New York City
Department of Environmental Protection

2003 Watershed Water Quality Annual Report

Prepared by the Division of Drinking Water Quality Control

July 2004

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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 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.

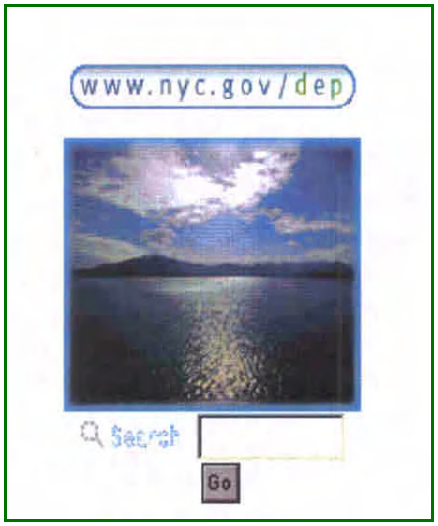
General guidance in the activities of the Division was provided by Dr. Michael Principe, Deputy Commissioner of the Bureau of Water Supply, Mr. Steven Schindler, Director of DWQC, and Dr. Lorraine Janus, Chief of Watershed Operations. Ms. Lori Emery and Mr. Andrew Bader were responsible for management 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, and Mr. Martin Rosenfeld, who expertly added a degree of editorial precision to the text.

Leading roles in authorship and editing were taken by Ms. Lori Emery, Mr. Andrew Bader, Mr. James Mayfield, Mr. Gerard Marzec, Mr. Charles Olson, Dr. Yves Mikol, Ms. Kerri Alderisio, Dr. Elliot Schneiderman, and Dr. Donald Pierson. Special mention of sub-section authors goes to Ms. Salome Freud, Mr. Christopher Nadareski, Mr. Richard Corradi, Mr. Richard Van Dreason, Mr. Bryce McCann, Ms. Kim Nezelek, Mr. Mark Zion, and Mr. Gerald Pratt.

1. Introduction

1.1 What is the purpose and scope of this report?



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 2003, 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 DEP's efforts 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.

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 14 separate Divisions (Figure1.1), which perform various functions to meet the Bureau's mission. Several of these Divisions are relatively new, added near or after the close of the reporting period, and serve to improve Bureau efficiency and effectiveness. Each of the 14 BWS Divisions and their functions are described below.

Operations – East- of-Hudson and West-of-Hudson (Two Separate Divisions)

- Operates and maintains the City's reservoirs, tunnels, aqueducts, shafts, chambers, and other facilities.
- Responsible for delivery of sufficient high quality water to the City and outside communities.
- Responsible for the operation and maintenance of approximately 175 facilities, 19 reservoirs, 4 treatment facilities, approximately 70 miles of roads, bridges, and 8 Wastewater Treatment Plants (WWTPs) and sewer collection systems.

BUREAU OF WATER SUPPLY

- OPERATIONS EAST-OF-HUDSON
- OPERATIONS WEST-OF-HUDSON
- DRINKING WATER QUALITY CONTROL
- ENGINEERING
- SEQRA COORDINATION & WATERSHED MANAGEMENT PROGRAMS
- WASTEWATER TREATMENT PLANT UPGRADE PROGRAM
- CAPITAL CONSTRUCTION & COMMUNITY SUPPLIES
- INFRASTRUCTURE DESIGN & CONSTRUCTION
- WATER SYSTEMS PLANNING
- WATERSHED LANDS & COMMUNITY PLANNING
- DEP ENVIRONMENTAL POLICE
- REGULATORY COMPLIANCE & FACILITIES REMEDIATION
- MANAGEMENT INFORMATION SYSTEMS
- MANAGEMENT SERVICES & BUDGET

Figure 1.1 The 14 separate Divisions of the Bureau of Water Supply.

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.
- Inspects all wastewater treatment plants in the watershed to ensure proper operation.
- Provides engineering support to other BWS units, including WWTP Upgrade Program.

State Environmental Quality Review Act (SEQRA) Coordination and Watershed Management Programs (New Program)

- Manages BWS process for participation in analyses of identification and mitigation of significant environmental impacts, alternatives, segmentation, and other issues pursuant to the SEQRA.
- Directs programs to control non–point sources of pollution in East-of-Hudson watershed.
- 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.

Wastewater Treatment Plant Upgrade Program (New 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.

Capital Construction and Community Supplies (New Program)

- Facilitates coordination of planning, design, and construction of major capital projects between DEP Bureau of Environmental Engineering and BWS.
- Oversees design and operation of connections to DEP infrastructure, negotiates terms of Water Supply Agreements and Excess Water Permits for community water supplies.

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 Environmental Engineering.
- 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

- Develops plans for security enhancement of water supply system infrastructure and response capability in coordination with DEP Police.
- Performs long–term planning and budget analysis for water supply system dependability in coordination with other Bureaus.
- Performs water resource management activities including the monitoring of storage, consumption, diversions, releases, and hydrologic conditions to optimize storage.

Watershed Lands and Community Planning

- Assists in community planning through the Catskill Watershed Corporation (CWC), New Infrastructure, Sewer Extensions, Westchester/Putnam Counties.
- 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, state/real estate services.
- Manages land to ensure appropriate public access and recreation, forestry activities through land use agreements (e.g., hay, maple syrup, community partnerships), reservoir and watershed lands patrol, and acquisition support.
- Manages streams through stream management plans, stream restorations, research and public education.

DEP Environmental Police

- Protects the water supply.
- Detects and prevents environmental threats from pollution, crime, and terrorism.
- Protects DEP employees and facilities.
- Monitors development within the watershed to ensure compliance with City, State, and local regulations.
- Communicates with other law enforcement agencies to provide comprehensive services and protection.
- Investigates intentional and unintentional acts which threaten the water supply, facilities, infrastructure, or employees.

Regulatory Compliance and Facilities Remediation

- Ensures compliance with all applicable 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 outside regulatory agencies.
- Provides emergency spill response and remediation.
- Provides supervision of contractors utilized for emergency spill response, hazardous waste/ materials remediation and disposal.
- Provides environmental, health and safety training to BWS personnel.

Management Information Systems

- Responsible for the design, installation, and maintenance of computer related systems.
- Supports communication infrastructure, local area networks, computer hardware, data storage, and digital archives.
- Serves other Divisions in an advisory capacity for projects that are dependent on applications or information management systems.

Management Services and Budget

- Responsible for the Bureau's overtime, capital, and expense 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 260 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. This report is specifically about the upstate watersheds and, in particular, the Field and Laboratory Operations.

DWQC's Watershed Operations are now divided into five sections: Watershed Field Operations; Watershed Laboratory Operations; Information Management and Reporting; Process Control and Remote Monitoring; and Health and Safety. The Watershed Field Operations Section consists of five Groups: Limnology; Hydrology; Pathogens/Early Warning Surveillance (plus Wildlife Studies); and Watershed Management Studies (Water Quality Impacts Assessment and Natural Resources). 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 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 East-of-Hudson). 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.

Figure 1.2 The DEP limnology staff monitors water quality in the City's 19 reservoirs.

DWQC's Watershed Laboratory Operations Section consists of five water quality laboratories located in the Delaware, Catskill and East-of-Hudson Watershed Systems. This Section also includes Quality Assurance, Operations, and the Research Microbiology and Pathogens Units. Laboratory Operations includes laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, scientists, and technical specialists. The laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for over 100 environmental analyses in the non–potable water and potable water categories. These analyses 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). In addition, this Section operates an EPA accredited Pathogen Laboratory that analyzes water samples for the protozoan pathogens *Cryptosporidium* spp. and *Giardia* spp. 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 2003 reporting period covered in this report, DWQC staff performed 222,514 analyses on 21,859 samples from 658 different sampling locations.

The Information Management and Reporting Section staff are responsible for Watershed and Reservoir Modeling, the administration of the Upstate Water Quality database, the development of a Water Quality Information System linking water quality and GIS data, and reporting. The Process Control and Remote Monitoring Section staff use remote sensing to track and maintain water quality, both Upstate and in Distribution. A new section, Health and Safety, deals with all aspects of staff health and safety in the numerous DWQC workplaces.

Figure 1.3 The five DEP laboratories processed almost 22,000 samples in 2003.

2. Water Quantity

2.1 What is NYC's source of drinking water?

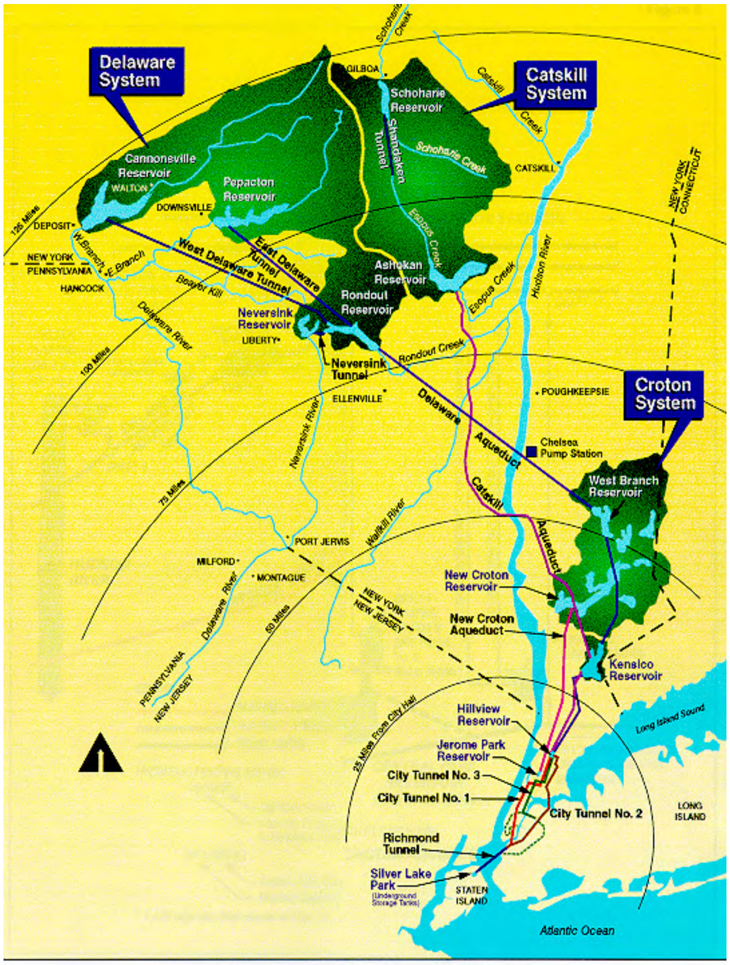
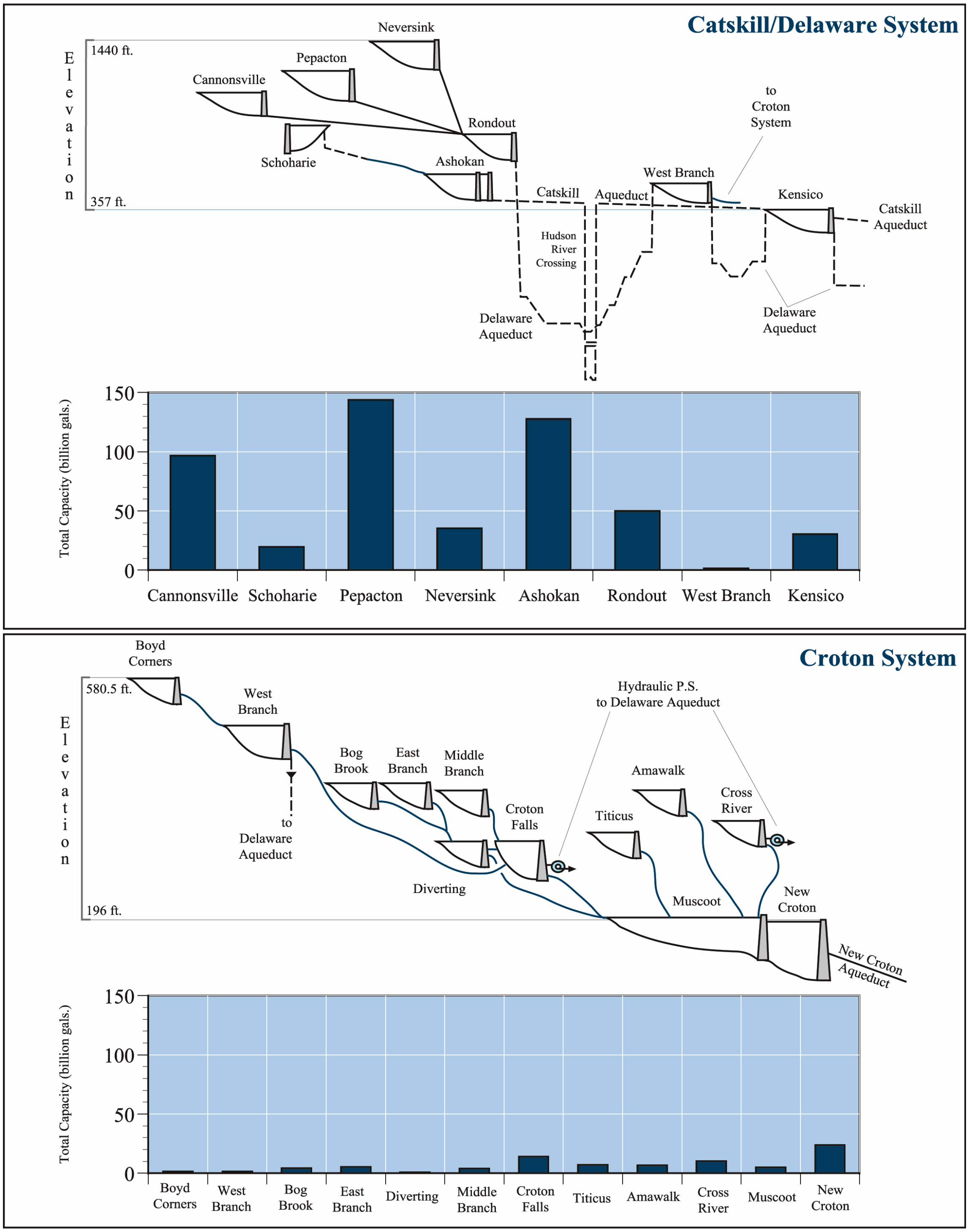


Figure 2.1 New York City water supply watershed.

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). 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 enters 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 reservoirs' water quality and productivity.

2.2 How much precipitation fell in the watershed in 2003?

The average precipitation for each basin was determined from a network of precipitation gauges located in or near each watershed that collects readings daily. The total monthly precipitation for each watershed is based on the average readings of the gauges located in the watershed. The 2003 monthly precipitation total for each watershed is plotted along with the historical monthly average (see Figure 2.3).



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.

The total monthly precipitation figures show that in general precipitation was about average or slightly below normal for January through April 2003. In May, June, and July 2003 the precipitation was about average or slightly above average for most watersheds. August, September, October, and December 2003 all had greater than average precipitation, with November having some watersheds receiving above average and some below average precipitation for the month. Overall the total precipitation in the watershed for 2003 was 1,433 mm (56.4 in), which is 295 mm (11.6 in) above normal. The bulk of this excess occurred in the summer and early fall. (August, September, and October had a combined precipitation of 245 mm (9.6 in) above normal.)

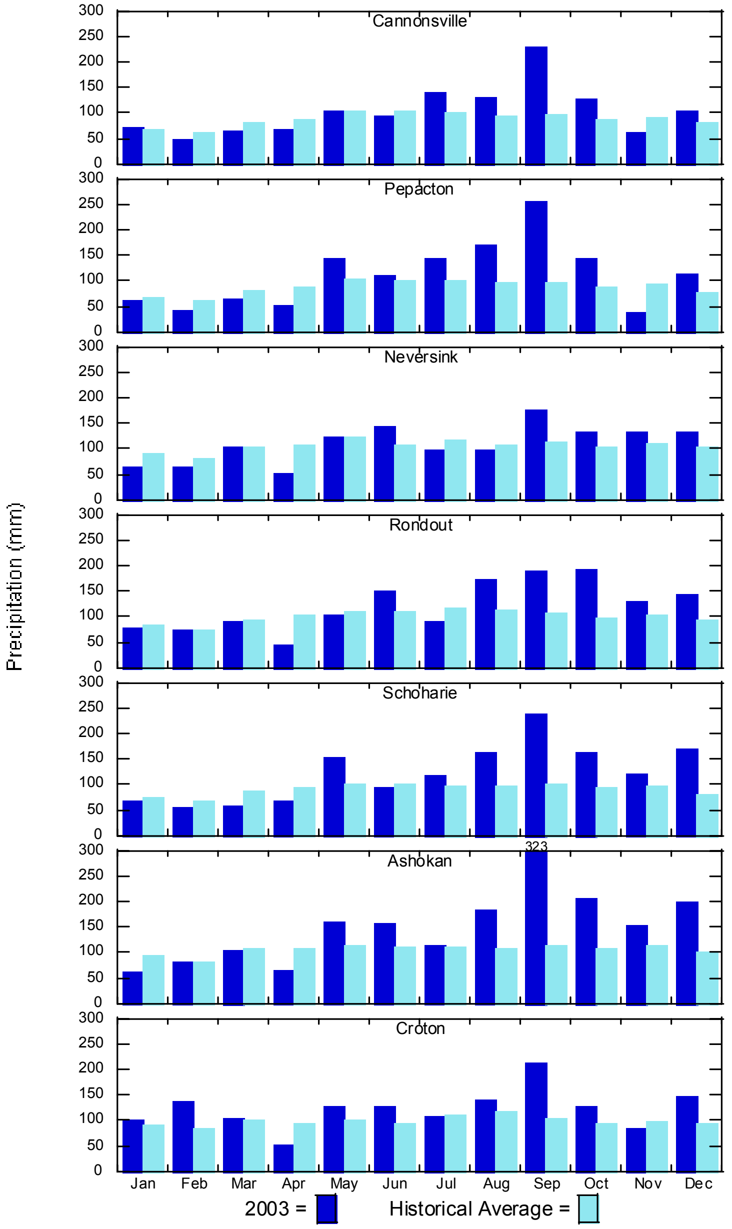


Figure 2.3 Monthly rainfall totals for NYC watersheds, 2003 and historical values.

2.3 How much runoff occurred in 2003?

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

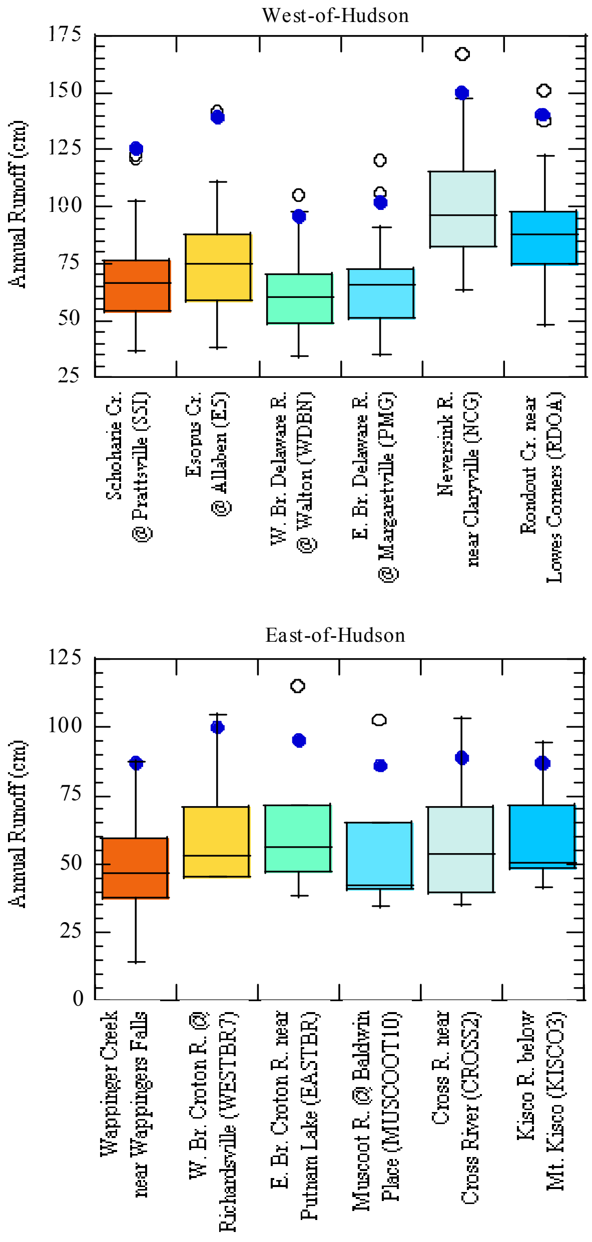


Figure 2.4 Historical annual runoff (cm) as box plots for the WOH and EOH watersheds with the values for 2003 displayed as a dot.

The USGS data collected after Sept. 30, 2002 are provisional.

Selected United States Geological Survey (USGS) stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.4). The total annual runoff from both the WOH and EOH watersheds were well above historical normals due to the precipitation excess for the year.

2.4 What was the storage history of the reservoir system in 2003?

The total available percent capacity (Actual) in 2002–2003 is compared to the monthly long–term average (Normal) in Figure 2.5. The long–term average was determined by calculating the monthly percent capacity during 1992–2001. During the first half of 2002 total capacity was generally 10–40 percent less than "Normal" capacity as a result of the drought, which began in 2001. Starting in late October of 2002 and continuing throughout 2003, increased rainfall resulted in much higher than normal storage capacity during this time period. In fact, for most of 2003, total capacity was at or near 100 percent, up to 30 percent greater than the historical norm.

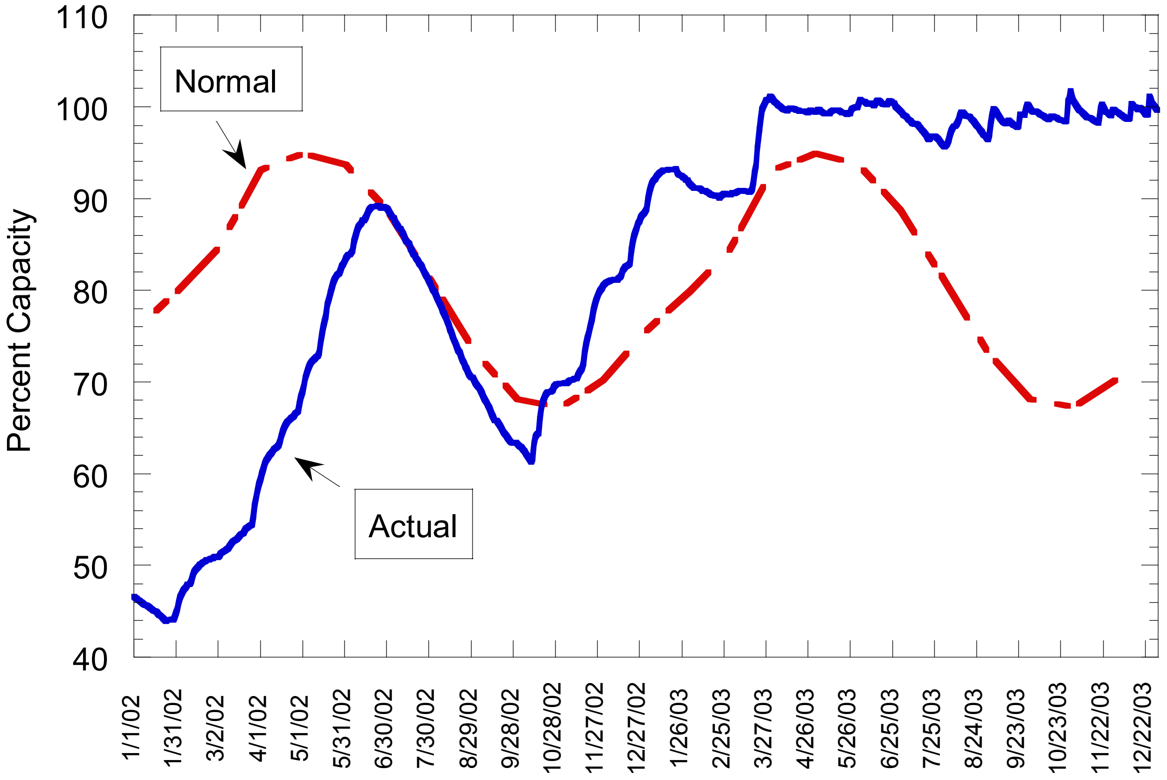


Figure 2.5 Total available percent capacity in 2002–2003 (Actual) compared to long-term (1992–2001) average (Normal) storage.

2.5 How and why does DEP collect meteorological data?

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 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) that covers 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 to help them make more accurate and timely severe weather warnings for watershed communities. These data are also important as input for DEP's hydrologic and water quality models (Chapter 5).

2.6 What is a Supervisory Control and Data Acquisition (SCADA) Telemetry System and how is it used in the NYC water supply?

A SCADA system (Process Control Remote Monitoring) is essentially a network of sensors, transmitters, and receivers that collect and transmit data and information, back and forth, from an array of selected remote locations to a central control station.

Historically, the operation of the New York City reservoir water supply system and the collection of hydrologic data was performed and compiled manually by DEP staff. This entailed the daily manual tasks of: opening and closing valves and gates; recording reservoir elevation; recording stream flow; recording precipitation and selected water quality variables; transcribing field data to electronic spreadsheets; creating daily, weekly, and monthly summary reports; and faxing or e-mailing reports to other divisions and/or governmental agencies. These were time-consuming, inefficient, labor-intensive tasks. To eliminate these inefficiencies, DEP has employed the use of a Supervisory Control and Data Acquisition (SCADA) Telemetry Network for the water supply. Data are continuously collected from each reservoir and aqueduct and transmitted to a central control room where reservoir or aqueduct operations can be performed remotely (Figure 2.6).

Figure 2.6 SCADA System control room depicting water supply status for water quantity and quality.

Aside from eliminating the inefficiencies described above, a SCADA System provides the following benefits to DEC:

- 24 hr surveillance, continuous real-time, reliable, and accurate water quantity and quality data throughout the water supply system. Any deflection in measurements of key water quality variables or disruptions of water flow throughout the system will be immediately recognized (24hrs/day, 7days/week) via alarms allowing for an immediate rectifying response.
- A secure network that eliminates system corruption from unauthorized access.
- Immensely enhances the efficiency of operating and managing the water supply system, resulting in 1) the conservation of water within the system and 2) reductions in chemical treatment.
- Allows for a continuous water supply performance assessment by NYC operating engineers and staff.
- Immensely enhances the efficiency of data management and data accessibility for all agency staff, making possible the inclusion of more accurate data in reports.

3. Water Quality

3.1 How did DWQC Watershed Operations ensure the delivery of the highest quality water from upstate reservoirs in 2003?

DWQC Watershed Laboratory Operations continued its extensive Aqueduct Monitoring Program with the daily collection and analysis of samples from reservoir intakes, tunnel outlets, and aqueducts within the Catskill, Delaware, and Croton Systems. In 2003, over 54,000 physical, chemical, and microbiological analyses were performed on 7,700 samples that were collected from 54 different monitoring locations. Process Control Remote Monitoring (PCRM) (see Section 2.6) stations remain in place at key locations, and continue to provide real-time water quality data for operational decision-making and compliance reporting. In 2003, DEP added three new stations in the West-of-Hudson watershed, expanding the coverage of outlying aqueduct locations. DWQC scientists continued to work closely with the Bureau's Division of Operations to determine the best operational strategy for delivering the highest quality water to NYC consumers.

In 2003, DEP was successful in utilizing reservoir and aqueduct design to optimize the quality of water distributed through the system. No watershed treatment operations were required other than routine disinfection and fluoridation. Watershed operational strategies for 2003 included:

Selective Diversion

DEP prevented negative impacts to downstream reservoirs by maximizing the flow from reservoirs with the best water quality and minimizing the flow from reservoirs with inferior water quality. For example, when a September storm event caused elevated turbidity and fecal coliform levels in the West Branch Reservoir, DEP isolated the reservoir from the Delaware System flow. By diverting water directly from the Rondout Reservoir to the Kensico Reservoir through the West Branch bypass tunnel, DEP prevented poor quality water from being diverted down the Delaware Aqueduct and into the Distribution System (Figure 3.1).

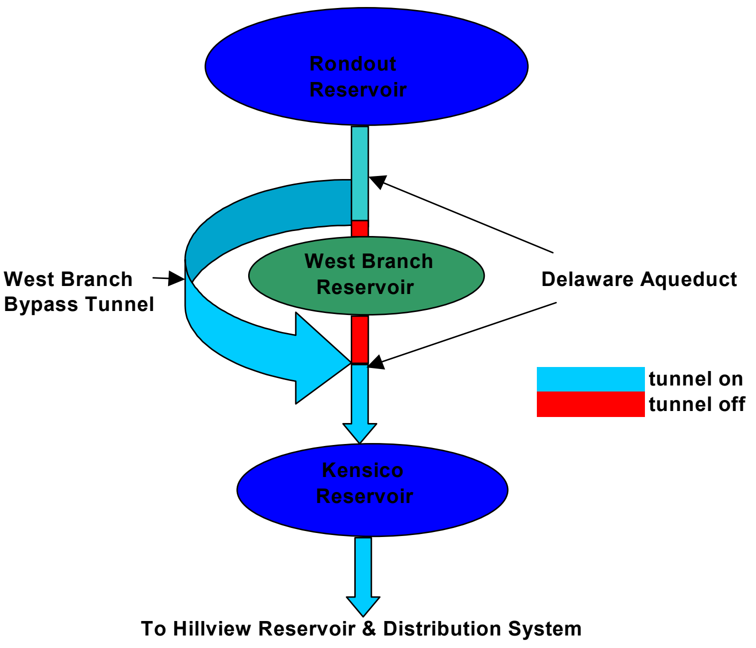


Figure 3.1 West Branch Reservoir Bypass Operation.

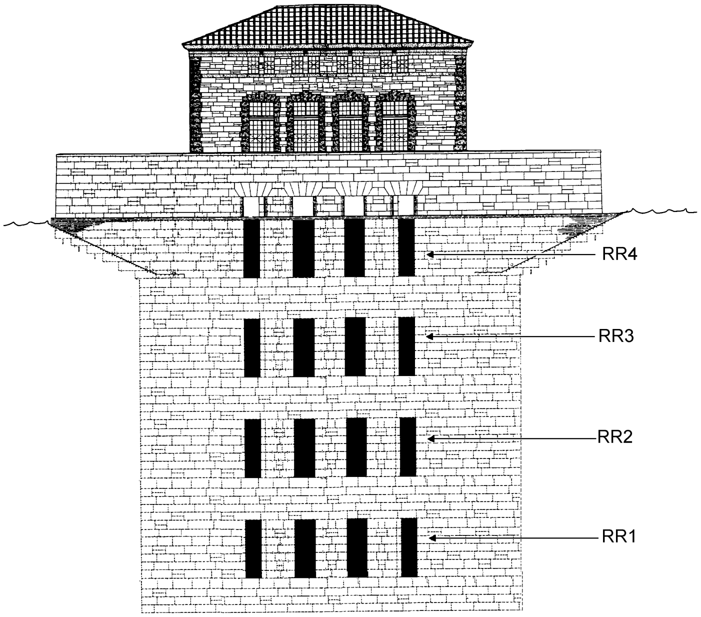


Figure 3.2 Rondout Effluent Chamber Intake elevations (RR1–RR4).

Selective Withdrawal

DEP monitored water quality at different elevations within the reservoirs and used that information to determine the optimal level of withdrawal. For example, an intake elevation change was made at the Rondout Reservoir in October when water quality monitoring indicated that turbidity levels had increased near the bottom of the reservoir. By moving the level of withdrawal away from the bottom (Figure 3.2; elevation RR1 at 219.5 m) and towards the surface (Figure 3.2; elevation RR3 at 239.0 m), DEP was able to optimize the quality of the water being sent down the Delaware Aqueduct.

Blending Operations

DEP blended water from a combination of intake levels and sites within individual reservoirs and between different reservoirs to optimize water quality. For example, water was blended from two different locations in the New Croton Reservoir in August when water quality monitoring indicated that manganese and bacterial levels were optimal near the gatehouse, but turbidity levels were optimal near the dam (Figure 3.3). By blending water from two different intake points, DEP was able to improve the quality of the water being sent down the New Croton Aqueduct until the system was taken off-line in September.

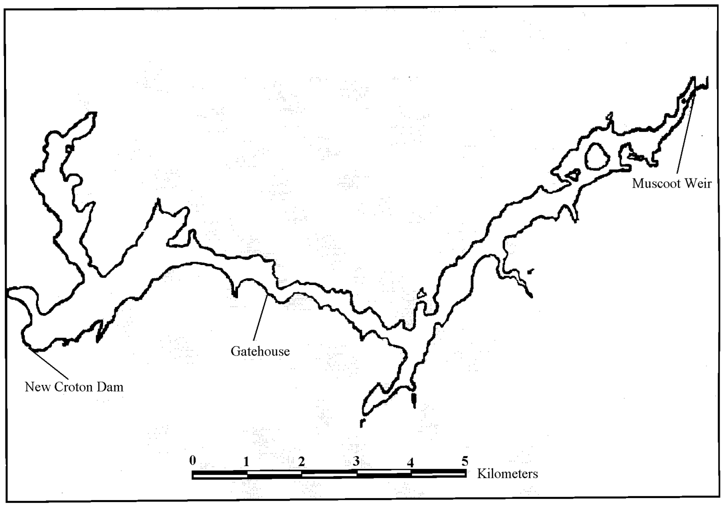


Figure 3.3 New Croton Reservoir.

3.2 How does the water quality of NYC's source waters compare with standards set by federal regulations?

The Surface Water Treatment Rule (SWTR) (40CFR171.71(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 3.4 and 3.5 depict fecal coliform and turbidity data for 1992–2003. Both figures include a horizontal line marking the SWTR limit.

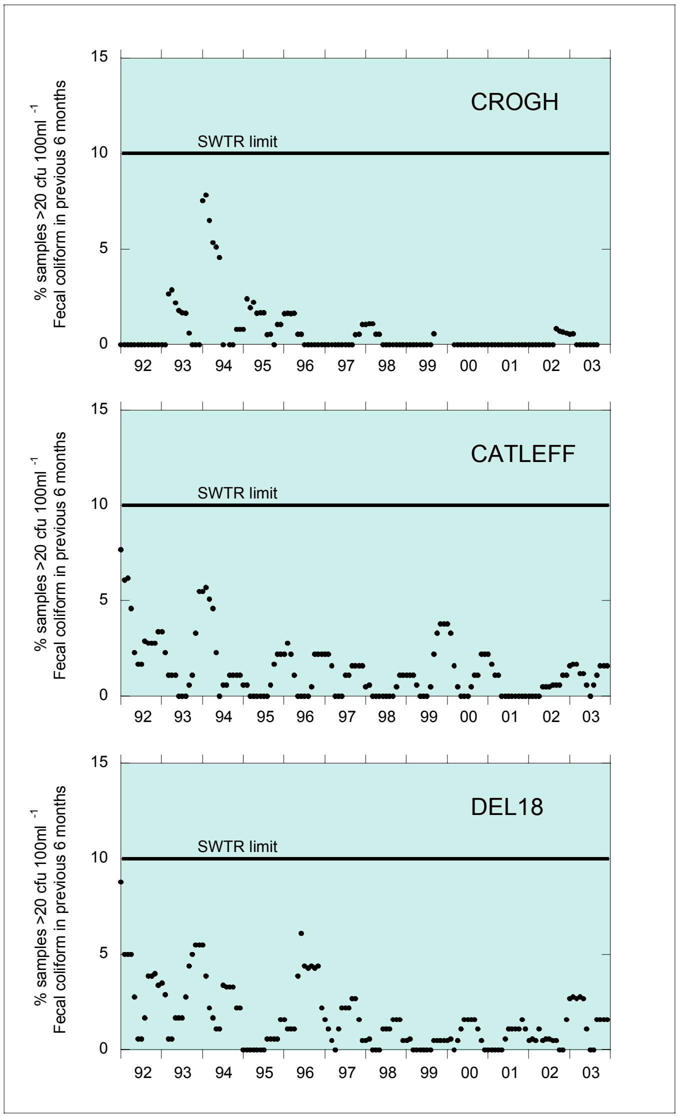


Figure 3.4 Temporal plots of fecal coliform (% of daily samples > 20cfu 100mL^{-1} in the previous six months) compared with Surface Water Treatment Rule limit.

As indicated in Figure 3.4, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; for 2003, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below the 10% limit set by the SWTR standard. For 2003, for raw water samples taken at the three keypoints CROGH, CATLEFF, and DEL18, the mean and median fecal coliform concentrations (cfu 100mL^{-1}) were 0.8 and 0, 2.8 and 1, and 3.3 and 2, respectively.

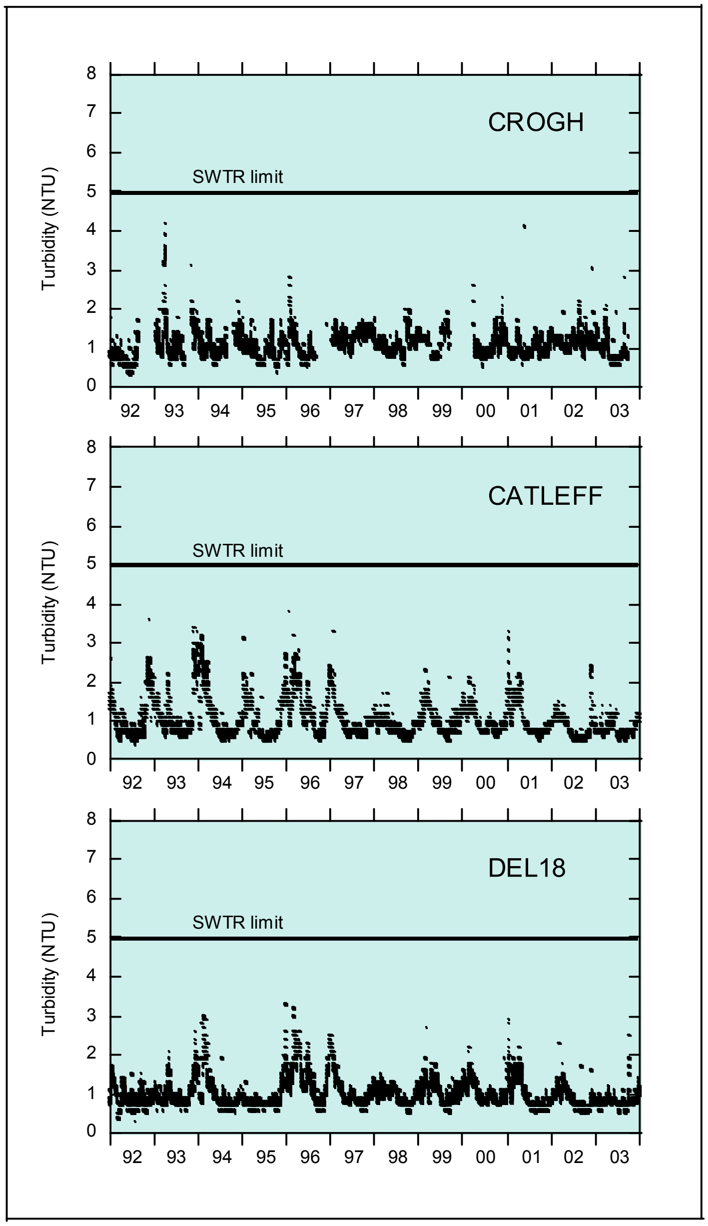


Figure 3.5 Temporal plots of turbidity (daily samples) compared with Surface Water Treatment Rule limit.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.5, all three effluent waters were consistently well below this limit in 2003. For the three keypoints CROGH, CATLEFF, and DEL18, the mean and median turbidity values (NTU) were 1.0 and 0.9, 0.8 and 0.8, and 0.8 and 0.8, respectively.

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

DEP began monitoring for the protozoan pathogens *Cryptosporidium* and *Giardia* at Kensico Reservoir's effluent chambers in 1992. Monitoring was extended in 1993 to include additional reservoir keypoints, other sites throughout the watershed, and the collection of human enteric virus samples at selected sites. In 2003, 913 samples from 133 sites were collected and analyzed for *Cryptosporidium* and *Giardia,* and 314 samples from 24 sites for human enteric viruses. Results from the monitoring at the effluents of Kensico Reservoir and New Croton Reservoir are posted weekly on the DEP web site www.nyc.gov/html/dep/html/pathogen.html. All monitoring results are presented in semi-annual reports. The distribution of the total number of samples collected and analyzed in 2003 is presented in Figure 3.6.

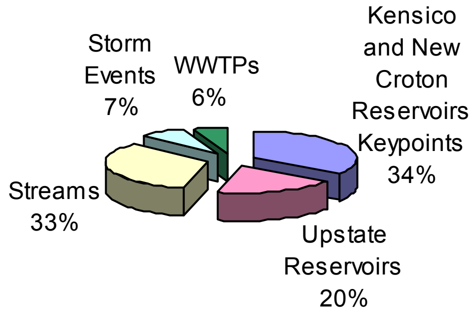


Figure 3.6 Distribution of the number of samples (including enhanced monitoring) per category of sampling sites, January 1 to December 31, 2003.

Analytical methods require the filtration of large volumes of water (50 liters for protozoans and 227 liters for viruses) to recover a few organisms. All samples collected and analyzed for protozoans in 2003 used USEPA Method 1623 (USEPA 2001a). Human enteric virus samples are analyzed in accordance with the USEPA ICR Microbial Laboratory Manual (USEPA 1996). Sampling frequency for each site is determined by objectives described in the Integrated Monitoring Report (NYCDEP 2002). Additionally, DEP collects samples during storm events at certain sites to estimate protozoan loads into reservoirs. Fixed frequency sampling locations include reservoir keypoints, streams, and wastewater treatment plants. Keypoints at Kensico Reservoir are at the influent and effluent chambers. Upstate reservoir sampling sites are defined as the effluent of the reservoir into an aqueduct (West-of-Hudson) or stream releases (East-of-Hudson). Stream sites measure non-point sources and can represent various types of land use and land cover.

Kensico Reservoir influent and effluent chambers and New Croton Reservoir effluent are sampled at least once a week. A total of 260 weekly samples were collected at these sites in 2003. Table 3.1 summarizes the results for 2003. Concentrations of pathogens in streams and reservoirs were very low.

Table 3.1: *Cryptosporidium* and *Giardia* weekly monitoring results at Kensico Reservoir influent and effluent chambers and New Croton Reservoir effluent, January to December 31, 2003.

Keypoints	Protozoan	Number of Samples	Number of Positive Samples	Percent Positive	Mean concentration ($50L^{-1}$)	Maximum concentration ($50L^{-1}$)
Catskill Effluent Chamber	Total *Giardia*	52	41	78.8%	2.2	7
	Total *Cryptosporidium*		12	23.1%	0.3	3
New Croton Reservoir Effluent	Total *Giardia*	52	26	50.0%	1.2	5
	Total *Cryptosporidium*		5	9.6%	0.1	2
Delaware Effluent Chamber	Total *Giardia*	52	39	75.0%	2.1	6
	Total *Cryptosporidium*		14	26.9%	0.4	2
Catskill Influent Chamber	Total *Giardia*	52	29	55.8%	1.0	5
	Total *Cryptosporidium*		8	15.4%	0.2	2
Delaware Influent Chamber	Total *Giardia*	52	48	92.3%	2.7	8
	Total *Cryptosporidium*		13	25.0%	0.3	2

Cryptosporidium was found in 31 samples (26 in the Kensico Reservoir effluents and 5 in the New Croton Reservoir effluent). *Giardia* was found in 104 samples (80 in the Kensico Reservoir effluents and 26 in the New Croton Reservoir effluent). *Giardia* was detected more often than *Cryptosporidium*. Similarly, *Cryptosporidium* detection in Kensico Reservoir influents was less frequent than detection of *Giardia* (21 of 104 samples for *Cryptosporidium,* 77 of 104 samples for *Giardia*). DEP also collected an additional 56 samples under enhanced monitoring periods at these keypoints. These samples are usually collected on Wednesdays to supplement samples collected on Mondays. Enhanced monitoring samples provide increased frequency data for public health protection.

Detection of human enteric viruses was an extremely rare event. One sample collected at the Catskill influent was positive for human enteric viruses. All other samples (259) were negative for human enteric viruses.

Fixed-frequency sampling of *Cryptosporidium* and *Giardia* from upstream reservoir effluents and streams feeding these reservoirs is summarized in Figures 3.7 and 3.8. The figures present the distribution of the sampling locations across the New York City watershed. Data from upstream keypoint sites (NRR2, PRR2, RDRRECMT, WDTO, and SRR2) show that (a) *Giardia* was found at more locations than *Cryptosporidium* (5 of 5 and 4 of 5, respectively), and (b) *Giardia* was found in greater concentrations than *Cryptosporidium* (4.3 $50L^{-1}$ and 0.2 $50L^{-1}$, respectively). Fixed-frequency results from stream sites also show (a) *Giardia* was found at more locations than *Cryptosporidium* (67 of 71 sites and 51 of 71 sites, respectively) and (b) *Giardia* was found in greater numbers than *Cryptosporidium* (15.6 $50L^{-1}$ and 1.1 $50L^{-1}$, respectively).

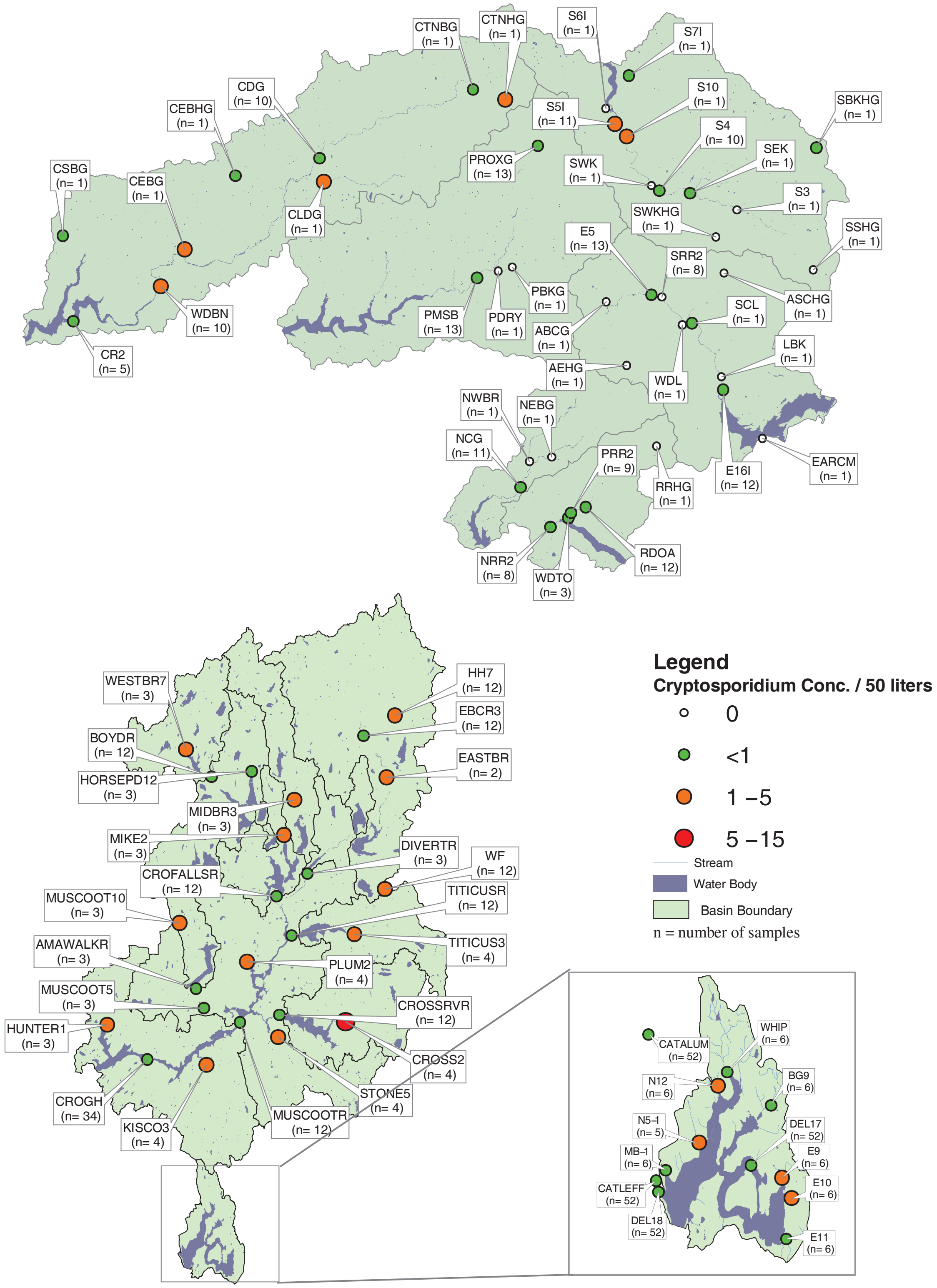


Figure 3.7 Average *Cryptosporidium* concentrations in streams and reservoir effluents, January 1 to December 31, 2003.

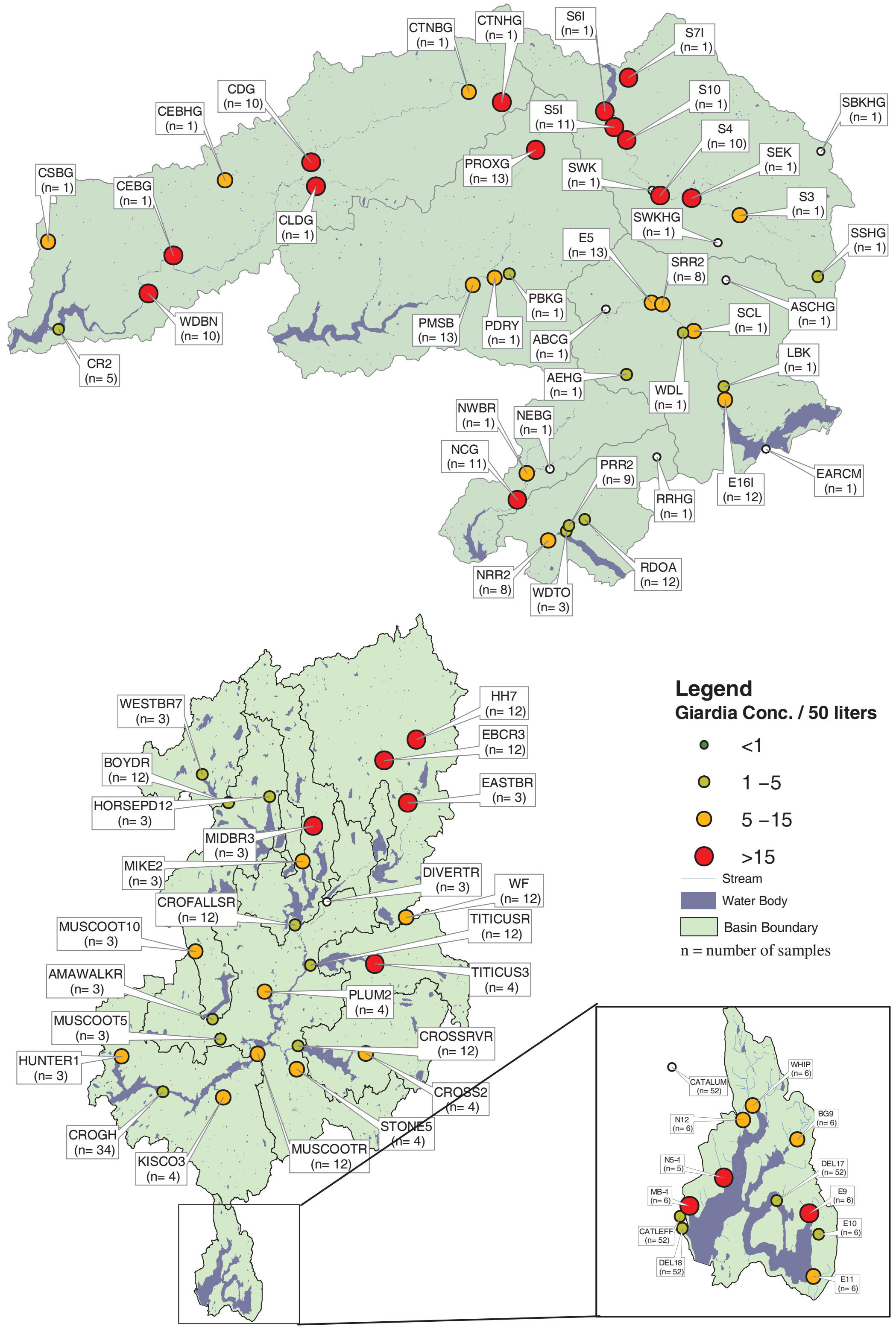


Figure 3.8 Average *Giardia* concentrations in streams and reservoir effluents, January 1 to December 31, 2003.

Fifty-one samples from wastewater treatment plant effluents were collected from January to December 2003 at ten plants located West-of-Hudson and one plant located East-of-Hudson (Brewster) (Figure 3.9). Upgrades for New York City-owned WWTPs were completed in 1997. Upgrades for non-City-owned WWTPs were completed in 2002 for the villages of Delhi, Walton, and Stamford, which added dual sand filtration, and for the village of Hobart, which added microfiltration to its treatment process. One *Cryptosporidium* was found in a sample collected at the Brewster plant. *Giardia* was found in two samples collected at RGC, a West-of-Hudson WWTP, and in four samples at the Brewster WWTP.

Human enteric viruses were not found at any of the West-of-Hudson upgraded plants. At the Brewster WWTP, which is sampled monthly, low concentrations of viruses were detected in two of the 12 samples (1 virus per 100 liters). Human enteric viruses were not found at upgraded WWTPs; the Brewster plant is scheduled for an upgrade.

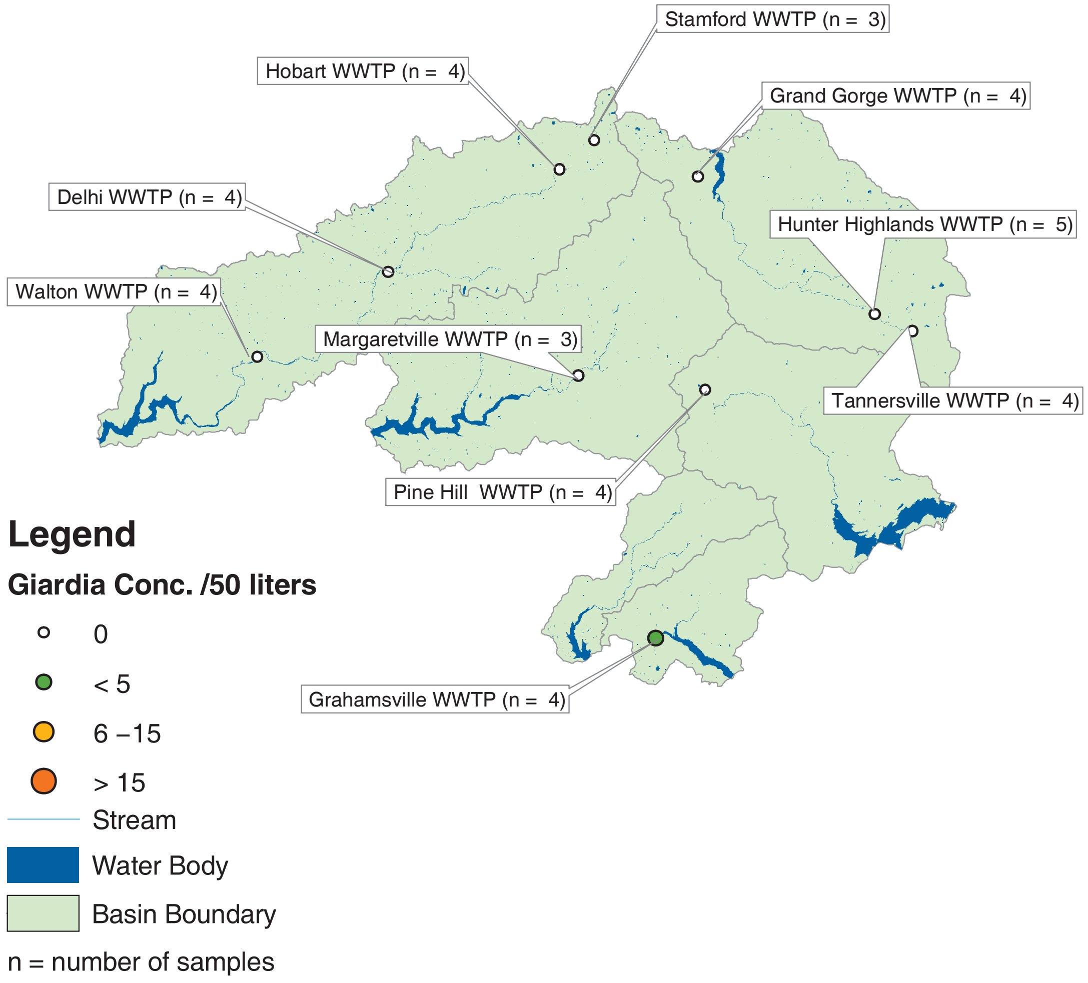


Figure 3.9 Average *Giardia* concentrations in the effluents of WWTPs, January 1 to December 31, 2003.

Sixty-five samples were also collected in 2003 during rainstorms that produced runoff. Results are used to (a) compare oocyst concentrations during fixed-sampling base flow monitoring and storm event sampling, and (b) conduct genotype studies. Results from the event-based monitoring are reported in semi-annual reports (e.g., NYCDEP 2003).

3.4 How do protozoan concentrations compare with regulatory levels?

At the present time, there are no state or federal regulatory levels for *Cryptosporidium*, *Giardia* or human enteric viruses in source water. DEP is continuously evaluating *Cryptosporidium* results with a treatment threshold proposed by USEPA. This proposed rule is known as the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA 2001b). The rule relies on analysis of *Cryptosporidium* by Method 1623 and will provide for increased protection against microbial pathogens in public water systems that use surface water sources. DEP began to use Method 1623 with 50-liter volumes (referred to as Method 1623HV) on October 15, 2001. Over two and a half years of weekly sampling results are available. *Cryptosporidium* average concentrations at the three source waters have been below the proposed rule limit of 0.01 oocyst per liter over a two-year period (Figure 3.10).

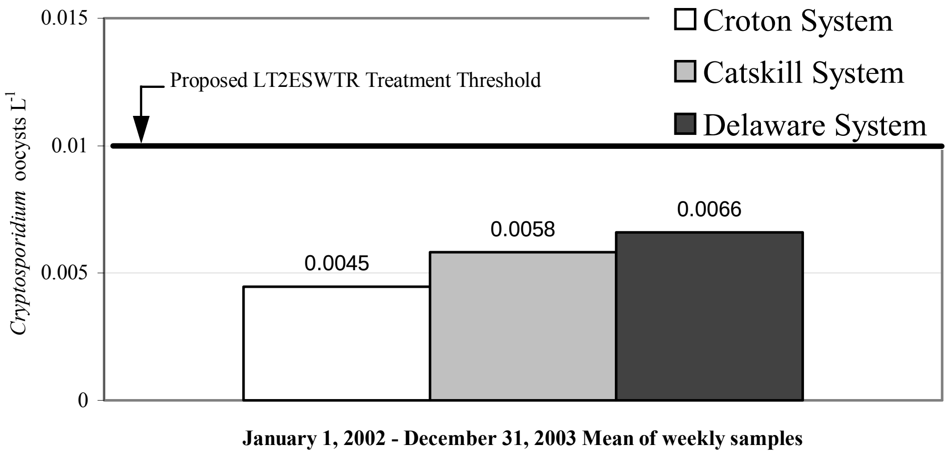


Figure 3.10 Comparison between the proposed LT2ESWTR treatment threshold and averages of 104 weekly analyses at each of the NYC Source Waters – January 1, 2002 to December 31, 2003.

3.5 Do protozoan concentrations change during the year?

DEP began using USEPA Method 1623 for Kensico and Croton Reservoirs keypoints on October 15, 2001. Detection of *Giardia* became more frequent and at higher concentrations than with previous analytical methods. Results from one year to the next appear comparable but concentrations are not constant during the year. Concentrations are the lowest from late spring to October and a seasonal increase is observed during winter months when transport from land to stream is enhanced by precipitation, snow, and snowmelt. This is also a period when small mammals may seek shelter from the cold in storm drains, for instance, and this may enhance disease transmission. This seasonal variation is observed at the five keypoints monitored weekly (Figure 3.11). An increase in *Giardia* concentrations was also observed during the winter months throughout the New York City watershed and in other watersheds in the State of New York. A similar trend may exist for *Cryptosporidium* but is more difficult to observe because *Cryptosporidium* concentrations are much lower than *Giardia* concentrations. The ten graphs presented in Figure 3.11 are temporal scatterplots of *Cryptosporidium* (left column) and *Giardia* (right column) at five keypoints. The horizontal axis represents the 365 days of the year to allow for comparisons of results from different years (October 15, 2001 to May 31, 2004). The line through each graph is a locally weighted scatterplot smooth (LOWESS) of all the data. A "smoothing factor" of 25% was used to show the natural trend of the center of the mass of the data. Curves in the LOWESS smooth indicate short-term fluctuations within the data.

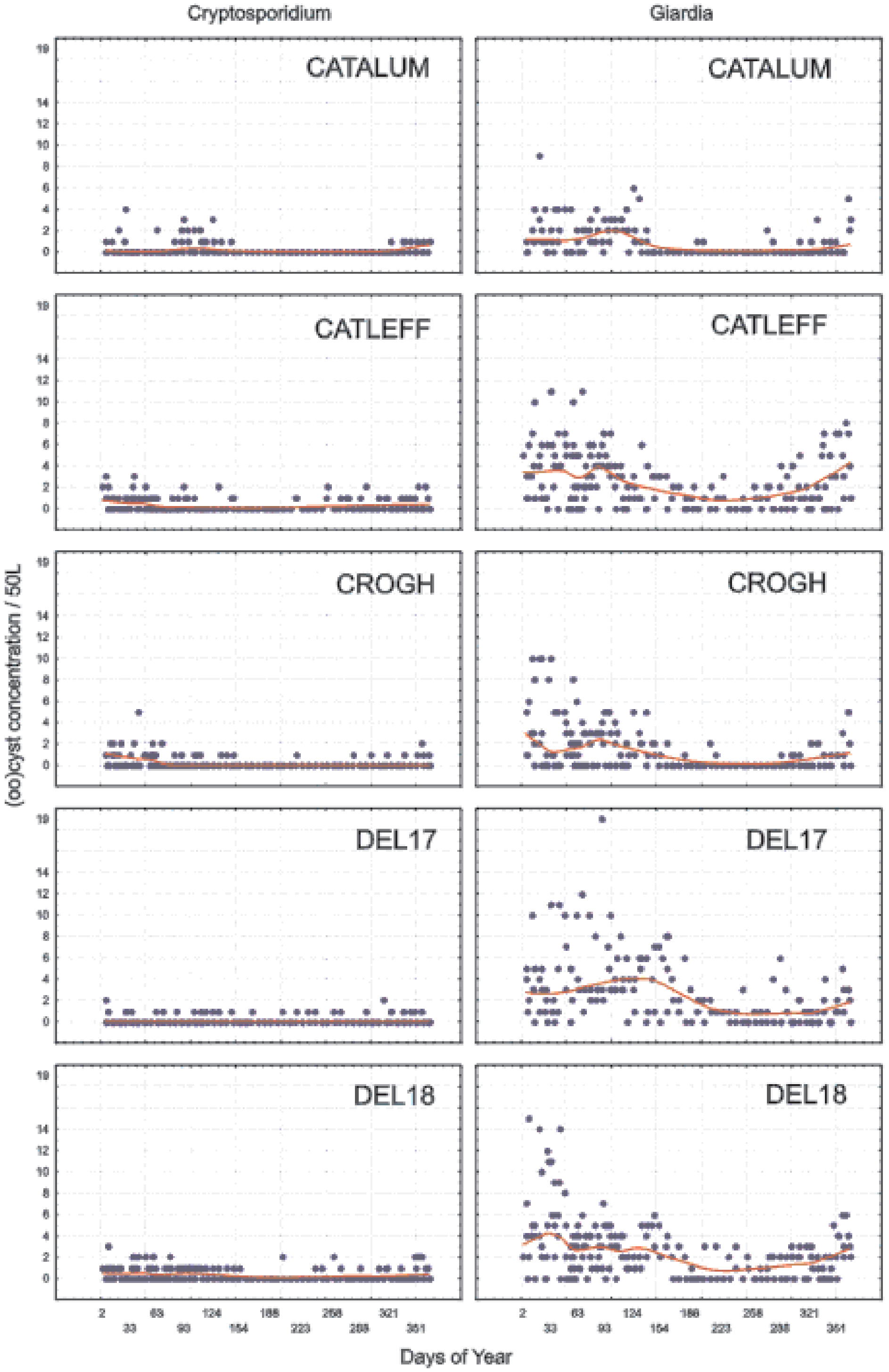


Figure 3.11 Keypoints *Cryptosporidium* and *Giardia* data for October 15, 2001 to May 31, 2004 plotted on an annualized basis.

The curves drawn are LOWESS with a 25% smoothing factor.

3.6 What were the sources of *Cryptosporidium* in NYC's water supply in 2003?

Since *Cryptosporidium* oocysts are a rare occurrence in the source water, DEP has turned to storm water from streams to capture oocysts for source identification. In all, *Cryptosporidium* oocysts were captured from 25 stream storm events in 2003, mainly from the N5 basin of Kensico Reservoir, with some samples also analyzed from Malcolm Brook. Samples were analyzed using a small-subunit rRNA based diagnostic tool utilizing polymerase chain reaction technology to identify the genetic patterns of the oocysts. Results indicate that all of the oocysts genotyped in 2003 originated from non-human sources, as in past years. Deer, muskrat, and skunks top the list of sources identified at N5. A summary and comparison of all the genotyping data gathered during DEP's studies in previous years can be found in Jiang et al. (2003). Sampling of the N5 stream for this study continued through the spring of 2004.

Figure 3.12 DEP Pathogen Laboratory staff micropipetting a concentrated water sample for microscopic analysis of *Giardia* and *Cryptosporidium*.

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

The stream sites reported on in this section are presented in Table 3.2 and shown pictorially in Figure 3.13. 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, meaning that they are the main stream sites immediately upstream of the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds.

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 coliform bacteria (fecal and total; Surface Water Treatment Rule limits).

The results presented are based on grab samples generally collected twice a month. The figures compare the 2003 median values against historic median annual values for the previous ten years (1993-2002). However, several of the EOH sites have shorter sampling histories. These include: WESTBR7 (1995-present), KISCO3 (1999-present), and HUNTER1 (1998-present).

Table 3.2: Site codes and site descriptions of the stream sample locations discussed in this section.

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 Boyds Corner 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.

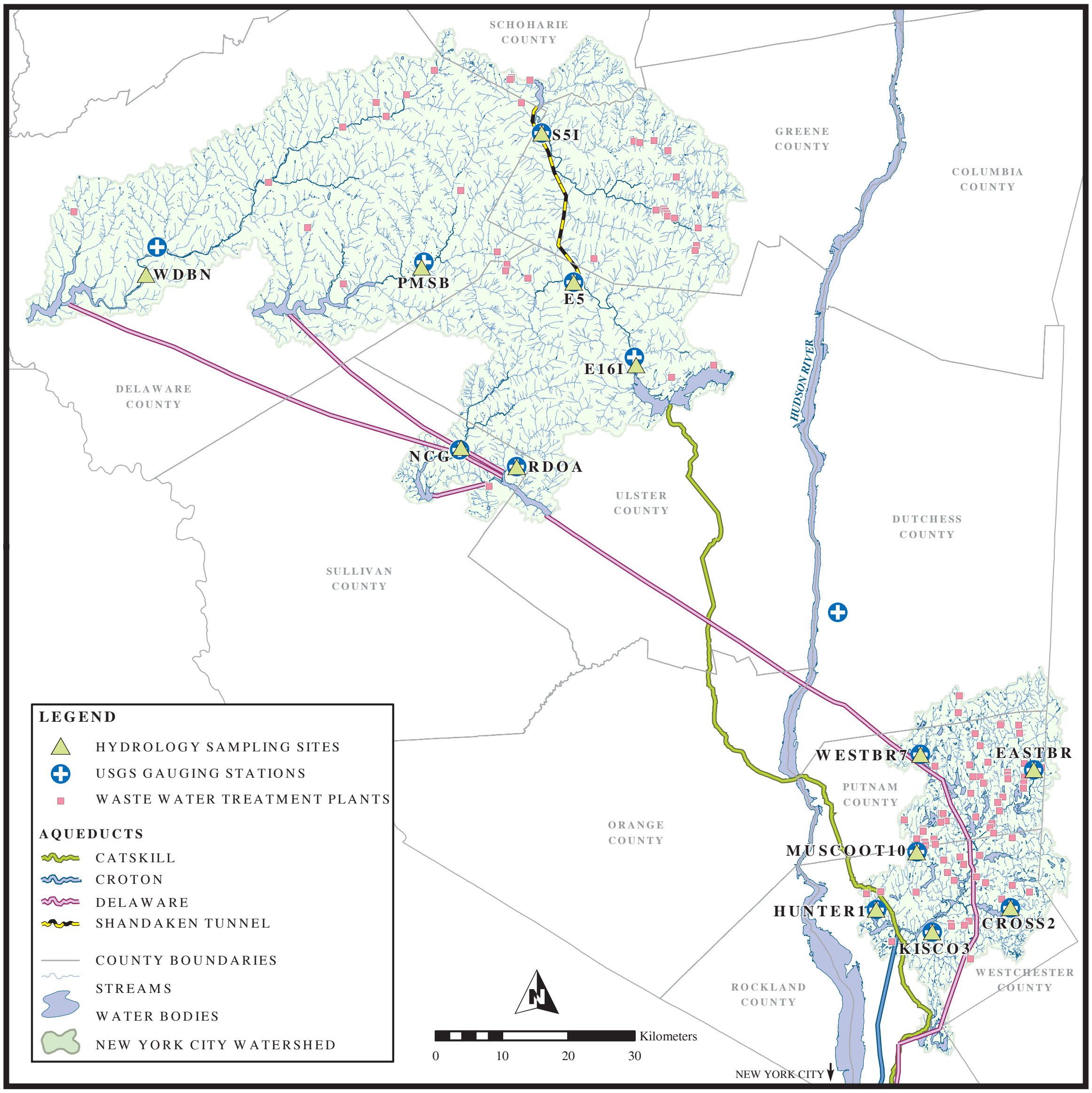


Figure 3.13 Locations of sampling sites and USGS stations.

Turbidity

The turbidity levels for 2003 were generally near “normal” values (Figure 3.14a).

Total Phosphorus

In the Catskill/Delaware System, the 2003 total phosphorus levels (Figure 3.14b) were for the most part near or slightly below typical historical values. In the Croton System total phosphorus values (Figure 3.14b) were either near or above historical values. Of the Croton inflows that exhibited an elevated median for total phosphorus for 2003, only Cross River Reservoir exhibited a corresponding elevated 2003 total phosphorus geometric mean value (see Section 3.10).

Coliforms (fecal and total)

The 2003 coliform levels (Figure 3.14c and d) in the Catskill/Delaware and Croton Systems were generally near the typical historical levels. A fecal coliform benchmark of 200 cfu 100 mL^{-1} is shown as a solid line in Figure 3.14c. This benchmark relates to the NYSDEC water standard (expressed as a monthly geometric mean of five samples, the standard being <200 cfu 100 mL^{-1}) for fecal coliforms. The 2003 median values for all streams shown here lie well below this value.

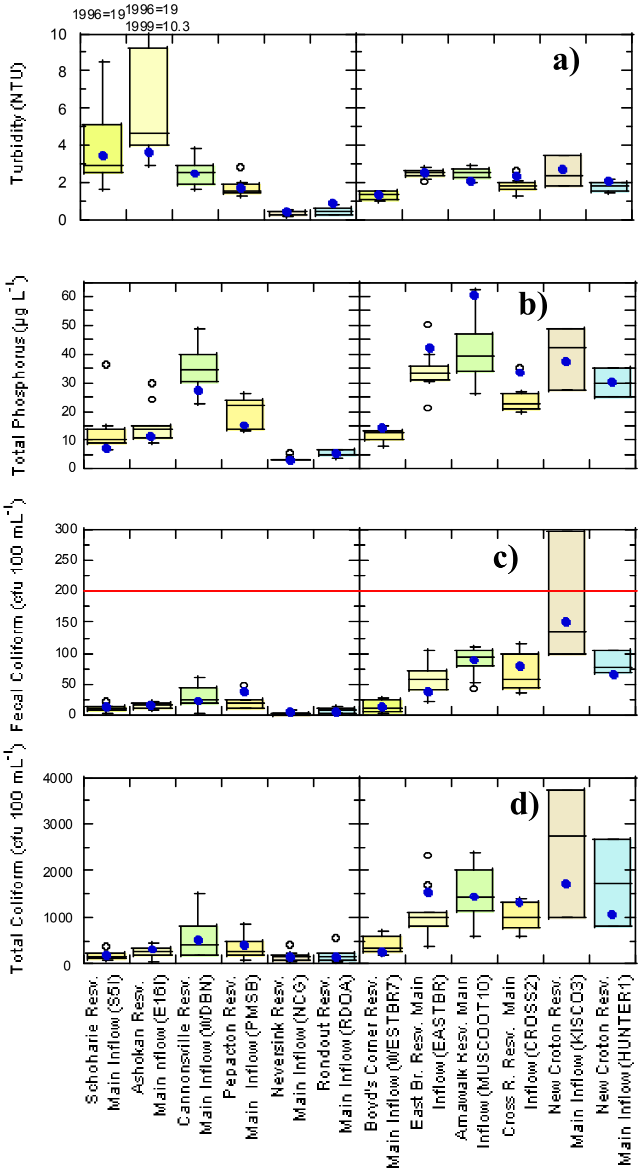


Figure 3.14 Box plot of annual medians (1993–2002) for a) turbidity, b) total phosphorus, c) fecal coliforms, d) total coliforms for selected stream (reservoir inflow) sites with the value for 2003 displayed as a dot.

3.8 How did the snow melt and increased precipitation affect turbidity in the reservoirs?

Figure 3.15 Sundown Creek in the Catskill System.

Turbidity in reservoirs is caused by organic and inorganic particulates (e.g., clay, silt, plankton) 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 (storm runoff in particular). In 2003, the median turbidity decreased through much of the system as compared to the annual medians of the past 10 years (Figure 3.16). This occurred despite increased runoff from snowmelt and precipitation for the year. One potentially important factor was that the precipitation and runoff events were not of sufficient intensity to cause major turbidity events. Another factor was that full reservoir elevations decreased the shoreline sediments' exposure to erosion. Notable exceptions to the decreased turbidity seen in 2003 include Kensico, Rondout, and West Branch Reservoirs. Kensico Reservoir had no change between these time periods, possibly as a result of a balance between the decreased turbidity from Ashokan's East Basin and the increased turbidity from Rondout. The increase at Rondout was likely due to contributions of turbidity from local streams since, as Figure 3.16 demonstrates, the three tributary reservoirs in the Delaware System all exhibited decreased median turbidity levels for the year. In the East-of-Hudson District, West Branch had increased turbidity levels most likely due to operational changes. When the reservoir is on bypass mode (water from Rondout bypasses West Branch completely), water from Boyd Corners Reservoir dominates the water quality in West Branch. Turbidity levels from Boyd Corners are typically higher than that of Rondout, and more typical of the Croton System. The three controlled lakes, Kirk, Gilead, and Gleneida, are also part of the Croton Reservoir System. Due to space constraints these data are not shown in Figure 3.16. The median turbidity during the time period 1996-2002 for Kirk, Gilead, and Gleneida was 3.2, 1.4, and 1.5 NTU, respectively. In 2003 the median turbidity was 2.9, 0.9, and 1.8 NTU, similar to past values.

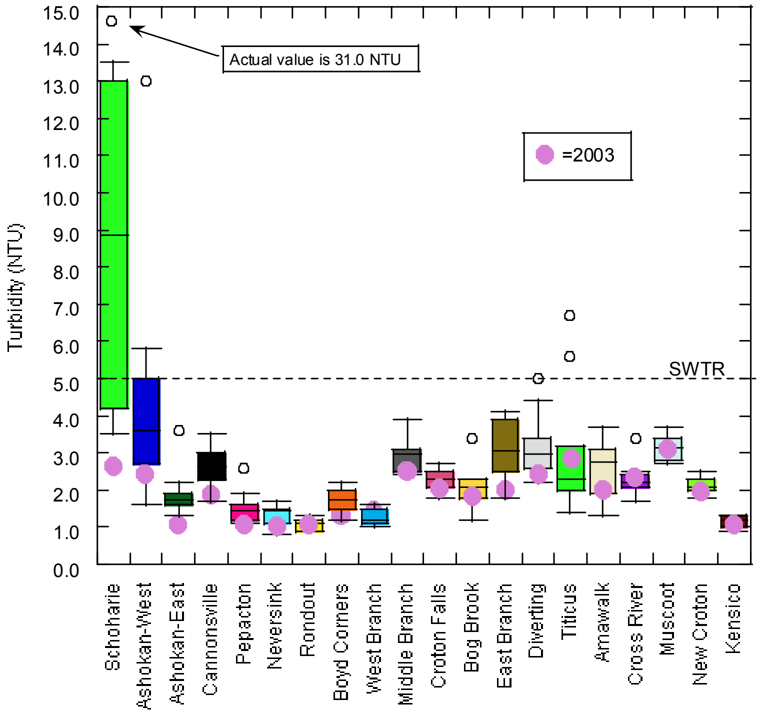


Figure 3.16 Annual median turbidity in NYC water supply reservoirs (2003 *vs.* 1993–2002).

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 two consecutive days > 5 NTU as a violation in source water reservoirs.

3.9 Were the total phosphorus concentrations in the reservoirs affected by the increased precipitation and runoff?

Phosphorus is an important nutrient for plant growth. Main sources of phosphorus in reservoirs include: soil erosion carried by inflowing streams, atmospheric deposition, sewage, and internal recycling from sediments. With the exceptions of Schoharie and Cannonsville, most Catskill and Delaware System reservoirs have relatively low long-term (1993–2002) concentrations of total phosphorus (Figure 3.17). Relatively high concentrations can occur at Schoharie because its watershed is relatively very large and highly susceptible to soil erosion. The long-term high phosphorus concentration at Cannonsville may be due to agricultural and urban non-point runoff, and seven waste water treatment plants (now remediated) that are located within the watershed. The 2003 median values for the Catskill and Delaware System reservoirs were substantially lower than the long-term data. This occurred despite a season with heavy snowfall and above average precipitation for the year. Since the snowmelt and precipitation events were gradual and of relatively low intensity (see Sections 2.2 and 2.3), the runoff could have provided a dilution effect compared to previous years of drought.

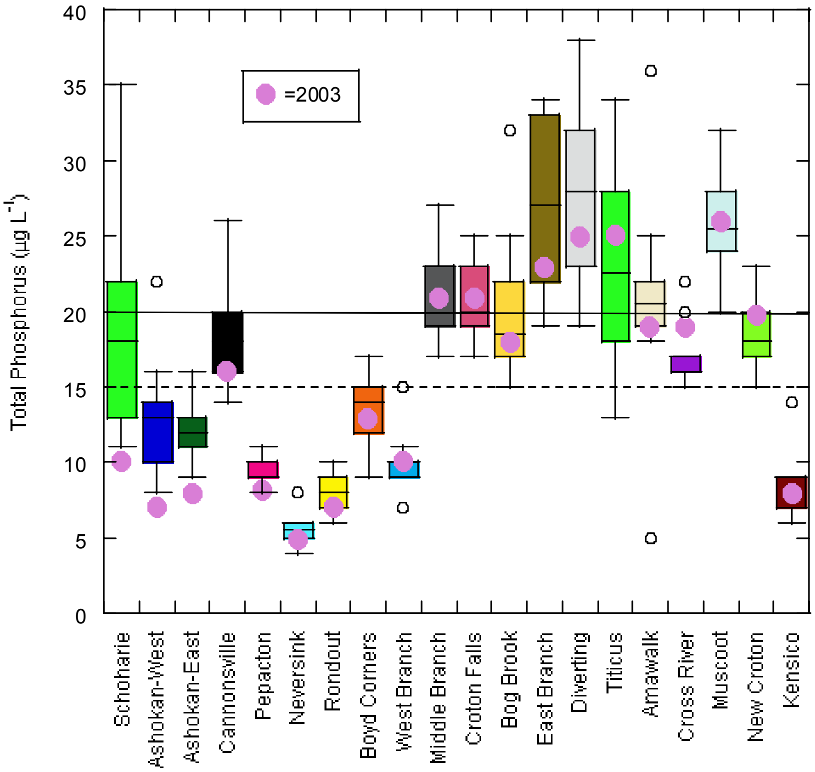


Figure 3.17 Annual median total phosphorus concentrations in NYC water supply reservoirs (2003 *vs.* 1993–2002).

The dashed line is the NYC guidance value for source water reservoirs. The solid line is the NYSDEC guidance value for other reservoirs.

Total phosphorus concentrations in the Croton System reservoirs are normally noticeably higher than in the Catskill and Delaware Systems due primarily to development pressure. There are 60 waste water treatment plants scattered throughout the Croton watershed. Septic systems are also prevalent. In 2003, TP concentrations in most of the reservoirs were at or below the annual median of past years. The exceptions include Titicus, Cross River, Muscoot, and New Croton Reservoirs. The 2003 data appear to reflect a return to the conditions reflected by the long-term median for EOH reservoirs. Interestingly, the Catskill System reservoirs had 2003 median TP values that were well below those found in the long-term statistics. This is probably because the long-term box plots include 1996 and 1999, both of which had incredible storms that had a short-term effect on the Catskill reservoirs. These data suggest that the effect of these storms on the watershed may be waning. Phosphorus concentrations for Kirk, Gilead, and Gleneida lakes in 2003 (not shown in Figure 3.17) were consistent with past data. In 2003 the median total phosphorus for Kirk, Gilead, and Gleneida was 29, 15, and 19 µg L^{-1}, respectively.

3.10 Which basins are phosphorus restricted?

The phosphorus-restricted basin status was derived from two consecutive assessments (1998–2002; 1999–2003) using the methodology stated in Appendix C. Table 3.3 lists, for each assessment, the annual growing season geometric mean phosphorus concentration for each of the City reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.18 graphically depicts the phosphorus restriction status of the NYC Reservoirs and the 2003 geometric mean for the phosphorus concentration.

There are a few changes, notes, and highlights in phosphorus-restricted basin status this year.

- Schoharie Reservoir has improved since last year's assessment. The impact of flooding caused by Tropical Storm Floyd in 1999 continued to affect the calculation of the five-year average. Since this event was unusual and unpredictable and did not result in eutrophication of the reservoir, the Department utilized its best professional judgment and did not designate Schoharie basin as phosphorus restricted. The improvement seen this year's assessment (Table 3.3) occurred despite record snowfall and snow melt, and above normal precipitation during the year.
- Kirk Lake had sufficient phosphorus data in 2003 and the geometric mean is provided in Appendix C. Data from previous years were incomplete due to laboratory error, field error, or inaccessibility, and thus did not fulfill the data requirement of three complete surveys during the growing season. The assessment could not be calculated for Kirk Lake since three years out of five are required to run the five-year mean.
- Cannonsville Reservoir continues its non-restricted status.
- *New Croton Reservoir is now phosphorus restricted.* Both the 1998-2002 and the 1999-2003 assessments showed that New Croton is above the 20 µg L^{-1} criterion.

Table 3.3: Phosphorus-restricted reservoir basins for 2003.

Reservoir Basin	98 – 02 Assessment (mean + S.E.) (µg L^{-1})	99 – 03 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus-Restricted Status
Delaware System			
Cannonsville Reservoir	18.2	18.0	Non-Restricted
Pepacton Reservoir	9.2	9.4	Non-Restricted
Neversink Reservoir	5.3	5.4	Non-Restricted
Rondout Reservoir	9.0	9.0	Non-Restricted
Catskill System			
Schoharie Reservoir	21.0	19.6	Non-Restricted
Ashokan-West Reservoir	12.6	11.1	Non-Restricted
Ashokan-East Reservoir	11.8	10.8	Non-Restricted

Table 3.3: Phosphorus-restricted reservoir basins for 2003.

Reservoir Basin	98 – 02 Assessment (mean + S.E.) (µg L^{-1})	99 – 03 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus-Restricted Status
Croton System			
Amawalk Reservoir	28.7	28.1	Restricted
Bog Brook Reservoir	27.3	26.9	Restricted
Boyd Corners Reservoir	14.7	14.9	Non-Restricted
Cross River Reservoir	17.5	17.8	Non-Restricted
Croton Falls Reservoir	23.4	23.5	Restricted
Diverting Reservoir	35.0	34.1	Restricted
East Branch Reservoir	34.9	33.8	Restricted
Middle Branch Reservoir	29.8	29.5	Restricted
Muscoot Reservoir	32.5	32.5	Restricted
Titicus Reservoir	35.2	32.8	Restricted
West Branch Reservoir	11.7	12.1	Non-Restricted
Lake Gleneida	29.0	29.2	Restricted
Lake Gilead	34.6	35.0	Restricted
Source Water			
Kensico Reservoir	8.2	8.5	Non-Restricted
New Croton Reservoir	21.8	22.2	Restricted

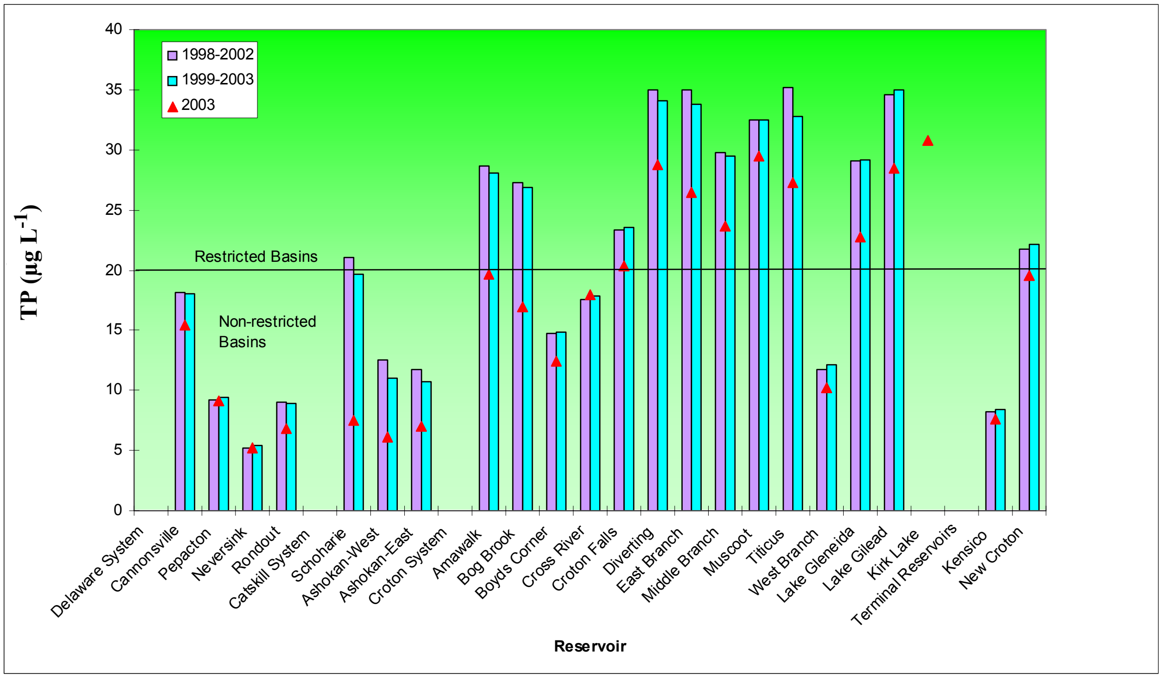


Figure 3.18 Phosphorus-restricted basin assessments, with the current year (2003) geometric mean phosphorus concentration displayed (as ▲) for comparison.

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

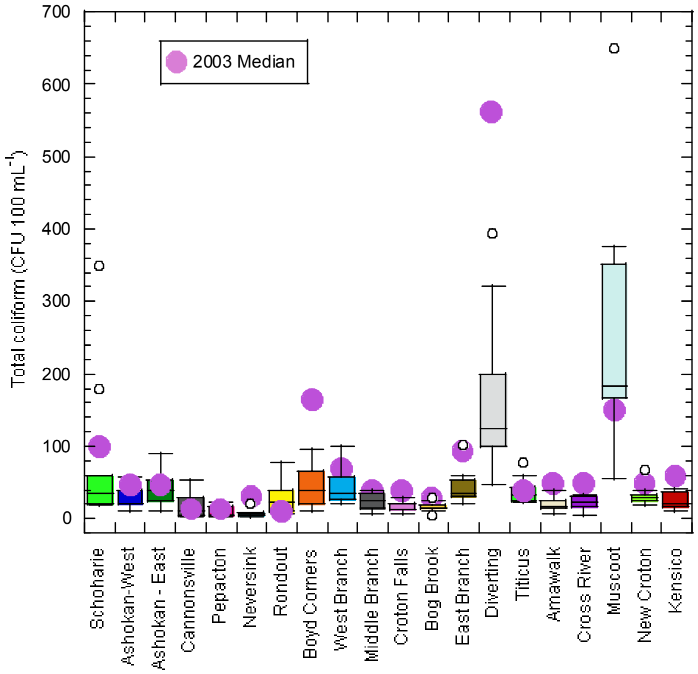


Figure 3.19 Annual median total coliform in NYC water supply reservoirs (2003 *vs.* 1994–2002).

Data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December.

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 3.19 shows that the long-term (1993-2002) annual median levels of total coliform have exceeded 100 cfu 100 mL^{-1} at times in Diverting and Muscoot Reservoirs. In 2003, Schoharie, Boyd Corners, East Branch, Diverting, and Muscoot had a median that exceeded this level. Although Muscoot's median for 2003 exceeded 100 cfu 100 mL^{-1}, the total coliform median was at the low end of the long-term range. This is unusual in that most other reservoirs were above the long-term median, probably as a result of the increased precipitation and runoff that occurred in 2003. Rondout total coliform were also at the low end of the long-term range. From a review of the temporal data, Muscoot had a distinct drop in total coliform levels as compared to past years. The East Basin of Ashokan continues to have an upward trend, while Rondout now appears to have a downward trend in total coliform counts. Although not shown in the plots, the controlled lakes (Gilead, Gleneida, and Kirk) all had elevated medians for 2003 as compared to previous years.

Figure 3.20 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, although both reservoirs had decreased levels in fecal coliform as compared to previous years. West Branch was the only reservoir that had a marked increase in fecal coliform in 2003. The controlled lakes all had median levels of fecal coliform in 2002 that were comparable to past data. The fact that water from Rondout was bypassing the reservoir during the end of the year probably affected the fecal coliform levels (see section 3.13 for further explanation). Another noteworthy increase, albeit small, was seen in Kensico.

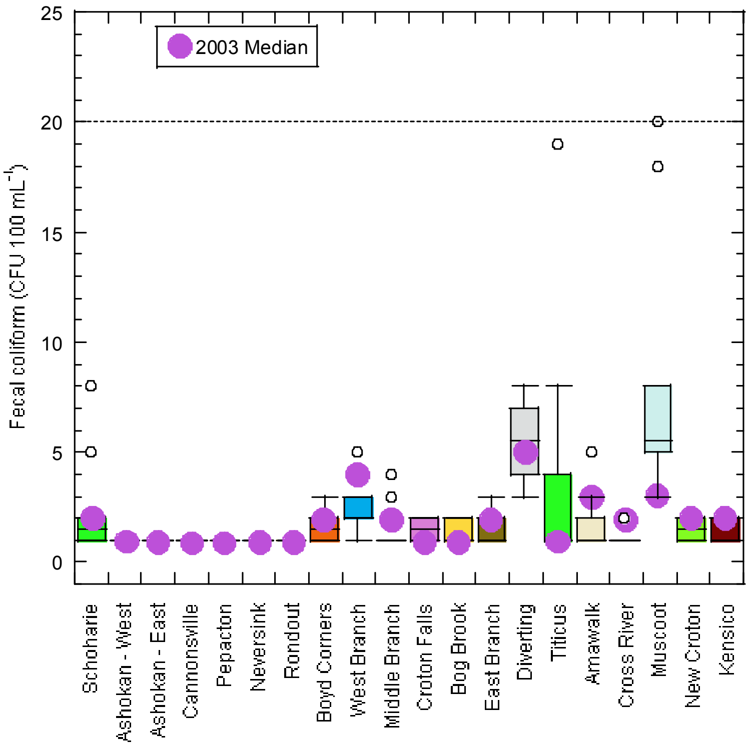


Figure 3.20 Annual median fecal coliform in NYC water supply reservoirs (2003 *vs.* 1994–2002).

The dashed line represents the SDWA standard for <u>source waters</u> as a reference. Data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December.

3.12 Which basins are coliform restricted?

New York City DEP's Watershed Rules and Regulations (WRR) 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 WRR regulations 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 2003 under Section 18-48(b)(1) using *fecal* coliform data at the effluent keypoints (Table 3.4). 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 100 mL^{-1}. If

10% of the effluent samples measured had values ≥ 20 cfu 100 mL^{-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 ≥ 20 cfu 100 mL^{-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 bacteria come from a variety of natural and anthropogenic sources, so using total coliform alone will not meet the spirit of the regulation. DEP has developed a draft methodology for determining coliform-restricted basins for these non-terminal reservoirs that 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. DEP is awaiting approval to proceed with the new methodology, before conducting the analysis; therefore, coliform-restricted basins have not been determined for the non-terminal reservoirs for 2003.

Table 3.4: Coliform-restricted basin status as per Section 18-48(b)(1) for 2003.

Reservoir Basin	**Effluent Keypoint**	**2003 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 keypoint data used in the 2003 assessment were not complete. The site CROGH provided data from January through June showing no coliform restriction during that six month period; the remainder of the year was only represented from July through September, so 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. There were not enough samples analyzed to meet this criterion.

3.13 How was conductivity in the reservoirs affected by the increased precipitation and runoff?

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. 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-sided, 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.

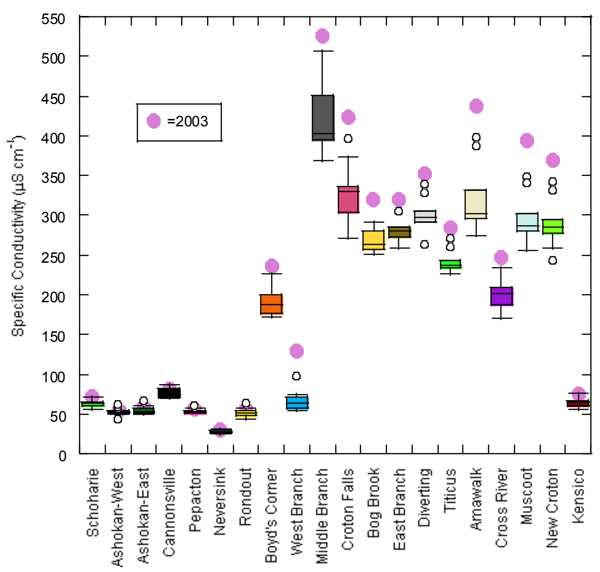


Figure 3.21 Annual median conductivity in NYC water supply reservoirs (2003 *vs.* 1993–2002).

Data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December.

The high runoff and precipitation for the year had little impact on the Catskill and Delaware System reservoirs, which had uniformly low median conductivities in 2003, as in previous years (Figure 3.21). These reservoirs, located west of the Hudson River, are in mountainous terrain underlain by relatively insoluble deposits, which produce extremely low conductivities in the 50 to 100 µS cm^{-1} range. Because West Branch and Kensico, located east of the Hudson River, 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 as well. However, in 2003 the median conductivity at West Branch increased to 130 µS cm^{-1} from a historical median of 64 µS cm^{-1}, a one-year increase of 102 percent. The increase is largely due to operational changes of the Delaware Aqueduct System. Normally water flows from Rondout Reservoir to West Branch via the Delaware Aqueduct, through West Branch and then down to Kensico. However, during two time periods in 2003 the Delaware Aqueduct was either shut down for inspection (January 18–24) or West Branch was bypassed to avoid elevated coliform counts in the reservoir (September 18–November 14). For either operational scenario, water from Rondout does not flow into West Branch. Without input from Rondout, the much more conductive Boyd Corners Reservoir (median conductivity of 237 µS cm^{-1} in 2003) becomes the largest input to West Branch and explains the higher conductivities observed in 2003.

Reservoirs of the Croton System, located east of the Hudson River, have higher base-line 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 easily soluble 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 2003, conductivity in the Croton System reservoirs increased from 14 to 49 percent compared to the historical ten-year median.

For similar reasons conductivity also increased in the controlled lakes of the Croton System (not shown in Figure 3.21). At Gilead Lake and Lake Gleneida conductivity was measured from 1995-2003. The past (1995-2002) median conductivity increased from 147 to 175 µS cm^{-1} in 2003 at Gilead and from 301 to 350 µS cm^{-1} at Gleneida. The 2003 median conductivity at Kirk Lake is 318 µS cm^{-1} compared to a median of 199 µS cm^{-1} determined from samples collected from1995-2002 (no samples were collected in 2000 or 2001).

3.14 How did source water quality compare with standards?

Table 3.5 depicts 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. There are several noticeable differences in New Croton Reservoir as compared to the other three. The pH tends to be higher because of primary production, which at times can cause measurements to be above the pH upper water quality standard of 8.5. Low alkalinity in the WOH reservoirs provides little buffering of acidic precipitation, causing some pH readings to be below the lower standard of 6.5 at times. The major cations were not available for comparison in the EOH reservoirs, but are generally higher, as are the consequent variables—alkalinity, hardness, and conductivity. Chloride levels have increased in New Croton as compared to last year, but remain well below the 250 mg L^{-1} standard. Higher nutrient inputs caused higher chlorophyll *a* and phytoplankton levels in New Croton, which at times caused the phytoplankton to exceed the DWQC internal limit of 2000 standard areal units (SAU). Likewise, the total phosphorus (TP) data summary demonstrates that TP exceeded the guidance value of 15 mg L^{-1} for source waters. The increased productivity also caused higher turbidity levels and lower Secchi disk transparency. Ashokan's East Basin was the only impoundment in Table 3.5 that exceeded 5 NTU for turbidity. However this was not due to primary productivity, but rather suspended particulates from the watershed. There are also higher levels of discoloration, iron, manganese, and organic carbon in New Croton. At times, water quality standards for these variables can be exceeded (with the exception of organic carbon). In contrast, Kensico's water quality is reflective of the large majority of water it receives from Rondout and Ashokan Reservoirs.

Table 3.5: Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the four source water reservoirs.

ANALYTES:	Water Quality Standard	Kensico Reservoir	New Croton Reservoir	East Ashokan Basin	Rondout Reservoir
PHYSICAL					
Temperature (C)		9.5	12.3	9.27	8.8
pH (units)	6.5-8.5[1]	6.9	7.4	6.985	6.47
Alkalinity (mg L^{-1})		11.1	60.2	10.3	5.98
Conductivity		77	370	60.35	55.35
Hardness (mg L^{-1})				16.32	15.73
Color (Pt-Co units)	(15)	10	22	9	13
Turbidity (NTU)	(5),[2]	1.2	2	1.3	1.1
Secchi Disk Depth (m)		4.9	2.9	4.2	4.3
BIOLOGICAL					
Chlorophyll *a*	7[3]	7.35	14.2	7	6.3
Total Phytoplankton (SAU)	2000[3]	330	580	190	180
CHEMICAL					
Dissolved Organic Carbon (mg L^{-1})		1.6	3.1	1.6	1.65
Total Phosphorus	15[3]	8	20	8	7
Total Nitrogen (mg L^{-1})		0.3	0.612	0.2	0.27
Nitrate+Nitrite–N (mg L^{-1})	10[1]	0.144	0.216	0.0985	0.2195
Total Ammonia–N (mg L^{-1})	2[1]	0.019	0.0285	0.03	0.004
Iron (mg L^{-1})	0.3[1]		0.095	0.045	0.04
Manganese (mg L^{-1})	(0.05)		0.05	0.043	0.0445
Lead (µg L^{-1})	50[1]	0.25	0.25	0.5	0.25
Copper (µg L^{-1})	200[1]	1.4	1.2	2.5	1
Calcium (mg L^{-1})				5.25	4.485
Sodium (mg L^{-1})				3.57	3.85
Chloride (mg L^{-1})	250[1]	10	69.1	7.15	5.76

Note: See Appendix A for explanation of symbols, data for other reservoirs, and references.

3.15 What are the trophic states of the City's 19 reservoirs and why is this important?

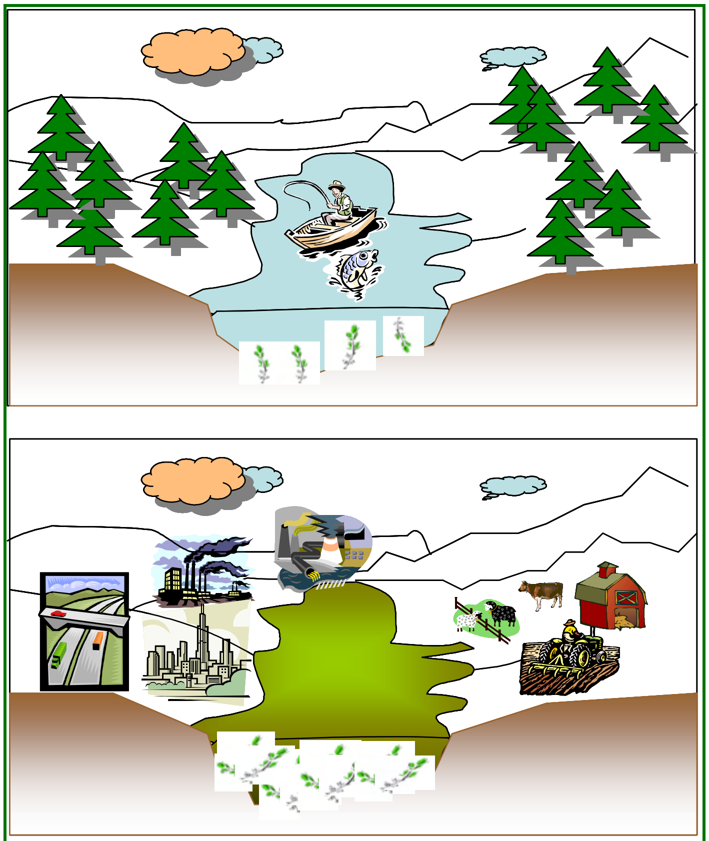


Figure 3.22 a) Pristine watershed produces water of high quality (oligotrophic). b) Disturbed watersheds produce water of low quality (eutrophic).

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 (Figure 3.22). Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (i.e., chlorophyll *a*, total phosphorus, and Secchi disk) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

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

where CHLA is the concentration of chlorophyll *a*

The Carlson Trophic State Index ranges from approximately 0 to 100 (there really 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 is 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.

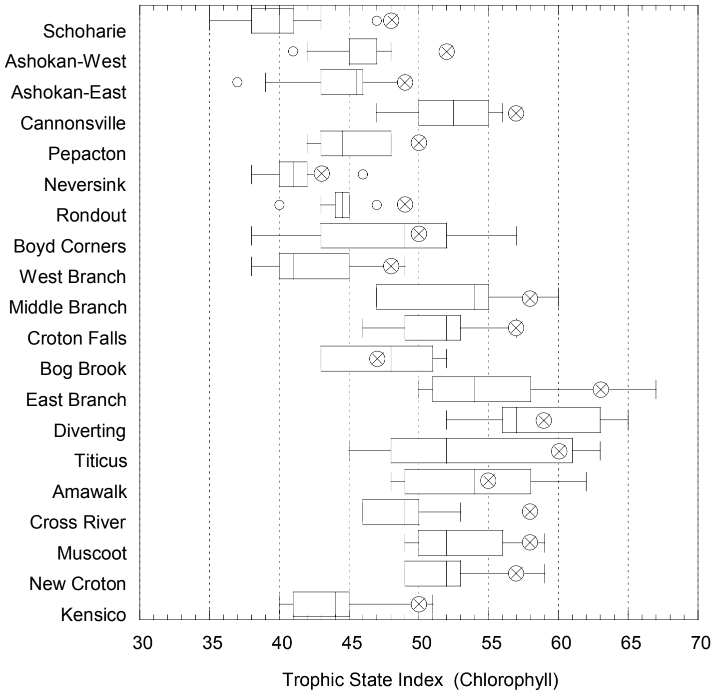


Figure 3.23 Box plots of annual Trophic State Index (1993–2002) and 2003 value (as x) for New York City reservoirs, based on chlorophyll *a* concentration.

Past annual median TSI based on chlorophyll *a* concentration is presented in box plots for all reservoirs in Figure 3.23. The 2003 annual median TSI appears in the figure as a circle containing an “x”. As a result of this analysis some reservoirs (Cannonsville, East Branch, Diverting, Muscoot, Titicus, Amawalk, Croton Falls, New Croton) can be classified as eutrophic in most years. The remaining reservoirs can usually be classified as mesotrophic. In 2003, median TSI values for most reservoirs appeared to be elevated compared to past data. The increase at West Branch is explained by operational changes, which resulted in more eutrophic water entering West Branch from Boyd Corners Reservoir relative to past years. The reason for the increase at the other reservoirs is not clear. Apparently, conditions (i.e., temperature, clarity, and nutrient levels) were favorable for algal growth in 2003.

3.16 What are disinfection by-products, where do they come from, and how are they regulated?

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. The USEPA has set limits on these groups of DBPs.

In January 2002, the Stage 1 Disinfectant/Disinfection by-products (D/DBP) rule took effect, lowering the Maximum Contaminant Level (MCL) for TTHM to 80 $\mu g\ L^{-1}$ and establishing a new MCL for five haloacetic acids (HAA5) of 60 $\mu g\ L^{-1}$. The Stage 1 Rule requires monitoring to be conducted quarterly from designated sites in the distribution system. The MCL is calculated as a running annual average based on quarterly samplings over a 12-month period. The 2003 annual running quarterly averages are presented in Table 3.6 and show system compliance for TTHM in both the Catskill/Delaware and Croton Systems but MCL violations of HAA5 for the 2nd and 4th Quarters of 2003 in the Croton System.

Table 3.6: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations ($\mu g\ L^{-1}$) for 2003.

	Catskill/Delaware		Croton	
2003 Quarter	TTHM	HAA5	TTHM	HAA5
1st	31	37	52	57
2nd	32	41	56	**65**
3rd	31	42	56	60
4th	34	45	49	**62**
MCL	80	60	80	60

Note: Averages in bold face indicate MCL violations.

3.17 Have the turbidity improvements in the Schoharie watershed been maintained?

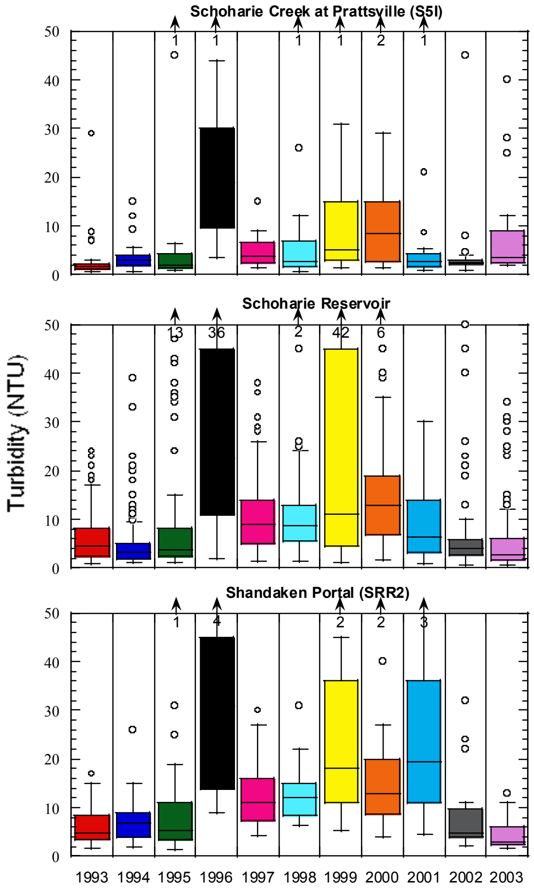


Figure 3.24 Box plot of turbidity values by year (1993–2003) for a) Schoharie Creek at Prattsville (S5I), b) Schoharie Reservoir, c) Shandaken Portal (SRR2).

On January 18-19, 1996, heavy rains fell on a substantial snow pack, which, along with unseasonably mild temperatures, resulted in widespread flooding in New York. The most severely affected region was within and surrounding the Catskill Mountains. This event had a major impact on water quality. In the Schoharie watershed, turbidity levels remained elevated compared to pre-flood levels (Figure 3.24), whereas turbidity returned to pre-flood levels in the Esopus watershed relatively quickly.

The storm apparently caused changes in the Schoharie watershed that enhanced the system's ability to entrain turbidity-causing material. This enhanced ability to mobilize turbidity-causing material under all flow conditions in the Schoharie watershed resulted in the sustained elevated turbidity levels observed in the Schoharie Reservoir and the Shandaken Tunnel. It would appear that beginning in 2001 and continuing into 2003, the turbidity levels in the Schoharie watershed have returned to pre-1996 levels. While the median turbidity at the Schoharie Creek at Prattsville was slightly higher in 2003 than 2002, this was most likely due to increased runoff from the excess precipitation in 2003. The 2003 data for the reservoir and tunnel show that the turbidity improvement has been maintained.

3.18 How does DEP use aquatic biota to monitor water quality?

DEP utilizes the sampling and data analysis methods developed by NYSDEC's Stream Biomonitoring Unit, and conducts a stream biomonitoring program under a Division-approved Quality Assurance Project Plan (QAPP). Stream benthic macroinvertebrates are collected from riffle habitat using the traveling kick method, and subsamples of 95–115 organisms are sent to a contractor for identification to the genus or species level. Four analytical metrics—total taxa richness, EPT richness (the total number of taxa from the orders of mayflies, stoneflies, and caddisflies), biotic index, and percent model affinity—are calculated, normalized, and averaged to derive a final water quality score from the subsample. Water quality scores of 7.5 and above reflect excellent water quality, while scores below 7.5 may indicate impaired water quality and/or habitat conditions. For quality control purposes, replicate subsamples are occasionally analyzed from a single raw sample. A full description of the field, lab, and data analysis methods are given in the program's QAPP.

3.19 How do biotic index scores vary along a transect of Schoharie Creek?

DEP began biomonitoring of Schoharie Creek in 1994, at a site located near the Hunter-Jewett Town line. In 1995, sampling began at Prattsville, approximately 20 kilometers downstream of the Hunter-Jewett site, at a location immediately above Schoharie Reservoir. Water quality scores at this site in the first six years of sampling were historically low for the Catskills Region; the mean score of 7.4 over the 1995-2000 period placed it just below the 7.5 non-impaired/slightly impaired threshold. The mean water quality score for the Hunter-Jewett site, on the other hand, was 8.3 for the 1994–2000 period, well into the non-impaired region. A third site, located at Lexington approximately halfway between the other two sites, was added in 1996; its mean water quality score for the 1996–2000 period was 7.8. This site, at the downstream end of a streambank stabilization project constructed in 1997, experienced particularly variable scores during these years, an outcome presumably attributable at least in part to stabilization of the biotic community following installation of the BMP. DEP had no explanation for the declining scores between Hunter and Prattsville, as land use remains relatively constant throughout the reach and there are no point-source discharges to Schoharie Creek between these sites. In an effort to narrow the search for the reach where water quality scores appear to change, DEP sampled a seven-site transect on the Creek between Prattsville and Elka Park in 2001 and 2002 (Figure 3.25). Three of the four new sites were added above the Hunter-Jewett site, while the remainder was located a short distance below Lexington. In 2003, DEP revisited these sites (except for one site in Hunter, which could not be sampled because of high water), as well as a new one situated approximately five kilometers above Prattsville, just downstream of a large failing streambank. DEP believed that if sediment loading from the streambank was contributing to the suboptimal community downstream, it might be more readily detectable by sampling immediately below the suspected source of impairment.

The results of the 2001–2003 survey are generally consistent with the initial observation that water quality scores begin to decline somewhere below the Hunter-Jewett (Site 202)/Lexington (Site 216) reach (Figure 3.25). The three sites added above Site 202—at Elka Park (Site 237), Rte. 214 (Site 238), and in Hunter itself at Bridge St. (Site 239)—had mean scores of 8, 7.9, and 8.6, respectively, all in the non-impaired range. Mean scores at Sites 202 and 216 remained non-impaired—8.4 and 8.2, respectively. The two sites added below Site 216—the streambank site first sampled in 2003 (Site 242) and the site located a short distance below Lexington (Site 240)—were both rated slightly impaired (Site 242—6.9, Site 240—mean, 7.3). The Prattsville site (Site 204) continued slightly impaired, with a mean score of 7.3.

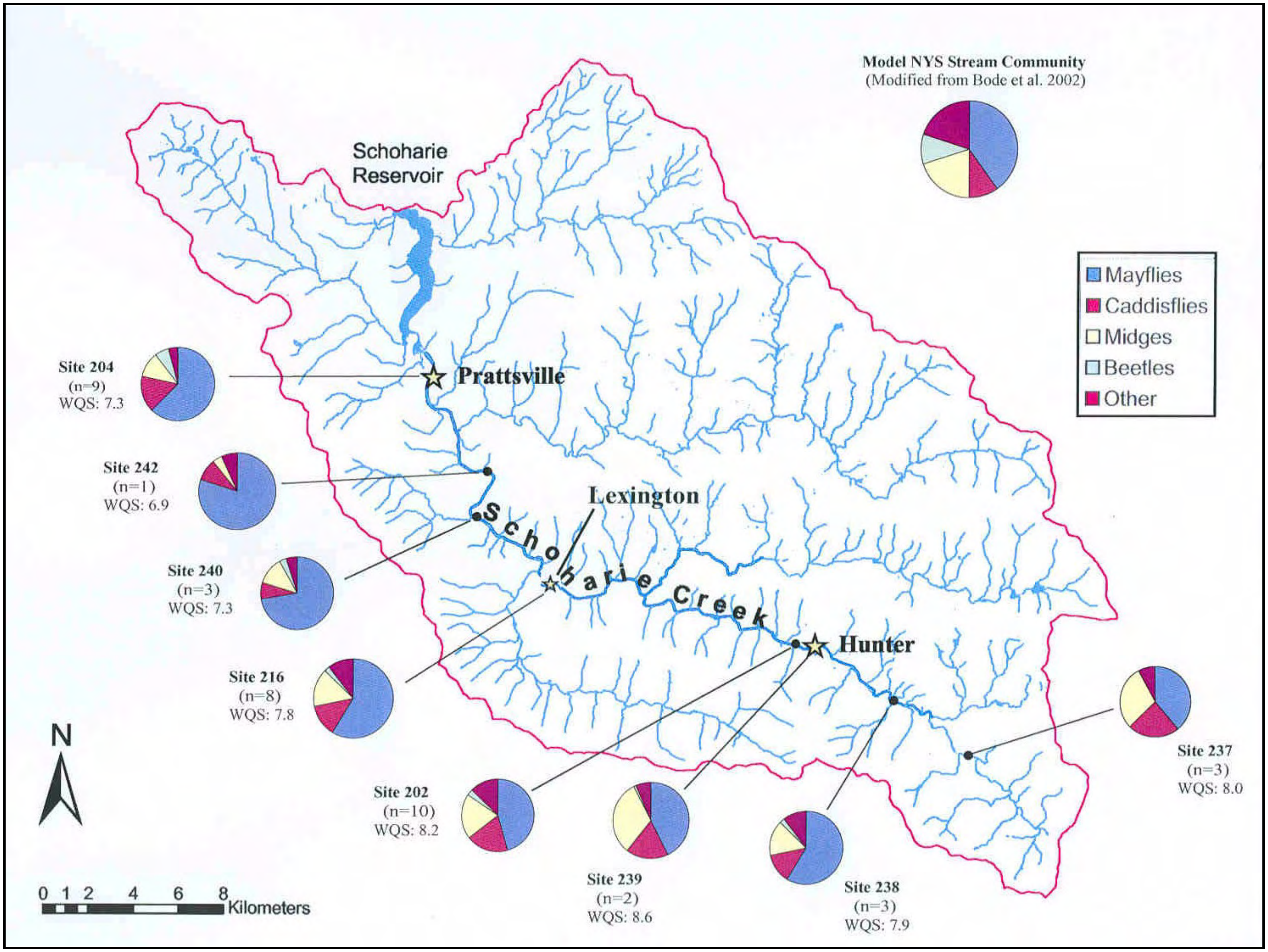


Figure 3.25 Biomonitoring sites on Schoharie Creek, showing mean percent composition of the macroinvertebrate community at each site.

Note: The NYSDEC model stream community is shown for comparison. It has been modified to make it consistent with the DEP graphs by including Plecoptera and Oligochaeta in the Other category. WQS = mean water quality score. Scores range from 0-10, with those falling below 7.5 indicative of impairment.

Figure 3.26 Biomonitoring site on Schoharie Creek at Prattsville.

Figure 3.27 Biomonitoring site on Schoharie Creek at Elka Park.

Figure 3.28 *Isonychia* sp., a common mayfly in Schoharie Creek.

A review of the metric data suggests that high mayfly dominance at the downstream sites (240, 242, 204) may be depressing both their percent model affinity and taxa richness scores, which in turn may be contributing to an overall reduction in water quality assessment scores at these sites (Figure 3.25). The underlying cause of the high percentage of mayflies at sites downstream of Lexington, however, is not clear, and needs to be investigated further. It is also probably true that the low richness scores below Lexington are not simply an expression of mayfly dominance, which likely results in the exclusion of less common taxa from the subsample, but also reflect actual differences in taxa numbers between upstream and downstream sites. The uncertainty over whether fewer taxa are indeed present downstream is attributable to the fact that these sites have in general been sampled less frequently than those upstream; in lotic systems, taxa richness is typically related to sampling effort (Allan 1995). Thus, additional sampling will be required to establish whether downstream sites do in fact support a reduced macrobenthic fauna.

In an effort to determine the causes of observed differences, DEP analyzed macroinvertebrate community data from all sites using the Impact Source Determination procedure developed by the New York State Stream Biomonitoring Unit to identify the source of impacts to suboptimal stream communities (Bode et al. 2002). Impacts assessed using this procedure include siltation, nonpoint nutrient, pesticide, municipal, industrial, sewage, animal waste, and impoundment. No impacts to Schoharie Creek were detected. (This includes no impacts from siltation to the site located below the failing streambank (Site 242).) All samples collected in 2002 and 2003 were most similar to naturally occurring communities.

Figure 3.29 *Ephemerella* sp., another common Schoharie Creek mayfly.

DEP will continue sampling the Schoharie Creek transect, focusing more of its efforts on the reach between 202 and 240, where the most pronounced changes in water quality scores and community composition appear to occur. Continued sampling will also allow DEP to reduce some of the considerable variability in its data and resolve the issue of low taxa richness at sites below Lexington.

4. Watershed Management

4.1 How can watershed management improve water quality?

The large contiguous forests of the WOH watersheds provide New York City with some of the best drinking water in the country. However, the water supply watersheds also contain farms, villages, ski resorts, golf ranges, and all the roads and buildings associated with human uses of the landscape. Increasing human population on the land is often associated with degradation of water quality and aquatic ecosystem health (e.g., the U.S. Geological Survey Fact Sheet 042–02 at http://water.usgs.gov/pubs/fs/fs04202/). Watershed management activities described in this chapter include those programs initiated and/or supported by DEP that mitigate adverse water quality impacts associated with human land uses. Management programs can be broadly classified as protective (anti–degradation) and remedial (reduction in pollution from identified sources). Protective programs include the Land Acquisition program and the Conservation Easement program. These programs seek to protect water quality now and preserve water quality for the indefinite future. The WWTP Upgrade program and the Septic System Rehabilitation Program are two examples of efforts to reduce or eliminate identified pollution sources.

In most cases, the beneficial water quality impacts of specific management programs are difficult to demonstrate. In the WOH watersheds, this is due in large part to the fact that water quality is already excellent, and improving already excellent water quality is hard to achieve, let alone conclusively prove. Documenting the persistence of excellent water quality in the streams and reservoirs assures that water quality is not degrading, which could be considered one success of the management programs. The following sections present brief summaries of some of the protective and remedial programs along with a summary of water quality in the reservoirs of each System. More information on the management programs can be found in the 2003 FAD Annual Report (NYCDEP 2004a). Information on research programs in the watershed can be found in the 2003 Research Objectives Report (NYCDEP 2004b).

Figure 4.1 The forested banks of the Esopus Creek.

4.2 What are the watershed management efforts in the Catskill System to improve water quality?

The Catskill System consists of the Ashokan and Schoharie basins. While several management programs are active in these watersheds, this report will update those programs which were discussed in the 2002 Watershed Water Quality Annual Report.

Wastewater Treatment Plant Upgrade Program – The vast bulk of the wastewater flows in this System (78%) come from NYC–owned facilities, all three of which were upgraded by the end of 1998 (Figure 4.2). Twelve percent of the currently permitted wastewater flow in the Catskill System will be captured by the New Infrastructure Program.

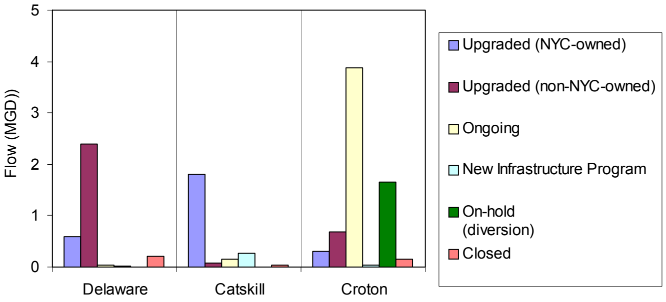


Figure 4.2 The status of the Wastewater Treatment Plant Upgrade Program through 2003.

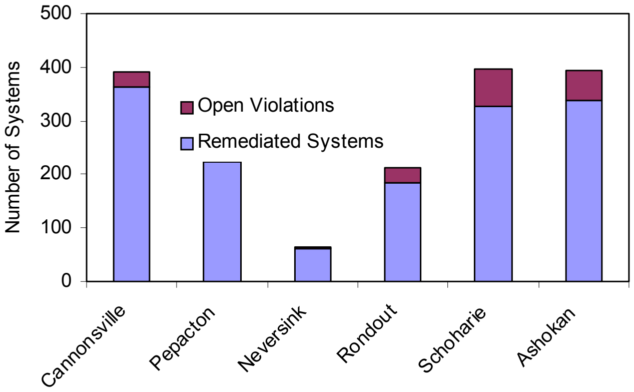


Figure 4.3 Remediated septic systems and systems with open violations since the inception of the program, 1997–2003.

Septic System Rehabilitation Program – Figure 4.3 illustrates the current status of the Septic System Rehabilitation Program. The number of remediated septic systems increased 12% from the end of 2002 throughout both the Ashokan and Schoharie watersheds. This program is managed by the Catskill Watershed Corporation (CWC) in conjunction with DEP.

Stormwater Retrofit Program– Four additional stormwater retrofit projects were completed in 2003 for a total of 16 projects, all located in the Schoharie Reservoir watershed (Figure 4.4). Eight new grants have been awarded for planning and assessment of stormwater retrofit projects. Two of those grants went to projects in the Ashokan Reservoir watershed. This program is managed by the Catskill Watershed Corporation in conjunction with DEP.

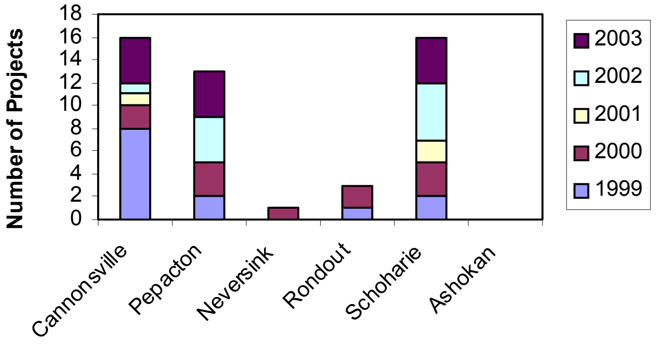


Figure 4.4 The number of completed stormwater retrofit projects by year.

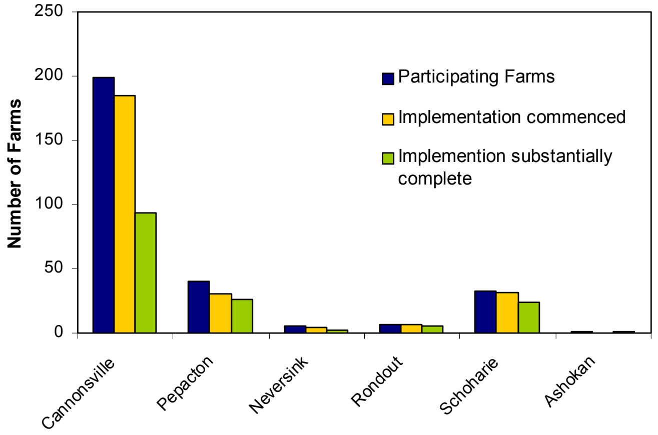


Figure 4.5 The number of farms participating in the Watershed Agricultural Program and the farms' implementation status per reservoir basin through 2003.

Watershed Agricultural Program – Thirty–four farms located in the Catskill System are participating in the Watershed Agricultural Program, which is a voluntary partnership program between the City and the farms. Implementation has commenced on 32 farms and is substantially complete on 25 of them (Figure 4.5). This program is administered by the Watershed Agricultural Council (WAC).

Watershed Forestry Program – Ninety–three private landowners in the Catskill watershed system have completed WAC forest management plans. These 93 plans represent 13,667 total acres, of which 11,957 acres are forest land. Twenty–two road BMP projects have also been completed in the Catskill system. These 22 projects include the proper design and installation of 11 new timber harvest access roads with associated BMPs, and the repair and remediation of 11 existing forest access roads having documented erosion problems.

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

A preponderance of the remediation programs WOH occur in the Cannonsville Reservoir watershed (Figures 4.2 and 4.5). If an actual water quality effect of the programs could be discerned in DEP's monitoring data, it would likely be in that basin, specifically in the West Branch Delaware River. Analysis of total phosphorus concentrations in the West Branch Delaware River over the period 1997–2003 suggest that concentrations are decreasing at the lower sampling sites in the river. A positive signal from the myriad watershed management programs, many of them targeted at nutrient reduction, does appear to be present in this major tributary. A summary of the status of some of the management programs follows.

Wastewater Treatment Plant Upgrade Program – Approximately 99% of the permitted wastewater flow in the Delaware System has either been closed or upgraded (Figure 4.2). The remaining facilities are a school (due to be upgraded in 2004) and some small seasonal facilities, some of which may opt to discharge subsurface.

Figure 4.6 Sand filter portion of a stormwater retrofit installed at the Margaretville Central School bus garage, Pepacton Reservoir watershed.

Septic System Rehabilitation Program – The number of septic systems that have either been remediated, replaced or identified as "Open Violations" totals 913, an increase of 6% over 2002 totals (Figure 4.3). This is an example of the aforementioned likelihood that as these programs progress, the annual number of identified and remediated problems will decrease.

Stormwater Retrofit Program – The total number of approved stormwater retrofit projects rose to 33 at the end of 2003. Three grants for planning and assessment of future projects were awarded in the Cannonsville and Pepacton watersheds. A new DEP/CWC Partnership monitoring program to assess the effectiveness of stormwater retrofits in Roxbury, Margaretville, and Walton is in the process of being implemented (Figure 4.6).

Watershed Agricultural Program – Two hundred and fifty farms are currently participating in the Watershed Agricultural Program in the Delaware System, and implementation of plans is substantially complete on 50% of them (Figure 4.5). Throughout the WOH watersheds, the Watershed Agricultural Council has identified 296 commercial farms (those earning more than $10,000 in gross annual agricultural sales), and 284 of those are participating in the Program. Thirty-five farms in the Delaware System have been designated as "inactive" due to gross annual sales not achieving the $10,000 threshold.

Watershed Forestry Program – Two hundred and seventy–two private landowners in the Delaware watershed system have completed WAC forest management plans. These 272 plans represent 55,429 total acres, of which 42,326 acres are forest land. Thirty–six road BMP projects have also been completed in the Delaware System. These 36 projects include the proper design and installation of 15 new timber harvest access roads with associated BMPs, and the repair and remediation of 21 existing forest access roads having documented erosion problems (Figure 4.7).

Figure 4.7 A properly installed timber harvest road culvert, a project of the Forestry Management Program, Neversink Reservoir watershed.

4.4 What is the link between watershed management and water quality in the Croton System?

In the Croton System, DEP provided funds to Putnam and Westchester Counties to support projects identified by the counties, rather than directly setting up and managing individual programs as in the WOH Systems. In 2003, both counties submitted drafts of the Croton System Water Quality Protection Plan for DEP review. This Plan provides a foundation for identifying and prioritizing projects which may be eligible for Water Quality Investment Program Funds as provided in the Memorandum of Agreement (MOA) between New York City and the watershed communities. A brief description of several projects that have been funded or approved for funding over the last year follows.

Peach Lake Wastewater – Peach Lake straddles the eastern border of Westchester and Putnam Counties. Once primarily a seasonal community, the Peach Lake area has evolved to a fairly built–up community of full–time dwellings still using individual septic systems on substandard-sized lots. A $150,000 study of wastewater management in the community around Peach Lake was begun to examine options and water quality benefits.

Septic Repair Licensing – Westchester County has requested approximately $500,000 to create a licensing and database program for people who conduct any repair or replacement of septic systems, including pumpouts.

Septic System Repair – Putnam County signed an agreement to authorize $3.3 million toward a program for septic system repair with a particular focus on areas located in the West Branch, Boyds Corner, and Croton Falls watersheds.

Land Acquisition – Putnam County used Water Quality Investment Program Funds to take ownership of land on the Tilly Foster Farm, at Mahopac Airport, and at a local golf course.

Stormwater Management – Putnam County has purchased three vacuum trucks to clean streets and maintain stormwater infrastructure, and has allocated funds to implement some drainage improvement projects in the towns of Carmel and Southeast.

Watershed Agricultural Program – This program has signed up 18 farms in the Croton System, and all have approved Whole Farm Plans. Twelve of these farms have commenced implementation of Best Management Practices (BMPs), and six of the farms are substantially complete.

Watershed Forestry Program – Nine private landowners in the East-of-Hudson watershed have completed WAC forest management plans. These 9 plans represent 534 total acres, of which 464 acres are forest land. One private landowner in Westchester County has completed a Timber Harvest Road BMP Project, which represents the proper design and installation of a forest access road and associated BMPs during an active timber harvest operation.

Most of the Wastewater Treatment Plants (WWTPs) in the Croton System are in the process of being upgraded to comply with the Watershed Rules and Regulations (WRRs) (Figure 4.2). Four non–City–owned facilities, comprising 10% of the total permitted wastewater flow in the System, have completed their upgrades. Six facilities, including three currently discharging subsurface, are being considered for diversion to existing plants or out of the Croton watershed entirely. A new WWTP planned for the Village of Patterson will take care of two subdivisions with poorly operating wastewater treatment systems as well as other areas with problematic subsurface disposal.

4.5 What information can case studies provide?

The preceeding sections discussed watershed management programs generally and in broad watershed–scale terms. Often, to observe the actual effect that management programs have, it is necessary to look closely at specific programs. This section presents some specific programs as examples of the broader efforts to protect or improve water quality.

Upgrade of the Delhi Village Wastewater Treatment Plant

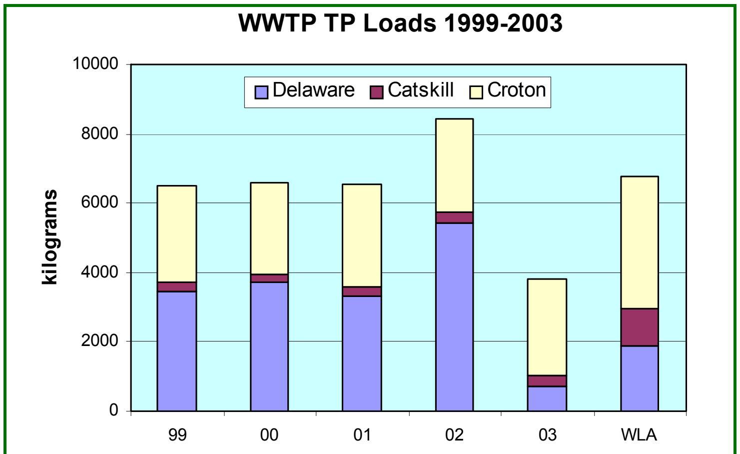


Figure 4.8 Total phosphorus loads from WWTPs by System (1999–2003).

The Wasteload Allocation for the entire watershed is shown in the right–hand bar for comparison.

The WRRs require that surface–discharging WWTPs upgrade their treatment processes to include phosphorus removal and microfiltration of pathogenic protozoans. As documented in previous reports, these upgrades have had measurable impacts on phosphorus loads from WWTPs. Figure 4.8 illustrates the sum of all the total phosphorus loads from surface–discharging WWTPs over the 1999–2003 period. The currently permitted wasteload allocation (WLA) or the sum of the loads if all WWTPs discharged at their maximum permitted flows and maximum permitted total phosphorus concentrations—is shown in the final right–hand stacked bar. In last year's Watershed Water Quality Annual Report, an increase in WWTP total phosphorus loads was apparent from the 2001 to 2002 period. This increase was largely due to a substantial increase in the total phosphorus load from a single WWTP, the one serving the Village of Delhi.

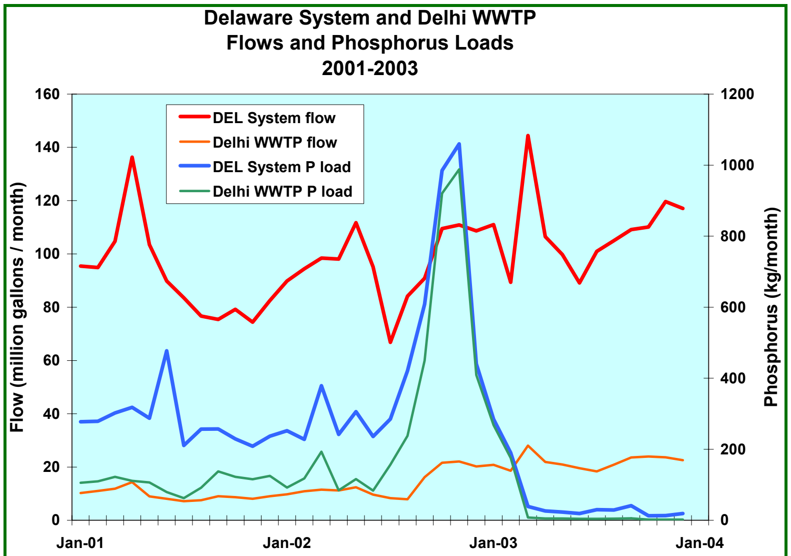


Figure 4.9 Comparison of flows and total phosphorus loads between the Delhi WWTP and all Delaware System plants combined.

In 2002, two dairy product manufacturing facilities which had been disposing of high strength secondary treatment effluent via spray irrigation were connected to the Village of Delhi's WWTP. Concurrently, the WWTP was upgrading its treatment process. The connection of the dairy manufacturers was completed prior to completion of the upgrade, and immediately the WWTP's effluent flows and total phosphorus concentrations increased. This led to an approximately five month spike in the total phosphorus load from the WWTP occurring near the end of 2002 (Figure 4.9). The upgrade was completed in early 2003, and as with all the WWTPs that have been upgraded, loads dropped. In Figure 4.9, the loads from Delhi's WWTP and the sum of the loads of all WWTPs in the Delaware System closely follow each other during the spike–and–decline period.

Pollutant Removal Efficiencies at Kensico Reservoir BMPs

DEP has developed a comprehensive storm water management plan for the Kensico Reservoir watershed, a key terminal reservoir in the water supply system. This plan includes the construction of extended detention basins on several streams draining the relatively urbanized area around the reservoir. The goal of this plan is to reduce the loads of fecal coliform bacteria and turbidity delivered to the reservoir from these streams during storm events. A monitoring program was initiated in 2000 with the goal of determining the effectiveness of these extended detention basins at reducing loads of fecal coliform, turbidity, total suspended solids (TSS), and total phosphorus delivered to the reservoir during storm events. Since that time, storm monitoring was completed at BMP 12 (at Malcolm Brook), and is ongoing at BMP 37 (at stream N5). To determine the removal efficiency, the Regression of Loads technique (Martin and Smoot 1986) was employed. Using this technique, inflow loads were plotted against outflow loads, and a regression line applied to the data. The removal efficiency could then be calculated by subtracting the slope of the regression line from 1 and reporting the value as a percentage. For individual storm events, a BMP's removal efficiency is calculated as follows:

$$\text{Efficiency} = [(\text{Inflow Load} - \text{Outflow Load})/\text{Inflow Load}] \times 100$$

Figures 4.10 and 4.11 display the BMP removal efficiencies calculated during each storm event monitored during the program. These data indicate that while the BMPs are effective at reducing the loads of analytes delivered to the reservoir during storm events, their effectiveness is quite varied from storm to storm, and from season to season. The best removal rates were identified for the analyte TSS, which is not surprising, as the basins are designed to allow materials to settle and be removed from the water column before being discharged to the reservoir. Smaller-sized particles, such as fecal coliform and the fine-grained sediments that cause the greatest turbidity values to be recorded, stay in suspension longer and are not removed by the BMP as well as the larger-sized particles that make up the bulk of the TSS loads.

Additional monitoring will continue at BMP 37 during 2004, allowing DEP's data collection to be finalized for that site. Monitoring will be relocated to another BMP facility during 2005.

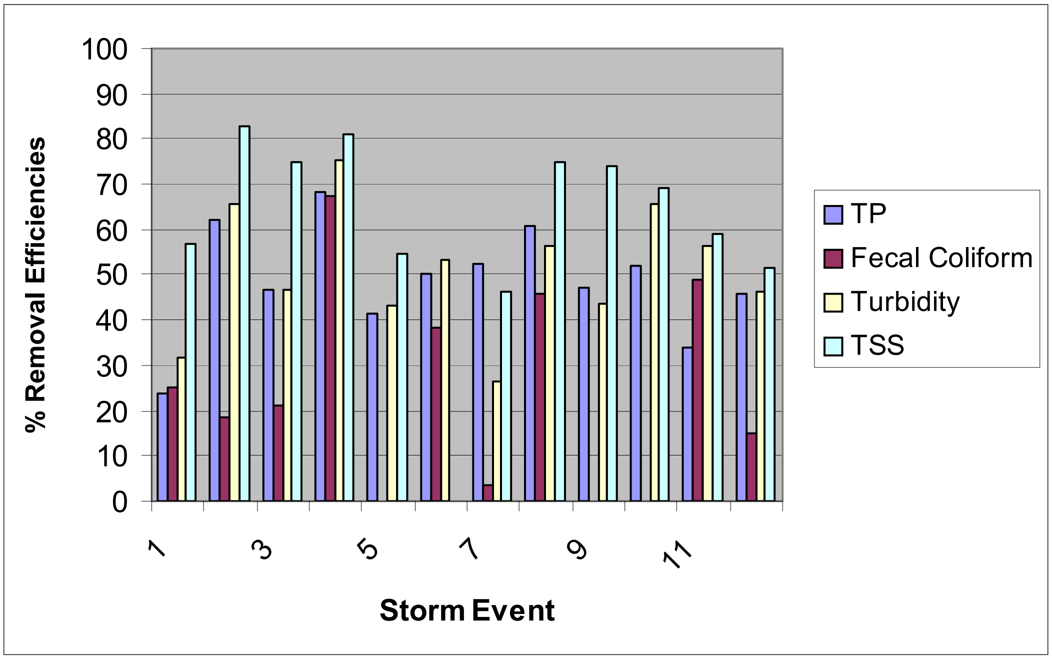


Figure 4.10 Pollutant removal efficiencies documented at Kensico Reservoir BMP 12.

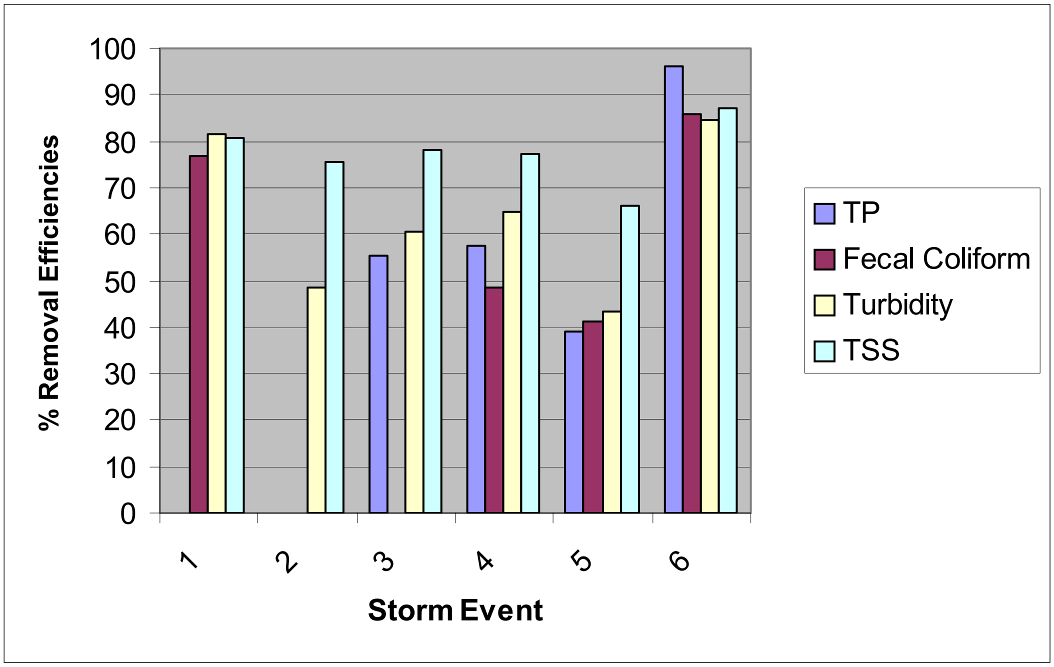


Figure 4.11 Pollutant removal efficiencies documented at Kensico Reservoir BMP 37.

4.6 How does DEP develop watershed management plans?

Management plans developed by DEP range from broad policy documents to specific goals for implementation. In 2003, DEP drafted a General Land Management Plan laying out the overall management priorities for NYC–owned lands associated with the water supply. Forest Management Plans are being developed for specific silvicultural projects EOH and WOH.

4.7 What special investigations were conducted during 2003?

Special investigations refer to non–routine collections of environmental samples in response to a specific concern or event. These events include fish kills and uncontrolled or otherwise illegal sewage discharges and petroleum spills. As notification of these events and subsequent response usually occur very quickly with little time to plan or prepare a sampling response, in 2003 DEP developed a Special Investigation Quality Assurance Project Plan in an effort to standardize investigation procedures, including where to collect samples, what analytes to seek, and how to report the results. Table 4.1 lists the special investigations that were conducted and reported on in 2003 utilizing the standardized procedures. While each of these incidents taken alone does not appear to have been a substantive threat to the quality of the water supply, DEP is now tracking these incidents, allowing the detection of patterns, such as similar occurrences at proximal locations, which might suggest that additional management measures are warranted.

Table 4.1: List of special investigations conducted in 2003 which utilized standardized response and reporting procedures.

Investigation Date	Reservoir Watershed	Incident Description
03/21/03	Bronx River (Outside Watershed)	Sampling of Turbid Discharge from DEL18 Work Area to Unnamed Tributary to the Bronx River. While the stream was turbid at the time of sampling, it actually began to clear by the time the sample collector was leaving the site. Turbidity and specific conductance were elevated compared to what has been typically measured for area streams. Mercury was not detected in the sample.
05/14/03	New Croton	Approximately 3200 gallons of raw sewage was estimated to have leaked from a break in one of the 12” force mains leaving the Mount Kisco pumping station. Sampling above and about 150 meters below the area of the leak approximately six hours after the leak had been repaired did not detect elevated bacteria concentrations in the stream.

Table 4.1: List of special investigations conducted in 2003 which utilized standardized response and reporting procedures.

Investigation Date	Reservoir Watershed	Incident Description
06/17/03	Kensico	DEP staff reported an unusual sheen on the surface of the detention basin at Kensico Reservoir subbasin N5 BMP. Sample analysis for VOCs and SVOCs failed to identify any associated water quality contamination.
06/27/03	New Croton	DEP Laboratory staff reported an overflow of an equalization tank at the Riverwoods WWTP. Analysis of samples collected upstream and downstream of the WWTP found no impact to the water quality of the Kisco River attributable to the spill.
07/2/03	Kensico	On 7/2/03, DEP staff reported unusual conditions at Kensico Reservoir tributary E10. On 7/3, DEP staff found evidence of a discharge from a sewage pumping station maintained by the Town of North Castle. The pumping station was found to be operational and the spill area was cleaned up on 7/3/03. Extensive sampling of tributary E10, Kensico Reservoir, and Reservoir Keypoints for bacteria, protozoa, and human enteric viruses was conducted, but no evidence of impact to reservoir water quality was found.
09/02/03	Muscoot	A motor vehicle accident in Yorktown resulted in a diesel fuel spill into a storm drain that discharges to a tributary of Hallocks Mill Brook. DEP Police and the DEP Hazardous Materials Incident Response Team (Hazmat) responded by placing absorbent booms across the tributary and brook. It was determined that there were no adverse environmental impacts due to the incident.
10/12/03	West Branch	A substantial fish kill in a private lake was reported to DEP Police. Over the 10/12–10/16 period, samples were collected for VOCs, SVOCs, heavy metals, fecal coliform bacteria, and physical parameters, and field measurements of temperature, dissolved oxygen, pH, and specific conductance were taken. The fish kill was due to extensive parasite infestation of the fish presumably aggravated by an undetermined environmental stressor. No threat to the water supply was found.

Table 4.1: List of special investigations conducted in 2003 which utilized standardized response and reporting procedures.

Investigation Date	Reservoir Watershed	Incident Description
11/07/03	Ashokan	DEP Police observed an oily sheen on Ashokan Reservoir near the West Basin Dam. DEP Police and Hazmat responded and contained the sheen using absorbent booms. Water samples were collected and analyzed for VOCs and SVOCs at both the spill site and the Reservoir Gatehouse. Analyses identified the surface contaminant to be No. 6 fuel oil or a similar substance. A dive team located and removed a rotted metal five–gallon pail which contained a tar–like material. The spill was found to pose no threat to the quality of the water supply.

4.8 What is DEP's Waterfowl Management Program and how successful was it in 2003/2004?

Figure 4.12 DEP contractor conducting bird harassment activities using pyrotechnics from shoreline of Kensico Reservoir.

In 1992, the Waterfowl Management Program (WMP) was developed in response to elevated levels of fecal coliform bacteria that occurred seasonally at Kensico Reservoir. There are three primary components to this Program: monitoring waterbird populations; waterbird mitigation (utilizing deterrence and harassment techniques); and eliminating reproduction attempts of locally-breeding Canada Geese by way of egg depredation. The WMP has been expanded to include five additional reservoirs under the November 2002 FAD. These reservoirs are West Branch, Rondout, Ashokan, Cross River, and Croton Falls. In addition, the WMP also manages waterbirds at the Hillview and Jerome Park distribution reservoirs.

Figure 4.13 Canada Goose defending nest at City reservoir.

The WMP at Kensico Reservoir in 2003 was very successful in its aims and resulted in very low coliform bacteria concentrations in the Kensico effluent waters, as in previous years (see Section 3.2).

Bird harassment activities at Cross River and Croton Falls Reservoirs are required only during droughts and did not require actions in 2003. West Branch and Ashokan Reservoirs were monitored for waterbird activity but also did not require mitigation actions for water quality improvement.

Slightly elevated fecal coliform bacteria counts were recorded for the effluent waters at Rondout Reservoir where elevated gull counts were observed close to the effluent chamber in December 2003 and into early January 2004. A limited emergency program (harassment) was carried out during this time period and resulted in a reduction of fecal coliform bacteria concentrations.

Waterbird deterrence (overhead wires) at Hillview and Jerome Reservoirs resulted in low waterbird populations and no impact to water quality.

5. Model Development and Applications

5.1 Why are models important?

Simulation models are important for forecasting the effects of watershed and reservoir management on water quality and quantity in the NYC water supply system. The models encapsulate the key processes and interactions that control generation and transport of water, sediment, and associated chemical constituents in the watersheds and reservoirs. This allows the estimation of watershed loads and reservoir eutrophication under varying scenarios of watershed and reservoir management. The models are calibrated and tested against stream flow and water quality data collected in the NYC watersheds and reservoirs.

Watershed 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 flow pathways that influence loads to reservoirs. Coupling simulated 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 being used to guide long-term watershed management?

DEP's Nutrient Management Eutrophication Modeling System (NMEMS) includes both a watershed model and reservoir models. The watershed model, Generalized Watershed Loading Functions (GWLF), simulates water and nutrient loadings from the landscape as a function of weather, watershed physiography (soils, topography), land use, and watershed management. Reservoir models simulate reservoir water levels, inflows, outflows, temperature, nutrient, and chlorophyll levels (indicators of eutrophication) as a function of weather, reservoir bathymetry, and nutrient loadings. The linkage of watershed and reservoir models provides a tool for simulating the effects of weather, land use, watershed management, and reservoir operations on water quality and quantity in the NYC reservoirs. The assessment of the potential impacts of land use and management is used to guide decisions on long-term watershed and reservoir management program emphasis and policy.

DEP's linked watershed-reservoir eutrophication models have been used to evaluate the effectiveness of watershed management in controlling nutrient loading and eutrophication in Catskill and Delaware System reservoirs. These model applications involve long-term (34 years) simulations of watershed loads and reservoir algal growth, incorporating various watershed management strategies. This type of analysis enables the prediction of changes in the frequency and magnitude of summer reservoir algal growth that result from the implementation of proposed watershed management programs.

The combined results of the linked models can help DEP target management programs to areas that will have significant effect on reservoir eutrophication. The linked modeling system has indicated that the greatest reduction in algal growth, as represented by simulated growing season chlorophyll *a* concentrations, is likely obtained by reducing dissolved phosphorus loads. Therefore, to the extent that watershed management is implemented to reduce reservoir eutrophication, DEP can use the model results to effectively target management programs by identifying the sources and the transport pathways for dissolved phosphorus.

During 2003, the NMEMS was used to investigate various watershed management strategies for achieving the TMDL (Total Maximum Daily Load) for the Cannonsville Reservoir. A Total Phosphorus (TP) TMDL for Cannonsville Reservoir was implemented to minimize the water quality impairment associated with eutrophication. The TMDL is expressed as an annual load of total phosphorus into the reservoir which will result in a target in–lake phosphorus concentration. The NMEMS system indicates that phosphorus loading reductions targeted on a seasonal basis or from specific sources and land uses may have similar reductions in annual TP load, yet might have different impacts on reservoir trophic state.

Figure 5.1 shows the effects of phosphorus loads on the distribution of summer average chlorophyll *a* concentrations in the reservoir. The left side of the figure shows the 34-year average monthly GWLF simulated phosphorus loading to the reservoir of TP, particulate phosphorus (PP), and dissolved phosphorus (DP). The right graph shows the distribution of growing season (May–October) chlorophyll *a* concentration for the 34-year period. Figure 5.1(a) shows the result of achieving the necessary loading reduction from point sources only, while Figure 5.1(b) shows the result of achieving the necessary loading reduction from non–point sources only. Comparison of these two figures shows that point source reductions have a much greater effect on lowering reservoir chlorophyll *a* concentration.

Further analysis of currently planned watershed management programs shows that these programs will produce TP loads well below the TMDL requirement. Figure 5.1(c) shows the predicted loading and resulting chlorophyll *a* concentration distribution when phosphorus loads are reduced in a manner consistent with the full implementation of watershed management programs. As chlorophyll *a* is an indicator of trophic state, the model results suggest that current watershed management strategies should have a significant effect on reducing eutrophic conditions in Cannonsville Reservoir.

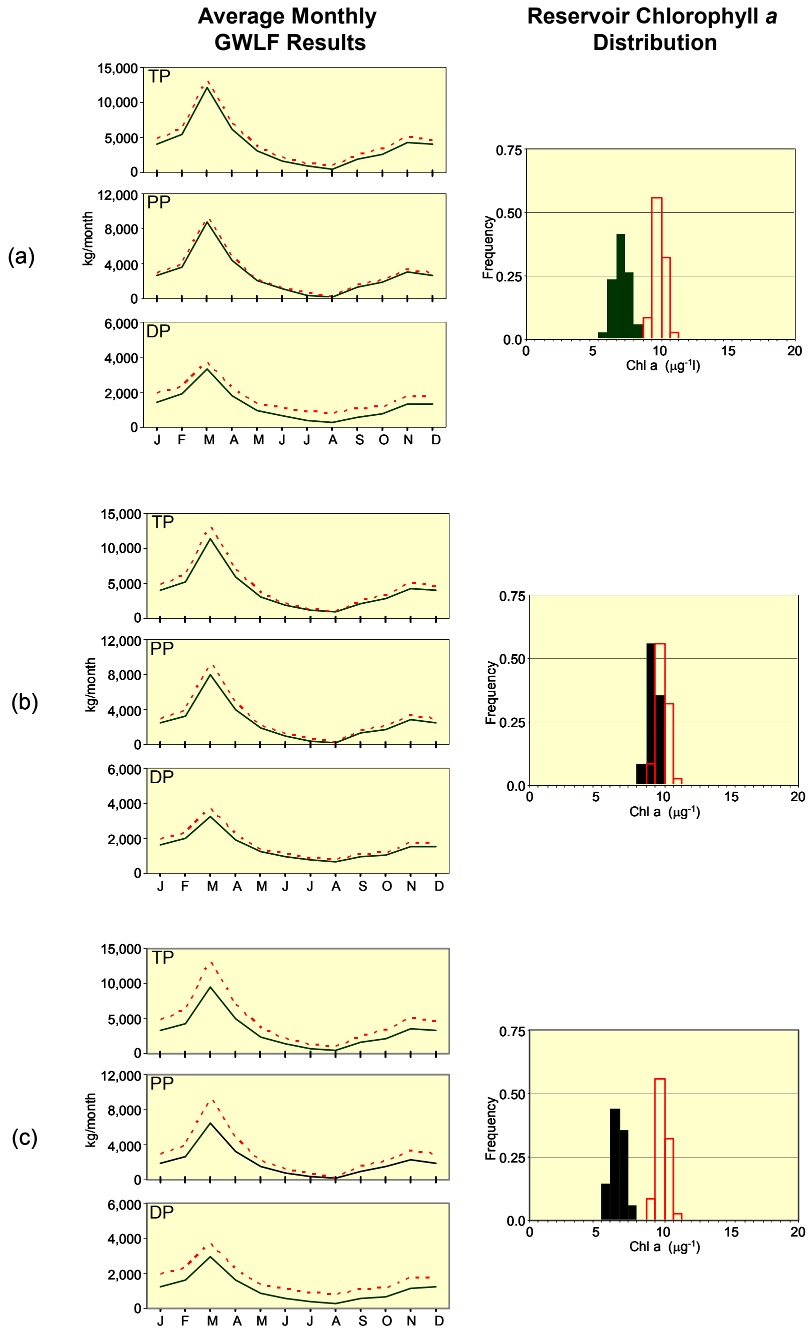


Figure 5.1 NMEMS results for reduction of phosphorus loads to Cannonsville Reservoir (a) by achieving TP TMDL load through reduction of point sources only; (b) by achieving TMDL TP load through reduction of non–point sources only; and (c) by reducing loads in a manner consistent with the full implementation of watershed management programs.

Average monthly GWLF results are shown for load reduction scenario (solid dark line) and the baseline run (dashed red line). Distributions of average growing season epilimnion chl *a* and TP concentrations are shown for reduction scenario (solid bars) and baseline run (red lines).

5.3 What can models tell us about flow pathways and the effect of 2003's weather on nutrient loads to reservoirs?

DEP is updating its watershed model applications annually to include the current year highlighted in the annual report. This provides DEP the capability to estimate flows and nutrient loads from different watershed land uses and sources to the reservoirs for the current year, in relation to long-term historical conditions. By examining current year model results relative to long-term flow and loading patterns, the yearly results are 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 of 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 overland flow and groundwater flow. Overland flow is water that moves rapidly on or near the land surface, as opposed to much slower-moving groundwater flow. Overland flow has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Figure 5.2 depicts the annual streamflow, overland flow, and dissolved nutrient loads simulated by the model for 2003 in relation to long-term (34 years) simulated annual statistics. These box plots show that 2003 was an extremely wet year with high streamflow and overland flow and correspondingly high dissolved nutrient loads to the reservoirs.

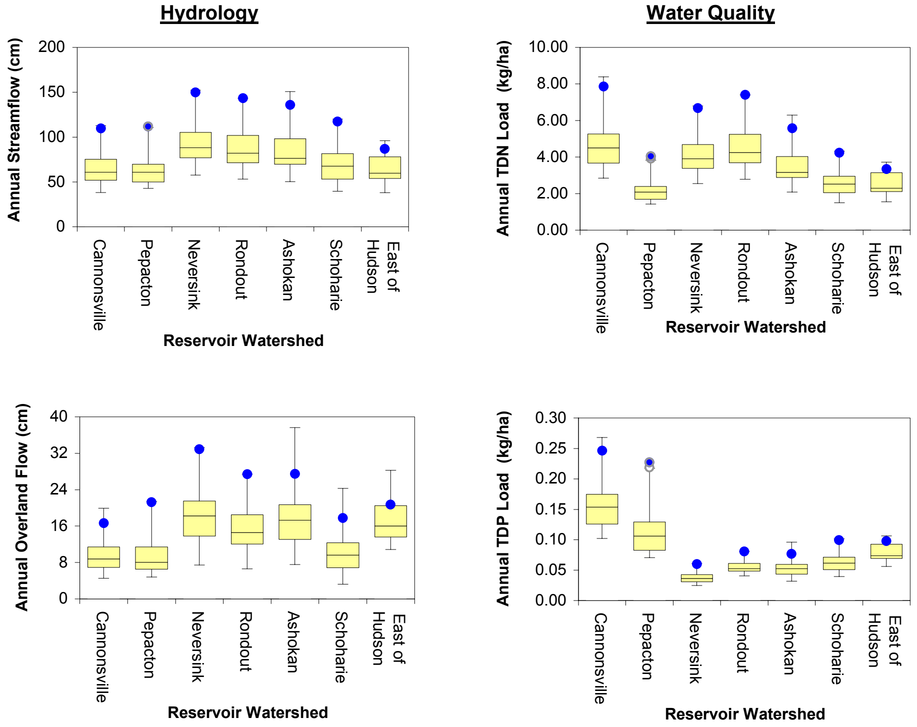


Figure 5.2 Annual streamflow, overland flow, and dissolved nutrient loads simulated by the GWLF model for 2003 in relation to long-term simulated annual statistics.

Box plots show long-term statistics. Blue dots show 2003 results.

5.4 What can models tell us about sources of nutrient loads to reservoirs?

The watershed models explicitly simulate overland flow and nutrient loads by land use and watershed source. The relative contributions of different watershed land uses and sources to total nutrient loads is an important consideration in watershed management. Figure 5.3 depicts the relative simulated contributions of point and non–point sources to TDP loads to the reservoirs for 2003 in relation to long–term (34 years) simulated annual statistics. These findings support DEP's emphasis on point source reductions and on agricultural BMPs to reduce agricultural loads, particularly in the Cannonsville watershed.

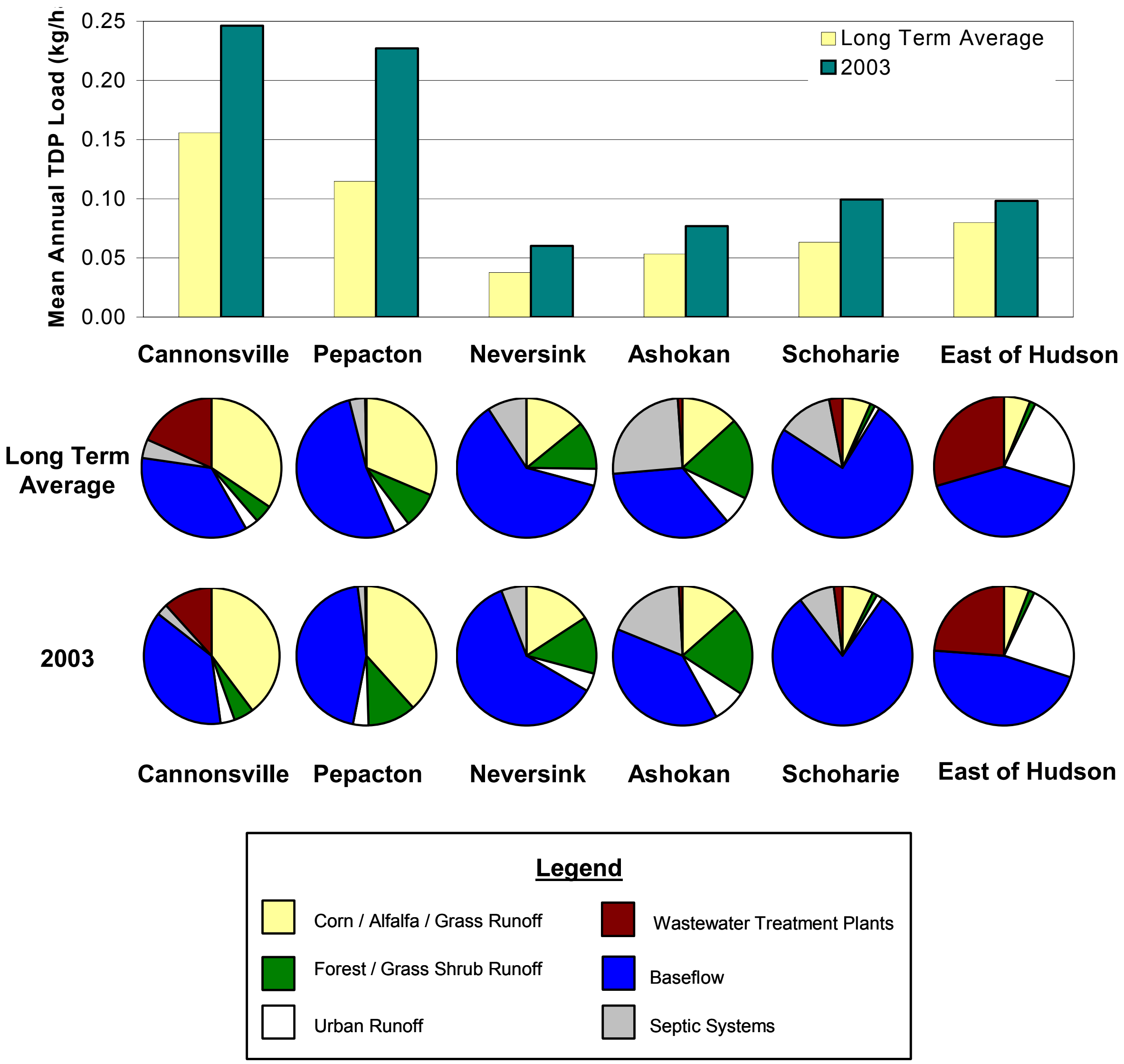


Figure 5.3 Relative simulated contributions of various non-point source land uses and point sources to TDP loads to the reservoirs for 2003 in relation to long-term simulated annual statistics.

5.5 How are monitoring data used to calibrate and test model performance?

DEP's watershed models are tested regularly against water quality data collected by DEP. This testing is important to ensure that the model results are consistent with actual conditions in the watersheds. For the GWLF watershed model, DEP collects water quality sampling data at sites along major streams that enter the reservoirs. These data are then used to test model results.

One such site where stream water quality sampling data are collected is along the Neversink River in Claryville, New York, near the location where the river flows into the Neversink Reservoir. Water samples are collected from the stream every two weeks and more frequently during selected storm events. The samples are analyzed to measure total suspended sediment concentrations and nutrient concentrations, such as dissolved phosphorus, total phosphorus, and dissolved nitrogen. In addition to the water quality samples, streamflow measurements are also collected at the site using a stream gage. The flow data and the water quality concentrations are then multiplied to give an estimate of the total load of each constituent that is transported by the stream. Provided that there is enough collected data to accurately estimate the total load for any month, the total load for that month is calculated.

This monthly loading data can be compared to results for the GWLF model. Figure 5.4 shows comparisons of GWLF model results for dissolved phosphorus and dissolved nitrogen load estimation for the Neversink River watershed for Oct. 1997 through Sept. 2001. The estimated monthly loads are indicated by red triangles, while dark circles show the GWLF results. The line shows the GWLF results for months between comparison data points. One measure of the performance of the model is the Nash–Sutcliff coefficient of model efficiency. This coefficient, referred to as R_{NS}^2, measures the goodness of fit of model–predicted versus measured data, and can range from –infinity to 1, with 1 indicating a perfect fit. If R_{NS}^2 is less than zero the model–predicted values are worse than simply using the observed mean. The Nash–Sutcliff coefficient values, shown in Figure 5.4, are 0.67 for phosphorus and 0.58 for nitrogen, showing that the model is performing well in simulating the loads for these constituents.

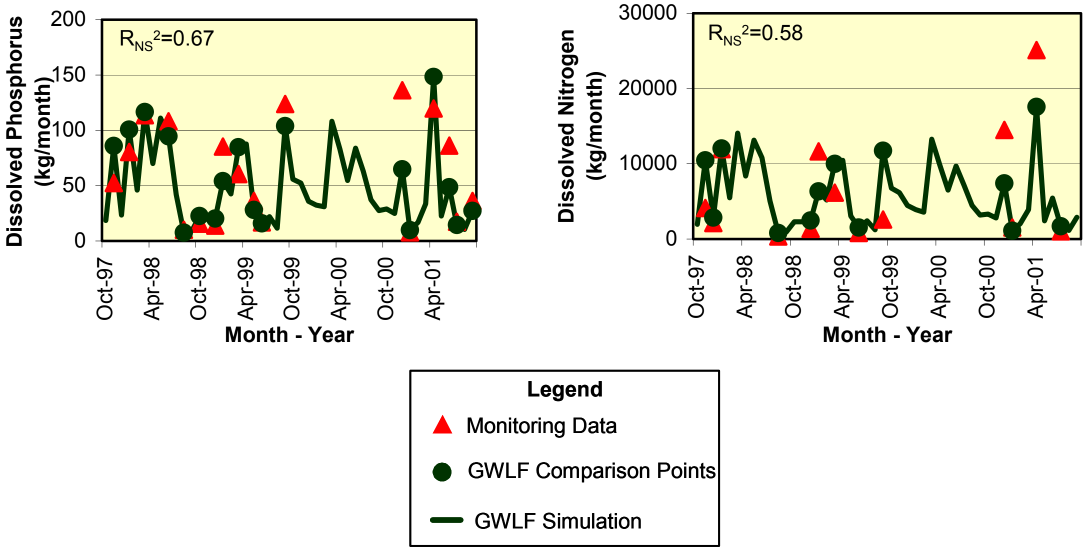


Figure 5.4 Comparison of loads estimated from stream monitoring data (red triangles) to GWLF model results (dark circles) for Neversink River at Claryville near the inlet to the Neversink River.

5.6 What was accomplished this year in the development of modeling capabilities?

Model development and improvement is an ongoing process as new data and research results become available. Modeling capabilities have been improved for both DEP's watershed and reservoir models.

Watershed model development in 2003 included improving the GWLF hydrologic calibration methodology to account for partitioning between direct runoff and baseflow as estimated from streamflow data. Previous GWLF modeling studies used default US Department of Agriculture (USDA) runoff curve numbers to calculate the partitioning of rain and snowmelt into infiltration and direct runoff. In 2003 DEP utilized baseflow separation techniques to generate time series of direct runoff and baseflow from measured streamflow data, and used the resulting direct runoff estimates to calibrate USDA runoff curve numbers in GWLF. This calibration procedure was successfully tested for the Cannonsville watershed, and will be applied in the final GWLF model calibrations for the other Catskill and Delaware System reservoir watersheds.

In 2003 DEP began developing and testing a SWAT (Soil Water Assessment Tool) model application of the Cannonsville watershed. The SWAT Model, developed and supported by the USDA, has advanced phosphorus (P) algorithms that calculate P loading coefficients dynamically and account for specific watershed conditions. In addition, SWAT explicitly models watershed management practices and their effects on loads. These features, which are not currently in

GWLF, should improve the accuracy of P loading coefficients for agricultural land uses and management practices used in DEP's watershed modeling applications. Initial work with SWAT focused on calibrating and testing the model's hydrologic predictions for the Cannonsville watershed.

Reservoir model development focused largely on upgrading the Cannonsville Reservoir eutrophication model to include simulation of sediment re–suspension, and the effects of sediment re–suspension on phosphorus cycling and light attenuation. A diverse and extensive program of measurements and process studies was conducted to support the development of modeling algorithms describing sediment re–suspension and its related effects. Based on these studies, the upgrade of the Cannonsville Reservoir nutrient–phytoplankton model included:

- A new sub–model that adds inorganic suspended solids as a variable predicted by the model.
- A modified phosphorus sub–model to accommodate the effects of phosphorus adsorption/desorption associated with re–suspended inorganic sediments. Mass balance calculations are conducted on a new state variable in this sub–model, total reactive phosphorus, which is composed of both particulate reactive (subject to adsorption/desorption transformations) and soluble reactive components.
- A strong empirical relationship, developed from observations, that describes the influence of suspended sediments on the underwater light levels that regulate phytoplankton growth.

Inclusion of sediment re–suspension in the model led to improved predictions of suspended solids, particulate phosphorus, and parameters related to phytoplankton primary production.

DEP is developing software tools, through a Safe Drinking Water Act (SDWA) contract with PAR Government Systems Corporation (PAR), to improve the integration of watershed and reservoir modeling components. The watershed modeling software consists of two main sub–programs: the Modeling Support Tool System (MSTS) and the Scenario Support Tool System (SSTS). The MSTS integrates the watershed and reservoir models, and includes tools for model data preparation and to facilitate model development and testing. The SSTS links the MSTS with a database of watershed management program implementation and effectiveness measures to provide support for evaluating the effectiveness of watershed management and BMPs in maintaining reservoir water quality. The MSTS and SSTS are set up to link directly to DEP's reservoir models. During 2003, software programming proceeded and draft individual tools were developed and tested. These tools will be combined in an integrated toolset to support multi–tiered water quality model applications. Additionally, two software tools specifically used to support reservoir modeling activities were received from PAR during 2003. One tool, LINKRES, allows simulations of two or more WOH reservoirs as a coupled system. The other, 2D tool set, facilitates data preparation needed to run the two dimensional models in the WOH system. Evaluation of both tools is underway.

5.7 What is the CLIME project and why is DEP a participant?

Variations in the weather, over time scales ranging from days to years, lead to important variations in water and nutrient inputs to the NYC drinking water reservoirs, and to the growth of phytoplankton in the reservoirs. When using models to predict hydrologic and water quality parameters it is necessary to consider the predictions relative to these "normal" levels of weather-induced variability. Many now believe that changes are occurring in the climate that will have effects on the hydrology and biogeochemistry of the watersheds supplying water to the NYC reservoirs, and on the limnology of the reservoirs themselves. Climate change could therefore, lead to changes in water quality, and also influence the background variability against which other management-related changes must be judged.

The CLIME project (Climate and Lake Impacts in Europe) is, as the name suggests, largely a European project, and is funded by the European Union (see also http://www.water.hut.fi/clime). The central aim of CLIME is to develop a suite of methods and models that can be used to manage lakes and watersheds under future as well as current climatic conditions. CLIME uses the GWLF model, including adaptations to the model made by DEP-DEP, to simulate watershed derived nutrient loads to a wide variety of lakes located in England, Ireland, Austria, Sweden, Finland, and Estonia. CLIME lake models, while not identical, are similar to reservoir eutrophication models used by DEP. DEP's involvement in CLIME stems from its modeling expertise, especially with the GWLF model, and due to overall similarities between DEP and CLIME modeling strategies. DEP has helped other CLIME participants set up and run the GWLF model, and past modeling work in the NYC watersheds has proven to be a useful benchmark for comparison with European simulation results.

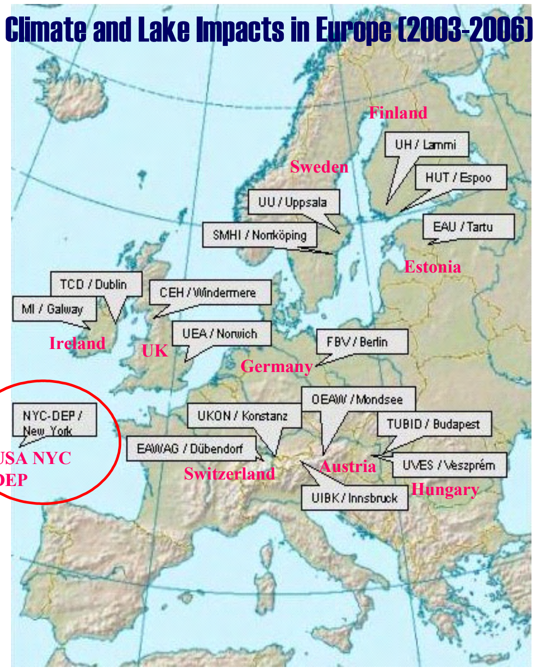


Figure 5.5 Climate and lake impacts in Europe (2003–2006).

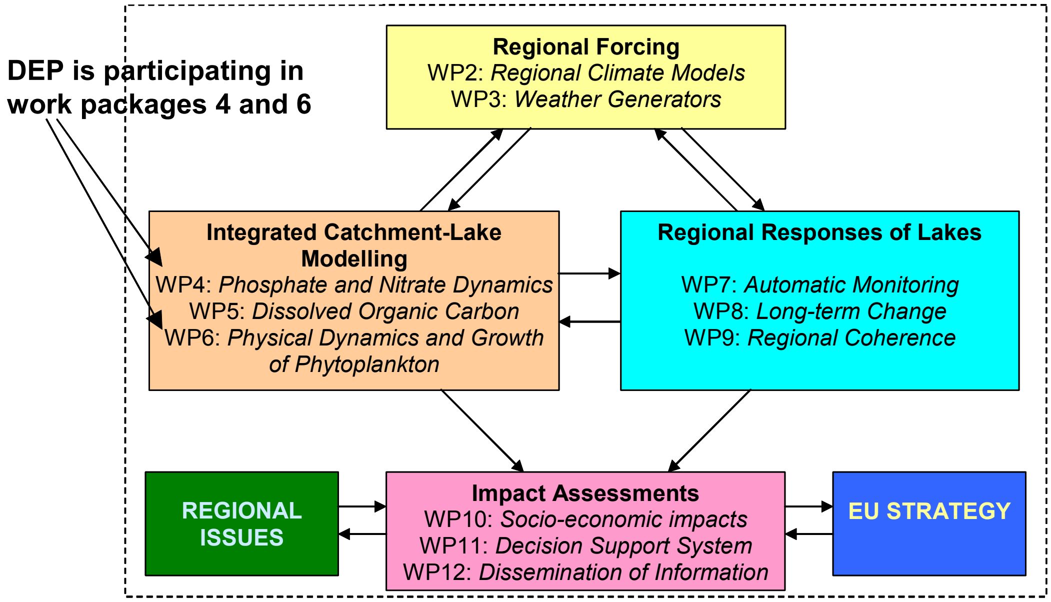


Figure 5.6 Overview of CLIME project structure.

In return, DEP has gained experience in coupling watershed and reservoir models to future climate simulations. As a result of participation in CLIME, DEP is pursuing contracts to obtain future climate simulations that will be similar to the simulations made by other CLIME participants in Europe. DEP has also gained insights into the functioning of the GWLF model by applying it to conditions outside the physiographic and climatic range typical of the NYC reservoir watersheds.

It is clear that DEP is both contributing to the CLIME project and benefiting from participation in it.

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. In recent years, the appropriation of approximately $20 million under the Safe Drinking Water Act (SDWA), earmarked for the NYC watershed, has supported a number of DEP projects devoted to guiding watershed management. These 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 the Division.

6.2 What DEP projects are supported through SDWA grants?

DEP's SDWA projects are listed in Table 6.1. The research conducted under these grants has enhanced DEP's ability to document the existing conditions of the watershed, including the hydrological database, streambed geometry, and distribution of microbial pathogens. Other projects have been devoted to understanding processes that affect water quality, such as the assessments of wetlands, stormwater control structures (BMPs), and forest management. Finally, several projects have been devoted to model development. Models allow DEP to extrapolate the effects of watershed management both into the future and throughout the nearly 2,000 square miles of NYC's water supply watershed. Models are of increasing importance because they guide decisions affecting watershed protection and remediation.

6.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 6.2. 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's current projects supported by SDWA grants.

Project Category	Projects Supported
Monitoring and Evaluation	
	Ambient Surface Water Monitoring
	Wetland Water Quality Functional Assessment
	Pathogen Fate, Transport, and Source Identification
	Identification of Watershed Sources of *E. coli*
	Genotyping of *Cryptosporidium* oocysts
	Ribotyping: Effects of Septics *vs.* Sewers
	USGS Forest Health and Soil Nutrient Status
Watershed Management	
	Stream Management: Reference Reach Design Distributed Sediment Loading Modeling Monitoring BMP Effectiveness
	TP Tracking System
	Stormwater BMP Monitoring Demonstration
Modeling	
	Croton System Modeling
	Kensico Model Enhancement
Data Analysis	
	Water Quality Data Analysis and Communication
	GIS Infrastructure Upgrade and Geodatabase Development

Table 6.2: DEP contracts related to water quality monitoring and research.

Contract Description	Contract Term
Operation and Maintenance	
Operation & Maintenance of DEP's Hydrological Monitoring Network (Stream Flow)	10/1/03–9/30/06
Operation & 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
Removal of Hazardous Waste from DEP's laboratories	5/20/04–5/19/05
SAS software contract	11/1/03–10/31/04
Monitoring	
Monitoring of NYC reservoirs for pathogens	7/1/00–7/1/04
Monitoring of NYC reservoirs for viruses	1/30/04–1/28/07
Monitoring of NYC's reservoirs for zebra mussels	4/24/03–6/30/04
Monitoring of NYC residences for lead and copper	1/1/03–12/31/05
Organic Analysis Laboratory Contract	3/1/04–2/28/07
Laboratory Analysis of Wetlands and Storm Runoff in the NYC watersheds	2/25/04–2/24/05
Analysis of Stormwater at Beerston Cannonsville watershed	11/1/02–10/31/04
Research and Development	
Design of Controls for Zebra Mussels in NYC's Water Supply System	1/5/94–12/31/06
Croton Watershed Management	12/7/00–7/7/04
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–11/25/06
Croton Process Study	4/1/99–3/31/04

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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 found in the intestinal tract of humans and warm-blooded animals used to indicate pollution by fecal contamination.

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

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

Cyst – A phase or a form of an organism produced either in response to environmental conditions or as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant cell wall. *Giardia* are shed as cysts.

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 water bodies.

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 water bodies 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 or a form of an organism produced either in response to environmental conditions or as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant cell wall. *Cryptosporidium* are shed as oocysts.

Pathogen – A disease-producing organism typically found in the intestinal tracts of mammals.

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 water bodies. 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 – Single cell 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 water bodies.

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 bypassed 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

Reservoir–wide summary statistics for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality Standard	Kensico			New Croton			East Ashokan Basin			Rondout		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		349	3.71 – 21.38	9.5	331	3.35 – 25	12.3	120	1.56 – 23.56	9.27	190	2.8 – 19.8	8.8
pH (units)	6.5–8.5[1]	339	5.59 – 7.63	6.9	313	6.6 – 8.8	7.4	108	6.18 – 7.99	6.985	190	5.87 – 8.2	6.47
Alkalinity (mg/l)		23	9.1 – 11.8	11.1	21	55.3 – 67.3	60.2	9	9.7 – 11.8	10.3	9	2.3 – 8.1	5.98
Conductivity (µS/cm)		334	47 – 87	77	329	325 – 404	370	108	40.8 – 66.2	60.35	190	39.9 – 63.1	55.35
Hardness (mg/l)		0	–		0	–		15	14.4 – 18.75	16.32	6	12.61 – 18.72	15.73
Color (Pt–color units)	(15)	352	5 – 16	10	332	12 – 40	22	120	2 – 19	9	180	8 – 18	13
Turbidity (NTU)	(5)[2]	352	0.6 – 1.8	1.2	332	0.7 – 3.6	2	120	0.6 – 5.1	1.3	180	0.5 – 2.25	1.1
Secchi transparency (m)		115	2.5 – 6.7	4.9	109	1.7 – 3.7	2.9	32	3.1 – 6.4	4.2	57	3.3 – 5.1	4.3
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7[3]	44	0.1 – 13.2	7.35	31	6.1 – 24.8	14.2	31	0.17 – 12.13	7	19	3.7 – 12.2	6.3
Total phytoplankton (SAU)	2000[3]	142	0.8 – 1600	330	157	2.5 – 2400	580	80	2.5 – 2600	190	113	2.5 – 1200	180
CHEMICAL													
Dissolved organic carbon (mg/l)		95	0.8 – 2.5	1.6	122	2.2 – 4.9	3.1	48	1.2 – 2	1.6	112	1.14 – 1.94	1.65
Total phosphorus (µg/l)	15[3]	160	1.5 – 11	8	161	7 – 34	20	84	3 – 13	8	148	1.3 – 12.8	7
Total nitrogen (mg/l)		159	0.02 – 0.367	0.3	149	0.2 – 0.86	0.612	48	0.09 – 0.34	0.2	42	0.173 – 0.462	0.27
Nitrate + nitrite – N (mg/l)	10[1]	183	0.025 – 0.276	0.144	170	0.011 – 0.603	0.216	48	0.011 – 0.197	0.099	112	0.041 – 0.358	0.220
Total ammoniacal – N (mg/l)	2[1]	183	0.005 – 0.039	0.019	170	0.005 – 0.103	0.029	48	0.005 – 0.09	0.03	112	0.002 – 0.017	0.004
Iron (mg/l)	0.3[1]	0	–		20	0.02 – 0.23	0.095	12	0.045 – 0.28	0.045	12	0.02 – 0.1	0.04
Manganese (mg/l)	(0.05)	0	–		20	0.02 – 0.385	0.05	12	0.007 – 0.63	0.043	12	0.011 – 0.399	0.045
Lead (µg/l)	50[1]	15	0.25 – 0.7	0.25	21	0.25 – 0.25	0.25	12	0.5 – 0.5	0.5	12	0.25 – 0.3	0.25
Copper (µg/l)	200[1]	15	0.7 – 1.9	1.4	21	0.8 – 1.4	1.2	12	2.5 – 2.5	2.5	12	1 – 2.2	1
Calcium (mg/l)		0	–		0	–		15	4.53 – 5.91	5.25	6	3.6 – 5.32	4.485
Sodium (mg/l)		0	–		0	–		15	2.71 – 4.3	3.57	6	2.93 – 4.53	3.85
Chloride (mg/l)	250[1]	26	5.9 – 11.3	10	25	56.9 – 75.9	69.1	48	4.4 – 7.9	7.15	6	4.38 – 6.71	5.76

continued on next page

Reservoir–wide summary statistics for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality Standard	Amawalk			Bog Brook			Boyd Corners			Croton Falls		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		39	5.7 – 26.31	12.85	29	6 – 25.4	10.6	70	5.5 – 25.57	14.6	108	4.1 – 23.32	13.715
pH (units)	6.5–8.5[1]	25	6.87 – 8.88	7.67	24	7 – 8.6	7.65	70	6.66 – 7.7	7.28	108	6.93 – 9.1	7.565
Alkalinity (mg/l)		6	68.8 – 81.6	71.35	5	62.6 – 67.5	64.2	4	27.2 – 34.1	30.55	17	51.5 – 69.5	56.6
Conductivity (µS/cm)		39	416 – 449	438	29	307 – 324	318	70	191 – 256	237	108	299 – 530	425
Hardness (mg/l)		0	–		0	–		0	–		6	33.07 – 33.89	33.5
Color (Pt–color units)	(15)	39	15 – 35	22	29	12 – 35	22	70	20 – 55	30	108	9 – 40	19
Turbidity (NTU)	(5)[2]	39	1.3 – 4.1	2.1	29	1.2 – 2.9	1.8	70	0.8 – 2	1.3	108	0.8 – 8.6	2.1
Secchi transparency (m)		16	1.5 – 3.5	2.95	7	2.8 – 4.3	3.6	27	2.9 – 5.5	4.6	37	1.1 – 5.2	3.2
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7[3]	6	7.3 – 18.2	12.2	10	2.3 – 23.8	5.25	15	1.8 – 14.1	7	25	4.8 – 61.2	15.4
Total phytoplankton (SAU)	2000[3]	14	260 – 3700	1150	11	90 – 4500	540	27	11 – 630	310	38	85 – 2100	560
CHEMICAL													
Dissolved organic carbon (mg/l)		13	3 – 3.8	3.5	25	2.9 – 3.7	3.2	46	2.3 – 7.2	3.65	55	2.3 – 3.5	2.9
Total phosphorus (µg/l)	15[3]	38	10 – 36	19	28	8 – 29	17.5	63	8 – 18	13	108	6 – 45	21
Total nitrogen (mg/l)		39	0.3 – 0.835	0.61	25	0.2 – 0.604	0.347	62	0.2 – 0.4	0.3	74	0.2 – 1.5	0.6
Nitrate + nitrite – N (mg/l)	10[1]	38	0.005 – 0.512	0.0345	29	0.005 – 0.301	0.026	70	0.005 – 0.226	0.053	108	0.005 – 0.968	0.209
Total ammoniacal – N (mg/l)	2[1]	38	0.005 – 0.099	0.0215	29	0.005 – 0.053	0.014	70	0.005 – 0.058	0.024	108	0.005 – 0.098	0.031
Iron (mg/l)	0.3[1]	0	–		3	0.95 – 1.14	1.07	5	0.07 – 0.13	0.09	6	0.04 – 0.15	0.105
Manganese (mg/l)	(0.05)	0	–		3	0.02 – 0.02	0.02	5	0.02 – 0.04	0.02	6	0.02 – 0.14	0.02
Lead (µg/l)	50[1]	5	0.25 – 1.6	1.1	3	0.6 – 0.8	0.7	3	0.25 – 0.25	0.25	6	0.25 – 0.25	0.25
Copper (µg/l)	200[1]	5	1 – 1.2	1.1	3	1.7 – 2.1	1.7	3	1.2 – 1.4	1.2	6	1.3 – 1.9	1.6
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		6	37.3 – 41.5	40.15
Chloride (mg/l)	250[1]	7	79.3 – 83.9	80.9	5	47.6 – 50.6	48.5	7	38 – 49.8	46.8	18	62.9 – 97.7	83.3

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Reservoir–wide summary statistics for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality Standard	Cross River			Diverting			East Branch			Lake Gilead		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		41	5 – 25.47	8.94	22	8 – 21.7	16.55	37	5.1 – 24.3	12.3	34	4.14 – 26.17	7.985
pH (units)	6.5–8.5[1]	24	6.54 – 8.64	7.415	14	7.2 – 8.1	7.7	27	6.9 – 8.7	7.4	29	6.29 – 8.1	7.08
Alkalinity (mg/l)		9	41.2 – 53.2	46.2	4	68.6 – 86.8	78	5	63.9 – 80.6	77.1	4	40.1 – 41	40.45
Conductivity (µS/cm)		41	232 – 259	248	22	334 – 367	353	37	293 – 343	319	29	169 – 192	174
Hardness (mg/l)		0	–		0	–		0	–		0	–	
Color (Pt–color units)	(15)	47	12 – 50	22	21	25 – 44	35	36	20 – 45	32.5	9	10 – 40	10
Turbidity (NTU)	(5)[2]	47	1.1 – 15	2.3	21	1.2 – 6.6	2.4	35	0.9 – 7	2	9	0.6 – 4.1	0.9
Secchi transparency (m)		16	2.3 – 4.1	2.7	8	1.4 – 3.5	2.6	12	1.4 – 4.1	2.5	9	3.4 – 10.5	6.1
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7[3]	7	5.5 – 45.4	16.4	10	7.4 – 31.9	17.65	10	2.9 – 97	26.9	3	1.3 – 2.8	2.3
Total phytoplankton (SAU)	2000[3]	14	110 – 4400	765	13	60 – 8500	1100	15	15 – 3300	660	3	10 – 61	15
CHEMICAL													
Dissolved organic carbon (mg/l)		24	2.6 – 4.5	3.15	14	2.7 – 3.6	3.3	27	2.7 – 4.6	3.6	6	1.9 – 2.6	2.3
Total phosphorus (µg/l)	15[3]	47	12 – 30	19	21	19 – 47	25	36	14 – 53	23	9	9 – 364	15
Total nitrogen (mg/l)		46	0.2 – 0.8	0.406	14	0.4 – 0.597	0.515	26	0.3 – 0.567	0.428	9	0.2 – 0.8	0.307
Nitrate + nitrite – N (mg/l)	10[1]	47	0.005 – 0.216	0.025	21	0.089 – 0.266	0.148	35	0.005 – 0.27	0.089	9	0.005 – 0.216	0.017
Total ammoniacal – N (mg/l)	2[1]	47	0.005 – 0.62	0.021	21	0.005 – 0.077	0.024	36	0.005 – 0.07	0.032	9	0.013 – 0.576	0.023
Iron (mg/l)	0.3[1]	2	0.07 – 0.13	0.1	2	0.95 – 0.98	0.965	3	0.93 – 1.11	1.04	3	0.06 – 0.09	0.06
Manganese (mg/l)	(0.05)	2	0.02 – 0.02	0.02	2	0.02 – 0.09	0.055	3	0.02 – 0.02	0.02	3	0.02 – 0.19	0.02
Lead (µg/l)	50[1]	6	0.25 – 2.5	0.25	2	0.8 – 3.7	2.25	3	0.9 – 1	1	3	0.25 – 0.25	0.25
Copper (µg/l)	200[1]	6	0.5 – 0.9	0.85	2	1.7 – 1.9	1.8	3	1.9 – 2	1.9	3	0.6 – 1.3	0.8
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		0	–	
Chloride (mg/l)	250[1]	9	40.7 – 42.7	41.7	4	50 – 56.9	53.95	5	37.9 – 48.4	45.5	9	21.7 – 45.9	23.3

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Reservoir–wide summary statistics for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality	Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		28	4.81 – 26.17	8.94	29	7.91 – 26.14	18.1	77	4 – 21.64	13.7	65	4.8 – 23.69	10.56
pH (units)	6.5–8.5[1]	23	6.85 – 8.94	7.57	24	7.19 – 8.8	7.49	57	6.94 – 8.47	7.4	49	6.85 – 8.95	7.5
Alkalinity (mg/l)		3	64.3 – 76.8	64.4	4	46.1 – 57.4	54.55	6	64 – 91.4	67.35	6	48.1 – 66.7	49.8
Conductivity (µS/cm)		23	337 – 366	344	24	300 – 333	323	77	280 – 487	391	65	465 – 553	523
Hardness (mg/l)		3	31.63 – 33.23	32.78	0	–		0	–		0	–	
Color (Pt–color units)	(15)	9	10 – 25	11	6	21 – 40	30	77	16 – 100	30	64	10 – 75	22
Turbidity (NTU)	(5)[2]	9	1.4 – 4.6	1.8	6	1.8 – 6.9	2.85	77	0.8 – 7.6	3.2	64	1.3 – 5.9	2.5
Secchi transparency (m)		8	3.8 – 5.2	4.75	15	2.2 – 4	3	33	1.8 – 3.7	2.4	18	2.5 – 4.2	3.05
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7[3]	5	1.1 – 7.3	3.9	3	5.7 – 32.4	23	27	5.9 – 45	15.6	16	0.05 – 34.6	15.55
Total phytoplankton (SAU)	2000[3]	5	15 – 720	230	3	590 – 2000	1800	40	2.5 – 1500	525	22	2.5 – 1100	680
CHEMICAL													
Dissolved organic carbon (mg/l)		6	2.3 – 3.1	2.65	4	2.6 – 3.5	3.1	42	2.6 – 4.7	3.1	36	2.2 – 5.7	2.9
Total phosphorus (µg/l)	15[3]	9	10 – 268	19	6	23 – 51	28.5	77	17 – 59	26	63	14 – 35	21
Total nitrogen (mg/l)		9	0.3 – 0.8	0.4	6	0.2 – 0.372	0.3	59	0.2 – 1.187	0.621	49	0.2 – 0.838	0.568
Nitrate + nitrite – N (mg/l)	10[1]	9	0.005 – 0.108	0.012	6	0.013 – 0.019	0.014	77	0.005 – 0.532	0.219	64	0.005 – 0.495	0.080
Total ammoniacal – N (mg/l)	2[1]	9	0.005 – 0.641	0.005	6	0.018 – 0.038	0.025	77	0.013 – 1.143	0.047	64	0.005 – 0.375	0.033
Iron (mg/l)	0.3[1]	3	0.06 – 0.13	0.07	2	0.09 – 0.13	0.11	0	–		0	–	
Manganese (mg/l)	(0.05)	3	0.02 – 0.29	0.02	2	0.02 – 0.08	0.05	0	–		0	–	
Lead (µg/l)	50[1]	6	0.25 – 1.1	0.25	2	0.25 – 4	2.125	2	0.25 – 1.3	0.775	3	0.25 – 0.25	0.25
Copper (µg/l)	200[1]	6	2.2 – 8.5	4.9	2	1 – 1.2	1.1	2	1.2 – 1.5	1.35	3	1.2 – 1.4	1.3
Calcium (mg/l)		0	–		0	–		0	–		0	–	
Sodium (mg/l)		0	–		0	–		0	–		0	–	
Chloride (mg/l)	250[1]	6	60.9 – 65.2	62.3	6	56.4 – 66.6	63.05	8	56.8 – 84.5	73.25	8	78.6 – 116.4	112.8

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Reservoir–wide summary statistics for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality Standard	Titicus			West Branch			West Ashokan Basin			Pepacton		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		33	5 – 25.58	10.25	143	1.77 – 22.57	13.29	180	2.36 – 22.595	9.72	266	3.1 – 23.91	8.075
pH (units)	6.5–8.5^1	18	6.79 – 8.73	7.77	143	6.4 – 7.74	7.24	162	6.06 – 7.6	6.89	250	6 – 8.63	6.67
Alkalinity (mg/l)		7	64.2 – 71.9	70	13	14.3 – 28.8	19.6	12	7.6 – 10.5	8.45	14	9.88 – 12.7	11.45
Conductivity (µS/cm)		33	264 – 295	283	143	66 – 180	140	161	33.7 – 56.7	52.6	233	52 – 64	60
Hardness (mg/l)		0	–		0	–		16	12.56 – 15.72	15.2	14	20 – 22.25	20.69
Color (Pt–color units)	(15)	33	15 – 50	24	141	6 – 25	13	175	6 – 18	11	220	8 – 17	13
Turbidity (NTU)	(5)^2	33	1.5 – 7.5	2.8	140	0.6 – 2.6	1.45	182	0.8 – 13	2.7	255	0.4 – 2.6	1.1
Secchi transparency (m)		16	1.8 – 5.6	2.75	57	2.7 – 6.9	5	48	1.4 – 4.9	3.2	82	1.7 – 5.3	3.9
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7^3	7	6.2 – 63.2	23.7	32	1 – 14.4	5.6	23	3.25 – 10.43	8.08	33	2.3 – 21.7	8.4
Total phytoplankton (SAU)	2000^3	14	110 – 1600	710	71	3 – 1300	200	98	2.5 – 1800	130	99	2.5 – 1500	220
CHEMICAL													
Dissolved organic carbon (mg/l)		12	2.6 – 3.5	3.2	63	0.3 – 2.8	2	74	1.1 – 2	1.5	109	1.07 – 2.1	1.46
Total phosphorus (µg/l)	15^3	33	16 – 64	25	111	4 – 24	10	125	3 – 14	7	218	1.3 – 22.4	8.7
Total nitrogen (mg/l)		33	0.2 – 0.8	0.48	102	0.2 – 0.5	0.3	74	0.1 – 0.39	0.285	85	0.112 – 0.408	0.289
Nitrate + nitrite – N (mg/l)	10^1	33	0.005 – 0.292	0.031	122	0.005 – 0.202	0.1145	74	0.031 – 0.301	0.217	109	0.011 – 0.338	0.22
Total ammoniacal – N (mg/l)	2^1	33	0.005 – 0.274	0.021	122	0.005 – 0.042	0.023	74	0.01 – 0.04	0.02	109	0.002 – 0.018	0.002
Iron (mg/l)	0.3^1	0	–		12	0.02 – 0.22	0.08	12	0.045 – 0.22	0.045	12	0.01 – 0.06	0.02
Manganese (mg/l)	(0.05)	0	–		12	0.02 – 0.89	0.02	12	0.007 – 0.115	0.037	12	0.005 – 0.297	0.045
Lead (µg/l)	50^1	6	0.25 – 1.9	0.25	8	0.25 – 1	0.25	12	0.5 – 0.5	0.5	12	0.25 – 0.25	0.25
Copper (µg/l)	200^1	6	0.6 – 0.8	0.75	8	0.5 – 1.6	1	12	2.5 – 5	2.5	12	1 – 1	1
Calcium (mg/l)		0	–		0	–		16	3.96 – 5.09	4.74	14	5.85 – 6.42	6.035
Sodium (mg/l)		0	–		0	–		16	1.87 – 3.94	3.32	14	3.44 – 4.35	4.02
Chloride (mg/l)	250^1	9	38.6 – 41.7	39.8	16	6.8 – 34.7	30.35	74	2.9 – 8.4	6.65	14	4.21 – 6.76	6.075

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Reservoir–wide median values for a variety of physical, biological, and chemical analytes.

Analytes	Water Quality Standard		Neversink			Schoharie			Cannonsville	
		N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL										
Temperature (°C)		179	4.2 – 22.85	9.75	156	3.33 – 22.82	8.79	242	3.6 – 23.24	9.7
pH (units)	6.5–8.5[1]	179	5.27 – 6.69	5.9	156	6.31 – 7.53	6.885	242	6 – 8.9	6.62
Alkalinity (mg/l)		6	2 – 2.84	2.2	9	8.7 – 17	10.8	21	11.6 – 17.4	15.8
Conductivity (µS/cm)		179	23 – 32.3	30	146	41 – 83.5	68.5	242	60.6 – 93	81.05
Hardness (mg/l)		6	8.29 – 10.01	8.90	15	15.56 – 24.65	17.9	18	22.99 – 28.1	26.175
Color (Pt–color units)	(15)	168	8 – 19	13	115	7 – 27	13	208	11 – 22	15
Turbidity (NTU)	(5)[2]	179	0.4 – 1.8	1	155	0.6 – 23	2.7	223	0.5 – 4.3	1.8
Secchi transparency (m)		55	3.7 – 8.8	5.3	48	0.6 – 5.9	2.8	82	1.4 – 6.6	3.7
BIOLOGICAL										
Chlorophyll *a* (µg/l)	7[3]	29	0.6 – 8.1	3.7	30	1.44 – 15.11	5.9	34	3.5 – 70.7	15.05
Total phytoplankton (SAU)	2000[3]	83	2.5 – 430	40	65	2.5 – 990	17	98	10 – 3700	260
CHEMICAL										
Dissolved organic carbon (mg/l)		93	1.05 – 2.17	1.69	90	1.7 – 3.2	2.1	95	1.32 – 2.41	1.89
Total phosphorus (µg/l)	15[3]	141	1.3 – 9.8	5.2	156	3 – 24	10	211	5 – 35.9	17.6
Total nitrogen (mg/l)		60	0.134 – 0.318	0.24	63	0.16 – 0.43	0.31	62	0.223 – 0.759	0.534
Nitrate + nitrite – N (mg/l)	10[1]	96	0.023 – 0.259	0.146	90	0.034 – 0.361	0.233	95	0.011 – 0.679	0.446
Total ammoniacal – N (mg/l)	2[1]	96	0.002 – 0.029	0.007	85	0.01 – 0.04	0.02	95	0.002 – 0.036	0.01
Iron (mg/l)	0.3[1]	12	0.02 – 0.12	0.05	6	0.045 – 0.44	0.13	12	0.02 – 0.55	0.09
Manganese (mg/l)	(0.05)	12	0.007 – 0.044	0.016	6	0.007 – 0.099	0.060	12	0.003 – 0.253	0.035
Lead (µg/l)	50[1]	12	0.25 – 0.25	0.25	6	0.5 – 0.5	0.5	12	0.25 – 0.6	0.25
Copper (µg/l)	200[1]	12	1 – 1	1	6	2.5 – 2.5	2.5	12	1 – 8.5	1
Calcium (mg/l)		6	2.33 – 2.82	2.5	15	4.92 – 7.99	5.65	18	6.29 – 7.94	7.35
Sodium (mg/l)		6	1.56 – 2.35	1.825	15	2.89 – 5.77	5.16	18	5.02 – 6.99	6.015
Chloride (mg/l)	250[1]	9	2.1 – 6.71	2.91	88	4 – 11.5	10.1	21	6.4 – 11.6	8.91

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 Objective 3.3 (Reservoir Status) of the Integrated Monitoring Report. 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] DEP 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 and color 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)
ND = non detect
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:

Chlorophyll *a* for 2003 represents the time period May – October for WOH; however, EOH data were only available through September and are provisional at this time.

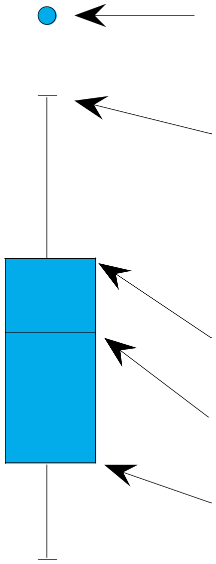
Chlorophyll *a* results were obtained through use of spectrophotometer or fluorometer method from 1991-2000, and by HPLC 2001-2003.

TP results were obtained by Valderamma method (1980) from 1991- 1999, and by APHA (1992, 1998) from 2000-2002.

Metals data for EOH were incomplete and provisional at the time of this report.

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 1999-2003, which produced slightly higher results (Smith and Hoover 1999; Smith 2001).

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 A Methodology for Determining Phosphorus Restricted Basins (NYCDEP 1997).

The list of phosphorus-restricted basins is updated annually. The data utilized in the analysis are 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 mg L^{-1}. A basin is **unrestricted** if the five-year mean plus standard error is below the guidance value of 20 mg L^{-1}, and phosphorus **restricted** if it is equal to or greater than 20 mg 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.

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	**1998** µg L^{-1}	**1999** µg L^{-1}	**2000** µg L^{-1}	**2001** µg L^{-1}	**2002** µg L^{-1}	**2003** µg L^{-1}
Delaware System						
Cannonsville Reservoir	17.06	17.27	17.20	19.3	17.9	15.4
Pepacton Reservoir	7.85	8.93	8.10	8.6	10.4	9.1
Neversink Reservoir	3.29	5.13	5.26	5.8	4.7	5.2
Rondout Reservoir	7.59	7.65	10.40	7.4	9.2	6.8
Catskill System						
Schoharie Reservoir	18.71	25.92	21.31	15.2	11.7	7.5
Ashokan–West Reservoir	14.23	14.23	9.56	9.4	9.6	6.1
Ashokan–East Reservoir	12.65	11.00	10.60	7.7	12.4	7.0
Croton System						
Amawalk Reservoir	23.52	22.12	38.63	19.8	22.2	19.6
Bog Brook Reservoir	19.83	18.01	34.73	21.4	*	16.9
Boyd Corners Reservoir	8.74	12.61	16.00	13.6	15.9	12.4
Cross River Reservoir	16.83	10.85	17.15	14.8	20.3	17.9
Croton Falls Reservoir	19.59	16.54	26.09	22.3	24.1	20.4
Diverting Reservoir	33.42	22.95	30.02	31.8	41.7	28.8
East Branch Reservoir	31.55	19.47	39.01	33.3	*	26.5
Middle Branch Reservoir	25.97	23.18	32.42	27.7	31.2	23.7
Muscoot Reservoir	29.34	26.46	35.00	29.7	33.9	29.5
Titicus Reservoir	38.13	37.31	33.58	28.7	26.9	27.3
West Branch Reservoir	6.56	7.12	13.29	11.5	12.9	10.2
Lake Gleneida	21.34	22.00	30.36	31.6	*	22.8
Lake Gilead	23.21	28.07	34.89	38.4	*	28.5
Kirk Lake	*	*	*	*	*	30.8
Source Water						
Kensico Reservoir	5.34	5.80	9.11	8.5	8.4	7.6
New Croton Reservoir	15.76	15.88	22.68	21.9	23.9	19.5

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

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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