New York City
Department of Environmental Protection

2007 Watershed Water Quality Annual Report

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Bureau of Water Supply

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Acknowledgements

The Deputy Commissioner of the Bureau of Water Supply, Mr. Paul Rush provided the framework for a general reorganization of the Bureau in 2007 with emphasis on accountability and compliance. Throughout the process of the reorganization a series of directives was issued by Deputy Commissioner Rush, and these were used to formulate the introductory chapter which describes the new Bureau. Within this reorganization, Mr. Steven Schindler, Director of the Water Quality Directorate (WQD), continued to provide general direction. Dr. Lorraine Janus, Chief of Watershed Water Quality Science and Research, provided the oversight for planning and production of this report. Ms. Lori Emery, Chief of Watershed Water Quality Operations, provided oversight of the sections devoted to watershed field and lab, quality assurance, and environmental health and safety; these staff members were responsible for providing the data used to produce this report. This is the first report produced under the reorganization of the Bureau of Water Supply.

In this report, leading authorship roles were taken by the members of Watershed Water Quality Science and Research Division. Dr. Lorraine Janus was responsible for overall organization of the report, the acknowledgement, and Chapter 1. Mr. James Mayfield was responsible as lead author for Chapter 2 on hydrology. He was also responsible for oversight of Chapter 3 on water quality. The lead authors of Chapter 3 were Mr. Gerry Marzec and Mr. Rich VanDreason. Ms. Kerri Alderisio, Section Chief of Pathogen Planning and Assessment was responsible for the direction of programs and as lead author for the pathogen research in Chapter 4, aided by Mr. Steve DiLonardo. Mr. Bryce McCann took responsibility as lead author for the diverse aspects of watershed management in Chapter 5. Dr. Don Pierson, Dr. Elliot Schneiderman, and Mr. Mark Zion were authors of the forward-looking modeling development and applications in Chapter 6. Mr. Martin Rosenfeld was the primary author of future research described in Chapter 7. Ms. Pat Girard, Supervisor of Reporting and Publications, was responsible for desktop publishing of the report, aided by Mr. Martin Rosenfeld who applied his editing and proofreading skills to finalize the document in a polished form. This report is intended to provide an accurate description of the scientific work needed to manage water quality for NYC, and at the same time be engaging for a wide audience, from regulatory agencies to the general public

The production of this report required the scientific expertise, creativity, and cooperation of many staff members in WQD. All deserve special recognition and thanks for their willing participation in the many facets of the Directorate's work. This report would not exist without the extensive field work, laboratory analysis, scientific interpretation, and administrative work needed to keep the watershed programs of the Directorate 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; the administrative, computing, health and safety, and quality assurance staff who support them; and the scientific staff responsible for planning, interpreting, and documenting the results of our collective work. Although we could not name everyone, thanks go to all those who contributed to this report.

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, regulators, and other stakeholders with a general overview of the City's water resources, their condition during 2007, and compliance with regulatory standards or guidelines during this period. It is complementary to another report titled "NYC 2007 Drinking Water Supply and Quality Report", a report that is distributed to consumers annually to provide information about the quality of the City's tap water. The purpose of this watershed report is to provide information on the water quality status of the City's drinking water sources upstream of the distribution system, and how watershed management protects those sources. The report also describes the efforts of the New York City Department of Environmental Protection (DEP) to evaluate the effectiveness of watershed protection and remediation programs, and to develop and use predictive models. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through the DEP website at http://www.nyc.gov/dep/ (Figure 1.1).

Figure 1.1 DEP website.

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

The Bureau of Water Supply underwent significant organizational changes in March 2007. At that time, the Deputy Commissioner, Agency and Bureau staff, and consultants worked together to develop an organizational structure for the Bureau of Water Supply (BWS) with greater emphasis on compliance and more sharply drawn lines of responsibility. The objective for the Bureau was the delivery of high quality water, rigorous compliance with all regulations, and commitment to the long-term sustainability of the system, which are all considered core elements of operating the water supply. The organizational changes were designed to improve stability of the Bureau and enable it to reliably meet its obligations to the people of the City of New York, now and in the future.

A geographic theme was one of the overarching principles that guided the re-design. The shift to a geographic organization, particularly for the field units, has given the Bureau a greater ability to improve and sustain the Department's compliance goals and better meet its primary mission of delivering high quality water to the City of New York. The purpose of a geographic-based organization is to ensure that each and every part of the system has a clearly designated chain of command with the responsibility, authority, and resources to address issues that arise for operational, compliance, maintenance, and other activities.

The Bureau currently consists of five major Directorates as follows: Compliance, Water Quality, Operations, Watershed Protection and Planning, and Management Services and Budget. Because of their critical role and complex responsibility, the Directorate's senior managers each has a Compliance Advisor. This enables them to keep these issues in mind and track progress on all compliance matters. The Compliance Advisors, along with many existing Environmental Health and Safety (EH&S) staff, enable the managerial team to achieve the level of excellence on compliance matters that both employees and consumers deserve. The primary functions of the five Directorates are described below.

Compliance

The Compliance Directorate consists of five divisions. They are overseen by a Director of Compliance who is assisted by an Administrator and Special Technical Assistant. The divisions include: Health and Safety Compliance, Environmental Engineering, Environmental Compliance, Compliance Training, and Compliance Audit. Compliance is responsible for ensuring that the Bureau operates within a safe work environment by meeting all regulations and standards. DEP and BWS have developed extensive, high quality, EH&S programs that include regular training of staff and on-going tracking systems to ensure maintenance of these programs.

Water Quality

The Water Quality Directorate was reorganized along geographic lines to provide a clearer definition of responsibility and focus. The water quality sampling, laboratory analyses, and compliance functions are now separate from the water quality planning, assessment, scientific research, and program reporting functions. This approach resulted in a geographic grouping of water quality field and laboratory staff, rather than organization by technical discipline. The goals of the reorganization are: a single chain of command for field and laboratory groups, increased efficiency in operations, and clear compliance accountability.

The Water Quality Directorate consists of four divisions; two are devoted to the watershed and upstate water sources and two are devoted to the downstate distribution system. The contents of the present report is generated by the two upstate divisions, whereas the distribution system annual report (NYC 2007 Drinking Water Supply and Quality Report) is generated by the two downstate divisions.

The functions of the two operational divisions, (i.e., Watershed Water Quality Operations and Distribution Water Quality Operations) include responsibility for sampling, analysis, and compliance. The functions of the two science and research divisions, (i.e., Watershed Water Quality Science and Research, and Distribution Water Quality Science and Research) include responsibility for planning, assessment, scientific research, and reporting. In addition, the Section Chief for Project Management and Budget and an Executive Assistant assist the Director with budget, personnel, and other administrative matters. More details on the organization and responsibilities of these divisions can be found in Section 1.3.

Operations

The newly-established Operations Directorate is designed to provide coherent oversight to all operations. It is divided into two geographical areas: Eastern and Western Operations. Eastern Operations consists of northern and southern regions, i.e., the Highlands Region and the Kensico Region, respectively. Western Operations consists of three geographic regions, i.e., the Downsville Region, the Grahamsville Region, and the Shokan Region. Each of the five regions is led by a manager who has broad, overall responsibility for all operations in the region's geographic area, including operations and maintenance, land management, hazardous material (HazMat) response, and overall compliance sustainability. The new role of Regional Manager provides the level of management and leadership required to ensure that BWS can handle its wide range of responsibilities in an integrated manner within each region. Additionally, Eastern and Western Operations have an Engineering and Technical group to support their division's operation.

Those hazardous material and land management functions that are not suitable for geographic dispersion continue to reside at the "central BWS" level, though with somewhat redefined responsibilities. Land stewards and HazMat personnel now work within the integrated regional structures, and their former units provide policy and programmatic support and guidance to the Regional Managers who are responsible for what happens "on the ground". The Regional Managers provide the management link to front line supervisors and staff and have an essential role in the Bureau's ability to sustain compliance.

Additionally, the Water Systems Operations group, Strategic Services, Community Supplies, and all reservoir operations operate under the direction of' one manager. This group is responsible for the long-term and day-to-day decision making regarding operations of the water supply system.

The Wastewater Operations Division is responsible for operation of the Bureau's seven wastewater treatment plants. This division includes a dedicated Compliance and Procurement group, as well as an Engineering and Technical group for support of the division.

Finally, a Technical Advisor to the Director coordinates all HazMat training and certifications, ensures quality control of HazMat responses, ensures that required supplies are available, and handles communications with outside agencies relating to HazMat responses.

Watershed Protection and Planning

Under the direction of an Assistant Commissioner, this group consolidates the majority of the Bureau's water quality protection and planning initiatives into one unit. There are three major divisions within Watershed Protection and Planning (WPP).

Watershed Lands and Community Planning (WLCP) is responsible for implementing key watershed protection programs including land acquisition, stream management, farm and forestry programs, and partnership programs. In addition, WLCP directs land management policy and planning for all City-owned land in the watershed, in close coordination with the regional managers within Operations. Further, the Natural Resources unit has been integrated into WLCP and continues to perform its current functions.

Regulatory Review and Engineering is a second division within WPP. It includes virtually all of DEP's watershed regulatory oversight functions, Infrastructure Design and Construction, and the Wastewater Treatment Plant Upgrade Program.

The third division, Planning, is responsible for all planning functions within the Bureau, including capital planning, long-term planning, emergency response planning and coordination with the Bureau of Engineering Design and Construction.

This Directorate is also supported by staff whom serve roles as a Compliance Advisor, a Special Assistant to the Director, and a Watershed Outreach specialist.

Management Services and Budget

Management Services and Budget (MS&B) serves the Bureau by providing administrative assistance for all aspects of procurement and personnel that are required to keep the Bureau functioning. The Director is assisted by an Administrative Assistant and oversees four units—Analysis and Support, Personnel, Expense, and Capital Budget.

Office of Information and Technology

A further change in the Bureau is that staff from the Management Information Systems (MIS) group are now part of the Office of Information and Technology (OIT), which is part of the larger DEP organization. This group is directed by an Assistant Commissioner for Information and Technology. The staff continue to support BWS, while unifying efforts to develop consistent computing systems and strengthening technological support and sophistication.

The BWS Directorates described above work together to operate and protect the water supply for the City of New York. The high quality of water and reliability of the supply demonstrate the success of the BWS watershed programs and operations. This report provides insight into how the Water Quality Directorate of BWS monitors the supply, and documents the final result of the combined programs and operations to demonstrate program effectiveness and compliance with all drinking water regulations.

1.3 How does the Watershed Water Quality Directorate monitor the condition of the reservoirs and watersheds?

The condition of the water supply is monitored by the Directorate of Water Quality. This Directorate has a staff of over 200, who are responsible for monitoring and maintaining high water quality for the entire (upstate and downstate) water supply. As mentioned above, it is the work of the two watershed (upstate) divisions that is described in this report.

The role of the watershed divisions is to (1) design scientific studies, (2) collect environmental samples for routine and special investigations, (3) analyze the samples in DEP's laboratories and enter the results into a permanent database, (4) provide regulatory reports, (5) statistically analyze and interpret the results, (6) document findings, and (7) provide recommendations for operating the water system. Extensive monitoring of a large geographic network of sites to support reservoir operations and watershed management decisions are the top priority of the Directorate.

The Watershed Water Quality Operations (WWQO) Division includes sections for West of Hudson (WOH) Water Quality Operations, East of Hudson (EOH) Water Quality Operations, Watershed Water Quality Compliance, and Wildlife Studies. These sections conduct all sampling and laboratory analysis work at four laboratory locations (Kingston, Grahamsville, Brewster, and Kensico) located throughout the watershed area. (The Ben Nesin Laboratory and Pathogen Laboratory were consolidated at the new Kingston Laboratory in early.) The sections are comprised of field managers, laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, technical specialists, and administrative staff. The four water quality laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for approximately 60 analytes in the non-potable water and potable water categories. These analytes include physical parameters (e.g., pH, turbidity, color, conductivity), chemical parameters (e.g., nitrates, phosphates, chloride, chlorine residual, alkalinity), microbiological parameters (e.g., total and fecal coliform bacteria, algae), trace metals (e.g., lead, copper, arsenic, mercury, nickel), and organic parameters (e.g., organic carbon). Daily monitoring of water quality at critical "keypoint" monitoring sites for rapid detection and tracking of any changes in water quality is one of WWQO's top priorities.

The Watershed Water Quality Science and Research (WWQSR) Division is responsible for planning scientific studies, reviewing and revising monitoring plans, analyzing data, writing reports, and providing recommendations for watershed protection programs. The division consists of four sections—Program Evaluation and Planning, Pathogen Planning and Assessment, Water Quality Modeling, and Reporting and Publications. WWQSR interacts with WWQO by providing monitoring plans and sampling recommendations, which are carried out by the field and laboratory personnel of WWQO and entered into the DEP water quality database. These results are then analyzed and presented in reports, like this one, to make water quality information accessible to regulators and the public.

2. Water Quantity

2.1 What is NYC's source of drinking water?

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

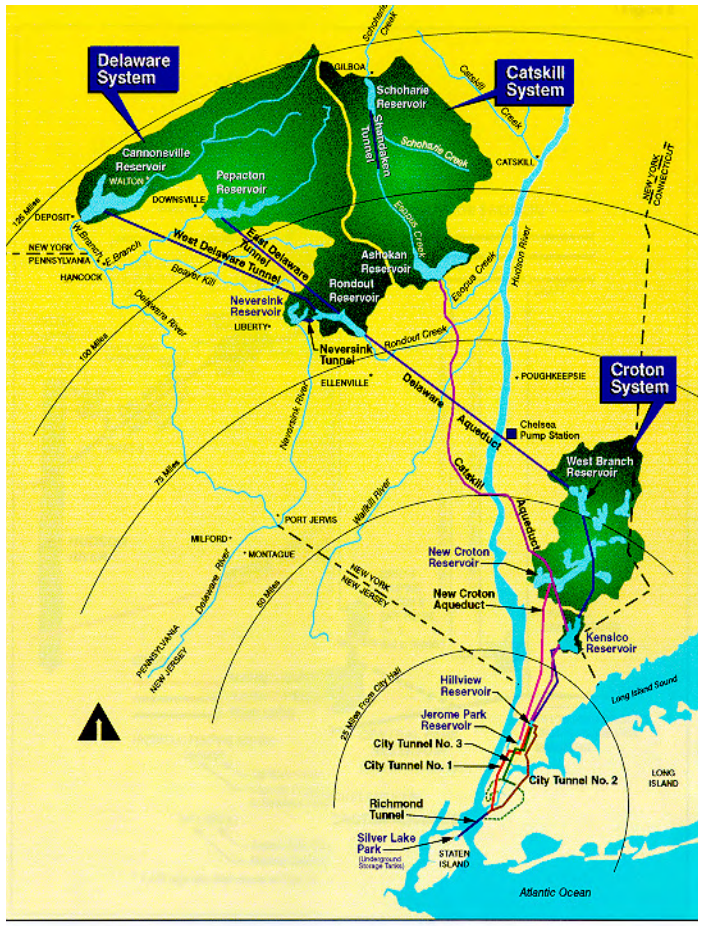

Figure 2.1 New York City water supply watershed.

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

2.2 How much precipitation fell in the watershed in 2007?

The average precipitation for each watershed was determined from a network of precipitation gages located in or near the watershed that collect readings daily. The total monthly precipitation for each watershed is based on the average readings of the watershed gages. The 2007 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.2.

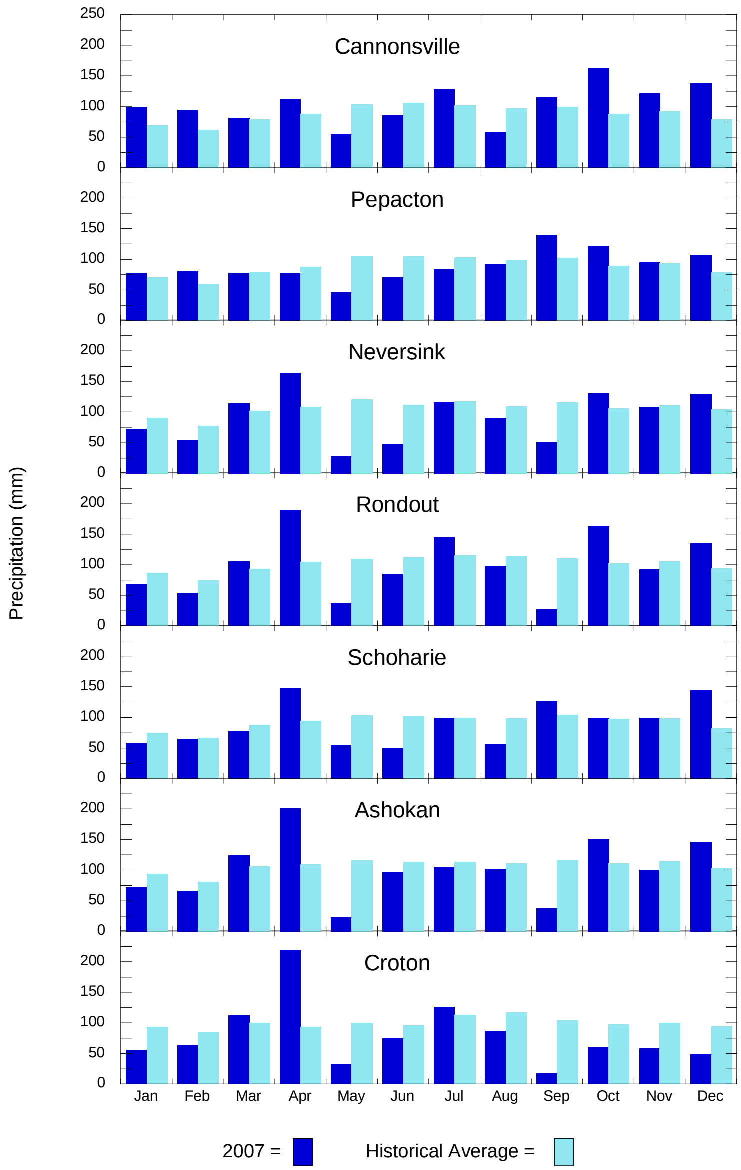

Figure 2.2 Monthly rainfall totals for NYC watersheds, 2007 and historical values.

The total monthly precipitation figures show that in general precipitation was about normal for January through March. In April a nor'easter brought heavy rains to the watershed. As reported by the National Weather Service, rainfall amounts of 6 to 8 inches were recorded across the eastern Catskills, mid-Hudson Valley, and western New England, resulting in widespread flooding. DEP recorded about 8.5 inches of rain at Kensico Reservoir. The United States Geological Service (USGS) reported record peaks at many of the Croton System reservoir outflow gages as a result of the storm. The impact of the storm on water quality is described in several sections of Chapter 3 of this report (3.1, 3.3, 3.9). In May, precipitation was well below the historical average. While precipitation in June was also generally below the historical average, a severe localized storm in and near the Pepacton watershed had a devastating impact on the community. As reported by the National Weather Service, slow moving thunderstorms dropped an estimated 6 to 8 inches over southern Delaware County at the western end of New York's Catskill Mountain Park, with most of the rain occurring in a 2-hour period. The impact on humans was that thirty-seven homes were damaged or destroyed by this flood and four lives were lost. The National Weather Service prepared a report on the storm that can be found at: http://www.erh.noaa.gov/bgm/research/2007/jun19/. July and August had fairly normal precipitation with some watersheds receiving greater than average amounts and some receiving less. September had below average precipitation in the Neversink, Rondout, Schoharie, and Croton watersheds and above average in Cannonsville, Pepacton, and Ashokan. In most watersheds, except Ashokan and Croton, October's precipitation was above average. November was fairly typical, while in December all watersheds, except Croton, had above average precipitation for the month. The total precipitation in the watershed for 2007 was 1,121 mm (44.1 inches), which is 25 mm (1 inch) below normal, but as noted above there were several months with above average precipitation, particularly in some of the WOH watersheds. Although the overall precipitation in the watershed was slightly less than normal, 2007 was New York State's fourteenth wettest year on record (1895-2007) according to the National Climatic Data Center's 2007 Annual Climate Review U.S. Summary (http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/us-summary.html).

2.3 What improvements were made to DEP's meteorological data network in 2007, and how were the data used?

Weather is one of the major factors affecting both water quality and quantity. As such, weather data is one of the critical components of an integrated data collection system. Timely and accurate weather forecasts are essential, especially with regard 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 responding, making operational decisions, understanding, and ultimately reducing, the amounts of sediment, turbidity, nutrients, and other pollutants entering the reservoirs.

Recognizing that, in addition to the precipitation data that have been historically collected, meteorological data are valuable in meeting DEP's mission of providing high-quality drinking water through environmental monitoring and research, DEP maintained and upgraded the network of 26 Remote Automated Weather Stations (RAWS) covering both the EOH and WOH watersheds. Each station measures air temperature, relative humidity, rainfall, snow depth, solar radiation, wind speed, and wind direction. A reading is taken every minute, and values are summarized hourly (summed or averaged). Most of the stations utilize radio telemetry to transmit data in near real-time. In addition to being used by DEP, these data are shared with the National Weather Service to help it make more accurate and timely severe weather warnings for watershed communities. The data are also important as input for DEP's water quality models (Chapter 6).

In 2007, DEP continued to upgrade its rain gages and telemetry system. The RAWS network originally used tipping bucket rain gages, which only measure liquid precipitation. These are being replaced with a weighing bucket gage (the Ott Pluvio) which can also measure frozen precipitation such as snow and freezing rain. The Pluvios are also more accurate than tipping buckets, and they are equipped with wind shields to help reduce catch error. Installation of these began in 2007 and will be completed in 2010. The telemetry upgrade is intended to improve the flow of data and will utilize multiple base stations at DEP facilities (wastewater treatment plants, valve chambers, etc.) spread throughout both the East and West of Hudson watersheds. Each RAWS will transmit data to the nearest base station, where it will be put onto the DEP computer network and routed to the master dataset at Grahamsville, as well as to a separate backup location. This upgrade should improve the reliability of data reception, increase data security, and incorporate EOH stations into the near-real-time data program.

DEP also purchased electronic, load-cell-based snow water sensors in 2007. These are a new device, developed by Dr. Jerry Johnson of the U.S. Army Corps of Engineers in Ft. Wainwright, Arkansas. They are not yet commercially available but Dr. Johnson fabricated two for DEP. The funding for these sensors was a grant from the National Oceanic and Atmospheric Administration (NOAA), obtained on DEP's behalf by the Delaware River Basin Commission (DRBC). The sensors will continuously monitor snowpack water content and transmit the data back via the meteorological telemetry system. Continuous snowpack data are being required by the DRBC as part of the Spill Mitigation program in the Pepacton and Neversink watersheds (http://www.state.nj.us/drbc/Flood_Website/Sept2006resolutions.htm). The sensors will be installed for a pilot program at two sites: New Kingston (Pepacton watershed) and Blue Hill (Neversink watershed) in early 2008. The near-real-time data will be monitored daily, and significant changes will trigger field staff to perform a manual snow survey to get a more accurate estimate of water equivalent in the basin.

2.4 How much runoff occurred in 2007?

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, and 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 coefficient 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.

Selected USGS stations (Figure 3.5) were used to characterize annual runoff in the different NYC watersheds (Figure 2.3). The annual runoff in 2007 from the WOH watersheds was generally above each watershed's historical median. In the EOH watersheds, the 2007 annual runoff was generally less than the watersheds' historical medians. These differences may be partly explained by differences in precipitation patterns, but are also due to differences in the periods of record. The EOH stations have a 12-year period of record, except for the Wappinger Creek site (79-year period of record), while the period of record for the WOH stations ranges from 44 years at the Esopus Creek Allaben station to 101 years at the Schoharie Creek Prattsville gage.

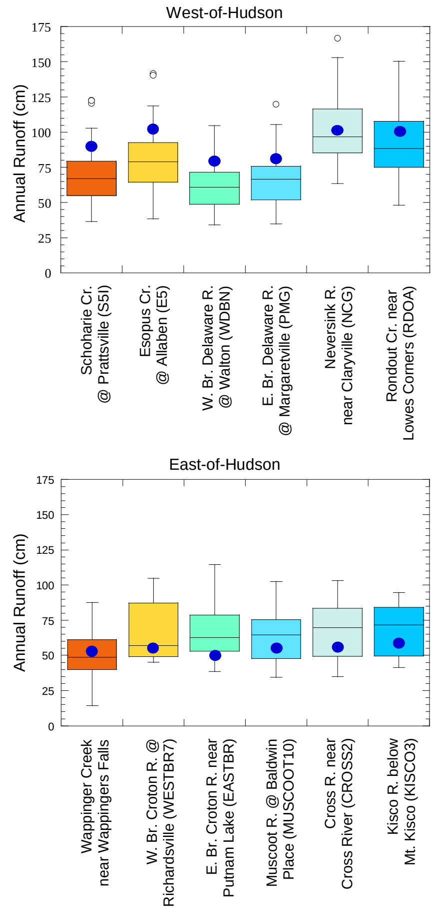

Figure 2.3 Historical annual runoff (cm) as box plots for the WOH and EOH watersheds, with the values for 2007 displayed as a dot.

2.5 What was the storage history of the reservoir system in 2007?

DEP has established typical or "normal" system-wide usable storage levels for each calendar day. These levels are based on historical storage values, which are a function of system demand, conservation releases, and reservoir inflows. Ongoing daily monitoring of these factors allows DEP to compare the present system-wide storage against what is considered typical for any given day of the year. In 2007 the actual system-wide storage values remained close to the typical or "normal" storage values (Figure 2.4). In order to meet system demand and required releases during the summer drawdown period, DEP aims to have the system-wide usable storage at 100% (547.53 billion gallons (bg)) on June 1 of each year. In 2007, the June 1 system-wide usable storage was at 96.58% of capacity (528.79 bg).

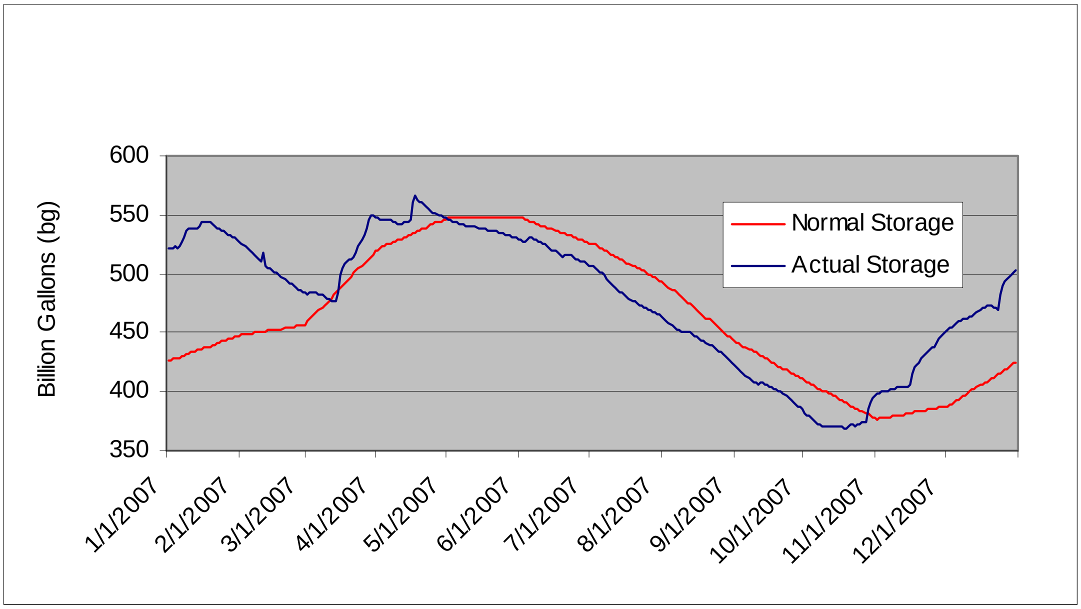

Figure 2.4 Actual system-wide usable storage compared to normal system-wide usable storage.

2.6 How is the probability of refill estimated?

Should ongoing hydrological monitoring and long-term weather forecasts suggest declining inflows, DEP Bureau of Water Supply Operations conducts probability-of-refill calculations. These calculations utilize historical inflows and reservoir storage conditions, as well as projected demand (including releases), to estimate the probability that the reservoir systems will fill to capacity by the following June 1, the beginning of the DEP's water year. If the probability that either the Catskill or Delaware Systems will fill by the following June 1 is less than 50%, a drought watch is declared. Should the probability of refill fall below 33%, a drought warning is declared. System-wide usable storage levels remained well within what is considered safe throughout 2007.

3. Water Quality

3.1 How did DEP help to ensure the delivery of the highest quality water from upstate reservoirs in 2007?

DEP continued to perform extensive water quality monitoring at multiple sampling sites from aqueducts, reservoir intakes, and tunnel outlets within the Catskill, Delaware, and Croton Systems. In 2007, over 69,700 physical, chemical, and microbiological analyses were performed on 6,376 samples that were collected from 58 different key aqueduct locations. DEP also continued to operate and maintain continuous monitoring instrumentation at critical locations to provide real-time water quality data to support operational decision making.

Scientists from the Bureau's Division of Watershed Water Quality Operations work cooperatively with the Bureau's Operations Divisions to determine the best operational strategy for delivering the highest quality water to NYC consumers. DEP continued to implement numerous operational and treatment techniques to effectively manage the Catskill, Delaware, and Croton Systems. Operational and treatment strategies employed in 2007 include:

- Selective Diversion

  DEP optimized the quality of water being sent into distribution by maximizing the flow from reservoirs with the best water quality and minimizing the flow from reservoirs with inferior water quality. For example, when an 8-inch rain event in April caused water quality to deteriorate in Ashokan Reservoir, DEP responded by installing stop shutters in the Catskill Aqueduct between Ashokan and Kensico Reservoirs (Figure 3.1). This operation allowed DEP to continue delivering water to outside communities while minimizing the amount of turbid water being diverted from Ashokan Reservoir into Kensico Reservoir. The success of this operation allowed DEP to avoid alum treatment.

Figure 3.1 Stop Shutter Installation in the Catskill Aqueduct at Moodna, NY (J. Helmuth).

- Selective Withdrawal

  DEP continued to monitor water quality at different intake elevations within the reservoirs and used that information to determine the optimal level of withdrawal. For example, in June, a slow moving storm dropped 6 to 8 inches of rain in the watershed of Pepacton Reservoir and extensive water quality monitoring indicated that the turbidity levels had increased near the surface of the reservoir as a result. By changing the level of withdrawal from the surface to the bottom, DEP was able to optimize water quality and place the East Delaware Tunnel back into service within one week of the storm.

3.2 How did the 2007 water quality of NYC's source waters compare with Surface Water Treatment Rule standards for fecal coliforms and turbidity?

The Surface Water Treatment Rule (SWTR) (40CFR141.71(a)(1)) requires that water at a point just prior to disinfection not exceed thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at "keypoints" just prior to disinfection (the Croton System at the Croton Lake Gate House (CROGH), the Catskill System at the Catskill Lower Effluent Chamber (CATLEFF) and the Delaware System at the Shaft 18 building (DEL18)). Figures 3.2 and 3.3 depict fecal coliform and turbidity data at each of these keypoints for 1992–2007. Both figures includes a horizontal line marking the SWTR limit.

As indicated in Figure 3.2, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard that no more than 10% of daily samples may contain >20 CFU $100mL^{-1}$. For 2007, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below this limit. Median fecal coliform concentrations (CFU $100mL^{-1}$) in raw water samples taken at these sites were 0, 1, and 1, respectively, while maxima were 8, 21, and 14, respectively.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.3, all three effluent waters, measured at 4-hour intervals, were consistently well below this limit in 2007. For CROGH, CATLEFF, and DEL18, median turbidity values (NTU) were 0.8, 1.0, and 1.0 and 0.9, respectively, while maximum values were 2.8, 3.4, and 2.0, respectively. (Note: The plot shows one high value at CROGH in 2006 that was caused by an operational adjustment, as discussed in the Watershed Water Quality Annual Report for 2006 (DEP 2007a).)

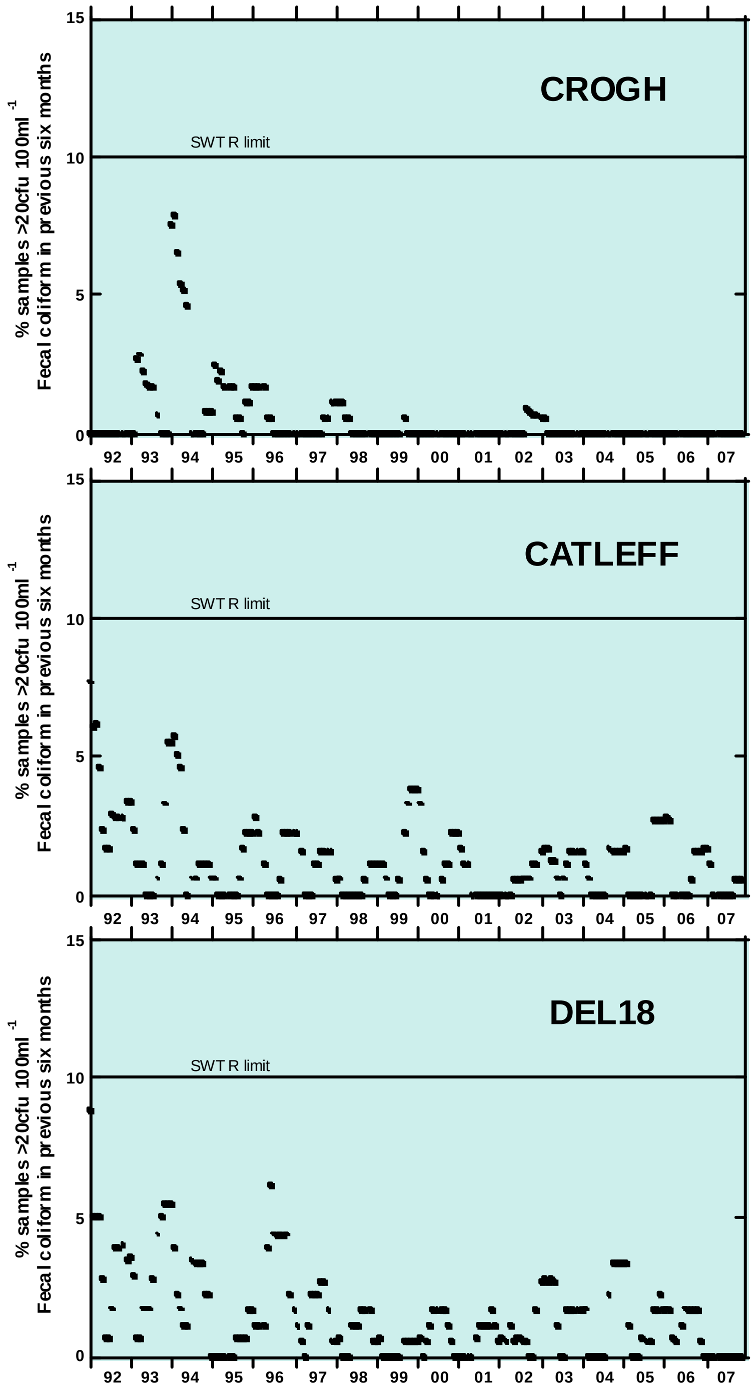

Figure 3.2 Fecal coliform (% of daily samples > 20 CFU 100ml^{-1} in the previous six months) at keypoints, compared with Surface Water Treatment Rule limit, for 1992 to 2007.

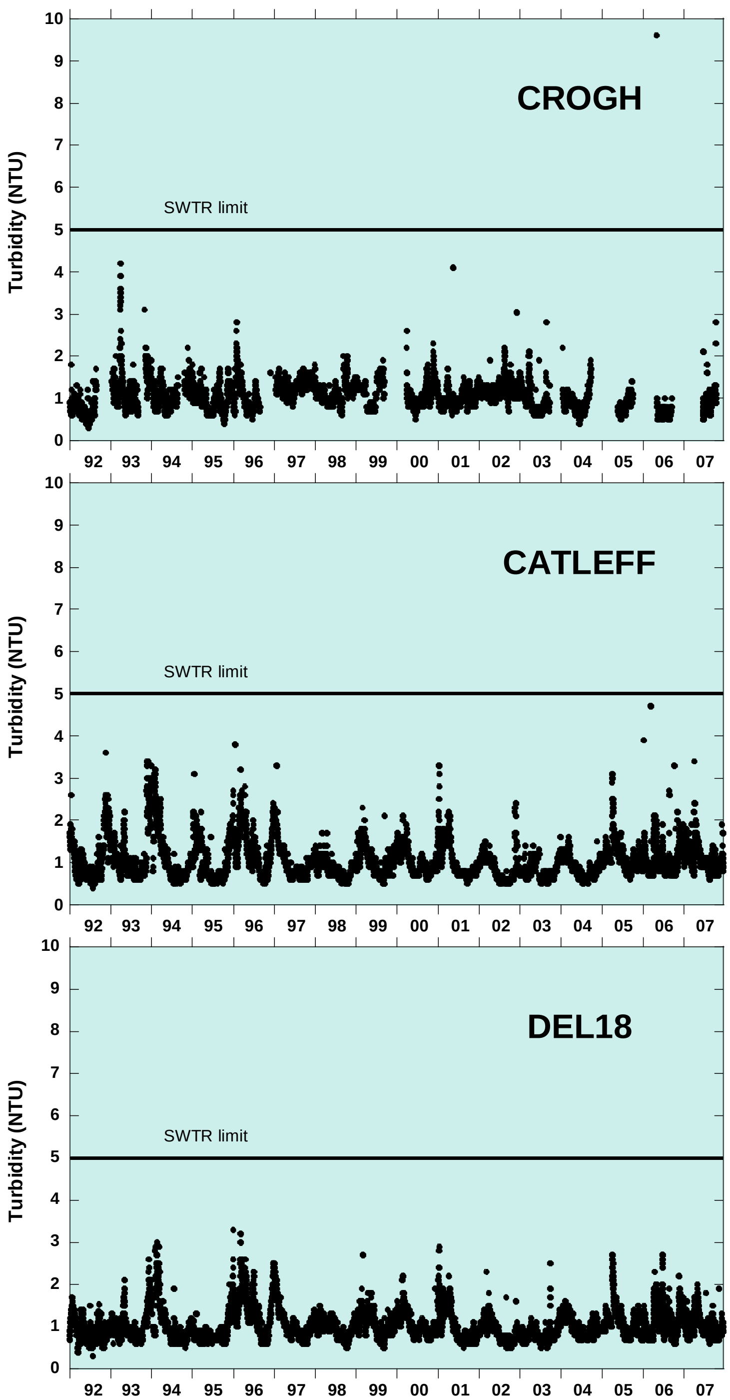

Figure 3.3 Turbidity at keypoints compared with Surface Water Treatment Rule limit, for 1992 to 2007.

3.3 What factors contributed to the turbidity patterns observed in the reservoirs in 2007?

Turbidity in reservoirs is caused by organic (e.g., plankton) and inorganic (e.g., clay, silt) particulates 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 2007, turbidity in Ashokan and Cannonsville was higher than normal due to runoff events in March, April, and early June, and a series of relatively small events in September and October (Figure 3.4). Interestingly, although precipitation patterns were similar in Schoharie and Neversink, turbidity in those reservoirs was lower than normal. The difference is that rain events in September, October, and November in the Neversink and Schoharie watersheds produced relatively little turbidity. Turbidity levels in Pepacton were at their highest in the past 11 years (although still very low) due primarily to the flash flooding that occurred in that basin on June 19, 2007 (see Section 2.2).

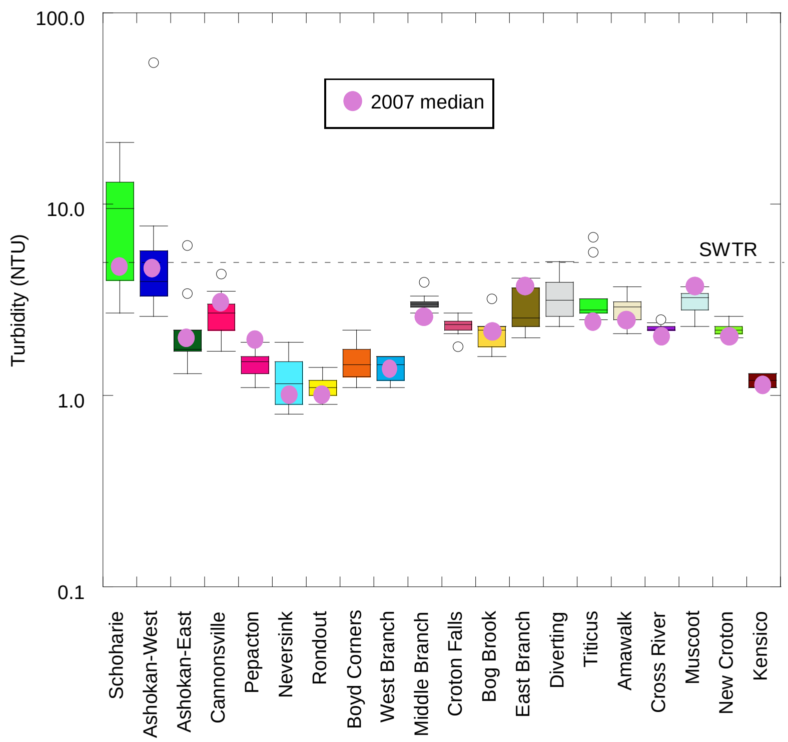

Figure 3.4 Annual median turbidity in NYC water supply reservoirs (2007 vs. 1997–2006). The dashed line at 5 NTU represents the SWTR criterion that considers 2 consecutive days > 5NTU a violation in source water reservoirs.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Medians were not calculated in 2007 for Boyd Corners, Croton Falls, and Diverting Reservoirs due to insufficient data.

West Branch Reservoir, a blend between Rondout and Boyd Corners water, was very close to its historical median. Kensico Reservoir, mostly a blend of Rondout and Ashokan water, had slightly lower than normal turbidity due to the greater percentage of lower turbidity Rondout water in the blend than is typically found, a function of how the system was operated in 2007.

Most of the Croton System reservoirs were close to or less than their historical median turbidity levels, a reflection of the fact that annual precipitation in the Croton System was at its lowest since 2001–2002, and major runoff events were limited. East Branch and Muscoot reservoirs, however, while experiencing the same general precipitation patterns as other Croton System reservoirs, had turbidity levels very close to their 11-year high. Elevated turbidity at East Branch was associated with an April storm and with algal blooms in July, October, and November. The elevated turbidity in Muscoot was caused by elevated algal counts from June through October. Muscoot was initially drawn down in June and did not spill for the rest of the year. This increased the residence time, thus creating conditions conducive to algal growth. Since Muscoot's surface water did not spill into New Croton, as normally occurs, New Croton's algal counts/turbidity were not elevated in 2007, but instead were very close to historical levels.

Insufficient data exists to calculate representative statistics for Boyd Corners, Croton Falls, and Diverting Reservoirs. For these reservoirs, only the historical range of annual medians is provided in Figure 3.4.

Results for the three controlled lakes in the Croton System—Kirk, Gilead, and Gleneida—were variable. In 2007, the median turbidity at Gilead and Kirk was 1.9 and 4.3 NTU, respectively, up approximately 40 percent from their historical medians. Reasons for the increase differ. Gilead was impacted by spring runoff while Kirk experienced significant algal turbidity in October. Although Gleneida was not sampled enough in 2007 to calculate a representative annual median, turbidity data from August and October were lower than historical values. (Note that box plots for these lakes are not included in Figure 3.4.)

3.4 What was the water quality in the major inflow streams of NYC'S reservoirs in 2007?

The stream sites referred to in Section 3.4 are presented in Table 3.1 and shown pictorially in Figure 3.5. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds (except for New Croton, where the major inflow is from the Muscoot Reservoir release). The Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed.

Table 3.1: Sites codes and site descriptions of the stream sample locations discussed in Section 3.4.

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

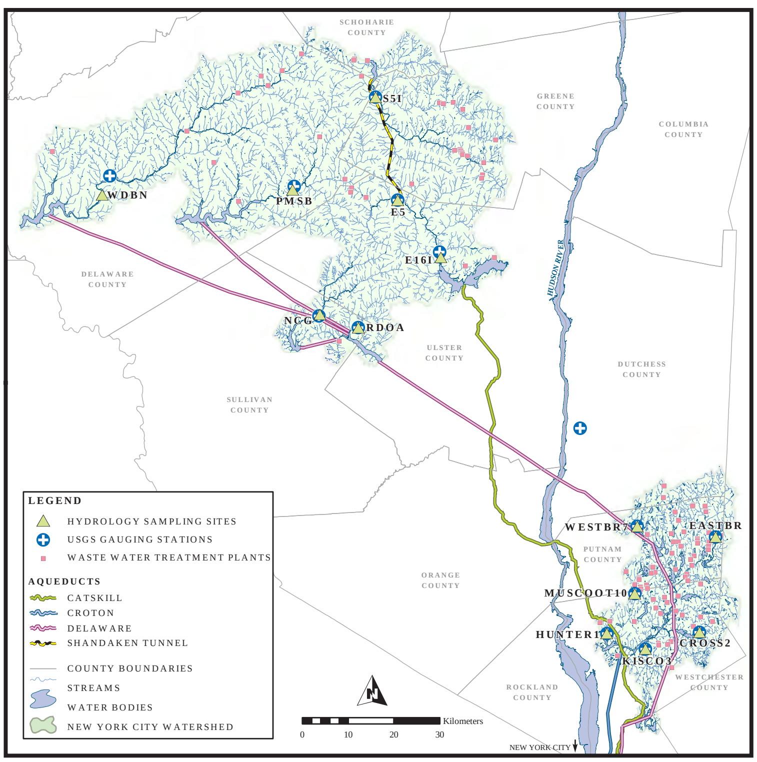

Figure 3.5 Locations of sampling sites discussed in Section 3.4 and USGS stations used to calculate the runoff values presented in Section 2.4.

Water quality in these streams was assessed by examining those analytes considered to be the most important for the City water supply. For streams, these are turbidity (values may not exceed Surface Water Treatment Rule limit), total phosphorus (nutrient/eutrophication issues), and fecal coliform bacteria (values may not exceed Surface Water Treatment Rule limits).

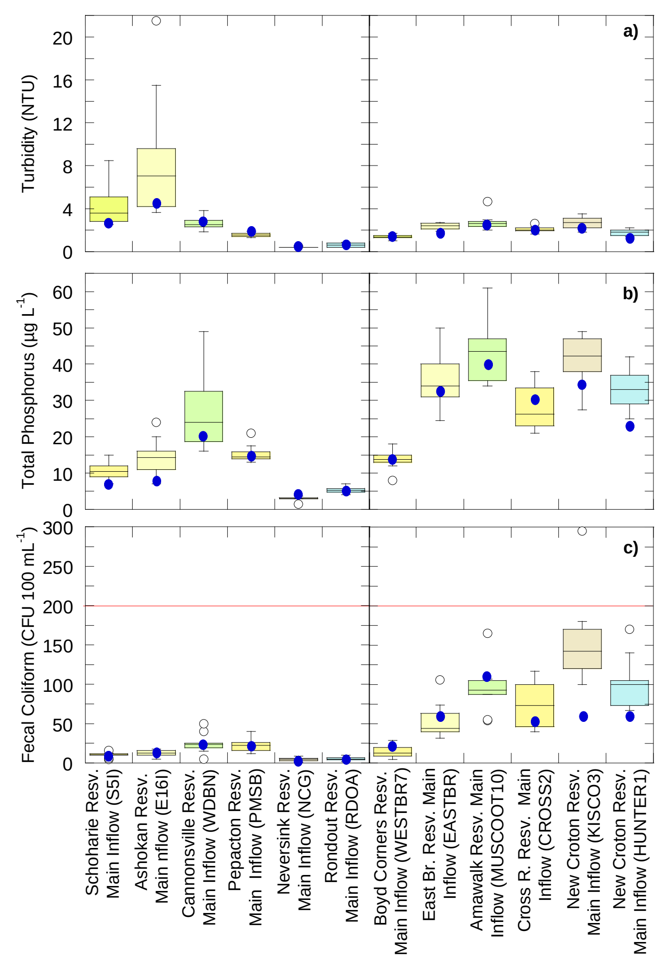

Figure 3.6 Boxplot of annual medians (1997–2006) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2007 displayed as a dot.

The results presented in Figure 3.6 are based on grab samples generally collected twice a month (but generally once a month for turbidity and total phosphorus for the East of Hudson (EOH) sites). The figures compare the 2007 median values against historical median annual values for the previous 10 years (1997–2006). However, two of the EOH sites have shorter sampling histories. These are: KISCO3 (1999–present) and HUNTER1 (1998–present). It should also be noted that the 2007 water quality data from the Catskill and Delaware Systems are still considered provisional in nature.

Turbidity

The turbidity levels for 2007 were generally near "normal" values (Plot a in Figure 3.6) with the 2007 median turbidity values in the inflows to Ashokan and Schoharie Reservoirs being somewhat less than the historical median for the previous 10 years. East of Hudson, the 2007 median turbidity values in the inflows to the East Branch and New Croton Reservoir tributaries were also less than the historical median for the previous 10 years.

Total Phosphorus

In the Catskill and Delaware Systems, the 2007 total phosphorus (TP) levels (plot b in Figure 3.6) were for the most part near typical historical values. As with turbidity, the annual total phosphorus median for 2007 for the inflows to Ashokan and Schoharie were somewhat less than the historical median for the previous 10 years. Also, the total phosphorus value in Cannonsville in 2007 remained below the historical median, perhaps reflecting the influence of improvements in agricultural practices and wastewater treatment plant (WWTP) upgrades. The 2007 total phosphorus values in the Croton System were variable but generally within the range of typical values, except for the tributaries to New Croton Reservoir, which were at less than historical values.

Fecal Coliform Bacteria

The 2007 fecal coliform bacteria levels (Plot c in Figure 3.6) in the Catskill, Delaware, and Croton Systems were generally near the typical historical levels. Only MUSCOOT10, the inflow to Amawalk Reservoir, showed a slightly elevated median value of fecal coliform in 2007, while the tributaries to New Croton Reservoir exhibited less than historical values. A fecal coliform benchmark of 200 CFU $100mL^{-1}$ is shown as a solid line in Figure 3.6c. This benchmark relates to the New York State Department of Environmental Conservation (DEC) water standard (expressed as a monthly geometric mean of five samples, the standard being <200 CFU $100mL^{-1}$) for fecal coliform (6 NYCRR §703.4b). The 2007 median values for all streams shown here lie below this value.

3.5 How were the total phosphorus concentrations in the reservoirs affected by precipitation and runoff in 2007?

Precipitation and runoff generated by precipitation are important mechanisms by which phosphorus is transported from local watersheds into streams and reservoirs. Primary sources of phosphorus include: human and animal waste, fertilizer runoff, atmospheric deposition, and internal recycling from reservoir sediments.

In 2007, median phosphorus results in all Catskill and most Delaware System reservoirs were at or near their lowest levels since 1997 (Figure 3.7). The only exception, Pepacton Reservoir, was slightly higher than normal due to an intense rainfall event on June 19, 2007, which produced flash flooding and elevated phosphorus levels in the reservoir until August (see Section 2.2). The diversion to Rondout Reservoir was shut down for several days, which greatly mitigated the storm's effect on Rondout water quality. This storm was regionally quite limited and water quality in the other reservoirs was not greatly affected. With the exception of this localized storm and a large region-wide, mid-April runoff event, storms were generally of low volume (<1 inch) and intensity in 2007, so transport of phosphorus to waterways was relatively low on an annual basis. Ongoing efforts to reduce phosphorus loads (e.g., agricultural BMPs and treatment plant upgrades) may also be a factor in the observed phosphorus reduction, particularly in the Cannonsville watershed (DEP 2006a).

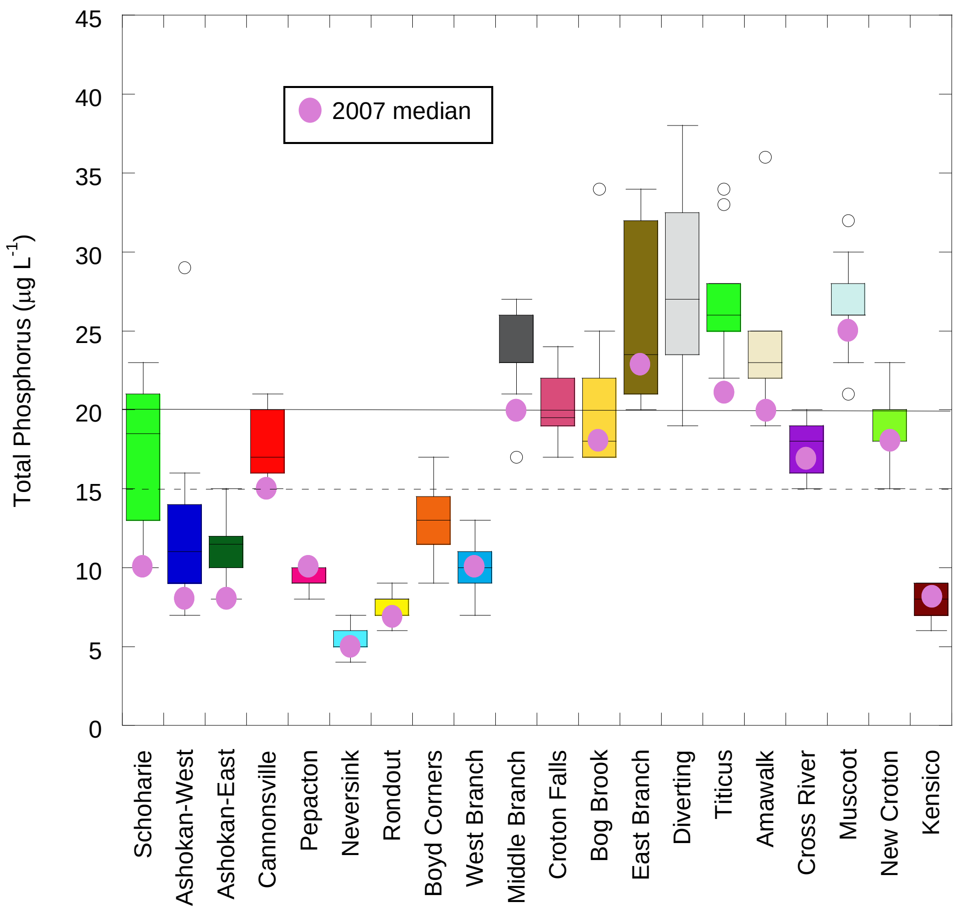

Figure 3.7 Annual median total phosphorus in NYC water supply reservoirs (2007 vs. 1997–2006). The horizontal dashed line at 15 µg L^{-1} represents the NYC TMDL guidance value for source waters (in the NYC water supply system, New Croton and Kensico Reservoir, but see note below). The horizontal solid line at 20µg L^{-1} represents the DEC ambient water quality guidance value appropriate for reservoirs other than source waters.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Medians were not calculated in 2007 for Boyd Corners, Croton Falls, and Diverting Reservoirs due to insufficient data.

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

West Branch Reservoir is a blend of Rondout water from the Delaware System and Boyd Corners water from the Croton System. Although phosphorus levels in Rondout were below the historical median in 2007, West Branch's was the same as the historical median, reflecting a greater than typical percentage of Boyd's water in the 2007 blend.

Kensico Reservoir, which receives water from both Rondout and Ashokan, showed no change in phosphorus compared to historical levels.

As shown in Figure3.7, total phosphorus concentrations in the Croton System are normally much higher than in the Catskill and Delaware Systems. The Croton watershed is more urbanized: there are 60 WWTPs, numerous septic systems and abundant paved surfaces scattered throughout the watershed. The 2007 phosphorus concentrations appear to be similar or low relative to past concentrations for all Croton reservoirs, reflecting the scarcity of runoff-producing rain events in 2007.

Data for Croton Falls and Diverting Reservoirs was very limited in 2007 due to continuing dam rehabilitation work that necessitated the drawdown of these two impoundments. Although accurate representative medians could not be calculated, the distribution of past annual medians is provided in Figure 3.7.

Results for the three controlled lakes in the Croton System—Kirk, Gilead, and Gleneida—were variable. The median phosphorus concentration at Gilead was 26µg L^{-1}, up approximately 36% from historical levels, while at Kirk it was down 30% to 20 µg L^{-1}. Gilead was noticeably impacted by spring runoff while Kirk was relatively unaffected. Phosphorus at Gleneida was not reported due to insufficient sampling in 2007.

3.6 Which basins were phosphorus-restricted in 2007?

Phosphorus-restricted basin status is presented in Table 3.2 and was derived from two consecutive assessments (2002–2006 and 2003–2007) using the methodology stated in Appendix C. The table in this appendix lists the annual growing season geometric mean phosphorus concentration for each of the NYC reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.8 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2007 geometric mean phosphorus concentration.

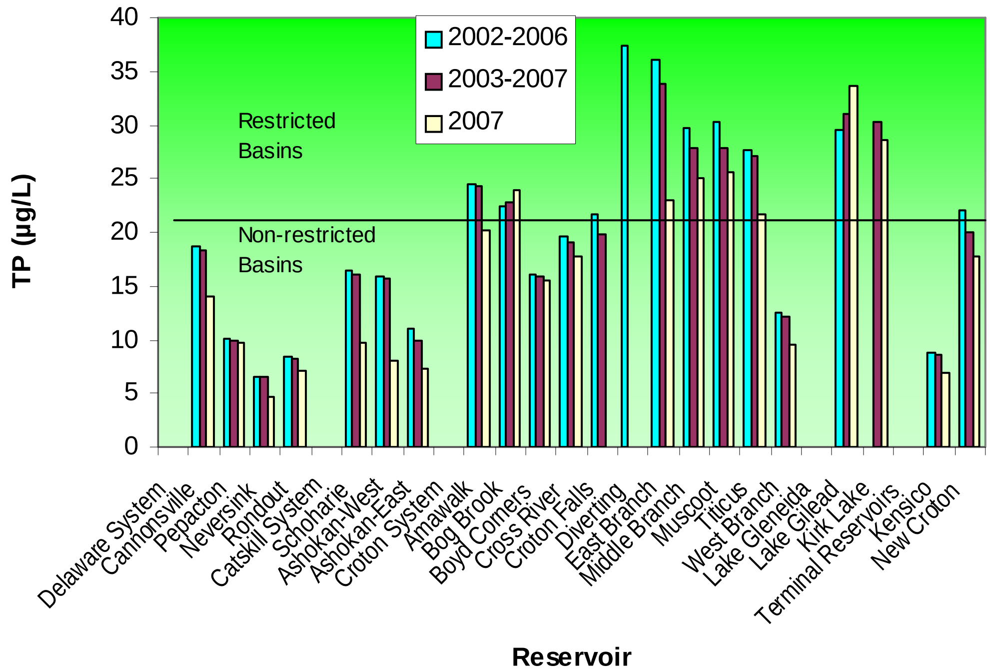

Figure 3.8 Phosphorus-restricted basin assessments, with the current year (2007) geometric mean phosphorus concentration displayed for comparison.

Some notes and highlights regarding phosphorus-restricted basin status in 2007:

- The Delaware System reservoirs showed similarity between the two assessment periods in all impoundments. All reservoirs remained non-restricted with respect to TP. Figure 3.8 shows that the 2007 geometric mean was lower than the mean for the two five-year assessment periods for three of the four reservoirs, the exception being Pepacton. The mean TP for the two assessment periods and 2007 were all similar in Pepacton.
- The Catskill System reservoirs also showed similar five-year assessments in each of the basins. The 2007 geometric mean decreased in all reservoirs compared to the two assessments. This may represent a return to a "baseline" level of TP as compared to the geometric mean TP in 2005 and 2006, when large storms contributed to higher phosphorus levels.
- The Croton System reservoir assessments remained unchanged in their phosphorus-restricted status. Croton Falls Reservoir was only sampled in the main basin during 2007 due to low elevations necessitated by dam repairs. A comparison of main-basin-only to full reservoir assessments for five years showed a low bias of about 4 µg L^{-1} for the main-basin-only assessment. Because the 2007 data would not be comparable to previous years, the data for 2007 were not considered. Diverting Reservoir was inaccessible for most of the year due to dam rehabilitation, so an assessment of the 2007 data was not possible. A decrease between the mean for the two assessment periods and the 2007 mean was found at East Branch. A poten-

tial cause of this decrease was that the 2004 data were biased high because no early season, low-concentration TP samples were collected. Subsequent sampling provided full growing season values. Lake Gleneida had insufficient samples for a full assessment due to access problems. Kirk Lake had sufficient data for its first five-year assessment, which will allow for a TP-restricted assessment next year.

- Kensico Reservoir had similar analyses for each of the last two five-year assessments, and remained unrestricted. While there was a slight decrease between the two five-year assessment periods for New Croton Reservoir, both remained above 20 µg L^{-1}. As a result, New Croton continued to be a phosphorus-restricted basin.

Table 3.2: Phosphorus-restricted reservoir basins for 2007.

Reservoir Basin	02–06 Assessment (mean + S.E.) (µg L^{-1})	03–07 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus-Restricted Status
Delaware System			
Cannonsville Reservoir	18.8	18.2	Non-Restricted
Pepacton Reservoir	10.1	9.9	Non-Restricted
Neversink Reservoir	6.5	6.5	Non-Restricted
Rondout Reservoir	8.5	8.2	Non-Restricted
Catskill System			
Schoharie Reservoir	16.4	16.1	Non-Restricted
Ashokan-West	15.9	15.7	Non-Restricted
Ashokan-East Reservoir	11.0	9.8	Non-Restricted
Croton System			
Amawalk Reservoir	24.5	24.3	Restricted
Bog Brook Reservoir	22.5	22.9	Restricted
Boyd Corners Reservoir	16.0	15.9	Non-Restricted
Cross River Reservoir	19.6	19.1	Non-Restricted
Croton Falls Reservoir	21.8	19.9	Restricted
Diverting Reservoir	37.3	Insufficient data	Restricted
East Branch Reservoir	36.0	33.7	Restricted
Middle Branch Reservoir	29.8	27.9	Restricted

Table 3.2: (Continued)Phosphorus-restricted reservoir basins for 2007.

Reservoir Basin	02–06 Assessment (mean + S.E.) (µg L^{-1})	03–07 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus-Restricted Status
Muscoot Reservoir	30.2	27.9	Restricted
Titicus Reservoir	27.7	27.0	Restricted
West Branch Reservoir	12.6	12.2	Non-Restricted
Lake Gleneida	Insufficient data	Insufficient data	Restricted
Lake Gilead	29.6	31.1	Restricted
Source Water			
Kensico Reservoir	8.8	8.6	Non-Restricted
New Croton Reservoir	22.0	20.0	Restricted

Note that all data in the 02–06 and 03–07 assessments is "verified", except for the 2007 data in the 03–07 assessment, which is "provisional".

3.7 Do reservoirs behave according to the general patterns of other northern temperate water bodies?

Eutrophication is an increase in nutrients, particularly phosphorus, and the effects of that increase, on a water body. The Organization for Economic Co-operation and Development (OECD) funded an international program on eutrophication of lakes in the late 1970s and early 1980s. Research on inland temperate lakes during the OECD program showed that chlorophyll *a* (chl *a*) (an indicator of algal biomass) is positively correlated with TP (Janus and Vollenweider 1981).

DEP conducted a comparison of NYC reservoirs and the OECD lakes using growing season (May through October) photic zone samples to determine whether the same relationship applied in the City's reservoirs. The long-term (1997–2006) mean and the annual mean for 2007 were compared to the regression line developed by the OECD program (Figure 3.9). An upper and lower 95% confidence interval are also shown in the figure. The shift in the NYC regression lines compared to the OECD line is likely due to methodology differences. The high performance liquid chromatography (HPLC) used by DEP is a more exact method for determination of chl *a* as compared with the older methods used to develop the OECD relationships in 1981.

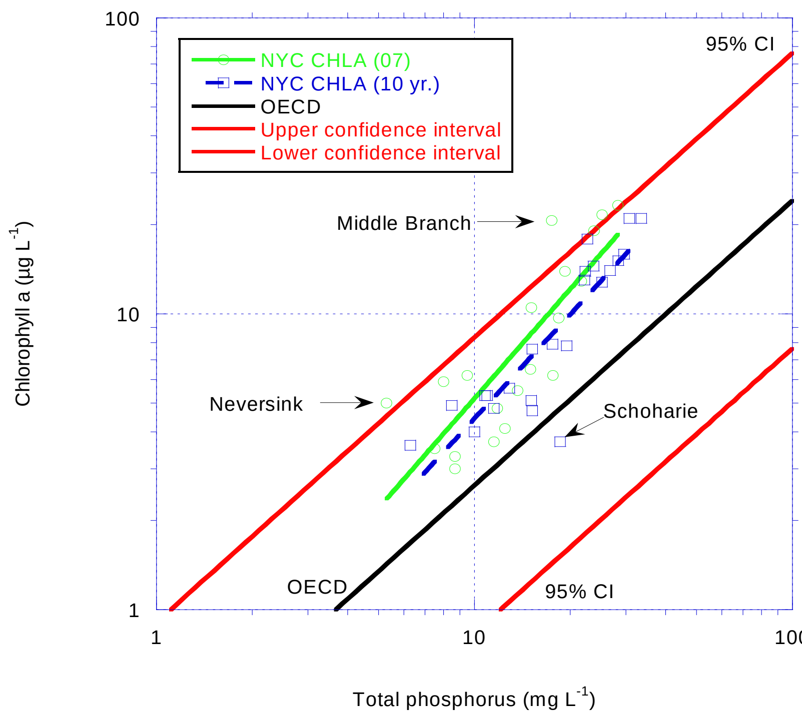

Figure 3.9 Mean chlorophyll *a* vs. total phosphorus concentration in NYC reservoirs compared to OECD Eutrophicaton Program lakes. For NYC reservoirs, samples were collected in the photic zone during the growing season (May–October) over a 10-year period (1997-2006) and in 2007.

Note: EOH chlorophyll data from 1997 were removed from the analysis. Chlorophyll *a* results were obtained through the use of a spectrophotometer or fluorometer from 1997-2000, and by HPLC thereafter. TP results were obtained by the Valderamma method (1980) from 1997–1999, and by APHA (1992, 1998) thereafter.

In general, reservoirs from the Catskill and Delaware Systems were lower in nutrient concentration (as measured by TP) and algal response (as indicated by chl *a*) than the OECD water bodies. Neversink Reservoir is an example indicated in the plot. Reservoirs of the Croton System tended to have higher nutrient concentrations and higher chl *a*. Middle Branch Reservoir is a notable example of this—its annual growing season mean was above the 95% confidence interval compared to the OECD water bodies. Schoharie Reservoir was an outlier, indicating the relationship between chl *a* and TP in this reservoir is different from the other NYC reservoirs. Apparently the low clarity of Schoharie inhibits algal response despite its moderate phosphorus concentration.

NYC reservoirs also generally conform to the expectations set by the OECD that Secchi transparency (Z_{SD}) is inversely related to chl *a* concentration (Janus and Vollenweider 1981) (Figure 3.10). Both the long-term and the 2007 regression lines are clustered about the OECD line. The higher bias found in NYC's reservoirs may be due to the chl *a* method difference stated above, as well as to Secchi readings taken with a viewer box. For 7 of the 10 years in the long-term data, a viewer box was used to aid Secchi readings. The viewer box generally increased the Secchi transparency as compared to readings without the box.

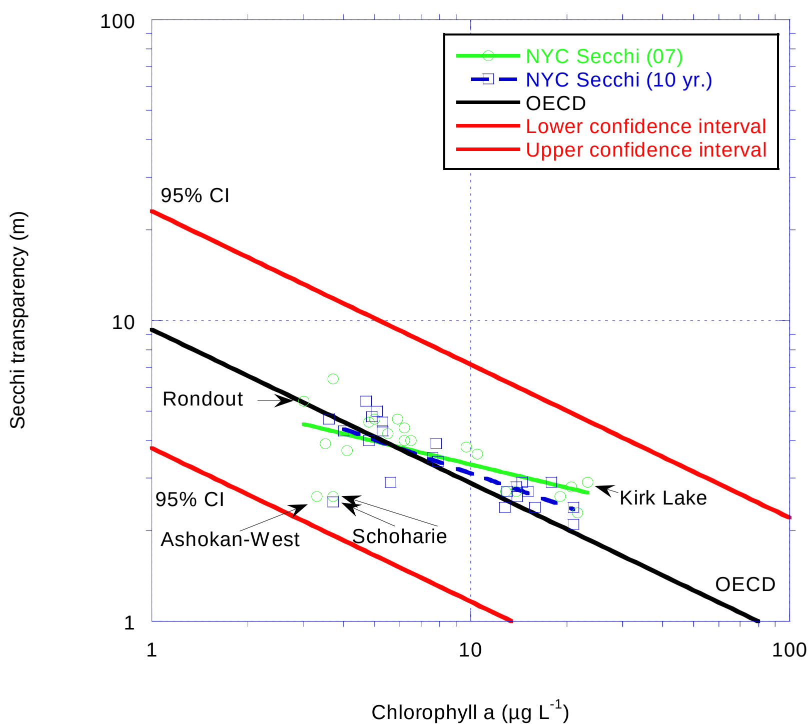

Figure 3.10 Mean chlorophyll *a* vs. Secchi transparency (Z_{SD}) in samples collected in the photic zone during the growing season (May–October) in NYC reservoirs over a 10-year period (1997–2006) and for 2007.

Note: EOH chlorophyll data from 1997 were removed from the analysis. Chlorophyll a results were obtained through the use of a spectrophotometer or fluorometer from 1997–2000, and by HPLC thereafter. Z_{SD} results were obtained on the shady side of the boat using the naked eye from 1997–1998, and by use of a viewer box on the sunny side of the boat 1999–2007, producing slightly higher results (Smith and Hoover 1999, Smith 2001).

The West of Hudson reservoirs tended to have lower chl *a* levels and deeper Secchi transparency as compared to East of Hudson impoundments. Rondout Reservoir and Kirk Lake are noted on the plot as examples. Schoharie and Ashokan's West Basin stand out because of their relatively low transparency and low chl *a* concentrations compared to other NYC reservoirs and OECD water bodies. The departure of Schoharie and Ashokan from the "standard" Z_{SD}-chl *a* relationship was due to the elevated concentration of suspended material that periodically occurs in those reservoirs. The higher turbidity blocks the transmission of light, resulting in lower transparency and lower primary production.

The combination of three plots (chl *a* vs. TP, chl *a* vs. $Z_{SD,}$ and Trophic State Index (TSI) (Section 3.12)) can be used to provide valuable information about the reservoirs. They suggest, for example, that algal growth is driven by TP for most reservoirs and that, in general, algae are the principal cause of light attenuation. The high TSI values indicate that reservoirs like Middle Branch and Muscoot are clearly eutrophic and that blue-green algae can become dominant in these impoundments. It can also be seen that the primary cause of light attenuation in Schoharie and Ashokan's West Basin is the presence of non-algal particulates, and that terminal receiving-water reservoirs (closer to distribution) tend to be at a lower trophic state than outlying reservoirs. With the exceptions of Cannonsville and Schoharie, Catskill and Delaware reservoirs have deeper Secchi transparency, less phosphorus, and less chl *a* than the Croton System reservoirs.

3.8 How did the reservoir water conductivity in 2007 compare to previous years?

Specific conductivity is a measure of the ability of water to conduct an electrical current. It varies as a function of the amount and type of ions that the water contains. The ions which typically contribute most to reservoir conductivity include: calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), potassium (K^{+1}), bicarbonate (HCO_3^{-1}), sulfate (SO_4^{-2}), and chloride (Cl^{-1}). Dissolved forms of iron, manganese, and sulfide may also make significant contributions to the water's conductivity given the right conditions (e.g., anoxia). Background conductivity of water bodies is a function of the watershed's bedrock, surficial deposits, and topography. For example, watersheds underlain with highly soluble limestone deposits will produce waters of high conductivity compared with watersheds comprised of relatively insoluble granite. If the topography of a watershed is steep, deposits tend to be thin and water is able to pass through quickly, thus reducing the ability of the water to dissolve substances. This type of terrain will also produce waters of low conductivity. Such is the case with NYC's water supply reservoirs. Catskill and Delaware System reservoirs displayed uniformly low median conductivities in the past as well as in 2007 (Figure 3.11). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits, which produce relatively low conductivities in the 25 to 100 µS cm^{-1} range. Because West Branch and Kensico generally receive most of their water from the Catskill and Delaware reservoirs, the conductivities of West Branch and Kensico are also low, usually in the 50 to 100 µS cm^{-1} range. Reservoirs of the Croton System have higher baseline conductivities than those of the Catskill and Delaware Systems. In part this is due to the flatter terrain of the Croton watershed as well as to the occurrence of soluble alkaline deposits (e.g., marble and/or limestone) within the watershed. Urban development is also higher in the Croton System, which contributes to its higher conductivity. One reason for this is that the higher percentage of paved surfaces within more urbanized areas facilitates transport of runoff to waterways and also yields higher salt concentrations due to roadway de-icing operations.

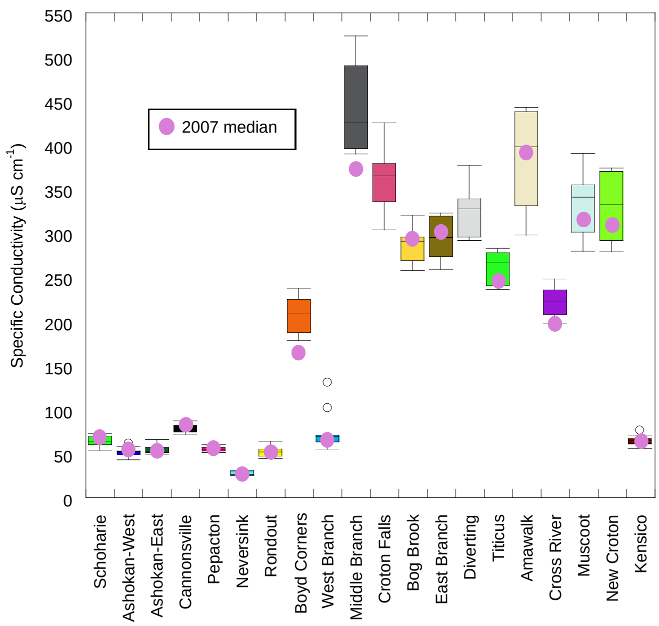

Figure 3.11 Annual median specific conductivity in NYC water supply reservoirs (2007 vs. 1997–2006).

Note: In general, data were obtained from multiple sites and depths, and at routine sampling frequencies (1 or 2x per month), from April through December. Medians were not calculated in 2007 for Croton Falls and Diverting Reservoirs due to insufficient data.

In 2007, conductivity in all Catskill and Delaware System reservoirs (including Kensico and West Branch) were all very close to their historical median levels. Median conductivity in Croton System reservoirs was near or below historical levels (Figure 3.11) (Sufficient data were not available to allow reporting on Croton Falls and Diverting Reservoirs.) All Croton Reservoirs including Kirk Lake have been trending downward since peaking in 2003–2005. The three controlled lakes (Kirk, Gilead, and Gleneida) are not represented in Figure 3.11, but summary statistics can be found for them in Appendix A. Unlike Kirk, conductivity at Gilead and Gleneida has remained stable since 2005.

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

Total coliform and fecal coliform bacteria are regulated at raw water intakes by the Surface Water Treatment Rule at levels of 100 CFU $100mL^{-1}$ and 20 CFU $100mL^{-1}$, respectively. Both are important as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals; total coliforms include both fecal coliforms and other coliforms that typically originate in water, soil and sediments.

Figure 3.12 shows that the 2007 median in Muscoot Reservoir was lower than the long-term (1997–2006) annual median levels of total coliform. This situation does not occur in any of the other Croton System reservoirs. Muscoot is much shallower than the other Croton System

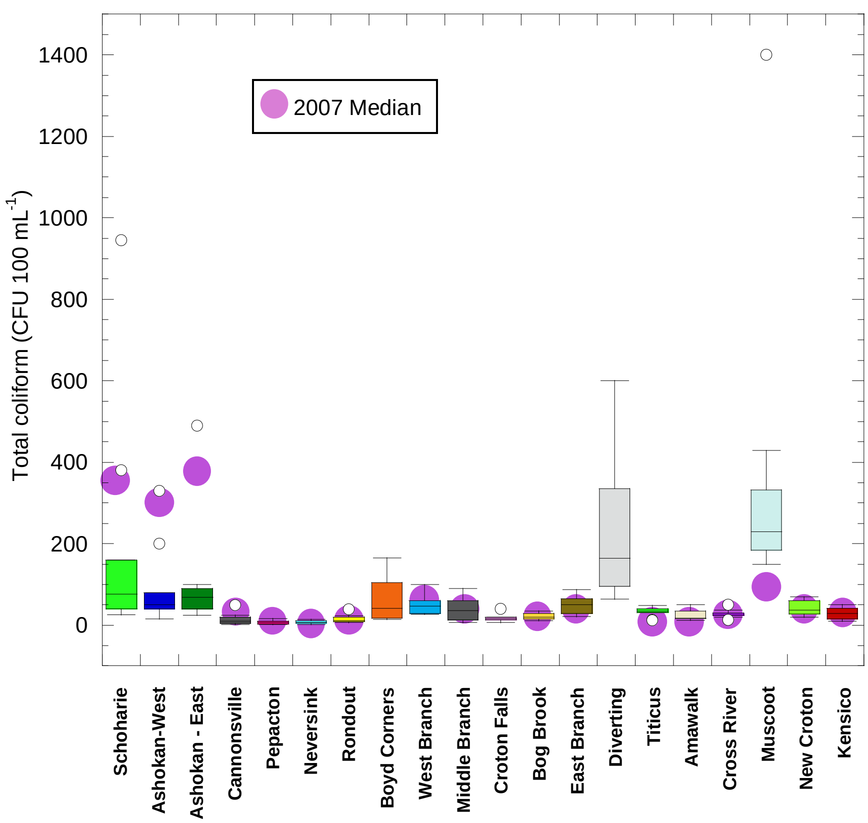

Figure 3.12 Annual median total coliform in NYC water supply reservoirs (2007 vs. 1997–2006).

Note: In general, data were obtained from multiple sites and depths, and at routine sampling frequencies (1 or 2x per month), from April through December. Medians were not calculated in 2007 for Boyd Corners, Croton Falls, and Diverting Reservoirs due to insufficient data.

reservoirs and is susceptible to wind-driven re-suspension events, which may distribute bacteria and detritus into the water column. Although not shallow, Diverting has a small volume, and rapid flow through this reservoir may influence total coliform levels. In 2007, dam rehabilitation at Diverting and Croton Falls Reservoirs curtailed sampling in those impoundments, as a result of which there was insufficient data to accurately estimate total coliform medians. Boyd Corners was sampled at varying sites due to its low elevation, so coliform samples in that reservoir were not used to estimate an annual median either. Of the remaining Croton reservoirs, most were very close to their historical annual medians. Muscoot was the exception, with total coliform counts at their lowest levels in the past 11 years. The most likely explanation is that annual precipitation was at its lowest since the drought of 2001–2002. There was an event in April and another in July, but both occurred after the reservoir was sampled for those months. Another possible explanation is that, of the five reservoirs from which Muscoot receives water, three had low total coliform counts and two were sampled infrequently in 2007 (Diverting and Croton Falls).

Results for the controlled lakes—Gilead, Gleneida and Kirk—are provided in Table 3.3 below. The higher total coliform counts observed at Kirk were probably due to sediment re-suspension events common in shallow water-bodies like Kirk, where the mean depth is 2 meters.

Table 3.3: Coliform summary statistics for NYC controlled lakes (CFU 100 mL^{-1}).

Lake	Median Total Coliform (1997–2006)	Median Total Coliform (2007)	Median Fecal Coliform (1997–2006)	Median Fecal Coliform (2007)
Gilead	15	15	<1	<1
Gleneida	8	15	<1	<1
Kirk	89	55	2	1

The Catskill reservoirs continued to have annual median total coliform levels in 2007 that were above their long-term medians. A large runoff event in April 2007 together with lesser storms later in the year contributed to this. In contrast, all of the Delaware reservoirs had medians similar to their historical levels. Research has shown that total coliforms commonly adhere to soil particles. Because soils are much less susceptible to erosion in the Delaware watersheds, an equal volume of runoff there tends to produce much lower total coliform counts than in the Catskill System.

Figure 3.13 compares the long-term (1997–2006) annual fecal coliform medians with the current 2007 annual median. Not enough data were collected in 2007 to estimate accurate medians for Diverting, Croton Falls, or Boyd Corners Reservoirs. Low fecal counts were observed in the remaining Croton reservoirs and controlled lakes. Reasons for the low counts are not clear, although there was a scarcity of runoff events from September through November.

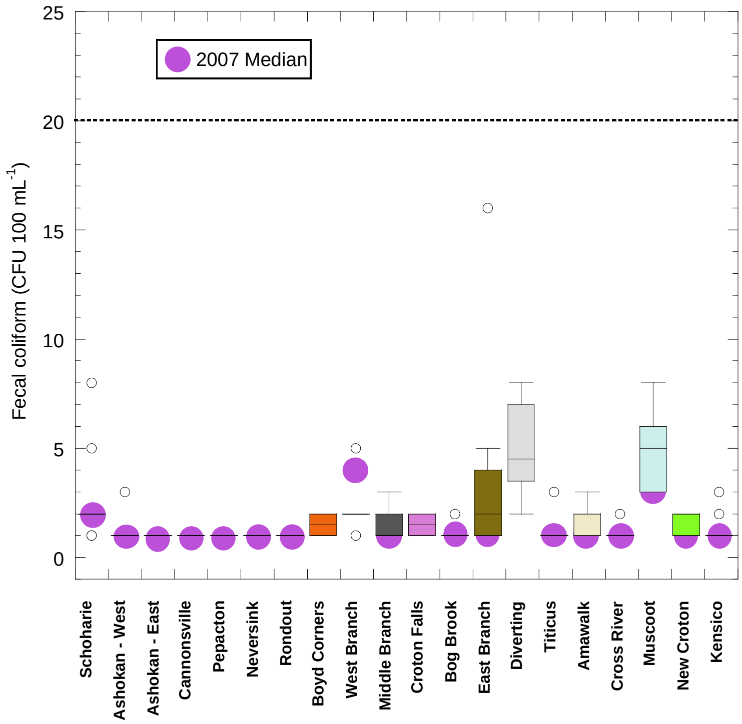

Figure 3.13 Annual median fecal coliform in NYC water supply reservoirs (2007 vs. 1997–2006). The dashed line represents the SDWA standard for source waters.

Note: In general, data were obtained from multiple sites and depths, and at routine sampling frequencies (1 or 2x per month), from April through December. Medians were not calculated in 2007 for Boyd Corners, Croton Falls, and Diverting Reservoirs due to insufficient data.

With the exception of West Branch, fecal counts in the Catskill and Delaware Systems were very close to their historical median levels in 2007. In contrast, West Branch was close to its 11-year high, driven largely by high counts in April, August, and October. The high counts in April and August coincided with large runoff events that occurred within one day prior to sampling. High counts in October were associated with elevated bird counts.

3.10 Which basins were coliform-restricted in 2007?

Coliform bacteria are used by water suppliers as potential indicators of pathogen contamination. To protect its water supply, New York City has promulgated regulations (the “Watershed Rules & Regulations”) that restrict potential sources of coliforms in threatened water bodies. These regulations require the City to perform an annual review of its reservoir basins to decide which, if any, should receive coliform-restricted determinations.

Coliform-restricted determinations are governed by two sections of the regulations, Section 18-48(a)(1) and Section 18-48(b)(1). Section 18-48(a)(1) applies to all reservoirs and Lakes Gilead and Gleneida ("non-terminal basins") and specifies that coliform-restricted assessments of these basins be based on compliance with NYS ambient water quality standard limits on *total* coliform bacteria (6 NYCRR Parts 701 and 703). Section 18-48(b)(1) applies to "terminal basins," those that serve, or potentially serve, as source water reservoirs (Kensico, West Branch, New Croton, Ashokan, and Rondout). The coliform-restricted assessments of these basins is based on compliance with federally-imposed limits on *fecal* coliforms collected from waters within 500 feet of the reservoir's aqueduct effluent chamber. (Note that in 2007, West Branch Reservoir Site CWB1.5 was sampled five days a week and replaced Site DEL10 for this assessment. Site 1.5 is more representative of the water in the basin as compared to DEL10, which could be influenced by water in the Delaware Aqueduct.)

Terminal basin assessments. In 2007, assessments were made for all five terminal basins, and none received a restricted assessment (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% or more of the effluent samples measured have values $\geq$ 20 CFU 100mL^{-1}, and the source of the coliforms is determined to be anthropogenic (man-made), the associated basin is deemed a coliform-restricted basin. If fewer than 10% of the effluent keypoint samples measure $\geq$ 20 CFU 100 mL^{-1}, the associated basin is deemed "non-restricted".

Table 3.4: Coliform-restricted basin status for terminal basins for 2007, as per Section 18-48(b)(1).

Reservoir Basin	Effluent Keypoint	2007 Assessment
Kensico	CATLEFF and DEL18	Non-restricted
New Croton	CROGH	Non-restricted*
Ashokan	EARCM	Non-restricted
Rondout	RDRRCM	Non-restricted
West Branch	CWB1.5	Non-restricted

* Site CROGH was only sampled from June through October due to shutdown of the Croton Aqueduct; therefore, Site CRO1T (located at the intake near the dam, sampled daily) was used for this assessment.

Non-terminal basin assessments. Because total coliform come from a variety of natural and anthropogenic sources, using total coliform alone to perform non-terminal basin assessments, as required by Section 18-48(a)(1), does not meet the spirit of the regulations. The draft methodology developed by DEP for conducting coliform-restricted basin determinations for non-terminal reservoirs uses the total coliform standard for an initial assessment, but also considers other microbial data to determine whether the source is anthropogenic. Since this proposed method is pending approval, coliform-restricted basin determinations were not performed for the non-terminal basins for 2007.

3.11 How did water quality in source water reservoirs compare with regulatory standards in 2007?

The NYC reservoir system is subject to the federal Surface Water Treatment Rule standards, NYS ambient water quality standards, and DEP's own target values. These standards are compared to the 2007 reservoir-wide medians for a variety of physical, biological, and chemical analytes for the four source water reservoirs—Kensico, New Croton, Ashokan (East Basin), and Rondout—in Table 3.11. (Ashokan's East Basin is the primary source of water from Ashokan Reservoir, with only occasional shifts to the West Basin.) Appendix A gives additional statistical information on these and other reservoirs in the system.

New Croton Reservoir water quality was noticeably different from the other three source water reservoirs. The median pH in New Croton was higher, as is often the case owing to its underlying geology and high primary production; the latter can at times cause the pH to rise above the water quality standard of 8.5. The median pH readings in WOH reservoirs were circumneutral; however, readings can at times drop below the standard of 6.5 as a result of low alkalinity, which provides little buffering of acidic precipitation. Median values for major cation metals (calcium, sodium, potassium) East of Hudson tended to be 4 to 10 times higher than in WOH reservoirs, which reflects the differences in underlying geology and increased anthropogenic sources of sodium in the EOH watershed. Chloride levels were higher in New Croton and other Croton System reservoirs as compared to the WOH impoundments, but remained well below the 250 mg L^{-1} water quality standard. Appendix A shows the chloride levels for all other EOH reservoirs.

The Croton System typically has greater nutrient inputs than the WOH reservoirs, which results in higher phytoplankton counts and chl *a* levels. This was true in 2007, when median values for total phytoplankton and chl *a* in New Croton exceeded those in the WOH reservoirs. Median phytoplankton values in New Croton were below the DEP guidance value of 2000 standard areal units (SAU), however, despite several occasions when total phytoplankton counts in the reservoir exceeded this limit (data not shown). Median chl *a* values, on the other hand, were above the guidance value. In contrast, Kensico, Rondout, and Ashokan Reservoirs did not exceed the chl *a* guidance value, and phytoplankton maxima were well below 2000 SAU (Appendix A). The median TP in New Croton was above the DEC's 15 µg L^{-1} guidance value for terminal reservoirs. Turbidity levels generally fell within a narrow range in all four reservoirs, with median values below 5 NTU. The deeper Secchi transparencies were found in Rondout and Kensico, which are less productive than New Croton and less turbid than Ashokan East. Higher levels of discoloration, iron, manganese, and organic carbon occurred in New Croton, reflecting its higher trophic state.

Table 3.5: Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the four source water reservoirs in 2007.

ANALYTES	Water Quality Standards	Kensico	New Croton	East Ashokan Basin	Rondout
PHYSICAL					
Temperature (C)		10.8	10.5	10.5	11.0
pH (units)	6.5-8.5[1]	7.0	7.5	7.2	7.0
Alkalinity (mg/l)		11.4	58.1	10.4	9.0
Conductivity		64	310	54	56
Hardness (mg/l)[2]		20	88	16	18
Color (Pt-Co units)	(15)	10	20	9	9
Turbidity (NTU)	(5)[3]	1.2	2.2	2.1	1.0
Secchi Disk Depth (m)		4.8	2.8	3.9	5.5
BIOLOGICAL					
Chlorophyll *a* (µg/l)	7[4]	5.3	10.5	3.3	3.1
Total Phytoplankton (SAU)	2000[4]	340	680	170	160
CHEMICAL					
Dissolved Organic Carbon (mg/l)		1.5	2.8	1.5	1.4
Total Phosphorus (µg/l)	15[4]	8	18	8	7
Total Nitrogen (mg/l)		.38	0.49	0.42	0.43
Nitrate+Nitrite-N (mg/l)	10[1]	.30	0.24	0.33	0.36
Total Ammonia-N (mg/l)	2[1]	0.01	0.03	0.01	0.01
Iron (mg/l)	0.3[1]	0.05	0.06	0.14	0.04
Manganese (mg/l)	(0.05)	0.01	0.06	0.01	0.01
Lead (µg/l)	50[1]	0.5	0.5	0.5	0.5
Copper (µg/l)	200[1]	1.5	1.5	1.5	1.5
Calcium (mg/l)		5.6	22.4	5.0	5.2
Sodium (mg/l)		4.9	27.6	3.6	4.2
Chloride (mg/l)	250[1]	7.7	50.2	5.2	6.2

Note: See Appendix A for water quality standards footnotes.

3.12 What were the trophic states of the City's 19 reservoirs in 2007 and why is this important?

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

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

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

where CHLA is the concentration of chlorophyll *a*

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

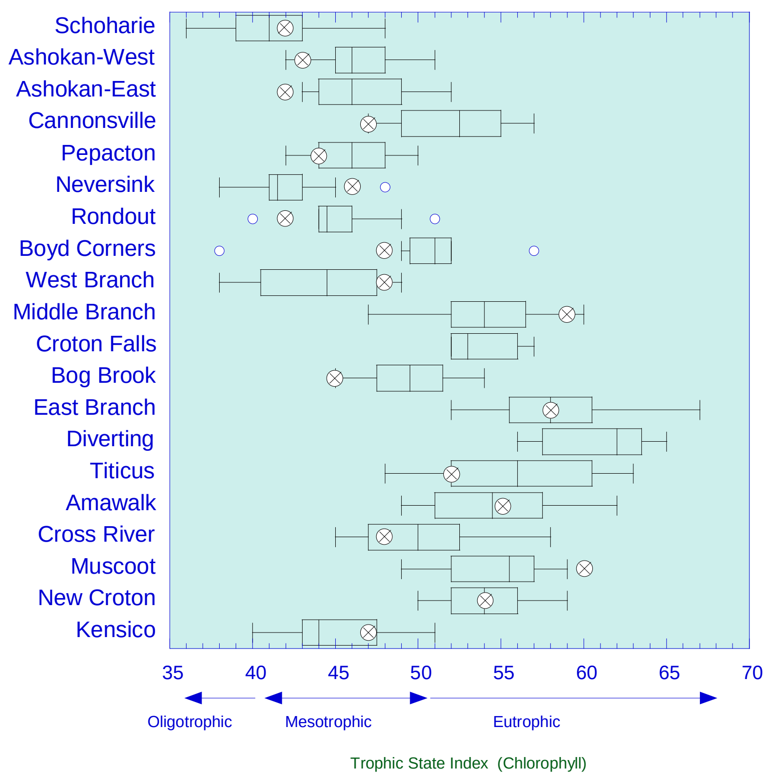

Figure 3.14 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2007 vs. 1997–2006).

Note: In general, data were obtained from epilimnetic depths at multiple sites and at routine sampling frequencies (1 or 2x per month) from May through October. TSI is based on chlorophyll *a* concentration.

Historical annual median TSI based on chl *a* concentration is presented in box plots for all reservoirs in Figure 3.14. Data for EOH reservoirs are from the years 1998–2004 and 2006, while Catskill and Delaware reservoir data are from 1997–2006. The 2007 annual median TSI appears in the figure as a circle containing an "x". This analysis usually shows a split between WOH reservoirs, which usually fall into the mesotrophic category, and EOH reservoirs, which are typically classified as eutrophic. The exceptions to these generalities are Cannonsville, which is usually considered eutrophic; West

Branch, which is considered mesotrophic due to incoming water from Rondout; and Kensico, which is considered mesotrophic due to inputs from Rondout (usually via West Branch) and from Ashokan.

TSI in the Catskill System is largely controlled by light availability, which for these reservoirs is chiefly a function of turbidity level. Schoharie Reservoir was generally low in turbidity in 2007. Taking advantage of the increased light, algal counts and corresponding chl *a* levels were up slightly. TSI in both Ashokan basins was down dramatically in 2007, most likely as a result of lower phosphorus levels.

With the exception of Neversink, TSI in the Delaware System was low in 2007. Pepacton Reservoir was down about 4% from the historical annual median TSI, which was likely due to the light-limiting turbid conditions produced by a June 19, 2007 flash flood. Flow through the reservoir was also relatively high in 2007, which can limit algal growth by reducing contact time with available nutrients. The largest TSI reduction, about 10%, was observed at Cannonsville Reservoir. Unlike Pepacton, Cannonsville did not experience excessively turbid conditions during the algal growing season. The decrease in TSI corresponded to a reduction in phosphorus, especially during the summer months, and is likely attributable to ongoing efforts to reduce phosphorus loading in this watershed (DEP 2006a). However, TSI in Neversink Reservoir, the most oligotrophic reservoir in the Delaware System, increased nearly 11% in 2007. The increase is likely due to reservoir operations: outflows were cut back starting in June resulting in increased water and nutrient residence times. The highest chl *a* levels were observed in October when outflows were at their lowest. All three of the aforementioned reservoirs flow into Rondout Reservoir. In 2007, TSI in Rondout decreased about 5% compared to historical data, similar to the decreases observed in its primary inputs, Pepacton and Cannonsville Reservoirs. TSI in West Branch Reservoir, a blend of Rondout and Boyd Corners Reservoirs, increased nearly 8%, reflecting the higher percentage of the more productive Boyd Corners water used in 2007. Higher (7%) TSIs were also apparent at Kensico Reservoir, which is a blend of Delaware and Catskill water. It is not clear why Kensico was high, especially when its primary inputs, Rondout and Ashokan, were generally lower in chl *a* throughout the year.

TSI patterns were not consistent for the Croton System reservoirs. New Croton, Amawalk, East Branch, and the controlled lakes were very close to their historical median TSI levels, while Middle Branch and Muscoot were close to or exceeded their highest TSI of the last 11 years. Normally Middle Branch and Muscoot spill much of the year, but in 2007 drawdown prevented both reservoirs from spilling from June through November. The resulting decreased flow and warm temperatures were likely responsible for the increased algal growth. The 2007 TSI in Bog Brook, Titicus, and Cross River Reservoirs was lower than their historical levels.

3.13 Has DEP monitoring of watershed streams revealed any changes to the macroinvertebrate community?

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994, using protocols developed by the DEC's Stream Biomonitoring Unit (DEC 2002). Streams are sampled in areas of riffle habitat, using the traveling kick method; collected organisms are preserved in the field and later identified, and a series of metrics generated from the tallies of macroinvertebrates found to be present. The metric scores are converted to a common scale and averaged, to produce a single water quality assessment score of 0-10 for each site, corresponding to non (7.5-10), slightly (5-7.5), moderately (2.5-5), or severely (0-2.5) impaired. A change (or lack of change) to the macroinvertebrate community, as reflected in the water quality assessment score, can provide important information to DEP managers, because sites are often selected to evaluate impacts from land use changes or BMPs, or to assess conditions in major reservoir tributaries.

Through the close of the 2007 sampling season, DEP had established 155 sampling sites in streams throughout the water supply watershed, with roughly equal numbers in the Catskill, Delaware, and Croton Systems. Many of these sites have been sampled for only a few years, because sampling began at later dates at some sites than at others, and because only routine sites are sampled annually. To investigate changes to the macroinvertebrate community, only sites with a 5-year record or better that were sampled in 2007 were examined, to reduce the chances that short-term variation, or aberrant samples, might cloud the analysis. (For sites with a five-year record or better not sampled in 2007, see DEP (2007a).) Twenty-three (23) sites met the 5-year criterion, 10 in the East of Hudson System, 6 in Catskill, and 7 in Delaware (Figure 3.15). Of these, all but two are routine sites (generally, major tributaries to receiving reservoirs). One site with a four-year record (Beaver Kill) is also discussed because of the sharp decline in scores experienced there in recent years.

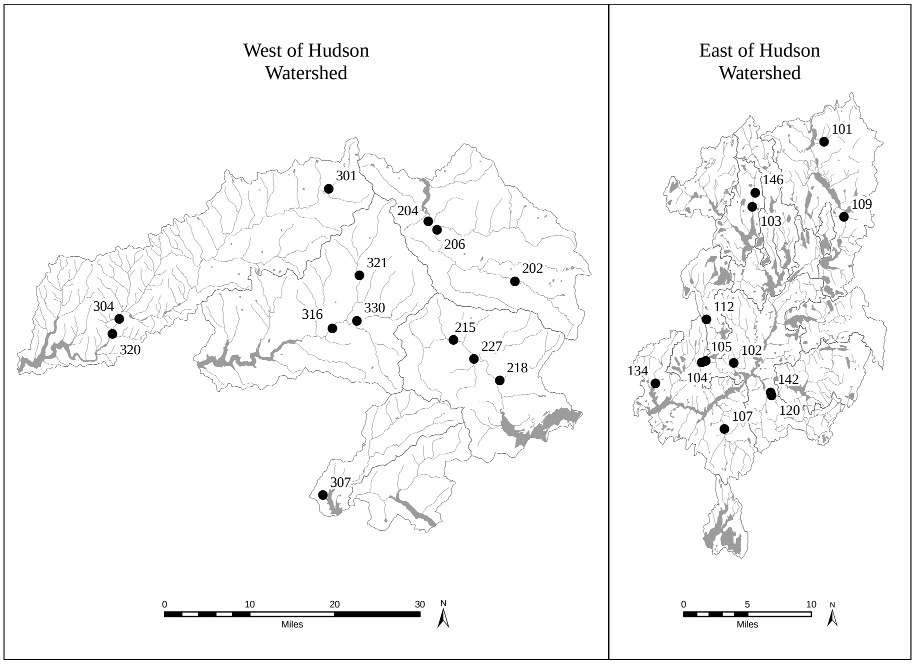

Figure 3.15 Stream biomonitoring sites sampled in 2007 with a 5-year record or better. (Note, however, that Site 218 has a four-year record only.)

The data are plotted in Figures 3.16 and 3.17 for the East of Hudson and West of Hudson watersheds, respectively. In most cases, long-term changes to the macroinvertebrate community were not observed. At a few sites, however, the data suggest otherwise. In 2007, following a dip in 2006, the generally upward trend in scores at the East Branch of the Croton River (Site 109) continued, reaching a new high of 7.82. 2007 also saw the highest number of EPT taxa (mayflies, stoneflies, caddisflies) ever recorded at the site (10). These are sensitive organisms whose presence in significant numbers is considered an indication of good water quality. The site has now assessed as non-impaired in two of the last three years of sampling, compared to the slightly impaired assessments of the previous 10 years. The most important factor in the improved assessments has been the decline in numbers of the tolerant caddisfly *Cheumatopsyche* sp., which has greatly improved the percent model affinity metric, a measure of the community's similarity to a model New York State stream community.

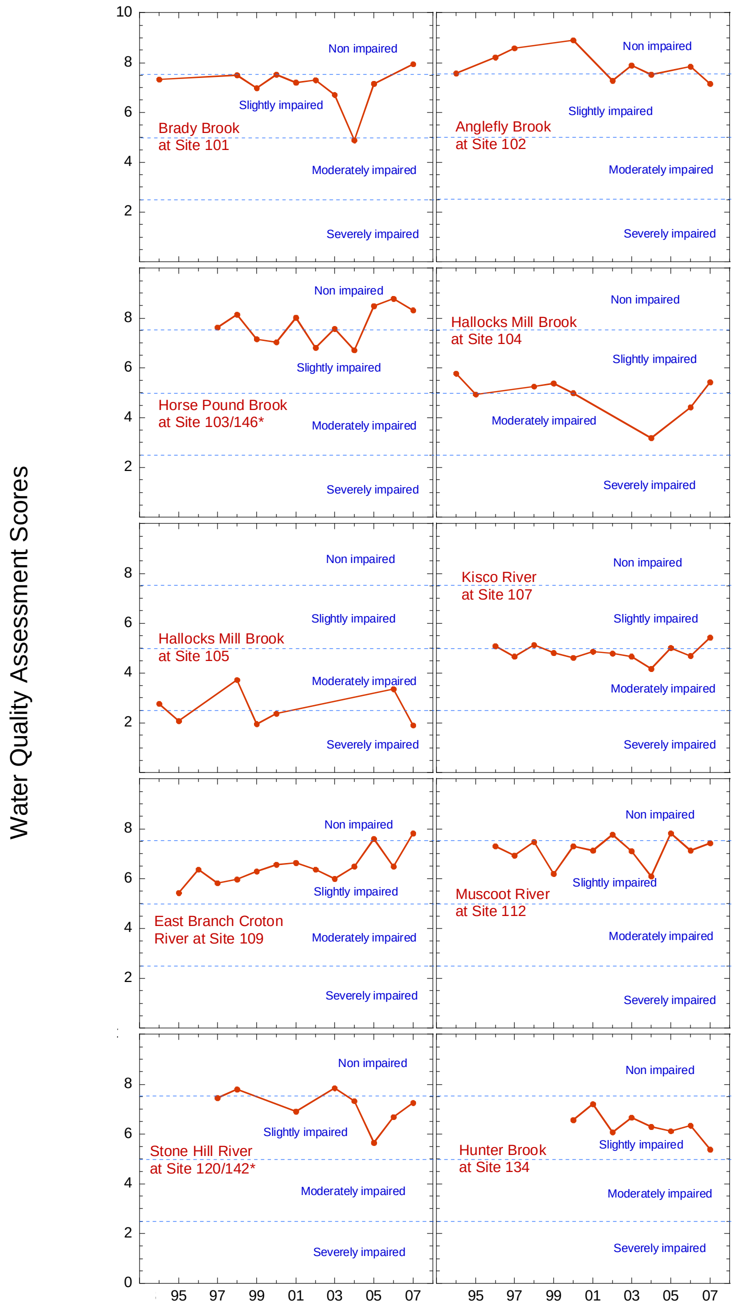

Figure 3.16 Water Quality Assessment scores based on stream biomonitoring data for East of Hudson streams sampled in 2007 with a 5-year record or better.

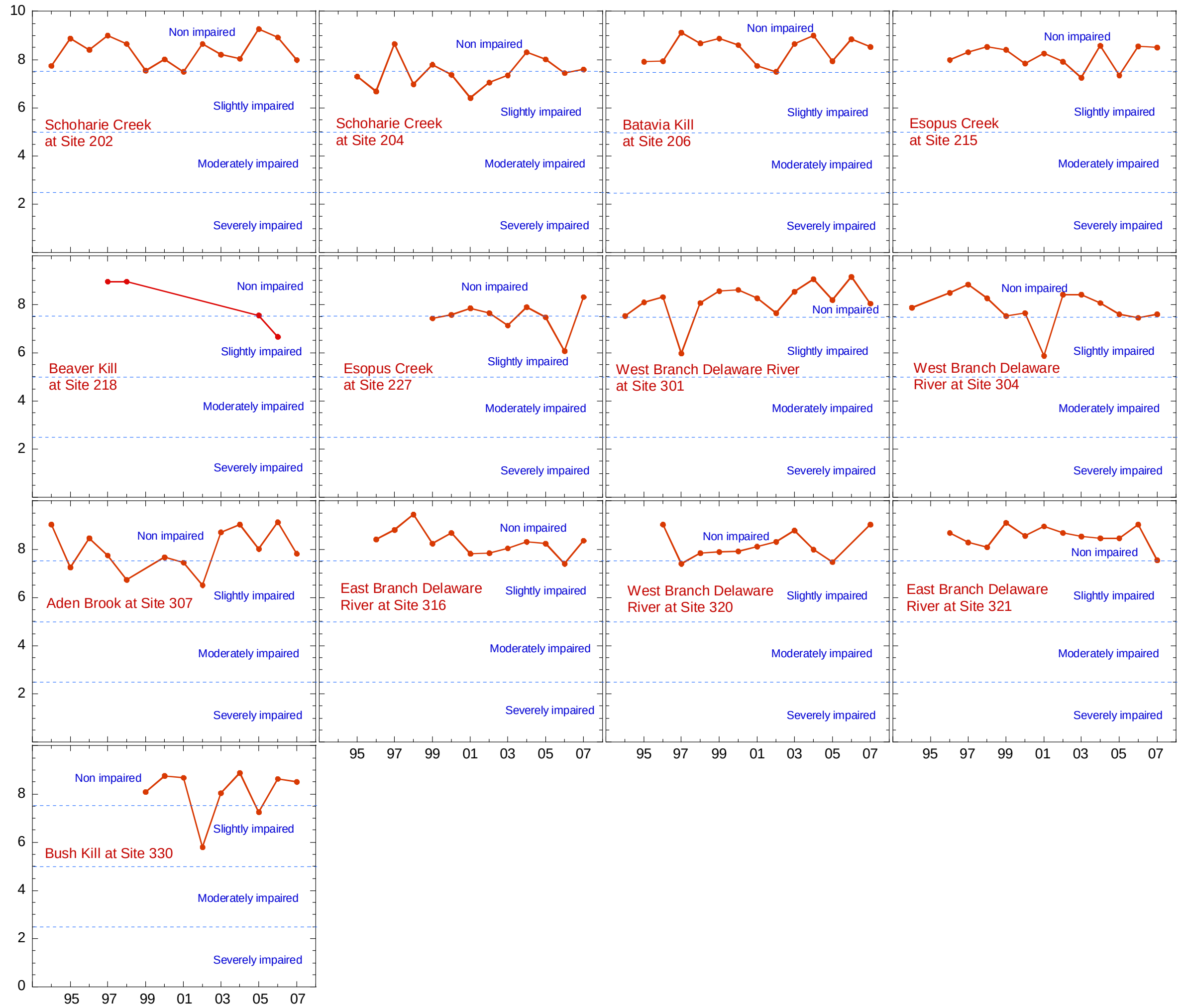

Figure 3.17 Water Quality Assessment scores based on stream biomonitoring data for West of Hudson streams sampled in 2007 with a 5-year record or better. (Note, however, that Site 218 has a four-year record only.)

At two other sites—Hallocks Mill Brook above the Yorktown Heights wastewater treatment plant (Site 104) and Stone Hill River (Sites 120 and 142)—assessment scores returned to historical levels after dipping to new lows in 2004 and 2005, respectively, following a spike in beetle abundance at both sites. It is unclear what caused the sudden increase in beetle counts, which have since returned to their previous levels.

Although it has only a four-year record, the Beaver Kill (a tributary to Esopus Creek in the Ashokan Reservoir watershed) is included here because of the sharp decline in scores it has experienced during its years of sampling (1997-1998 and 2005-2006). The stream was assessed as non-impaired in both 1997 and 1998 (scores of 8.94 and 8.95), with taxa counts of 34 (mean of two replicates, one of which was the highest taxa count DEP has ever recorded (42)) and 35, and EPT counts of 19 (mean of two replicates) and 15. When the site was resampled in 2005, however, the score had dropped to 7.54, barely above the non-impaired/slightly impaired threshold, and total taxa and EPT taxa counts had dropped to 28 and 13, respectively. In 2006, the score had dropped still further, to 6.66, resulting in a change of water quality assessment to slightly impaired. Total taxa also declined (to 19) and EPT dropped to 9. Flooding upstream in 2005 and 2006, as well as the presence of several failing streambanks, has led to a significant increase in streambank erosion, which may be related to the declining scores. On the other hand, much of the decline in 2006 may be attributable to a spike in numbers of the mayfly *Acentrella turbida*, which in that year represented over 40% of the total assemblage, compared to no more than 5-6% in previous years. The increase in *Acentrella* depressed the taxa richness metric and probably the EPT metric as well. Spikes in *Acentrella* have occurred in Catskill streams before (often, but not always, during periods of high flows), with similar effects on scores to those reported here. Following such events, numbers of this mayfly usually retreat to previous levels. DEP will return to the site in 2008 to see if recent scores represent the effects of a one-time event and/or natural variability, or if they are reflective of a continuing downward trend.

3.14 What are disinfection by-products, and did organic concentrations in source waters allow DEP to meet compliance standards in the distribution system in 2007?

Drinking water is disinfected by public water suppliers to kill protozoans, bacteria, and viruses that can cause serious illnesses. Chlorine is the most commonly used disinfectant in New York State to accomplish this purpose. During drinking water treatment, however, chlorine reacts with certain acids in naturally-occurring organic material (e.g., decomposing vegetation like tree leaves, algae, or other aquatic plants) in surface water to form disinfection by-products (DBPs). The quantity of DBPs in drinking water can change from day to day depending on the temperature, the quantity of organic material in the water, the quantity of chlorine added, and a variety of other factors.

DEP monitors two important groups of DBPs, trihalomethanes and haloacetic acids. Total 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. EPA has set limits on these groups of DBPs under the Stage 1 Disinfectant/Disinfection By-Products Rule. The Maximum Contaminant Level (MCL) for TTHM is 80 $\mu g\ L^{-1}$ and the MCL for the five haloacetic acids listed above (HAA5) is 60 $\mu g\ L^{-1}$. According to the Stage 1 Rule, monitoring is required to be conducted quarterly from designated sites in the distribution system which represent the service areas and not necessarily the source water for each system. The MCL is calculated as a running annual average based on quarterly samplings over a 12- month period. The 2007 annual running quarterly averages are presented in

Table 3.6. and show system compliance for TTHM and HAA5 in both the Catskill/Delaware and Croton Distribution areas of New York City. DBPs are one reason that eutrophication must be controlled in NYC's reservoirs.

Table 3.6: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations (μg L^{-1}) for 2007.

	Catskill/Delaware		Croton	
2007 Quarter	TTHM	HAA5	TTHM	HAA5
1st	40	44	48	48
2nd	40	45	48	48
3rd	38	43	46	48
4th	37	40	46	45
MCL	80	60	80	60

4. Pathogens

4.1 How many samples did DEP collect for *Cryptosporidium*, *Giardia* and human enteric viruses in 2007, and what were the occurrences and concentrations in the "source waters"?

DEP conducts compliance and surveillance monitoring for protozoan pathogens and human enteric viruses (HEV) throughout the 1,972-square-mile NYC watershed. DEP staff collected and analyzed a total of 1,015 routine samples for protozoan analysis during 2007, which does not include 264 additional samples related to special projects. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2007 sampling effort, accounting for 33% of the samples, followed by stream samples, which were 25% of the sample load. Storm events, Hillview Reservoir sampling, upstate reservoir effluents, and wastewater treatment plants made up the remaining 42% of samples (Figure 4.1).

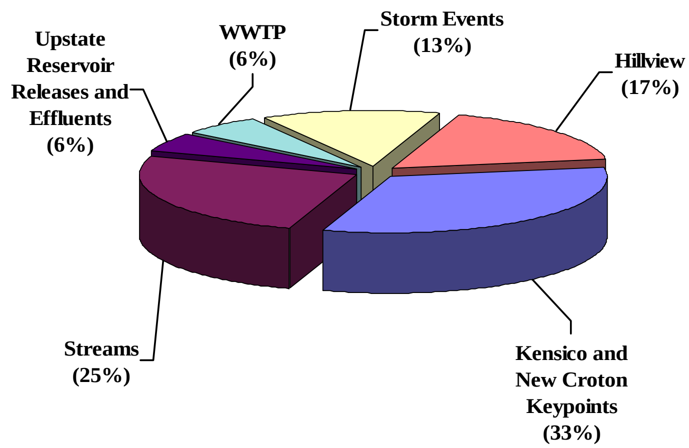

Figure 4.1 DEP sample type distribution for 2007.

Under routine reservoir operation, the two influents and the two effluents of Kensico Reservoir and the one effluent of New Croton Reservoir are considered the source water sampling sites for the NYC water supply. Filtration Avoidance compliance requires weekly sampling at these five sites for *Cryptosporidium*, *Giardia*, and HEV. The effluent results are posted weekly on DEP's website (DEP 2006b), monthly in the Croton Consent Decree and EPA reports, and semi-annually in the Filtration Avoidance Determination reports (DEP 2006c, d).

Catskill Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at CATALUM (Catskill influent to Kensico Reservoir) were very low, with a mean of 0.02 oocysts 50L^{-1} and only 1 positive detection out of 53 samples (1.9%) (Table 4.1). The *Cryptosporidium* data at CATLEFF (Catskill effluent of Kensico Reservoir) were also very low, although slightly greater than at CATALUM, with a mean of 0.08 oocysts 50L^{-1} and 4 positive detections out of 53 samples (7.5%).

The *Giardia* cyst concentration and detection frequency at CATALUM were a mean of 0.70 cysts $50L^{-1}$ and 23 positive detections out of 53 samples (43.4%) (Table 4.1). The results at CATLEFF were notably greater than at CATALUM, with a mean of 2.52 cysts $50L^{-1}$ and 43 positive detections out of 53 samples (81.1%).

Table 4.1: Summary of *Giardia*, *Cryptosporidium*, and human enteric virus compliance monitoring data at the five DEP keypoints for 2007.

	Keypoint Location	# of samples	# of positive samples	Mean***	Max
Cryptosporidium oocysts $50L^{-1}$	Catskill Influent	53	1	0.02	1.00
	Catskill Effluent	53	4	0.08	1.00
	Delaware Influent**	53	6	0.11	1.00
	Delaware Effluent	53	1	0.02	1.00
	New Croton Effluent*	53	3	0.06	1.00
Giardia cysts $50L^{-1}$	Catskill Influent	53	23	0.70	4.00
	Catskill Effluent	53	43	2.52	10.00
	Delaware Influent**	53	32	1.51	7.00
	Delaware Effluent	53	41	1.88	8.00
	New Croton Effluent*	53	28	1.36	9.00
Human Enteric Viruses $100L^{-1}$	Catskill Influent	53	11	0.85	20.83
	Catskill Effluent	53	6	0.33	10.25
	Delaware Influent**	53	12	0.64	10.13
	Delaware Effluent	53	5	0.18	10.13
	New Croton Effluent*	53	8	0.22	3.22

*Includes alternate sites for CROGH during “off-line” status.
**Includes alternate sites for DEL17 during “off-line” status.
***Non-detects are considered “0” when calculating mean.

HEV concentrations and detection frequency at CATALUM were low with a mean of 0.85 MPN $100L^{-1}$ and 11 positive detections out of 53 samples (20.7%) (Table 4.1). As in the past, the HEV results at CATLEFF were lower than at CATALUM, with 0.33 MPN $100L^{-1}$ and 6 positive detections out of 53 samples (11.3%), indicating a reduction in virus concentrations as water passes through the reservoir.

Delaware Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at DEL17 (Delaware influent to Kensico Reservoir) were very low with 0.11 oocysts $50L^{-1}$ and 6 positive detections out of 53 samples (11.3%) (Table 4.1). Similarly, the *Cryptosporidium* oocyst results at DEL18 (Delaware effluent of Kensico Reservoir) were very low, with 0.02 oocysts $50L^{-1}$ and 1 positive detection out of 53 samples (1.9%).

Giardia sampling at DEL17 revealed a mean of 1.51 cysts $50L^{-1}$ and 32 positive detections out of 53 samples (60.4%) (Table 4.1). The results at DEL18 were similar to those at DEL17, with 1.88 cysts 50 L^{-1}, while the occurrence was higher with 41 positive detections out of 53 samples (77.4%).

The HEV results at DEL17 were low, with a mean of 0.64 MPN $100L^{-1}$ and 12 positive detections out of 53 samples (22.6%) (Table 4.1). Concentration and detection frequency at DEL18 were lower than at DEL17, with a mean of 0.18 MPN $100L^{-1}$ and 5 positive detections out of 53 samples (9.4%).

New Croton Reservoir Aqueduct

The *Cryptosporidium* oocyst data at CROGH (New Croton Reservoir effluent) were very low with a mean of 0.06 oocysts $50L^{-1}$ and 3 positive detections out of 53 samples (5.7%). The concentration and detection frequency of Giardia cysts at this site were a mean of 1.36 cysts $50L^{-1}$ and 28 positive detections out of 53 samples (52.8%) (Table 4.1). HEV results at the New Croton effluent were low, with a mean of 0.22 MPN $100L^{-1}$ and 8 positive detections out of 53 samples (15.0%).

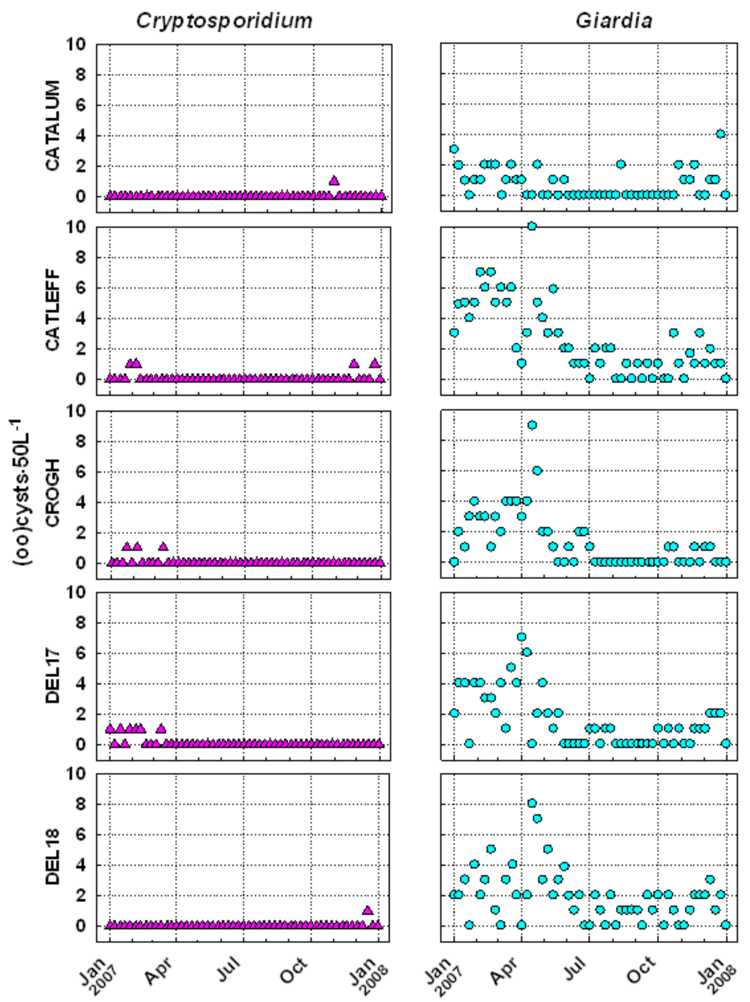

Figure 4.2 Routine weekly source water keypoint monitoring results for 2007.

In summary, the weekly occurrence of *Cryptosporidium* during this period was relatively infrequent compared to *Giardia*, and *Cryptosporidium* concentrations were approximately an order of magnitude lower. The concentrations of *Giardia* varied throughout 2007. Seasonal variation in *Giardia* concentrations were more pronounced than for *Cryptosporidium*, with higher numbers occurring in the winter and spring compared to the summer months (Figure 4.2). This pattern is consistent with what DEP has seen historically at other watershed locations.

4.2 How did protozoan concentrations compare with regulatory levels in 2007?

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) (EPA 2006) requires that utilities conduct source water monitoring for *Cryptosporidium* monthly for a two-year period, though a more frequent sampling schedule may be used. The LT2ESWTR monitoring results are used to classify utilities into one of four categories ("bins"). This bin classification system determines if the utility is required to provide any additional treatment for *Cryptosporidium*. The bin classification is calculated by calculating the mean of the data for a given month over the course of two years, and then taking a mean of those monthly means. For perspective, results have been calculated here using data from the most recent two-year period (January 1, 2006 to December 31, 2007) and were based on all routine and non-routine samples (Table 4.2).

Table 4.2: Number and type of samples used to calculate the LT2 bin classification set under the LT2ESWTR from January 1, 2006 to December 31, 2007.

Aqueduct	# of routine samples	# of non-routine samples	Total
Croton	105	0	105
Catskill	105	16	121
Delaware	105	15	120

The average number of *Cryptosporidium* oocysts at each of the three source waters was below the LT2ESWTR threshold level of 0.01 oocysts per liter, achieving the 99% (2-log reduction) bin classification set under the LT2ESWTR. Water systems that fall into this bin require no further treatment. The averages, as shown in Figure 4.3, are as follows: 0.0018 oocysts L^{-1} at the Croton effluent, 0.0020 oocysts L^{-1} at the Catskill effluent, and 0.0017 oocysts L^{-1} at the Delaware effluent.

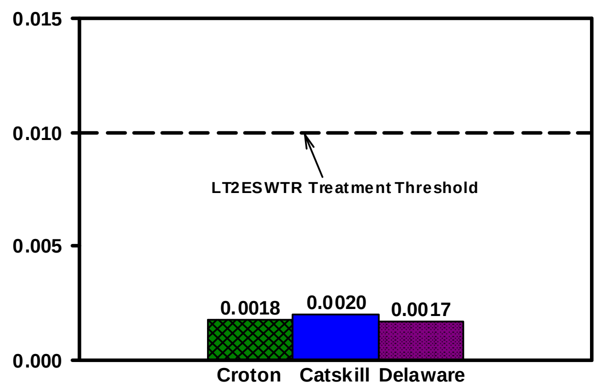

Figure 4.3 Comparison between the LT2ESWTR treatment threshold and averages of all samples at DEP's three source waters—January 1, 2006 to December 31, 2007.

4.3 How do 2007 source water concentrations compare to historical data?

The source water sampling locations are the two influents and effluents representing the Catskill and Delaware Systems in Kensico Reservoir, and the effluent of New Croton Reservoir. These locations represent their respective upstate watersheds and reservoirs, which are dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the source water reservoirs in each of the three watershed systems. Thus, as water quality conditions change upstate, conditions at the source water keypoints may change too. As such, the protozoan concentrations often differ from year to year. A review of several years of source water data (2001–2007) shows that *Cryptosporidium* oocyst detection was very low in 2007, with slightly fewer detects than in previous years (Figure 4.4). The detections were at low concentrations and occurred mostly in the late fall, winter, and early spring months. Due to the high number of non-detects and low concentrations when detected, it is not possible to attribute the detection pattern to a seasonal cycle (Figure 4.5a).

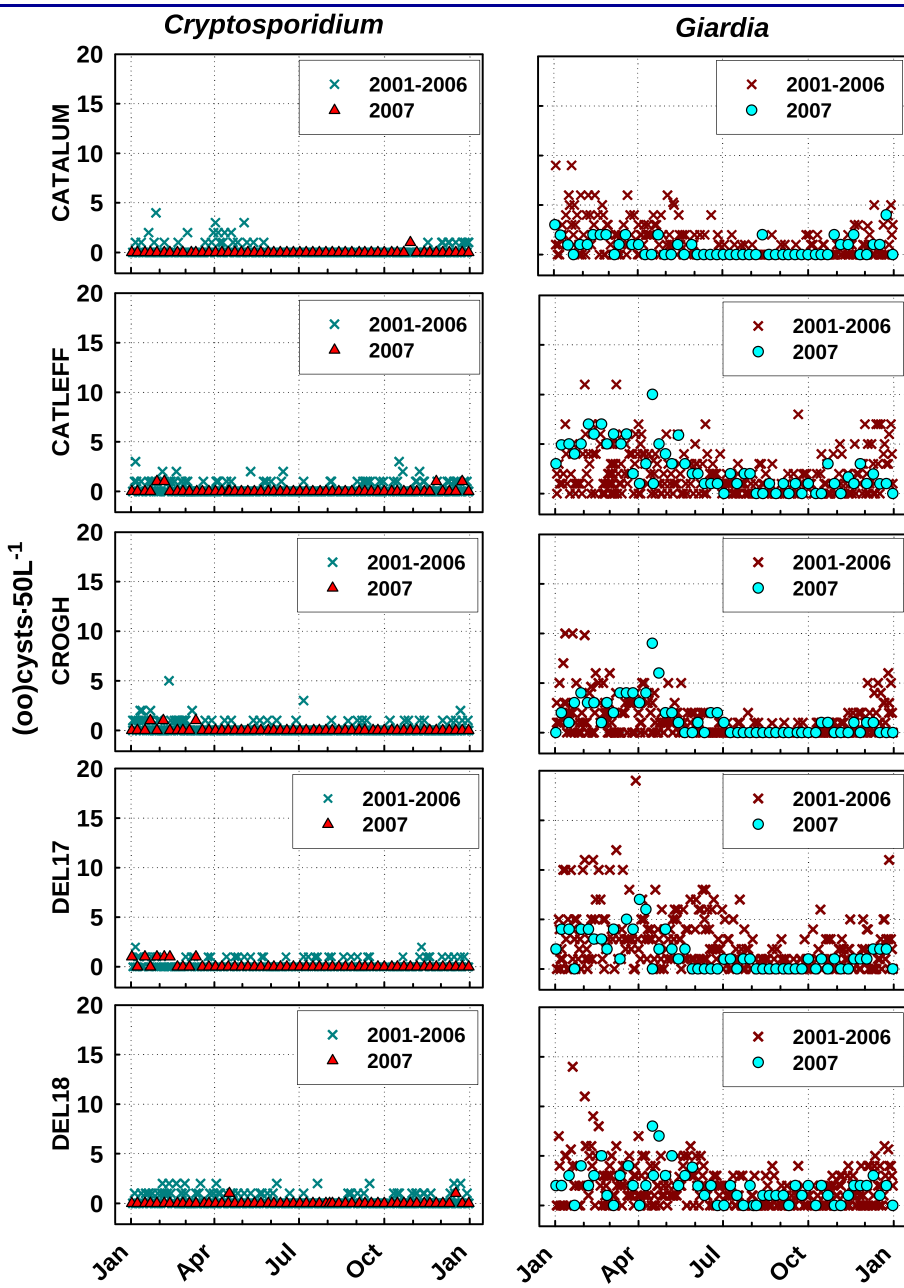

Figure 4.4 Source water keypoint weekly sampling results from October 2001–December 2007. For *Cryptosporidium* the red triangles represent 2007 and the blue "X" represents 2001–2006 data (left). For *Giardia*, the blue circles represent the 2007 data, whereas the red "X" represents the 2001–2006 data (right).

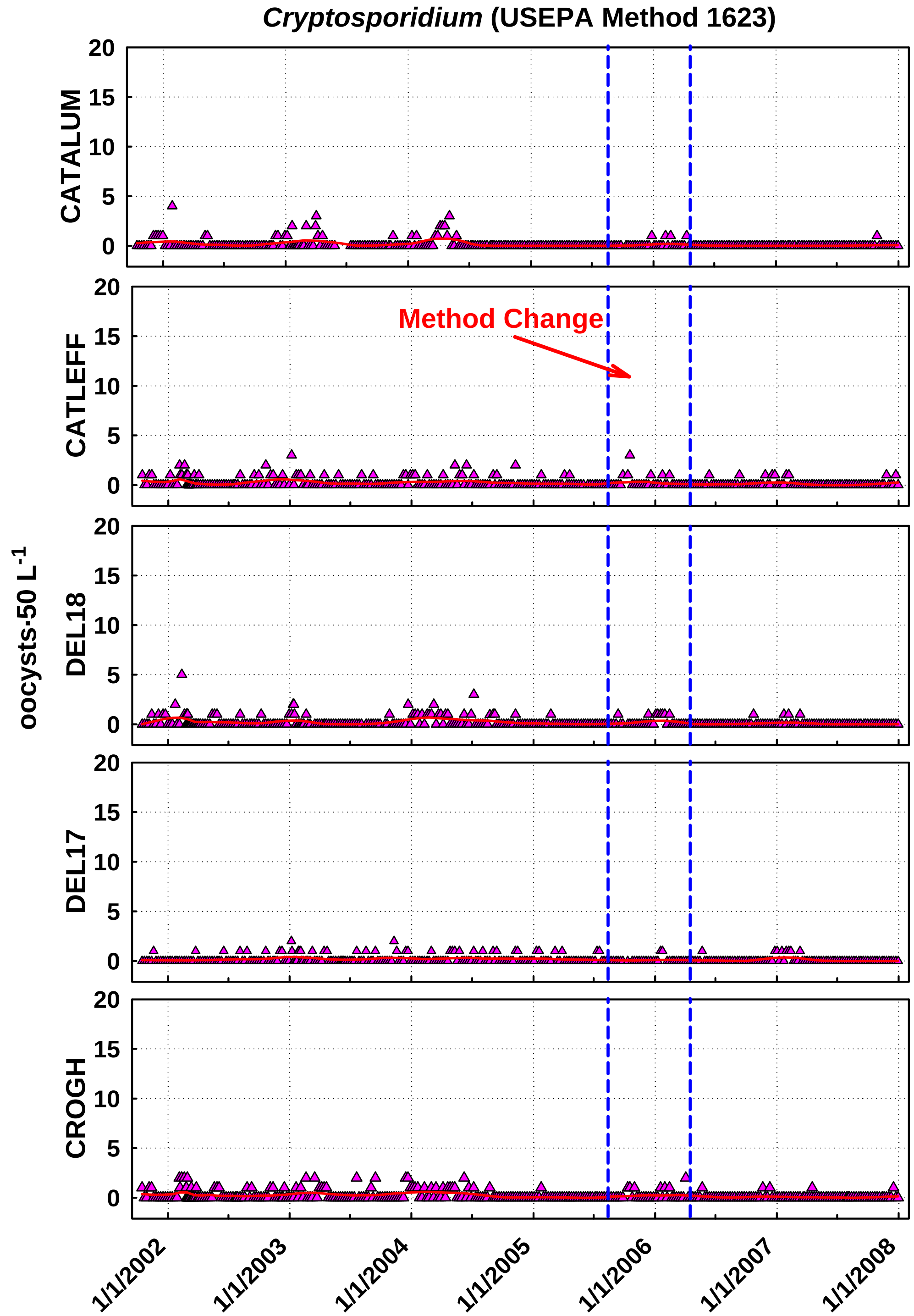

Figure 4.5.a Weekly routine source water keypoint results for *Cryptosporidium* (lowess smoothed - 0.1) from October 15, 2001 to December 31, 2007. The area between the blue dotted lines indicates the period during which the DEP laboratory temporarily switched to a different EPA-approved stain (Method Change).

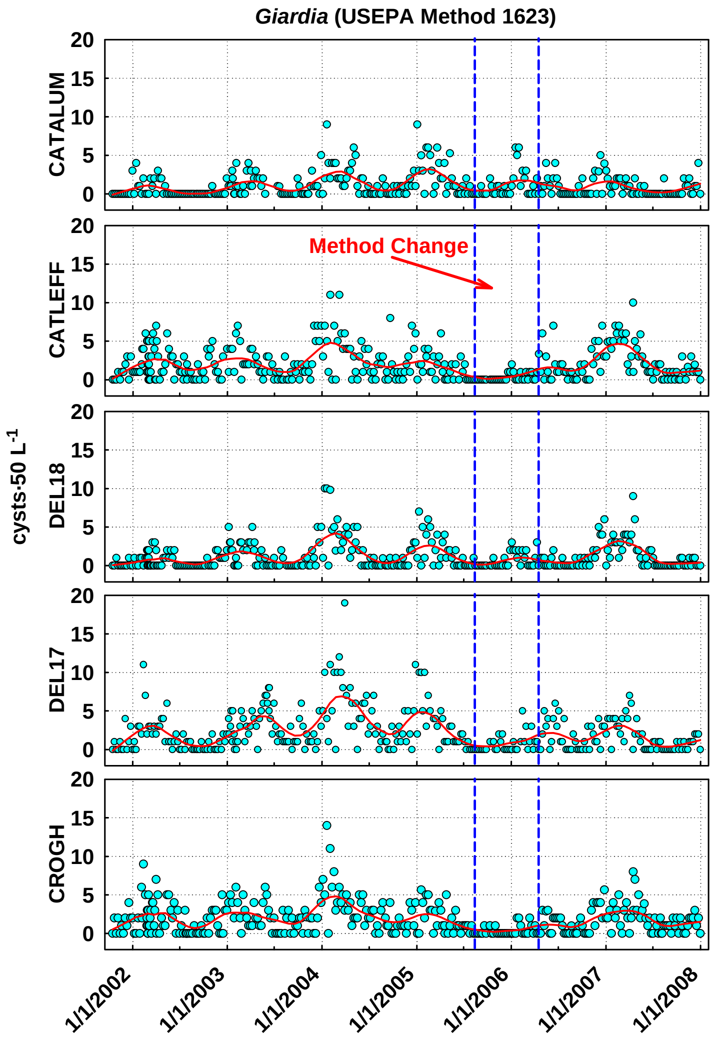

Figure 4.5.b Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2007. The area between the blue dotted lines indicates the period during which DEP laboratory temporarily switched to a different EPA- approved stain (Method Change). Note the absence of a seasonal peak during that period.

Giardia detection was generally similar than in previous years at all sites (Figure 4.4). Compared to *Cryptosporidium* oocysts, *Giardia* are more frequently detected and are found at higher concentrations. As in past years, and similar to *Cryptosporidium*, most *Giardia* cysts detects and higher concentrations have occurred in the late fall, winter, and early spring months when temperatures are lower and periods of high runoff into the reservoirs associated with greater precipitation and snowmelt occur. Unlike *Cryptosporidium*, *Giardia* concentrations are high enough to observe an annual seasonal cycle at the source waters, although the magnitude of this cycle varies between years (Figure 4.5b). The cause of the seasonal cycle is still unknown and represents one of DEP's future research endeavors. To better illustrate the seasonal trend, a locally weighted scatterplot smooth (LOWESS) line is plotted through the data points (Figures 4.5a,b). The line is intended to show the natural trend of the center-of-mass of the data. Curves in the LOWESS line indicate short-term fluctuations within the distribution of the data.

4.4 What concentrations of *Cryptosporidium* and *Giardia* were found in the various NYC watersheds in 2007?

The watershed sample sites for *Cryptosporidium* and *Giardia* are located in streams, upstate reservoir releases, and the upstate reservoir effluents. Fewer sites were sampled in 2007 than in the past because in 2006, DEP satisfied Objectives 4.2.3, 4.3.1, and 4.3.2 of the 2003 Integrated Monitoring Report (DEP 2003). Figures 4.6 through 4.11 depict sampling sites as well as the *Cryptosporidium* and *Giardia* (oo)cyst concentrations for each of the NYC water supply systems and watersheds.

Monitoring results indicate very low concentrations of *Cryptosporidium* in 2007, with no means above 2.5 oocysts $50L^{-1}$ for all sites, and mostly non-detects for nearly all samples collected (Figures 4.6–4.8). This represents a decrease from the 2006 findings, although fewer sites were sampled in 2007. The highest mean concentration was observed at the MB-1 stream site (a tributary of Kensico Reservoir) at a low 1.8 oocysts $50L^{-1}$. The highest value obtained for an individual sample occurred at S5I along Schoharie Creek on March 15, 2007, with a value of 9.2 oocysts $50L^{-1}$.

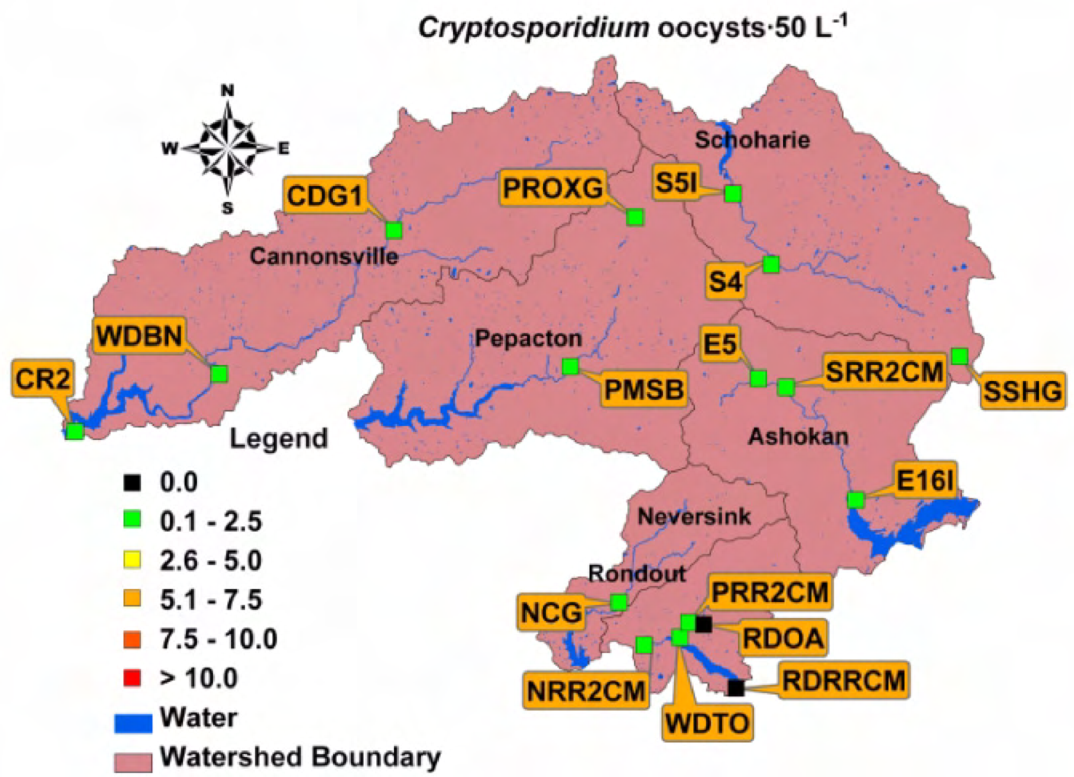

Figure 4.6 Means of total *Cryptosporidium* oocysts $50L^{-1}$ for sampling locations in the Delaware and Catskill Systems in 2007.

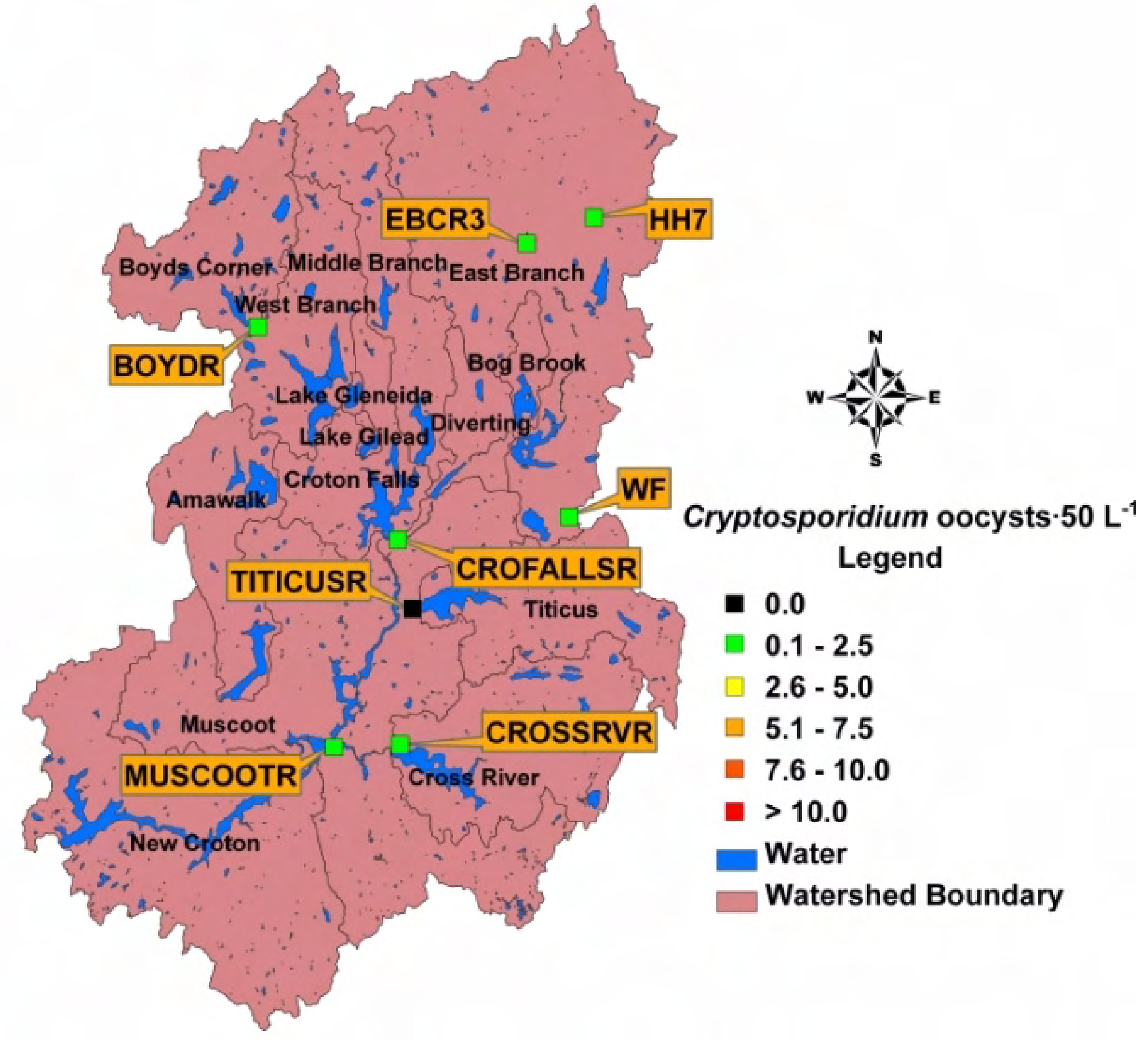

Figure 4.7 Means of total *Cryptosporidium* oocysts $50L^{-1}$ for the New Croton watershed sampling locations in 2007.

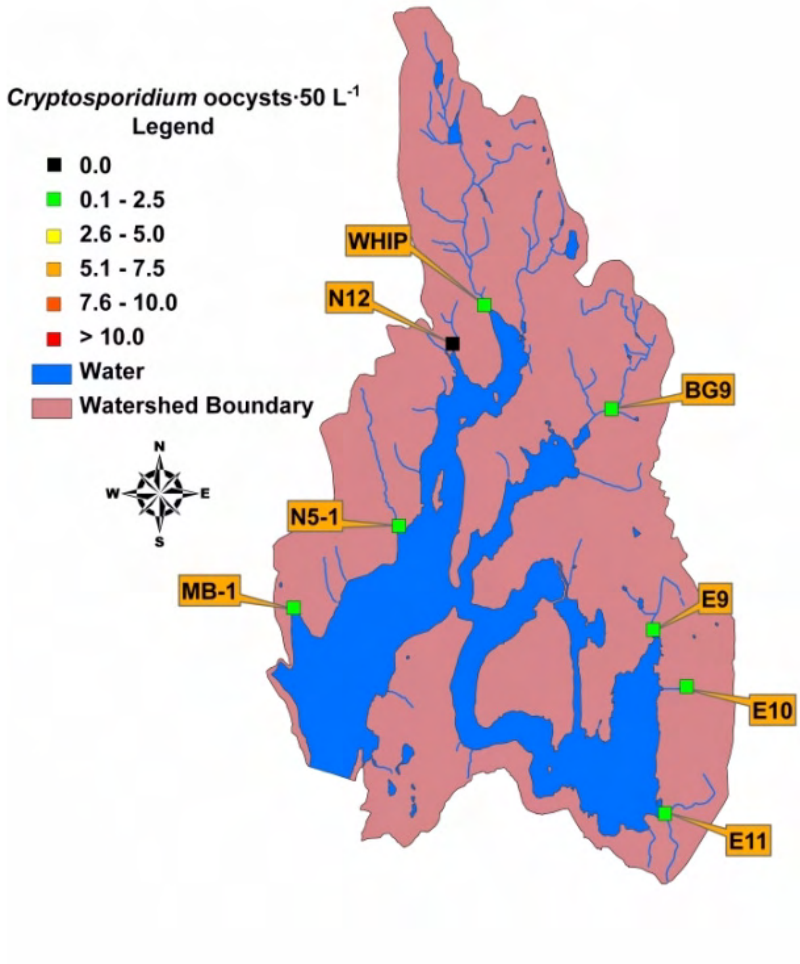

Figure 4.8 Means of total *Cryptosporidium* oocysts 50L^{-1} for the Kensico watershed sampling locations in 2007.

In 2007, as in previous years, the average *Giardia* cyst concentrations were higher than *Cryptosporidium* oocysts (Figures 4.9– 4.11). Nearly all sample locations were positive for *Giardia*, although concentrations were notably lower than in 2006, with the exception of the New Croton watershed, which had results similar to those observed in 2006. However, as mentioned previously, fewer sites were monitored in the Catskill/Delaware and New Croton Systems in 2007. The average *Giardia* cyst concentration for the Catskill/Delaware System ranged from 0.2 to 54.3 cysts 50L^{-1}, though most were less than 25 cysts 50L^{-1} (Figure 4.9). The *Giardia* cyst concentration at the New Croton System monitoring sites ranged from 2.2 to 29.2 cysts 50L^{-1}, with most sites below an average concentration of 8 cysts 50L^{-1} (Figure 4.10). Lastly, the Kensico Reservoir watershed average *Giardia* cyst concentration ranged from 3.0 to 22.3 cysts 50L^{-1}, with most less than 13.7 cysts 50L^{-1} (Figure 4.11).

In general, *Cryptosporidium* and *Giardia* (oo)cyst concentrations were variable between sites and between watersheds, which likely reflected local sub-basin conditions, including different animal populations or densities, watershed physiographic characteristics, land use, and so on. Moreover, the sites with the highest concentrations were generally also high in previous years. For example, the Schoharie basin exhibited the highest *Giardia* concentrations among the watershed sampling locations in 2007 (Figure 4.9) and was also the highest in 2006.

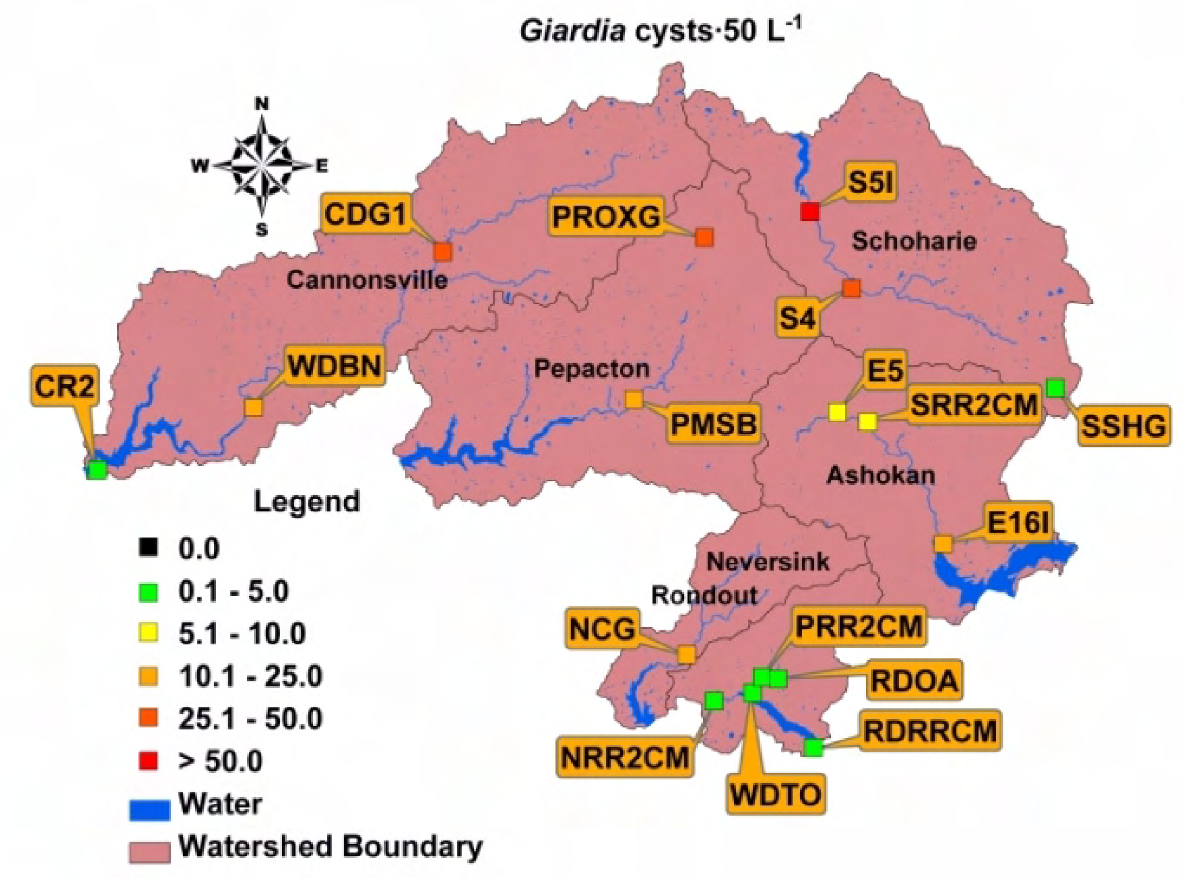

Figure 4.9 Averages of total *Giardia* cysts $50L^{-1}$ for sampling locations in the Delaware and Catskill Systems in 2007.

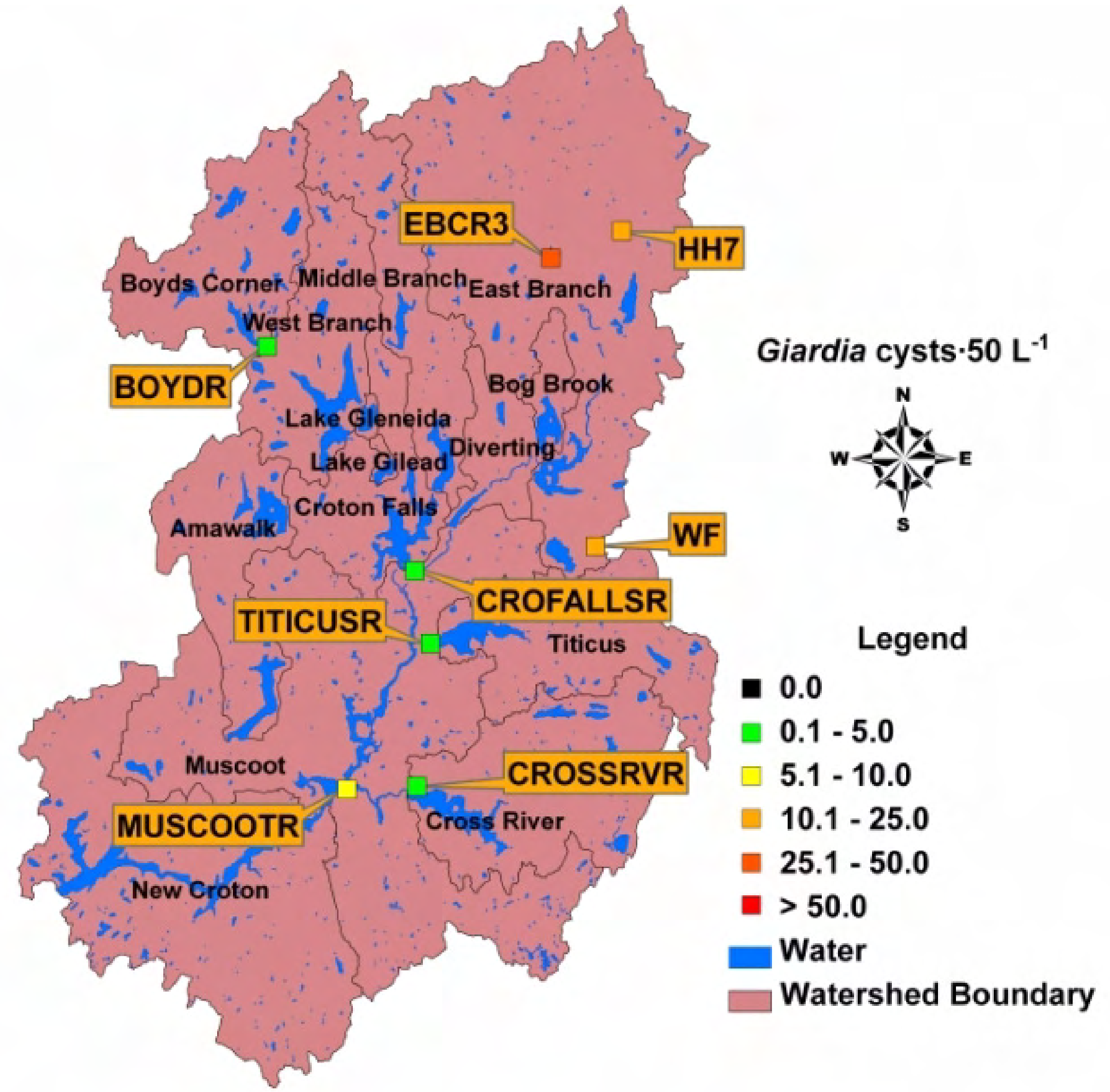

Figure 4.10 Averages of total *Giardia* cysts $50L^{-1}$ for the New Croton sampling locations in 2007.

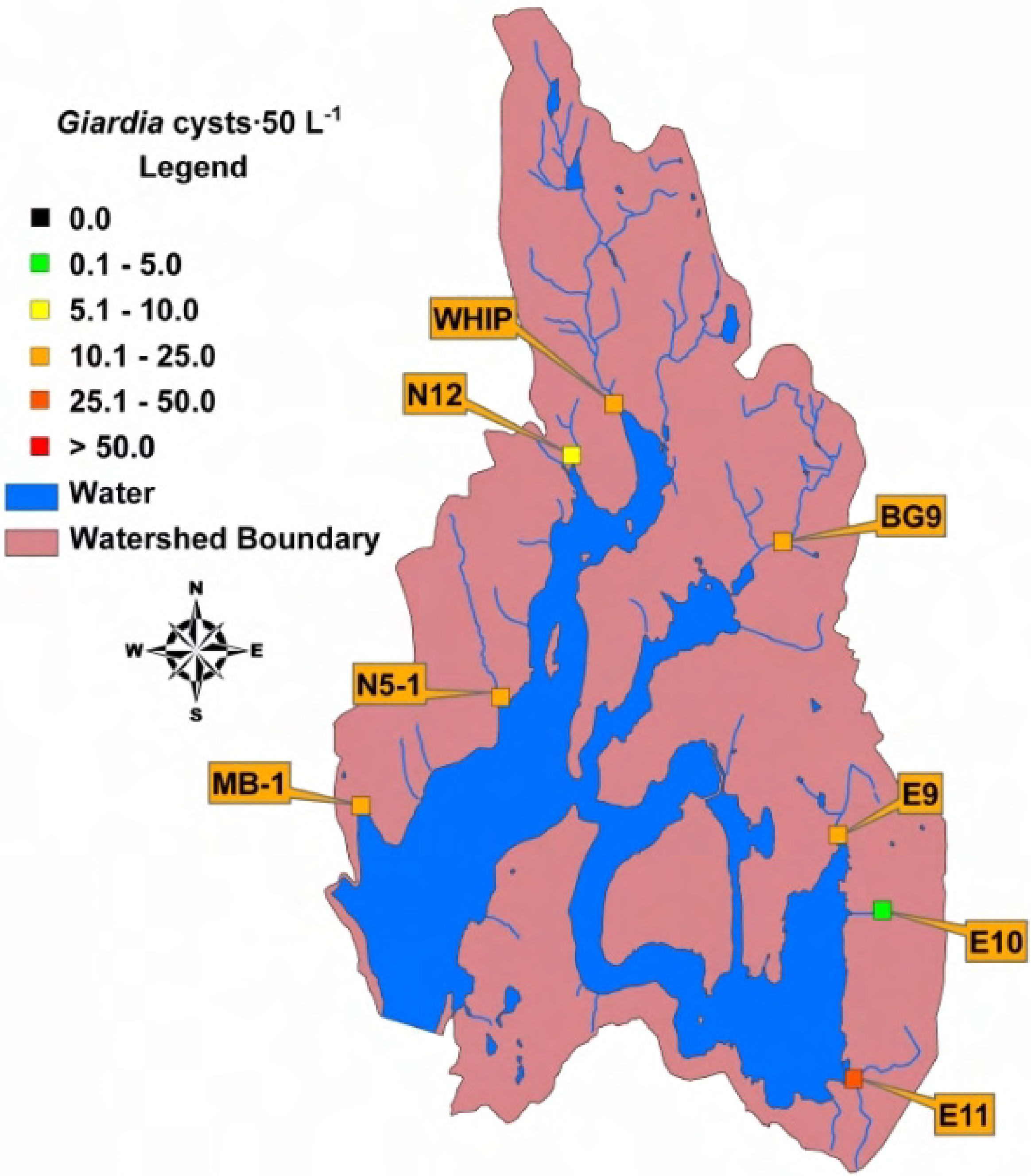

Figure 4.11 Averages of total *Giardia* cysts $50L^{-1}$ for the Kensico watershed sampling locations in 2007.

4.5 What levels of protozoa and human enteric viruses were found in waste water treatment plant effluents?

DEP began monitoring pathogens at 10 West of Hudson (WOH) waste water treatment plants (WWTPs) in July 2002. Sampling of each plant's final effluent is conducted a minimum of four times a year. The WWTPs that were monitored in 2007 were Hunter Highlands, Delhi, Pine Hill, Hobart, Margaretville, Grahamsville, Grand Gorge, Tannersville, Stamford, and Walton (Figure 4.12). In addition, the EOH Brewster Sewage Treatment Plant (BSTP) was monitored as part of the Croton Consent Decree. All plants were monitored at least four times. Of the 41 WWTP samples collected, 2 were positive for *Cryptosporidium* and 6 were positive for *Giardia*. The 2 positive *Cryptosporidium* samples were collected at Grahamsville WWTP on September 19, 2007 and September 25, 2007, with results of 2 oocysts $50L^{-1}$ each time. The September 25, 2007 sample (which was a follow-up from the first positive sample) accompanied a sample collected post-microfiltration, which was negative. No further sampling was pursued. The 6 positive *Giardia* results occurred at Grand Gorge (once), Hunter Highlands (twice), and Grahamsville (three times). The Hunter Highlands occurrence of 4 *Giardia* in March resulted in an early second quarter sample in April, which was negative. The occurrence of protozoa at WWTPs was more frequent in 2007 compared to 2006; however, the concentrations remained very low.

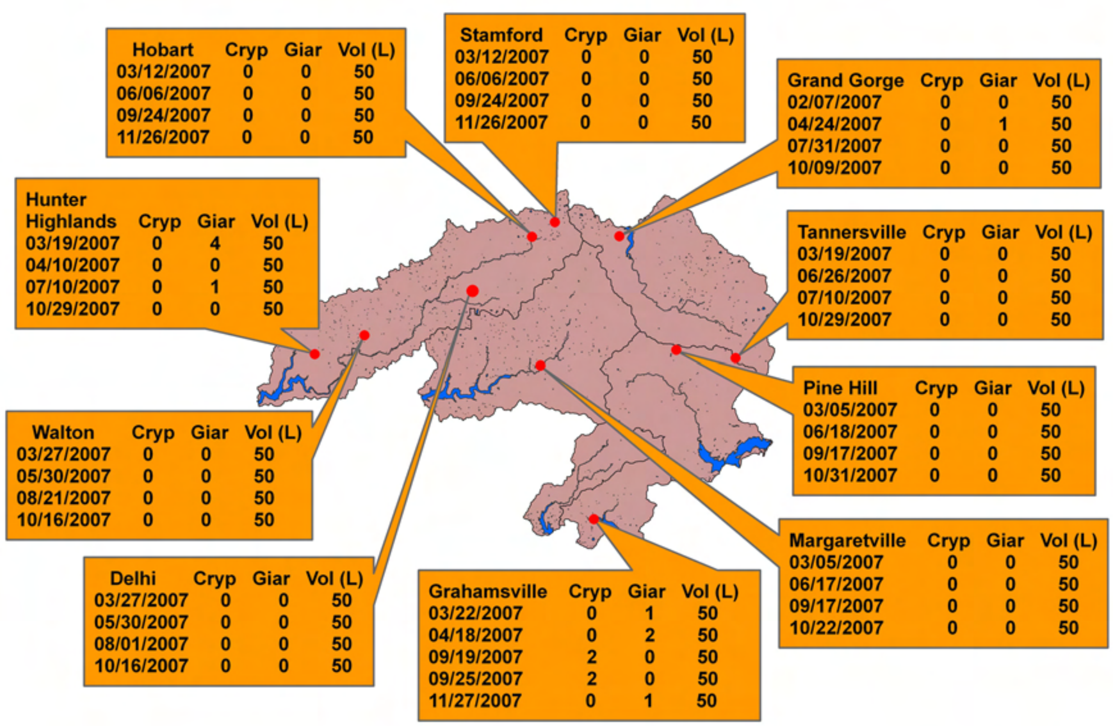

Figure 4.12 2007 *Cryptosporidium* and *Giardia* sample results for Catskill and Delaware System WWTPs.

In addition to *Cryptosporidium* and *Giardia*, DEP collected 42 virus samples at the 10 WOH WWTPs. All samples were negative for the viruses tested, and this was comparable to the 2006 results.

In addition, DEP monitored one East of Hudson (EOH) WWTP (BSTP) monthly for *Cryptosporidium* and *Giardia* (oo)cysts and bi-monthly for viruses. Of the 13 protozoan samples collected in 2007, none were positive for *Cryptosporidium* and 3 were positive for *Giardia* (Table 4.3). Of the 6 virus samples collected in 2007, all were negative for the viruses tested.

Table 4.3: *Cryptosporidium* and *Giardia* oocysts $50L^{-1}$ results for BSTP in 2007. nsr = no sample required.

Date	*Cryptosporidium* oocysts $50L^{-1}$	*Giardia* cysts $50L^{-1}$	Human Enteric Viruses MPN $100L^{-1}$
1/10/07	0	13	nsr
1/23/07	0	15	0
2/21/07	0	0	nsr
3/21/07	0	0	0
4/18/07	0	0	nsr
5/8/07	0	0	0
6/12/07	0	1	nsr
7/24/07	0	0	0
8/14/07	0	0	nsr
9/18/07	0	0	0
10/9/07	0	0	nsr
11/27/07	0	0	0
12/11/07	00	0	nsr

4.6 What concentrations of *Cryptosporidium* and *Giardia* were found in various NYC reservoirs in 2007?

The data from watershed streams and upstate keypoints allow for the broad evaluation of the spatial variation in *Cryptosporidium* and *Giardia* (oo)cyst occurrence within the NYC watershed. It has also helped identify sites with high protozoan concentrations and with possible land features or uses that may be associated with high numbers (e.g., wetlands, sewer mains, farms). Additionally, the data are helpful when determining the efficacy of the reservoirs' natural settling and improvement as water travels to the terminal reservoirs (Kensico and New Croton Reservoirs).

Cryptosporidium concentrations continued to be very low in 2007, with each site averaging below 1 oocyst $50L^{-1}$ (EOH, n = 60; WOH, n = 109) (Figure 4.13a). *Giardia* concentrations also remained low, although they are typcally higher than the *Cryptosporidium* levels. (*Giardia* averages by site ranged from 1 to 9 oocysts $50L^{-1}$.) (Figure 4.13b). This same pattern has been seen for many years throughout the watershed.

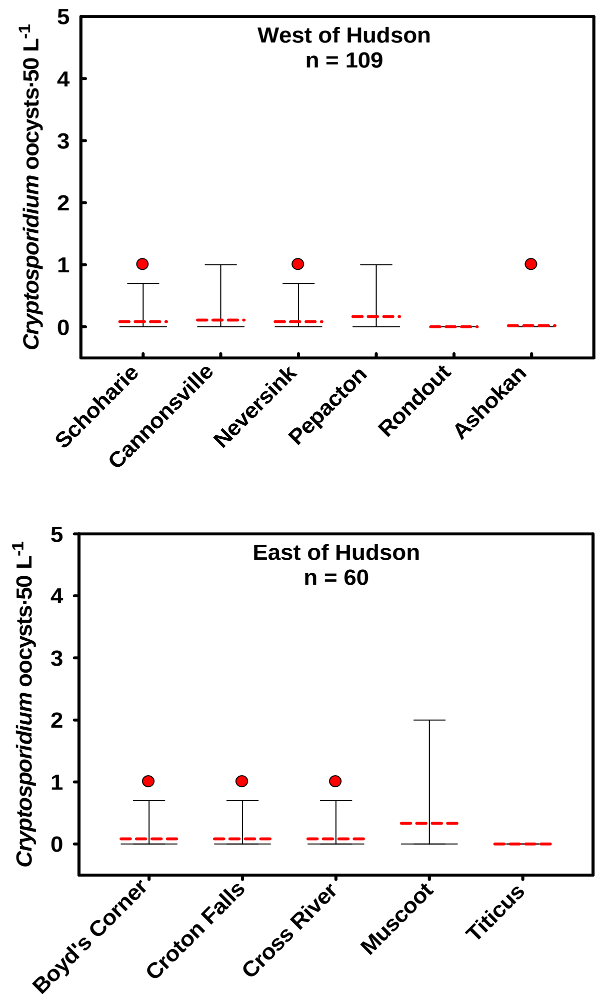

Figure 4.13a 2007 summary of *Cryptosporidium* distribution among WOH and EOH basins (--- Mean, — Median, ● outliers).

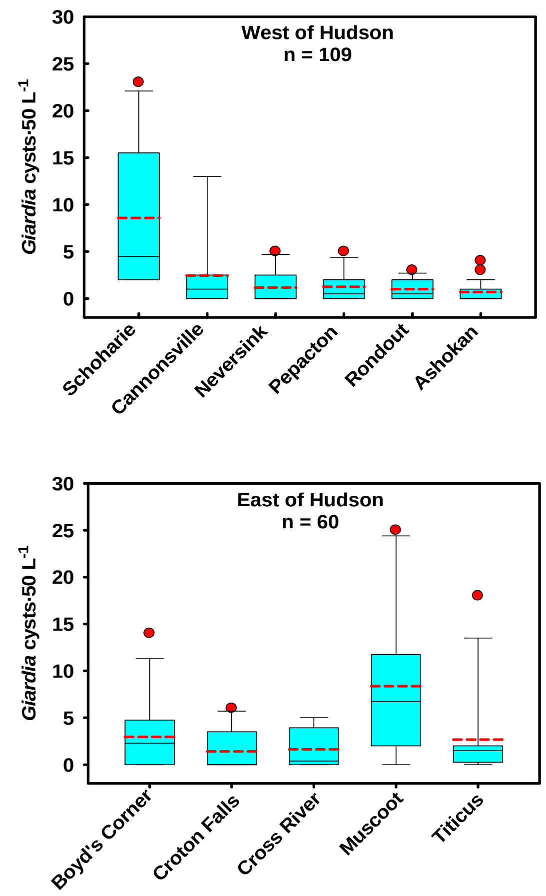

Figure 4.13b 2007 summary of *Giardia* distribution among WOH and EOH basins (--- Mean, — Median, ● outliers).

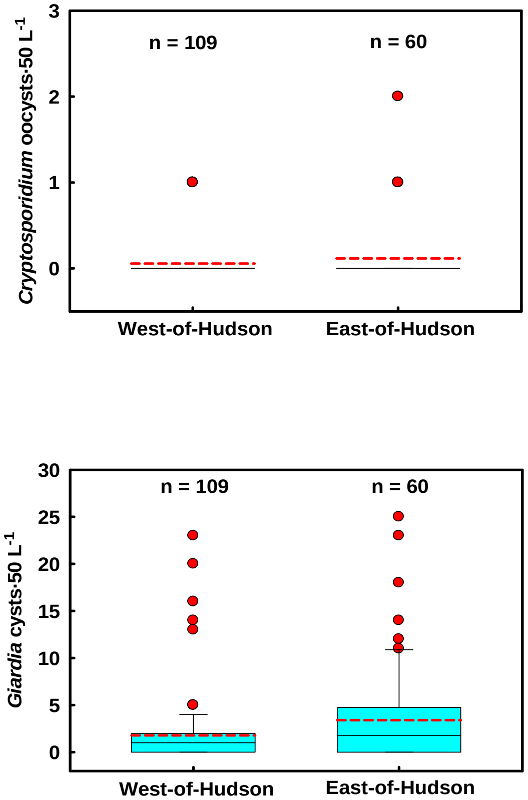

Figure 4.13c Comparison of WOH and EOH *Cryptosporidium* and *Giardia* concentrations 50L^{-1}.

In general, *Cryptosporidium* and *Giardia* (oo)cyst concentrations were slightly higher in the EOH watershed in 2007 than they were West of Hudson (Fig. 4.13c). Concentrations for both watersheds, however, were generally lower in 2007 than in 2006. DEP will continue to monitor selected sites within the NYC watersheds in order to identify possible sources of pathogens to the reservoirs.

4.7 Do protozoans adhere to particles in the water and does this tend to accelerate their sedimentation and removal from the drinking water?

Background

Microbial fate and transport are critical concerns for DEP reservoir management in order to maintain filtration avoidance. The Safe Drinking Water Act grant project designed to begin to explore these processes was completed at the end of August 2007. When modeling microbial transport behavior, characterizing the "partitioning" of the organisms—the fraction of organisms attached to particles in the water column versus the fraction that exists in the "free", unattached, phase—can be important, given its potential impact on microbial settling. Our current pathogen models assume pathogens to be in the free living, or unattached, state, but we know this is not necessarily the case since they can attach to particulate matter of various size fractions which may or may not settle, depending on the particle density and water residence time (Figure 4.14).The improved understanding derived from this study of microbial partitioning behavior and the effectiveness of coagulation in encouraging greater microbial removal should lead to improved modeling of microbial fate and transport in Kensico Reservoir.

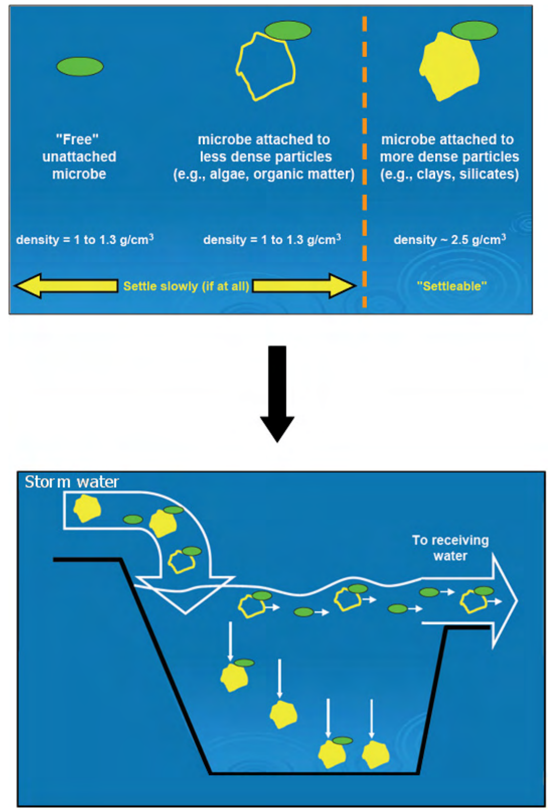

Figure 4.14 Illustration of pathogen state ("attached" or "unattached") and the potential transport or settling across a reservoir depending on state. Pathogens attached to dense particulate matter will settle to the bottom of the reservoir before reaching aqueduct intakes.

Results

Results of the study suggest that a significant fraction of both bacterial indicator organisms and a protozoan indicator organism could potentially be removed by sedimentation. The evidence for this is that the estimated fraction of the total loadings associated with settleable particles during storm events was 20-30%, and up to 80%, respectively. The protozoa examined, *Giardia* and *Cryptosporidium,* experienced smaller fractions associated with settleable particles (0-20%). This association with particles more closely resembles that of fecal coliforms than *C. perfringens* spores, which are also used as a surrogate for protozoa.

While the fraction of microbes associated with particles tends to vary by microbe type, partitioning behavior does not appear to change dramatically for indicator organisms. However, *Giardia* and *Cryptosporidium* tend to have initially higher settleable fractions early in a storm, which decrease over the duration of the storm. Estimates of cumulative microbial loading also confirmed that wet-weather periods contribute significantly to the total microbial load in the tributaries, and therefore to Kensico Reservoir. These results should prove useful in the design and development of models and strategies for better predictions and management of water quality, specifically with regard to *Giardia* and *Cryptosporidium* in Kensico Reservoir. These SDWA Grant 5 project results and interpretation were submitted in final report format in September 2007, and were also presented in part at the 2007 NY Water Environment Association Watershed Science and Technical Conference (Di Lonardo et al. 2007).

4.8 What is the status of DEP's Hillview Reservoir protozoan monitoring project?

The objectives of this study are to monitor the uptakes and downtakes of Hillview Reservoir keypoint facilities for *Giardia* and *Cryptosporidium* (oo)cyst concentrations to determine if the uncovered reservoir acts as a source of these protozoa. This work is in response to EPA requirements stating that uncovered finished water reservoirs need to be covered to protect against the contamination of water that occurs in open reservoirs. Given the naturally low occurrence of *Cryptosporidium* and *Giardia* in NYC source waters, DEP's response to this requirement was to first assess whether covering Hillview Reservoir would measurably improve water quality.

Monitoring began in September 2006 and initially ended in September 2007 along the Catskill Aqueduct at the BX-1 (Hillview influent), BX-3 (Hillview effluent) sites, and along the Delaware Aqueduct at the BX-2 and BX-58 sites, which generally bypassed Hillview Reservoir. Initially the sample frequency was once weekly with one matrix spike (MS) sample at one site per week and one matrix spike duplicate (MSDUP) at one site monthly on a rotational basis. Following a preliminary analysis of the data, a decision was made by DEP to resume monitoring in March 2008 and end it in August 2008. The sample design was modified by dropping the BX-2 and BX-58 sites and adding MS and sample duplicates for both BX-1 and BX-3 for each sample period. In addition, the sampling effort was increased to twice weekly. This decision was made in response to a very high number of non-detects for *Cryptosporidium*, as well as a bias in the recovery data, possibly based on differences in operational treatments at the influent and effluent. Consequently, the additional sampling will provide necessary information on the recovery bias and duplicate error, and increase the sample size of the dataset. The results of this project will be provided in a separate report and in next year's semi-annual and annual FAD reports.

4.9 What pathogen research was published, reported, or presented by DEP in 2007?

Alderisio K. A., S. S. Di Lonardo, G. W. Characklis, M. D. Sobsey, O. Simmons III, A. Cizek, and J. Hayes. 2007. Occurrence and partitioning of *Giardia* and *Cryptosporidium* (oo)cysts within the Kensico drainage basin of the New York City watershed. Submitted to New York State Department of Environmental Conservation as part of Safe Drinking Water Act Grant 5.5.

Alderisio K. A. and L. A. Blancero. 2007. The effect of two approved stains on pathogen results for the New York City Water Supply. In: Proceedings of the 2007 New York City Watershed Science and Technical Conference, September 10-11. West Point, New York.

Di Lonardo S. S., K. A. Alderisio, and G. Characklis. 2007. Settling characteristics of *Giardia* and *Cryptosporidium* (oo)cysts in storm water flow to a New York City drinking water reservoir. 2007. In: Proceedings of the 2007 New York City Watershed Science and Technical Conference, September 10-11. West Point, New York.

DiLonardo, K. A. Alderisio, G. Characklis, M. Sobsey, Otto Simmons III, L. Blancero, D. Wait**.** 2007. Partitioning and Settling Characteristics of *Giardia* and *Cryptosporidium* Associated with Suspended Particles in a New York City Drinking Water Reservoir. August 17, SIL Conference, Montreal, Canada.

Dorner, S. M., K. A. Alderisio, J. Wu, S. C. Long and P. Rees**.** 2007. Integrating Microbial Source Tracking and Hydrology to Better Anticipate Microbial Loading to Source Waters. January 28-30, AWWA Source Water Protection Symposium.

Feng, Yayu; K. A. Alderisio, W. Yang, L. Xiao, L. A. Blancero, W. G. Kuhne, C. A. Nadareski and M. Reid. 2007. *Cryptosporidium* Genotypes in Wildlife from a New York City Watershed. Appl. Environ. Microbiol. **73**: 6475 - 6483

LaFiandra P. 2007. Storm event monitoring for pathogens on the Esopus Creek in 2006. In: Proceedings of the 2007 New York City Watershed Science and Technical Conference, September 10-11. West Point, New York.

Pace C. J., K. A. Alderisio, J. C. Alair, and S. S. Di Lonardo. 2007. Storm water loading of *Giardia* spp. and *Cryptosporidium* spp. in perennial streams of a New York City Reservoir. In: Proceedings of the 2007 New York City Watershed Science and Technical Conference, September 10-11. West Point, New York.

Pratt G. and K. A. Alderisio. 2007. Incidence of enteric viruses in surface water from New York City's Catskill and Delaware Watersheds. In: Proceedings of the 2007 New York City Watershed Science and Technical Conference, September 10-11. West Point, New York.

Xiao L. and K. A. Alderisio. 2007. *Cryptosporidium* genotyping. Submitted to New York State Department of Environmental Conservation as part of Safe Drinking Water Act Grant 5.5.

5. Watershed Management

5.1 How can watershed management improve water quality?

There is a close relationship between activities within a drainage basin and the quality of its water resources. This is the underlying premise of all watershed management programs. DEP has a comprehensive watershed protection program that focuses on implementing both protective (antidegradation) and remedial (specific actions taken to reduce pollution generation from identified sources) initiatives. Protective programs, such as the Land Acquisition Program, protect against potential future degradation of water quality from land use changes. Remedial programs are directed at existing sources of impairment (Figure 5.1). A brief summary of the watershed protection program is provided in the section below. More information on the management programs and water quality analysis can be found in the 2006 Watershed Protection Program: Summary and Assessment report (DEP 2006a). Information on research programs in the watershed can be found in the 2006 Research Objectives Report (DEP 2007b).

Figure 5.1 Remediation of an eroded watercourse in the East of Hudson watershed.

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

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

While DEP is responsible for the collection, monitoring, treatment, and delivery of high quality water to the City, it relies heavily on the work of partner organizations to carry out watershed protection efforts. Numerous towns, counties, state and federal agencies, not-for-profit organizations, and private businesses have participated in and helped make the watershed protection programs a success (Figure 5.2). Highlights of some key watershed programs are:

- *Watershed Agricultural Program*: To date, more than 94.4% of the 307 large farms in the Catskill/Delaware watershed have Whole Farm Plans. Of these 97% have commenced implementation and 84.4% have substantially completed implementation. The Conservation Reserve Enhancement Program has protected more than 181.4 miles of farm stream buffers.
- *Land Acquisition*: Between 1997 and the end of 2007, the City secured more than 83,000 acres in the Catskill/Delaware systems (including fee simple and conservation easements acquired or under contract by DEP, and farm easements acquired by the Watershed Agricultural Council). This brings the total land area (excluding reservoirs) throughout the Cat/Del system under City ownership for purposes of protecting drinking water to over 118,000 acres, more than triple the land area held before the program began.
- *Wastewater Treatment Plant (WWTP) Upgrades*: The five City-owned WWTPs in the Catskill/Delaware Systems were upgraded in the late 1990s. Of the total flow from all non-City-owned Catskill/Delaware plants, 97% emanates from plants that have so far been upgraded.
- *New Infrastructure Program*: Five new WWTPs and one collection system/force main project have been completed in communities with failing or likely-to-fail septic systems.
- *Partnership Programs*: Partnering with DEP, the Catskill Watershed Corporation administers a number of watershed protection and partnership programs including, among others, the Septic Program, the Community Wastewaters Management Program, and the Stormwater Retrofit Program. The Septic Program funded the remediation of 272 failing septic systems in 2007. (Since 1997 more than 2,600 failing septic systems have been repaired or replaced.) Through the Community Wastewater Management Program, one community has established a septic maintenance district, while another has completed a community septic system. Two additional communities are presently constructing community septic systems, while two others are in the design phase for WWTP projects. Over 60 stormwater retrofit projects have been funded through 2007 by the Catskill Watershed Corporation, resulting in the construction and implementation of stormwater BMPs throughout the City's West of Hudson (WOH) watershed. In addition, 30 facilities that store road deicing materials have been upgraded.

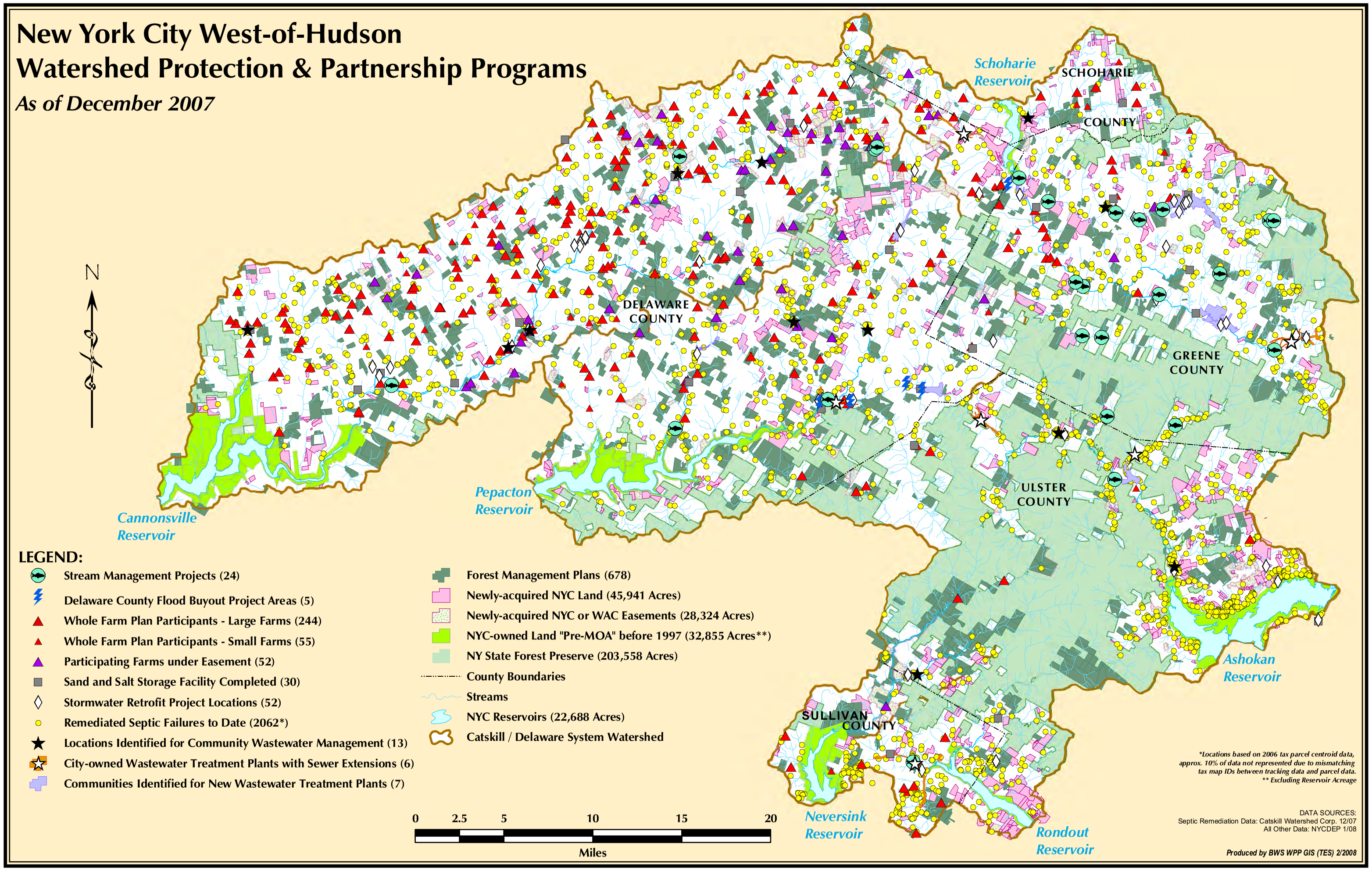

Figure 5.2 New York City West of Hudson Watershed Protection and Partnership Programs as of December 2007.

Water quality has been and continues to be excellent in the Catskill and Delaware Systems. Over the time period 1993-2007, many positive changes in water quality have been observed. The most dramatic change has been the reduction in phosphorus in the Catskill/Delaware basins due to the upgrade of the wastewater treatment plants. As an example, Figure 5.3 shows phosphorus loads and flows from WWTPs in the Cannonsville basin. The reduction in total phosphorus loads from 1994 to 1999 was due to the intervention and assistance of DEP at the Village of Walton's WWTP and at Walton's largest commercial contributor, Kraft. The substantial additional reductions in phosphorus loads realized after 1999 can be attributed to final upgrades of five plants and the diversion of another. As a result, Cannonsville was taken off the phosphorus-restricted basin list in 2002.

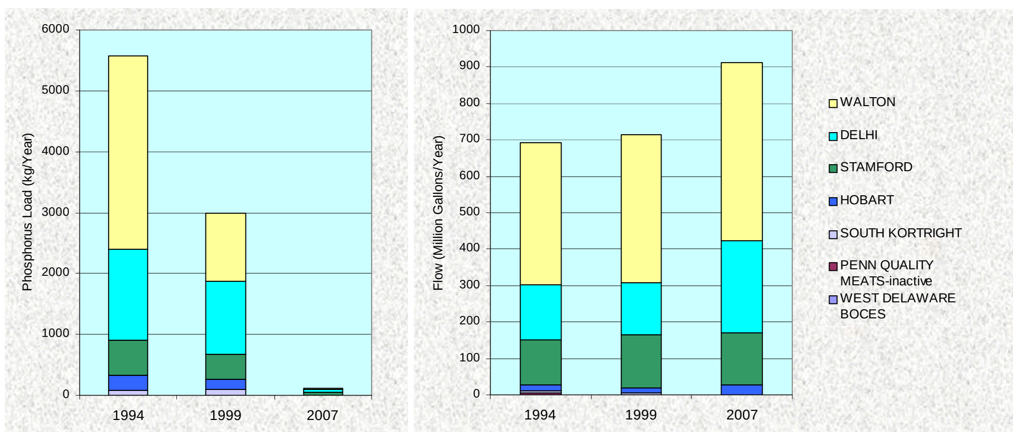

Figure 5.3 Wastewater treatment plant TP loads and flow in the Cannonsville watershed, 1999–2007.

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

The watershed management programs are designed somewhat differently in the Croton System from those in the Catskill and Delaware Systems. Instead of explicitly funding certain management programs (e.g., the Stormwater Retrofit Program), DEP provided funds to Putnam and Westchester Counties to develop a watershed plan ("Croton Plan") and to support water quality investment projects in the Croton watershed. In addition to funding watershed management activities undertaken by the counties, DEP has implemented an East of Hudson (EOH) Nonpoint Source Pollution Control Program to address specific watershed concerns. Other DEP management programs (e.g., the Wastewater Treatment Plant Upgrade Program, the Watershed Agricultural Program) operate similarly in all districts.

Croton Plan and Water Quality Investment Program

In the Croton System, DEP provided funds to Putnam and Westchester Counties to develop a watershed plan to protect water quality and guide the decision-making process for Water Quality Investment Program (WQIP) funds. Many municipalities have begun implementing actions proposed in the Draft Croton Plans, including zoning modifications, regulatory updates, stormwater retrofits, and wastewater control programs. The counties have continued the distribution of the WQIP funds, which were provided by the City for use on watershed improvement projects. The total sum of the used and remaining WQIP funds exceeds $100 million. A few notable projects for 2007 are described below.

- *Putnam County Septic Repair Program (SRP)*. Putnam County continued the implementation of the Septic Repair Program in high priority areas and has repaired over 70 systems to date. Since the program's start, the county has allocated an additional $1,050,000 to the original $3.3 million allocation to rehabilitate additional systems in close proximity to water bodies.
- *Putnam County Stormwater.* Putnam County continues to provide funding for specific stormwater improvements and retrofits that improve water quality.
- *Westchester County Local Grant Program*. Twelve Westchester County municipalities continued the use of $312,500 in grant funding for projects, including sanitary sewer extensions, stormwater improvements, and enhanced storage of highway de-icing materials.
- *Westchester County Septic Program*. Westchester County continues to track septic repairs and license septic contractors.
- *Putnam and Westchester: Peach Lake Project.* The counties have jointly allocated a total of $12.5 million toward a project that will provide for the wastewater collection and treatment of sewage around Peach Lake.

Wastewater Treatment Plant Upgrade Program

The Croton watershed has a large number of wastewater treatment plants, with the bulk of them serving schools, developments, or commercial properties. Of the total of 70 non-City-owned WWTPs located East of Hudson, 60 are in the Croton System (totaling 4.99 million gallons per day) and 10 are in the West Branch, Croton Falls, or Cross River basins (totaling 1.36 million gallons per day). Of these WWTPs, 88.6% have flows of less than 100,000 gallons per day. Upgrade plans for three EOH WWTPs are on hold pending decisions on diversion to existing plants or out of the Croton watershed. Twenty-two facilities within the Croton System, comprising 38.3% of the System's permitted flow, completed their upgrades as of December 2007 and are either ready to start up or have already done so. Of the 32 WWTPs located within the 60-day travel time (comprising 46% of the non-City-owned WWTPs located East of Hudson), seven (comprising 56.5% of the permitted flow) have completed their upgrades. This equates to 20% of the permitted flow within the 60-day travel time. An additional 22 WWTPs (68.6% of the flow) either have commenced construction of the upgrades or are in the design phase.

Watershed Agricultural Program

The farms in the EOH district tend to be smaller and more focused on equestrian-related activities than the WOH farms, and the EOH Watershed Agricultural Program has been specially tailored to address these issues. At the end of 2007, 38 farms in the Croton System had approved Whole Farm Plans. Thirty-three of these farms have commenced implementation of Best Management Practices (BMPs) and a total of 277 BMPs have been installed.

Nonpoint Source Management Program

Figure 5.4 Stormwater collection system inspection: pipe deformation.

The EOH Nonpoint Source Pollution Control Program is a comprehensive effort to address nonpoint pollutant sources in the four EOH Catskill/Delaware watersheds (West Branch, Croton Falls, Cross River, Boyd Corners). The program supplements DEP's existing regulatory efforts and nonpoint source management initiatives. Data on the watershed and its infrastructure is generated and that information is used to evaluate, eliminate, and remediate existing nonpoint pollutant sources, maintain system infrastructure, and evaluate DEP's programs. Some recent highlights include:

- DEP contracted with a firm to complete the mapping and inspection of the stormwater collection system in the West Branch and Boyd Corners basins. This continues the video inspection and digital mapping of the stormwater infrastructure that was initiated in 2005. The program identified the locations, conditions, and potential pollution threats associated with stormwater infrastructure (Figure 5.4).
- Stormwater remediation projects continue to be identified and implemented. Small remediation projects are completed annually (Figure 5.5). The designs and permitting necessary for the larger remediation projects are currently underway.
- Design, permitting, and survey work was continued on upcoming roadway and drainage improvement projects that will reduce erosion potential and turbidity from unpaved roads. The retrofit project will improve the functionality of the existing stormwater conveyance system along the roadways.

Figure 5.5 Stormwater swale repair.

5.4 What is the status of the DEC Freshwater Wetlands Remapping Program to increase wetlands protection in the New York City watershed and how has DEP aided the remapping effort?

The New York State Department of Environmental Conservations's (DEC's) Freshwater Wetlands Remapping Program was completed for the watershed in Westchester County in 2004 and Putnam and Dutchess Counties in 2006. With the help of DEP's Wetlands Program staff, which includes extensive field work, DEC added approximately 7,000 acres to the state's existing wetlands maps in the EOH watershed. These wetlands, which include 100-foot buffer zones, are now regulated by New York State. This helps strengthen New York City's Watershed Rules and Regulations (WR&R), since the City's WR&R are linked to the state's Freshwater Wetlands maps. In addition, DEC has agreed to honor DEP's request that EOH wetlands that are connected to or within 165 feet of a reservoir be designated as "of Unusual Local Importance." This will have the effect of protecting critical wetlands and their water quality protection functions, even if they are smaller in area than the usual 12.4-acre regulatory threshold.

5.5 How is the Forest Science Program contributing to development of DEP's Forest Management Plan?

The Forest Science Program has been collecting data on forest ecosystems located on water supply lands since 1999. In recent years, including 2007, efforts have been focused on establishing a system of permanent forest inventory plots throughout the watershed that will help DEP's forest managers understand the dynamics of watershed forests, including eventual development of prediction models for estimating tree growth, recruitment of young seedlings into the forest stand, and mortality of older or more susceptible species or stands of trees. With the planned hiring of a full-time forest science intern for a one-year period, DEP expects to make significant progress toward completing the establishment of these Continuous Forest Inventory (CFI) plots in the large land areas of the Pepacton and Cannonsville Reservoirs. Data from the CFI plots will aid in the development of test statistics for the upcoming watershed forest inventory that will feed into DEP's Forest Management Plan. This long-term CFI dataset will be useful in improving modeling tools, ground-truthing remote sensing of forest stand types, and tracking progress and results of applied management activities. In addition, data from the CFI plots dataset will provide periodic updates to aid managers looking at larger-scale processes in DEP's watershed forests.

5.6 How did trout spawning affect stream reclassification in the Cannonsville Reservoir drainage basin?

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

Reclassification surveys concentrate on sections of streams with likely trout habitat, including riffles, pools, and undercut banks. Streams are electrofished and all stunned fish are collected and held for processing (identification, length, and weight) (Figure 5.6). The fish are released when all data are collected. The presence of trout less than 100 mm in length (young-of-the-year fish) is used to indicate the occurrence of trout spawning. Physical and chemical stream data (temperature, depth, width, dissolved oxygen, pH, conductivity, stream gradient, and estimated discharge) are then collected to assess stream conditions suitable for trout spawning. Bottom substrate and land characteristics are also described. Collection reports and reclassification petitions are compiled and submitted to DEC on an annual basis. DEC updates the stream classification based on these petitions.

Figure 5.6 DEP and DEC staff electrofishing Esopus Creek.

In 2007, surveys of the Cannonsville Reservoir basin streams, which began in 2006, were continued; these surveys will be completed in 2008. Research East of Hudson will commence in 2008.

5.7 How do environmental project reviews help protect water quality and how many were conducted in 2007?

DEP staff review a wide variety of projects to assess their potential impacts on water quality and watershed natural resources. Under the New York State Environmental Quality Review Act (SEQRA), DEP is often an involved agency because of its regulatory authority over certain actions. By participating in the SEQRA process, DEP can ensure that water quality concerns are addressed early on in the project planning process. In 2007, DEP staff reviewed a total of 210 SEQRA actions, including Notices of Intent to Act as Lead Agency, Determinations of Action Types, Environmental Assessment Forms, Scoping Documents, Draft, Final and Supplemental Environmental Impact Statements, and Findings to Approve or Deny.

In addition to projects in the SEQRA process, DEP staff review other projects upon request. Review of these projects helps ensure that they are designed and executed in such a manner as to minimize impacts to water quality. DEP provides its expertise in reviewing and identifying on-site impacts to wetlands, vegetation, fisheries, and wildlife, and makes recommendations on avoiding or mitigating proposed impacts. These reviews also provide guidance on interpreting regulations as they apply to wetlands as well as threatened and endangered species. Approximately 94 of these projects were reviewed and commented on by DEP in 2007. Many of them were large, multiyear projects with ongoing review and many others were smaller scale projects scattered throughout the NYC watershed.

DEP also coordinates review of federal, state, and local wetland permit applications in the watershed for the Bureau of Water Supply. In 2007, approximately 30 wetland permit applications were reviewed and commented on.

5.8 What was the status of WWTP TP loads in the watershed in 2007?

Figure 5.7 displays the sum of the annual total phosphorus (TP) loads from all surface-discharging wastewater treatment plants (WWTPs) by district for the period 1999–2007. The far right bar displays the calculated wasteload allocation (WLA) for all these WWTPs, which is the TP load allowed by the State Pollutant Discharge Elimination System (SPDES) permits. The TP load equals the maximum permitted effluent flow multiplied by the maximum permitted TP concentration. Overall, the TP loads from WWTPs remain far below the WLA. The fact that loads in the Delaware and Catskill Systems remain so far below their respective WLAs reflects the effect of the WWTP upgrade program, which is largely complete West of Hudson. Similarly, TP loads from East of Hudson WWTPs are expected to decrease as upgrades progress.

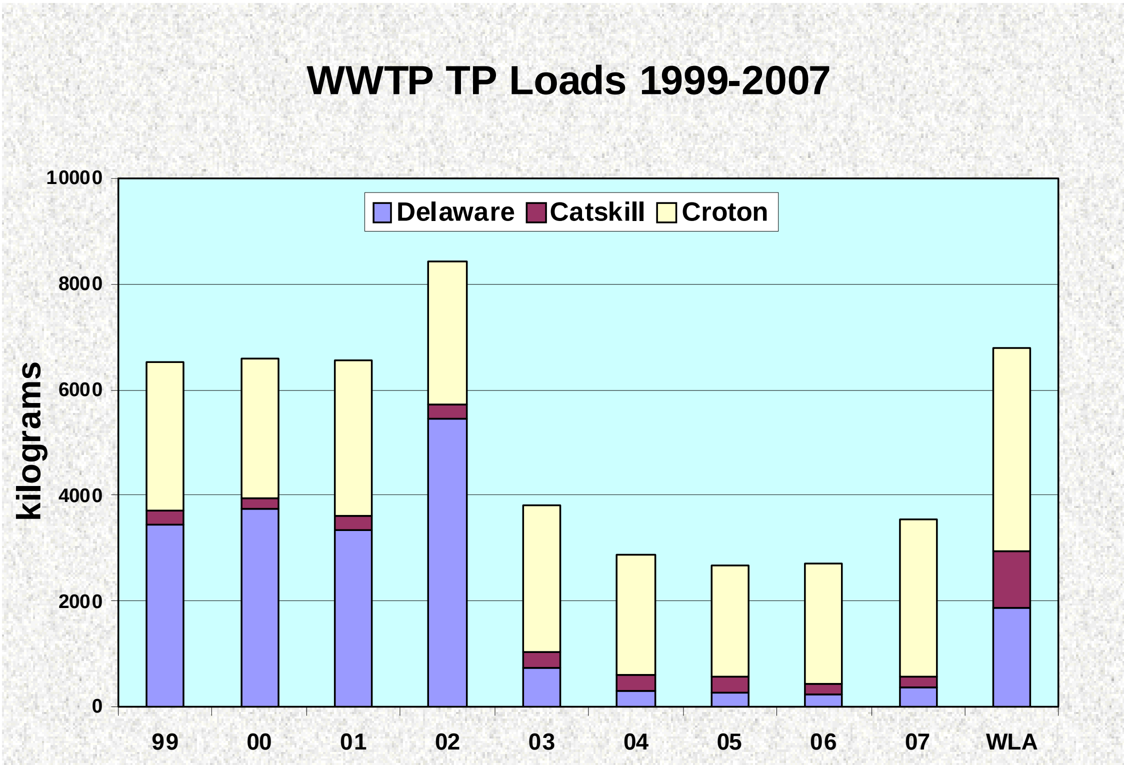

Figure 5.7 Wastewater treatment plant TP loads, 1999–2007. The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

Upgrades to WWTPs include phosphorus removal and microfiltration to make the plants comply with the WR&R. All NYC-owned WWTPs in the watershed have been upgraded, including the Brewster WWTP, which was transferred to the Village of Brewster in 2007 after its upgrade was completed. Several non-NYC-owned WWTPs have already been upgraded, while a number of others are being connected to plants in the New Infrastructure Program (NIP).

The NIP is another major wastewater management program funded by DEP. It builds new WWTPs in communities previously relying on individual septic systems. Since many of the older septic systems in village centers such as Andes, Roxbury, Windham, Hunter, Fleischmanns, and Prattsville could not be rehabilitated to comply with current codes, this program seeks to reduce potential nonpoint source pollution by collecting and treating wastewater with compliant systems. As NIPs are completed and sewer districts expand to their full capacities, TP loads are expected to eventually approach the WLAs for the respective Systems.

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

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

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

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

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

- *Steam cleaning boats and equipment*. DEP requires that all boats allowed on NYC reservoirs for any reason be inspected and thoroughly steam cleaned prior to being allowed on the reservoir (Figure 5.8). Any organisms or grasses found anywhere on the boat are removed prior to the boat being steam cleaned. The steam cleaning kills all zebra mussels, juveniles, and veligers that may be found anywhere on the boat, thus preventing their introduction into the NYC reservoir system. The requirement that all boats be steam cleaned applies to all boats that will be used on the reservoirs, whether they're rowboats used by the general public, or motorboats used by DEP. Additionally, all contractor boats, barges, dredges, equipment (e.g., anchors, chains, lines), and trailer parts must be thoroughly steam cleaned inside and out. All water must be drained from boats, barges, their components (including outdrive units, all bilge water (if applicable), and raw engine cooling systems), and equipment at an offsite location, away from any NYC reservoirs or streams that flow into NYC reservoirs or lakes, prior to arrival for DEP inspection.

Figure 5.8 Steam cleaning a boat to prevent transport of zebra mussels.

- *Public Education*. DEP provides educational pamphlets to fishermen on NYC's reservoirs and to bait and tackle shops in NYC's watersheds about preventing the introduction and spread of zebra mussels to bodies of water that do not have them. Fishermen can inadvertently introduce zebra mussels to a body of water through their bait buckets that may have zebra mussels in them (depending upon where the bait was obtained), or by failing to clean equipment that's been used in bodies of water infested with zebra mussels before using it in bodies of water not infested with zebra mussels. The brochures help educate fishermen as to how they can prevent the spread of zebra mussels.

5.10 What "Special Investigations" were conducted in 2007?

The term "Special Investigation" (SI) refers to limited non-routine collection of environmental data, including photographs and/or analysis of samples, in response to a specific concern or event. In 2007, 8 SIs were conducted. Reports are prepared to document each incident and DEP's response and remedial actions as appropriate. More investigations were conducted East of Hudson (6) than West of Hudson (2). Actual or possible sewage-related problems were the commonest incident investigated (4). Other incidents included an oil spill, an organic sheen, a fish kill, and a hydrocarbon odor detection. None of the investigations conducted in 2007 identified a pollution problem that was considered an immediate threat to consumers of the water supply. Below is a list of reservoir watersheds in which investigations occurred in 2007, with the date and reason for each investigation.

Muscoot Reservoir
- September 16, a sewage overflow occurred at the Yorktown Heights WWTP.

Bronx River Drainage System
- April 5, a sewer line disruption at Westlake Drive and Columbus Avenue.

Amawalk Reservoir
- August 1, a fish kill within Lake Shenorock.

Kensico Reservoir
- April 16, an oil spill occurred at the Del17 Reservoir.
- July 31, a sewage spill occurred at the North Castle Sewage System.
- October 10, a visible organic sheen was detected in the Del17 (Delaware Aqueduct influent to Kensico Reservoir) Channel.

Cannonsville Reservoir
- September 9, a hydrocarbon detection at the Cannonsville Elevation Tap CR-2.

Rondout Reservoir
- September 19, *Cryptosporidium* was detected at the Grahamsville WWTP.

6. Model Development and Application

6.1 Why are models important and how are they used by DEP?

DEP uses models as essential tools for ensuring the continued reliability and high quality of the NYC drinking water supply. Changing land use, population, and climate conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to. Shifting patterns of land use and population in the watersheds influence nutrient loadings, which cause eutrophication in reservoirs, and other anthropogenic pollutants. Stream channel erosion related to climate and to urbanization may exacerbate turbidity in the water supply system. Climate change may impact both the future quantity and quality of water in the upstate reservoir system. Understanding the effects of changing conditions is critical for decision making, long-term planning, and management of the NYC watersheds and reservoir system (Figure 6.1).

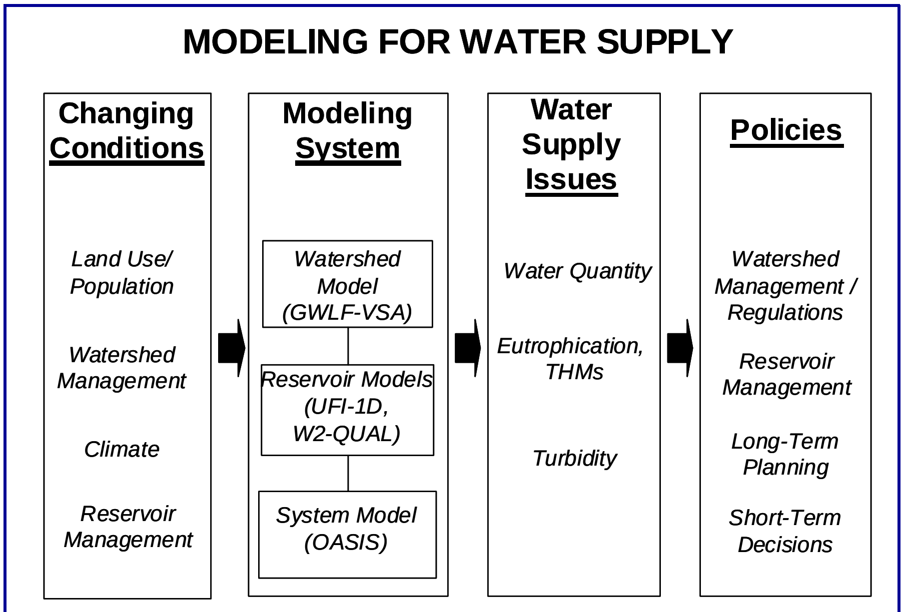

Figure 6.1 Use of models for the NYC Water Supply.

The DEP modeling system consists of a series of linked models that simulate the transport of water and contaminants within the watersheds and reservoirs that comprise the upstate water supply Catskill and Delaware Systems. Watershed models, including a DEP-adapted version of the Generalized Watershed Loading Function model (GWLF-VSA) (Schneiderman et al. 2007), simulate generation and transport of water, sediment, and nutrients from the land surface to the reservoirs. Reservoir models (including the UFI-1D and the CE-QUAL-W2 models) simulate hydrothermal structure, hydrodynamics, and nutrient and sediment distribution within the reservoir body and outlets. The water supply system model (OASIS) simulates the operation of the multiple reservoirs that comprise the water supply system. The modeling system is used to explore alternative future scenarios and examine how the water supply system and its components may behave in response to changes in land use, population, climate, watershed/reservoir management, and system operations.

Major water supply issues that the modeling system is used to address include turbidity in the Catskill System, eutrophication in the Delaware System, and water quantity to meet NYC demand. Simulations are performed during and in the aftermath of storm events to provide guidance for operating the Catskill and Delaware Systems in response to elevated turbidity levels, particularly in the Catskill System (see Section 6.4). Model simulations have been used to confirm the need for alum treatment when necessary, and to suggest aqueduct flow levels that can reduce the duration of treatment or eliminate the need for it altogether. The models have been used to identify major sources of turbidity and to examine alternative structural and operational changes in Schoharie and Ashokan Reservoirs to mitigate the need to use alum to treat elevated turbidity, as part of the CAT211 project (Gannett Fleming and Hazen and Sawyer 2007). The effects of changing land use and watershed management on nutrient loading and eutrophication in Delaware System reservoirs (Cannonsville and Pepacton) have been analyzed using linked watershed and reservoir models (DEP 2006a). The first phase of a project to examine the effects of climate change on the water supply is underway (see Section 6.3), using the modeling system to examine climate change effects on turbidity in Schoharie Reservoir, eutrophication in Cannonsville Reservoir, and system-wide water quantity.

6.2 What can models tell us about the effects of 2007's weather on nutrient loads and flow pathways to reservoirs?

Watershed modeling provides insight into the flow paths that water and nutrients take in the watershed. Total streamflow is comprised of direct runoff and baseflow. Direct runoff is water that moves rapidly on or near the land surface during and after storm events, as opposed to much slower-moving baseflow that sustains streamflow between storm events. Direct runoff has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Frequent and intense storm events may produce above-average nutrient loads to reservoirs due to increased direct runoff. Long-term watershed model simulations that include the current year are used to place annual results for 2007 in a historical context.

Figure 6.2 depicts the annual streamflow, direct runoff, and nonpoint source (NPS) dissolved nutrient loads simulated by the model for 2007 in relation to long-term simulated annual statistics. These box plots show that 2007 was similar to a median year for Neversink, Rondout, and Ashokan, while somewhat wetter than normal for Cannonsville, Pepacton, and Schoharie, all of which had higher than normal streamflow and direct runoff. Consistent with these high flows, 2007 NPS dissolved nutrient loads were also higher than normal for Cannonsville, Pepacton and Schoharie. The relationship between 2007 and long-term annual total dissolved nitrogen (TDN) loads follows a pattern similar to that for annual streamflow, while the relationship between the 2007 and long-term annual total dissolved phosphorus (TDP) loads closely follows direct runoff.

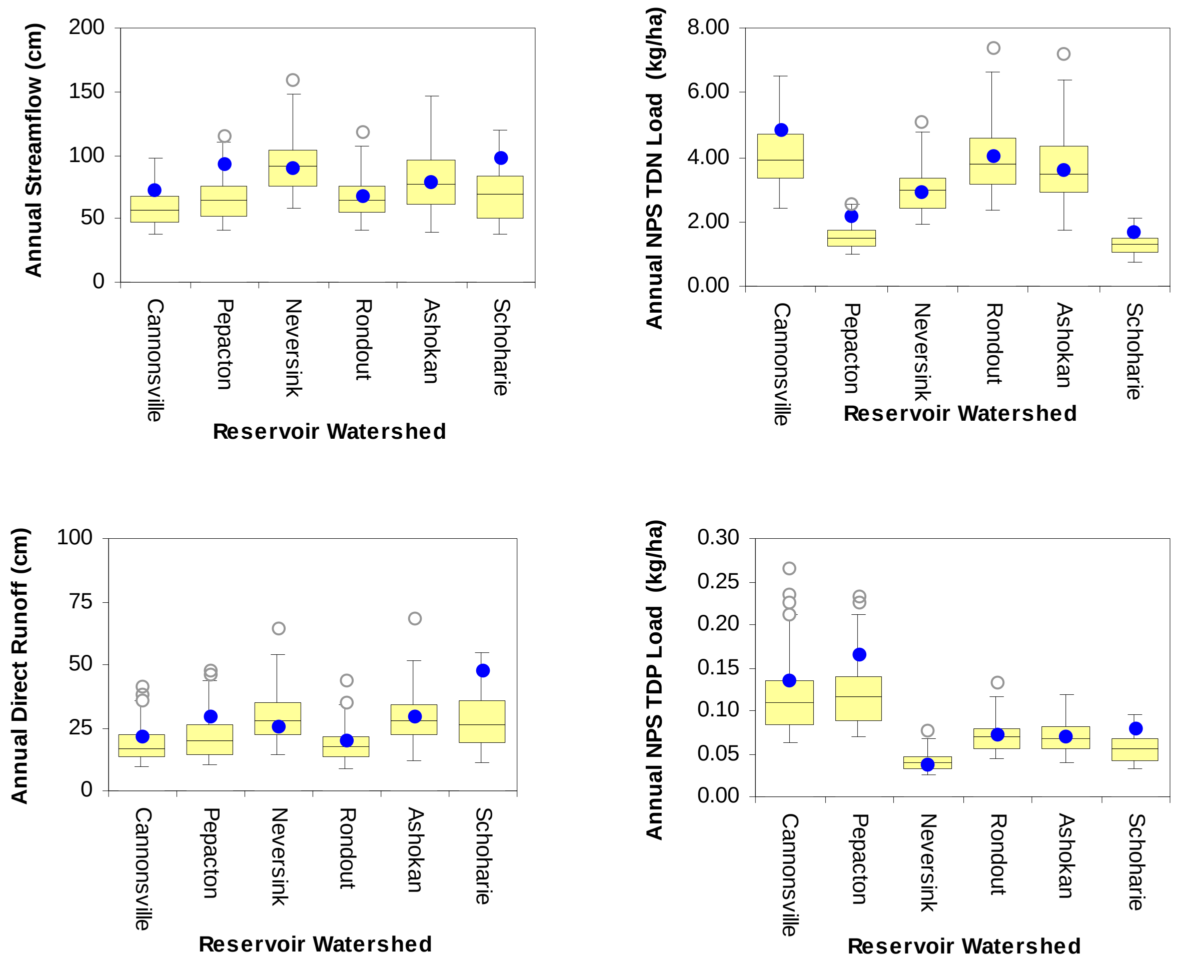

Figure 6.2 Annual streamflow, direct runoff, and nonpoint source dissolved nutrient loads simulated by the GWLF model for 2007 in relation to long-term simulated annual statistics. Box plots show long-term statistics. Blue dots show 2007 results.

6.3 How will DEP be using its modeling capabilities to investigate the effects of climate change on water supply quantity and quality?

During 2007, planning began for an integrated modeling project to estimate the effects of future climate change on the quantity and quality of water in the NYC water supply. Under future climate conditions, temperatures are expected to increase, bringing more evaporation and less water, while at the same time overall levels of precipitation will likely increase. The complete effect of climate change-affected processes on water quantity and quality are as yet unknown; however, it is anticipated that longer growing seasons, earlier snowpack melting, changes in the timing of streamflow, sediment transport, and nutrient delivery, and changes in timing and duration of seasonal reservoir thermal stratification are possible. Given the potential impacts of climate change, three areas of concern have been identified, and each will be addressed through applications of DEP's watershed, reservoir, and system models:

- Overall quantity of water in the entire water supply. Possible effects include altered inputs to the system, potential changes in the dynamics of the system (e.g., change in the timing of inputs, spill, and drawdown), and resultant adjustments in reservoir operations.
- Turbidity in Catskill System reservoirs, including Kensico Reservoir. Changes in the frequency, timing, and intensity of precipitation may lead to changes in the turbidity loading to Catskill System reservoirs. Increased turbidity inputs could become a water quality concern that would limit the use of Catskill System water, and could also require treatment of Catskill System water with alum.
- Eutrophication in Delaware System reservoirs. Changes in the timing and magnitude of nutrient inputs to NYC reservoirs as well as changes in thermal structure, mixing, and stratification could potentially lead to changes in reservoir trophic status. If the frequency and/or intensity of algal blooms increase, water use from some reservoirs may need to be adjusted, and water treatment could become more costly.

The project is planned in two phases. Phase I is an initial phase aimed at providing a first-cut evaluation of the effects of climate change on water quantity and quality, using the existing modeling system and data readily available from existing global climate models (GCM). Phase I will examine, in a preliminary way, water quantity system-wide, turbidity in Schoharie Reservoir and eutrophication in Cannonsville Reservoir. Phase II will be similar to Phase I, but with upgraded models and data sets. This phase will examine water quality as well as quantity on a system-wide basis.

The project will combine the use of GCM-derived climate change predictions, DEP water quality and water supply models, and analytical measures of system indicators to further understand the potential effects of climate change on the water supply system. Each aspect of this integrated program is described below.

Climate Input

The climate inputs needed for the project will include scenarios of temperature, precipitation, wind, solar radiation, and humidity. For Phase I, GCM runs will be used to calculate delta change (Hay et al. 2000) coefficients, representing mean monthly change in a given climate variable between control and future prediction periods. Delta changes will be applied to the historical control period data, additively for air temperature and as a multiplicative ratio for precipitation, generating a future prediction time series. The need to apply the delta change method to wind and solar radiation data used by the reservoir models will be evaluated.

It is anticipated that for Phase II, climate inputs will be refined using downscaling techniques. GCM output is currently based on the spatial (2^{o}-4^{o} latitude-longitude grids) and temporal resolution of the GCM model. Downscaling techniques are used to better define climate changes specific to smaller areas and shorter time scales than are available from GCMs alone. Downscaling through the use of both Regional Climate Models (RCM) and statistical techniques will be investigated.

Modeling System

Models that DEP has already developed and applied in the past will be upgraded and utilized for the integrated modeling project. These models include: DEP's variable source hydrology version of the Generalized Watershed Loading Function model (GWLF-VSA) (Schneiderman et al. 2007), a 1-dimensional reservoir hydrothermal and eutrophication model (Owens 1998, Doerr et al. 1998), the CE-Qual-W2 two-dimensional reservoir turbidity transport model (Cole and Wells 2002); and the OASIS operating model for the overall water supply system (Hydrologics 2007). These four models taken together with the climate scenarios make the proposed integrated assessment possible.

GWLF-VSA simulates water quality and quantity, including dissolved and particulate nutrient loads, on a daily time step. The 1D reservoir model outputs daily vertical profiles of dissolved and particulate phosphorus and nitrogen as well as chlorophyll. This model is normally run over long time periods (approximately 30 years), driven by measured time series of meteorological and reservoir operations data and simulated GWLF-VSA loads. Typically GWLF-VSA and the 1D reservoir model have been used to evaluate the effects of changes in land use and watershed management on long-term variations in reservoir chlorophyll (Owens et al. 1998; DEP 2001, 2006a).

The 2D reservoir model has vertical and longitudinal segmentation, similar inputs to the 1D model, and a daily time step for output. The 2D model (CE-Qual-W2) is usually used to simulate turbidity transport in cases where turbidity levels at specific locations (e.g., reservoir withdrawals) and the time of transport of turbidity through a reservoir need to be known. This model has been used extensively to forecast reservoir turbidity levels and to guide reservoir operations and alum treatment in response to high turbidity (See Section 6.4).

The entire NYC water supply can be simulated using the OASIS system operation model to provide assessments of supply status and system operating policies. In its present form the model is driven with historical streamflow inputs. The initial setup of OASIS for the NYC water supply system simulated only water quantity and did not explicitly consider issues of water quality. Work has been underway to couple the CE-Qual-W2 reservoir model for turbidity to OASIS for the Catskill System (Gannett Fleming and Hazen and Sawyer 2007). This allows simulations where turbidity as well as water availability influence system status and operating policies.

As the project progresses through Phases I and II, further model enhancements and integration will be implemented (Figure 6.3). Under DEP's present system of water quality and supply system models, simulations are driven by known historical variations in meteorological data, river flow, and reservoir operations. With Phase I the modeling system will be further integrated to allow use of modeled flows as input to the system and reservoir models. Additionally, reservoir operations derived from the OASIS system model will be incorporated into reservoir water quality simulations (Figure 6.3B); water quality, however, will not influence the OASIS operating rule set. Finally, complete model coupling including feedback between reservoir water quality and the OASIS system model will be incorporated in Phase II (Figure 6.3C). Other Phase II model enhancements include: elements relating to hydrologic balance, sediment generation, ecosystem effects, and land use for the watershed model; additional upgrades and calibration for the reservoir models; enhanced coupling of the watershed and reservoir models to OASIS for the integrated system; and statistical downscaling and RCM simulations for climate inputs.

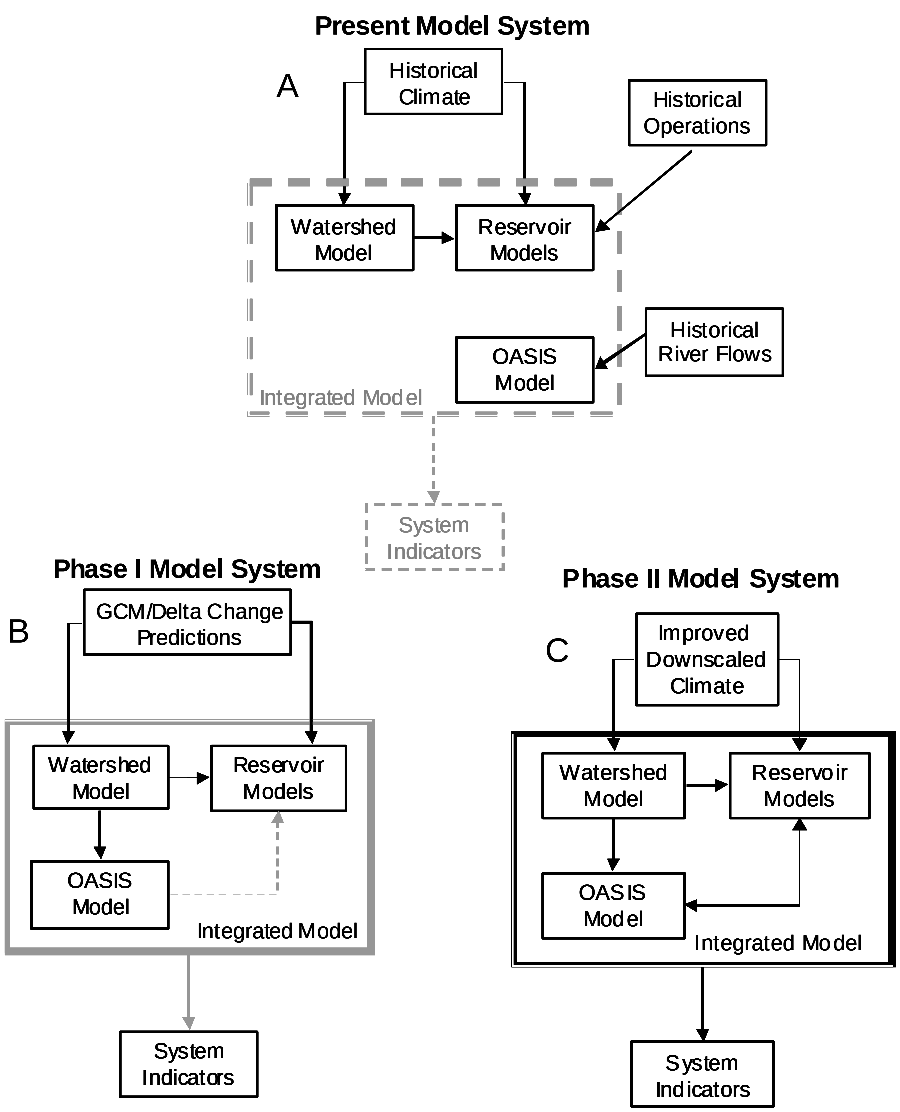

Figure 6.3 Integrated modeling framework for estimating the effects of climate change on quantity and quality of NYC's water supply. A) DEP's present system of water quality and supply system models, B) Proposed phase I modeling system, C) Proposed phase II modeling system.

System Indicators

The result of the project will be a better understanding of the NYC water supply system under climate change. A number of system indicators of water system quantity and quality will be developed and used to measure climate change effects. These indicators include total water quantity, probabilities of refill, probabilities of drawdown, keypoint turbidity levels, frequency of alum use (Kensico), reservoir phosphorus and chlorophyll concentrations, and restrictions in water use due to eutrophication. These results will provide the basis for recommendations about system operation now and in the future.

Upon completion of initial project planning, a workshop with invited outside experts was held in spring 2007 to review the project plan. The panel found that the project outline was basically sound and appropriate. In addition, valuable recommendations were obtained from the review related to all aspects of the proposed project.

6.4 How did DEP use model simulations in 2007 to support turbidity management and avoid alum treatment?

DEP has a suite of models that can be used to predict the transport of turbidity and levels of turbidity throughout the Catskill system of reservoirs, including Kensico Reservoir (Figure 6.4). Kensico Reservoir is of great importance for the water supply since it is the location where water from the Catskill and Delaware Systems mix prior to final transport to the drinking water distribution system. Water leaving Kensico Reservoir must, as specified by the Surface Water Treatment Rule, remain below the turbidity limit of 5 NTU. DEP has always released high quality water with turbidity below this regulatory limit, despite the fact that Catskill stream turbidity levels can occasionally exceed 1000 NTU during high runoff (e.g., Esopus Creek). Naturally, episodic inputs of turbid water elevate turbidity levels in Ashokan Reservoir, and the Catskill System water withdrawn from it. The reservoir, however, attenuates the extreme turbidity levels which enter it, leading to moderate levels of turbidity that persist until the turbidity- producing particles settle out of the water. Following a large runoff event, turbidity levels in the range of 7-50 NTU can occur in the East Basin of the reservoir at the location of the Catskill Aqueduct withdrawal (Figure 6.4), and turbidity levels can remain above 7 NTU for weeks or months following such an event (Table 6.1). Anytime turbidity in Catskill System water withdrawn from Ashokan Reservoir approaches 7 NTU, model simulations are used to evaluate potential effects on Kensico Reservoir turbidity levels. At such times, the challenge for DEP is to devise operating strategies that will meet water supply demands while minimizing the impact of elevated Catskill System turbidity on the Kensico effluent, such that water withdrawn from Kensico always remains below the 5 NTU regulatory limit.

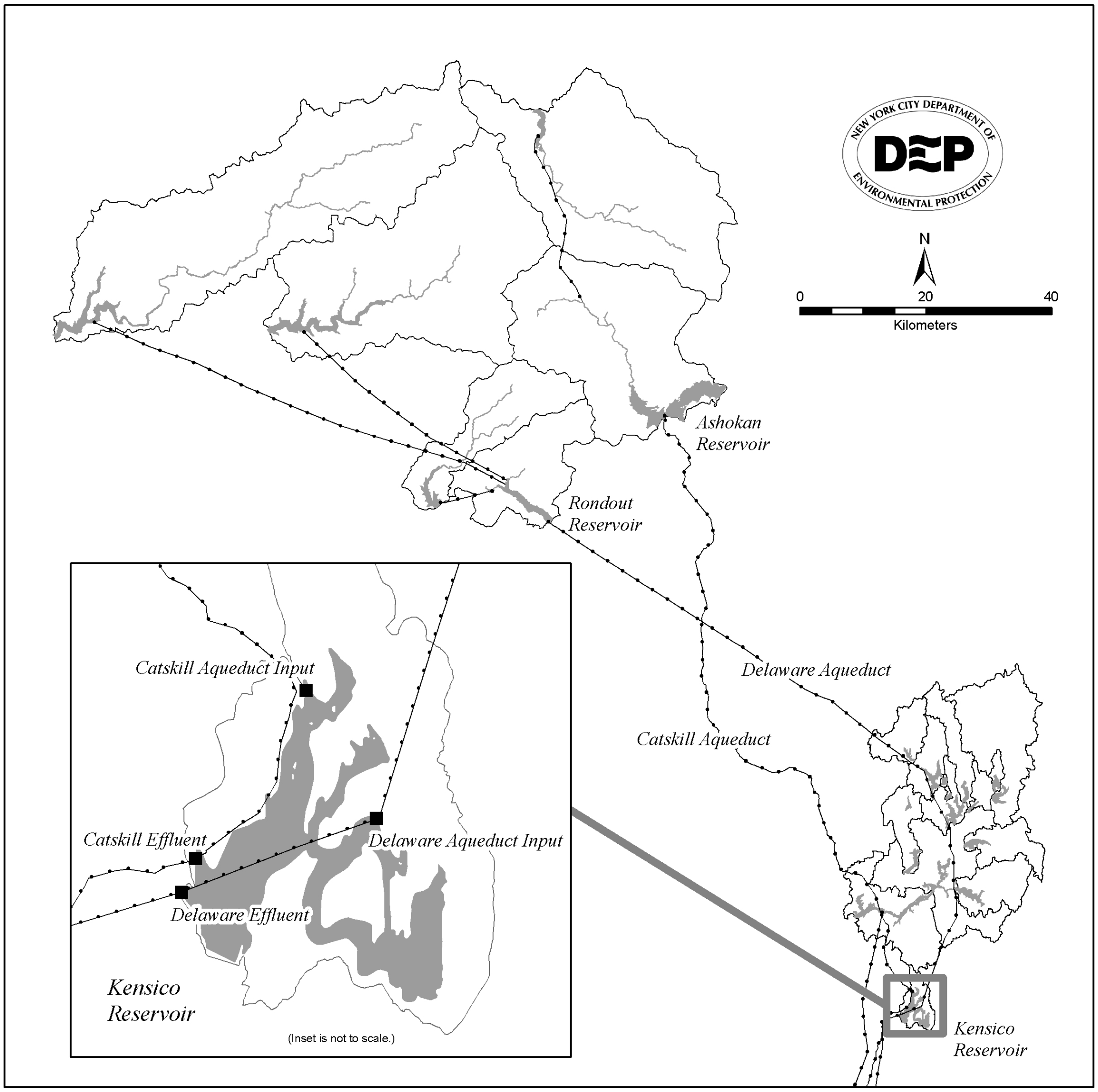

Figure 6.4 New York City Water Supply Reservoirs. Water from the two Catskill System reservoirs enters the Catskill Aqueduct from Ashokan Reservoir; water from the four Delaware System reservoirs enters the Delaware Aqueduct from Rondout Reservoir. Inserts show details of inflows and outflows in Ashokan and Kensico Reservoirs.

Table 6.1: Summary of turbidity and flow data associated with elevated turbidity periods in Ashokan Reservoir between 2005–2007. These periods are times during which water withdrawn from the reservoir exceeds 7 NTU.

Periods of elevated turbidity (Effluent Turbidity > 7 NTU)	Alum Use*	Duration (days)	Peak Effluent Turbidity (NTU)	Median Effluent Turbidity (NTU)	Median Effluent Flow (MGD)
4 Apr 05 - 22 Jun 05	Yes	80	160	22	315
12 Oct 05 - 3 Apr 06	Yes	174	45	12	563
27 Jun 06 - 4 Jul 06	Yes	28	140	18	585
17 Apr 07 - 29 Apr 07	No	13	21	13	132

At times in order to meet the 5 NTU regulatory requirement, DEP must resort to chemical treatment with alum to remove excess turbidity in Catskill System water as it enters Kensico Reservoir. Alum treatment was required in 2005 and 2006 (Table 6.1), and at these times model simulations of Kensico Reservoir were used to demonstrate the need for alum treatment and optimize the length of treatment in order to minimize the use of alum when required.

During April 2007 a different situation occurred. A moderate storm event led to elevated levels of turbidity entering Ashokan Reservoir, and in the days following the event, the Ashokan West Basin turbidity ranged between 20–60 NTU and the turbidity entering the Catskill Aqueduct from the Ashokan East Basin withdrawal did exceed 7 NTU for a significant period of time (Table 6.1). Despite this, alum treatment was avoided, largely due to the fact that DEP had a greater ability to reduce the flow of water withdrawn from the Catskill System, that this period of elevated turbidity was relatively short in duration, and that only moderate increases in turbidity occurred as compared to previous events (Table 6.1).

Following completion of repairs to the Gilboa Dam (Schoharie Reservoir), greater flexibility in operating the reservoir system was possible. During 2006 DEP continuously attempted to maintain low Schoharie Reservoir water elevations and, therefore, always tried to maintain high flows in the Shandaken Tunnel, and, in turn, maximum flows out of Ashokan Reservoir through the Catskill Aqueduct. During the 2007 turbidity event it was possible to reduce the Catskill System flow so that the median daily flow of water to Kensico was approximately one-third of that exported in the previous three events (Table 6.1). Given this additional operational flexibility, model simulations were used to project the effects of reducing flows from Ashokan Reservoir on Kensico effluent turbidity levels. Such simulations provided guidance for choosing an optimal Catskill flow rate, and provided assurance that at reduced flows Kensico effluent turbidity could be maintained at safe levels without the use of alum.

An example of simulations predicting the turbidity levels at the Kensico effluent withdrawals is shown in Figure 6.5. These simulations examined the effects of reducing Catskill System flow rates to either 100 MGD or 250 MGD. The model simulations of Kensico Reservoir were performed during April 2007. The model was initialized by starting the simulation period on January 1, 2007 and using measured variations in flow and turbidity in the Catskill and Delaware Aqueducts as inputs. Following this initial "spin up" period, constant flow and turbidity conditions were used as input to the model for one month into the future (April 19–May 19, 2007). For this future forecast, near maximum Delaware System flow rates of 850 MGD were used to compensate for the reduction in Catskill System flow. Turbidity levels in the Catskill System were assumed to be 30 NTU, a maximum level based on limnological surveys of the reservoir. Delaware System turbidity was assumed to be 1.5 NTU based on measurements made at the Delaware Aqueduct withdrawal in Rondout Reservoir. Simulations were run varying the sinking rate of turbidity-causing particles from 0.2 m d^{-1}–0.7 m d^{-1} in order to examine the sensitivity of the turbidity predictions to plausible variations in particle sinking.

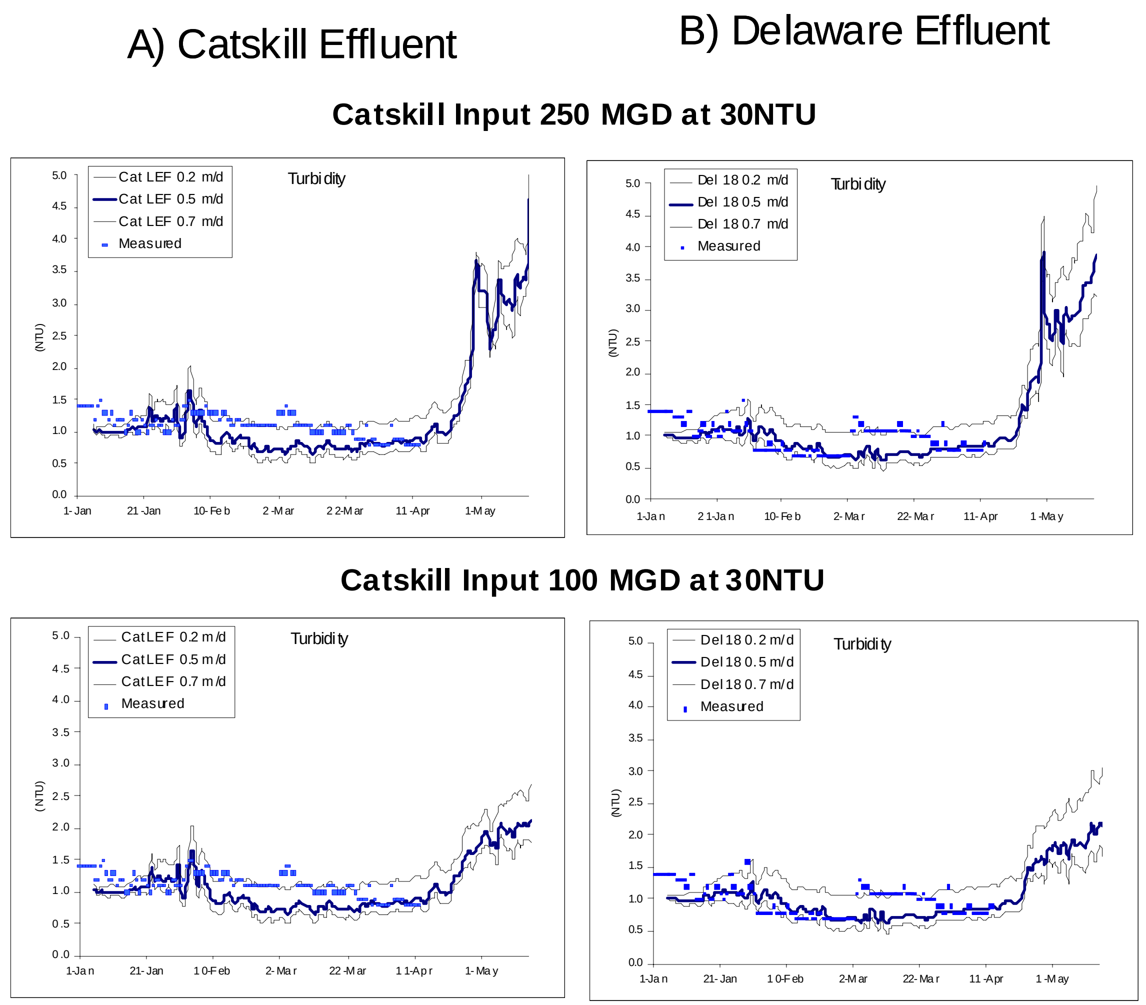

Figure 6.5 Simulated turbidity levels in the water withdrawn from Kensico Reservoir via A) the Catskill Aqueduct or B) the Delaware Aqueduct. Simulations based on three different settling rates (see insets) are shown as lines. Prior to the event, measured turbidity at the aqueduct effluents are shown as blue points. Projected turbidity levels starting on 19 April assume a constant 30 NTU input of Catskill System turbidity to Kensico at two possible flow rates.

Comparison of the simulated and measured Kensico effluent turbidity levels (Figure 6.5) show that the model was capable of predicting the pre-event turbidity levels within the margin of error related to uncertainty in particle sinking. Previous simulations showed that the model is capable of simulating increases in Kensico effluent turbidity in response to increased inputs of turbidity to the reservoir. However, in this case, prior to the actual event, there was little variation in either simulated or measured effluent turbidity levels.

Future turbidity projections suggested that under the worst case Catskill System turbidity level of 30 NTU, a reduction in the Catskill Aqueduct flow rate to 250 MGD would probably keep Kensico effluent turbidity below the 5 NTU limit, but that turbidity would be uncomfortably close to the regulatory limit. Greater reductions in Catskill System flow to 100 MGD or somewhat greater would, however, lead to relatively small and acceptable increases in Kensico effluent turbidity. In the period following these simulations Catskill Aqueduct flow was regulated between 100-150 MGD, and Kensico effluent turbidity levels remained well below the 5 NTU limit.

In the case of this event, where turbidity increases were not so extreme or long lasting and a greater degree of flexibility in operating the reservoir system was possible, use of alum treatment was not required. Rather, it was possible to mitigate the effects of elevated Catskill turbidity by cutting back on the Catskill System flow entering Kensico Reservoir. The use of models to examine the potential impacts of changing conditions and constraints on operating conditions in order to help optimize reservoir operations during this event was a powerful tool which helped DEP avoid the use of alum treatment.

7. Further Research

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

DEP extends its capabilities through grants and contracts. In the past, Safe Drinking Water Act (SDWA) grants (contracted to DEP through DEC) supported a number of DEP projects devoted to guiding watershed management. Through the end of 2007, these grants totaled approximately $3.7 million. Projects supported by the grants allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. DEP also enters into contracts to support its work, as discussed below.

7.2 What is the status of DEP projects supported through SDWA grants?

All of DEP's SDWA projects funded under Grants 5 and 6 were completed in 2007, and final reports submitted. DEP has no other SDWA grants outstanding at this time. A summary of the projects concluded in 2007 follows, along with citations to the project reports.

Kensico Stormwater BMP Efficiency Assessment

In 2007, DEP contracted with EA Engineering, P.C., and its affiliate EA Science and Technology, Inc., to assess DEP's Kensico Reservoir watershed stormwater BMP monitoring program and then, using data generated by this program, evaluate the efficiency of these BMPs in removing pollutants. The contract yielded two reports, *Kensico Stormwater BMP Monitoring Program Assessment Report* and *Evaluation of BMP Removal Efficiency—Kensico Reservoir Watershed* (EA Science and Technology 2007a, b). The reports concluded that there were no deficiencies in the sampling program, and that the BMPs produced a significant reduction in TSS, turbidity, and TP.

Modeling of Pathogen Fate and Transport in DEP Reservoirs

This project developed a particle tracking model for fate and transport of pathogens in the NYC water supply reservoirs, particularly pathogens present in low concentrations (DEP 2007c). A particle tracking model permits calculation of the statistical likelihood that a pathogen cell will reach a point of interest under specified environmental (weather, hydrology, reservoir operation) and loading conditions. The framework on which the particle tracking model was based was the two-dimensional surface water model CE-QUAL-W2, which supplied predictions of advective and diffusive transport and water temperature. Settling and inactivation rates for pathogens were also included in the model. When the model was applied in a dynamic simulation of pathogen fate and transport in Kensico for the period 2003-04, it was determined that, despite its lower average flow rate, the Catskill Aqueduct potentially has a greater influence on pathogen abundance in the withdrawal than the Delaware Aqueduct.

Characterization of Pathogen-Particle Associations in the Water Column and Their Impact on the Management of New York City Source Water Quality

This project studied the concentration and settling characteristics of particles, pathogens (*Giardia* and *Cryptosporidium*), and microbial indicators in Kensico Reservoir during base flow, storm, and intrastorm conditions, to determine these pathogens' potential for transport to aqueducts leaving the reservoir (DEP 2007d). The research found higher concentrations of particles, pathogens, and microbial indicators during the rising limb of a storm. For *Giardia*, greater settling occurred during the rising limb and decreased during later storm stages. No significant settling was observed for *Cryptosporidium*. The microbial indicators had various settling characteristics, but fecal coliform was the strongest indicator of *Cryptosporidium* and *Giardia* concentration and settling. Insights derived from this investigation will allow DEP to refine its models of pathogen transport and provided a valuable template for future research efforts pertaining to stream monitoring and reservoir modeling.

Genotyping of *Cryptosporidium* Oocysts from Wildlife Fecal Samples within the New York City Watershed

This is a project initially funded under SDWA Grant 4. Because the targeted number of samples could not be collected during the Grant 4 study sampling period, additional samples were collected in 2007, to complete the genotyping work. A total of 463 specimens from 34 species of wildlife and 51 samples of stream sediment were analyzed, using a polymerase chain (PCR)—restriction fragment length polymorphism method . Eighty-seven (18.8%) of the wildlife specimens were PCR positive. Altogether, 18 *Cryptosporidium* genotypes were found in wildlife samples, five of which were from previously unknown animals. Three new genotypes were found and the animal hosts for six genotypes were expanded. With the exception of the cervine (deer) genotype, most genotypes were found in a limited number of animal species. Six genotypes were found in seven positive sediment samples. Almost all of the genotypes found in the study pose little risk to public health. The study concluded, therefore, that while wildlife may contribute to *Cryptosporidium* contamination in water, it has no major public health significance. Nevertheless, the study recommended that watershed protection programs attempt to control these pathogen inputs, and that more attention be directed to pathogen monitoring in watersheds deemed protected or pristine (DEP 2007e).

Advancements of Croton System Reservoir Models: 2D Water Quality Models

This project developed a fully calibrated and verified 2D water quality model for the New Croton Reservoir, examining both vertical and longitudinal variations in water quality (DEP 2007f). The model also incorporates both pelagic and sediment-water exchange water quality algorithms. Special emphasis was placed on integrating the sediment-water nutrient exchange sub-model because sediment-water processes are known to be of particular importance in influencing the reservoir's water quality.

7.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 7.1. The primary types of contracts are: (1) Operation and Maintenance, (2) Monitoring, and (3) 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 7.1: DEP contracts (including SDWA grants) related to water quality monitoring and research

Contract Description	Contract Term
Operation and Maintenance	
Operation and Maintenance of DEP's Hydrological Monitoring Network (Stream Flow)	10/1/06–9/30/09
Operation and Maintenance of DEP's Hydrological Monitoring Network (Water Quality)	10/1/06–9/30/10
Waterfowl Management at Kensico Reservoir	8/1/07–3/31/10
SAS Software Contract	6/24/03–6/30/08
Monitoring	
Monitoring of NYC Reservoirs for Viruses	1/29/07–7/31/08
Monitoring of NYC Reservoirs for Zebra Mussels	8/1/07–7/31/08
Monitoring of NYC Residences for Lead and Copper	1/1/07–12/31/09
Organic Analysis Laboratory Contract	3/1/07–6/30/08
Bulk Chemical Analysis	8/1/05–7/31/08
Analysis of Stormwater at Beerston, Cannonsville Watershed	11/1/07–10/31/09
Research and Development	
Design of Controls for Zebra Mussels in NYC's Water Supply System	1/5/94–6/30/08
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–12/31/09
Pathogen Monitoring Stations Project in the Counties of Delaware, Ulster, Greene, Sullivan, and Westchester, New York	7/7/04–8/15/07
Croton System Model Development and Protech (partially funded by SDWA grant and partially funded by DEP)	11/15/05–11/14/08
Cryptosporidium Oocysts in Wildlife and Stream Sediments (partially funded by SDWA Grant 5)	3/1/06–8/31/07

Table 7.1: (Continued) DEP contracts (including SDWA grants) related to water quality monitoring and research

Contract Description	Contract Term
Occurrence and Partitioning of *Giardia* and *Cryptosporidium* within the Kensico Drainage Basin of the NYC Watershed (includes Modeling of Pathogen Fate and Transport in NYCDEP Reservoirs) (funded by SDWA Grant 5)	9/1/06–8/31/07
Advancements of Croton System Reservoir Models	11/26/06–11/26/07
Best Management Practices Efficiency Assessment Project	2/5/07–2/5/08

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

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Kensico			New Croton			East Ashokan Basin			Rondout		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		355	4.0- 22.1	10.8	326	3.7 - 23.7	10.5	118	2.7 - 23.9	10.5	188	2.1 - 20.6	11.0
pH (units)	6.5-8.5 [1]	333	6.2 - 7.6	7.0	300	6.6 - 8.7	7.5	118	6.4 - 7.9	7.2	158	5.9 - 8.2	7.0
Alkalinity (mg/L)		31	10.2 - 12.6	11.4	30	50.2 - 67.3	58.1	9	9.8 - 12.4	10.4	9	7.36 - 11.7	9.0
Conductivity		330	50 - 77	64	310	253 - 341	310	118	49 - 61	54	178	41 - 66	56
Hardness (mg/L) [2]		24	18 - 21	20	30	76 - 98	88	9	16 - 18	16	9	15 - 20	18
Color (Pt-Co units)	(15)	355	8 - 15	10	325	10 - 45	20	120	6 - 16	9	191	4 - 14	9
Turbidity (NTU)	(5) [3]	355	0.4 - 2.4	1.2	325	0.6 - 7.6	2.2	120	0.9 - 8.4	2.1	191	0.5 - 2	1.0
Secchi Disk Depth (m)		109	2.5 - 6	4.8	105	1.1 - 4.2	2.8	31	0.7 - 4.8	3.9	54	2.3 - 7.4	5.5
BIOLOGICAL													
Chlorophyll a (µg/L)	7 [4]	62	0.2 - 9.5	5.3	47	6.5 - 27.9	10.5	16	1.3 - 5.7	3.3	30	1.6 - 5.0	3.1
Total Phytoplankton (SAU)	2000 [4]	113	10 - 1200	340	104	110 - 3200	680	80	26 - 360	170	117	2.5 - 1000	160
CHEMICAL													
Dissolved Organic Carbon (mg/L)		196	1.2 - 1.9	1.5	148	2.2 - 3.4	2.8	48	1.2 - 1.7	1.5	112	1.1 - 1.8	1.4
Total Phosphorus (µg/L)	15 [4]	195	1.5 - 14	8	150	5 - 36	18	90	2.5 - 12	8	157	1.5 - 15.6	7
Total Nitrogen (mg/L)		194	0.26 - 0.49	0.38	150	0.18 - 0.73	0.49	42	0.26 - 0.52	0.42	80	0.33 - 0.54	0.43
Nitrate+Nitrite-N (mg/L)	10 [1]	195	0.19 - 0.41	0.30	150	0.01 - 0.53	0.24	48	0.08 - 0.68	0.33	112	0.25 - 0.51	0.36
Total Ammonia-N (mg/L)	2 [1]	195	0.01 - 0.04	0.01	150	0 - 0.28	0.03	42	0.01 - 0.04	0.01	108	0.01 - 0.03	0.01
Iron (mg/L)	0.3 [1]	7	0.02 - 0.08	0.05	121	0.01 - 0.25	0.06	8	0.06 - 0.62	0.14	8	0.02 - 0.72	0.04
Manganese (mg/L)	(0.05)	7	0.01 - 0.2	0.01	121	0.02 - 0.53	0.06	8	0.01 - 0.03	0.01	8	0.01 - 0.08	0.01
Lead (µg/L)	50 [1]	7	0.5 - 0.5	0.5	6	0.5 - 0.5	0.5	8	0.5 - 0.5	0.5	8	0.5 - 0.5	0.5
Copper (µg/l)	200 [1]	7	1.5 - 5.7	1.5	6	1.5 - 1.5	1.5	8	1.5 - 4.2	1.5	8	1.5 - 26.5	1.5
Calcium (mg/L)		24	5.1 - 6.0	5.6	30	19.3 - 24.6	22.4	9	4.8 - 5.5	5.0	9	4.4 - 5.9	5.2
Sodium (mg/L)		24	3.8 - 5.8	4.9	30	24.2 - 31.3	27.6	9	3.3 - 3.7	3.6	9	3.4 - 4.7	4.2
Chloride (mg/L)	250 [1]	24	5.7 - 9	7.7	20	43.3 - 58.8	50.2	48	4.9 - 5.7	5.2	9	4.5 - 6.9	6.2

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Amawalk			Bog Brook			Boyd Corners			Croton Falls		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		35	4.4 - 24.8	9.7	38	6.1 - 24.5	10.1	35	7.9 - 24.3	20.4	46	4.2 - 22.8	10.4
pH (units)	6.5-8.5 [1]	30	6.9 - 9.2	7.9	33	7.1 - 8.8	7.6	35	6.7 - 8.2	7.4	41	6.8 - 8.8	7.4
Alkalinity (mg/L)		9	64.1 - 77.8	70.1	11	63.8 - 72.3	66.4	2	20.3 - 24.7	22.5	6	39.9 - 61.6	43.1
Conductivity		35	374 - 424	389	38	274 - 304	290	35	133 - 197	164	46	206 - 391	303
Hardness (mg/L) [2]		9	87 - 107	105	9	83 - 92	89	4	31 - 49	41	6	59 - 83	61
Color (Pt-Co units)	(15)	35	10 - 45	20	40	1.2 - 50	19	20	15 - 28	20	40	10 - 40	20
Turbidity (NTU)	(5) [3]	35	1 - 4.3	2.5	40	0.8 - 6.8	2.3	20	1 - 4.6	1.4	40	1.1 - 6.35	2.0
Secchi Disk Depth (m)		15	2.1 - 4.4	2.7	15	2.6 - 6.5	4.1	17	2.2 - 4.7	3.8	13	2 - 5.6	3.3
BIOLOGICAL													
Chlorophyll a (µg/L)	7 [4]	12	3.9 - 26.2	8.9	16	2.5 - 16.4	5.3	11	4 - 25.4	6.2	12	6.6 - 15.9	9.6
Total Phytoplankton (SAU)	2000 [4]	3	520 - 3100	790	6	100 - 4400	1550	3	450 - 580	480	6	280 - 4500	785
CHEMICAL													
Dissolved Organic Carbon (mg/L)		34	3 - 4	3.4	38	2.8 - 3.9	3.4	18	2.6 - 3.4	3.1	40	2.1 - 3.4	2.7
Total Phosphorus (µg/L)	15 [4]	35	9 - 61	20	40	10 - 152	18	19	12 - 66	14	29	9 - 41	16
Total Nitrogen (mg/L)		34	0.22 - 0.8	0.43	34	0.19 - 0.72	0.27	18	0.14 - 0.3	0.20	40	0.15 - 1.2	0.45
Nitrate+Nitrite-N (mg/L)	10 [1]	10 [1]	35	0.01 - 0.38	0.09	40	0.01 - 0.07	0.01	20	0.01 - 0.16	0.01	40	0.01 - 0.97
Total Ammonia-N (mg/L)	2 [1]	2 [1]	35	0.01 - 0.52	0.01	40	0.01 - 0.4	0.01	20	0.01 - 0.03	0.01	40	0.01 - 0.3
Iron (mg/L)	0.3 [1]	0.3 [1]	3	0.02 - 0.14	0.09	2	0.05 - 0.06	0.06	2	0.05 - 0.1	0.08	4	0.03 - 0.12
Manganese (mg/L)	(0.05)	(0.05)	3	0.02 - 0.47	0.04	2	0.01 - 0.01	0.01	2	0.01 - 0.11	0.06	4	0.01 - 1.1
Lead (µg/L)	50 [1]	50 [1]	3	0.5 - 1.1	0.5	2	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	4	0.5 - 0.5
Copper (µg/l)	200 [1]	200 [1]	3	1.5 - 3.4	3.0	2	1.5 - 1.5	1.5	2	1.5 - 1.5	1.5	4	1.5 - 4.6
Calcium (mg/L)			9	21.2 - 26.3	25.5	9	20.5 - 23	22.1	4	7.5 - 11.9	9.9	6	15.1 - 21.1
Sodium (mg/L)			9	31.9 - 39	37.9	9	21.9 - 24.5	23.7	4	13.8 - 18.2	16.6	6	19.5 - 27.4
Chloride (mg/L)	250 [1]	250 [1]	6	68.2 - 70.6	68.8	6	44.1 - 45.5	44.8	4	23.3 - 29.2	27.8	3	33.9 - 44.1

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Cross River			Diverting			East Branch			Lake Gilead		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		46	4.8 - 25.9	9.1	4	10.5 - 12.9	11.7	42	6.1 - 23.0	16.6	25	4.7 - 23.4	5.3
pH (units)	6.5-8.5 [1]	40	6.7 - 8.8	7.3	4	7.6 - 7.7	7.7	37	7.0 - 9.0	7.5	15	6.6 - 9.1	7.1
Alkalinity (mg/L)		9	37.7 - 45.6	41.2	3	74.2 - 82	76.9	11	58.5 - 92.2	83.1	6	39.2 - 46.7	40.4
Conductivity		46	178 - 210	197	4	227 - 253	235	42	208 - 325	300	20	184 - 213	192
Hardness (mg/L) [2]		9	53 - 65	63	3	100 - 108	103	9	78 - 123	107	9	54 - 62	58
Color (Pt-Co units)	(15)	46	10 - 60	20	7	27 - 35	30	42	20 - 45	25	9	10 - 25	15
Turbidity (NTU)	(5) [3]	46	0.9 - 11	2.1	7	2.3 - 5.9	4.4	42	1.3 - 7	3.7	9	1.3 - 3.2	1.9
Secchi Disk Depth (m)		16	2.8 - 5.4	4.0	2	1.8 - 2.1	2.0	16	1.8 - 3.9	2.2	6	3.3 - 4.8	4.3
BIOLOGICAL													
Chlorophyll a (µg/L)	7 [4]	15	3.6 - 9	5.4	3	7.7 - 13.7	9.1	16	4.4 - 41.3	13.8	3	3 - 10.9	4.8
Total Phytoplankton (SAU)	2000 [4]	4	430 - 1900	755	1	870 - 870	870	6	440 - 2600	1025	1	3000 - 3000	3000
CHEMICAL													
Dissolved Organic Carbon (mg/L)		43	2.8 - 3.3	3.1	7	3.2 - 4.1	3.3	37	2.6 - 4.7	3.8	10	2.5 - 3.4	3.0
Total Phosphorus (µg/L)	15 [4]	40	Oct-36	17	7	24 - 31	27	42	15 - 33	23	10	14 - 230	25
Total Nitrogen (mg/L)		43	0.17 - 0.65	0.26	7	0.3 - 0.56	0.37	34	0.21 - 0.49	0.36	9	0.24 - 0.84	0.32
Nitrate+Nitrite-N (mg/L)	10 [1]	46	0.01 - 0.3	0.06	7	0.01 - 0.22	0.18	42	0.01 - 0.22	0.03	10	0.01 - 0.34	0.01
Total Ammonia-N (mg/L)	2 [1]	46	0.01 - 0.26	0.01	7	0.01 - 0.17	0.01	42	0.01 - 0.15	0.02	10	0.01 - 0.64	0.01
Iron (mg/L)	0.3 [1]	3	0.02 - 1.24	0.09	1	0.29 - 0.29	0.29	2	0.06 - 0.25	0.16	3	0.03 - 0.26	0.04
Manganese (mg/L)	(0.05)	3	0.01 - 1.66	0.02	1	0.03 - 0.03	0.03	2	0.01 - 0.02	0.02	3	0.02 - 2.02	0.02
Lead (µg/L)	50 [1]	3	0.5 - 0.5	0.5	1	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5
Copper (µg/l)	200 [1]	3	1.5 - 5.1	1.5	1	1.5 - 1.5	1.5	2	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5
Calcium (mg/L)		9	14.2 - 17.5	16.9	3	25.6 - 27.5	26.5	9	19.3 - 30.3	26.8	9	13.4 - 15.8	14.6
Sodium (mg/L)		9	13.3 - 15.8	15.5	3	24.5 - 25.1	24.6	9	17.3 - 23.2	21.8	9	13.8 - 15.7	15.0
Chloride (mg/L)	250 [1]	6	27.9 - 31	29.2	2	44.8 - 45.3	45.1	6	34.5 - 41	37.6	6	28 - 29.3	28.4

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		20	5.1 - 24.1	6.2	25	8.1 - 25.2	17.8	70	5.4 - 23.8	17.5	60	5.3 - 24.9	9.9
pH (units)	6.5-8.5 [1]	15	6.1 - 8.7	7.5	15	7.1 - 9.1	7.6	70	7.2 - 8.7	7.8	55	6.9 - 9.1	7.5
Alkalinity (mg/L)		3	64.3 - 74.4	65.3	6	45.3 - 49.8	45.9	6	56.7 - 70.1	64.9	9	46.2 - 61.3	52.6
Conductivity		15	363 - 411	376	20	255 - 294	268	70	279 - 374	315	55	353 - 413	372
Hardness (mg/L) [2]		6	94 - 100	96	6	67 - 76	69	6	87 - 105	97	9	73 - 85	78
Color (Pt-Co units)	(15)	6	8 - 35	10	7	20 - 35	20	69	17 - 40	25	55	15 - 70	22
Turbidity (NTU)	(5) [3]	6	0.8 - 5.6	1.0	7	1.1 - 10	4.3	69	1.8 - 8.3	3.7	55	1.1 - 9.4	2.6
Secchi Disk Depth (m)		4	4.2 - 7.2	6.0	12	1.5 - 5.7	2.2	39	1.3 - 3.7	2.3	21	2.1 - 3.5	2.7
BIOLOGICAL													
Chlorophyll a (µg/L)	7 [4]	2	1.7 - 5.6	3.7	3	7.3 - 45.4	17.3	39	2.2 - 47.2	15.4	20	2.3 - 62.8	16.3
Total Phytoplankton (SAU)	2000 [4]	0	-		1	570 - 570	570	22	35 - 12000	2050	8	150 - 2200	1220
CHEMICAL													
Dissolved Organic Carbon (mg/L)		5	2.9 - 3.1	3.0	8	3.5 - 4.8	4.3	70	0.1 - 3.7	3.3	55	1.2 - 3.9	3.0
Total Phosphorus (µg/L)	15 [4]	5	12 - 271	14	8	17 - 78	20	70	15 - 34	25	55	11 - 151	20
Total Nitrogen (mg/L)		5	0.24 - 0.96	0.27	8	0.25 - 0.62	0.34	63	0.24 - 0.78	0.44	55	0.2 - 0.83	0.38
Nitrate+Nitrite-N (mg/L)	10 [1]	5	0.01 - 0.01	0.01	8	0.01 - 0.12	0.02	70	0 - 0.47	0.23	55	0 - 0.34	0.04
Total Ammonia-N (mg/L)	2 [1]	5	0.01 - 0.64	0.01	8	0.01 - 0.3	0.09	70	0.01 - 0.23	0.02	55	0.01 - 0.71	0.03
Iron (mg/L)	0.3 [1]	3	0.03 - 0.99	0.04	2	0.05 - 0.06	0.06	3	0.03 - 0.47	0.14	3	0.06 - 1.83	0.11
Manganese (mg/L)	(0.05)	3	0.01 - 1.09	0.02	2	0.01 - 0.09	0.05	3	0.03 - 0.54	0.04	3	0.04 - 1.19	0.06
Lead (µg/L)	50 [1]	3	0.5 - 0.5	0.5	2	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5	3	0.5 - 0.5	0.5
Copper (µg/l)	200 [1]	3	1.5 - 1.5	1.5	2	1.5 - 3.6	2.6	3	1.5 - 1.5	1.5	3	1.5 - 1.5	1.5
Calcium (mg/L)		6	23.6 - 25.1	23.9	6	15.8 - 18.5	17.0	6	22.1 - 26.9	24.4	9	18.3 - 21.2	19.5
Sodium (mg/L)		6	37.6 - 39.1	38.4	6	22.1 - 23.9	22.8	6	26.3 - 29.7	27.7	9	41.5 - 45.6	44.0
Chloride (mg/L)	250 [1]	2	71.4 - 73.9	72.7	6	44.7 - 46.2	45.6	4	48.6 - 56.3	54.8	6	73.1 - 79.8	75.0

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Titicus			West Branch			West Ashokan Basin			Pepacton		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		40	4.6 - 25.9	10.3	137	4.6 - 18.7	13.4	193	2.9 - 21.7	9.4	236	3.7 - 22.8	9.9
pH (units)	6.5-8.5 [1]	35	6.9 - 9.1	7.8	137	6.3 - 7.8	7.2	193	6.2 - 7.7	7.1	168	6.1 - 8.9	7.2
Alkalinity (mg/L)		9	58.3 - 68.6	65.0	9	8.5 - 13.1	10.9	12	6.8 - 13.1	8.9	21	9.06 - 13.8	11.0
Conductivity		40	216 - 263	245	137	53 - 128	68	193	40 - 67	52	218	50 - 66	55
Hardness (mg/L) [2]		9	75 - 92	87	9	16 - 22	20	12	14 - 19	16	21	18 - 22	20
Color (Pt-Co units)	(15)	38	10 - 50	20	135	10 - 23	11	187	7 - 18	12	187	3 - 15	12
Turbidity (NTU)	(5) [3]	38	1.3 - 11	2.4	135	0.7 - 3.2	1.4	195	1.4 - 19	5.2	229	0.6 - 11	2.0
Secchi Disk Depth (m)		16	2.7 - 5.7	3.5	58	2.2 - 5.4	4.3	48	0.6 - 3.9	2.1	75	1.2 - 5.2	3.7
BIOLOGICAL													
Chlorophyll a (µg/L)	7 [4]	14	2.5 - 18.7	8.5	51	2.1 - 10.5	6.3	24	1 - 4.8	3.0	34	1.4 - 7.4	3.8
Total Phytoplankton (SAU)	2000 [4]	4	250 - 1800	535	57	100 - 2200	560	100	10 - 475	140	82	2.5 - 1300	210
CHEMICAL													
Dissolved Organic Carbon (mg/L)		38	2.8 - 3.5	3.3	110	1.3 - 2.4	1.6	77	1.1 - 1.9	1.3	114	0.98 - 1.7	1.3
Total Phosphorus (µg/L)	15 [4]	38	11 - 85	21	120	1.5 - 22.5	10	145	2.5 - 19	9	239	3 - 27.3	10
Total Nitrogen (mg/L)		38	0.19 - 0.66	0.26	119	0.15 - 0.49	0.37	77	0.35 - 0.78	0.70	115	0.25 - 0.62	0.51
Nitrate+Nitrite-N (mg/L)	10 [1]	38	0.01 - 0.31	0.02	111	0.01 - 0.41	0.30	77	0.24 - 0.73	0.64	114	0.11 - 0.59	0.44
Total Ammonia-N (mg/L)	2 [1]	38	0.01 - 0.48	0.01	120	0.01 - 0.03	0.01	67	0.01 - 0.02	0.01	114	0.01 - 0.03	0.01
Iron (mg/L)	0.3 [1]	3	0.02 - 0.31	0.07	6	0.03 - 0.23	0.06	7	0.07 - 2.33	0.51	8	0.04 - 1.33	0.12
Manganese (mg/L)	(0.05)	3	0.01 - 0.35	0.02	6	0.01 - 0.05	0.03	7	0.01 - 0.09	0.03	8	0.01 - 0.1	0.02
Lead (µg/L)	50 [1]	3	0.5 - 0.5	0.5	6	0.5 - 0.5	0.5	7	0.5 - 1.6	0.5	8	0.5 - 1.3	0.5
Copper (µg/l)	200 [1]	3	1.5 - 5.1	3.8	6	1.5 - 1.5	1.5	7	1.5 - 1.5	1.5	8	1.5 - 5.6	1.5
Calcium (mg/L)		9	19.1 - 23.4	22.3	9	4.4 - 6.1	5.5	12	4.3 - 5.9	5.0	21	5.4 - 6.5	5.8
Sodium (mg/L)		9	14.4 - 17.1	15.9	9	4.2 - 5.3	4.7	12	3.1 - 3.9	3.3	21	3.3 - 4.0	3.5
Chloride (mg/L)	250 [1]	6	29.3 - 32	30.8	6	7 - 8.1	7.4	77	4.9 - 6.6	5.3	14	4.7 - 6.5	5.7

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2007.

		Neversink			Schoharie			Cannonsville		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL										
Temperature (°C)		171	3.6 - 22.5	8.3	157	1.3 - 22.9	10.8	217	2.1 - 23.5	11.7
pH (units)	6.5-8.5 [1]	148	5.3 - 7.3	6.4	157	6.0 - 7.7	7.2	173	6.4 - 8.9	7.2
Alkalinity (mg/L)		9	1.8 - 3.3	2.7	9	6.5 - 16.2	10.8	18	11.3 - 22.9	16.9
Conductivity		171	22.7 - 30.9	27	157	38 - 91	68	205	70 - 108	85
Hardness (mg/L) [2]		9	8.6 - 9.2	9	9	12 - 28	18	18	22 - 35	27
Color (Pt-Co units)	(15)	162	4 - 16	10	98	7 - 23	16	194	3 - 22	12
Turbidity (NTU)	(5) [3]	171	0.5 - 2.4	1.1	158	1.3 - 36	5.1	203	0.5 - 13	3.1
Secchi Disk Depth (m)		53	3.3 - 6	4.6	51	0.4 - 4	2.4	75	1.3 - 8	3.2
BIOLOGICAL										
Chlorophyll a (µg/L)	7 [4]	39	0.45 - 9.8	4.2	35	0.2 - 8.7	2.9	34	0.2 - 19.0	5.5
Total Phytoplankton (SAU)	2000 [4]	81	2.5 - 420	77	64	2.5 - 790	68	89	2.5 - 1200	200
CHEMICAL										
Dissolved Organic Carbon (mg/L)		101	1.1 - 2.2	1.5	82	1.5 - 2.4	1.9	102	1.2 - 1.9	1.5
Total Phosphorus (µg/L)	15 [4]	169	1.5 - 9.4	6	144	2.5 - 31	10	217	4.3 - 38.9	16
Total Nitrogen (mg/L)		83	0.2 - 0.46	0.40	65	0.2 - 0.7	0.48	103	0.31 - 0.8	0.60
Nitrate+Nitrite-N (mg/L)	10 [1]	113	0.11 - 0.43	0.34	85	0.07 - 0.65	0.31	103	0.03 - 0.78	0.53
Total Ammonia-N (mg/L)	2 [1]	113	0.01 - 0.06	0.01	73	0.01 - 0.03	0.01	103	0.01 - 0.05	0.01
Iron (mg/L)	0.3 [1]	8	0.03 - 0.13	0.09	4	0.16 - 0.33	0.26	8	0.03 - 0.28	0.10
Manganese (mg/L)	(0.05)	8	0.01 - 0.03	0.02	4	0.01 - 0.11	0.01	8	0 - 0.56	0.03
Lead (µg/L)	50 [1]	8	0.5 - 0.5	0.5	4	0.5 - 0.5	0.5	8	0.5 - 2.4	0.5
Copper (µg/l)	200 [1]	8	1.5 - 38.5	1.5	4	1.5 - 5.3	1.5	8	1.5 - 58.8	11.5
Calcium (mg/L)		9	2.4 - 2.6	2.5	9	3.9 - 7.0	5.5	18	6.2 - 10	7.7
Sodium (mg/L)		9	1.6 - 2.0	1.7	9	3.3 - 5.9	4.7	18	5.7 - 9.4	7.4
Chloride (mg/L)	250 [1]	9	2.6 - 3.8	2.8	85	5.4 - 9.7	7.7	18	8.8 - 14.5	11.2

Notes for Appendix A:

Footnotes:

1 = Numeric water quality standards, from 6NYCRR, Part 703.

2 = Hardness calculated as follows:

$$Hardness=2.497[Ca^{+2}] + 4.118[Mg^{+2}]$$

3 = Narrative water quality standards.

4 = NYCDEP target values are listed for chlorophyll *a*, total phosphorus and total phytoplankton. The total phosphorus target value of 15 µg L^{-1} applies to source water reservoirs only and has been adopted by NYSDEC in the TMDL Program.

The turbidity, color, and manganese standards in parentheses are applicable only to key-point 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

Data Analysis Considerations:

Reservoirs are sampled at least monthly from April to November, except for the controlled lakes Gleneida, Kirk, and Gilead, which are only sampled 3 times per year. Some reservoirs (e.g., Croton Falls and Diverting) were sampled less than monthly because of limited access due to dam rehabilitation work. The 2007 data were provisional at the time this report was written.

For most parameters, the data for each reservoir represent a statistical summary of all samples taken at the sites and depths listed in Section 3.3, Reservoir Status, of the Integrated Monitoring Report (DEP 2003).

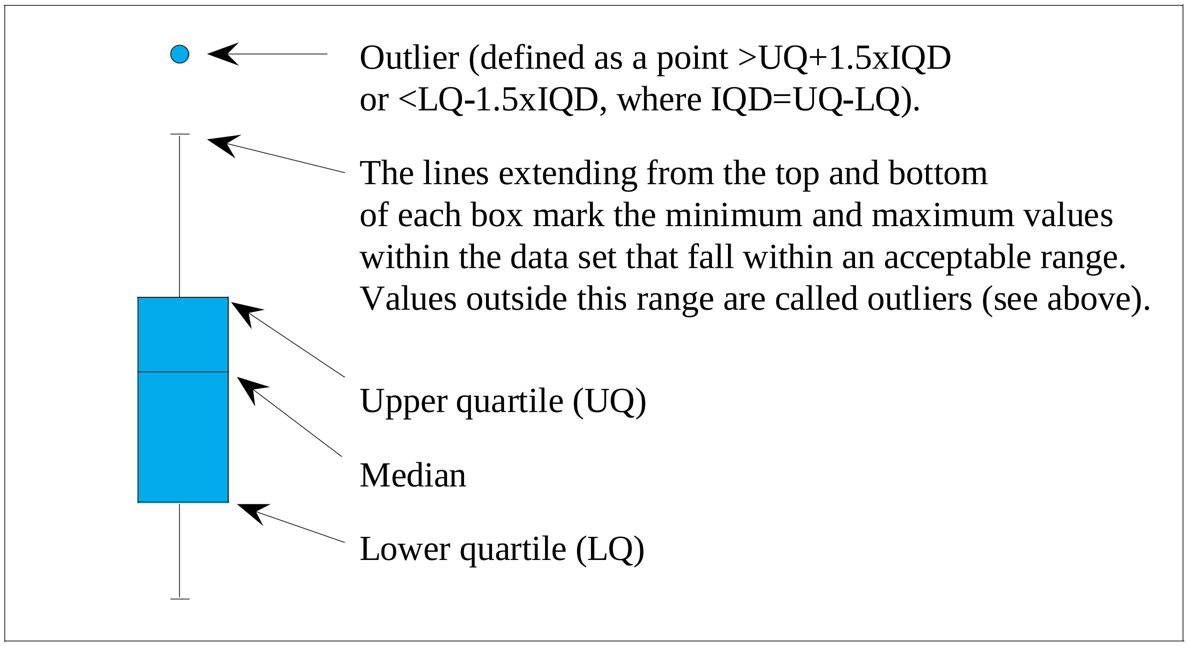
Chlorophyll *a* results are from surface samples collected at a 3-meter depth from April –November. Note that this differs from the trophic status box plots presented in Chapter 3, which only consider photic samples collected during the growing season (May–October).

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.

Analytical Methods:

In general all analytical methods are taken from Standard Methods. Details are available on request.

Appendix B Key to Box Plots



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 (DEP 1997).

The list of phosphorus-restricted basins is updated annually. The data utilized in the analysis is from the routine limnological monitoring of the reservoirs. All reservoir samples taken during the growing season, which is defined as May 1 through October 31, are used. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit. The detection limit for DEP measurements of total phosphorus is assessed each year by the DEP laboratories, and typically ranges between 2–5 $\mu g\ L^{-1}$. Phosphorus concentration data for the reservoirs approaches a lognormal distribution; therefore, the geometric mean is used to characterize the annual phosphorus concentrations. Appendix Table C1 provides the annual geometric mean for the past six years.

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

Appendix Table C.1. Geometric Mean Total Phosphorus Data utilized in the Phosphorus-Restricted Assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit.

Reservoir Basin	2002 $\mu g\ L^{-1}$	2003 $\mu g\ L^{-1}$	2004 $\mu g\ L^{-1}$	2005 $\mu g\ L^{-1}$	2006 $\mu g\ L^{-1}$	2007 $\mu g\ L^{-1}$
Delaware System						
Cannonsville Reservoir	17.9	15.4	15.1	19.6	20.5	14.0
Pepacton Reservoir	10.4	9.1	9.2	8.7	10.8	9.7
Neversink Reservoir	4.7	5.2	5.0	7.3	7.3	4.7
Rondout Reservoir	8.8	6.8	8.6	7.8	8.6	7.1
Catskill System						
Schoharie Reservoir	11.7	7.5	13.3	20.6	17.4	9.7
Ashokan-West Basin	9.6	6.1	9.3	26.0	11.2	8.1
Ashokan-East Basin	12.4	7.0	10	11.0	9.9	7.3
Croton System						
Amawalk Reservoir	22.2	19.6	26.5	24.0	24.5	20.2
Bog Brook Reservoir	*	16.9	26.8	18.6	18.7	24.0
Boyd Corners Reservoir	15.9	12.4	13.8	*	17.4	15.6
Cross River Reservoir	20.3	17.9	20.2	18.7	18.6	17.8
Croton Falls Reservoir	24.1	20.4	18.1	*	19.2	*
Diverting Reservoir	41.7	28.8	28.3	*	*	*
East Branch Reservoir	*	26.5	44.2	28.3	28.4	23.0
Middle Branch Reservoir	31.2	23.7	*	31.5	24.2	25.0
Muscoot Reservoir	33.9	29.5	26.0	26.8	27.9	25.7
Titicus Reservoir	27.3	27.3	25.4	24.6	29.6	21.6
West Branch Reservoir	12.1	10.2	11.5	14.8	10.3	9.6
Lake Gleneida	*	22.8	*	*	24.2	*

Appendix Table C.1. (Continued) 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	2002 μ**g** L^{-1}	2003 μ**g** L^{-1}	2004 μ**g** L^{-1}	2005 μ**g** L^{-1}	2006 μ**g** L^{-1}	2007 μ**g** L^{-1}
Lake Gilead	*	28.5	21.8	*	30.5	33.6
Kirk Lake	*	30.8	*	*	29.7	28.6
Source Water						
Kensico Reservoir	8.4	7.6	8.8	9.7	7.6	7.0
New Croton Reservoir	25.0	19.5	22.4	18.2	18.1	17.7

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

The hellgrammite *Corydalus* sp., a common inhabitant of Catskill streams.”