects.

1.3 How does the City monitor the condition of its reservoirs and watersheds?

The condition of the water supply is monitored by the Division of Drinking Water Quality Control (DWQC). DWQC has a staff of approximately 255 who are responsible for monitoring and maintaining high water quality for the entire (upstate watershed and downstate distribution system) water supply, with over half within the upstate operations.

DWQC's Watershed Operations are now divided into five sections: Watershed Field Operations, Watershed Laboratory Operations, Information Management and Modeling, Pathogen Monitoring and Research, and Health and Safety.

The Watershed Field Operations Section consists of five units: Limnology, Hydrology, Wildlife Studies, Watershed Management Studies (including Natural Resources), and Water Quality Impacts Assessment. These staff are responsible for: i) designing scientific studies, ii) collecting environmental samples for routine and special investigations, iii) submitting these samples to the Laboratory Operations (or contracted lab) for analysis, iv) organizing and interpreting data, v) documenting findings, and vi) making recommendations for effective watershed management.

Field Operation staff members are located in all three water supply Systems (Catskill, Delaware, and Croton). Extensive monitoring of a large geographic network of sites to support reservoir operations and watershed management decisions are the top priority of the Field Operations Section.

DWQC's Watershed Laboratory Operations Section also consists of five units: East-of-Hudson Laboratory & Compliance Operations (including the Brewster and Kensico Laboratories), West-of-Hudson Laboratory and Compliance Operations (including the Ben Nesin and Grahamsville Laboratories), Quality Assurance, Technical Operations, and the Watershed Administrative Unit. The units are comprised of laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, scientists, technical specialists, and administrative staff. The four water quality laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for approximately 60 analytes in the non-potable water and potable water categories. These analytes include physical parameters (e.g., pH, turbidity, color, conductivity), chemical parameters (e.g., nitrates, phosphates, chloride, chlorine residual, alkalinity), microbiological parameters (e.g., total and fecal coliform bacteria, algae), trace metals (e.g., lead, copper, arsenic, mercury, nickel), and organic parameters (e.g., organic carbon). Daily monitoring of water quality at critical “keypoint” monitoring sites for rapid detection and tracking of any changes in water quality is one of the top priorities of the Watershed Laboratory Operations Section. For the 2005 reporting period covered in this report, DWQC staff performed 210,795 analyses on 23,120 samples from 646 different sampling locations.

The Information Management and Modeling Section is responsible for Watershed and Reservoir Modeling, the administration of the Upstate Water Quality database, some data analysis and production of many of the reports for the Division and Bureau. The Pathogen Monitoring and Research Section deals with field sampling and laboratory analysis of samples, and laboratory methodological research. The Health and Safety Section deals with all aspects of staff health and safety in the numerous DWQC workplaces.

2. Water Quantity

2.1 What is NYC's source of drinking water?

New York City's water supply is provided by a system consisting of 19 reservoirs and three controlled lakes with a total storage capacity of approximately 2 billion cubic meters (550 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (see Figure 2.1).

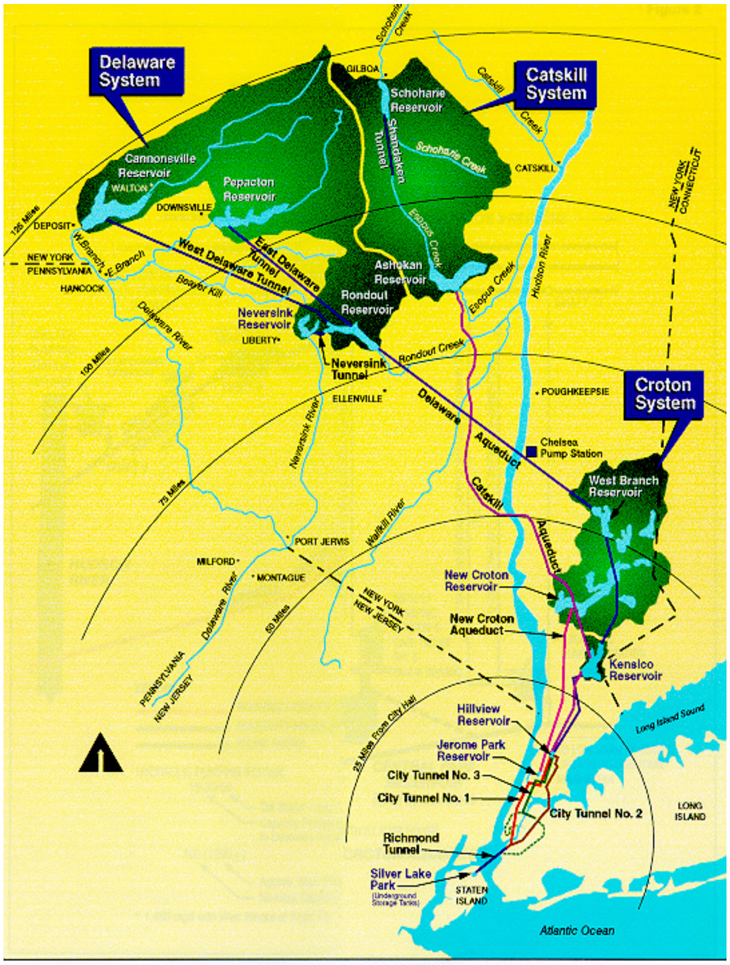
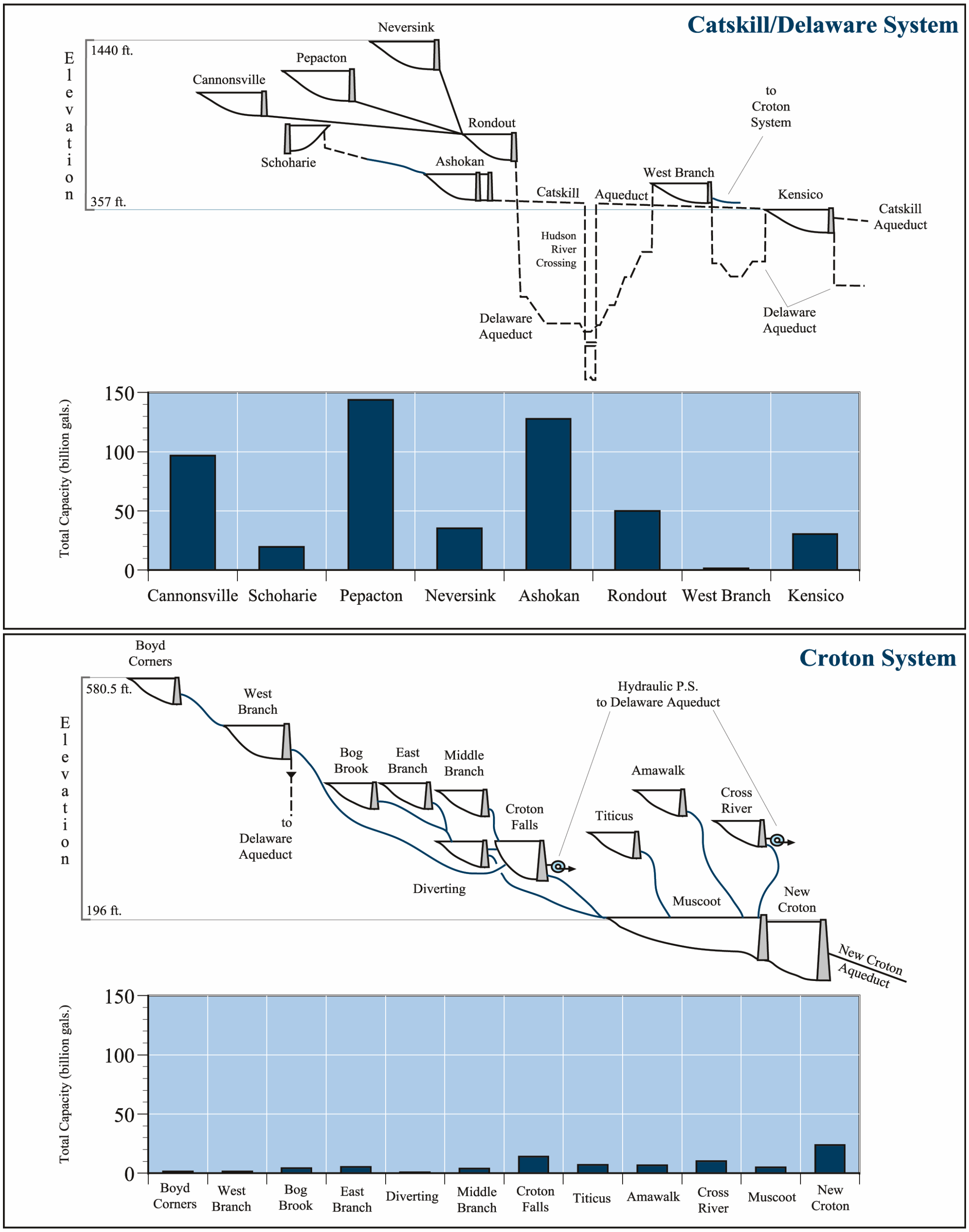


Figure 2.1 New York City water supply watershed.

The system is dependent on precipitation (rainfall and snow melt) and subsequent runoff to supply the reservoirs in each of three watershed systems, the Catskill, Delaware, and Croton Systems. The first two are located West-of-Hudson (WOH) and the Croton System is located East-of-Hudson (EOH) (see Figure 2.2). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the pollutant loads and hydraulic residence time, which in turn directly influence the reservoir's water quality and productivity.



Elevations of reservoirs are at masonry crest of spillway (MSI Sandy Hook)

Total Available Capacity (Above Sill or Outlet)

Figure 2.2 NYC water supply reservoirs and their available storage capacities.

2.2 How much precipitation fell in the watershed in 2005?

The average precipitation for each basin was determined from a network of precipitation gauges located in or near the watershed that collect readings daily. The total monthly precipitation for each watershed is based on the average readings of the gauges located in the watershed. The 2005 monthly precipitation total for each watershed is plotted along with the historical monthly average (see Figure 2.3).

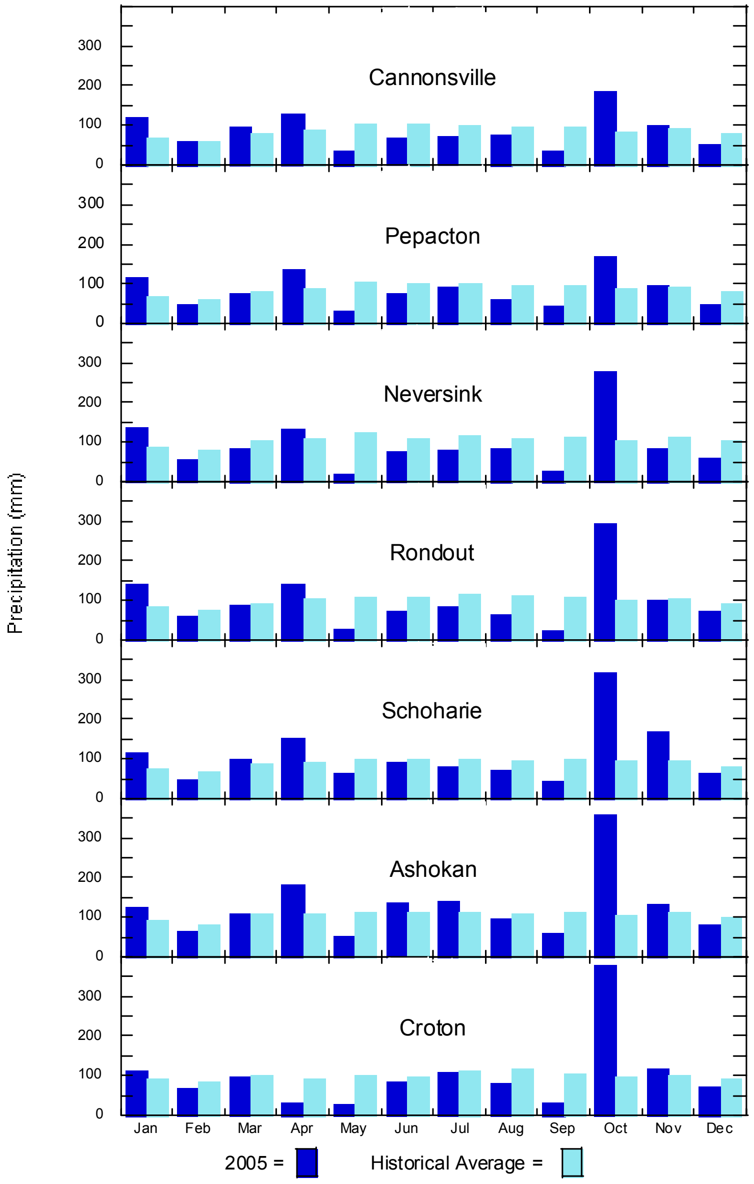


Figure 2.3 Monthly rainfall totals for NYC watersheds, 2005 and historical values.

The total monthly precipitation figures show that in general precipitation was above normal for January and about normal for February and March. April was above normal, except in the Croton system, and will be discussed in more detail below. May through September saw below average precipitation, except for in the Ashokan basin during June and July. October had precipitation totals well above the historical totals, and will be discussed below. November's precipitation totals were fairly typical, except for Schoharie, which was high. December's precipitation was somewhat less than normal in all basins. The below average precipitation in the summer impacted the reservoir storage, while the October storms filled the reservoirs (see Section 2.5). Overall the total precipitation in the watershed for 2005 was 1,186 mm (46.7 in), which is 48 mm (1.9 in) above normal. Based on data from the National Climatic Data Center's website (http://www.ncdc.noaa.gov/img/climate/research/2005/us-final/01-12Regionalprank-pg.gif) for the period from 1895-2005, 2005 was the fourth wettest year in the northeast region of the U.S. Also, several significant precipitation events occurred which led to water quality issues.

On April 1-3, 2005 a 3-day rain-on-snow event produced extensive runoff and flooding in the Catskill and Delaware System Water Supply watersheds. The Ashokan Reservoir watershed received the highest amount of rainfall with 103 mm (4.05 in) over the three-day period. Four days prior to this event the area received a significant 2-day rainfall event which swelled watershed streams and saturated the ground. Stream levels did not have time to recover from this first event before the April 1-3 rain occurred. The combination of high streams along with full reservoirs and the release of a large amount of snow-water contributed to converting a typical spring rain event into a significant runoff event. This event created the conditions that required DEP to treat the water supply with alum (see section 3.2).

Another unusual event occurred when a very intense, but highly localized storm inundated the Kensico Reservoir area on the afternoon of June 29 with over 127 mm (>5 inches) of rain with over 76 mm (>3 inches) falling in a one hour period. For comparison purposes, only 19 mm (0.76 inches) of precipitation were recorded in the Croton watershed. This event led to some short-lived water quality problems in the Kensico Reservoir.

On October 7-9, 2005 the remnants of tropical storm Tammy passed over the West-of-Hudson watershed delivering heavy rainfall. The Ashokan Reservoir watershed received 174.5 mm (6.9 inches) of rainfall over a three-day period; an event of this magnitude generally has about a 25-year return interval. This event also created water quality problems in the Catskill System that again required alum treatment. Additional rains later in the month resulted in October 2005 being the wettest October on record for NY state (http://www.ncdc.noaa.gov/img/climate/research/2005/oct/10Statewideprank_pg.gif).

2.3 What improvements were made to DEP's meteorological data network in 2005, and how were the data used?

Weather is one of the major factors affecting both water quality and quantity. As such, weather data is one of the critical components of the integrated data collection system. Timely and accurate weather forecasts are essential, especially with regards to rainfall. The worst episodes of stream bank erosion and associated nutrient, sediment, and pollutant transport occur during high streamflow events caused by heavy rain. Monitoring these events is critical to understanding, and ultimately reducing, the amounts of sediment, turbidity, nutrients, and other pollutants entering the reservoirs, as well as making operational decisions.

Recognizing that, in addition to the precipitation data that have been historically collected (see Section 2.2), meteorological ("met") data were valuable in meeting the Division's mission of providing high-quality drinking water through environmental monitoring and research, DWQC installed a network of 26 Remote Automated Weather Stations (RAWS) covering both the EOH and WOH watersheds. Each station measures air temperature, relative humidity, rainfall, snow depth, solar radiation, wind speed, and wind direction. A reading is taken every minute, and values are summarized hourly (summed or averaged). Most of the stations utilize radio telemetry to transmit data in near real-time. In addition to being used by DEP, these data are shared with the National Weather Service (NWS) to help them make more accurate and timely severe weather warnings for watershed communities. These data are also important as input for DEP's water quality models (Chapter 5).

In 2005, DEP began the process of upgrading its raingages and telemetry system. The RAWS network currently uses tipping bucket raingages, which only measure liquid precipitation. These will be upgraded to a weighing bucket gage (the Ott Pluvio) which can also measure frozen precipitation such as snow and freezing rain. The Pluvios are also more accurate than tipping buckets, and they are equipped with wind shields to help reduce catch error. The telemetry upgrade is intended to improve the flow of data and will utilize multiple base stations at DEP facilities (wastewater treatment plants, valve chambers, etc.) spread throughout both the East-and West-of-Hudson watersheds. Each RAWS will transmit data to the nearest base station, where it will be put onto the DEP computer network and routed to the master dataset at Grahamsville Laboratory as well as to a separate backup location. This upgrade should improve the reliability of data reception, increase data security, and incorporate EOH stations into the near-real-time data program.

Figure 2.4 An Ott Pluvio precipitation gage located at DEP's Remote Automated Weather Station near Ashland, NY in the Batavia Kill sub-basin of the Schoharie watershed.

This type of weighing bucket gage, which can accurately measure frozen precipitation, will be installed at all of DEP's meteorological sites as part of a network upgrade.

DEP also began the process in 2005 of purchasing and installing "snow pillows" in the WOH watershed. Snow pillows continuously monitor snowpack water content and transmit the data back via the meteorological telemetry system. The pillows are stainless steel "envelopes" filled with environmentally safe anti-freeze; a pressure transducer measures the pressure exerted by snow on the pillows, which is then converted to a water equivalent value. Continuous snowpack data are being required by the downbasin states as part of the Spill Mitigation program (Pepacton and Neversink watersheds), and will be used to monitor the snowpack in Schoharie watershed in conjunction with the Gilboa Dam emergency. Pillows will be installed at three sites: New Kingston (Pepacton watershed), Blue Hill (Neversink watershed) and Ashland (Schoharie watershed). The near-real-time data will be monitored daily, and significant changes will trigger field staff to perform a manual snow survey to get a more accurate estimate of water equivalent in the basin.

The ongoing coordination efforts between DEP and NWS resulted in several valuable products for DEP in 2005. NWS produced new software for small stream forecasting and updated their products for DWQC's storm event sites. These forecasts estimate the timing and magnitude of peak flow for pending storm events, facilitating planning for storm event sampling. Ashokan and Schoharie Reservoir forecasts were added to the Advanced Hydrologic Prediction Service (AHPS) website (http://www.weather.gov/ahps/). NWS also added 60- and 90-day inflow forecasts for selected reservoirs, and added tabular data, all per request from DEP (previously, only 30 day graphical forecasts were available). These forecasts assist Operations in managing reservoir elevations. DEP Operations began providing reservoir data (elevation, spill, release, diversion) to NWS along with the DWQC meteorological data stream, and NWS posts these data on the internet. This facilitates DEP staff and the public accessing the data. These products can be found at: http://www.crh.noaa.gov/product.php?site=BGM&issuedby=BGM&product=RR1&format=ci&version=1&glossary=0 . This page presents a variety of products, including DEP hourly meteorological data. Clicking on the numbers across the top of the page will bring up the different products, including archived versions going back several hours.

DEP met data were used by DEP and others for a large and diverse array of projects in 2005. For example, the DWQC Modeling Program used met data to support their Filtration Avoidance-mandated modeling efforts and to run simulations of Kensico Reservoir turbidity associated with alum treatment of Catskill system water. The Upstate Freshwater Institute (UFI) also used met data in a model to support management of turbidity and temperature in Schoharie Reservoir and Esopus Creek. Researchers at the Institute for Ecosystem Studies in Millbrook, NY used DEP met data for several ongoing biogeochemical research projects they are conducting in the Catskills. The met data were also used in several floodplain mapping projects, and in various other watershed projects.

2.4 How much runoff occurred in 2005?

Runoff is defined as the part of the precipitation and snowmelt that appears in uncontrolled surface streams and rivers, i.e. “natural” flow. The runoff from the watershed can be affected by meteorological factors such as: type of precipitation (rain, snow, sleet, etc.), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, antecedent precipitation and resulting soil moisture. The physical characteristics of the watersheds also affect runoff. These include: land use, vegetation, soil type, drainage area, basin shape, elevation, slope, topography, direction of orientation, drainage network patterns, and ponds, lakes, reservoirs, sinks, etc. in the basin which prevent or alter runoff from continuing downstream. The annual runoff statistic is a useful statistic to compare the runoff between watersheds. It is calculated by dividing the annual flow volume by the drainage basin area. The total annual runoff is the depth to which the drainage area would be covered if all the runoff

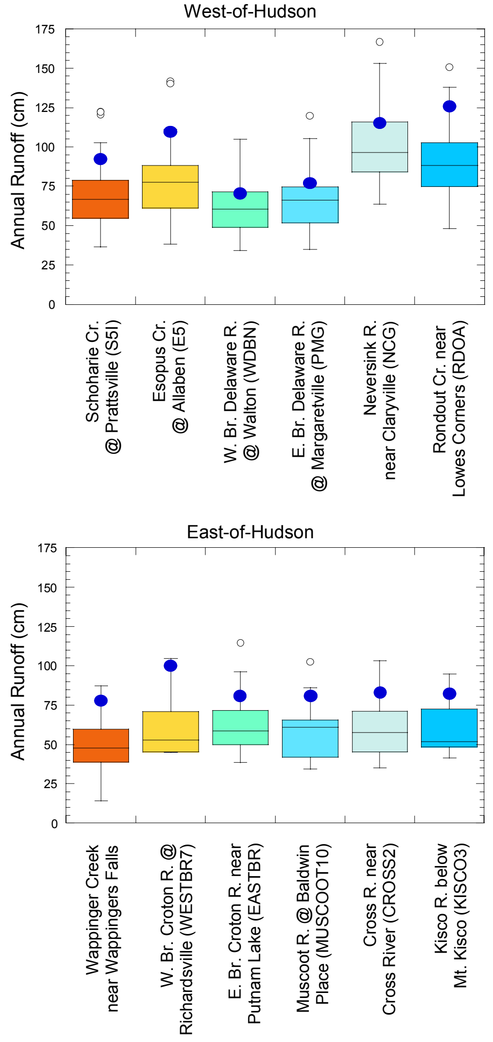


Figure 2.5 Historic annual runoff (cm) as boxplots for the WOH and EOH watersheds with the values for 2005 displayed as a dot. The USGS data collected after Sept. 30, 2004 are provisional

for the year were uniformly distributed over the basin. This statistic allows comparisons to be made of the hydrologic conditions in watershed of varying sizes.

Selected United States Geological Survey (USGS) stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.5). The total annual runoff from the both the WOH and EOH watersheds were all well above historic medians. The majority of the total runoff occurred as a result of the storms in April and October.

2.5 What was the storage history of the reservoir system in 2005?

The total available percent capacity of the NYC water supply (Actual) in 2004-2005 is compared to the long-term storage average (Normal) in Figure **2.6**. The long-term average was determined by calculating the mean of monthly percent capacity estimates observed during the period 1994-2003. Historically, seasonal patterns in water storage are readily discernible. Capacity normally ranges from a high of 95 percent in the spring to about 75 percent in the fall. In 2004, however, capacity very briefly dropped to a low of 90 percent in the fall reflecting the high precipitation rates that year. At the start of 2005, capacity again was unusually high actually exceeding 104 percent by early April. Normal patterns in reservoir storage resumed thereafter as capacity decreased throughout the spring and summer to a low of 63 percent during the first week of October. Drought was avoided, however, as exceptionally high rainfall during the remainder of October and above average rainfall in November brought total capacity to about 94 percent by year's end.

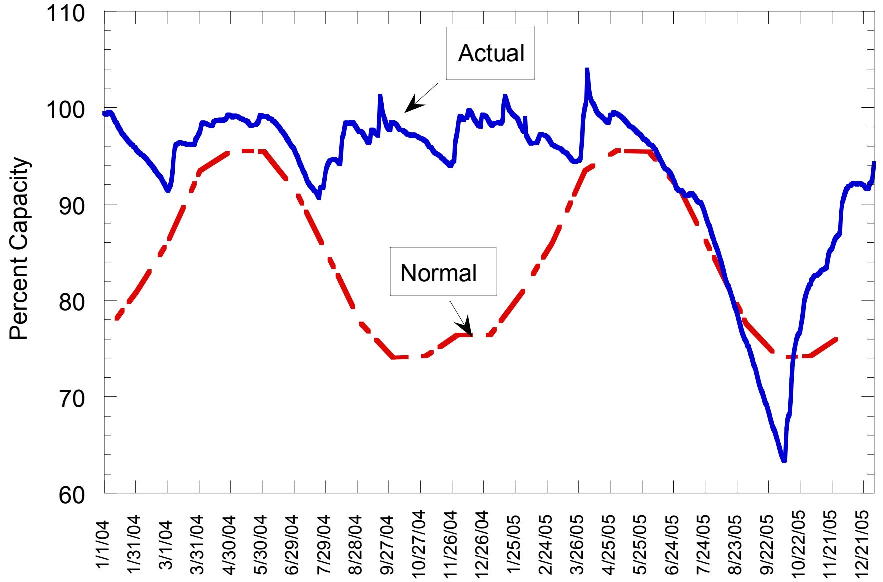


Figure 2.6 Percent usable storage in 2004-2005 (Actual) compared to long-term (1994-2003) average (Normal) storage.

3. Water Quality

3.1 How did DWQC Watershed Operations ensure the delivery of the highest quality water from upstate reservoirs in 2005?

DWQC Watershed Operations conducted extensive water quality monitoring at multiple sampling sites from aqueducts, reservoir intakes and tunnel outlets within the Catskill, Delaware and Croton Systems. In 2005, approximately 49,000 physical, chemical and microbiological analyses were performed on nearly 9,000 samples that were collected from 55 different key aqueduct locations. DWQC also continued to operate and maintain continuous monitoring instrumentation at critical locations to provide real-time water quality data to support operational decision-making (Figure 3.1). Scientists from DWQC review data from the aqueduct and limnology monitoring programs on a continuous basis, and work cooperatively with the Bureau's Division of Operations to determine the best operational strategy for delivering the highest quality water to NYC consumers.

Figure 3.1 Continuous monitoring turbidity instrumentation at the Catskill Lower Effluent Chamber.

2005 was an historic year for DWQC in terms of water quality management. In response to unprecedented storm events, DEP implemented numerous operational and treatment techniques to effectively manage the City's water supply. Operational and treatment strategies employed in 2005 included:

- Selective Diversion

  DEP optimized the quality of water being sent into distribution by maximizing the flow from reservoirs with the best water quality and minimizing the flow from reservoirs with lesser water quality. For example, a severe rain and wind storm occurred at the Kensico Reservoir in January causing turbid run-off to enter the reservoir near the entrance to the Kensico to Hillview section of the Catskill Aqueduct. The elevated turbidity was detected with continuous monitoring instrumentation, and DEP responded quickly and closed the reservoir gates at the Catskill Upper Effluent Chamber. This emergency shutdown of the Catskill Aqueduct minimized the amount of turbid water being sent downstream to the Hillview Reservoir and into the distribution system.

- Selective Withdrawal

  DEP continued to monitor water quality at different intake elevations within the reservoirs and used that information to determine the optimal level of withdrawal. In April, an intake elevation change was made at the Rondout Reservoir when water quality monitoring indicated that turbidity levels had increased near the bottom of the reservoir following a 3.5” rain event. By changing the level of withdrawal from the bottom to the surface, DEP was able to optimize the quality of the water being sent from the Rondout Reservoir down the Delaware Aqueduct and into the Kensico Reservoir.

- Treatment Operation

  When selective diversion, selective withdrawal, and blending operations fail to adequately address water quality problems such as turbidity, bacterial events and algal blooms, DEP has the ability to implement various treatment options. During 2005, major storm events in the Catskill Watershed caused turbidity levels within the Ashokan Reservoir to be elevated for an extended period of time (see Figure 3.2). DEP was able to maintain use of the Catskill supply by adding aluminum sulfate (alum) to the Catskill Aqueduct at the

Figure 3.2 Turbidity plume in the Ashokan Reservoir following the October 2005 storm event.

Pleasantville Alum Plant. Alum causes the particles in the water to coagulate and settle out before they adversely impact water quality in the Kensico Reservoir (see Section 3.2 for more detail).

3.2 What is alum treatment: how and why it was used during 2005?

In April 2005, New York City's Water Supply watershed located in the Catskill Mountains, received several days of heavy rainfall which along with melting snow caused record flooding in area streams and reservoirs. As a result of this event, the normally relatively clear stream waters of the Catskills became very turbid due to the entrainment of the fine, glacially-deposited clay material which is ubiquitous in the stream channels of the Catskills. The light-scattering property of water is referred to as "turbidity" and is measured in the laboratory by an instrument called a nephelometer; this instrument assesses side-scattered light in arbitrary units known as nephelometric turbidity units (NTU). The clay particles that entered these Catskill streams are highly efficient at scattering light and therefore readily caused these streams to appear highly turbid.

The suspended particles are very fine, and can remain in suspension for weeks or months. They can limit the use of water as a drinking water supply by affecting the water's color and taste, interfering with chemical disinfection, increasing the occurrence of disinfection by-products and by providing a basis for the growth of potentially harmful bacteria and other microorganisms. Due to these concerns, state and federal agencies have set a limit on the level of turbidity allowed in public drinking water. The limit for an unfiltered surface water source is set forth in the federal Surface Water Treatment Rule (SWTR) (40CFR 141.71) and in the New York State Sanitary Code (10 NYCRR Section 5-1.1). Both the SWTR and the State Sanitary Code specify that raw water turbidity immediately prior to the first or only point of disinfection cannot exceed 5 NTU.

In response to this flooding event, and in order to comply with the NYS Drinking Water turbidity standards, DEP began treatment of the Catskill Water Supply with alum (aluminum sulfate) to control turbidity. Alum is a coagulant. When added to water, it reacts with suspended particles causing them to clump together forming larger heavier particles called floc, which then settles out of the water column. This process of coagulation, flocculation and sedimentation is a commonly accepted water treatment industry practice for the removal of impurities.

Treatment of the Catskill Supply with alum is a rare occurrence and in fact, prior to 2005, treatment has only been necessary four times over the past 20 years. DEP normally implements operational controls to manage turbidity within the Water Supply system. These actions are intended to ensure that the suspended particles which cause turbidity settle out. When treatment does become necessary, DEP applies alum by injecting it as a slurry into the Catskill Aqueduct just upstream of where it enters Kensico Reservoir. The alum mixes with the water in the aqueduct and forms a floc containing the suspended particles which then settle out as the water enters Kensico Reservoir (Figure 3.3).

Figure 3.3 Photograph of the Catskill Influent Chamber Cove on Kensico Reservoir taken in May 2005 during alum treatment (looking approximately northwest).

The incoming turbid water can be seen to the north of the chamber (mid photograph) with the suspended material flocculating out very quickly as water moves to the south (to the left of the photograph). Some turbid water that entered the Reservoir prior to the treatment can be seen hugging the shoreline to the south of the chamber.

The addition of alum is generally considered to be harmless to both the ecology of lakes and reservoirs, and to drinking water consumers. In fact, the use of alum by lake managers to control eutrophication is considered a safe and effective practice (NALMS, 2004). Aluminum is the most abundant metal on Earth, and is found in soil, water and air. In the Catskills, it is naturally occurring as aluminosilicates in the ubiquitous glacial clay deposits. Aluminum is pervasive in the environment to the point of being unavoidable. Its chemical and physical proprieties make it ideal for a wide variety of uses such as in food additives, in drugs (e.g., antacids) and in consumer products such as cooking utensils and aluminum foil. Aluminum also occurs naturally in many foods such as dairy products and grains. About 95% of the normal daily intake of aluminum for an adult comes from food. Thus, the intake of aluminum in drinking water generally amounts to less than 5% of the total daily intake (Health Canada, 2003). Since nearly all of the alum added to water during the treatment process settles out prior to consumption the aluminum content of treated water is only slightly higher than untreated water.

DEP intensively monitors the drinking water supply for many analytes including aluminum. Aluminum is generally considered to be non-toxic so there are no State or Federal regulations limiting its concentration in drinking water. However, the USEPA has published a secondary standard for aluminum of 50-200 μg L^{-1} to be used as a guidance value. Since 2000 approximately 75% of DEP's measurements of aluminum in water leaving Kensico Reservoir were below this range. In addition, only one value exceeded the 200 μg L^{-1} upper limit. This reading was measured in a sample collected immediately before the aqueduct was closed due to storm activity, and so was not indicative of water sent to consumers.

3.3 What concentrations of *Cryptosporidium* and *Giardia* and human enteric viruses were found in source waters and in the watershed in 2005?

DEP staff collected over 1,000 samples for protozoan analysis during 2005. Under routine operations, "source waters" are the waters in the influent and effluent chambers of Kensico Reservoir (four chambers altogether, one influent and effluent for each of the Catskill and Delaware aqueducts) and the effluent chamber of New Croton Reservoir. Results from the weekly monitoring of 50 liter samples of these source waters are posted weekly on the DEP web site at www.nyc.gov/html/dep/html/pathogen.html. To provide some perspective, the number of source water samples collected comprised 35% of all samples, second only to the number of stream samples collected throughout the watershed (Figure 3.4).

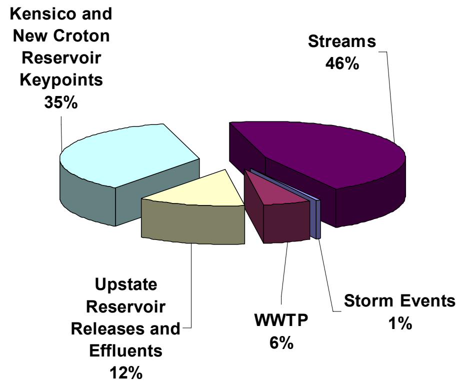


Figure 3.4 Breakdown of sample type collected by DEP in 2005.

The "watershed samples" are stream samples, upstate reservoir release and effluent samples, and WWTP and storm event samples collected within the 125 mile radius watershed in New York State. Stream samples comprised the greatest number of samples for 2005, while upstate reservoir releases and effluents, wastewater treatment plants, and storm events made up the remaining 19% of monitoring, with the exception of special projects.

Kensico Influent Source Water

Concentrations of *Giardia* entering Kensico Reservoir at the Catskill and Delaware influents were similar in 2005. The mean concentration of *Giardia* was 1.55 cysts 50L^{-1} the Catskill influent chamber, and 2.12 cysts 50L^{-1}at the Delaware influent chamber (Table 3.1). These data showed a positive detection for *Giardia in* 55% and 61% of samples, with maximum concentrations of 9 and 10 cysts 50L^{-1}for the Catskill and Delaware sites, respectively.

Table 3.1: Summary of *Giardia* and *Cryptosporidium* data at the five DEP keypoints for 2005.

Site	Pathogen	Number of Samples	Number of Positive Samples	Percent Positive	Mean concentration 50L^{-1}	Maximum concentration 50L^{-1}
Catskill Influent Chamber	Total *Giardia*	51	28	55%	1.549	9
	Total *Cryptosporidium*	52	1	2%	0.019	1
Catskill Effluent Chamber	Total *Giardia*	51	23	45%	0.980	6
	Total *Cryptosporidium*	52	6	12%	0.154	3
Delaware Influent Chamber	Total *Giardia*	51	31	61%	2.118	10
	Total *Cryptosporidium*	52	6	12%	0.1154	1
Delaware Effluent Chamber	Total *Giardia*	51	27	53%	1.216	6
	Total *Cryptosporidium*	52	5	10%	0.096	1
New Croton Reservoir Effluent	Total *Giardia*	51	23	45%	1.176	7
	Total *Cryptosporidium*	52	3	6%	0.058	1

Although the *Cryptosporidium* concentrations were much lower than *Giardia* concentrations at both influent chambers to Kensico Reservoir, results were comparable at both locations. The Catskill influent mean *Cryptosporidium* concentration was 0.02 oocysts 50L^{-1} and it was 0.12 oocysts 50L^{-1}.at the Delaware influent. There was a 2% and12% positive detection rate at these effluent chambers, with a maximum concentration of 1 oocyst 50L^{-1} at both sites.

Human enteric viruses (HEV) were detected in 64% and 39% of the Kensico influent chamber samples at the Catskill and Delaware aqueducts, respectively (Table 3.2). Mean and maximum concentrations of HEV were 4.04 and 49.62 $100L^{-1}$ at the Catskill aqueduct, and 1.36 and 11.96 $100L^{-1}$ at the Delaware location.

Table 3.2: Summary of Human Enteric Virus data for the five DEP keypoints for 2005.

Keypoint	Number of Samples	Number of Positive Samples	Percent Positive	Mean concentration MPN($100L^{-1}$)	Maximum concentration MPN($100L^{-1}$)
Catskill Influent Chamber	52	33	63.5%	4.04	49.62
Catskill Effluent Chamber	52	11	21.2%	0.73	20.996
Delaware Influent Chamber	52	20	38.5%	1.36	11.96
Delaware Effluent Chamber	52	14	26.9%	0.64	7.14
New Croton Reservoir Effluent	52	25	48.1%	1.12	7.13

Kensico Effluent Source Water

The waters leaving Kensico Reservoir at the Catskill and Delaware effluent chambers had very similar *Giardia* mean concentrations in 2005, 0.98 cysts $50L^{-1}$and 1.22 cysts $50L^{-1}$, respectively. The maximum concentration of *Giardia* at both effluents was 6 cysts $50L^{-1}$, which falls below the influent maximum results of 9 and 10 cysts, for the Catskill and Delaware systems respectively, suggesting that the reservoir is acting as a sink and reducing the pathogen concentration as water travels through the system.

Cryptosporidium concentrations at the effluent chambers of Kensico Reservoir were very similar to the influent mean concentrations in 2005 at 0.15 and 0.01 $50L^{-1}$for Catskill and Delaware, respectively. These results suggest two possibilities: either oocysts entering the reservoir are passing through unchanged, or they are being eliminated by reservoir processes and new oocysts may be entering locally.

Human enteric virus results for Kensico's Catskill and Delaware effluent chambers indicated a 21% and 27% positive sample detection rate, respectively, lower than the influent detection rate. Overall mean and maximum HEV concentrations were 0.73 and 21 $100L^{-1}$ for the Catskill effluent while the Delaware mean and maximum values were 0.64 and 7.14 $100L^{-1}$.

New Croton Effluent Source Water

New Croton Reservoir protozoan data are comparable to the Kensico Reservoir data. Mean concentrations of *Giardia* were 1.18 cysts $50L^{-1}$, while the *Cryptosporidium* mean was 0.06 oocysts $50L^{-1}$. The percent of samples positive for *Giardia* and *Cryptosporidium* were 45% and 6%, with maximum concentrations of 7 and 1 $50L^{-1}$ for cysts and oocysts respectively. Although it had a higher percent detection of positive samples (48%) than the Delaware effluent (27%) in 2005, the New Croton HEV mean and maximum concentrations were 1.12 and 7.13 $100L^{-1}$, respectively, which compare closely to the Delaware effluent results.

Watershed Samples

For the purposes of this report, watershed samples were divided into four different categories: streams, upstate reservoir releases and effluents, storm events and wastewater treatment plant effluents. Stream samples collected in 2005 had the highest mean *Giardia* and *Cryptosporidium* concentration, with a mean of 19.94 cysts $50L^{-1}$and 0.7 oocysts $50L^{-1}$. Releases and effluents of upstate reservoirs resulted in a *Giardia* mean concentration of approximately 6.93 cysts $50L^{-1}$, while the mean *Cryptosporidium* value was 0.15 oocysts $50L^{-1}$. Wastewater treatment plant samples are collected in the effluents from the plants' post-treatment in order to aid in monitoring the effectiveness of the plant processes. In 2005, treatment plant samples remained low for protozoan pathogens, with mean concentrations of 0.28 *Giardia* and 0.06 *Cryptosporidium* $50L^{-1}$. Surprisingly storm water samples collected in the watershed had no positive detects for *Cryptosporidium* or *Giardia,* though there were only 6 samples and they were all less than 50 liters.

3.4 How did protozoan concentrations compare with regulatory levels in 2005?

Currently, there are no New York State, or Federal, regulations established for *Giardia* or *Cryptosporidium* in source water. There is, however, a new rule for *Cryptosporidium* submitted by the US Environmental Protection Agency (USEPA) called the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA, 2001), which was promulgated in January 2005. The rule requires that samples will be analyzed using an approved USEPA Method 1623 laboratory and it provides for increased protection against microbial pathogens in drinking water. The DEP Pathogen Laboratory was approved for use of this method in August of 2001, and DEP began analyzing source water samples with Method 1623 later that year, providing DEP with nearly five years of data at this time. The three source water effluent sites are covered by the LT2, one for each system—the Catskill and Delaware effluent chambers at Kensico Reservoir and the New Croton Reservoir effluent chamber.

Data from all three sites for 2004 – 2005 are compared to the proposed LT2 threshold for *Cryptosporidium* (Figure 3.5). Results for this two year period once again fell below the proposed regulatory levels for the LT2, as they did for 2002 through 2004.

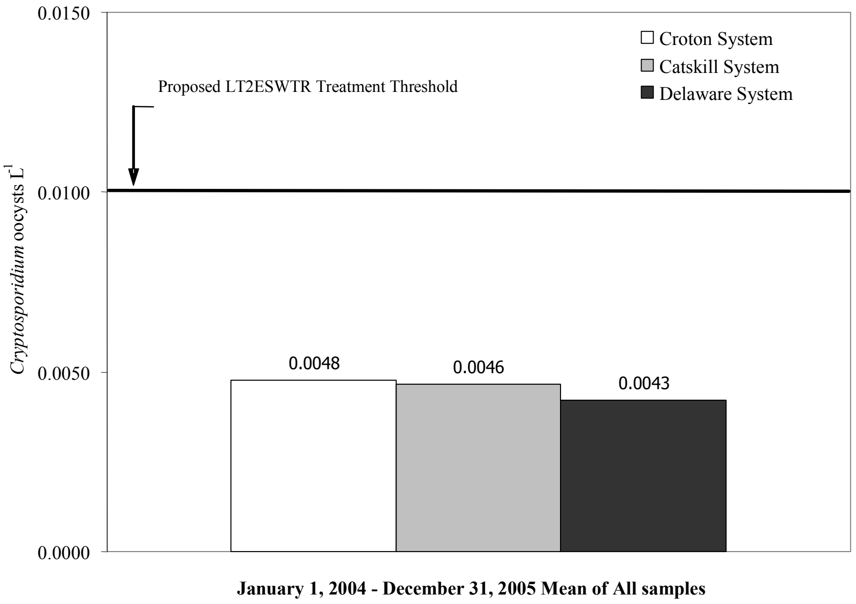


Figure 3.5 DEP *Cryptosporidium* results for 2004 and 2005 calculated as per the LT2 guidelines compared to the US EPA LT2 treatment threshold.

3.5 How did the 2005 water quality of NYC's source waters compare with standards set by Federal regulations for fecal coliforms and turbidity?

The Surface Water Treatment Rule (SWTR) (40CFR141.71(a)(1)) requires that water at a point just prior to disinfection not exceed thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at "keypoints" just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF and the Delaware System at DEL18). Figures 3.6 and 3.7 depict fecal coliform and turbidity data for 1992-2005. Both figures include a horizontal line marking the SWTR limit.

As indicated in Figure 3.6, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; for 2005, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 are far below the 10% limit set by the SWTR standard. For 2005, for raw water samples taken at the three keypoints CROGH, CATLEFF, and DEL18, the mean and median fecal coliform concentrations $(100\text{mL})^{-1}$ were 0.6 and 0, 2.8 and 1, and 3.5 and 2, respectively.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.7, all three effluent waters were consistently well below this limit in 2005. For the three keypoints CROGH, CATLEFF, and DEL18, the mean and median turbidity values (NTU) were 0.8 and 0.8, 1.2 and 1.1, and 1.1 and 1.0, respectively.

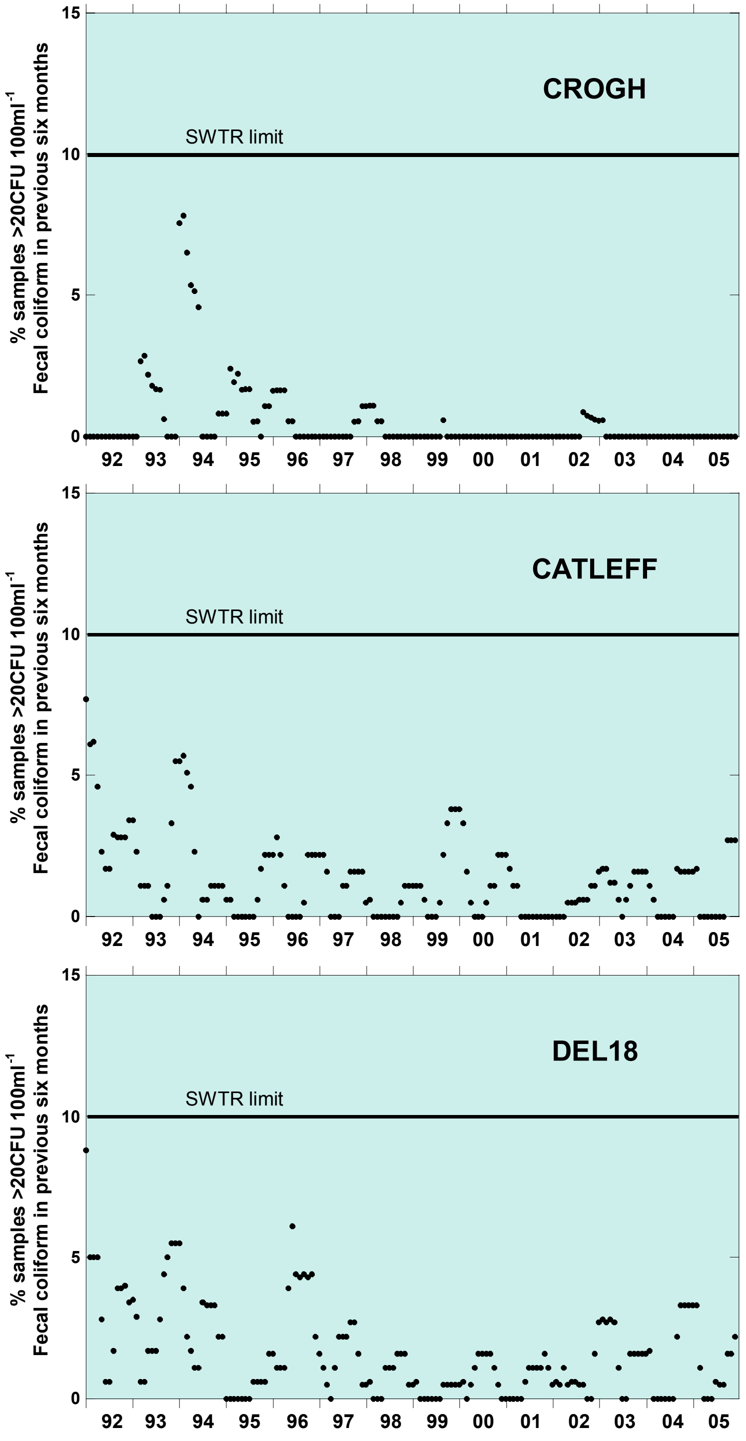


Figure 3.6 Temporal plots of fecal coliform (% of daily samples > 20CFU 100mL^{-1} in the previous six months) compared with Surface Water Treatment Rule limit.

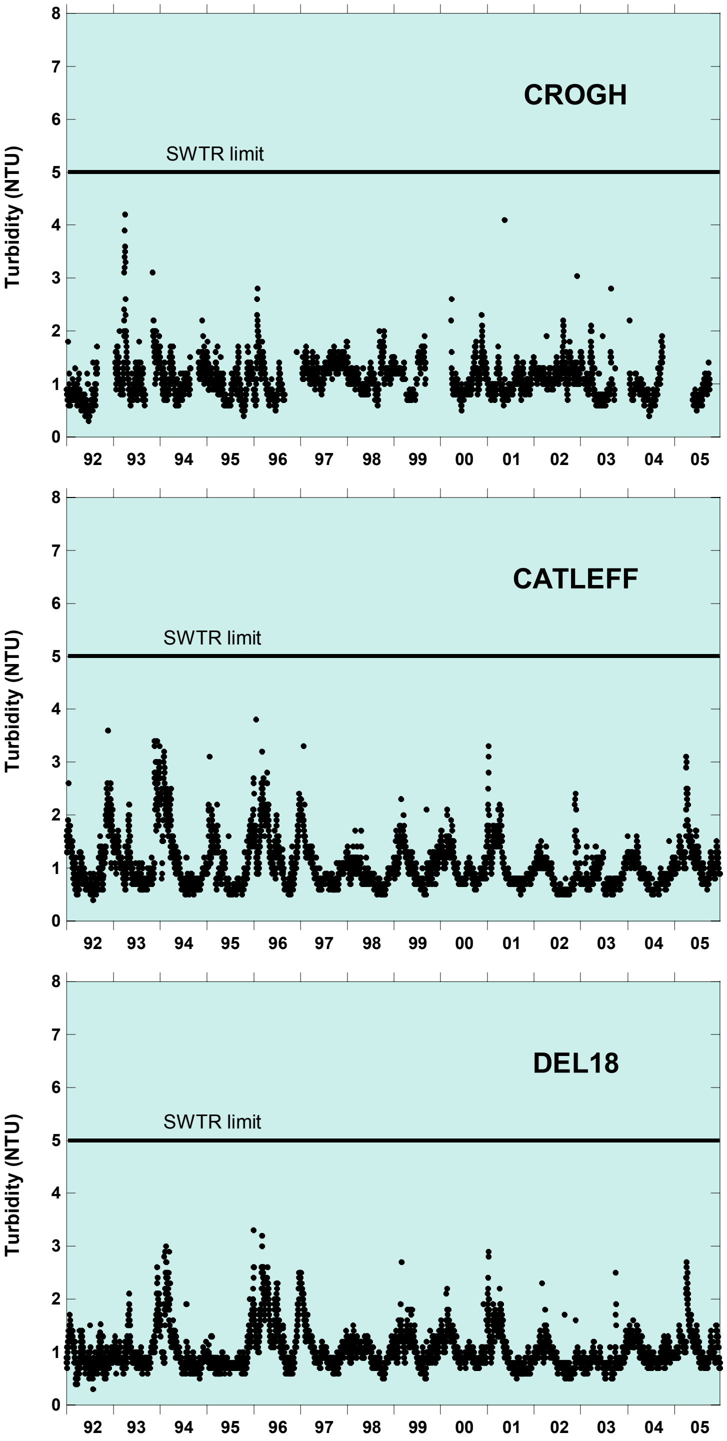


Figure 3.7 Temporal plots of turbidity (daily samples—Hach 2100AN instrument) compared with Surface Water Treatment Rule limit.

3.6 What was the water quality in 2005 in the streams that represent the major flow into NYC's reservoirs?

The stream sites used this report are presented in Table 3.3 and shown pictorially in Figure 3.8. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds.

Table 3.3: Sites codes and site descriptions of the stream sample locations discussed in this report.

Site Code	Site Description
S5I	Schoharie Creek at Prattsville, above Schoharie Res.
E16I	Esopus Creek at Boiceville bridge, above Ashokan Res.
WDBN	West Br. Delaware River at Beerston, above Cannonsville Res.
PMSB	East Br. Delaware River below Margaretville WWTP, above Pepacton Res.
NCG	Neversink River near Claryville, above Neversink Res.
RDOA	Rondout Creek at Lowes Corners, above Rondout Res.
WESTBR7	West Branch Croton River, above Boyd Corners Res.
EASTBR	East Branch Croton River, above East Branch Res.
MUSCOOT10	Muscoot River, above Amawalk Res.
CROSS2	Cross River, above Cross River Res.
KISCO3	Kisco River, input to New Croton Res.
HUNTER1	Hunter Brook, input to New Croton Res.

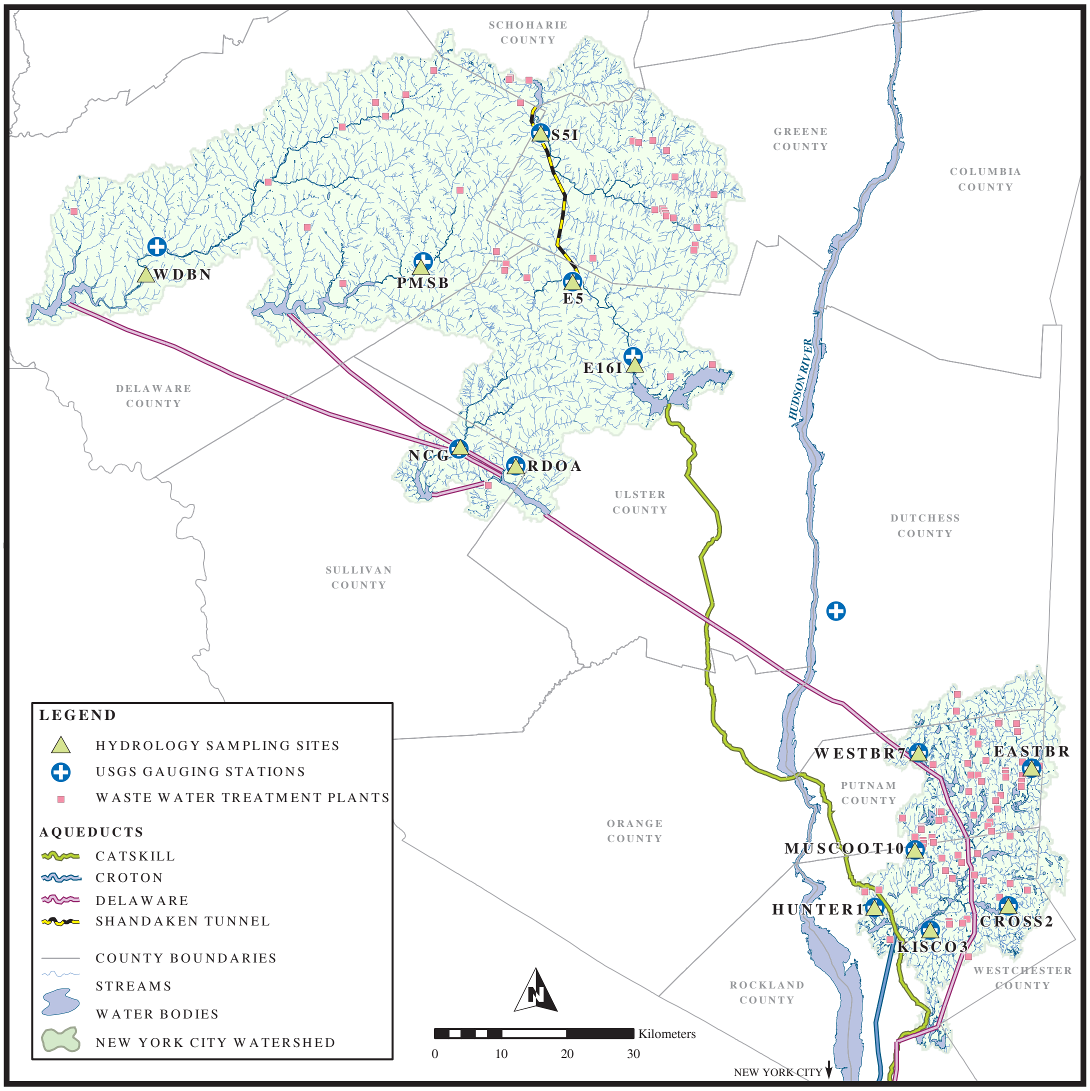


Figure 3.8 Locations of sampling sites and USGS stations.

The analytes chosen are considered to be the most important for the City water supply. For streams, they are turbidity (Surface Water Treatment Rule limit), total phosphorus (nutrient/ eutrophication issues), and fecal coliform bacteria (Surface Water Treatment Rule limits).

The results presented are based on grab samples generally collected twice a month (generally once a month for turbidity and total phosphorus for the EOH sites although fecal coliform samples are generally collected twice a month.). The figures compare the 2005 median values against historic median annual values for the previous ten years (1995-2004). However, two of the EOH sites have shorter sampling histories. These are: KISCO3 (1999-present), and HUNTER1 (1998-present). It should also be noted that the 2005 data from EOH are still considered provisional in nature.

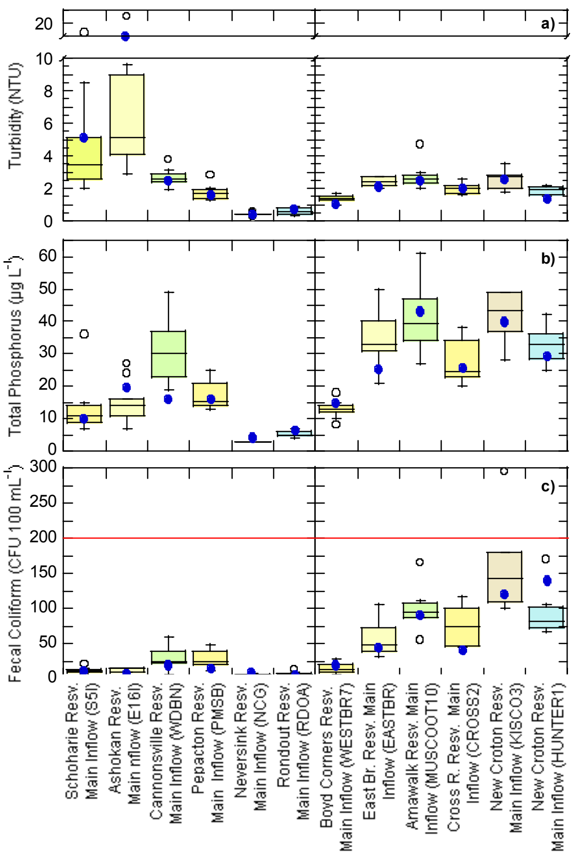


Figure 3.9 Boxplot of annual medians (1995–2004) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2004 displayed as a dot.

Turbidity

The turbidity levels for 2005 were generally near "normal" values (Figure 3.9a) except for the Catskill sites (S5I and E16I), with the inflow to Ashokan (E16I) showing an exceptionally elevated median turbidity value for 2005. The high turbidities in the Esopus Creek were a result of the April and October precipitation events (see section 2.2). These events resulted in NYCDEP treating the Catskill System with alum (see section 3.2) for turbidity.

Total Phosphorus

In the Catskill/Delaware System, the 2005 total phosphorus levels (Figure 3.9b) were for the most part near typical historical values, except for Ashokan, which was moderately elevated, likely due to runoff from the storm events discussed above. The total phosphorus value in Cannonsville continues to show improvement, and is well below the historic median, perhaps reflecting the influence of improvements in agricultural practices and wastewater treatment plant upgrades. The 2005 total phosphorus values in the Croton System (Figure 3.9b) were generally within the range of typical values, except for the East Branch, which was less than historical values. The lower phosphorus levels were also seen in the East Branch Reservoir data, and will be discussed in Section 3.8.

Fecal Coliform Bacteria

The 2005 fecal coliform bacteria levels (Figure 3.9c) in the Catskill/Delaware and Croton Systems were generally near the typical historical levels. Only Hunter Creek, an inflow to the New Croton Reservoir, showed an elevated median value of fecal coliforms in 2005.

A fecal coliform benchmark of 200 CFU 100 mL^{-1} is shown as a solid line on Figure 3.9c. This benchmark relates to the NYS DEC (1998) water standard (expressed as a monthly geometric mean of five samples, the standard being <200 CFU 100 mL^{-1}) for fecal coliforms. The 2005 median value for all streams shown here lie below this value.

3.7 How did the snowmelt and the increased precipitation in April and October/November 2005 affect turbidity in the reservoirs?

Turbidity in reservoirs is caused by organic (e.g., plankton) and inorganic particulates (e.g. clay, silt, etc.) suspended in the water column. Turbidity may be generated within the reservoir itself (e.g. plankton, sediment re-suspension) or it may be derived from the watershed by erosional processes (e.g. storm runoff in particular).

In 2005, median turbidity increased in all Delaware and Catskill System reservoirs as compared to their annual medians of the past 10 years (Figure 3.10). For most of these reservoirs, it was the highest annual median turbidity in the last 11 years. The largest increases occurred in the Catskill System Reservoirs where annual turbidities were 2.5 to 15 times higher than the historic annual medians. Twenty to fifty percent increases were observed in the Delaware System. The bulk of the turbidity increase was caused by surface runoff generated by rain-on-snow events in late-March and early-April, and was most pronounced in the Esopus watershed, as reflected in Ashokan's West Basin turbidity median. Surface runoff from very high rainfall amounts in October also contributed to the turbidity increase in 2005. Although Kensico Reservoir receives 40% of its water from Ashokan-East, turbidity levels in Kensico were kept low by treatment of the Ashokan-East water with alum, a coagulant, before allowing it to enter Kensico (See Section 3.2). West Branch Reservoir, which receives about 90% of its water from Rondout experienced elevated turbidity levels in April and May but its annual median turbidity was only slightly higher than normal.

Spring runoff was much less problematic in the reservoirs of the Croton watershed. Turbidity levels at Middle Branch, Titicus and Cross River were well within their historic ranges. Unfortunately, insufficient data exists to calculate accurate annual medians for Boyd Corners, Croton Falls, Bog Brook, East Branch, Muscoot, Diverting and New Croton. For these reservoirs only the historic annual medians are provided in Figure 3.10. The software (Kaleidagraph) cannot display the additional data from the three controlled lakes, Kirk, Gilead and Gleneida in Figure 3.10. In 2005, the median turbidity at Gilead was 1.3 NTU, very similar to past levels. Insufficient data exists in 2005 to calculate reliable annual medians for Kirk and Gleneida Lake.

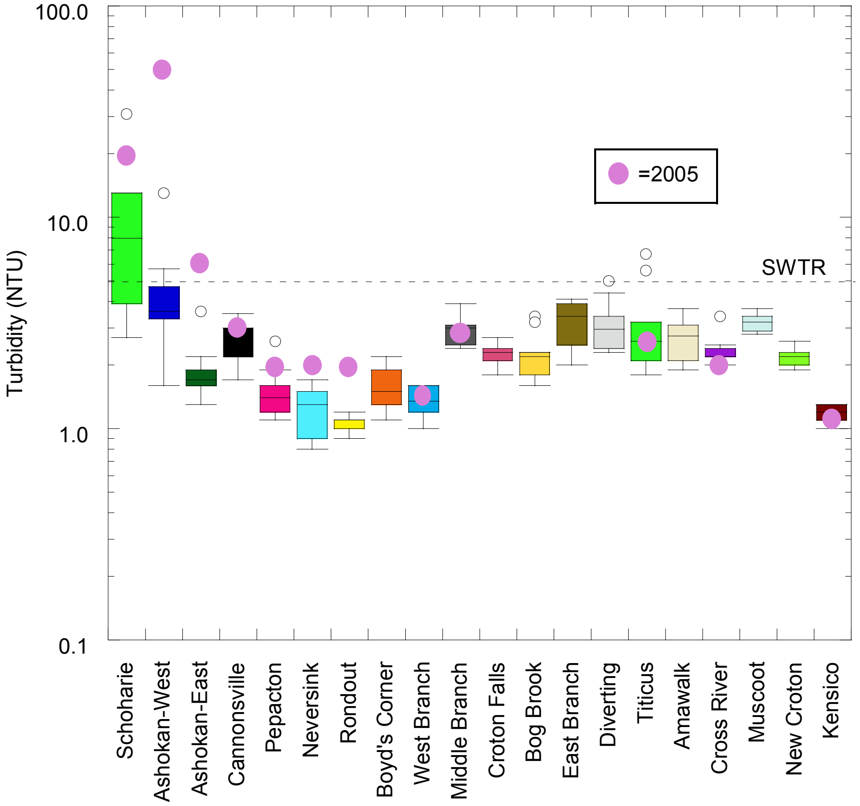


Figure 3.10 Annual median turbidity in NYC water supply reservoirs (2005 vs. 1995–2004). Turbidities were measured using a Hach 2100AN instrument.

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. The dashed line at 5 NTU refers to the SWTR criterion that considers 2 consecutive days > 5NTU as a violation in source water reservoirs.

3.8 Were the total phosphorus concentrations in the reservoirs affected by precipitation and runoff in 2005?

Precipitation and runoff generated by precipitation are important mechanisms by which phosphorus is transported from local watersheds into streams and reservoirs. Primary sources of phosphorus include: human and animal waste, fertilizer runoff, atmospheric deposition, and internal recycling from reservoir sediments. With the exceptions of Schoharie and Cannonsville, most Catskill and Delaware System Reservoirs have relatively low long-term (1995-2004) concentrations of total phosphorus (Figure 3.11). Relatively high concentrations are prevalent at Schoharie because its stream channels, which contain glacial clay deposits, are highly susceptible to erosion. In Cannonsville Reservoir, elevated phosphorus is likely due to runoff from agricultural land and, prior to upgrades, from several waste water treatment plants located within the watershed.

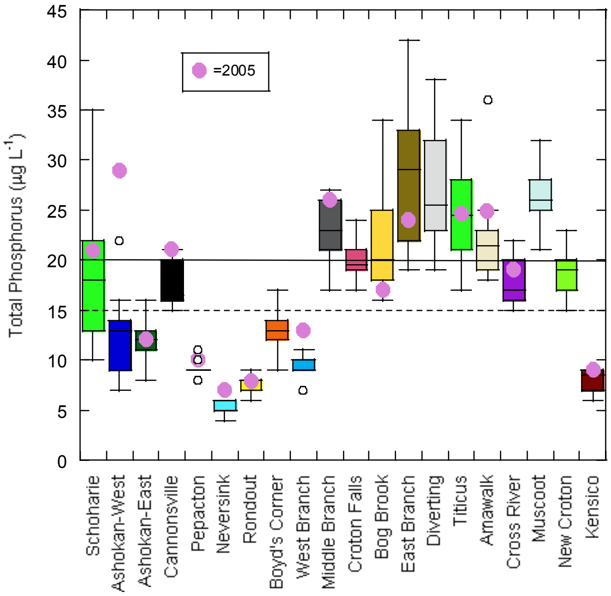


Figure 3.11 Annual median total phosphorus in NYC water supply reservoirs (2005 vs. 1995-2004).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Due to limited data in 2005, representative annual medians could only be calculated for Middle Branch, Cross River, Titicus, Gilead, East Branch, Bog Brook and Amawalk.

The horizontal dashed line at 15 µg L^{-1} refers to the NYC TMDL guidance value based on epilimnetic samples collected bi-weekly from June-September. This guidance value is appropriate for source waters. Although Kensico and New Croton are usually operated as source waters, these reservoirs can be by-passed so that any or all of the following can be operated as source waters: Rondout, Ashokan East, Ashokan West and West Branch. The horizontal solid line at 20µg L^{-1} refers to the NYS DEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs).

Elevated spring and fall runoff in 2005 caused phosphorus concentrations to increase considerably in Neversink, Cannonsville and especially in Ashokan's West Basin where the 2005 median total phosphorus was nearly 2.5 times the historic median (Figure 3.11). The phosphorus increase at Ashokan was due solely to local watershed inputs since Schoharie Reservoir water was prevented from entering Ashokan (via the Esopus creek) during the spring rain-snow event. Most of the phosphorus load was confined to the West Basin as the 2005 median phosphorus in the adjoining East Basin was equivalent to the historic median. Schoharie, Pepacton and Rondout Reservoirs were also affected by the spring and fall runoff events, but phosphorus levels were only slightly elevated compared to historic data. The 2005 median phosphorus at Schoharie, however, was probably biased low since October data was not available for the calculation.

As expected, West Branch, a balancing reservoir for the Delaware System, also experienced elevated phosphorus in 2005 (Figure 3.11). High loadings from Rondout, associated with the April runoff event and extremely high phosphorus levels in July contributed to the increase. Reasons for the high July values are not clear as all phosphorus inputs to West Branch were comparatively low during this time. Kensico Reservoir, which receives water from both Rondout (via West Branch) and the East Basin of Ashokan, showed no change in phosphorus compared to historic levels.

As shown in Figure 3.11 total phosphorus concentrations in the Croton System Reservoirs are normally much higher than in the Catskill and Delaware Systems. Development pressure is the difference. There are 60 waste water treatment plants, numerous septic systems and abundant paved surfaces scattered throughout the Croton watershed. Unfortunately, 2005 data was relatively scarce, so accurate annual medians could only be calculated for Middle Branch, Cross River, Titicus, Gilead, East Branch, Bog Brook and Amawalk. Compared to historic levels, phosphorus concentrations were slightly elevated at Middle Branch, Cross River, Amawalk and Gilead in 2005. Although reasons for the increase are not clear, April and May phosphorus levels (where available) were normal, indicating that spring runoff was not the cause. In contrast, total phosphorus levels at Bog Brook and East Branch were lower than in the past despite runoff and precipitation patterns that were roughly similar to those reservoirs where phosphorus was shown to increase. Total phosphorus concentrations in the main input to East Branch Reservoir (and Bog Brook Reservoir via East Branch), the East Branch of the Croton River, were also below average. Perhaps during periods of low precipitation, such as the summer of 2005, the contribution of relatively phosphorus free base-flow becomes a more important control of water quality in this particular sub-basin. The large percentage of wetlands in the watershed may also play a part in retention of phosphorus during times of low precipitation.

3.9 Which basins were phosphorus-restricted in 2005?

The phosphorus restricted basin status is provided in Table 3.4 and was derived from two consecutive assessments (2000-2004; 2001-2005) using the methodology stated in Appendix C. The table in this appendix lists the annual growing season geometric mean total phosphorus concentration for each of the City reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.12 graphically depicts the phosphorus restriction status of the NYC Reservoirs and the 2005 geometric mean for the phosphorus concentration.

Table 3.4: Phosphorus-restricted reservoir basins for 2005.

Reservoir Basin	00 - 04 Assessment (mean + S.E.) (µg L^{-1})	01-05 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus Restricted Status
Delaware District			
Cannonsville Reservoir	17.8	18.4	Non-Restricted
Pepacton Reservoir	9.5	9.5	Non-Restricted
Neversink Reservoir	5.4	6.1	Non-Restricted
Rondout Reservoir	8.6	8.3	Non-Restricted
Catskill District			
Schoharie Reservoir	16.1	15.8	Non-Restricted
Ashokan-West Reservoir	9.4	15.6	Non-Restricted
Ashokan-East Reservoir	10.6	10.7	Non-Restricted
Croton District			
Amawalk Reservoir	28.9	23.7	Restricted
Bog Brook Reservoir	28.5	23.1	Restricted
Boyd Corners Reservoir	15.0	14.7	Non-Restricted
Cross River Reservoir	19.1	19.4	Non-Restricted
Croton Falls Reservoir	23.6	22.5	Restricted
Diverting Reservoir	34.6	35.8	Restricted
East Branch Reservoir	40.1	38.3	Restricted
Middle Branch Reservoir	30.7	30.4	Restricted
Muscoot Reservoir	32.5	30.6	Restricted
Titicus Reservoir	29.8	27.4	Restricted
West Branch Reservoir	12.2	12.7	Non-Restricted
Lake Gleneida	31.0	Insufficient Data	Insufficient Data
Lake Gilead	34.6	34.4	Restricted
Source Water			
Kensico Reservoir	8.7	8.9	Non-Restricted
New Croton Reservoir	23.2	22.6	Restricted

Note that the 00-04 assessment now uses 'verified' data whereas the 01-05 assessment uses 'provisional' data for 2005.

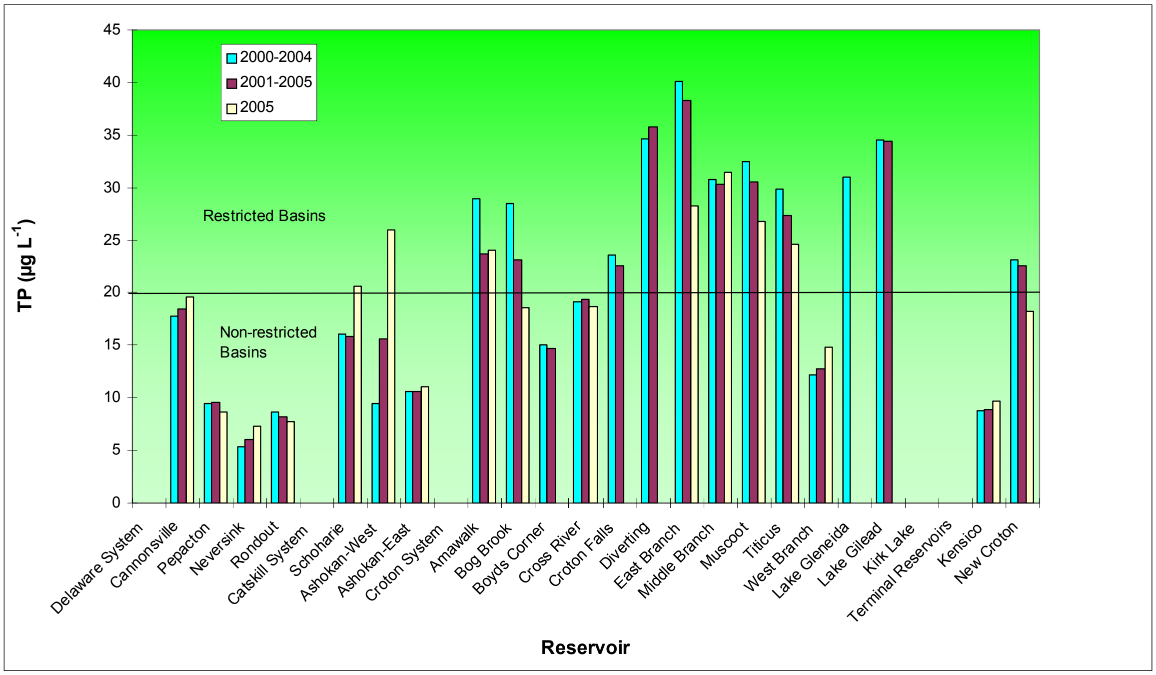


Figure 3.12 Phosphorus restricted basin assessments with the current year (2005) geometric mean phosphorus concentration displayed for comparison.

There are a few notes and highlights in the Phosphorus-Restricted Basin Status this year.

- Cannonsville Reservoir and all other Delaware District reservoirs remained non-restricted. The annual geometric mean TP in Cannonsville and Neversink was elevated in 2005 as compared to previous years (Appendix C), probably due to the impact of runoff events during the year.
- Schoharie Reservoir and Ashokan's East Basin had little change in phosphorus concentrations between the five-year assessments for 2000-2004 as compared to 2001-2005. However, the annual average TP for all three Catskill basins increased in 2005 compared to 2004 (Appendix C). Most dramatic of these was Ashokan's West Basin, which had a TP increase of 6 µg L^{-1} for the five year assessment period. This increase was primarily due to the major runoff event in April in the Esopus watershed, and subsequent events in the fall. Much of the phosphorus is not biologically available, however.
- Croton System reservoir assessments remained unchanged in their phosphorus-restricted status. However, Lake Gleneida, which was restricted, could not be assessed for 2001-2005 because of insufficient data. New Croton Reservoir continues its phosphorus-restricted status. Amawalk and Bog Brook had decreased mean TP levels for the 2001-2005 assessment. All the remaining Croton System reservoirs, as well as Kensico, had TP levels that were similar for both assessment periods. The assessment could not be calculated for Kirk Lake since three years out of five are required to derive the five year mean.
- Reservoir access issues (e.g. draw down, dam rehabilitation) limited the number of months that were used for the calculation of the 2005 geometric mean on Muscoot Reservoir. New

Croton could only be assessed for three out of six months. One survey was missed due to scheduling conflicts. TP data from two surveys were unavailable due to analytical problems.

- Boyd Corners, Croton Falls, Diverting, Kirk Lake, Lake Gilead, and Lake Gleneida reservoirs did not fulfill the data requirement of three complete surveys during the growing season in 2005 because of scheduling issues, and access issues. The annual average for these reservoirs and lakes is not included in Figure 3.12.

3.10 What were the total and fecal coliform concentrations in NYC's reservoirs?

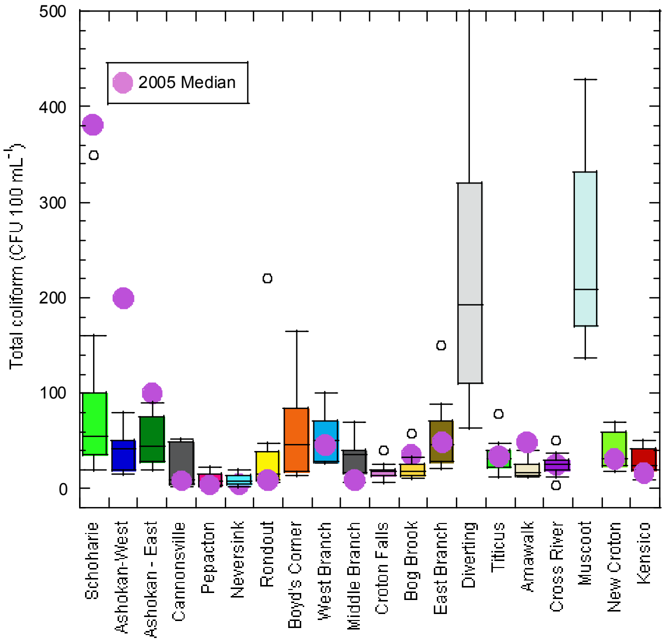


Figure 3.13 Annual median total coliform in NYC water supply reservoirs (2005 vs. 1995-2004).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. However, the medians were not calculated in 2005 for Boyd Corners, Croton Falls, Diverting and Muscoot because of a very limited number of samples that may not be an accurate representation of the year.

Coliform bacteria include total coliform and fecal coliform counts, which are regulated in source waters by the Safe Drinking Water Act (SDWA) at levels of 100 CFU 100 mL^{-1} and 20 CFU 100 mL^{-1}, respectively. Both are used as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals.

Figure 3.13 shows that the long-term (1995-2004) annual median levels of total coliform have exceeded 100 CFU 100 mL^{-1}, primarily in Diverting and Muscoot reservoirs. In 2005, insufficient data exists from these reservoirs, as well as Croton Falls and Boyd Corners to calculate representative annual medians. Of the remaining East-of-Hudson reservoirs, most were very close to, and in some cases slightly lower than, their historic annual medians. Exceptions occurred at Amawalk and Bog Brook where total coliform levels were somewhat higher than in the past. These reservoirs, in particular, appeared to have been impacted by heavy rains in October and November. Although not shown in the plots, the controlled lakes (Gilead, Gleneida and Kirk) all continued to have elevated medians for 2005 as compared to previous years.

The Catskill reservoirs were all well above their long-term medians for total coliform bacteria in 2005. Spring runoff and heavy rainfall in October are the probable causes for this increase. Oddly enough all the Delaware reservoirs were equivalent to their historic levels of bacteria despite precipitation patterns similar to those of the Catskills. Research in the literature has shown that total coliforms commonly adhere to soil particles. Because soils are much less susceptible to erosion in the Delaware watersheds, an equal volume of runoff there tends to produce a much lower total coliform concentration than in the Catskill System.

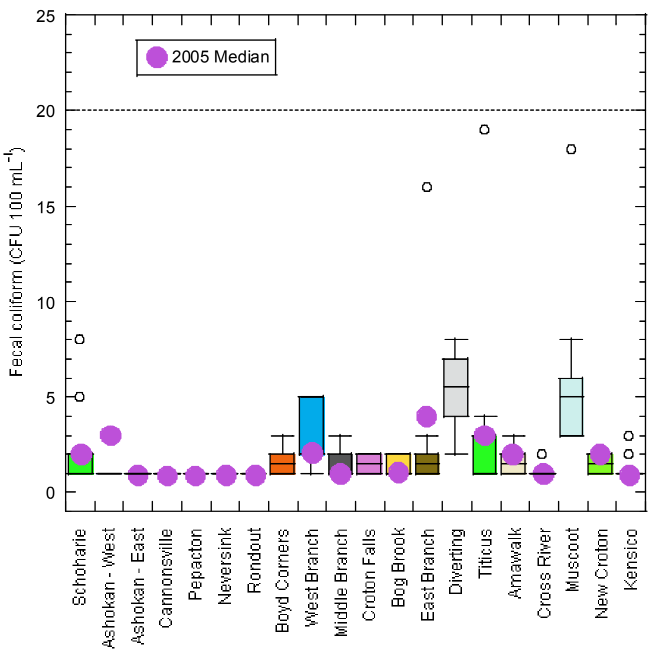


Figure 3.14 Annual median fecal coliform in NYC water supply reservoirs (2005 vs. 1995-2004).

The dashed line represents the SDWA standard for source waters as a reference. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. However, the medians were not calculated in 2005 for Boyd Corners, Croton Falls, Diverting and Muscoot because of a very limited number of samples that may not be an accurate representation of the year.

Figure 3.14 shows that the long-term annual medians for fecal coliform never exceeded 20 CFU 100 mL^{-1} for any of the reservoirs. Muscoot and Diverting were among the reservoirs having the highest long-term levels, but along with Croton Falls and Boyd Corners, these reservoirs did not have enough data in 2005 to calculate a representative median. Of the remaining East-of-Hudson reservoirs, East Branch was the only reservoir that had a marked increase in fecal coliform in 2005. Although reasons are not clear, much of the increase is coincident with heavy rainfall in October and November. The controlled lakes, which are not shown in the figure due to software limitations, all had median levels of fecal coliform in 2005 that were comparable to past data. However, the 2005 median was comprised of a small number of samples for each lake.

Most West-of-Hudson reservoirs continued to have uniformly low levels of fecal coliform in 2005, as demonstrated by the medians in Figure 3.14. Only the West Basin of Ashokan experienced higher than normal fecal levels in 2005, the highest values being associated with high spring and fall runoff events.

3.11 Which basins were coliform-restricted in 2005?

DEP's Watershed Rules and Regulations state that an annual review of the City reservoirs will be performed to determine which, if any, should receive a coliform-restricted designation in regards to coliform bacteria. There are two parts to be considered in the determination of which basins are coliform restricted: Section 18-48 (a)(1) considers the water in all reservoirs and in Lakes Gilead and Gleneida; Section 18-48 (b)(1) considers the waters within 500 feet of the aqueduct effluent chamber located at a terminal reservoir (Kensico, West Branch, New Croton, Ashokan, and Rondout). Terminal basins are those that serve, or potentially serve, as source-water reservoirs.

With respect to NYC's five terminal basins, an assessment has been made for 2005 under Section 18-48 (b)(1) using *fecal* coliform data at the effluent keypoints (Table 3.5). Currently, coliform restriction assessments are made using data from a minimum of five samples each week over two consecutive six-month periods. The threshold for fecal coliform is 20 CFU 100mL^{-1}. If 10% of the effluent samples measured had values $\geq$ 20 CFU 100mL^{-1}, and the cause determined to be from anthropogenic (man-made) sources, the associated basin would be deemed a "coliform-restricted" reservoir. If < 10 % of the effluent keypoint samples measured $\geq$ 20 CFU 100mL^{-1}, then the associated reservoir would be "non-restricted" in regards to coliform bacteria.

With respect to non-terminal basins, the water quality standard is for *total* coliform only and this poses several problems for reservoir basin designation. Total coliform come from a variety of natural and anthropogenic sources, so using total coliform alone will not meet the spirit of the regulation. The draft methodology developed by DEP for determining coliform restricted basins for these non-terminal reservoirs will use the total coliform standard as an initial assessment, but will also go further to consider other microbial data to determine whether the source is anthropogenic. This method is pending approval and is not in use at this time; therefore, coliform restricted basins have not been determined for the non-terminal reservoirs for 2005.

Table 3.5: Coliform-restricted basin status as per Section 18-48 (b) (1) for 2005

Reservoir Basin	Effluent Keypoint	2005 Assessment
Kensico	CATLEFF and DEL18	Not Restricted
New Croton	CROGH	Not Determined*
Ashokan	EARCM	Not Restricted
Rondout	RDRRCM	Not Restricted
West Branch	DEL10	Not Determined**

* The site CROGH was only represented from May through October due to shut-down of the Croton Aqueduct, therefore, a complete assessment could not be made.

** The WRR relies on five representative samples analyzed per week over each six month period to be used for the coliform restriction assessment of terminal basins. Since the keypoint at West Branch (DEL10) is only sampled once per week, there were not enough samples analyzed to meet this criterion.

3.12 How did source water quality compare with standards in 2005?

Table 3.6 provides reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs: Kensico, New Croton, Ashokan (East Basin) and Rondout. Appendix A gives additional statistical information on these and other reservoirs in the system. New Croton Reservoir water quality is noticeably different from the other three source water reservoirs. The pH in New Croton tends to be higher because of the underlying geology and because of primary production, which at times can cause an excursion above the 8.5 pH water quality standard. The pH readings in WOH reservoirs tend to be lower than the standard of 6.5 pH units at times as a result of low alkalinity which provides little buffering of acidic precipitation. Cation data were unavailable for comparison in the EOH reservoirs in 2005, but the concentrations of these ions are usually higher, as are the consequent variables - alkalinity, hardness and conductivity, than in WOH reservoirs. Chloride levels are much higher in New Croton than in other reservoirs and the levels continue to increase. The chloride levels, however, remain well below the 250 mg L^{-1} NY state ambient water quality standard. Appendix A shows the chloride levels for all other EOH reservoirs, which have had similar increases.

Table 3.6: Reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs in 2005.

ANALYTES	Water Quality Standards	Kensico	New Croton	East Ashokan Basin	Rondout
PHYSICAL					
Temperature (C)		11.3	11.1	10.5	10.0
pH (units)	6.5-8.5[1]	7.0	7.5	7.1	6.6
Alkalinity (mg L^{-1})		10.7	59.7	9.3	7.8
Conductivity		67	374	51	52
Hardness (mg L^{-1})		*	*	15	16
Color (Pt-Co units)	(15)	10	20	12	14
Turbidity (NTU)	(5)[2]	1.1	2.0	6.1	1.4
Secchi Disk Depth (m)		4.8	2.7	2.0	4.6
BIOLOGICAL					
Chlorophyll *a*	7[3]	*	*	3.72	4.7
Total Phytoplankton (SAU)	2000[3]	295	480	115	110
CHEMICAL					
Dissolved Organic Carbon (mg L^{-1})		1.5	2.9	1.6	1.5
Total Phosphorus	15[3]	9	20	12	8.2
Total Nitrogen (mg L^{-1})		0.3	0.48	0.29	0.333
Nitrate+Nitrite-N (mg L^{-1})	10[1]	0.216	0.234	0.212	0.254
Total Ammonia-N (mg L^{-1})	2[1]	0.015	0.022	0.02	0.003

Table 3.6: Reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs in 2005.

ANALYTES	Water Quality Standards	Kensico	New Croton	East Ashokan Basin	Rondout
Iron (mg/l)	0.3	0.04	0.06	0.25	0.10
Manganese (mg L^{-1})	(0.05)	0.013	0.033	0.018	0.031
Lead (μg L^{-1})	50 [1]	0.5	0.5	0.5	0.5
Copper (μg L^{-1})	200 [1]	1.5	1.5	1.5	1.5
Calcium (mg L^{-1})		*	*	4.8	4.5
Sodium (mg L^{-1})		*	*	3.0	3.6
Chloride (mg L^{-1})	250 [1]	7.5	70	5.3	5.6

Note: See Appendix A for water Quality Standards footnotes.

Typically, higher nutrient inputs can cause higher chlorophyll *a* and phytoplankton levels in New Croton, however, the phytoplankton levels were all below the DWQC internal limit of 2000 standard areal units (SAU) for 2005. EOH reservoir chlorophyll *a* data were still under review at the writing time of this report and so are not reported here. The total phosphorus (TP) data summary demonstrates that TP in New Croton exceeded the NYSDEC guidance value of 15 mg L^{-1}, which applies to source waters. Other reservoirs in the Croton System also exceeded this value in 2005 (Appendix A). New Croton's turbidity levels are typically associated with primary productivity, whereas in Ashokan Reservoir, turbidity levels are associated with terrestrial sources of clay. The deeper Secchi disc transparencies are found in Rondout and Kensico, which are less productive and less turbid. There are also higher levels of discoloration, iron, manganese and organic carbon in New Croton. At times, water quality standards for these variables were exceeded (with the exception of organic carbon for which there is no standard) but the annual median was below the standard. In contrast to New Croton, Kensico's water quality is reflective of the large majority of water it receives from Rondout and Ashokan reservoirs. Kensico was affected by a rain on snow flood event in Ashokan in April, 2005, and additional storm water run-off that occurred in the fall. The elevated turbidity levels in Ashokan were attenuated by the use of alum addition to the aqueduct. As a result of the alum treatment, the turbidity in Kensico was kept below 5 NTU for most sites in 2005.

3.13 What were the trophic states of the City's 19 reservoirs in 2005 and why is this important?

Trophic state indices (TSI) are commonly used to describe the productivity of lakes and reservoirs. Three trophic state categories, oligotrophic, mesotrophic, and eutrophic are used to separate and describe water quality conditions. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters on the other hand are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate.

The indices developed by Carlson (1977, 1979) use commonly measured variables (i.e., chlorophyll *a*, total phosphorus, and Secchi disk depth) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

$$\mathrm{TSI} = 9.81 \times (\ln(\mathrm{CHLA})) + 30.6$$

where CHLA is the concentration of chlorophyll *a*

The Carlson Trophic State Index ranges from approximately 0 to 100 (there are no upper or lower bounds), and is scaled so that values under 40 indicate oligotrophy, values between 40 and 50 indicate mesotrophy, and values greater than 50 indicate eutrophy. Trophic indices are generally calculated from data collected in the photic zone of the reservoir during the growing season (the DEP definition of this as May through October) when the relationship between the variables is tightest. DEP water supply managers prefer reservoirs of a lower trophic state to reduce potential chemical treatments and produce better water quality at the tap. For instance, eutrophic waters may be aesthetically unpleasant from a taste and odor perspective.

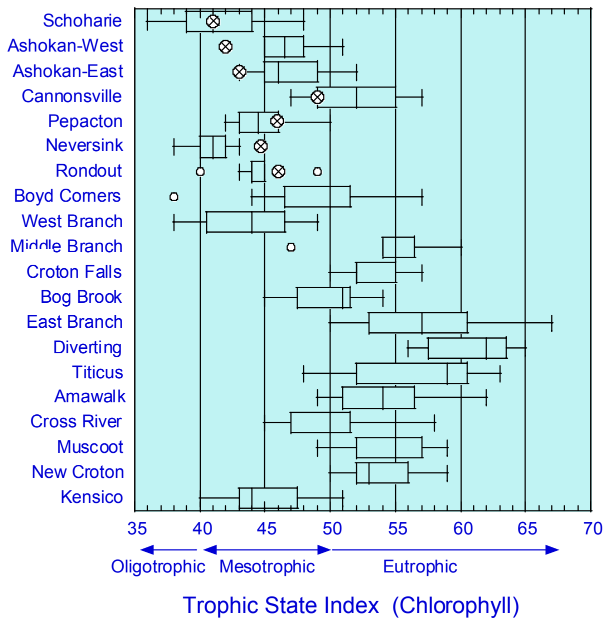


Figure 3.15 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2005 vs. 1995-2004).

In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies (1 or 2x per month) from May through October. The 2005 chlorophyll *a* data were still under review, and in some cases, insufficient to calculate annual TSI for any reservoir or controlled lake located in the East-of-Hudson district. Therefore, the box plots in this figure are only representative of past conditions for these water bodies. TSI is based on chlorophyll *a* concentration.

Historic (approximately 1995-2004) annual median TSI based on chlorophyll *a* concentration is presented in box plots for all reservoirs in Figure 3.15. The 2005 annual median TSI appears in the figure as a circle containing an "x". This analysis usually shows a split between West-of-Hudson reservoirs falling into the mesotrophic category, while the East-of-Hudson reservoirs are typically classified as eutrophic. The exceptions to these generalities are Cannonsville, which is usually considered eutrophic, West Branch which is considered mesotrophic due to incoming water from Rondout Reservoir and Kensico which is considered mesotrophic due to inputs from Rondout (usually via West Branch) and from the East Basin of Ashokan.

In 2005, the median TSI for both Ashokan basins decreased substantially compared to past data, indicating decreased algal production. The decrease in production is attributed to reduced light transparency (light is an essential requirement for algal growth) resulting from the relatively turbid water conditions in 2005. Although turbid conditions were also prevalent at Schoharie Reservoir, a decrease in TSI was not observed here because low TSI and elevated turbidity are historically common in this reservoir.

Most Delaware reservoirs experienced substantial Trophic State increases in 2005. The largest increase, 41 to 45 TSI units, occurred at Neversink Reservoir with lesser increases, 1.5 TSI units, at Pepacton and Rondout. The cause of these increases is attributed to increased nutrient availability resulting from spring runoff. Although runoff also created more turbid conditions, water clarity soon improved enough for algae to take advantage of the excess nutrients. Interestingly, despite the same general conditions, Cannonsville Reservoir continued to remain in the mesotrophic range, as defined by Carlson (1977). The TSI for 2005 was 49, which was the same as last year, and below the long-term median of 52 TSI units. The persistence of mesotrophic conditions may be further evidence of New York City's on-going efforts to control nutrient loads to Cannonsville. In particular, upgrades at the Walton WWTP and a Walton food production plant had essentially eliminated phosphorus loads from these sources by the end of 2004 (DEP 2006a).

The 2005 chlorophyll *a* data were still under review, and in some cases, insufficient to calculate annual TSI for any reservoir or controlled lake located in the East-of-Hudson district. Therefore, the box plots in Figure 3.15 are only representative of past conditions for these water bodies.

3.14 How did the reservoir water conductivity in 2005 compare to previous years?

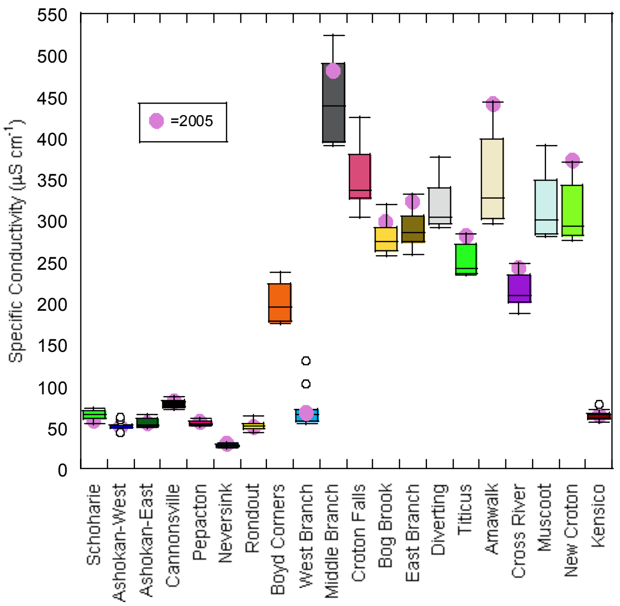


Figure 3.16 Annual median specific conductivity in NYC water supply reservoirs (2005 vs. 1995-2004).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Note that insufficient data were available to calculate representative annual medians for Croton Falls, Muscoot, Diverting, and Boyd Corners Reservoirs as well as the controlled lakes, Gleneida and Kirk.

Specific conductance (conductivity) is the measurement of the ability of water to conduct an electrical current. It varies as a function of the amount and type of ions that the water contains. The ions which typically contribute most to reservoir conductivity include: calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), potassium (K^{+1}), bicarbonate (HCO_3^{-1}), sulfate (SO_4^{-2}) and chloride (Cl^{-1}). Dissolved forms of iron, manganese and sulfide may also make significant contributions to the water's conductivity given the right conditions (i.e. anoxia). Background conductivity of water bodies is a function of both the bedrock and surficial deposits, which comprise the watershed, as well as the topography of the watershed. For example, watersheds underlain with highly soluble limestone deposits will produce waters of high conductivity compared with watersheds comprised of relatively insoluble granite. If the topography of a watershed is steep, deposits tend to be thin and water is able to pass through quickly thus reducing the ability of the water to dissolve substances. This type of terrain will also produce waters of low conductivity. Such is the case with NYC's water supply reservoirs. Catskill and Delaware System Reservoirs displayed uniformly low median conductivities in the past as well as in 2005 (Figure 3.16). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits, which produce relatively low conductivities in the 25 to 100 µS cm^{-1} range. Because West Branch and Kensico generally receive most of their water from the Catskill and Delaware reservoirs, the conductivities of West Branch and Kensico are usually in the 50 to 100 µS cm^{-1} range. In 2005, conductivity in the Catskill and Delaware System reservoirs, including West Branch and Kensico, were all very close to historic medians.

Reservoirs of the Croton System have higher baseline conductivities than those of the Catskill and Delaware Systems. In part this is due to the flatter terrain of the Croton watershed as well as to the occurrence of soluble alkaline deposits (i.e. marble and/or limestone) within the watershed. However, most of the reservoirs have displayed steady increases in conductivity since the early 1990s most likely associated with development pressure in the watershed (e.g. increased use of road salt). In 2005, conductivity in the Croton System reservoirs (including Lake Gilead, not shown) continued to rise. Note that insufficient data were available to calculate representative annual medians for Croton Falls, Muscoot, Diverting, and Boyd Corners Reservoirs as well as the controlled lakes, Gleneida and Kirk.

3.15 What "Special Investigations" were conducted in 2005?

The term "Special Investigations" (SIs) refers to limited non-routine collection of environmental data, including photographs and/or analysis of samples, in response to a specific concern or event.

Figure 3.17 Conducting a special investigation in the Kensico watershed.

In 2005, 16 SIs were conducted and reported on (cf. 18 in 2004). More investigations were conducted EOH (12) than WOH (4) and more involved the investigation of actual or possible sewage discharges from sewer collection systems (7 SIs) than any other potential incident. This suggests that potentially harmful environmental pollution incidents may be more likely to occur in the more densely populated EOH watershed, where there are many more communities served by sewage collection systems and other infrastructure associated with urbanization, than in the WOH watershed.

None of the investigations conduced in 2005 identified a pollution problem that was considered an immediate threat to consumers of the water supply. Below is a list of reservoir watersheds in which investigations occurred in 2005, with dates and a brief description of each investigation. Individual reports are not provided here, but are available upon request.

Kensico Reservoir

- April 23, a small aircraft impacted the ground and burned. There were no water quality concerns, but there was some soil disturbance and tree scarring.

- December 28, a sewer line ruptured along Route 120.

New Croton

- January 3, an oily sheen was observed on the Kisco River, and was traced back to a leaking underground storage tank.
- April 23, a building fire in Yorktown.
- July 14, a sewage overflow from a manhole in Yorktown.
- October 15, heavy rainfall induced an inflow and infiltration impact on the Village of Mt. Kisco sewage collection system, causing an overflow from their surge tank.

Muscoot Reservoir

- April 8, a small oil spill (<100 gallons) near the Stonehill River.
- May 2, a malfunction at a WWTP released untreated sewage.
- August 12, a release of water from a water treatment lagoon into the Muscoot River.

Croton Falls Reservoir

- April 13, a sewage overflow from a manhole in Carmel.
- August 14, a fish kill in the reservoir was found to be caused by elevated temperatures and low dissolved oxygen.

Diverting Reservoir

- April 5, a fish kill in the East Branch of the Croton River, found to be caused by entrainment mortality from the East Branch Reservoir Release, and some indication of gas bubble disease.

Figure 3.18 Investigating an oily surface sheen and rust-colored streambed in the Ashokan watershed.

Causes for these separate phenomena were believed to be lipids from decomposing organic material, and iron-oxidizing bacteria.

Ashokan Reservoir

•May 10, iron staining of an un-named tributary of the Little Beaver Kill.

•November 11, responded to a complaint that a former manufacturing facility was negatively impacting water quality on Esopus Creek. No apparent pollutant source or water quality concern was identified.

Schoharie Reservoir

•April 9, a spill from a septage receiving area.

•May 4, a sewer overflow caused by a blocked sewer line.

3.16 Has DEP monitoring of aquatic biota in streams feeding the reservoirs revealed any changes in the macroinvertebrate community?

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994, using protocols developed by the NYSDEC's Stream Biomonitoring Unit. Streams are sampled in areas of riffle habitat, using the traveling kick method (Figure 3.19); collected organisms are preserved in the field and later identified, and a series of metrics generated from the tallies of macroinvertebrates found to be present. The metric scores are converted to a common scale and averaged, to produce a single water quality assessment score of 0-10 for each site, corresponding to non (7.5-10), slightly (5-7.5), moderately (2.5-5), or severely (0-2.5) impaired. A change (or, for that matter, a lack of change) to the macroinvertebrate community as reflected in the water quality assessment score can provide important information to DEP managers, because sites are often selected to evaluate impacts from land use changes or BMPs, or to assess conditions in major reservoir tributaries.

Figure 3.19 Collecting a biomonitoring sample using the traveling kick method under low flows....

...and high flows.

Through the close of the 2005 sampling season, DEP had established 145 sampling sites in streams throughout the water supply watershed, with roughly equal numbers in each of the system's three Districts. Many of these sites have been sampled for only a few years, because sampling began at later dates at some sites than at others, and because only routine sites are sampled annually. To investigate changes to the macroinvertebrate community, only those sites with a 5-year or better record were examined, to reduce the chances that short-term variation, or aberrant samples, might cloud the analysis. Twenty-seven (27) sites met the 5-year criterion, 10 in the East-of-Hudson District, 9 in Catskill, and 8 in Delaware (Figure 3.20). Of these, 20 are routine sites (generally, major tributaries to receiving reservoirs); the rest were sampled to monitor the impacts of existing pollution sources or proposed development, or to evaluate the effectiveness of streambank stabilization projects.

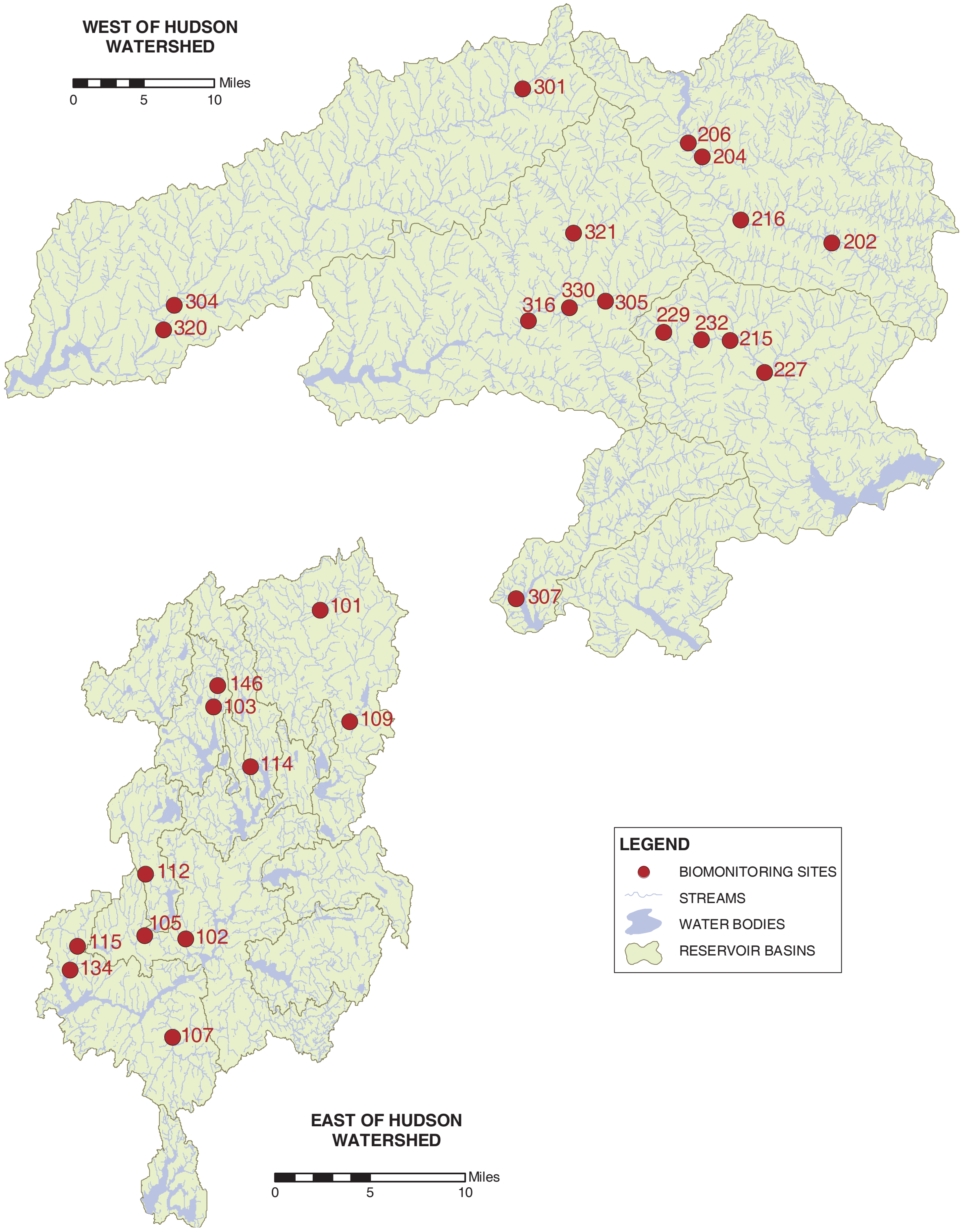


Figure 3.20 Stream biomonitoring sites with a 5-year or better record.

The data are plotted in Figures 3.23 through 3.25 for the East-of-Hudson, Catskill, and Delaware Districts, respectively. With two *possible* exceptions (see below), no long-term changes to the macroinvertebrate community were observed at any of the 27 sites. In each case, assessments either remained the same over the entire period (6 sites) or alternated between adjoining categories (non-impaired/slightly impaired, slight/moderate, moderate/severe) (21 sites). Among sites whose assessments varied, 9 had the same assessment in every year but one and 5 in every year but two. The remainder experienced more frequent year-to-year fluctuations, but still without any observable trend.


NABS (www.benthos.org)

Figure 3.21 The predaceous fly *Atherix* sp. is found in clear, fast-flowing streams.


NABS (www.benthos.org)

Figure 3.22 *Hydropsyche* sp., the commonest caddisfly in NYC watershed streams.

At two sites, however, the data suggest that a change may in fact have occurred. In both cases, macroinvertebrate communities appear to have returned to their non-impaired condition after several years of less than optimal scores. The first case involves a streambank stabilization project on Schoharie Creek in 1997 that caused extensive disturbance to the stream's channel. The site (Site 216, Figure 3.24) was assessed as non-impaired in 1996, the year preceding construction, then alternated between slightly impaired and non-impaired for the next three years (1997–1999). From 2000-2004, however, the site was consistently rated non-impaired, with scores substantially higher than in most years of prior sampling, suggesting that the post-construction community had stabilized. The number of mayfly taxa in those years was also consistently high for the first time since 1997, reaching levels exceeding those of 1996, the year before construction started. (Mayflies are a group of insects considered particularly intolerant to disturbance.)

A very similar situation prevails at Aden Brook in the Neversink watershed (Site 307, Figure 3.25). That stream experienced significant flooding in 1995, after which maintenance crews removed the heavy riparian vegetation along the stream's bank and replaced the trees and shrubs with rocks. Although the site had received a very high score in 1994, scores in the years following the canopy removal were lower and, as at Schoharie Creek, fluctuated between non and slightly impaired assessments. For the last three years, however (2003-2005), the stream has been rated non-impaired, with scores approaching, and in one case equalling, those achieved prior to canopy removal. If confirmed by future monitoring, this shift in the macroinvertebrate community would

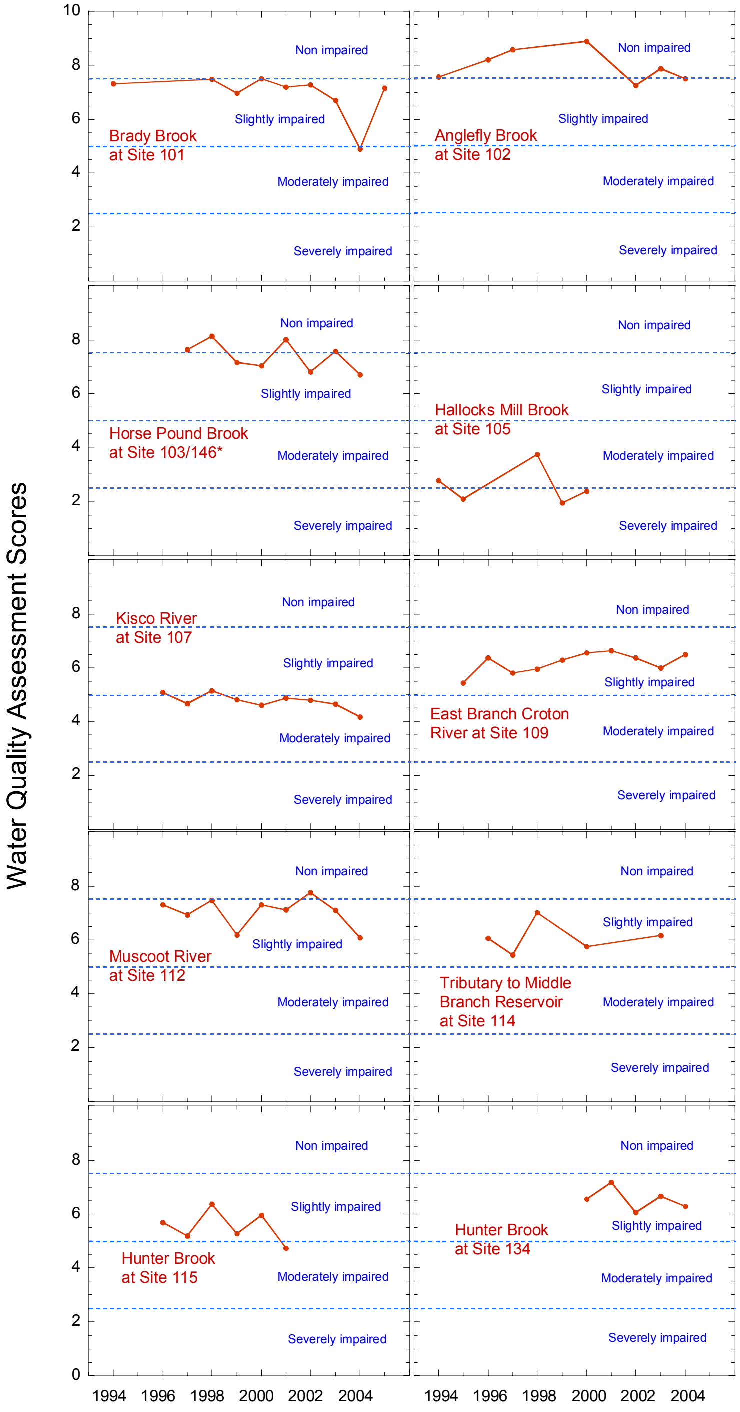


Figure 3.23 Water Quality Assessment Scores based on stream biomonitoring data for East-of-Hudson streams with a 5-year record or better.

*The Horse Pound Brook site was moved from Site 103 to Site 146 in 2004—both sites are combined here.

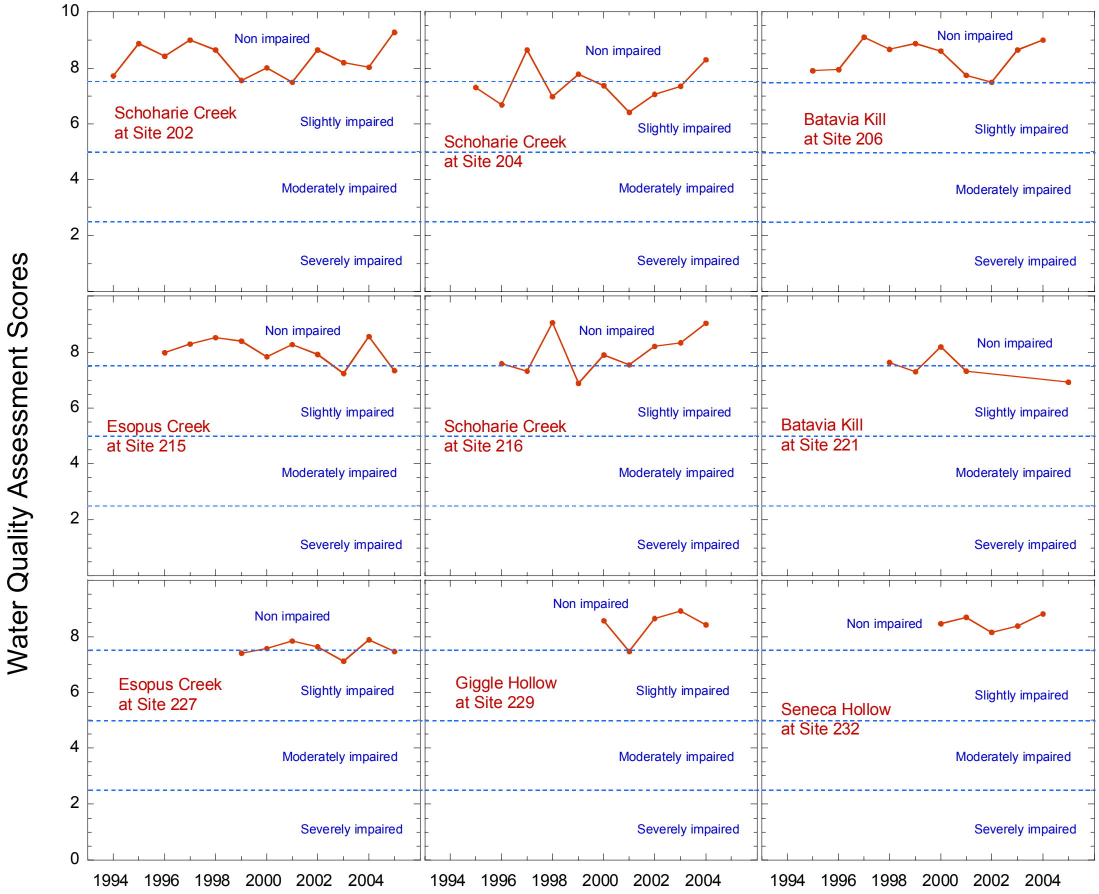


Figure 3.24 Water Quality Assessment Scores based on stream biomonitoring data for Catskill streams with a 5-year record or better.

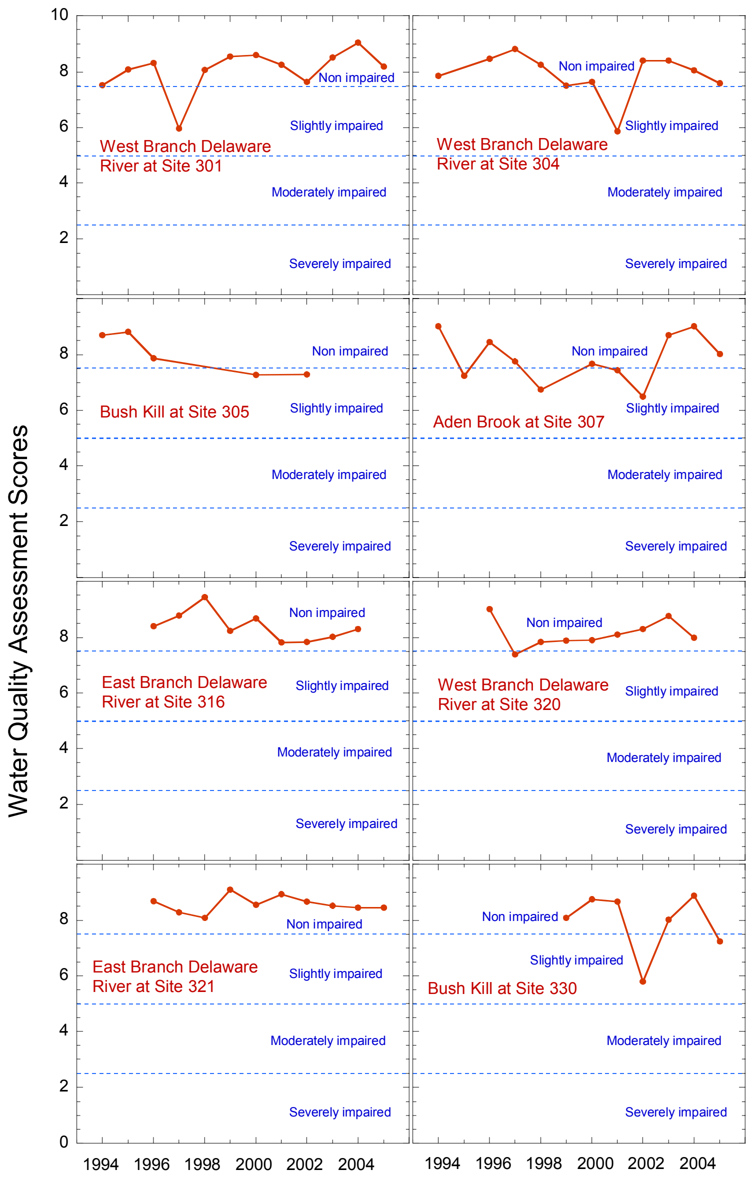


Figure 3.25 Water Quality Assessment Scores based on stream biomonitoring data for Delaware streams with a 5-year record or better.

indicate that in streams subjected to significant channel alteration it may take a substantial number of years for an optimal community to reestablish itself. DEP will continue to monitor both sites to provide the long-term record needed to document this recovery.

3.17 What are disinfection by-products, and what were their concentrations in the distribution system in 2005?

Disinfection by-products (DBPs) are formed in drinking water during treatment with chlorine, which reacts with certain acids that are in naturally-occurring organic material (e.g., decomposing vegetation such as tree leaves, algae, or other aquatic plants) in surface water such as rivers and lakes. The amount of DBPs in drinking water can change from day to day, depending on the temperature, the amount of organic material in the water, the amount of chlorine added, and a variety of other factors. Drinking water is disinfected by public water suppliers to kill bacteria and viruses that could cause serious illnesses. Chlorine is the most commonly used disinfectant in New York State. For this reason, disinfection of drinking water by chlorination is beneficial to public health.

DEP monitors two important groups of DBPs: trihalomethanes and haloacetic acids. Trihalomethanes (TTHM) are a group of chemicals that includes chloroform, bromoform, bromodichloromethane, and chlorodibromomethane, of which chloroform is the main constituent. Haloacetic acids (HAA) are a group of chemicals that includes mono-, di- and trichloroacetic acids and mono- and dibromoacetic acids. USEPA has set limits on these groups of DBPs under the Stage 1 Disinfectant/Disinfection By-Products Rule. The Maximum Contaminant Level (MCL) for TTHM is 80 µg L^{-1} and the MCL for five haloacetic acids (HAA5) is 60 µg L^{-1}. The Stage 1 Rule requires monitoring to be conducted quarterly from designated sites in the distribution system which represent the service areas and not necessarily the source water for each system. The MCL is calculated as a running annual average based on quarterly samplings over a 12-month period. The 2005 annual running quarterly averages are presented in Table 3.7 and show system compliance for TTHM and HAA5 in both the Catskill/Delaware and Croton Distribution Areas of New York City.

Table 3.7: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations (µg L^{-1}) for 2005.

	Catskill/Delaware		Croton	
2005 Quarter	TTHM	HAA5	TTHM	HAA5
1st	38	46	49	45
2nd	37	46	46	46
3rd	36	44	44	44
4th	36	46	43	46
MCL	80	60	80	60

4. Watershed Management

4.1 How can watershed management improve water quality?

Figure 4.1 Preserving land protects against future water quality degradation.

There is a close relationship between activities within a drainage basin and the quality of its water resources. This is the underlying premise of all watershed management programs. DEP has a comprehensive watershed protection program that focuses on implementing both protective (antidegradation) and remedial (specific actions taken to reduce pollution generation from identified sources) initiatives. Protective programs, such as the Land Acquisition Program, protect against potential future degradation of water quality from land use changes (Figure 4.1). Remedial programs are directed at existing sources of impairment. DEP recently completed a comprehensive analysis of the watershed protection program and a brief summary is provided below. More information on the management programs and water quality analysis can be found in the 2006 Watershed Protection Program: Summary and Assessment Report (DEP, 2006a). Information on research programs in the watershed can be found in the 2005 Research Objectives Report (DEP, 2006b).

4.2 How has DEP assessed the water quality improvements of watershed management efforts in the Catskill/Delaware Systems?

DEP recently released the 2006 Watershed Protection Program: Summary and Assessment Report (DEP, 2006a). This report not only provides a status report of the City's watershed protection program but also presents an analysis of water quality covering 12 years of data collection and program implementation. Five critical analytes were chosen for analysis: fecal coliform, turbidity, phosphorus, conductivity and trophic status. Case studies were done for selected monitoring sites that had sufficient proximity and sampling intensity to demonstrate program effects. Modeling was conducted to attribute program effects to programs on a watershed-wide basis.

While DEP is responsible for the collection, monitoring, treatment and delivery of high quality water to the City, DEP relies heavily on the work of partner organizations to carry out watershed protection efforts. Numerous towns, counties, State and federal agencies, not-for-profit organizations, and private businesses have participated in and helped make the watershed protection programs a success (Figure 4.2). Highlights of some key watershed programs are:

- Watershed Agricultural Program: To date, more than 95% of large farms in the Catskill/Delaware watershed have Whole Farm Plans, 91% have commenced implementation and 68% have substantially completed implementation. The Conservation Reserve Enhancement Program has protected more than 165 miles of farm stream buffers.

- Land Acquisition: To date the City has acquired, or has under contract, more than 70,000 acres which triples the land area held for watershed protection before the program began.

- Wastewater Treatment Plant (WWTP) Upgrades: The five City-owned WWTPs were upgraded in the late 1990s, 96% of the flow from the remaining non-City-owned WWTPs have been upgraded leading to measurable improvements in water quality.

- New Infrastructure Program: Two new WWTPs in communities with failing or likely to fail septic systems have been completed, four are under construction and another plant is in the design phase.

- Partnership Programs: DEP, in conjunction with its partners, have remediated more than 2,000 failing septic systems, upgraded 30 facilities that store winter road de-icing materials and constructed stormwater BMPs.

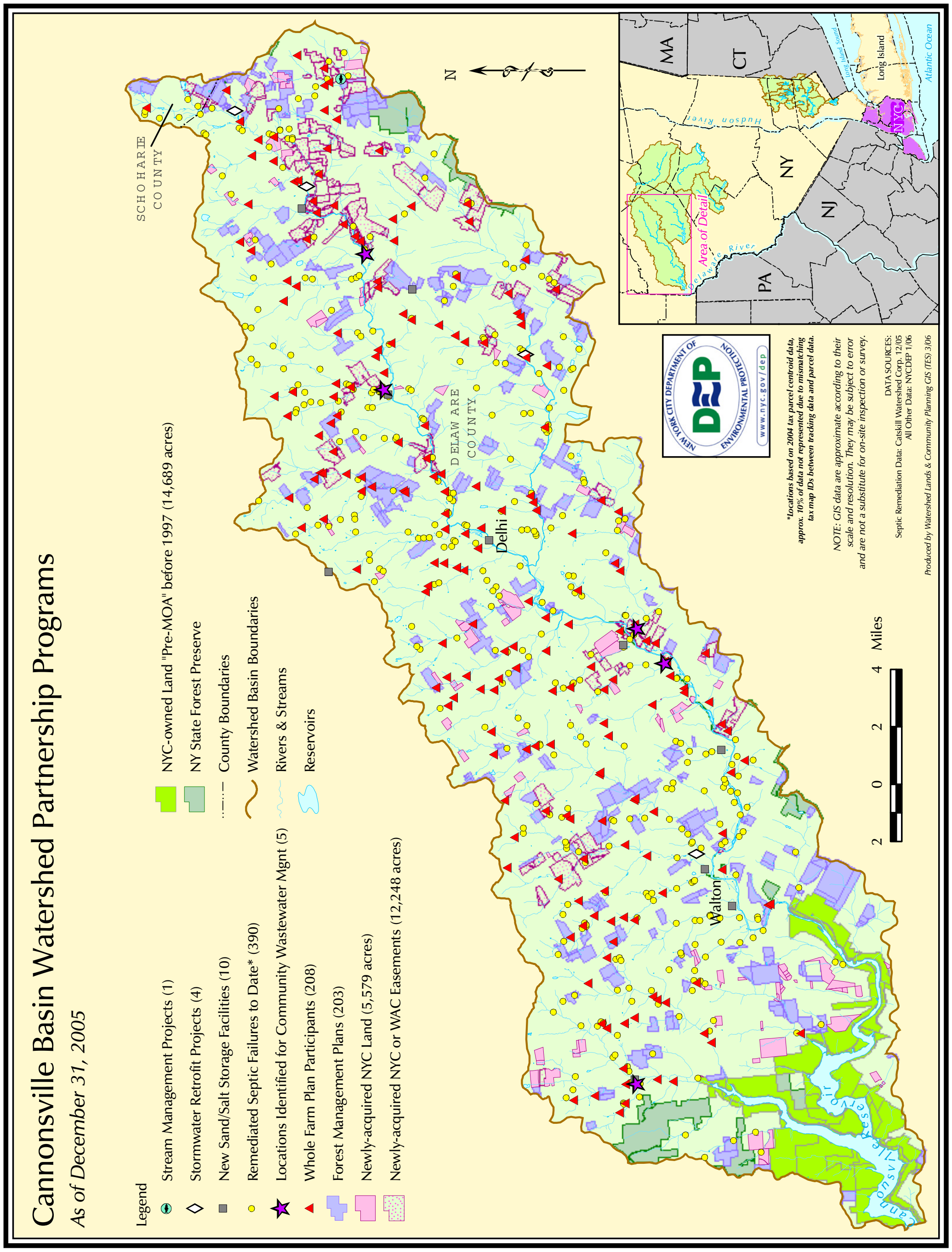


Figure 4.2 Cannonsville basin Watershed Partnership Programs as of December 31, 2005.

Water quality has been and continues to be excellent in the Catskill and Delaware systems. Even though watershed hydrology is the dominant factor in controlling water quality, as demonstrated by recent flood events and the resulting turbidity in the Catskill System, many positive changes in water quality were observed over the time period (1993 – 2004) studied. The most dramatic change has been the reduction in phosphorus in the Catskill/Delaware basins due to the upgrade of the wastewater treatment plants. As an example, Figure 4.3 shows phosphorus loads and flows from WWTPs in the Cannonsville basin. The reduction in total phosphorus loads from 1994 to 1999 was due to the intervention and assistance of DEP at Walton and at Walton's largest commercial contributor, Kraft. The substantial additional reductions in phosphorus loads realized after 1999 can be attributed to final upgrades of several plants and diversion of another. As a result, Cannonsville was taken off the phosphorus-restricted basin list in 2002.

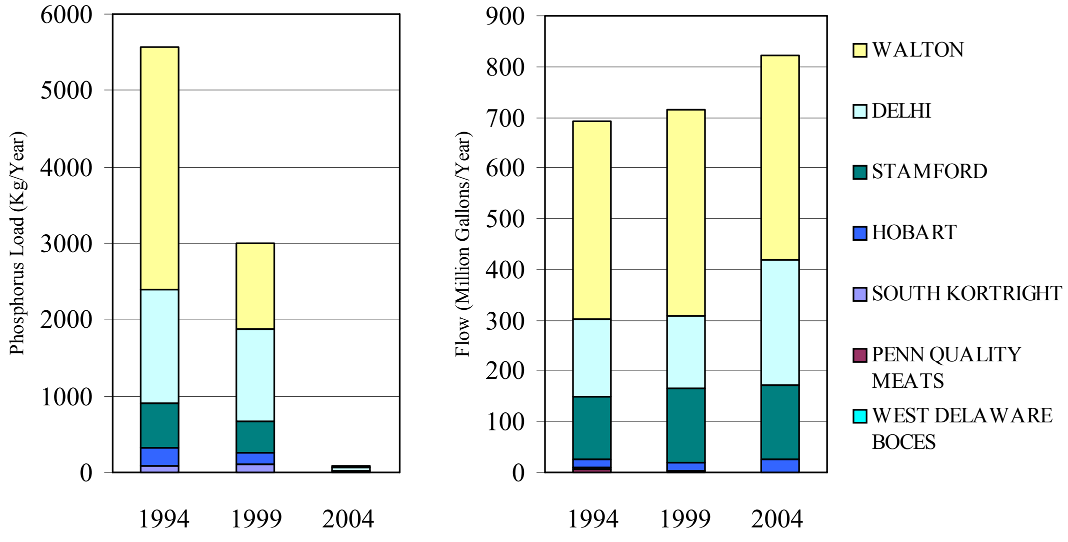


Figure 4.3 WWTP TP loads and flow from Cannonsville basin.

4.3 What are the watershed management efforts in the Croton System to improve water quality?

The watershed management programs are designed differently in the Croton District from those in the Catskill and Delaware Districts. Instead of explicitly funding certain management programs (e.g. Stormwater Retrofit Program), DEP provided funds to Putnam and Westchester Counties to develop a watershed plan ("Croton Plan") and to support water quality investment projects in the Croton watershed. Other management programs (e.g. Wastewater Treatment Plan Upgrade Program, Watershed Agricultural Program) operate similarly in all districts. Finally, some management programs are targeted to the Croton System, such as the EOH Nonpoint Source Program.

Croton Plan and Water Quality Investment Program

In the Croton System, DEP provided funds to Putnam and Westchester Counties to develop a watershed plan to protect water quality and guide the decision-making process for the Water Quality Investment Program (WQIP) funds. In 2005, both Counties worked to finish remaining workplan tasks as well as incorporate comments from DEP and municipalities for the Final Draft Croton Plans. Distribution of the WQIP funds has continued and a few notable projects for 2005 are given below.

- *Peach Lake* – The 2004 Peach Lake Study concluded that the basin is not suitable for a high density of septic systems (Figure 4.4). In 2005, Putnam County allocated $2.5 million toward the construction of a centralized wastewater system that has a total estimated cost of $21 million dollars. Westchester County has also reserved WQIP funds for this project.
- *Putnam County Septic Repair Program (SRP)* – Putnam County completed the Septic Repair Program Plan and has begun implementation of the $3.3 million-dollar program. Implementation of the SRP program began in the high priority areas of the 60-day travel time.
- *Putnam County Stormwater* – Putnam County authorized approximately $800,000 for several stormwater improvements to around Putnam Lake in Patterson, NY.
- *Westchester County Local Grant Program* – Westchester County authorized the use of up to $312,500 for each of the twelve municipalities in the EOH watershed. Several projects entered the planning stage including sanitary sewer extensions, stormwater improvements and enhanced storage of highway de-icing materials.
- *Westchester County Septic Program* – Westchester County continues to track septic repairs and license septic contractors.

Figure 4.4 Photo of algae around Peach Lake.

Wastewater Treatment Plant Upgrade Program

The Croton System has a large number of wastewater treatment plants with the bulk of them serving schools, developments or commercial properties. Sixty four percent of the WWTP have flows of less than 100,000 gallons per day. Eight non-City-owned facilities, comprising 16% of the total permitted flow in the System, have completed their upgrades as of December 2005. Eighteen percent of the WWTP within the 60 day travel time, comprising 24% of the permitted flow, have their upgrades complete and an additional 64% either have the upgrades in process or are in the design phase. Upgrade plans for eight facilities are on hold pending decisions on diversion to existing plants or out of the Croton watershed.

Watershed Agricultural Program

The farms in the EOH district tend to be smaller and more focused on equestrian-related activities than the WOH farms and the EOH Watershed Agricultural Program has been specially tailored to address these issues. At the end of 2005, 28 farms in the Croton System have approved Whole Farm Plans. Eighteen of these farms have commenced implementation of Best Management Practices (BMPs) and a total of 113 BMPs have been installed.

Nonpoint Source Management Program

The Nonpoint Source Management Plan was designed to identify and eliminate sources and incidents of nonpoint source pollution in the Catskill/Delaware reservoirs located East-of-Hudson. The nonpoint sources targeted for remediation programs include wastewater, stormwater, turf management chemicals and hazardous materials. Some recent highlights include:

- Over 6000 feet of sanitary sewer has been video inspected and mapped. No cross-connections, illicit connections, pump station failures or defects that may lead to exfiltration were identified.
- Nearly 8000 stormwater structures (e.g. manholes, outfalls) have been inspected and mapped (Table 4.1). Any problems or defects were reported immediately to the appropriate authorities for remediation and/or enforcement action.
- Stormwater remediation projects continue to be identified and implemented. Ten small remediation projects are repaired each year, and approximately 8 larger projects are currently underway (Figure 4.5).
- In conjunction with Cornell Cooperative Extension, DEP initiated a residential survey of lawn care practices designed to obtain data on fertilizer applications and assess the potential for adverse water quality impacts (Figure 4.6). A final report is expected in 2006 (DEP et. al., 2006d).

Table 4.1: Inspected and Mapped Stormwater Infrastructure in NPS Management Program.

Reservoir Basin	*Length of Pipe (ft)*	*Length of Ditches (ft)*	*Number of Structures**
Boyd Corners	3,540	11,275	427
West Branch	49,560	18,279	1,064
Croton Falls	55,850	29,860	3,848

Table 4.1: Inspected and Mapped Stormwater Infrastructure in NPS Management Program.

Reservoir Basin	*Length of Pipe (ft)*	*Length of Ditches (ft)*	*Number of Structures**
Cross River	46,690	18,515	2,644
Total	155,640	77,929	7,983

* Structures refer to manholes, stormwater outfalls, etc.

Figure 4.5 Photo of Pennebrook basin.

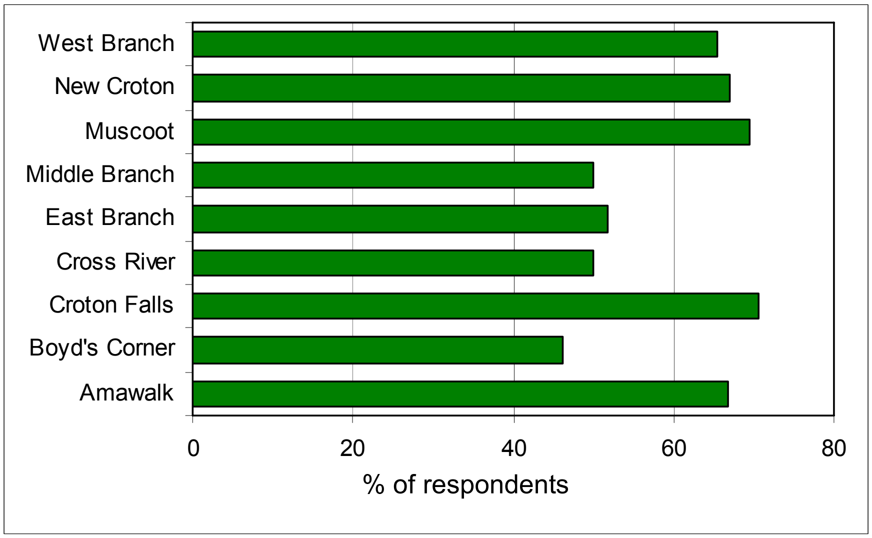


Figure 4.6 Percent of respondents indicating that fertilizer is applied to their lawn by reservoir basin

More detailed information on the Nonpoint Source Management Program can be found in the 2006 Watershed Protection Program: Summary and Assessment Report (DEP, 2006a) and the Nonpoint Management Plan for the East-of-Hudson Catskill/Delaware Water Supply System January 2006 Semiannual FAD report (DEP, 2006c).

4.4 How has DEP aided the DEC Freshwater Wetlands Remapping Program to increase wetlands protection in the New York City Watershed?

Wetlands are critical for protecting the high quality of drinking water supplied by the New York City Watershed. The New York State Department of Environmental Conservation (DEC) regulates wetlands under the Freshwater Wetlands Act, Article 24 of the New York State Environmental Conservation Law. DEC regulates wetlands 12.4 acres (5 hectares) or greater in size, certain smaller wetlands identified as unusual local importance (ULI), and a 100-foot buffer area around mapped wetlands. Only wetlands identified on the official Article 24 Freshwater Wetland (FWW) Maps are regulated under the Act.

Shortly after the National Wetlands Inventory mapping (NWI) was completed for the New York City Watershed in 1995, DEP conducted a GIS analysis to identify NWI wetlands that met the 12.4 acre regulatory threshold of the Freshwater Wetlands Act but were not included on the states regulatory FWW maps. DEP then provided DEC with the locations of several such wetlands throughout the New York City Watershed and requested that they be considered for amendment to the FWW maps (Figure 4.7). This prompted a detailed review of the state wetland maps:

- Catskill/Delaware watersheds: DEC added 15 additional wetland areas, totaling 651 acres; revisions promulgated in 2001.
- Croton watershed (Westchester County): DEC added 3,370 acres of wetlands, including 75 ULIs; revisions promulgated in July 2004.
- Croton watershed (Putnam and Dutchess Counties): DEC added 4,500 acres of wetlands; revisions promulgated in April 2006.

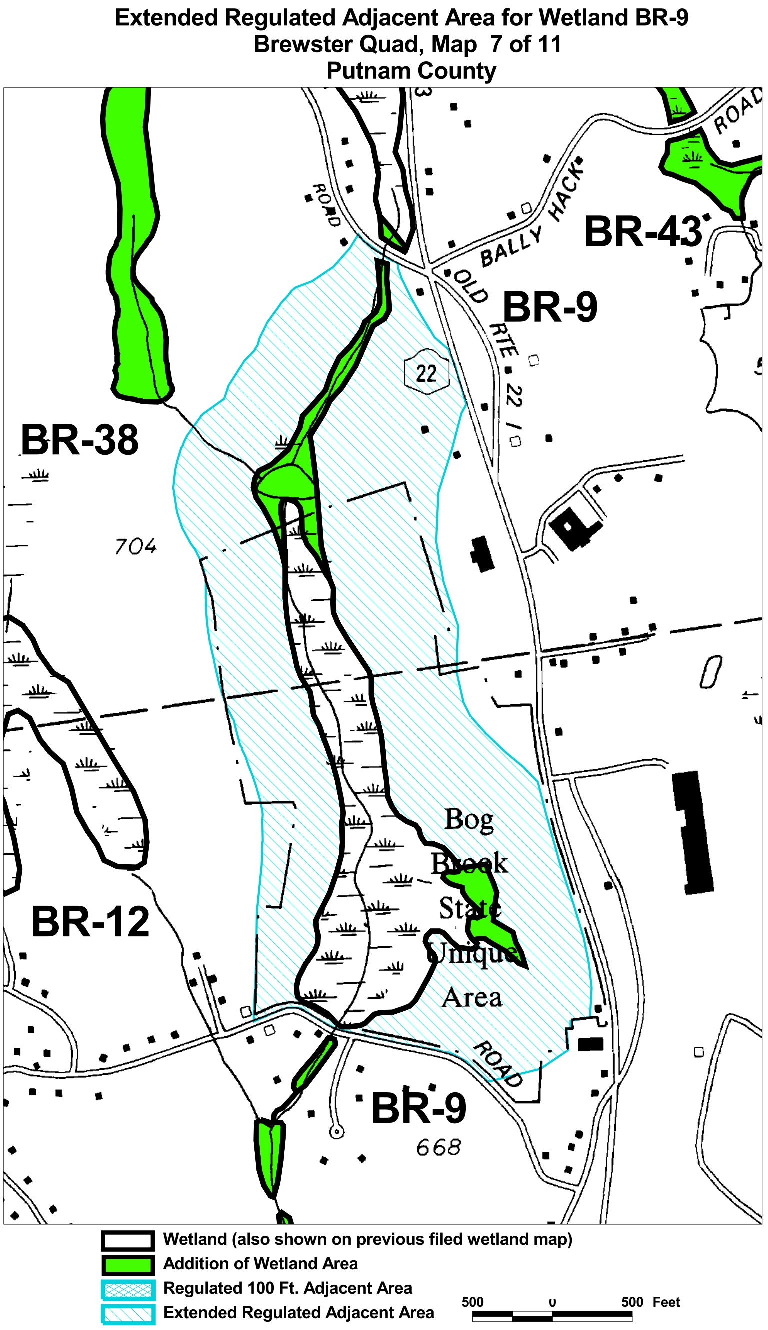


Figure 4.7 Amendments to DEC Freshwater Wetland BR-9 in Brewster, NY.

The NWI project provided baseline information to support the NYS DEC's FWW remapping program in the New York City Water Supply Watershed. Through information sharing and joint field work with DEP, DEC identified over 8,500 acres of wetlands for amendment to the FWW maps. This represents a 30% increase in the acreage of wetlands in the New York City

Watershed that are protected under Article 24 of the Environmental Conservation Law. This has provided DEP increased scrutiny of proposed activities in wetlands, as it reviews and comments on Article 24 permit applications in the New York City Watershed. In addition, these map amendments have increased DEP's regulatory oversight as several provisions of the NYC WR&Rs apply to DEC Freshwater Wetlands, such as the prohibition on the creation of impervious surfaces or installation of septic systems within limiting distances to DEC-mapped wetlands.

4.5 What are the preliminary findings of the Forest Science Program's study on the effects of silvicultural treatments on forest ecosystem health?

Maintaining healthy forest cover on the watershed is one of the most effective and cost effective ways to ensure good water quality. Intact multi-layer forest ecosystems have been shown in many studies to produce the highest quality water. A system of forest research plots was established in several East-of-Hudson watershed areas from 1999 to 2001 to take various forest health measurements in order to determine the effectiveness of silvicultural treatments on increasing quantity of understory native tree seedlings and saplings and reducing numbers of undesirable exotic invasive species. Simply having larger numbers of seedlings will not assure forest cover over the next 100 years if the seedlings do not survive to grow into larger size classes in adequate numbers. Native species are generally considered most desirable as they have co-evolved with native wildlife, landforms, hydrological systems, etc. to create ecosystems that are diverse and resistant to disturbances.

The silvicultural treatments used in this study include: 1) thinning overstory trees to create canopy gaps to encourage germination and growth of seedlings and saplings and 2) managing invasive exotic plants by removal and/or stump treatment with herbicide to prevent re-growth of undesirable plants (Figure 4.8). Preliminary data show the following trends:

- Treatments have yielded little advantage for increased numbers of saplings and shrubs over 4.5 feet tall
- There was, however, a reduction of exotic species in the sapling and shrub layer for most study sites.
- Total numbers of native tree and shrub seedlings under 4.5 feet tall increased on most study areas
- Numbers of exotic seedlings decreased on most areas.

Figure 4.8 Silvicultural crew thinning stand.

Overall results are promising. Continued measurements of these plots will help determine the longer-term effects of the treatments and guide management decisions regarding forests on watershed lands.

4.6 How does the DEP determine the cause of fish kills and how are they indicative of water quality changes?

Fish are indicators of the health and condition of the aquatic environment in which they live. Since a die-off can be an early indication of a serious degradation of water quality, investigating fish kills in the New York City Water Supply and determining their cause is essential for maintaining high water quality and for ensuring public health for over half the population of New York State. Fish kills can be attributed to a variety of causes ranging from simple changes in environmental conditions with no implications for water quality, such as elevated temperature, to more serious causes such as pathogenic or chemical exposures.

Figure 4.9 Fish kill investigation in progress.

The first step in a fish kill investigation is assessing the scene to determine numbers and species of fish involved, unusual fish behavior (gulping at the surface, flaring gills, flashing, lethargy, swimming in circles, rapid swim bursts, or rubbing on the bottom), exact location and extent of the kill, environmental conditions and obvious potential causes (Figure 4.9). Dying or freshly dead fish are then collected and examined for clinical signs of disease or impairment (external lesions, parasites, bulging eyes, fins (clamped down, frayed or bloody), gills (bloody, discolored, frayed), excessive mucous formation, missing scales, unusual coloration and visible injury). Fish are then sent to a fish disease diagnostic laboratory for necropsy, bacteriological, virological and toxicological analysis to determine cause of death. Concurrently with the collection of biological samples and information on the fish, water quality samples are taken to determine the environmental conditions at the time of the kill.

In 2005, there were three reported fish kills investigated by DEP. The first was due to the fish becoming entrained in an aeration intake and dying from supersaturation of oxygen. The remaining two were attributed to environmental conditions leading to anoxic or lethally low levels of oxygen.

- The first kill was reported on April 5, 2005 just below the East Branch Croton Reservoir dam release. The kill consisted of Yellow Perch, White Perch and Black Crappie. The kill was attributed to entrainment mortality at the intake because of the physical trauma and the species were reservoir species.
- The second fish kill was reported on August 14, 2005 at Croton Falls Reservoir. This kill involved 300+ dead fish (yellow perch, alewife, white perch, bluegill, pumpkinseed, carp and yellow bullhead) along the shoreline up to 3 ft above current water elevation. All fish were in an advanced state of decomposition and no samples were submitted for laboratory analysis. At the time of the field investigation, all live fish appeared healthy with no observable signs of distress. The presumed cause of the kill was a combination of elevated surface temperatures and low dissolved oxygen in zones with the more suitable temperature range.
- The final fish kill investigated in 2005 was reported on September 13 at the New Croton Reservoir. The initial Police investigation was of 15 dead yellow perch. As post-mortem decay was advanced, no specimens were submitted to the fish disease diagnostic laboratory. At the time of the field investigation, the upper portion of the water column with adequate dissolved oxygen had temperatures approaching the lethal limit for yellow perch. Preferred temperature zones had inadequate levels of dissolved oxygen to support most fish. Although water quality

data at the time of the investigation was inconclusive, high temperature and low oxygen were assumed to have resulted in the limited kill.

4.7 How did trout spawning affect stream reclassification in the Pepacton Reservoir drainage basin?

Streams in New York State are classified and regulated by NYSDEC based on existing or anticipated best use standards and the purpose of the stream reclassification program is to enhance the protection of water supply source tributaries by determining best use standards for trout and trout spawning. These standards strengthen compliance criteria for dissolved oxygen, ammonia, ammonium, temperature and volume permitted under any currently regulated action, and further increases the number of protected streams in the watershed.

Reclassification surveys concentrate on sections of streams with likely trout habitat including riffles, pools and undercut banks. Streams are electrofished and all stunned fish are collected and held for processing (identification, length & weight) (Figure 4.10). The fish are then released when all data are collected. The presence of trout shorter than 100mm (young-of-the-year) in length is used to indicate the occurrence of trout spawning. Physical and chemical stream data (temperature, depth, width, dissolved oxygen, pH, conductivity, stream gradient and estimated discharge) are then collected to assess stream conditions suitable for trout spawning. Bottom substrate and land characteristics are also described. Collection reports and reclassification petitions are compiled and submitted to DEC on an annual basis. DEC then updates the stream classification based on these petitions.

Figure 4.10 Electrofishing a stream.

DEP is systematically surveying each reservoir drainage basin in the West-of-Hudson watershed. The Pepacton Reservoir basin was completed in 2005 and surveys will begin in the Cannonsville Reservoir basin in 2006. Of the 29 streams surveyed in the Pepacton drainage, 25 will be petitioned for upgrade to trout spawning, one to trout, and 3 were not recommended for reclassified.

4.8 How do environmental project reviews help protect water quality?

DEP staff review a wide variety of projects to assess their potential impacts on water quality and watershed natural resources. Under the New York State Environmental Quality Review Act (SEQRA), DEP is often an involved agency because of its regulatory authority over certain actions. By participating in the SEQRA process, DEP can ensure that water quality concerns are addressed early on in the project planning process. In 2005, DEP staff reviewed a total of 108 SEQRA actions, including 16 draft or final Environmental Impact Statements.

In addition to projects in the SEQRA process, DEP staff review other projects upon request. Review of these projects helps ensure that they are designed and executed in such a manner so as to minimize impacts to water quality. DEP provides its expertise in reviewing and identifying on-site impacts to wetlands, vegetation, fisheries and wildlife and makes recommendations on avoiding or mitigating proposed impacts. These reviews also provide guidance on interpreting regulations as they apply to wetlands as well as threatened and endangered species. DEP also coordinates review of Federal, State and local wetland permit applications in the watershed for the Bureau.

Approximately 50 projects were reviewed and commented on by DEP in 2005. Many of those projects were large, multiyear projects with ongoing review and many others were smaller scale projects scattered throughout the NYC watershed.

4.9 What is the status of WWTP TP loads in the watershed in 2005?

Figure 4.11 displays the sum of the annual total phosphorus (TP) loads from all surface-discharging wastewater treatment plants (WWTPs) by district for the period 1999-2005. The far right bar displays the calculated wasteload allocation (WLA) for all these WWTPs, which is the TP load allowed by the State Pollutant Discharge Elimination System (SPDES) permits – in other words, the maximum permitted effluent flow multiplied by the maximum permitted TP concentration. Overall, the TP loads from WWTPs remain far below the WLA. The fact that loads in the Delaware and Catskill Systems remain so far below their respective WLAs reflects the effect of the WWTP upgrade program, which is largely complete WOH.

Upgrades to WWTPs include phosphorus removal and microfiltration to make the plants comply with the Watershed Rules and Regulations. All NYC-owned WWTPs in the watershed have been upgraded with the exception of the Brewster WWTP, which will be transferred to the

Village of Brewster when its upgrade is complete. Several non-NYC-owned WWTPs have already been upgraded, while a number of others are being connected to plants in the New Infrastructure Program.

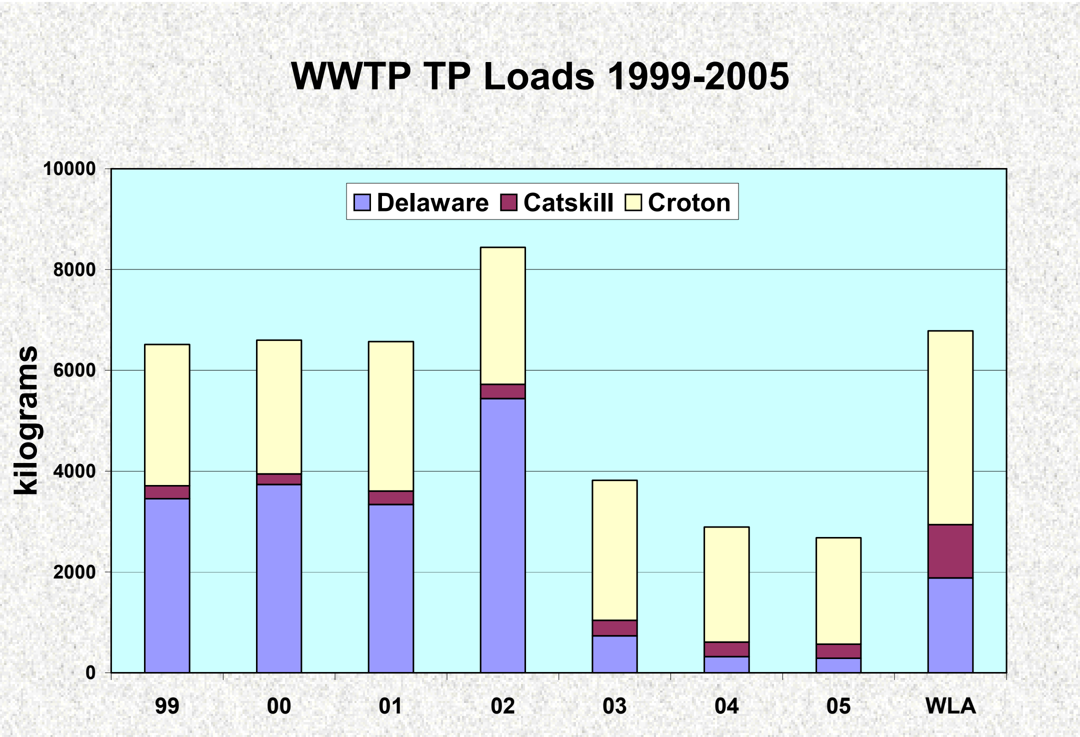


Figure 4.11 Wastewater Treatment Plant TP loads, 1999-2005. The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

The New Infrastructure Program (NIP) is another major wastewater management program funded by New York City. The NIP builds new WWTPs in communities previously relying on individual septic systems. Since many of the older septic systems in village centers such as Andes, Roxbury, Windham, Hunter, and Fleischmanns could not be rehabilitated to comply with current codes, this program seeks to reduce potential nonpoint source pollution by collecting and treating wastewater with compliant systems. The Village of Andes NIP began operation in 2004, and the villages of Hunter and Windham NIPs began in 2005.

Although WWTP TP loads in 2005 are lower than they were in 2004, as new NIPs are completed and sewer districts expand to their full capacities, eventually TP loads are expected to approach the WLAs for the respective Systems.

4.10 What does DEP do to protect the water supply from Zebra mussels?

Zebra mussels were first introduced to North America in the mid-1980s, and first identified on this continent in 1988. It is believed that they were transported by ships from Europe in their freshwater ballast, which was discharged into freshwater ports of the Great Lakes. Since their arrival in the United States, zebra mussels had been reproducing rapidly and migrating to other bodies of water at a much faster rate than any of our nation’s scientists had predicted. They have been found as far west as Oklahoma, as far south as Louisiana, as far east as New York State, and north well into Canada. They have been found in all of the Great Lakes and many major rivers in the Midwest and the South. In New York State, in addition to Lakes Erie and Ontario, zebra mussels have migrated throughout the Erie Canal, and are found in the Mohawk River, the St. Lawrence River, the Susquehanna River, and the Hudson River, as well as several lakes.

DEP is concerned about infestation of New York City’s reservoirs by this mollusk, because they can reproduce quickly and are capable of clogging pipes. This would seriously impair DEP’s operations, preventing an adequate flow of water from the reservoirs to the City and those upstate communities dependent on the New York City water supply. In addition, they create taste and odor problems in the water.

To protect the system from zebra mussels, DEP does the following:

- *Monitoring*. As suppliers of water to over nine million people, it is DEP’s responsibility to monitor New York City’s water supply for zebra mussels, since early identification of a zebra mussel problem will allow us to gain control of the situation quickly, will allow us to preserve the excellent water quality of this system, and will save us money in the long run. DEP has been monitoring NYC’s reservoirs for zebra mussels since the early 1990s, via contract with a series of laboratories that have professional experience in identifying zebra mussels. The objective of our contract is to monitor all 19 of New York City’s Reservoirs for the presence of zebra mussel larvae (veligers) and settlement on a monthly basis April, May, June, October and November, and on a twice-monthly basis during the warm months of July, August, and September. Sampling includes pump/plankton net sampling to monitor for veligers, and substrate sampling as well as "bridal veil" (a potential mesh-like settling substrate) sampling to monitor for juveniles and adults. The contract laboratory analyzes these samples and provides a monthly report to the project manager as to whether or not zebra mussels have been detected. To date, zebra mussels have not been found within the NYC reservoir system.

Figure 4.12 Steam cleaning a boat to prevent transport of zebra mussels.

- *Steam Cleaning boats and equipment*. DEP requires that all boats allowed on the NYC reservoirs for any reason, be inspected and thoroughly steam cleaned prior to being allowed on the reservoir. Any organisms or grasses found anywhere on the boat are removed prior to the boat being steam cleaned. The steam cleaning kills all zebra mussels, juveniles and veligers that may be found anywhere on the boat, thus preventing their introduction into the NYC reservoir system. This requirement for all boats being steam cleaned applies to all boats that will be used on the reservoirs, whether they be rowboats used by the general public, or motor boats used by DEP. Additionally, all contractor boats, barges, dredges, equipment (e.g., anchors, chains, lines), and trailer parts must be thoroughly steam cleaned inside and out. All water must be drained from boats, barges, their components (including outdrive units; all bilge water (if applicable), and raw engine cooling systems), and equipment at an offsite location, away from any NYC reservoirs or streams that flow into NYC reservoirs or lakes, prior to arrival for DEP inspection.

- *Public Education*. DEP provides educational pamphlets to fishermen on NYC's reservoirs and to bait and tackle shops in NYC's watersheds on preventing the introduction and spread of zebra mussels to bodies of water that do not have them. Fishermen can inadvertently introduce zebra mussels to a body of water through their bait buckets that may have zebra mussels in them (depending upon where the bait was obtained), or by not cleaning their equipment from use in bodies of water that have zebra mussels, before using this equipment in bodies of water that are not infested with zebra mussels. The brochures help educate fishermen as to how they can prevent the spread of zebra mussels. In addition, signs are put up throughout the watershed providing information as to how to prevent the spread of zebra mussels.

5. Model Development and Applications

5.1 Why are models important?

Simulation models are important for understanding and quantifying the effects of climate, watershed management and reservoir operations on the quality and reliability of the New York City water supply system. The models encapsulate the key processes and interactions that control generation and transport of water, sediment and nutrients from the land surface, through the watersheds and within the reservoirs. This allows the estimation of watershed loads and reservoir eutrophication under varying scenarios of watershed and reservoir management.

Model simulations provide guidance for watershed-management and planning. By providing information on flow pathways and nutrient sources, watershed management and planning can be focused on the critical land uses and transport pathways that influence loads to reservoirs. Coupling simulated watershed loading estimates to reservoir eutrophication models allows the timing of nutrient delivery and the source of nutrient loads to be examined in relation to simulated changes in reservoir nutrient and phytoplankton concentrations.

5.2 How are models used to evaluate the effects of land use and watershed management on eutrophication in Delaware System reservoirs?

New York City, in cooperation with local municipalities and land owners, has expanded and continues to expend considerable resources to prevent and control reservoir eutrophication. Watershed management programs have implemented best management practices (BMPs) to control nutrients from non-point sources, and wastewater treatment plants have been upgraded to control point source nutrients. Along with implementation of watershed management, land use and population change due to natural shifts in human activity are occurring in these watersheds where much of the land is in private ownership. Evaluating the relative effectiveness of watershed management programs and the effects of changing land use on eutrophication is important for guiding DEP's efforts to maintain the quality of the NYC Water Supply.

The effects of land use change and BMPs implemented by watershed management programs are evaluated by using DEP's water quality models in conjunction with stream and reservoir monitoring data. DEP has developed a eutrophication modeling system (Figure 5.1), consisting of DEP's version of the Generalized Watershed Loading Functions (GWLF) model (Schneiderman et al., 2002) linked to a one-dimensional reservoir hydrothermal and eutrophication receiving water model (UFI, 2002). The GWLF model simulates nutrient concentrations from different non-point and point sources and accounts for the effects of BMPs. The reservoir model takes simulated watershed loads as input, and simulates in-lake phosphorus and chlorophyll levels that are indicators of trophic status. A modeling scenario is run using a long term record (1966-2004) of meteorological and operational data to generate a statistical distribution of in-lake trophic state indicator over a range of historical meteorological conditions. By running alternative scenarios of non-point source management, point source control, and land use change, the relative effects of these factors under current and future conditions can be predicted.

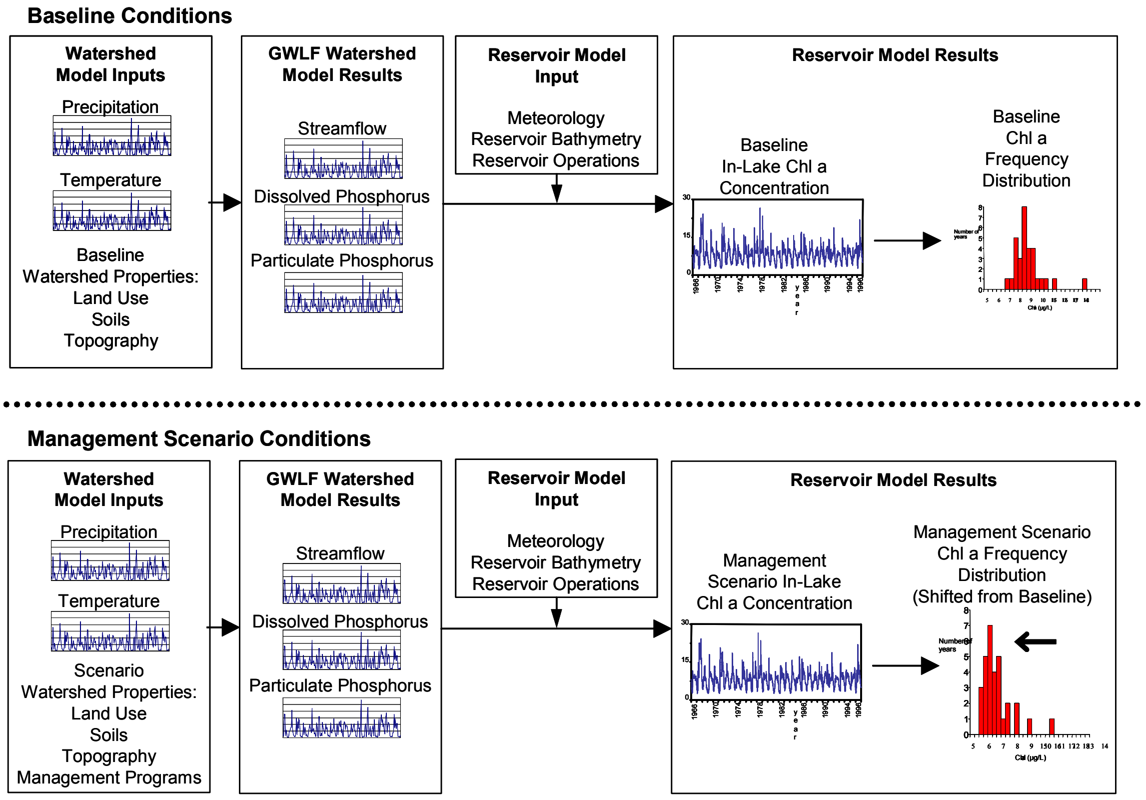


Figure 5.1 Schematic of Eutrophication Modeling System.

The eutrophication modeling system was applied to evaluate land use change and watershed management that occurred in Cannonsville and Pepacton watersheds over the last decade. During this period the intensity of agricultural activity declined, with ~10% reduction in active agricultural land use area and ~30% reduction in farm animal herd density. Human population increased in these two basins during the period. These changes were evaluated as a land use change that occurred independent of watershed management. Watershed management programs that were evaluated include: Watershed Agricultural Program, Urban Stormwater Retrofit Program, Septic Remediation and Replacement Program, and Waste Water Treatment Plant (WWTP) Upgrade Program.

Model scenarios were run and compared to analyze the separate and combined effects of land use and watershed management programs on levels of nutrient loading and the trophic status of Cannonsville and Pepacton Reservoir. The scenarios were developed with different combinations of land use change, BMPs for non-point source management, and point source management (WWTP upgrades). The five scenarios used in this analysis were:

1. *BASELINE* Scenario – land use and population conditions representative of conditions prior to implementation of BMPs or Point Source Upgrades,
2. *LU* Scenario – post-2000 land use and population; without BMPs or Point Source Upgrades
3. *LU-BMP-PS* Scenario - post-2000 land use and population; with BMPs and Point Source Upgrades
4. *LU-BMP* Scenario - post-2000 land use and population; with BMPs
5. *LU-PS* Scenario - post-2000 land use and population; with Point Source Upgrades

In the Cannonsville watershed, significant phosphorus loading reductions were predicted due to the decline in agricultural activity that occurred independent of watershed management, with ~20% reduction in predicted total dissolved loads (~13% reduction in runoff and ~7% reduction in baseflow loads) and ~30% reduction in total particulate phosphorus loads to Cannonsville Reservoir (Figure 5.2), comparison of BASELINE and LU scenarios). When watershed management programs in Cannonsville watershed are considered in addition to the land use change, predicted load reductions are quite substantial, exceeding 46% for dissolved phosphorus and 68% for particulate phosphorus. For dissolved phosphorus, Point Source WWTP upgrades and the implementation of agricultural BMPs by the Watershed Agricultural Program provide most of the loading reductions. Particulate phosphorus load reductions stem mostly from the Watershed Agricultural Program. Urban stormwater management provides relatively small reductions in both dissolved and particulate phosphorus, due to the lack of urban acreage in the watershed

Similarly in Pepacton watershed, significant load reductions of ~15% for dissolved phosphorus and ~25% for particulate phosphorus were attributed changes in the level of agricultural activity (Figure 5.2). With watershed management programs, predicted load reductions increased to over 27% and 58% for dissolved and particulate phosphorus, respectively. For Pepacton watershed, most of the reductions in dissolved phosphorus due to management programs are provided by the Watershed Agricultural Program and the Point Source WWTP upgrades. Septic Systems also provided some reductions in dissolved phosphorus load. The Watershed Agricultural Program accounts for much of the particulate phosphorus reductions.

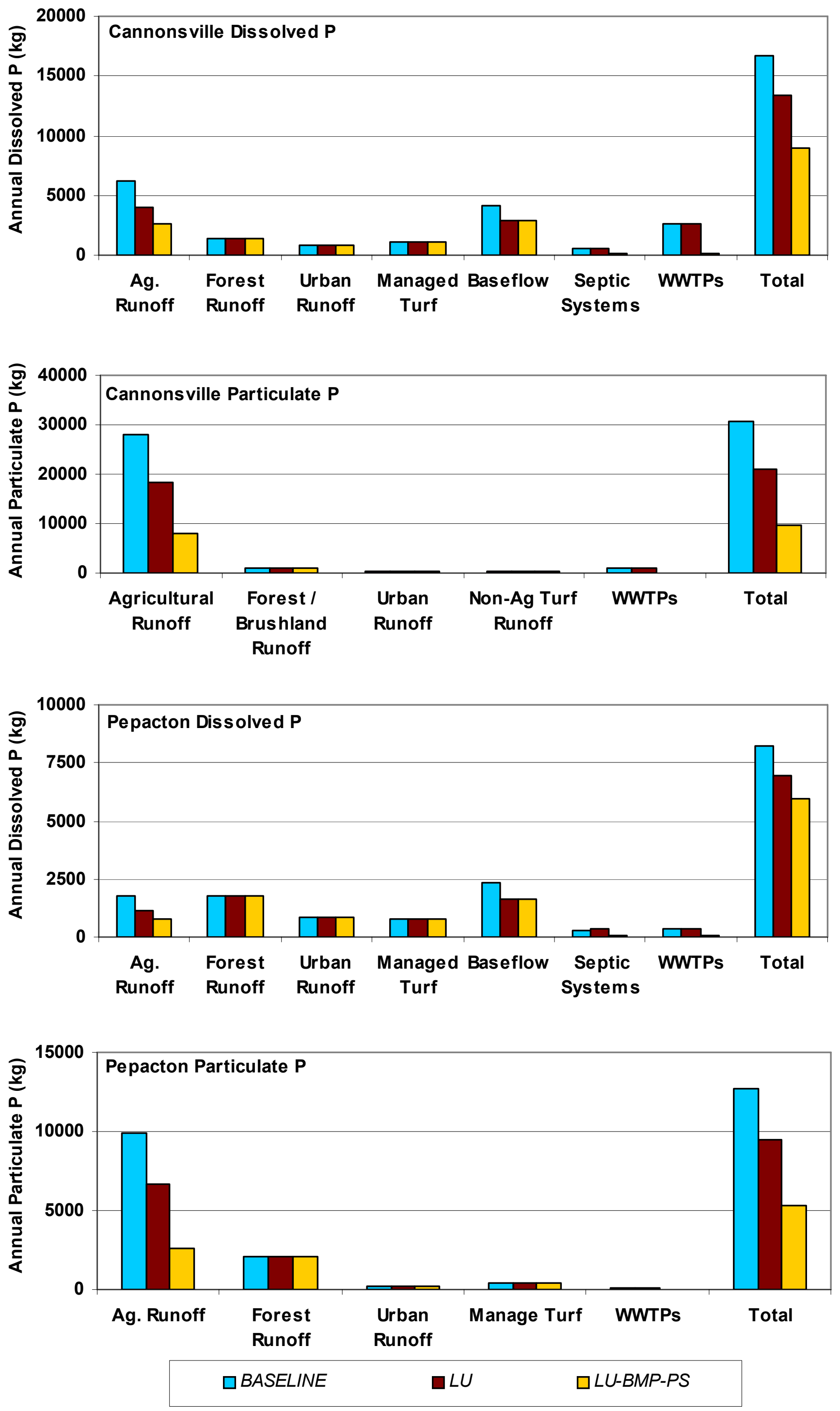


Figure 5.2 Dissolved and particulate phosphorus loadings (kg·yr^{-1}) for *BASELINE* (blue), *LU* (red) and *LU-BMP-PS* (orange) scenarios for the Cannonsville and Pepacton Reservoir watersheds.

The GWLF model predicts the magnitude of phosphorus load reductions due to watershed changes but does not predict the amount of time it will take for these reductions to become apparent in observed loading data collected at the watershed outlet. A time lag between implementation of BMPs (and land use changes) and phosphorus reductions at the watershed scale may occur as pre-existing phosphorus stores that have built up prior to BMPs and land use change are depleted. The lengths of these time lags will depend on the extent, distribution, and form of the stored nutrients, and are difficult to predict. Stores of particulate phosphorus associated with soil particles that transport slowly will take a long time to deplete to a new equilibrium level following a watershed change. In contrast, stores of soluble phosphorus on the soil surface (e.g. spread manure) that are readily transported by surface runoff may deplete to a new equilibrium level rapidly. Observable reductions in phosphorus export following BMP implementation would thus be expected to occur sooner for soluble than for particulate nutrients.

GWLF predictions were compared to observed phosphorus data at West Branch Delaware River (WBDR) at Beerston, the major tributary to Cannonsville Reservoir. Phosphorus loads collected at WBDR over the last 13 years were separated into two distinct periods. The first period, 1992-1999, representing the baseline period, precedes the majority of recent land use changes and is prior to or at the initial stages of much of DEP's watershed management implementation. The 2000-2004 period encompasses recent land use changes (mainly reductions in the intensity of agriculture) and the implementation of many of the DEP supported non-point source watershed management programs.

For dissolved phosphorus, observed loads for 2000-2004 were considerably reduced from the 1992-1999 period (Figure 5.3 – upper plate). For the 2000-2004 period, the BMP scenario, representing only the influence of watershed management program implementation, predicts a reduction in loading, but this reduction does not completely account for the reductions in the observed data. A closer match between observed and scenario dissolved phosphorus loads occurs only when the effects of recent land use changes are combined with the effects of watershed management program implementation in scenario BMP-LU. This shows that for Cannonsville watershed the combined effects of land use change and BMPs on dissolved phosphorus loading, mainly due to reductions in highly-available soluble P in surface-spread manure, were rapidly (within a decade) realized.

In contrast, while the model predicts future reductions in particulate phosphorus, this signal has not yet been observed in the 2000-2004 period (Figure 5.3 – lower plate.) This suggests that the watershed response to land use change and watershed management on particulate phosphorus is much slower than for dissolved phosphorus. Particulate phosphorus export is more dependent on the slow process of changing soil concentrations of phosphorus and the episodic processes of erosion and transport of these phosphorus stores through the stream network. Continued monitoring will be needed to determine how long it will take for particulate phosphorus reductions to be realized.

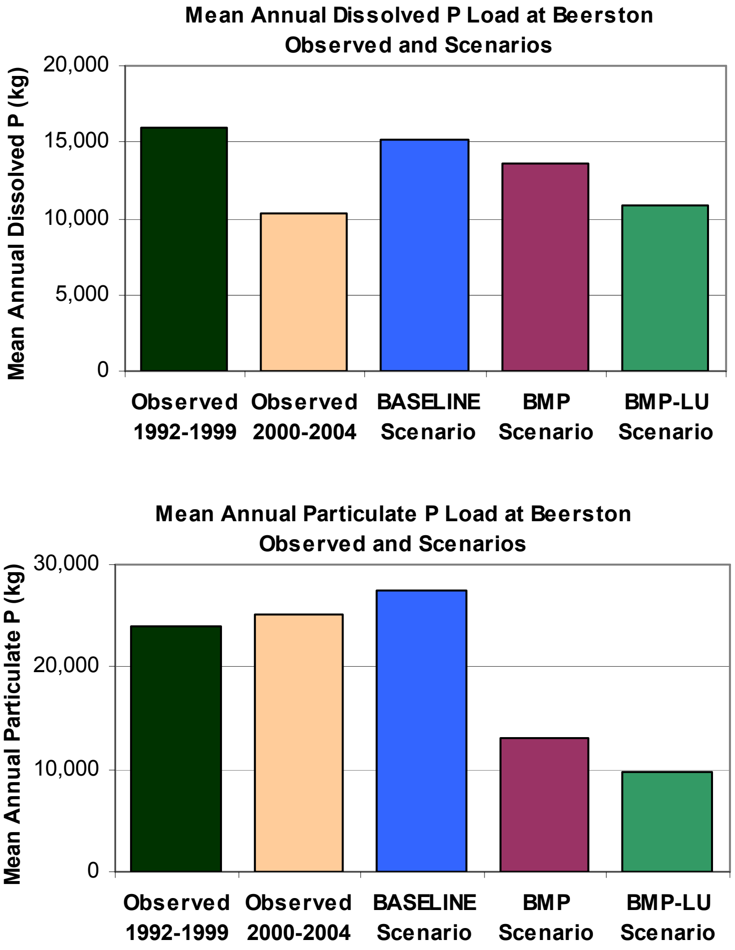


Figure 5.3 Observed and model scenario mean annual dissolved and particulate phosphorus loads at WBDR for two time periods: 1992-1999 (generally prior to land use changes and BMP implementation) and 2000-2004 (after land use changes and BMP implementation).

Reductions in dissolved phosphorus are observed between the two periods and in model results suggesting a quick dissolved phosphorus watershed response to watershed management. Predicted reductions in particulate phosphorus have not yet been observed, suggesting a longer lag time for particulate phosphorus reductions to appear at the watershed outlet.

The effects of land use change, non-point BMPs, and point source management on the trophic status of the Cannonsville and Pepacton reservoirs were evaluated by driving reservoir water quality models with the different nutrient loading scenarios simulated using GWLF. Trophic status is commonly measured in terms of phytoplankton chlorophyll concentration or total phosphorus concentration, and it is the model output of these two variables that is examined here. Furthermore, water quality issues related to eutrophication almost always occur during the summer period, and in the epilimnion (upper mixed layer) of the reservoir. For this reason, chlorophyll and total phosphorus are examined during the summer period (June-September) using data contained within the epilimnion. In Figures 5.4 and 5.5 histograms of mean summer epilimnetic chlorophyll and total phosphorus concentrations derived from the 39 years of simulation results are plotted for Cannonsville and Pepacton reservoirs. Measures of central tendency associated with these histograms give an overall estimate of the effects of the programs, while the range of variability provides a realistic description of the variations in water quality that will be experienced under any given nutrient loading scenario.

For Cannonsville Reservoir, lower watershed loads due to the decline in farming that occurred between 1992 and 2004 resulted in considerable reductions of 13% for in-lake growing season chlorophyll *a* and 16% for total phosphorus. Greater reductions were predicted when non-point and point source watershed management in addition to land use change were considered (38% for chlorophyll and 43% for total phosphorus). A similar, but smaller, shift in chlorophyll (-5 %) and total phosphorus (-3 %) occurred in the Pepacton reservoir as a result of land use change. When Pepacton nutrient reductions related to land use were combined with point and non-point source reductions an overall reduction of approximately 13% for chlorophyll and 8% for total phosphorus occurred.

The relative shifts in the chlorophyll and total phosphorus frequency distributions between simulations scenarios or the relative differences in the long term mean concentrations simulated for each scenario are similar for both reservoirs; however, the absolute magnitude of the differences is less for Pepacton. This is due to the fact that Cannonsville was the most eutrophic reservoir in the WOH system, and therefore, that the FAD watershed programs have had a proportionally greater effect there. Secondly, Cannonsville is also the reservoir watershed which had the most agricultural land use of any WOH reservoir. Implementation of agricultural BMP programs and reduction in agricultural activity therefore, has had the greatest effect on this reservoir.

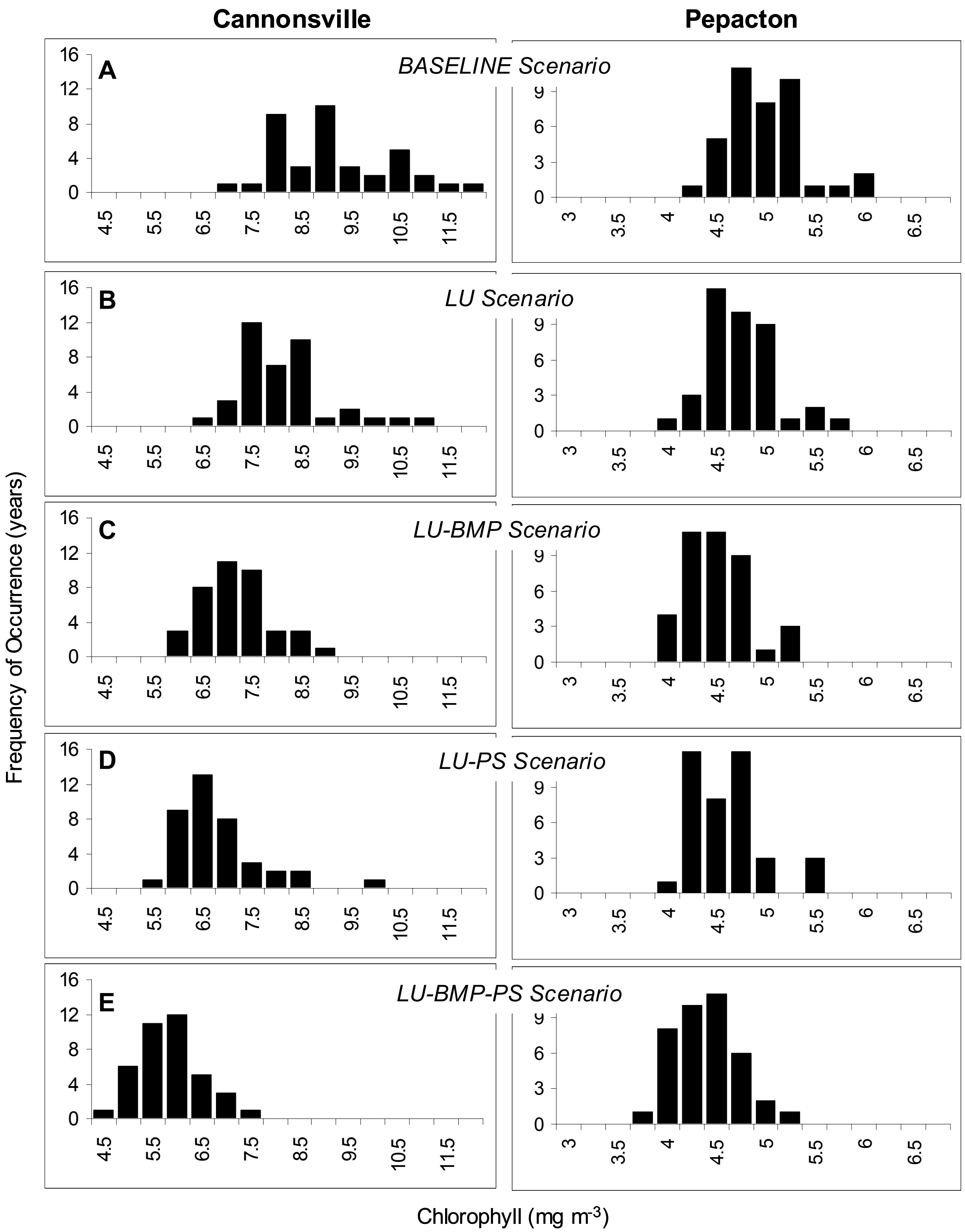


Figure 5.4 Frequency distributions of the mean summer epilimnetic chlorophyll concentrations that are calculated from the output of the reservoir model simulations of Cannonsville and Pepacton reservoirs driven by the differing nutrient loading scenarios.

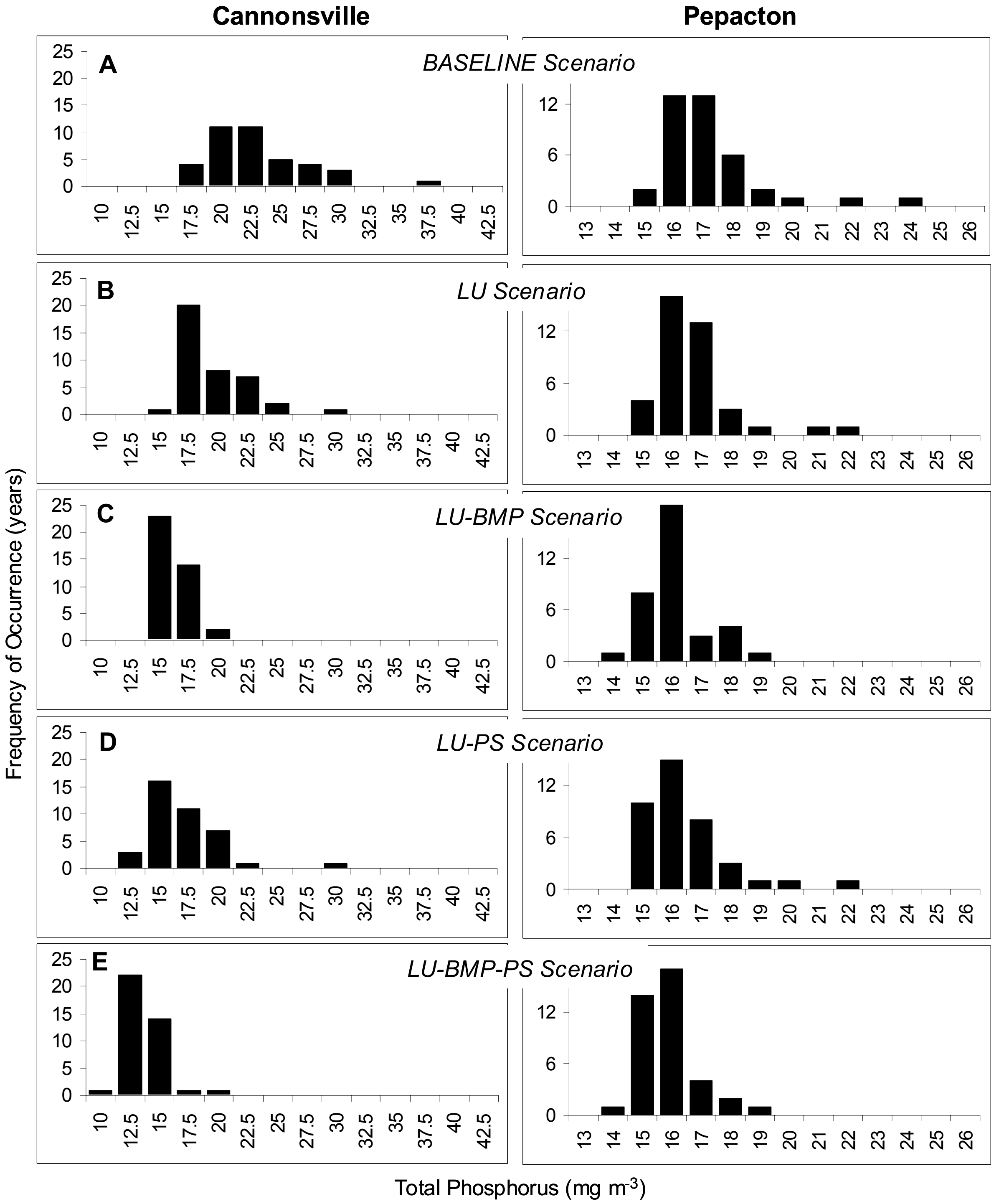


Figure 5.5 Frequency distributions of the mean summer epilimnetic total phosphorus concentrations that are calculated from the output of the reservoir model simulations of Cannonsville and Pepacton reservoirs driven by the differing nutrient loading scenarios.

5.3 What can models tell us about the effects of 2005's weather on nutrient loads and flow pathways to reservoirs?

Applying watershed models to include the current year allows a better understanding of how 2005 nutrient loads to the reservoirs compare to long term flow and loading patterns.

Using the model results, annual results for 2005 can be placed in an appropriate historical context that accounts for the effects of natural meteorological variability on water quality. This variability is the background within which watershed management operates, and provides an important context for judging the effects watershed management.

Watershed modeling of streamflow and nutrient loads provides insight into the flow paths that water and nutrients take in the watershed. Total streamflow is comprised of direct runoff and baseflow. Direct runoff is water that moves rapidly on or near the land surface, as opposed to much slower-moving baseflow that infiltrates and moves underground to the stream. As direct runoff interacts with P sources on the land surface, there is a high potential for transporting phosphorus.

Figure 5.6 depicts the annual streamflow, direct runoff, and dissolved nutrient loads simulated by the model for 2005 in relation to long-term simulated annual statistics. These box plots show that 2005 was wetter year than normal with both higher than normal streamflow and direct runoff. Consistent with these high flows, 2005 dissolved nutrient loads were also higher than normal. The relationship between 2005 and long-term annual total dissolved phosphorus (TDP) loads follow a similar pattern to direct runoff, while total dissolved nitrogen (TDN) loads closely mirror the pattern for annual streamflow. These results have important consequences for watershed management, suggesting that management of non-point sources of dissolved phosphorus in direct runoff can be particularly effective in controlling TDP loads, to which algal growth in the reservoirs is particularly sensitive.

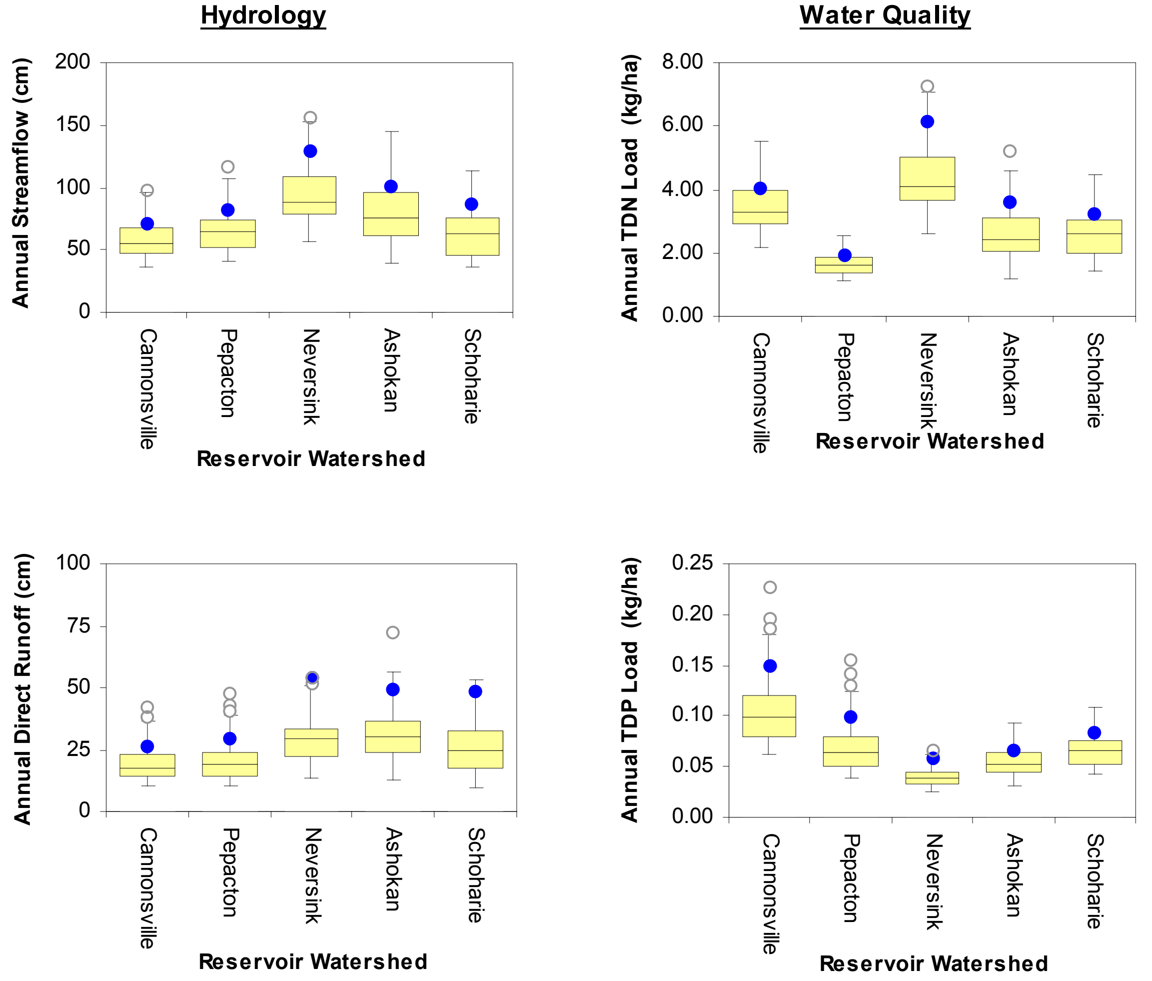


Figure 5.6 Annual streamflow, direct runoff and dissolved nutrient loads simulated by the GWLF model for 2005 in relation to long term simulated annual statistics.

Box plots show long term statistics. Blue dots show 2005 results.

5.4 What was accomplished in 2005 in the development of modeling capabilities?

Model development and improvement is an ongoing process as new data and research results become available. Modeling capabilities continue to be improved for both DEP's watershed and reservoir models. (NYCDEP, 2005a; 2006e)

Watershed model developments in 2005 included revisions and additions to both hydrology and water quality modules. The Priestley-Taylor method for calculating potential evapo-transpiration (PET) was added as an option. Priestley-Taylor calculates PET as a function of solar radiation and relative humidity as well as air temperature, whereas the original GWLF method, based on Hamon-Bosen equations, is strictly a temperature index method. A simplified method for calculating runoff curve numbers as a function of soil moisture, based on the SPAW model, was also added to the hydrology module. In the water quality module, the ability to vary dissolved nutrient concentrations as a function of flow was added, to account for observed flow-concentration relationships in storm monitoring data. A channel erosion algorithm was added to account for the component of sediment load from the basin that originates from channel erosion.

Data to support model testing and applications were improved. A GIS coverage of land use based on 2001 remotely-sensed data was refined for use with the GWLF model. Additional GIS coverages acquired to support modeling included point coverage of buildings with septic systems, and wetness index maps based on topography and soils data. A collaborative project with DEP and the Delaware County Scientific Support Group began to develop an agricultural database for Delaware System watersheds that would provide reliable data on farming in the watersheds. GIS tools for developing GWLF model inputs were improved to support new model versions. Time series data of meteorology, streamflow, and water quality monitoring were updated through 2005.

GWLF model calibration for Cannonsville and Pepacton was revisited, using new hydrologic and water quality calibration routines. The new hydrology calibration routine fine-tunes the runoff calibration to account for seasonal variation, using the recently implemented SPAW method for runoff curve number calculation. The new water quality calibration optimizes parameters that control the flow-concentration relationship for dissolved nutrients. Water quality GWLF model calibrations for Ashokan and West Branch watersheds were also completed utilizing recently collected storm event data.

The reservoir modeling group used 1D eutrophication models driven by long term (over 35 year) data sets of weather, reservoir operations, and nutrient inputs derived from GWLF simulations to evaluate the effects of nutrient loading on reservoir trophic status. Multiple simulations are often made using differing nutrient loads associated with different watershed land use and management scenarios, and multiple runs are also made for the purposes of model testing and sensitivity analysis. During the last year a new version of the 1D reservoir model was created that allowed multiple simulations to be run in an automated (batch) mode and which also had more extensive and flexible data output capabilities. This model was used extensively in our FAD evaluation simulations (Section 5.2).

DEP also uses 2D models to predict turbidity transport in the Catskill system and Kensico Reservoir. These models are often run over shorter time periods (months-years) with the goal of quantifying the transport and spatial distribution of turbidity in the Schoharie, Ashokan and Kensico reservoirs. Simulations using these models have been used to identify the relative importance of Schoharie and Ashokan watershed turbidity sources on Ashokan Reservoir turbidity (Section

5.5) and to evaluate the effects of elevated Catskill system turbidity on the turbidity occurring at the Kensico effluent locations (Section 5.6). When running the 2D models, multiple simulations are required to account for a range of possible particle sinking rates, and aqueduct turbidity levels in order to account for the uncertainty in future (forecast) turbidity levels. The 2D models were upgraded to allow for automated processing, and this capability has improved our ability to rapidly set up and run the multi- simulations that are needed to define the uncertainty in reservoir turbidity forecasts. Our 2D modeling system (LinkRes) was also upgraded to make it possible to explicitly account for sources of turbidity originating in the Ashokan Reservoir watershed.

5.5 What is the importance of Schoharie and Ashokan Reservoir watershed turbidity sources in influencing the turbidity levels in Ashokan Reservoir?

Turbidity in the Ashokan Reservoir is largely associated with two sources, which in turn are related to two different watershed areas (Figure 5.7):

1. Schoharie Reservoir releases that enter the Esopus Creek as a point source via the Shandaken Tunnel, and which are derived from turbidity sources within the Schoharie Reservoir watershed
2. Non point source turbidity generated within the Esopus Creek (Ashokan Reservoir), watershed.

There are reasons to believe that Schoharie Reservoir derived turbidity could have important effects on the Ashokan turbidity. The Schoharie Reservoir has a larger watershed area and shorter residence time than the Ashokan Reservoir, and median Schoharie turbidity levels are greater that those associated with the Ashokan Reservoir. On the other hand, there are a number of reasons to believe that the Schoharie sources are not of great importance in influencing the Ashokan Reservoir. Most importantly is the fact that there are also significant sources of turbidity in the Esopus Creek Watershed (DEP 1994; 2005b), which would more directly influence the Ashokan turbidity, especially since during storm events when turbidity levels are greatest, and the Shandaken tunnel is normally closed. Also, one would expect the importance of the Schoharie turbidity sources to be reduced as levels of turbidity are attenuated as water moves through the system (DEP 2004).

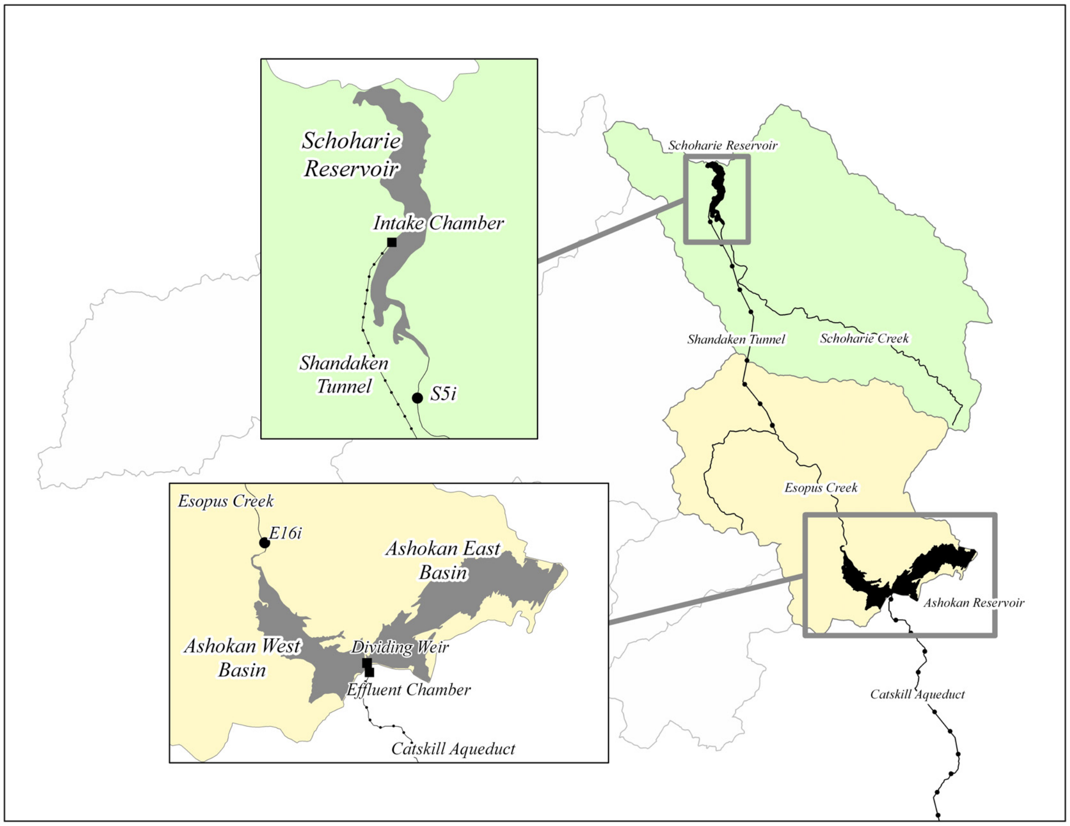


Figure 5.7 Map of the Catskill reservoir system showing locations of reservoir inflow outflow locations.

Note: The majority of water enters Ashokan reservoir in the West basin from the Esopus Creek. Water and turbidity entering from the Esopus Creek can either come from the Esopus watershed or the Schoharie reservoir which discharges into the Esopus Creek by the Shandaken Tunnel.

Water quality models provide a method to address this question which is not possible by actual physical measurement or experimentation — one of the two turbidity sources can be eliminated and not allowed to influence the simulated levels of turbidity in the Ashokan reservoir. Two parallel sets of simulations were therefore, run (Figure 5.8) where: 1) both Schoharie and Ashokan watershed turbidity sources were allowed to influence the Ashokan reservoir turbidity levels; and 2) only Schoharie turbidity sources were input to the reservoir models and allowed to influence Ashokan Reservoir turbidity. The relative importance of Schoharie turbidity sources on Ashokan Reservoir turbidity levels can then be assessed by comparing the predicted turbidity levels associated with these two series of simulations.

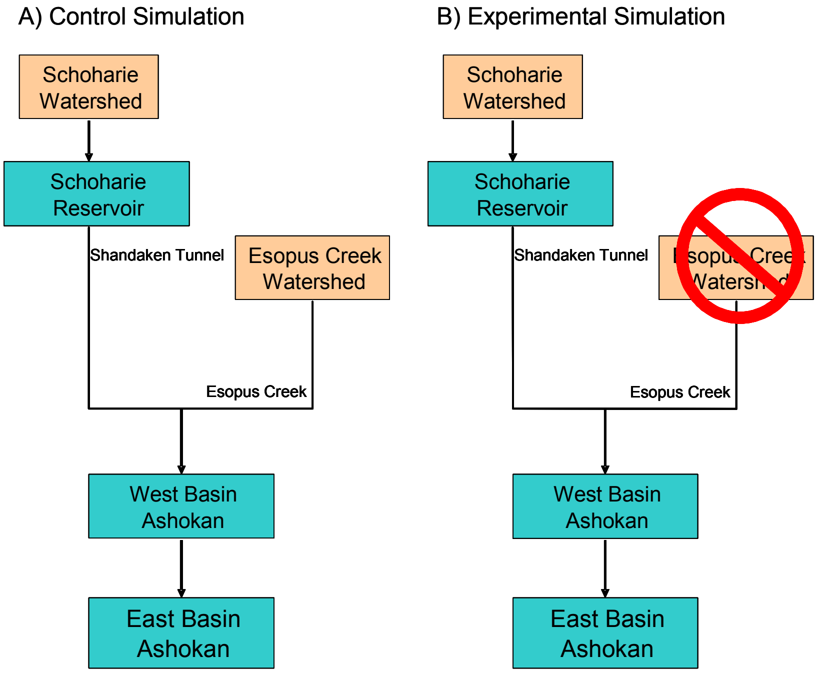


Figure 5.8 Schematic diagram of the method used to access the importance of Schoharie Reservoir turbidity sources on the turbidity levels in the Ashokan Reservoir. For the Control Simulations (A) Turbidity inputs were allowed for both Schoharie and Esopus Reservoirs. For the Experimental Simulation (B) only Schoharie turbidity inputs were used.

This is a first attempt to quantitatively estimate the importance of Esopus vs. Schoharie turbidity sources on Ashokan Reservoir in a consistent manner over a relatively long time period, using the best data and models available to DEP. We chose to examine the effects of watershed turbidity sources on Ashokan Reservoir turbidity since it is turbidity that is important to DEP from a water quality stand point, and since reservoir turbidity levels provide integrated measure of turbidity inputs which are known to vary widely through time. We do not address the effects of differing turbidity sources on Esopus Creek turbidity levels, and we do not examine the short-term variations in the importance of the two turbidity sources, on stream or reservoir turbidity. The work has also been reported on at the 2005 New York City Watershed Science and Technical Conference (Pierson et al. 2005), and in the Jan. 2006 Multi-tiered modeling status report to EPA (DEP 2006e). In the later source a more detailed description of the modeling methods is provided.

The results of the simulations are quite simple to interpret and are most clearly summarized by Figure 5.9 which shows the variations in turbidity simulated as occurring in the West Basin of the Ashokan Reservoir. The upper portion of the figure shows the simulated turbidity when both Ashokan Reservoir watershed and Schoharie Reservoir turbidity sources are input to the Ashokan Reservoir. The lower portion of the figure shows the same simulation, but with only the Schoharie sources. The difference between the top and bottom portions of these figures therefore, shows the relative importance of the Ashokan watershed turbidity sources in influencing the turbidity of the Ashokan reservoir, and these data clearly suggest that it is indeed the Ashokan watershed sources that have the greatest affect on the Ashokan Reservoir turbidity levels.

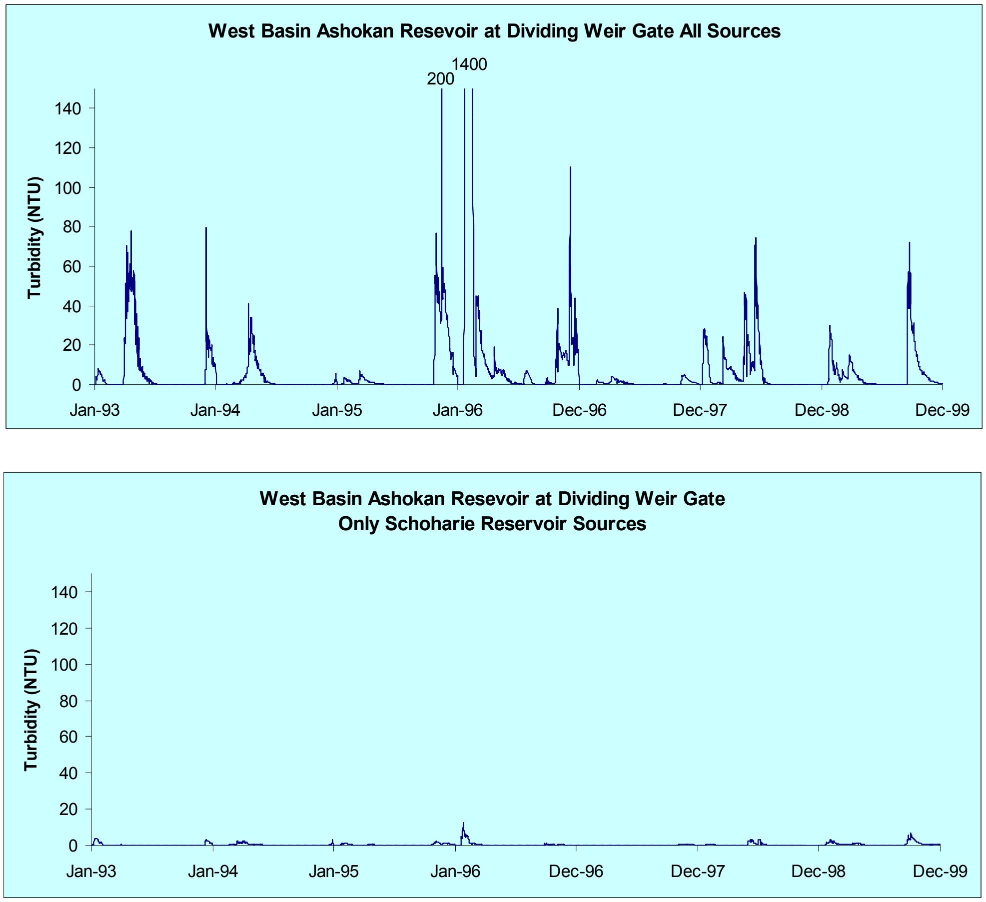


Figure 5.9 Turbidity levels simulated in the West Basin of Ashokan at the location the dividing weir gates.

Note: Top panel show the result for simulations where turbidity from Ashokan Reservoir watershed sources and the Shandaken Tunnel are input to the simulation. Bottom panel is the result when only the Shandaken tunnel sources are input to the simulation

A simple quantitative estimate of the importance of the Schoharie Reservoir turbidity sources on Ashokan Reservoir Turbidity levels was also calculated as the ratio of the mean turbidity level calculated in the two simulations series shown in Figure 5.9. This ratio suggested that over the long term, Schoharie reservoir sources accounted for approximately 4 percent of the turbidity simulated to occur in the Ashokan Reservoir.

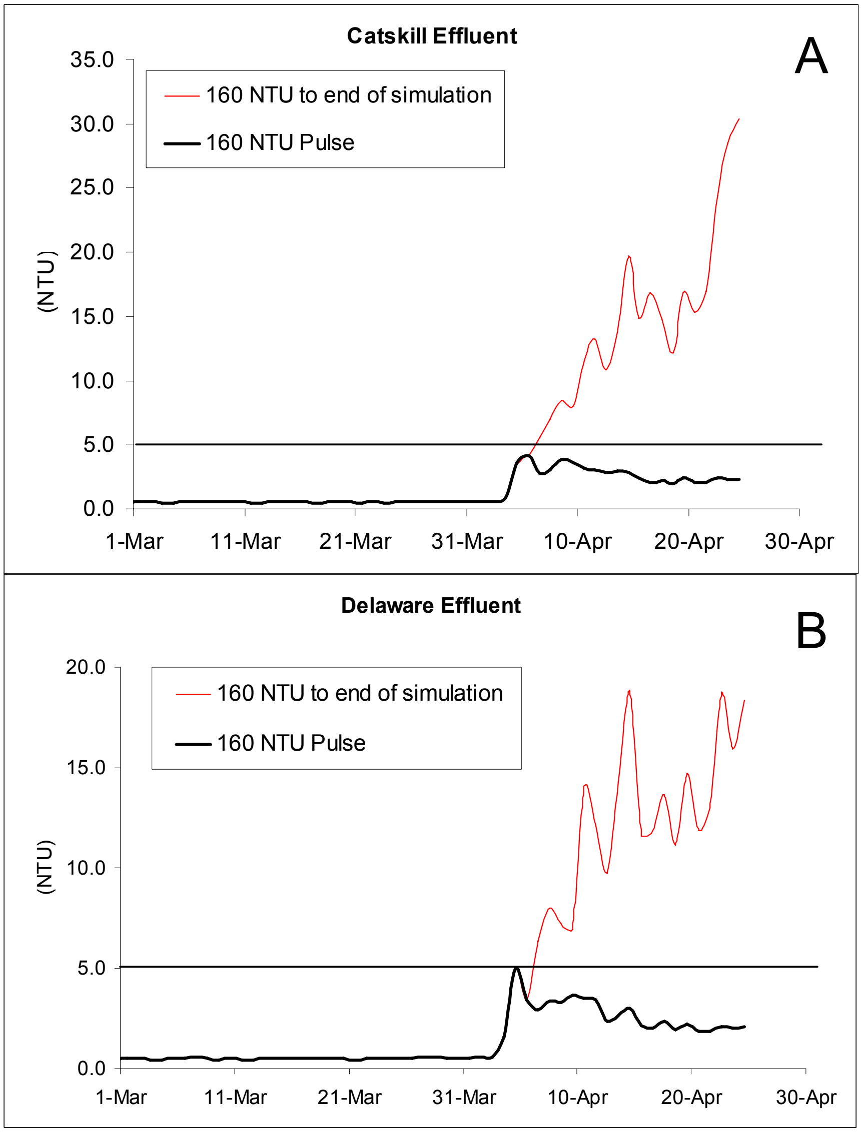
The data presented in Figure 5.9 clearly focus on the largest storm events. It is these events that are of greatest significance for the turbidity budget of the Ashokan reservoir, and it is these events that lead to turbidity-related water quality problems. This analysis clearly suggests that it is sources of turbidity located in the Ashokan Reservoir watershed, not the Schoharie Reservoir, which are responsible for the elevated turbidity levels that can lead to water quality problems in the Ashokan Reservoir for New York City's drinking water supply.

5.6 How does DEP use model simulations to support decision making regarding the need for alum treatment?

During 2005-2006, a record breaking number of storm events affected the Catskill portion of the NYC water supply. These caused elevated turbidity levels in the Schoharie and Ashokan reservoirs to occur over a period of time that was of a longer duration than normally experienced. High and sustained levels of Catskill system turbidity impaired DEP's ability to use this water, and required treatment with alum in order to reduce the turbidity of the water transferred to Kensico Reservoir from Ashokan Reservoir (Figure 5.7). Simulations of the transport and attenuation of turbidity in Kensico Reservoir have provided an important source of guidance in determining the need for alum treatment, and in determining the time, when turbidity declined sufficiently, that alum treatment could be terminated. Here we provide two examples of 1) how simulation results were used to demonstrate the need for alum treatment, and 2) how simulations were used to show that alum treatment could be terminated. More detailed descriptions of the simulation methods and results associated with these two examples can be found in the DEP Multi-tiered modeling status reports submitted to EPA in July of 2005 and January of 2006 (DEP 2005a, 2006e)

The first and largest turbidity event occurred in April 2005, when between 50 and 150 mm of rain fell across the NYC West-of-Hudson (WOH) reservoir watersheds. This followed an earlier storm that had already led to large discharges and filled most reservoirs to near capacity. As a consequence of high levels of antecedent wetness, snowmelt in the upper watershed elevations, and low storage capacity in the reservoirs, record high discharge, turbidity levels, and reservoir spill occurred through out the WOH reservoir system. Ultimately this led to very high turbidity of up to 160 NTU in water entering the Catskill aqueduct from Ashokan Reservoir, and elevated turbidity approaching 12 NTU in water entering the Delaware Aqueduct from Rondout Reservoir. Due to a number of operational and regulatory constraints, it was not possible to immediately turn off Catskill aqueduct flow, or immediately begin alum treatment, and as a result there was an initial pulse of 160 NTU water, which entered the Catskill aqueduct and flowed out into Kensico reservoir over a period of approximately one day. The Catskill aqueduct was then shut down and a series of simulations were run to determine the effects of the pulse of highly turbid water on the aqueduct effluent turbidity levels leaving Kensico reservoir. A second scenario was run to justify the need for alum treatment. In this case the Catskill aqueduct turbidity was fixed at the 160 NTU level and the aqueduct flow rate was reduced from the pre-event level of 450 MGD to 350 MGD, with a compensatory increase in Delaware aqueduct flow rates. The results of these simulations

(Figure 5.10) suggested that the pulse of turbidity that had already entered the reservoir would lead to a rapid increase in effluent turbidity levels, but that turbidity levels would remain at or near the 5 NTU regulatory limit. The worse case scenario which allowed for continued inputs of highly turbid water clearly showed that alum treatment would be needed, and that inputs of untreated Catskill system would drive Kensico effluent turbidity well above the regulatory limits.


Catskill Effluent

Delaware Effluent

Figure 5.10 Turbidity levels simulated at the Catskill (A) and Delaware (B) Kensico Reservoir effluents in response to the April turbidity event.

Two scenarios were simulated. One simulates a shutdown of the Catskill Aqueduct following a one-day pulse of 160 NTU water entering the reservoir. The other did not shut down the Catskill aqueduct, but provided a constant 160 NTU Catskill turbidity until the end of the simulation. The horizontal line shows the 5 NTU regulatory turbidity limit.

A second set of simulations (Figure 5.11), illustrates the use of modeling to determine when alum treatment could be terminated. These simulations were run during April 2006 at the end of a period of alum treatment that began in November of 2005. The simulations were driven by measured variations in aqueduct flow and turbidity until 6 April, after which an increase in turbidity corresponding with the end of alum treatment was simulated. When alum treatment was underway, the measured Catskill aqueduct turbidity input to Kensico was reduced, and the efficiency of the alum precipitation was calibrated based on parallel measurements of aqueduct and reservoir turbidity. Following 6 April the Catskill aqueduct turbidity was set at a constant value of 7 NTU, which was the expected value in the absence of alum treatment (i.e. the turbidity of water leaving Ashokan on the day of the simulations). Reasonable aqueduct flow levels were maintained, and a range of particle sinking rates was used to examine the sensitivity of the predictions to reasonable variations in sinking.

In Figure 5.11 measured turbidity levels at the two Kensico effluent locations closely match the simulated turbidity levels, and are bracketed by the simulations made using differing particle sinking rates. These results suggest that the model is capable of accurately predicting the turbidity levels at the aqueduct effluent locations, and consequently the transport of turbidity through Kensico reservoir. Following the simulated end of alum treatment and the increase in Catskill aqueduct turbidity to 7 NTU, there is a rapid increase in effluent turbidity levels, follow by a gradual increase to the end of May. However, despite this increase, effluent turbidity levels remained below the 5 NTU limit. These results suggested that alum treatment could be safely terminated, especially considering the fact that a constant 7 NTU turbidity input was a conservative worse case scenario, since it was expected that Ashokan turbidities would continue to decline as time progressed. Alum treatment was terminated on 11 April 2006 and these simulations were used to support that decision.

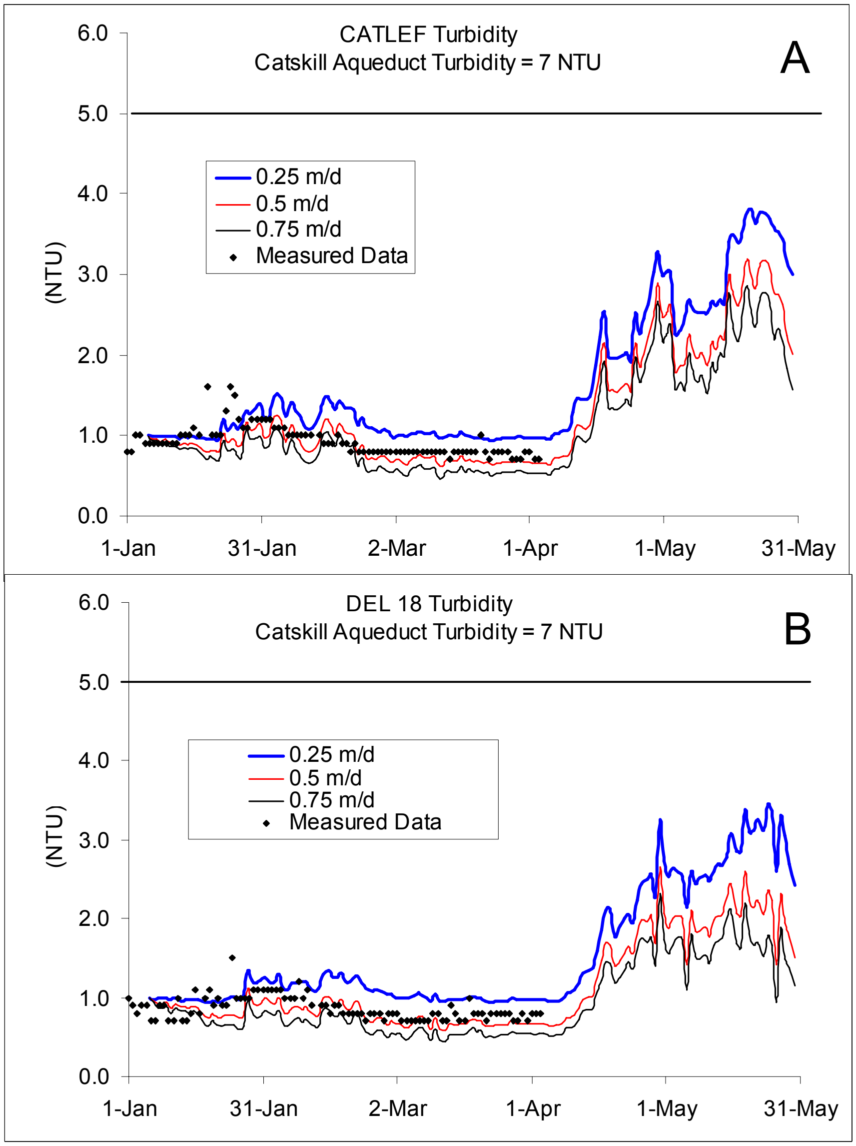


Figure 5.11 Turbidity levels simulated at the Catskill (A) and Delaware (B) Kensico Reservoir effluents.

Up to April 6, 2005, simulations are based on measured aqueduct flow and turbidity inputs to Kensico reservoir. From April 7, 2005, the Catskill aqueduct turbidity is increased to 7 NTU to simulate the effects of terminating alum treatment. The horizontal line shows the 5 NTU regulatory turbidity limit.

5.7 Testing and application of turbidity and temperature models for Schoharie Reservoir and Esopus Creek

Background

The Upstate Freshwater Institute (UFI) is under contract with DEP to develop, test and apply scientifically credible models for temperature and turbidity for Schoharie Reservoir and Esopus Creek. This work has been supported by integrated programs of field measurements with rapid profiling instrumentation, runoff event-based sampling, laboratory analyses, and process studies conducted by UFI. Part of the field program included frequent measurements with a robotic monitoring network. These support studies were conducted from mid-summer 2002 through 2005. Development and early testing of the models proceeded during that period. Model testing is completed for the Schoharie Reservoir models and is nearing completion for Esopus Creek. The reservoir models are being applied to evaluate the efficacy of three different management options under consideration to meet water quality goals: (1) a multi-level intake facility, (2) a baffle adjoining the existing intake, and (3) changes in reservoir operations.

Model Descriptions and Testing

Hydrodynamic, or transport, models are a key building block to overall water quality models. These generally range in structure and complexity according to the manifestations of water quality problems and needs associated with the various management options. Commonly, these include either, one-, two- or three dimensional frameworks for stratifying reservoirs. One-dimensional frameworks consider vertical variation only; i.e., longitudinal and lateral uniformity is assumed. Two-dimensional models consider vertical and longitudinal variations; i.e., lateral uniformity. Three-dimensional frameworks consider variations in all three dimensions.

While temperature simulations for the reservoir could be adequately supported by a one-dimensional framework, observed turbidity distribution patterns following runoff events dictated a two-dimensional transport model to support turbidity simulations. The segmentation adopted for the two-dimensional transport model for Schoharie Reservoir applications is schematically represented in Figure 5.12a. Testing of this transport model has focused on performance in simulating temperature. The high level of performance for 7 different years is illustrated in a time plot that compares observed and predicted epilimnetic and hypolimnetic temperatures (Figure 5.13). This model also performed well in simulating tracer patterns. This framework is being used to address the multi-level intake and `operation changes´ alternatives. The inclusion of a baffle management option, that invalidates the lateral uniformity assumption of the two-dimensional model, dictated the inclusion of a three-dimensional framework. The much more spatially detailed segmentation used for the three-dimensional model, along with the position of a hypothetical baffle, is depicted in Figure 5.12b. In contrast to the reservoir, but typical of streams, the Esopus Creek model consists of longitudinal segments. Model calibration efforts for creek temperatures have yielded promising results, as illustrated in Figure 5.14 for short-term dynamics measured at a site 18 km downstream of the Shandaken tunnel discharge.

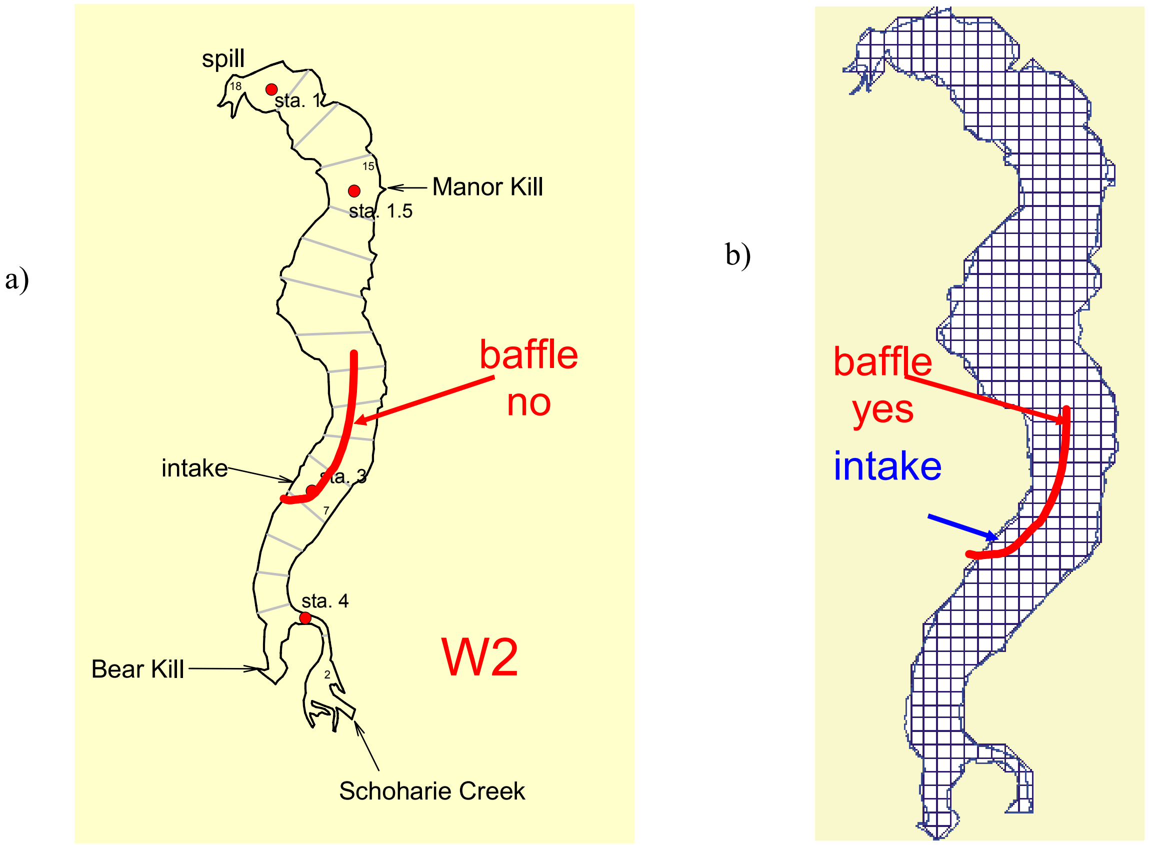


Figure 5.12 Transport model segmentation for Schoharie Reservoir: (a) two-dimensional framework, and (b) three-dimensional framework.

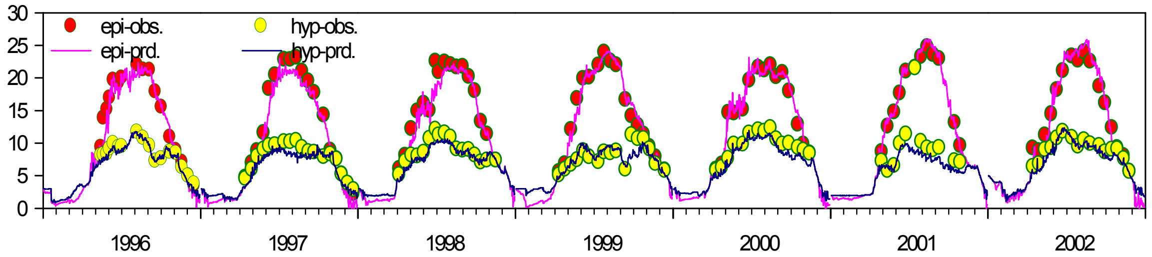


Figure 5.13 Performance of two-dimensional transport/hydrothermal model in simulating epilimnetic and hypolimnetic temperatures in Schoharie Reservoir, 1996 – 2002.

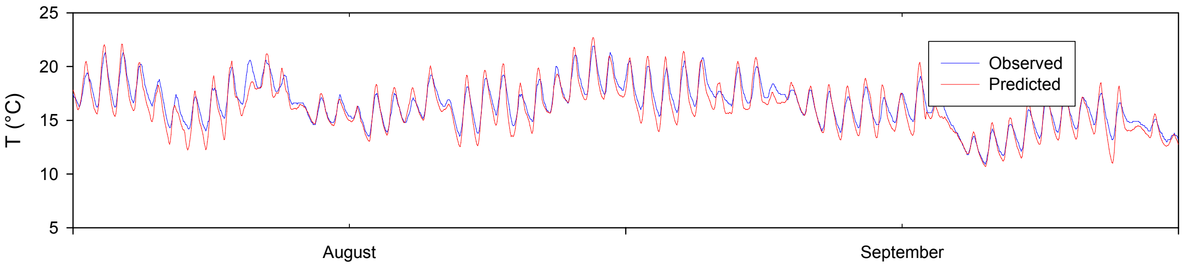


Figure 5.14 Performance of stream temperature model for Esopus Creek for the August – September interval of 2004, 18 km downstream of Shandanken Tunnel discharge.

The developed turbidity model simulates the effects of: (1) external turbidity inputs that enter primarily from Schoharie Creek during runoff events, (2) resuspension inputs received from bottom sediments, particularly during intervals of drawdown, and (3) settling of turbidity causing particles. The model has been rigorously tested against cases of high turbidity associated with a wide array of runoff events. Model performance is illustrated for October 13, 2002, following a major runoff event (Figure 5.15); the reservoir had experienced extensive drawdown before the event. The format of this presentation is a series of vertical profiles of turbidity observations and predictions for segments of the two-dimensional model extending from upstream (left) to downstream (right) portions of the reservoir. Two prediction lines appear in each plot, one representing the case of not including the effect of resuspension, the other including the simulated effect of this internal source of turbidity (Figure 5.15). The overall model performed well, and resuspension is shown to be important for the condition of extensive drawdown of the reservoir.

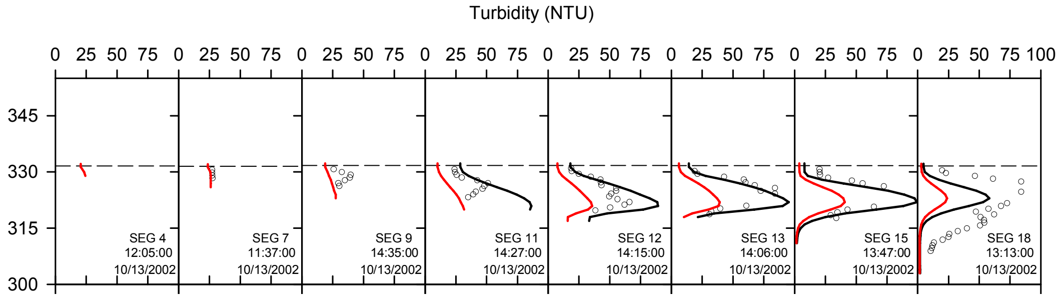


Figure 5.15 Performance of the two-dimension Schoharie Reservoir turbidity model for a mid-October runoff even in 2002 as vertical profiles in model segments (left is upstream adjoining Schoharie Creek inflow) for two cases: without resuspension inputs (solid red line), and with resuspension inputs (open circles).

Model Applications

UFI is working collaboratively with Hazen and Sawyer Engineers (also under contract with DEP) to apply the tested models to evaluate management options to meet both turbidity and temperature goals. Great care is being taken to develop representative model inputs in these applications, as these have important effects on model predictions. Development of such inputs for Schoharie Reservoir is complicated by the wide variations in environmental conditions experienced by this system associated not only with natural meteorological variations but also with major variations in reservoir operations (e.g., extent of drawdown). One approach used to address this issue has been the development of model inputs representative of the last 50 years of conditions experienced by the reservoir. The corresponding model predictions (50 years) are therefore representative of a realistic level of variability experienced by the reservoir.

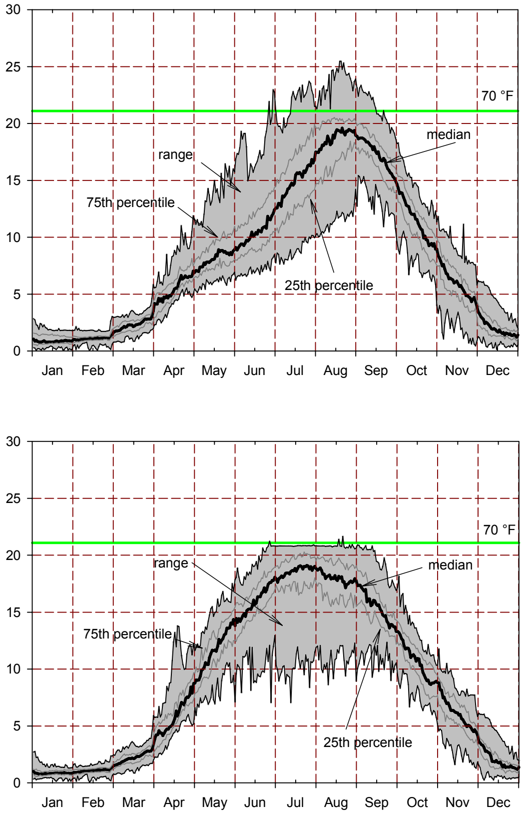


Figure 5.16 Predictions of the temperature of the withdrawal from Schoharie Reservoir for 50 years of meteorological and operating conditions for two cases: (a) for the existing single intake, and (b) for a multi-level intake facility at the existing intake site.

An example application of the two-dimensional model to evaluate the benefits of a multi-level intake for reaching the 70º F (21.1º C) goal for the Shandaken Tunnel is presented in Figure 5.16. Note the probabilistic character of the predictions formed from 50 years of simulations. Predictions for the case of the prevailing single intake depth (Figure 5.16a) depict occurrences of exceedences of the goal in certain years in August and September. However, operation of a hypothetical multi-level intake facility, at the same position as the existing intake, is predicted to essentially eliminate such exceedences (Figure 5.16b).

A baffle is intended to avoid short-circuited (direct) flow of turbid Schoharie Creek water to the intake following runoff events. It also will promote settling losses of turbidity following these events, by increasing the effective travel time to the intake of the inflow from this stream. An example application of the three-dimensional model to evaluate a hypothetical baffle configuration is presented as Figure 5.17. Note the protection of the intake from short-circuited turbid inflow for the September 2003 runoff event is clearly depicted.

A wide array of design features is presently being evaluated with the tested hydrodynamic and water quality models. These tools are providing objective quantitative input to engineering evaluations that will contribute to the selection of effective management options to protect water quality.

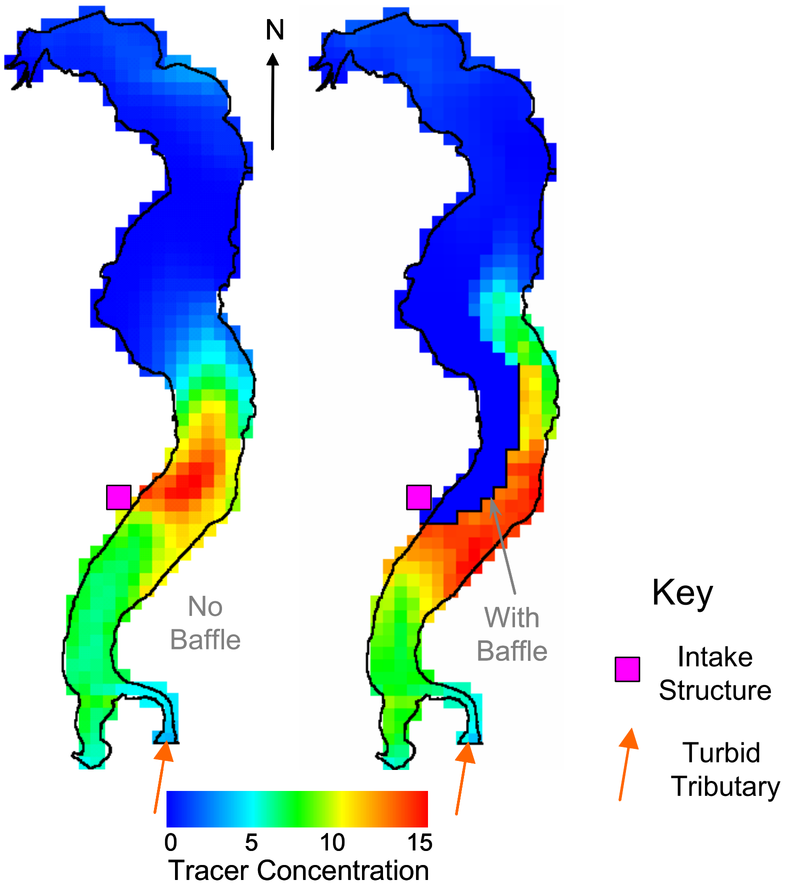


Figure 5.17 Three-dimensional model simulation of flow pattern of Schoharie Creek turbid inflow following a runoff event, without (left) and with (right) a baffle. This simulation was carried out with a conservative tracer and does not allow for settling of solids.

6. Further Research

6.1 How does DEP extend its capabilities for water quality monitoring and research?

DEP extends its capabilities through grants and contracts. To date, Safe Drinking Water Act (SDWA) grants (contracted to DEP through the New York State Department of Environmental Conservation (DEC)) have supported a number of DEP projects devoted to guiding watershed management. Up to the end of 2005 these grants have totalled approximately $4.1 million and it is hoped that additional SDWA funds will be earmarked for the NYC watershed for future work. It should be noted that this amount is less than the amount stipulated in last year's report because not all the funds allocated could be used within the timeframe of the grant. Such projects have typically allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. In addition, contracts are needed to support the work of DWQC.

6.2 What new DEP projects were supported in 2005 through SDWA grants?

DEP secured funding under a 4th SDWA grant to further several water quality research investigations. These research projects include:

Wetland Water Quality Functional Assessment

The objectives of this project are to characterize the water quality, vegetation, soils, and hydro-periods of wetlands among various landscape positions throughout the Catskill and Delaware watersheds.

Genotyping of *Cryptosporidium* Oocysts and Ribotyping of *Escherichia coli* isolates from Wildlife Fecal Samples within the New York City Watershed

The objectives of this study include: 1) the collection of fecal samples from wildlife in the New York City watershed, 2) the analysis of these samples for *Cryptosporidium* genotypes and *E. coli* ribotypes, and 3) the comparison of these data with those previously collected by DEP from the watershed, and with those in the Center for Disease Control and Prevention (CDC) database.

Survey of Residential Fertilization Practices in the Croton Watersheds

The objective of this study is to create, distribute, and analyze surveys of lawn fertilization practices among homeowners and professional landscapers with clients in the Croton watersheds so that we can assess whether these practices are likely to be an important non-point source of total phosphorus in urban and suburban areas.

Croton System Reservoir Model Development

This project continues the phased development and testing of reservoir models for the East-of-Hudson (EOH) reservoir system. These models are to serve as in-house management tools for the New York City Department of Environmental Protection (NYCDEP), and will contribute to the effective management of this reservoir system. In this project, hydrothermal models will be completed, providing a hydrodynamic framework upon which future water quality models can be built.

New Croton Sediment – Nutrient Sub-model

The objective of this project is to develop a new modeling algorithm (sub-model), which predicts sediment-water exchange of phosphorus in response to redox conditions and depositional inputs of decomposable organic material. This work is being undertaken since it is recognized that internal sediment derived phosphorus loading is a factor that plays an important role in regulating reservoir nutrient availability in the EOH reservoirs, and is a process that was not explicitly accounted for in the present generation of WOH water quality models.

6.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 6.1. The primary types of contracts are: i) Operation and Maintenance, ii) Monitoring, and iii) Research and Development. The Operations and Maintenance contracts are typically renewed each year because they are devoted to supporting the ongoing activities of the Laboratory and Field Operations. The Monitoring contracts are devoted to handling some of the laboratory analyses that must be done to keep up-to-date on the status of the water supply. Research and Development contracts typically answer questions that allow DEP to implement effective watershed management and plan for the future.

Table 6.1: DEP contracts related to water quality monitoring and research

Contract Description	Contract Term
Operation and Maintenance	
Operation and Maintenance of DEP's Hydrological Monitoring Network (Stream Flow)	10/1/03–9/30/06
Operation and Maintenance of DEP's Hydrological Monitoring Network (Water Quality)	10/1/03–9/30/06
Waterfowl Management at Kensico Reservoir	10/1/03–9/30/06
SAS software contract	6/24/03–6/30/08
Monitoring	

Table 6.1: DEP contracts related to water quality monitoring and research

Contract Description	**Contract Term**
Monitoring of NYC reservoirs for viruses	1/30/04–1/28/07
Monitoring of NYC's reservoirs for zebra mussels	7/1/05–6/30/07
Monitoring of NYC residences for lead and copper	1/1/06–12/31/06
Organic Analysis Laboratory Contract	3/1/04–2/28/07
Bulk Chemical Analysis	8/1/05-7/31/08
Analysis of Stormwater at Beerston Cannonsville watershed	11/1/05–10/31/07
Research and Development	
Design of Controls for Zebra Mussels in NYC's Water Supply System	1/5/94–12/31/06
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–11/25/06
Croton System Model Development and Protech (partially funded by SDWA grant and partially funded by DEP)	11/15/05-11/14/08

References

Carlson, R. E. 1977. “A trophic state index for lakes.” Limnol. Oceanogr. 22: 361-369.

Carlson, R. E. 1979. A review of the philosophy and construction of trophic state indices. Lake and reservoir classification systems. T. Maloney, USEPA. Ecol. Res. Serv.: 1-52.

DEP, 1994. BMP Strategy to Reduce Turbidity and Status of Implementation: Progress Report – EPA Filtration Avoidance Deliverable Report. New York City Department of Environmental Protection, Valhalla, New York.

DEP, 2004. “Multi Tiered” Water Quality Modeling Program Semi-Annual Status Report – EPA Filtration Avoidance Deliverable Report. New York City Department of Environmental Protection, Valhalla, New York. July 2004.

DEP, 2005a. “Multi Tiered” Water Quality Modeling Program Semi-Annual Status Report – EPA Filtration Avoidance Deliverable Report. New York City Department of Environmental Protection, Valhalla, New York. July 2005.

DEP, 2005b. Photo-documentation of Esopus Creek turbidity following the April 3 2005 flood. Stream Management Program Report. New York City Department of Environmental Protection, Kingston, New York. April 2005.

DEP. 2006a. 2006 Watershed Protection Program: Summary and Assessment. Valhalla, NY, New York City Department of Environmental Protection.

DEP. 2006b. 2005 Research Objectives Report, Valhalla, NY, New York City Department of Environmental Protection.

DEP. 2006c. Nonpoint Management Plan for the East-of-Hudson Catskill/Delaware Water Supply System January 2006 Semiannual FAD report, Valhalla, NY, New York City Department of Environmental Protection.

DEP. 2006d, Cornell Cooperative Extension of Putnam County, and Cornell Cooperative Extension of Westchester County, Lawn Fertilization Practices on Private Property in the Croton System, Final Draft Report.

DEP, 2006e. “Multi Tiered” Water Quality Modeling Program Semi-Annual Status Report – EPA Filtration Avoidance Deliverable Report. New York City Department of Environmental Protection, Valhalla, New York. January 2006.

Health Canada, 2003. Aluminum and Human Health, at http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/aluminum-aluminium_e.html, Updated on 2003-06-20 and accessed on 2006-06-05.

NALMS, 2004. North American Lake Management Society: Position Statement 2 . Adopted by the NALMS Board of Directors on February 26, 2004.

Pierson, D.C., R. Gelda, M. Zion, and E. Schneiderman. 2005. Relative Importance of turbidity sources to the Ashokan Reservoir. Presentation to the 2005 New York City Watershed Science and Technical Conference, Fishkill, New York.

Schneiderman, E. M., D. C. Pierson, D. G. Lounsbury and M. S. Zion, 2002. Modeling of Hydrochemistry of the Cannonsville Watershed with Generalized Watershed Loading Functions (GWLF). *J. of the American Water Resources Association* 38(5): 1323-1347.

USEPA, 2001. Long Term 2 Enhanced Surface Water Treatment Rule & Stage 2 Disinfectants and Disinfection Byproducts Rule. <http://www.epa.gov/OGWDW/mdbp/mdbp.html>

UFI (Upstate Freshwater Institute) 2002. User's Manual: One- and Two-Dimensional Models for Six Catskill/Delaware Reservoirs. July 2002. NYCDEP. Valhalla N.Y.

Glossary

Alkalinity – The acid-neutralizing (or buffering) capacity of water.

Anthropogenic – Man-made.

Best management practice (BMP) – Physical, structural, and/or managerial practices that, when used singly or in combination, prevent or reduce pollution of water (i.e., extended detention basin).

Clarity (Visual) – The distance an underwater target can be seen. Measured horizontally with a black disk (cf. Secchi disk).

Coliforms – A group of bacteria used as an indicator of microbial contamination in water.

Conductivity – A measure of the ability of a solution to carry an electrical current.

***Cryptosporidium* –** A protozoan causing the disease cryptosporidiosis.

Cyst – the infectious stage of *Giardia*, and some other protozoan parasites, that has a protective wall which provides resistance to environmental stress.

Dissolved oxygen (DO) – The amount of oxygen dissolved in water expressed in parts per million (ppm) or milligrams per liter (mg L^{-1}) or percent saturation.

E. coli – A bacterial species inhabiting the intestinal tract of humans and other warm-blooded animals. Some *E. coli* can cause serious diseases.

Eutrophic – Water with elevated nutrient concentrations, elevated algal production, and often low in water clarity.

Eutrophication – Refers to the process where nutrient enrichment of water leads to excessive growth of aquatic plants, especially algae.

Fecal coliforms – A group of bacteria found in the intestinal tracts of people and warm-blooded animals. Their presence in water usually indicates pollution that may pose a health risk.

Giardia – A protozoan that causes the disease giardiasis.

Hydrology – The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.

Keypoint – A sampling location where water enters or leaves an aqueduct.

Limnology – The study of the physical, chemical, hydrological, and biological aspects of fresh waterbodies.

Macroinvertebrate – Organism that lacks a backbone and is large enough to be seen with the naked eye.

Mesotrophic – A waterbody intermediate in biological productivity between oligotrophic (low productivity) and eutrophic (high productivity) conditions.

Nitrate – A nutrient that is essential to plants and animals. Can cause algal blooms in water if all other nutrients are present in sufficient quantities.

Nitrogen – An element that is essential for plant and animal growth.

Nutrients – Substances necessary for the growth of all living things, such as nitrogen, carbon, potassium, and phosphorus. High concentrations of nutrients in waterbodies can contribute to algal blooms.

Oligotrophic – Water with low nutrient concentrations, low in algal production, and tending to have high water clarity.

Oocyst – A phase of the normal life cycle of an organism. It is characterized by a thick and environmentally resistant cell wall. *Cryptosporidium* are shed as oocysts.

Pathogen – A disease-producing agent, often a microorganism .

pH – A symbol for expressing the degree to which a solution is acidic or basic. It is based on a scale from roughly 0 (very acid) to roughly 14 (very basic). Pure water has a pH of 7 at 25°C.

Phosphates – Certain chemical compounds containing phosphorus. A plant nutrient.

Phosphorus – An essential chemical food element that can contribute to the eutrophication of lakes and other waterbodies. Increased phosphorus levels result from discharge of phosphorus-containing materials into surface waters.

Photic zone – Uppermost part in a body of water into which daylight penetrates in sufficient amounts to permit primary production.

Phytoplankton – Portion of the plankton community comprised of tiny plants, e.g., algae.

Protozoa – Mostly motile, single-celled organisms. Pathogenic intestinal protozoa can cause diarrhea or gastroenteritis of varying severity.

Runoff – Water from rain, snowmelt, or irrigation that flows over the ground and returns to streams. It can collect pollutants from air or land and carry them to streams and other waterbodies.

Secchi disk – A black-and-white disk used to measure the visual clarity of water. The disk is lowered into the water until it just disappears and then raised until it just reappears. The average of these two distances is the Secchi disk transparency (or depth).

SPDES – State Pollution Discharge Elimination System. The permitting program which regulates all discharges to surface water.

Source Waters – Kensico and New Croton are usually operated as source waters, but these reservoirs can be by-passed so that any or all of the following can be operated as source waters: Rondout, Ashokan East, Ashokan, and West Branch.

Trophic State – Refers to a level of biological productivity in a waterbody (i.e., eutrophic, mesotrophic, oligotrophic).

Turbidity – An arbitrary assessment of a water's cloudiness (actually, light side-scatter). For cloudy water, turbidity would be high; for clear water, turbidity would be low. It is inversely related to visual clarity.

Watershed – The area of land that drains into a specific waterbody.

Wetland – An area where water covers the soil or is present either at or near the surface of the soil all year (or at least for periods of time during the year).

Appendix A Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes.

Analyte		Kensico			New Croton			East Ashokan Basin			Rondout		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (C)		295	4.14 - 22.5	11.31	288	2.9 - 24.01	11.05	115	3.21 - 24.92	10.45	193	3.56 - 21.57	10.03
pH (units)	6.5-8.5[1]	251	5.63 - 7.55	6.96	249	6.7 - 8.7	7.5	103	5.79 - 7.92	7.05	193	4.57 - 8.75	6.57
Alkalinity (mg/l)		20	9.9 - 11.3	10.7	24	48.3 - 67.5	59.7	9	8.5 - 10.8	9.3	9	7.54 - 8.94	7.8
Conductivity		274	53 - 84	67	270	282 - 403	374	110	47.6 - 57.5	51	193	37.5 - 59.8	51.9
Hardness (mg/l)		0	–		0	–		9	14 - 16.99	15.21	9	15.15 - 18.46	15.79
Color (Pt-Co units)	(15)	283	5 - 15	10	288	10 - 40	20	106	6 - 23	12	197	7 - 19	14
Tubidity (NTU)	(5) [2]	293	0.5 - 2.4	1.1	288	0.6 - 4.5	2	116	1.1 - 50	6.1	197	0.6 - 8.4	1.4
Secchi Disk Depth (m)		91	2 - 6.2	4.8	99	1.5 - 3.5	2.7	30	0.05 - 4.2	2	56	1 - 5.8	4.55
BIOLOGICAL													
Chlorophyll a (µg/l)	7 [3]	30	0.005 - 3	1.2	32	0.05 - 10.9	4.85	17	2.17 - 5.79	3.72	22	3 - 8.4	4.65
Total Phytoplankton (SAU)	2000 [3]	124	10 - 880	295	125	30 - 1300	480	78	5 - 430	115	119	2.5 - 800	110
CHEMICAL													
Dissolved Organic Carbon (mg/l)		172	1.1 - 1.9	1.5	106	2.1 - 3.7	2.85	46	1.4 - 1.9	1.6	108	1.1 - 2.18	1.515
Total Phosphorus (µg/l)	15 [3]	171	5 - 13	9	69	9 - 33	20	86	2.5 - 30	12	157	1.5 - 22.2	8.2
Total Nitrogen (mg/l)		167	0.15 - 0.39	0.3	107	0.02 - 0.76	0.48	48	0.14 - 0.38	0.29	77	0.187 - 0.439	0.333
Nitrate+Nitrite-N (mg/l)	10 [1]	172	0.046 - 0.313	0.216	107	0.005 - 0.586	0.234	48	0.006 - 0.291	0.212	109	0.063 - 0.371	0.254
Total Ammonia-N (mg/l)	2 [1]	172	0.005 - 0.039	0.015	106	0.005 - 0.208	0.022	48	0.01 - 0.04	0.02	109	0.003 - 0.015	0.003
Iron (mg/l)	0.3 [1]	4	0.02 - 0.09	0.04	30	0.02 - 0.26	0.055	8	0.03 - 2.33	0.245	8	0.01 - 2.11	0.1
Manganese (mg/l)	(0.05)	4	0.008 - 0.029	0.0125	30	0.013 - 0.304	0.0325	8	0.005 - 0.053	0.018	8	0.013 - 0.145	0.0305
Lead (µg/l)	50 [1]	4	0.5 - 0.5	0.5	30	0.5 - 0.5	0.5	8	0.5 - 1.5	0.5	8	0.5 - 3.1	0.5
Copper (µg/l)	200 [1]	4	1.5 - 1.5	1.5	30	1.5 - 1.5	1.5	8	1.5 - 1.5	1.5	8	1.5 - 3.5	1.5
Calcium (mg/l)		0	–		0	–		9	4.32 - 5.37	4.77	9	4.39 - 5.3	4.48
Sodium (mg/l)		0	–		0	–		9	2.64 - 3.18	3.04	9	3.36 - 4.29	3.63
Chloride (mg/l)	250 [1]	18	0.33 - 9.1	7.45	27	12.9 - 76.5	69.9	48	4.9 - 5.7	5.3	9	4.65 - 7.05	5.61

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes.

Analyte		Amawalk			Bog Brook			Boyd Corners			Croton Falls		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (C)		25	5.4 - 23.8	12.3	20	8.08 - 26.55	15.445	20	8.58 - 20.85	10.63	16	4.15 - 12.72	8.985
pH (units)	6.5-8.5[1]	25	7.26 - 8.9	7.7	12	7.4 - 9.02	8.35	20	7.1 - 8.2	7.31	16	7.07 - 8.37	7.73
Alkalinity (mg/l)		5	65.9 - 71.8	71.1	4	58.6 - 62.7	60.9	0	–		0	–	
Conductivity		25	387 - 465	440	20	261 - 311	295.5	14	196 - 223	201	16	316 - 441	364.5
Hardness (mg/l)		0	–		0	–		0	–		0	–	
Color (Pt-Co units)	(15)	30	12 - 45	25	19	8 - 45	18	22	18 - 45	25	16	20 - 30	20
Tubidity (NTU)	(5)[2]	30	1.4 - 3.6	2.3	19	0.7 - 3.4	1.6	22	1.1 - 2.1	1.65	16	1.5 - 4.9	2.4
Secchi Disk Depth (m)		10	2.1 - 3.8	2.8	9	2.5 - 6.1	4.5	9	2.7 - 3.8	3.7	6	1.8 - 3.4	2.85
BIOLOGICAL													
Chlorophyll a (µg/l)	7[3]	7	2.6 - 15.8	9.4	3	0.05 - 4.7	4.5	6	0.4 - 2.4	1.5	0	–	
Total Phytoplankton (SAU)	2000[3]	7	140 - 1100	410	6	20 - 1100	405	8	95 - 2400	515	4	420 - 880	810
CHEMICAL													
Dissolved Organic Carbon (mg/l)		29	2.9 - 5	3.9	19	2.6 - 5.7	3.1	22	2.1 - 5.1	3.1	15	2 - 3.4	2.3
Total Phosphorus (µg/l)	15[3]	30	13 - 63	24.5	19	6 - 49	17	22	10 - 26	17.5	16	15 - 48	20.5
Total Nitrogen (mg/l)		29	0.2 - 0.7836	0.37	15	0.2 - 0.38	0.24	22	0.1 - 0.29	0.225	16	0.36 - 0.72	0.46
Nitrate+Nitrite-N (mg/l)	10[1]	30	0.005 - 0.393	0.088	19	0.005 - 0.132	0.024	22	0.005 - 0.153	0.005	16	0.268 - 0.625	0.3695
Total Ammonia-N (mg/l)	2[1]	30	0.005 - 0.471	0.021	19	0.005 - 0.051	0.013	18	0.005 - 0.019	0.005	2	0.021 - 0.022	0.0215
Iron (mg/l)	0.3[1]	3	0.05 - 0.08	0.05	3	0.02 - 0.11	0.04	2	0.05 - 0.11	0.08	1	0.05 - 0.05	0.05
Manganese (mg/l)	(0.05)	3	0.025 - 0.044	0.025	3	0.006 - 0.059	0.007	2	0.019 - 0.035	0.027	1	0.024 - 0.024	0.024
Lead (µg/l)	50[1]	3	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	1	0.5 - 0.5	0.5
Copper (µg/l)	200[1]	3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5	2	1.5 - 1.5	1.5	1	1.5 - 1.5	1.5
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		0	–	
Chloride (mg/l)	250[1]	6	77.8 - 86.8	84.2	5	5 - 48.1	48	1	29.7 - 29.7	29.7	0	–	

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes. .

Analyte		Cross River			Diverting			East Branch			Lake Gilead		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	
PHYSICAL													
Temperature (C)		30	4.6 - 26.48	9.41	5	14.27 - 15.21	14.71	29	3.99 - 26.41	14.69	20	3.68 - 25.175	4.79
pH (units)	6.5-8.5[1]	30	6.46 - 8.8	7.2	0	–		19	7.09 - 9	7.57	20	6.54 - 8.54	7.235
Alkalinity (mg/l)		9	41 - 52.7	44.3	0	–		9	63.7 - 91.9	76.5	5	39.3 - 62.2	41.3
Conductivity		30	212 - 260	236.5	5	297 - 334	327	29	196 - 362	323	20	178 - 213	189
Hardness (mg/l)		0	–		0	–		0	–		0	–	
Color (Pt-Co units)	(15)	35	10 - 70	25	5	50 - 60	55	29	20 - 60	25	8	8 - 15	11
Tubidity (NTU)	(5)[2]	35	1.1 - 14	2	5	3.5 - 4.2	3.8	29	0.9 - 7.2	2.2	8	0.5 - 3.9	1.3
Secchi Disk Depth (m)		12	2.6 - 4.8	2.95	2	1.8 - 2.1	1.95	10	1.5 - 4.8	2.35	3	4.6 - 6.2	4.6
BIOLOGICAL													
Chlorophyll a (µg/l)	7[3]	9	0.4 - 5.2	2.2	0	–		4	0.05 - 24.5	1.75	2	1.4 - 1.4	1.4
Total Phytoplankton (SAU)	2000[3]	8	95 - 690	325	1	270 - 270	270	8	170 - 2900	705	3	140 - 480	250
CHEMICAL													
Dissolved Organic Carbon (mg/l)		34	2.6 - 3.6	3.1	5	5.2 - 6.1	5.3	28	3.1 - 6.1	4.3	9	2.5 - 2.9	2.8
Total Phosphorus (µg/l)	15[3]	35	5 - 57	19	5	46 - 58	51	29	16 - 51	24	9	11 - 338	22
Total Nitrogen (mg/l)		35	0.02 - 0.8	0.26	5	0.58 - 0.63	0.61	24	0.25 - 0.49	0.32	9	0.2 - 0.94	0.24
Nitrate+Nitrite-N (mg/l)	10[1]	35	0.005 - 0.37	0.026	5	0.24 - 0.321	0.27	29	0.005 - 0.121	0.005	9	0.005 - 0.096	0.005
Total Ammonia-N (mg/l)	2[1]	35	0.005 - 0.473	0.017	5	0.044 - 0.089	0.084	29	0.005 - 0.254	0.028	9	0.005 - 0.86	0.005
Iron (mg/l)	0.3[1]	4	0.04 - 0.16	0.055	0	–		3	0.06 - 0.56	0.08	2	0.02 - 0.13	0.075
Manganese (mg/l)	(0.05)	4	0.008 - 0.099	0.014	0	–		3	0.008 - 0.084	0.01	3	0.011 - 0.411	0.011
Lead (µg/l)	50[1]	4	0.5 - 0.5	0.5	0	–		3	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5
Copper (µg/l)	200[1]	4	1.5 - 1.5	1.5	0	–		3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		0	–	
Chloride (mg/l)	250[1]	9	35.7 - 40.6	39.2	0	–		9	35.8 - 50.7	46.9	6	26.4 - 28.8	27.95

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes.

Analyte		Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (C)		15	3.79 - 25.56	5.78	10	19.3 - 25.14	20.45	35	4.65 - 22.27	11.77	40	6.03 - 26.785	12.16
pH (units)	6.5-8.5[1]	15	6.94 - 8.74	7.35	10	7.04 - 8.9	7.45	35	6.86 - 8.23	7.58	40	6.9 - 9.095	7.46
Alkalinity (mg/l)		6	63 - 75.7	64.55	2	53 - 58.9	55.95	3	49.8 - 58.3	54.7	5	49 - 67.7	54.4
Conductivity		15	190 - 400	360	10	315 - 321	315.5	35	289 - 475	355	40	401 - 520	481
Hardness (mg/l)		0	–		0	–		0	–		0	–	
Color (Pt-Co units)	(15)	6	8 - 15	10	2	25 - 40	32.5	35	20 - 35	30	40	10 - 95	25
Tubidity (NTU)	(5)[2]	6	0.6 - 5	1.3	2	4.5 - 11	7.75	35	1.7 - 3.5	2.3	40	1.1 - 15.5	2.65
Secchi Disk Depth (m)		3	5 - 6.5	6.2	6	1.9 - 2	1.95	20	1.7 - 3.9	2.75	14	2 - 4	2.9
BIOLOGICAL													
Chlorophyll a (µg/l)	7[3]	1	0.05 - 0.05	0.05	1	15.8 - 15.8	15.8	12	1.3 - 11.1	4.55	7	3.3 - 45.1	5.9
Total Phytoplankton (SAU)	2000[3]	2	60 - 400	230	1	1100 - 1100	1100	18	190 - 2600	620	12	190 - 1500	370
CHEMICAL													
Dissolved Organic Carbon (mg/l)		6	2.5 - 2.9	2.65	2	3.4 - 4	3.7	27	2.4 - 3.9	3.2	38	2.3 - 4.2	3
Total Phosphorus (µg/l)	15[3]	6	9 - 287	16	2	26 - 76	51	35	18 - 44	23	39	15 - 203	26
Total Nitrogen (mg/l)		6	0.2 - 0.86	0.235	2	0.25 - 0.43	0.34	27	0.2 - 1.04	0.44	37	0.17 - 1.03	0.43
Nitrate+Nitrite-N (mg/l)	10[1]	6	0.005 - 0.005	0.005	2	0.005 - 0.005	0.005	35	0.019 - 0.741	0.281	39	0.005 - 0.389	0.074
Total Ammonia-N (mg/l)	2[1]	6	0.005 - 0.759	0.005	2	0.005 - 0.237	0.121	35	0.005 - 0.351	0.029	39	0.005 - 0.982	0.016
Iron (mg/l)	0.3[1]	2	0.02 - 0.32	0.17	2	0.05 - 0.06	0.055	3	0.06 - 0.34	0.14	3	0.07 - 3.13	0.08
Manganese (mg/l)	(0.05)	3	0.007 - 2.07	0.008	3	0.015 - 0.019	0.017	3	0.014 - 0.236	0.072	3	0.018 - 1.3	0.041
Lead (µg/l)	50[1]	3	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5
Copper (µg/l)	200[1]	3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		0	–	
Chloride (mg/l)	250[1]	6	70.6 - 75.8	71.9	2	64.3 - 64.8	64.55	4	56.1 - 81.3	68.4	8	50.5 - 119.8	101.365

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes.

Analyte		Titicus			West Branch			West Ashokan Basin			Pepacton		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (C)		30	5 - 26.92	12.85	120	3.87 - 19.6	12.165	188	1.37 - 22.92	9.63	242	2.73 - 25.19	7.36
pH (units)	6.5-8.5[1]	30	7 - 8.9	7.685	102	6.28 - 7.59	7.105	169	5.82 - 7.59	6.92	242	5.93 - 8.69	6.645
Alkalinity (mg/l)		9	62.2 - 75.1	65.7	8	8.5 - 23.8	15.8	12	6.3 - 11.8	8.55	21	9.62 - 14.1	11
Conductivity		30	253 - 305	276.5	97	52 - 150	69	179	40 - 74.4	49.3	223	39.9 - 66.9	54.5
Hardness (mg/l)		0	–		0	–		12	11.63 - 17.45	15.015	21	18.71 - 24.26	20.34
Color (Pt-Co units)	(15)	34	2.2 - 50	22.5	118	10 - 30	15	55	8 - 27	14	220	6 - 18	13
Tubidity (NTU)	(5)[2]	34	1.2 - 4.7	2.65	118	0.6 - 5	1.6	197	1.4 - 390	50	248	0.5 - 7.9	1.9
Secchi Disk Depth (m)		12	2.1 - 3.6	2.8	53	1.2 - 5.4	3.7	45	0.075 - 3.5	1	80	0.9 - 6.05	3.8
BIOLOGICAL													
Chlorophyll a (µg/l)	7[3]	10	2 - 11.6	4	16	0.005 - 4.6	0.24	18	0.78 - 7.88	3.12	29	2.3 - 7.5	4.6
Total Phytoplankton (SAU)	2000[3]	7	55 - 1200	150	63	45 - 760	370	99	2.5 - 610	42	92	2.5 - 870	155
CHEMICAL													
Dissolved Organic Carbon (mg/l)		28	2.4 - 3.7	3.2	64	1.3 - 3	1.7	80	1.4 - 2.15	1.7	117	1.01 - 1.67	1.38
Total Phosphorus (µg/l)	15[3]	29	13 - 69	25	66	7 - 44	14	149	6 - 158	28	261	1.5 - 21.6	10.4
Total Nitrogen (mg/l)		26	0.14 - 0.58	0.27	60	0.02 - 0.395	0.3	80	0.15 - 0.54	0.46	117	0.121 - 0.405	0.276
Nitrate+Nitrite-N (mg/l)	10[1]	29	0.005 - 0.379	0.01	66	0.005 - 0.268	0.2125	80	0.041 - 0.441	0.3715	117	0.011 - 0.336	0.176
Total Ammonia-N (mg/l)	2[1]	29	0.005 - 0.318	0.015	60	0.005 - 0.0295	0.0075	80	0.01 - 0.035	0.02	117	0.003 - 0.022	0.003
Iron (mg/l)	0.3[1]	3	0.03 - 0.08	0.07	2	0.03 - 0.06	0.045	8	0.05 - 21.1	7.38	8	0.01 - 1.17	0.07
Manganese (mg/l)	(0.05)	3	0.012 - 0.051	0.023	2	0.015 - 0.047	0.031	8	0.009 - 0.394	0.135	8	0.01 - 0.101	0.036
Lead (µg/l)	50[1]	3	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	8	0.5 - 11.1	3.9	8	0.5 - 0.5	0.5
Copper (µg/l)	200[1]	3	1.5 - 1.5	1.5	2	1.5 - 1.5	1.5	8	1.5 - 16.1	4.5	8	1.5 - 1.5	1.5
Calcium (mg/l)		0	–		0	–		12	3.57 - 5.57	4.72	21	5.4 - 7.26	5.92
Sodium (mg/l)		0	–		0	–		12	2.18 - 3.31	2.61	21	3.46 - 4.69	3.78
Chloride (mg/l)	250[1]	7	9.2 - 39.8	37.8	15	0.38 - 47.8	7.9	70	3.9 - 6.8	5.3	18	4.94 - 6.12	5.73

Appendix Table 1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes.

Analyte		Neversink			Schoharie			Cannonsville		
	WQS	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL										
Temperature (C)		183	3.13 - 23.63	7.98	169	3.34 - 24.76	7.61	204	3.94 - 25.35	12.615
pH (units)	6.5-8.5[1]	183	5.17 - 6.93	5.83	139	6.41 - 7.46	6.98	186	5.5 - 9.6	6.755
Alkalinity (mg/l)		9	1.84 - 3.42	2.3	9	8.1 - 18.9	9.8	26	11 - 19.3	15
Conductivity		183	22.2 - 29.1	26	169	45 - 100	62	203	64.9 - 107.2	81.5
Hardness (mg/l)		9	8.1 - 8.98	8.31	9	12.74 - 25.69	16.76	26	21.66 - 29.14	25.75
Color (Pt-Co units)	(15)	175	6 - 27	16	60	9 - 34	17	171	10 - 24	17
Tubidity (NTU)	(5)[2]	183	0.7 - 14	2.1	172	1.3 - 260	17.5	189	0.8 - 12	3
Secchi Disk Depth (m)		59	0.9 - 5.8	3.5	43	0.1 - 4.3	1.4	71	0.3 - 6.1	2.6
BIOLOGICAL										
Chlorophyll a (µg/l)	7[3]	30	1.8 - 8	4.55	30	0.26 - 5.98	2.985	30	2 - 29.7	6.45
Total Phytoplankton (SAU)	2000[3]	87	2.5 - 1300	160	63	2.5 - 290	36	86	2.5 - 3000	160
CHEMICAL										
Dissolved Organic Carbon (mg/l)		114	1.2 - 2.82	1.605	95	1.7 - 3.3	2.4	115	1.26 - 5.74	1.58
Total Phosphorus (µg/l)	15[3]	173	1.5 - 20.2	8	142	7 - 95	20	169	6.8 - 47.6	20.8
Total Nitrogen (mg/l)		93	0.164 - 0.42	0.323	80	0.13 - 0.515	0.36	115	0.163 - 0.63	0.482
Nitrate+Nitrite-N (mg/l)	10[1]	114	0.052 - 0.36	0.2465	95	0.006 - 0.381	0.221	115	0.011 - 0.577	0.356
Total Ammonia-N (mg/l)	2[1]	111	0.003 - 0.053	0.009	95	0.01 - 0.05	0.02	115	0.003 - 0.086	0.014
Iron (mg/l)	0.3[1]	8	0.05 - 0.97	0.165	4	0.07 - 24.2	1.96	8	0.02 - 0.4	0.08
Manganese (mg/l)	(0.05)	8	0.023 - 0.089	0.048	4	0.021 - 0.615	0.228	8	0.009 - 0.222	0.0435
Lead (µg/l)	50[1]	8	0.5 - 0.5	0.5	4	0.5 - 11.4	1.35	8	0.5 - 0.5	0.5
Copper (µg/l)	200[1]	8	1.5 - 1.5	1.5	4	1.5 - 12.1	3.75	8	1.5 - 1.5	1.5
Calcium (mg/l)		9	2.27 - 2.54	2.32	9	4.21 - 8.11	5.31	26	5.92 - 8.29	7.255
Sodium (mg/l)		9	1.44 - 1.86	1.66	9	2.31 - 5.61	3.65	26	5.65 - 7.51	6.885
Chloride (mg/l)	250[1]	6	2.14 - 2.87	2.41	92	4.2 - 10.5	6.5	26	5.24 - 11.4	10.165

Notes for Appendix A:

Sites: For most parameters, the data for each reservoir represent a statistical summary of all samples taken at the sites listed in the Section 3.3, Reservoir Status, of the Integrated Monitoring Report (DEP 2003). Chlorophyll *a* statistics were calculated from photic zone samples only. Secchi disk depth statistics were calculated from all reservoir sites.

Water Quality Standards:
1 Numeric water quality standards, from 6NYCRR, Part 703.
2 Narrative water quality standards.
3 NYCDEP target values are listed for chlorophyll *a,* total phosphorus and total phytoplankton. The total phosphorus target value of 15 $\mu g\ L^{-1}$ applies to source water reservoirs only and has been adopted by NYSDEC in the TMDL Program.
( ) The turbidity, color and manganese standards in parentheses are only applicable to keypoint and treated water, respectively, but are supplied to provide context for the reservoir data.

Abbreviations:
N = number of samples,
Range = minimum to 95%-ile (to avoid the occasional outlier in the dataset),
SAU = standard areal units

Detection Limits: Values less than the detection limit have been converted to half the detection limit for all calculations. Analytical detection limits vary by analyte and laboratory.

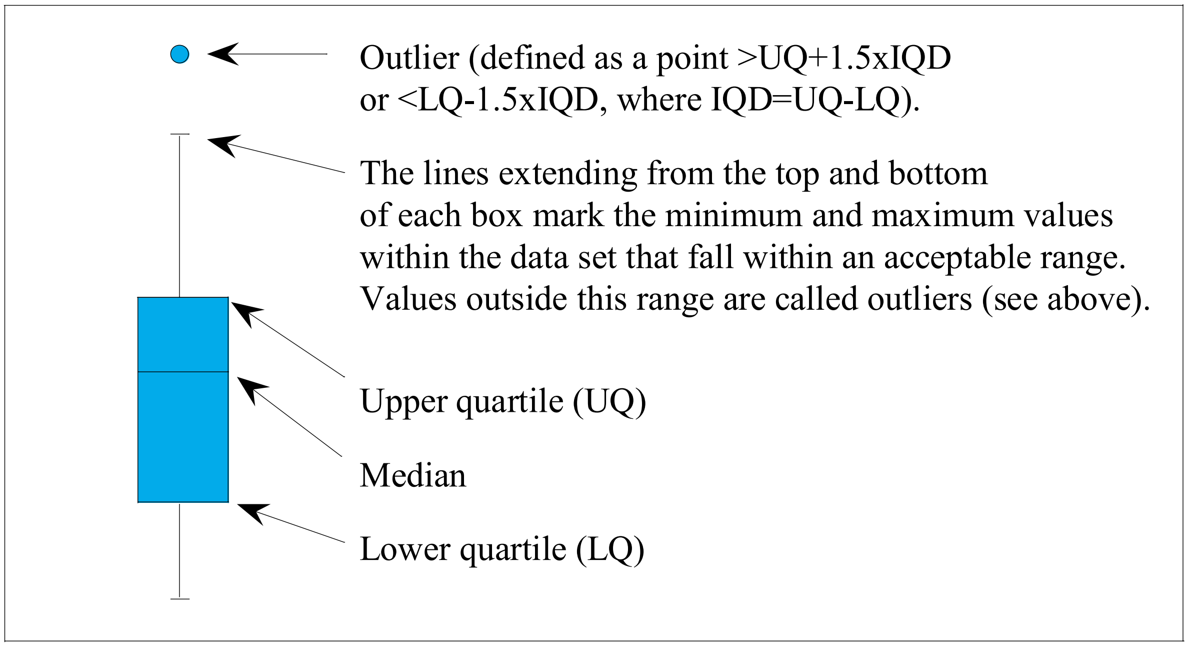
Methods:
All 2005 EOH water quality data are considered provisional at this time. Some reservoirs had fewer samples due to limited access from dam rehabilitation and other work. The criterion for including the 2005 EOH reservoir water quality data in the plots was a minimum of 50% of the scheduled limnological surveys had to be completed for the year.
Calcium and sodium were not analyzed at EOH during 2005. Hardness (derived from Ca and Mg), therefore, could not be calculated for these reservoirs.
Chlorophyll *a* measurements are made during the summer growing period (May – October); however, EOH chlorophyll data were under review at the time of writing this report.
Chlorophyll *a* results were obtained through use of spectrophotometer or fluorometer method from 1991-2000, and by HPLC 2001-2005.
TP results were obtained by Valderamma method (1980) from 1991- 1999, and by APHA (1992, 1998) from 2000-2005.
Secchi transparency results were obtained on the shady side of the boat using the naked eye from 1991-1998, and by use of a viewer box on the sunny side of the boat 1999-2005, which produced slightly higher results (Smith and Hoover, 1999; Smith, 2001).

References:

Smith, D.G. 2001. A protocol for standardizing Secchi disk measurements, including use of a viewer box. Journal of Lake and Reservoir Management 17: 90–96. (By invitation)

Smith, D.G., Hoover, C.M. 1999. Use of a viewer box in Secchi disk measurements. Journal of the American Water Resources Association 35:1183-1190.

Appendix B Key to Box Plots



Outlier (defined as a point >UQ+1.5xIQD or <LQ-1.5xIQD, where IQD=UQ-LQ).

The lines extending from the top and bottom of each box mark the minimum and maximum values within the data set that fall within an acceptable range. Values outside this range are called outliers (see above).

Upper quartile (UQ)

Median

Lower quartile (LQ)

Appendix C Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Regulations as "the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D." The designation of a reservoir basin as phosphorus-restricted has two primary effects, 1) new or expanded wastewater treatment plants with surface discharges are prohibited in the reservoir basin, and 2) stormwater pollution prevention plans required by the Watershed Regulations must include an analysis of phosphorus runoff, before and after the land disturbance activity, and must be designed to treat the 2-year, 24-hour storm. A summary of the methodology used in the phosphorus-restricted analysis will be given here, the complete description can be found in (DEP 1997).

The list of phosphorus-restricted basins is updated annually. The data utilized in the analysis is from the routine limnological monitoring of the reservoirs. All reservoir samples taken during the growing season, which is defined as May 1 through October 31, are used. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit. The detection limit for DEP measurements of total phosphorus is assessed each year by the DEP laboratories, and typically ranges between 2 – 5 µg L^{-1}. Phosphorus concentration data for the reservoirs approaches a lognormal distribution, therefore the geometric mean is used to characterize the annual phosphorus concentrations.

The five most recent annual geometric means are averaged arithmetically, and this average constitutes one assessment. The "running average" method weights each year equally thus reducing the effects of unusual hydrology or phosphorus loading for any given year, while maintaining an accurate assessment of the current conditions in the reservoir. If any reservoir has less than three surveys during a growing season, then that annual average may or may not be representative of the reservoir, and the data for the under-sampled year is removed from the analysis. In addition, each five year assessment must incorporate at least three years of data.

To provide some statistical assurance that the five year arithmetic mean is representative of a basin's phosphorus status, given the interannual variability, the five year mean plus the standard error of the five year mean is compared to the NYS guidance value of 20 µg L^{-1}. A basin is **unrestricted** if the five year mean plus standard error is below the guidance value of 20 µg L^{-1}, and phosphorus **restricted** if it is equal to or greater than 20 µg L^{-1}, unless the Department, using its best professional judgment, determines that the phosphorus-restricted designation is due to an unusual and unpredictable event unlikely to occur in the future. A reservoir basin designation, as phosphorus-restricted or unrestricted, may change through time based on the outcome of this annual assessment. However, a basin must have two consecutive assessments (i.e., two years in a row) that result in the new designation in order to officially change the designation.

Appendix Table 1: Geometric mean total phosphorus data utilized in the phosphorus-restricted assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit.

Reservoir Basin	2000 µg L^{-1}	2001 µg L^{-1}	2002 µg L^{-1}	2003 µg L^{-1}	2004 µg L^{-1}	2005 µg L^{-1}
Delaware District						
Cannonsville Reservoir	17.2	19.3	17.9	15.4	15.1	19.6
Pepacton Reservoir	8.1	8.6	10.4	9.1	9.2	8.7
Neversink Reservoir	5.3	5.8	4.7	5.2	5.0	7.3
Rondout Reservoir	9.2	7.4	8.8	6.8	8.6	7.8
Catskill District						
Schoharie Reservoir	21.3	15.2	11.7	7.5	13.3	20.6
Ashokan-West Reservoir	9.6	9.2	9.6	6.1	9.3	26
Ashokan-East Reservoir	10.8	7.9	12.4	7.0	10	11.0
Croton District						
Amawalk Reservoir	38.6	19.8	22.2	19.6	26.5	24.0
Bog Brook Reservoir	34.7	21.4	*	16.9	26.8	18.6
Boyd Corners Reservoir	16.0	13.6	15.9	12.4	13.8	*
Cross River Reservoir	17.2	14.8	20.3	17.9	20.2	18.7
Croton Falls Reservoir	26.1	22.3	24.1	20.4	18.1	*
Diverting Reservoir	30.0	31.8	41.7	28.8	28.3	*
East Branch Reservoir	39.0	33.3	*	26.5	44.2	28.3
Middle Branch Reservoir	32.4	27.7	31.2	23.7	*	31.5
Muscoot Reservoir	35.0	29.7	33.9	29.5	26.0	26.8
Titicus Reservoir	33.6	28.7	27.3	27.3	25.4	24.6
West Branch Reservoir	13.3	11.2	12.1	10.2	11.5	14.8
Lake Gleneida	30.4	31.6	*	22.8	*	*
Lake Gilead	34.9	38.4	*	28.5	21.8	*
Kirk Lake	*	*	*	30.8	*	*
Source Water						
Kensico Reservoir	9.1	8.5	8.4	7.6	8.8	9.7
New Croton Reservoir	22.7	21.9	25.0	19.5	22.4	18.2

* indicates less than three successful surveys during the growing season (May–October).

Reference

DEP, 1997. Methodology for Determining Phosphorus-Restricted Basins. New York City Department of Environmental Protection, Valhalla, NY.