New York City
Department of Environmental Protection
Bureau of Water Supply

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Environmental Protection
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2008 Watershed Water Quality Annual Report

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Acknowledgements

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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 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 and Chapter 5. 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 and Mr. Christian Pace. 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 sections describing model 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. Other contributors included: Tracy Lawrence, Andrew Bader, Christopher Nadareski, David Quentin, Ray Homolac, Michael Usai, Deborah Layton, Thomas Baudanza, Michael Meyer, Thomas Stalter, Eve Fox, Edward Blouin, Marilyn Shanahan, David Tobias, Terry Spies, Carla Paltridge, Sharon Neuman, Donald Kent, David Lounsbury, Kelly Seelbach, and Yucel Tokuz.

This report is intended to provide an accurate description of the scientific work conducted in 2008 to manage water quality for NYC, and at the same time to be engaging for a wide audience, from regulatory agencies to the general public. Its production 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 2008, and compliance with regulatory standards or guidelines during this period. It is complementary to another report titled "New York City 2008 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 for management of the water supply. 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).

Visit "The Future Beneath Us: 8 Great Projects Under New York"

Rain Barrel Giveaway Program

Figure 1.1 DEP website.

1.2 What constitutes the New York City water supply system?

Figure 1.2 New York City water supply watershed.

The New York City water supply system (Figure 1.2) supplies drinking water to almost half the population of the State of New York, which includes over eight million people in New York City and one million people in upstate counties, plus millions of commuters and tourists. New York City's Catskill-Delaware System is one of the largest unfiltered surface water supplies in the world. (The Croton System, which can supply on average 10% of the City's demand, is expected to be filtered by 2012.) The water is supplied from a network of 19 reservoirs and three controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system is approximately 5,100 square kilometers (1,972 square miles), extending over 200 kilometers (125 miles) north and west of New York City.

1.3 What are the objectives of water quality monitoring and how are the sampling programs organized?

Primary Objectives and Design of the Monitoring Program

In order to ensure high quality drinking water, DEP conducts extensive water quality monitoring that encompasses all areas of the watershed, including sites at aqueducts (keypoints), streams, and reservoirs. The watershed monitoring program meets the sampling needs for regulatory compliance requirements and also forms the basis for the DEP's ongoing assessment of watershed conditions, changes in water quality, and ultimately for developing any modifications to the policies, strategies, and management of the watershed protection programs.

The overall goals of DEP are documented in the Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2008a), which establishes an objective-based water quality monitoring network. This provides scientifically defensible information regarding the understanding, protection, and management of the New York City water supply. The objectives of this monitoring plan have been defined by the requirements of those who ultimately require the information, including DEP program administrators, regulators, and other external agencies. As such, monitoring requirements were derived from legally binding mandates, stakeholder agreements, operations, and watershed management information needs. The plan covers four major areas that require ongoing attention: Compliance, Filtration Avoidance Determination (FAD) Program Evaluation, Modeling Support, and Surveillance Monitoring, with many specific objectives within these major areas. These objectives are described below.

Monitoring design must consider several elements, including choice of sites, analytes, analytical methodology and detection limits, and sampling frequency. Statistical features of the water quality database were used to guide the sampling design. For example, analyses of past data revealed that some sites were not significantly different from others, indicating that they could be adequately represented by similar sites. Sampling frequencies were based approximately on the rates of processes governing variability in water quality data. This statistical screening of differences between sites and collection times was used to streamline the monitoring site plans and to determine appropriate collection frequencies.

Compliance Sampling

The objectives of this sampling are focused on meeting the regulatory compliance monitoring requirements for the New York City watershed. This includes the requirements of the Surface Water Treatment Rule (SWTR) and its subsequent extensions, as well as the New York City Watershed Rules and Regulations (WR&R) (DEP 2002a), the Croton Consent Decree (CCD), Administrative Orders, and State Pollution Discharge Elimination System (SPDES) permits. The sampling sites, analytes, and frequencies are defined in each objective according to each specific rule or regulation and are driven by the need of the water supply as a public utility to comply with all regulations. These include regulations issued by the United States Environmental Protection Agency (USEPA), New York State Department of Health (NYSDOH), and DEP.

Filtration Avoidance and Watershed Protection Program Evaluation

New York City's water supply is one of the few large water supplies in the country that qualifies for Filtration Avoidance, based on both objective water quality criteria and subjective watershed protection requirements. USEPA has specified many requirements in the 2007 FAD that must be met to protect public health. These objectives form the basis for the City's ongoing assessment of watershed conditions, changes in water quality, and ultimately any modifications to the strategies, management, and policies of the long-term watershed protection program (DEP 2006a). As watershed protection programs develop and analytical techniques for key parameters change, it is necessary to reassess the monitoring program to ensure that it continues to support DEP's watershed management program. The periodic reassessment of the City's monitoring program is achieved by critical review and revision of the monitoring plan approximately every five years. The City also conducts a periodic assessment of the effectiveness of the watershed protection program. DEP's water quality monitoring data are essential to evaluate watershed programs. Program effects on water quality are reported in the Watershed Protection Summary and Assessment reports, also produced approximately every five years.

The 2007 FAD also requires that DEP's watershed-wide monitoring program meets the needs of the Long-Term Watershed Protection Program (DEP 2006b). The goals of this program are to:

- Provide an up-to-date, objective-based monitoring plan for the routine watershed water quality monitoring programs, including aqueducts, streams, reservoirs, and pathogens.
- Provide routine water quality results for aqueduct, stream, reservoir, and pathogen programs to assess compliance, provide comparisons with established benchmarks, and describe ongoing research activities.
- Provide mid-term results from routine watershed (e.g., stream and WWTP) pathogen monitoring.
- Use water quality data to evaluate the source and fate of pollutants, and the effectiveness of watershed protection efforts at controlling pollutants.
- Provide a comprehensive evaluation of watershed water quality status and trends to support assessment of the effectiveness of watershed protection programs.

These goals are met by targeting specific watershed protection programs and examining overall status and trends of water quality. Water quality represents the cumulative effects of land use and DEP's watershed protection and remediation programs. The ultimate goal of the watershed protection programs is to maintain the status of the City's water supply, as one of the few large unfiltered systems in the nation, far into the future.

Water Quality Modeling Data Requirements

Modeling data are used to meet the long-term goals for water supply policy and protection and to provide guidance for short-term operational strategies when unusual water quality events occur. The modeling goals of FAD projects include: implementation of watershed and reservoir model improvements based on ongoing data analyses and research results; ongoing testing of DEP's watershed and reservoir models; updating of data necessary for models, including land use, watershed program implementation data, and time series of meteorological data, stream flow and water chemistry; development of data analysis tools supporting modeling projects; and applications of DEP models to support watershed management, reservoir operations, climate change analysis and long-term planning, as identified in DEP's Climate Change Task Force Action Plan (DEP 2008b).

There are three types of data needed to generate models: stream, reservoir and aqueduct, and meteorological. Stream monitoring includes flow monitoring and targeted water quality sampling to support watershed and reservoir model development, testing, and applications. Reservoir monitoring provides flow and reservoir operations data to support reservoir water balance calculations. The water balance and reservoir water quality data are necessary model inputs, and are required to continue to test, apply, and further develop DEP's one and two dimensional modeling tools. The meteorological data collection effort provides critical input necessary to meet both watershed and reservoir modeling goals.

Water Supply Surveillance

The surveillance monitoring plan contains several objectives that provide information to guide the operation of the water supply system, other objectives to help track the status and trends of constituents and biota in the system, and specific objectives that include aqueduct monitoring for management and operational decisions. The aqueduct network of sampling points consists of key locations along the aqueducts, developed to track the overall quality of water as it flows through the system. Data from these key aqueduct locations are supplemented by reservoir water quality data. Another surveillance objective relates to developing a baseline understanding of potential contaminants that include trace metals, volatile organic compounds, and pesticides, while another summarizes how DEP monitors for the presence of zebra mussels in the system, a surveillance activity meant to trigger actions to protect the infrastructure from becoming clogged by these mussels. The remaining objectives pertain to recent water quality status and long-term trends for reservoirs, streams, and benthic macroinvertebrates in the Croton System. It is important to track the water quality of the reservoirs to be aware of developing problems and to pursue appropriate actions. Together, these objectives allow DEP to maintain an awareness of water quality for the purpose of managing the supply to provide the highest quality drinking water possible.

1.4 What types of monitoring networks are used to provide coverage of such a large watershed?

DEP's watershed monitoring networks cover the entire watershed and include meteorological stations, snow surveys, stream sites, reservoir sites, aqueducts, and wastewater treatment plants. Each network provides data that are used to characterize "state variables" (quantities), as well as their transformation rates, which are important components of the water supply's hydrology and water quality. Hydrological flow is the essential underlying element of water quality phenomena and water quality models are based on the hydrodynamics of the system. The interplay of water flow rates and physical, chemical, and biological rates determine water quality outcomes. These outcomes can only be estimated through water quality modeling. Therefore, it is essential to know the basic hydrology of the watershed in order to anticipate water quality changes for proactive management of the water supply.

Meteorological stations are located throughout the watershed. There are 20 sites west of the Hudson River and five sites east of the Hudson. This network was designed to provide the best data characterization of the conditions throughout the watershed in order to allow extrapolation and estimation of total precipitation entering the system. Orographic effects (such as greater precipitation at higher elevation on the windward side of mountains) were considered during site selection, so different site elevations were selected to represent the full range of conditions, i.e., from the mountain peaks in the Catskills to the lower elevations of the Croton System. Sites were also located on the reservoirs in order to characterize the temperature, wind, and solar radiation (including photosynthetically active radiation) needed for model input.

During the winter, snow surveys are periodically conducted to estimate how much water is stored on the watershed as snow and ice. These estimates are important in anticipating spring runoff and the impacts of rain-on-snow events, which may result in unusually large influxes of water to the reservoirs. Snow survey results also are used to determine reservoir release rates in accordance with the Flexible Flow Management Plan for DEP's Delaware System reservoirs. Snow is an important part of the hydrological cycle and has an impact on stream and reservoir water temperatures throughout the spring.

Stream sampling sites are presented in Figures 1.3, 1.4, and 1.5. They were established as water quality monitoring sites in order to meet several objectives including: assessing the status and trends of stream water quality, monitoring and pinpointing various potential sources of pollution, evaluating the effectiveness of watershed programs, and providing calibration and verification data fro water quality models. They also allow quantification of pollutants entering the system so that appropriate measures can be taken to minimize impairment of the drinking water. A typical stream site being sampled for pathogens is shown in Figure 1.6. Water quality of the streams and tributaries provides essential input for reservoir models that guide the management of the NYC reservoirs. A companion network to DEP's water quality stream sites is the network of US Geological Survey (USGS) stream gages. Most of the gage sites are operated and maintained by the USGS on behalf of DEP and provide important flow data. These data are available on the internet and are used widely by a variety of stakeholders. They are used by DEP to track the current condition of the system's stream flows, guide operational decisions, including meeting mandated flow targets, and also during droughts and floods. Stream flow data are particularly important to modeling, as they can provide key inputs to reservoir models that are used to evaluate the consequences of different operating strategies. They also provide data to calibrate and verify watershed models, which can estimate loads of water and nutrients to the reservoirs.

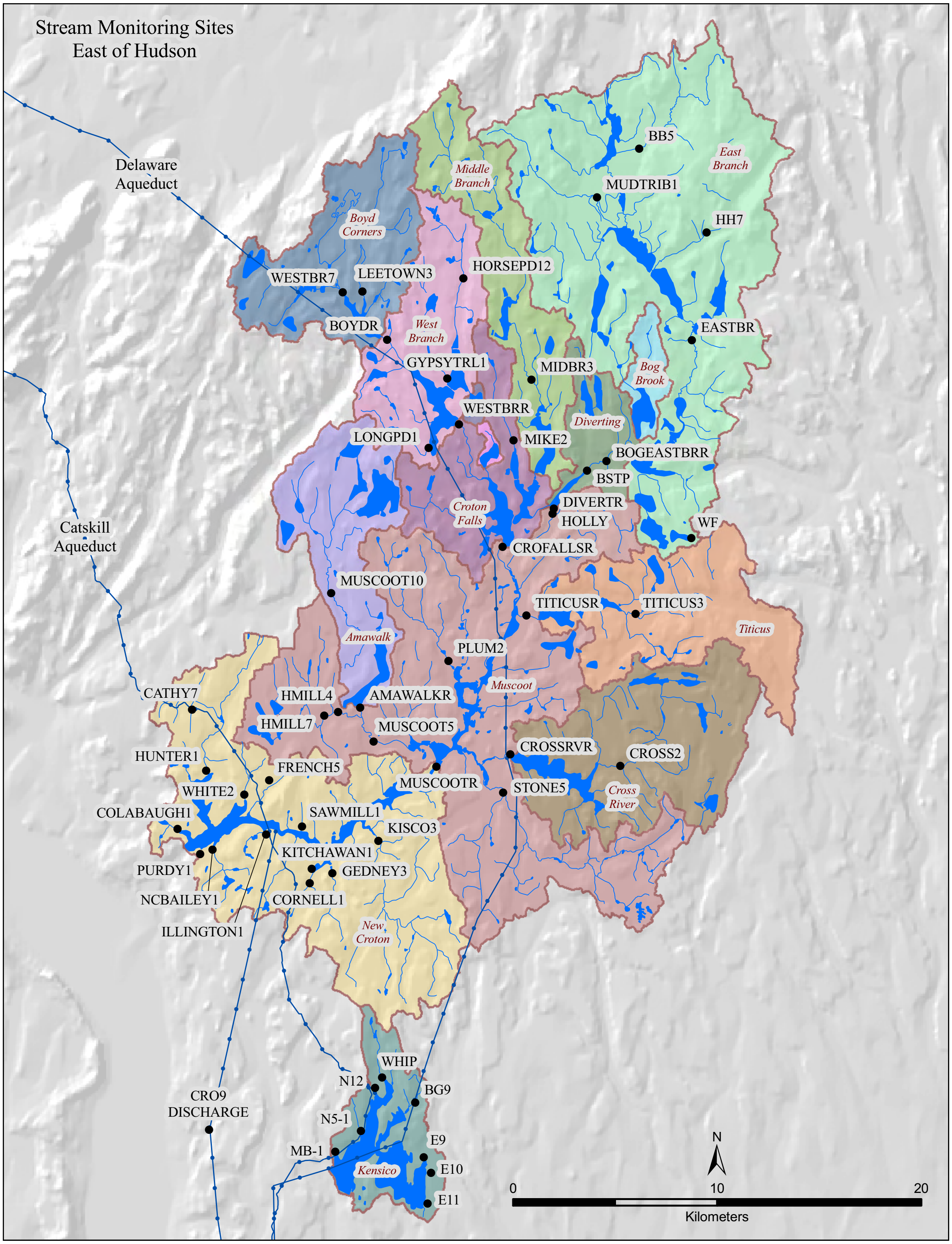


Figure 1.3 Stream sampling sites east of the Hudson River.

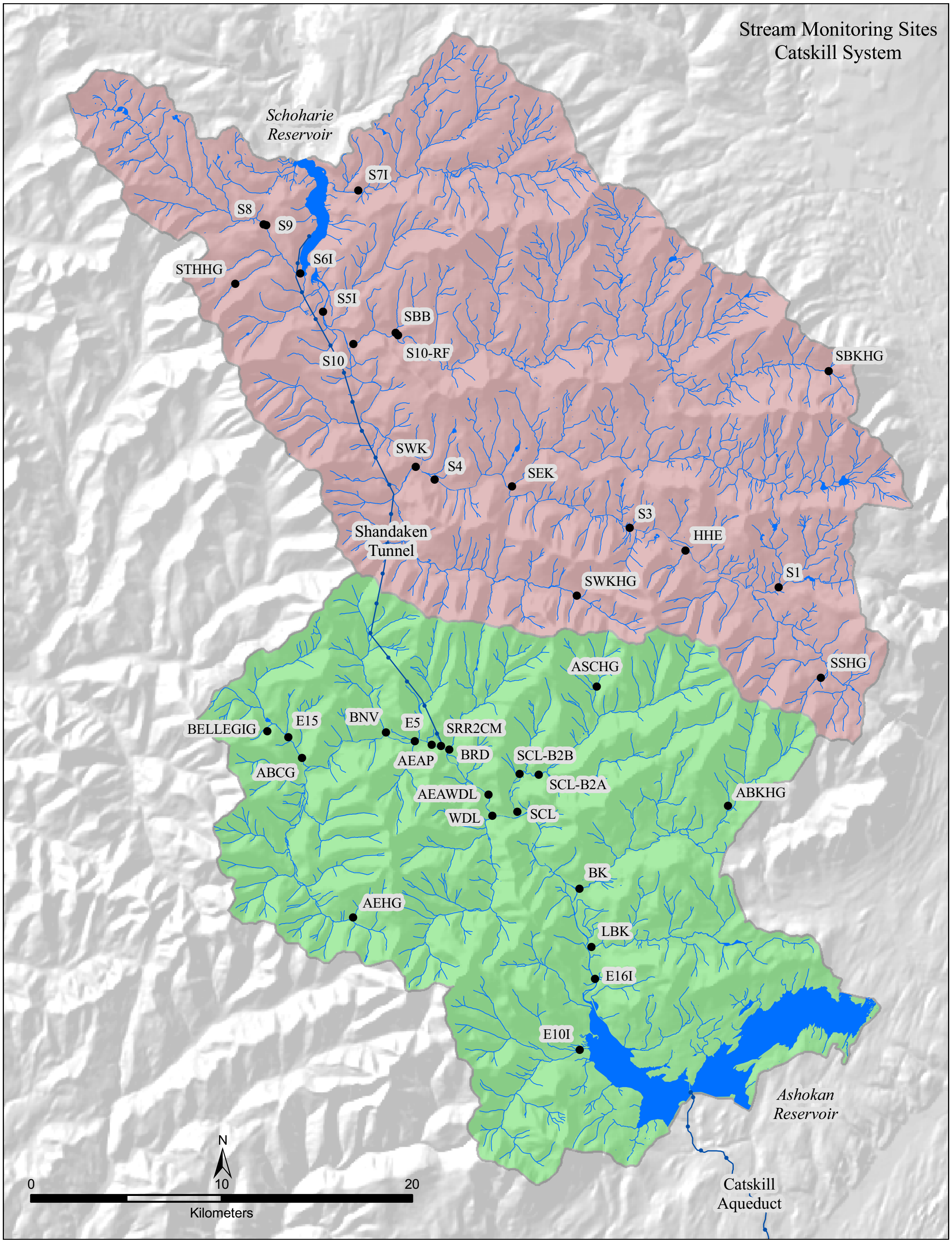


Figure 1.4 Stream sampling sites within the Catskill System drainage basins.

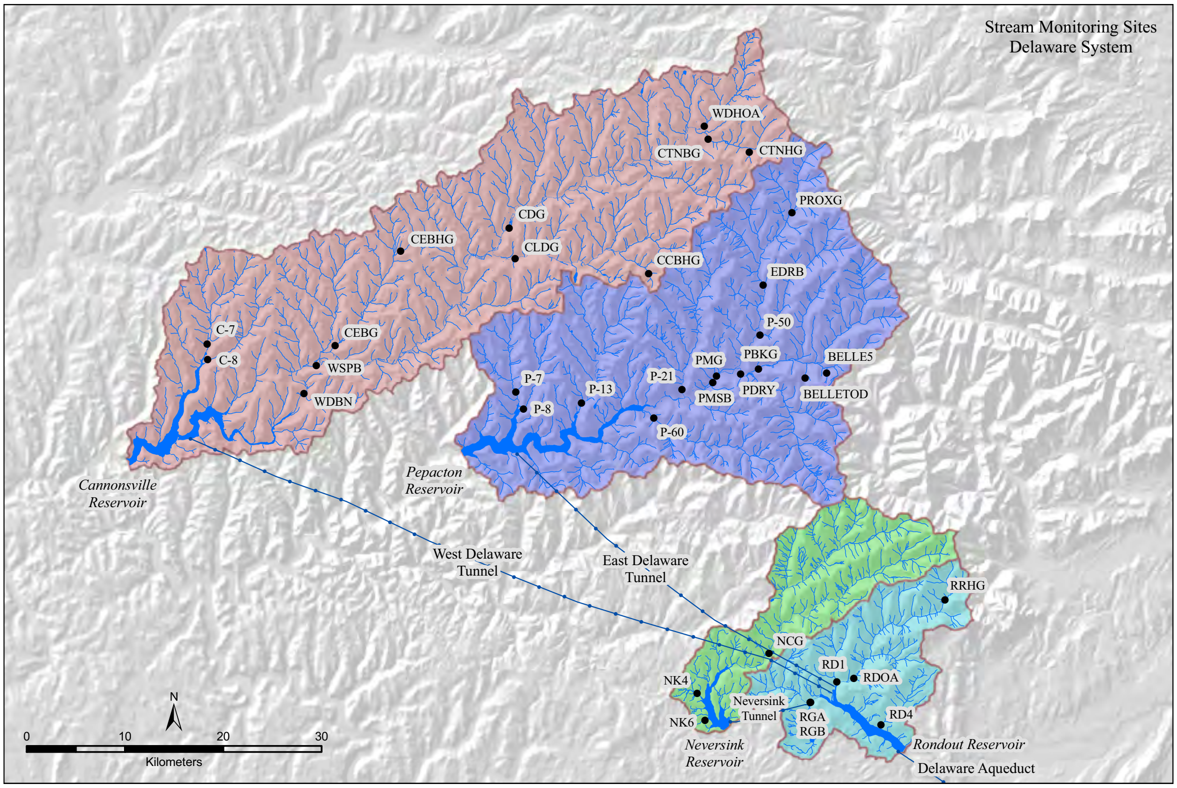


Figure 1.5 Stream sampling sites within the Delaware System drainage basins.

Figure 1.6 Pathogen sampling.

Reservoir sampling is shown in Figure 1.7 and reservoir sites for the west of the Hudson River and the east of the Hudson River reservoirs are shown in Figures 1.8 and 1.9, respectively. Sites were selected to provide coverage of water quality and physical conditions throughout each reservoir, and are typically sampled at multiple depths,. Limnological surveys are important in serving many objectives. They provide information on the current status of basic physical, chemical, and biological conditions that determine water quality in the system, allow tracking of trends, provide data for models, and guide current operational decisions.

Figure 1.7 Limnology survey in progress.

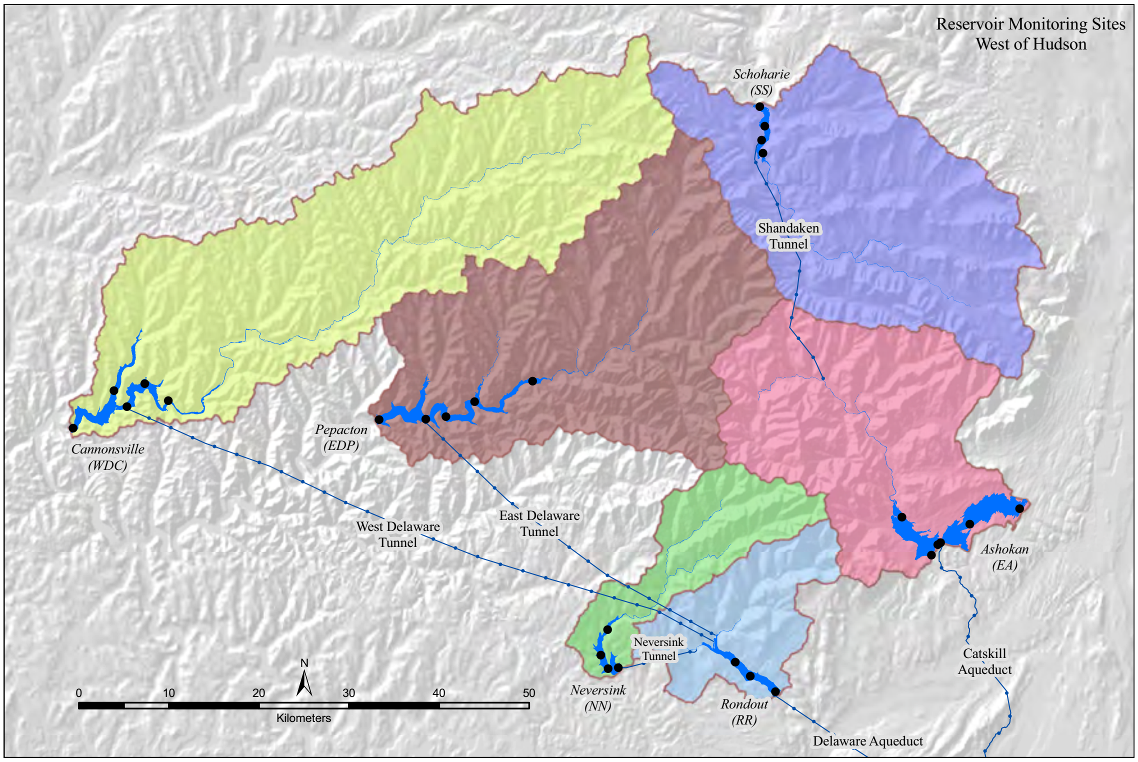


Figure 1.8 Limnological sampling sites for reservoirs west of the Hudson River.

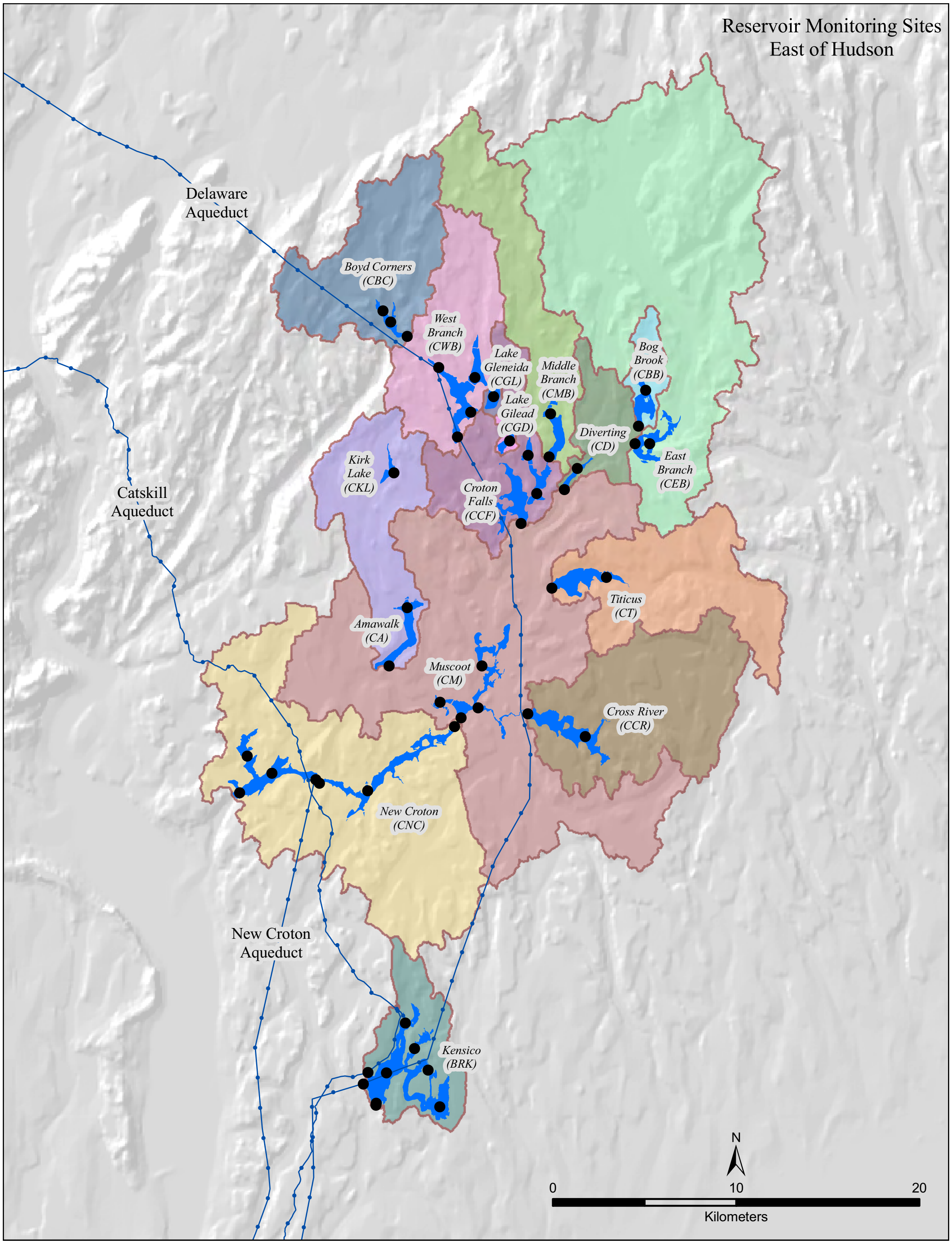


Figure 1.9 Limnological sampling sites for reservoirs east of the Hudson River.

Aqueduct “keypoint” monitoring is conducted as a means of keeping a “finger on the pulse” of the water supply with respect to the major water flowing through the system and into distribution. Monitoring at these sites is conducted through the use of continuous monitoring equipment, and taking daily or weekly grab samples. These sites have some of the highest frequencies of sampling, the purpose of which is to maintain a high degree of reliability in the quality of water entering the distribution system. In addition to sites used for operational decisions, aqueduct monitoring includes compliance sites for the Surface Water Treatment Rule (SWTR) and are of utmost importance for operation of the system to maintain the status of Filtration Avoidance.

Finally, DEP monitors wastewater treatment plants (WWTPs) located throughout the watershed. These treatment plants are potential sites of impairment. However, this risk has been enormously reduced in recent years because nearly all the discharge from treatment plants in the watershed is now microfiltered (or the equivalent) with tertiary treatment (nutrient removal). (For details on the WWTP upgrade program, see Chapter 5.) Plant upgrades have nearly eliminated the impacts that these plants formerly had in terms of nutrient and microbiological inputs. In the WWQMP, WWTP monitoring relies primarily on compliance monitoring to meet SPDES permits. Although DEP only owns six of the treatment plants and conducts monitoring according to their SPDES permits, additional monitoring of all plants is conducted to ensure that no problems arise.

1.5 How do the different monitoring efforts complement each other?

The WWQMP should be seen as superimposed networks that build on each other, and provide multidimensional information and multiple lines of evidence to support operational and policy decisions. Water quality management often requires a network design that can address water quality issues that demand distinct spatial and temporal monitoring efforts. These efforts may, for example, require a combination of long-term fixed-frequency surveys, supplemented by intensive short-term strategies. The design of water quality monitoring networks can be significantly enhanced by the coordination and integration of such monitoring strategies. The integration of water quality monitoring networks is essential for deriving the best value from the water quality data collected. The use of data gathered by the water quality monitoring network is routinely used to support water supply operations. In addition, the importance of the monitoring networks and full value of the data materializes when scientists provide analysis and interpretation for scientific reports and publications.

The monitoring plan has been designed to meet the broad range of DEP’s many regulatory and informational requirements. These requirements include: compliance with all federal, state, and local regulations to ensure safety of the water supply for public health; watershed protection and improvement to meet the terms of the 2007 FAD; the need for current and future predictions of watershed conditions and reservoir water quality to ensure that operational decisions and policies are fully supported over the long term; and ongoing surveillance of the water supply to ensure continued delivery of the best water quality to consumers.

1.6 Why did DEP operate the Croton Falls Pump Station in 2008 and what effect did the operation of the pump station have on Kensico Reservoir water quality?

The NYC Water Supply System is an interconnected system of cascading reservoirs and connecting aqueducts. This system design provides DEP the flexibility to route and deliver water from many different sources. In October 2008, scheduled system maintenance required that the Delaware Aqueduct be temporally shut down. While the Delaware System was offline, DEP needed to rely more heavily on the Catskill and Croton Systems to meet the City's water demand. One system configuration option to deliver more water from the Croton System is the operation of the Croton Falls Pump Station (CFPS). Located at Croton Falls Reservoir, this station provides DEP with the ability to pump water from Croton Falls Reservoir into the Delaware Aqueduct (downstream of the shutdown), where it is delivered to Kensico Reservoir. Terms of operation of the CFPS are explicitly described in the 2007 FAD. The DEP must justify the need for operation and receive approval from NYSDOH prior to operation. In 2008, DEP received approval for and operated the CFPS to help supplement the supply while Delaware System repairs were being performed.

In response to this change in the delivery configuration of the water supply, DEP also modified its water quality monitoring program to closely track the quality of Croton Falls water and the effects, if any, of this alternate supply on Kensico Reservoir. Elements of this enhanced monitoring program included collecting daily samples of the water entering the CFPS and of the water exiting the Delaware Aqueduct into Kensico Reservoir. Also, the quality of Croton Falls Reservoir was closely monitored with weekly reservoir surveys. In addition to this water quality monitoring, DEP also increased surveillance of potential contaminant sources by conducting weekly reservoir waterfowl surveys and increasing inspections of watershed wastewater treatment plants. As a condition of the approval to operate, the DEP provided regulators with a weekly update on the status of the enhanced water quality monitoring program.

The operation of the CFPS was successful. The Station operated as designed to help augment the supply. The quality of water delivered from Croton Falls Reservoir was closely monitored and the quality of water within Kensico Reservoir remained high throughout the entire operation. Accordingly, the quality of water leaving Kensico Reservoir also remained high and appeared unaffected throughout this period.

1.7 What enhancements were made to DEP's monitoring capabilities in 2008?

A new, state-of-the-art laboratory was opened in Kingston, NY, in February 2008. The new laboratory replaced the Ben Nesin Laboratory that was located in Shokan, NY, and allowed for the consolidation of several laboratory processes with the transfer of some staff and analyses from DEP's Grahamsville Laboratory in Grahamsville, NY. The Kingston Laboratory performs water quality analyses for the WOH watersheds (Catskill and Delaware) as well as pathogen and metals analyses for both EOH and WOH watersheds. Altogether, the modern laboratory provides 19,000 square feet for performing water quality analyses and maintenance of equipment.

The laboratory consists of several individual laboratories with unique analytical functions. Three separate Field Laboratories are available so that field staff can perform the calibration of field instruments, the programming of automated sampling equipment, and the repair and maintenance of field equipment, including sample pumps and flow measuring devices. The Sample Receiving and Preparation Laboratory is where samples are officially received by the laboratory, and other tasks including instrumentation calibration, turbidity analysis, and sample distillation occur in this laboratory. The facility also includes a Microbiology Laboratory for the performance of phytoplankton and bacterial analysis and a Metals Laboratory for the analysis of metals, such as lead and mercury. The Wet Chemistry Laboratory performs the widest variety of analyses including solids, biochemical oxygen demand, alkalinity, chloride, sulfate, total organic carbon, nitrogen, phosphorus, ammonia and silica. These laboratories are certified by New York State's Environmental Laboratory Approval Program. The Pathogen Laboratory, certified by the USEPA, performs *Giardia* and *Cryptosporidium* analysis. The Wildlife Studies Laboratory is dedicated to performing dissections on wildlife specimens inhabiting the watershed environment for bacteria, pathogens, and nutrient analysis. Wildlife specimens are preserved and stored for a species reference collection and endangered species management work. The facility is also equipped with Organics and Research Chemistry Laboratories which currently allow for chlorophyll analysis, instrument repair, and instrument validation. These two laboratories will also allow DEP to expand analytical capabilities in the watershed in the future, as needed. Finally, the facility contains a small Quality Assurance/Quality Control Laboratory which is currently being utilized to house a Laboratory Information Management System (LIMS) pilot program. The implementation of the LIMS will result in more efficient data processing and record keeping for laboratory and field analyses.

The laboratory also features several analytical support rooms including walk-in coolers, clean rooms, a balance room, a wash room (complete with autoclaves and glassware washers) and sample receiving garage bays. New safety features include laboratory assessment and security systems, modern laboratory air flow and ventilation systems, and computerized environment monitoring.

The laboratory is located on the first floor of a two-story, 98,500-square-foot facility that currently houses 190 DEP employees. Also located on the first floor, which is dedicated entirely to the Water Quality Directorate, are field, administrative, compliance, and management staff (approximately 67 people) in 11,000 square feet of office space.

The second floor of the building provides office space for several Bureau of Water Supply programs as well as a GIS laboratory, numerous training rooms (including dedicated rooms for environmental health and safety training), a cafeteria, and conference rooms.

The Kingston headquarters provides an efficient, modern, and safe environment to conduct the work of DEP. It also has the space and capabilities to allow for growth, and should serve DEP well into the future.

1.8 How is the Bureau of Water Supply organized to provide stewardship for such a vast and important resource?

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 Bureau currently consists of five major Directorates, as follows: Compliance, Water Quality, Operations, Watershed Protection and Planning, and Management Services and Budget. The Directorate's senior managers each has a Compliance Advisor. This enables them to keep track of progress on all compliance matters. The primary functions of the five Directorates are described below.

Compliance

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, Environmental Health & Safety (EH&S) programs that include regular training of staff and on-going tracking systems to ensure maintenance of these programs. 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 are Health and Safety Compliance, Environmental Engineering, Environmental Compliance, Compliance Training, and Compliance Audit.

Water Quality

The Water Quality Directorate consists of four divisions; two are devoted to the upstate watershed and two are devoted to the downstate distribution system. The functions of the two operational divisions, (i.e., Watershed Water Quality Operations and Distribution Water Quality Operations) include responsibility for sampling, analysis, quality assurance, compliance data management and reporting, and environmental health and safety. 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 and scientific research. Watershed Water Quality Science and Research is also responsible for FAD reporting, while Distribution Science and Research is responsible for drinking water compliance reporting. ~~P~~roject Management and Budget provides assistance to the Director and Divisions with budget, personnel, and other administrative matters. See Section 1.9 for more detail on the two upstate watershed water quality divisions.

Operations

The Operations Directorate is designed to provide oversight to all engineering operations. It is divided into two geographical areas: Eastern and Western Operations. Eastern Operations consists of northern and southern regions (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 Regional 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. Regional Managers provide the 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. Land stewards and HazMat personnel work within the integrated regional structures, and provide policy and programmatic support and guidance to the Regional Managers.

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, many of which are specified in the FADs issued periodically by USEPA. These include 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 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

The Office of Information and Technology (OIT) is part of the larger Department's organization. This group is directed by an Assistant Commissioner for Information and Technology. The staff support BWS, while unifying and developing 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.

1.9 What are the roles of the upstate watershed water quality divisions within the Water Quality Directorate?

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 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 water supply, and documents the final result of the combined programs and operations to demonstrate program effectiveness and compliance with all drinking water regulations.

The Watershed Water Quality Operations (WWQO) Division includes sections for WOH Water Quality Operations, 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. 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 NYSDOH Environmental Laboratory Approval Program (ELAP) for approximately 60 analytes in the non-potable water and potable water categories. These analytes include physical, chemical, microbiological, trace metals, and organic compounds. The NYC DEP Pathogen Laboratory has been granted "Approved" status by the US EPA for the analysis of *Cryptosporidium* under the SDWA using Method 1623. Watershed Water Quality Operations conducts monitoring of wastewater treatment, streams, reservoirs potable water sites and key aqueduct sites. Working with Bureau Operations to provide water quality information and input for Water Supply Operations 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 managers, 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 (580 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (Figure 2.1).

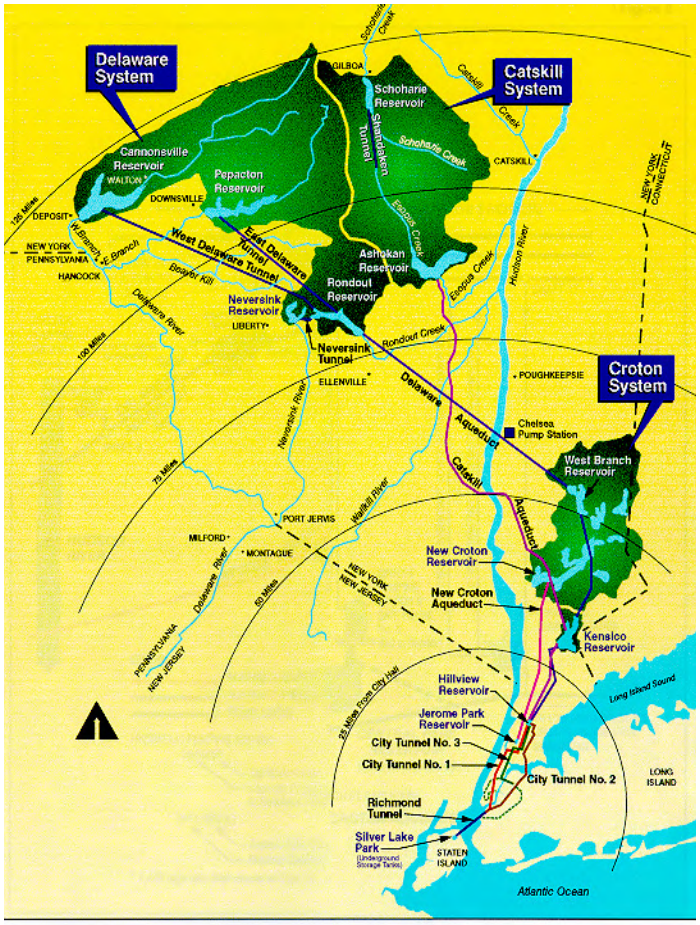


Figure 2.1 New York City water supply watershed.

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 nutrient and turbidity 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 2008?

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 is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2008 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.2.

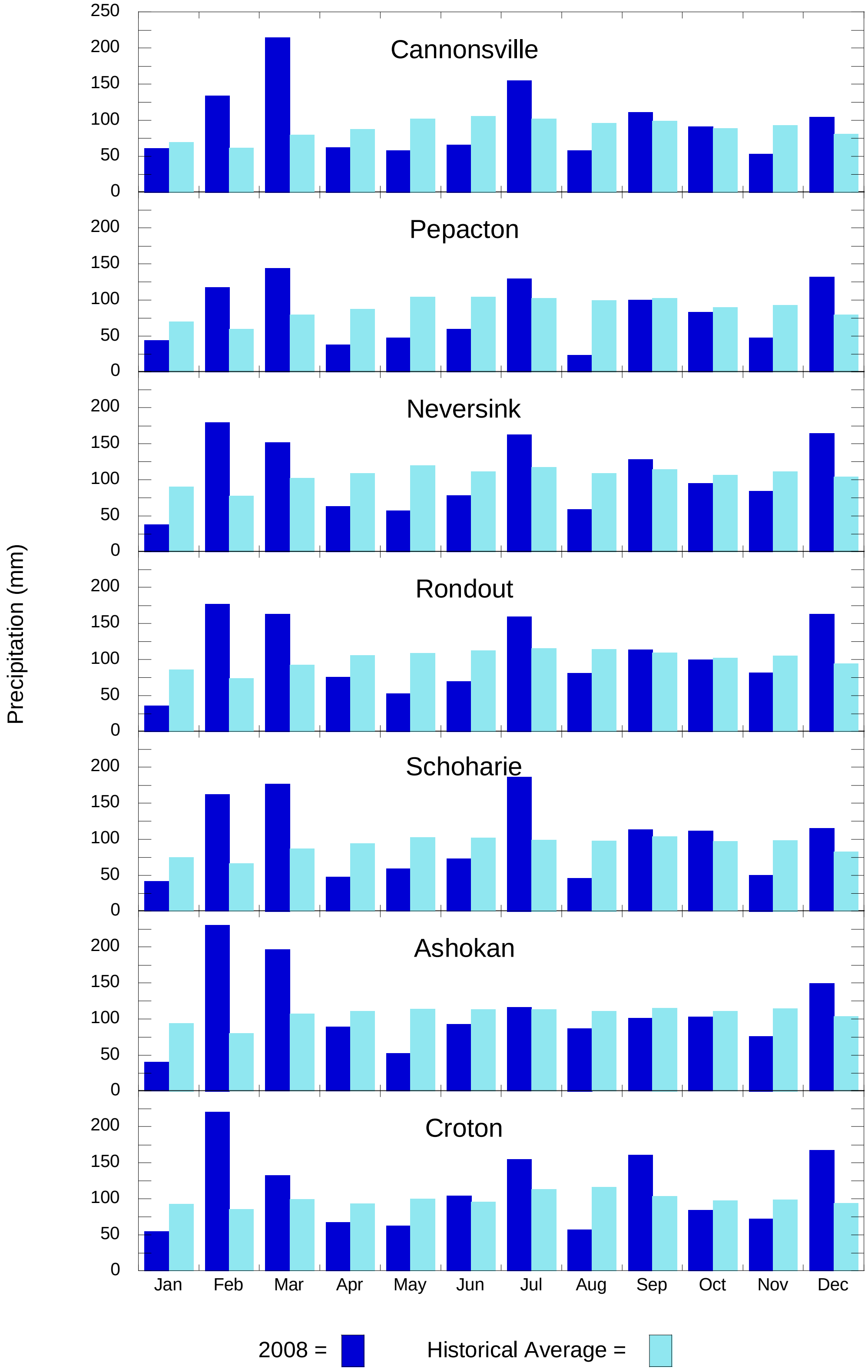


Figure 2.2 Monthly rainfall totals for NYC watersheds, 2008 and historical values.

The total monthly precipitation figures show that in general precipitation was below normal for January, but well above normal for February and March due to a series of winter storms. (As a result of these storms DEP used model simulations to support turbidity management and avoid alum treatment (see Section 6.4).) In fact, the National Climatic Data Center's (NCDC) 2008 Annual Climate Review U.S. Summary (http://www.ncdc.noaa.gov/oa/climate/research/2008/ann/us-summary.html) reports that New York State had its wettest winter (December-February) on record (1895-2008). From April through June precipitation was below normal, except for the Croton watershed in June which was slightly above average. Precipitation was above normal in July for all watersheds (see Section 2.5 to see how July precipitation impacted reservoir storage), and below normal in August. September and October precipitation was fairly typical, although the Croton watershed in September was slightly above average. Precipitation in all watersheds was below normal in November for all watersheds and above normal in December. The total precipitation in the watershed for 2008 was 1,198 mm (47.2 inches), which is 53 mm (2.1 inches) above normal. Overall, 2008 was New York State's seventh wettest year on record (1895-2008) according to the NCDC 2008 Annual Climate Review U.S. Summary.

2.3 What improvements were made to DEP's meteorological data network in 2008, 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 25 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). All but one of the stations now 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 2008, 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 between 2010 and 2012. The telemetry upgrade was completed in 2008 (with the exception of one remote base station site, which was still awaiting installation of high-speed networking capability, expected to occur in early 2009). This upgrade utilizes multiple base stations located at DEP facilities (wastewater treatment plants, valve chambers, etc.) spread throughout both the East and West of Hudson watersheds. Each RAWS transmits data to the nearest base station, where it is put onto the DEP computer network and routed to the master dataset at Grahamsville, as well as to a separate backup location. This upgrade has improved the reliability of data reception, increased data security, and brought EOH stations into the near-real-time data program.

DEP continued to develop the automated snow water monitoring system it started building in 2007. Based on experience with the original sensors from the Army Corps of Engineers, DEP developed a modified design which is smaller, lighter, less expensive, and easier to install than the original. A prototype was built by a contractor and installed by DEP staff in January 2008. Preliminary data were very encouraging. DEP will purchase several more “SnoScale” devices for expanded testing in the future with the ultimate goal of eventually developing a watershed-wide, continuous automated snow water monitoring program that would greatly reduce the use of manual snow surveys while providing much more timely and useful data.

2.4 How much runoff occurred in 2008?

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.

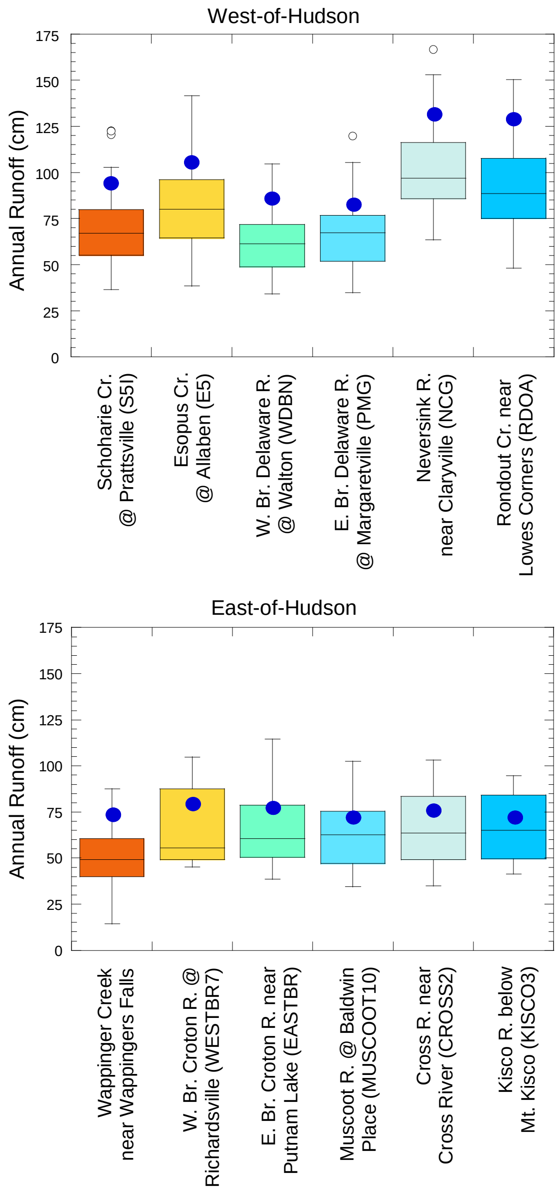


Figure 2.3 Historical annual runoff (cm) as box-plots for the WOH and EOH watersheds, with the values for 2008 displayed as a dot.

Selected USGS stations (Figure 2.8) were used to characterize annual runoff in the different NYC watersheds (Figure 2.3). The annual runoff in 2008 from the WOH watersheds was generally above the 75th percentile of the annual runoff from each watershed's historical record (i.e., more than 75 percent of the annual runoff values were below the values observed in 2008). In the EOH watersheds, the 2008 annual runoff was generally above the watersheds' historical medians (50th percentile). The differences between EOH and WOH 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 13-year period of record, except for the Wappinger Creek site (80-year period of record), which, like the WOH watersheds, showed a 2008 annual runoff above the 75th percentile. On the other hand, the period of record for the WOH stations ranges from 45 years at the Esopus Creek at Allaben station to 102 years at the Schoharie Creek at Prattsville gage.

2.5 What was the storage history of the reservoir system in 2008?

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 2008 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 2008 the June 1 system-wide usable storage was at 95.34 % of capacity, or 522.02 bg. A late July storm brought the storage values back to normal levels.

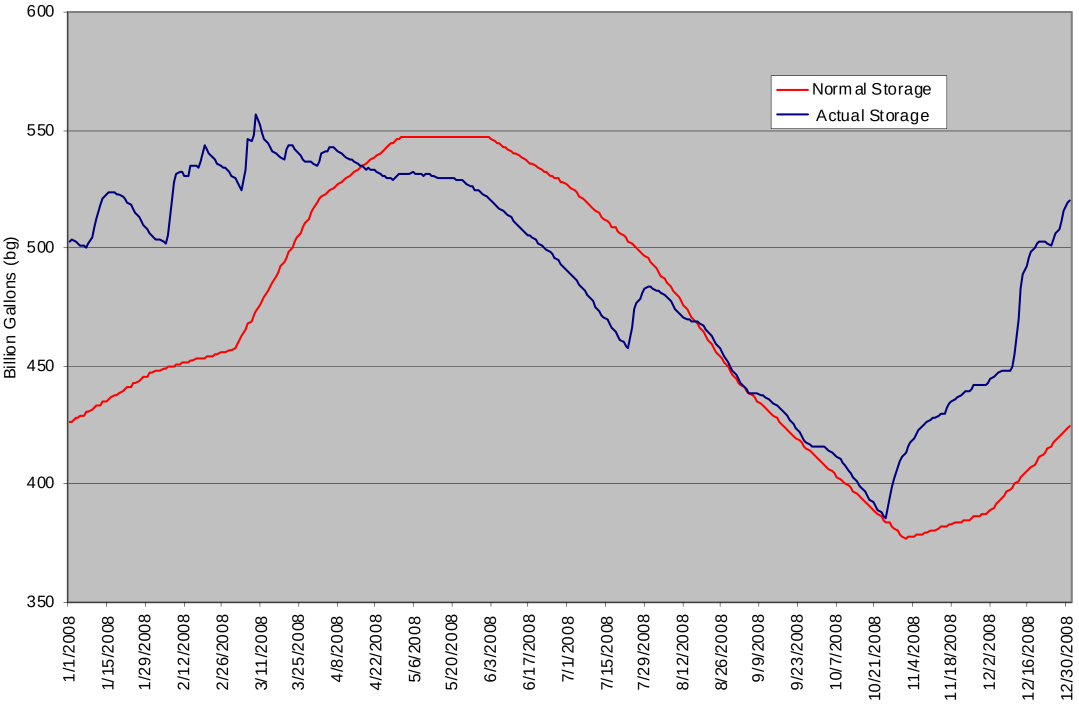


Figure 2.4 Actual system-wide usable storage compared to normal system-wide usable storage.

3. Water Quality

3.1 How did DEP ensure the delivery of the highest quality water from upstate reservoirs in 2008?

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 2008, over 69,292 physical, chemical, and microbiological analyses were performed on 6,659 samples that were collected from 53 different key aqueduct locations. DEP's Early Warning Remote Monitoring Group 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 in the Watershed Water Quality Operations Division work cooperatively with the Bureau's Operations Directorate 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 2008 included:

- Selective Diversion

DEP optimized the quality of water being sent into distribution by maximizing the flow from reservoirs with the best water quality and minimizing the flow from reservoirs with inferior water quality. In the fall of 2008, DEP diverted acceptable quality water from the West Basin of Ashokan Reservoir to keep Kensico Reservoir full and to create a void in the West Basin (Figure 3.1).

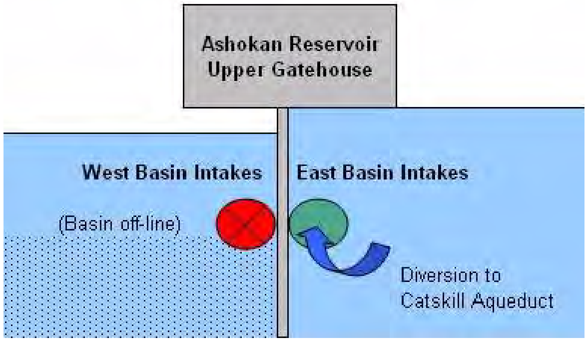


Figure 3.1 Water being diverted into the Catskill Aqueduct from the West Basin of Ashokan Reservoir.

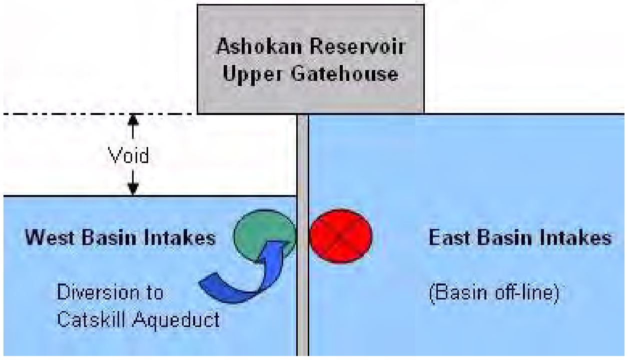


Figure 3.2 Water being diverted into the Catskill Aqueduct from the East Basin of Ashokan Reservoir with increasing turbidity levels in the West Basin.

When turbidity levels in the Ashokan West Basin began to increase in October due to rain events, DEP responded by isolating the West Basin and diverting water from the East Basin where turbidity levels were lower. These basin operations allowed DEP to continue to deliver a sufficient quantity of good quality water to Kensico Reservoir and to absorb the impacts of storms in the isolated West Basin (Figure 3.2).

- Selective Withdrawal

DEP continued to monitor water quality at different intake elevations within the reservoirs and used the data obtained to determine the optimal level of withdrawal. While operating the Croton System during the fall, DEP monitoring results indicated that turbidity and manganese levels were increasing at lower elevations in New Croton Reservoir in late October. By changing the level of withdrawal from the bottom to the surface, DEP was able to optimize water quality and continue to operate the Croton System into the month of December.

- Other Strategies

DEP continued to look for strategies to protect water quality near the intakes at Kensico Reservoir. In August, Eastern Operations staff installed a 15-inch wave stabilization boom (Figure 3.3) that starts at the southeast corner of the Catskill Upper Effluent Chamber (Figure 3.4) and extends 600 feet south along the western shoreline of Kensico Reservoir (Figure 3.5). The bottom half of the boom consists of a weighted curtain while the top half floats above the water surface. The boom has served to decrease surface water activity as well as the resuspension of shoreline sediments. This has assisted DEP in minimizing the effects of wind-induced turbidity in the Catskill Influent cove and the diversion to Hillview Reservoir.


Figure 3.3 Wave stabilization boom installation.


Figure 3.4 Wave stabilization boom connection to the Catskill Upper Effluent Chamber.


Figure 3.5 Wave stabilization boom extending along the western shoreline of Kensico Reservoir.

3.2 How did the 2008 water quality of NYC’s source waters compare with SWTR standards for fecal coliforms and turbidity?

The Surface Water Treatment Rule (SWTR) (40 CFR141.71(a)(1)) requires that water at a point just prior to disinfection not exceed the thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the water supply systems at “keypoints” (entry points from the reservoirs to the aqueducts) just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF, and the Delaware System at DEL18). Figures 3.6 and 3.7 depict fecal coliform and turbidity data, respectively, for 1992-2008. Each graph includes a horizontal line marking the SWTR limit.

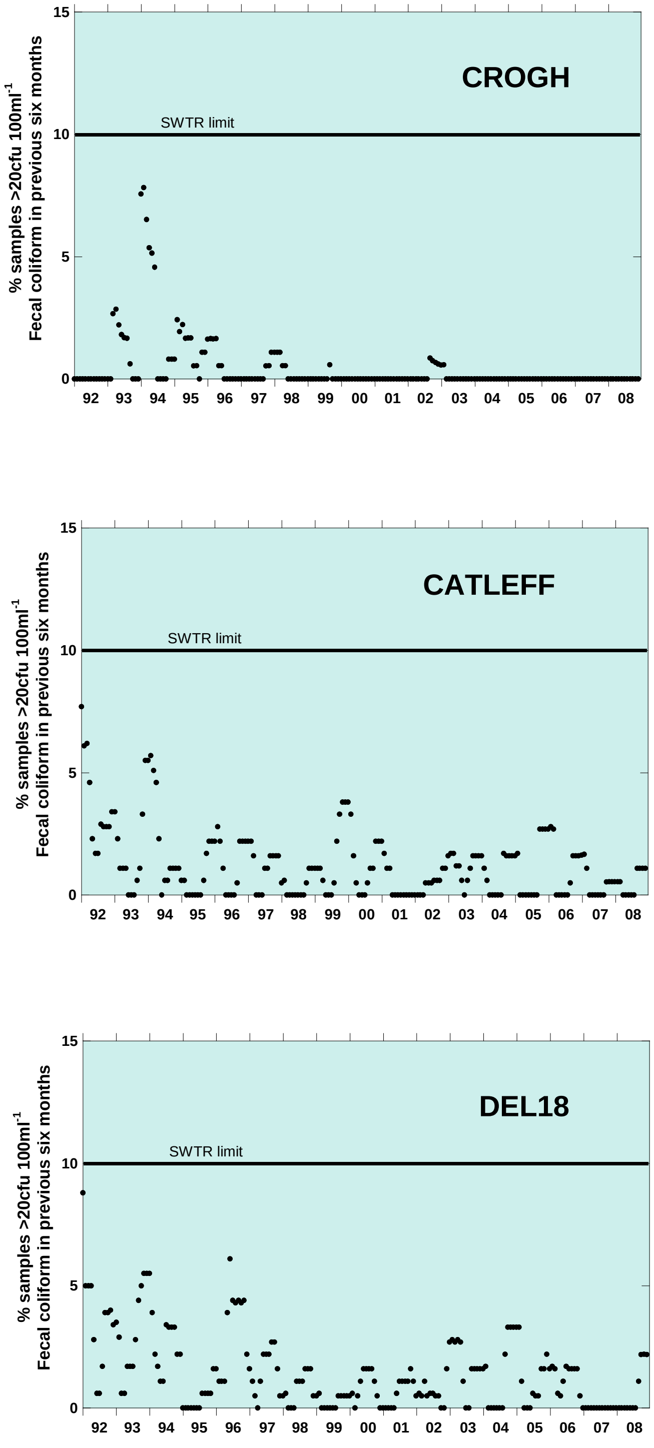


Figure 3.6 Fecal coliform (percent of daily samples > 20 CFU 100ml^{-1} in the previous six months) at keypoints compared to Surface Water Treatment Rule limit, 1992–2008.

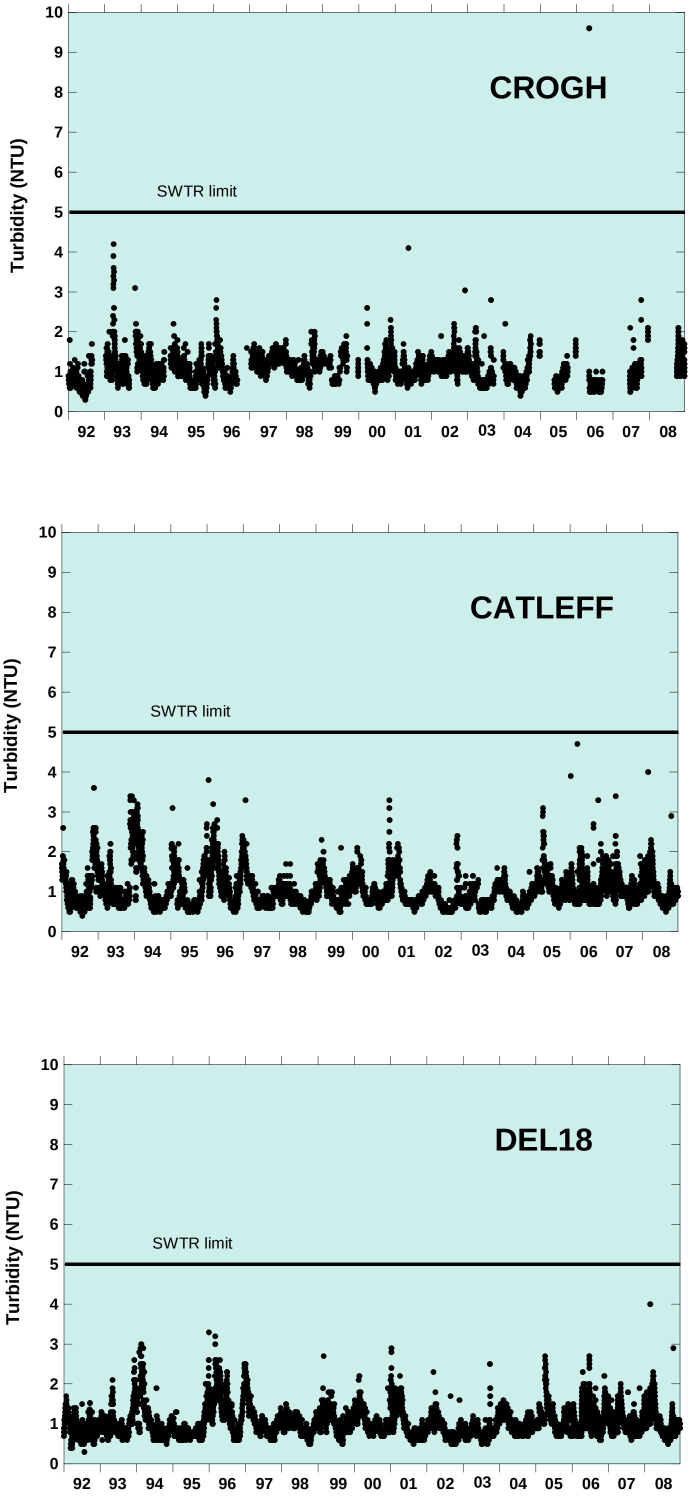


Figure 3.7 Turbidity at keypoints compared to Surface Water Treatment Rule limit, 1992–2008.

As indicated in Figure 3.6, the fecal coliform counts at all three keypoints consistently met the SWTR standard that no more than 10% of daily samples may contain > 20 CFU 100mL^{-1}. The 2008 calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below this limit. Median fecal coliform counts (CFU 100mL^{-1}) in raw water samples taken at these sites were the same, at 1 CFU 100mL^{-1}, while maxima were 7, 45, and 74, respectively.

The SWTR limit for turbidity is 5 NTU. As indicated in Figure 3.7, all three effluent waters, measured at 4-hour intervals, were consistently well below this limit in 2008. For CROGH, CATLEFF, and DEL18, median turbidity values (NTU) were 1.2, 1.0, and 1.0, respectively, while maximum values were 2.1, 4.0, and 2.2, 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).)

3.3 What was the water quality in the major inflow streams of NYC's reservoirs in 2008?

The stream sites discussed in this section are listed in Table 3.1 and shown pictorially in Figure 3.8. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds (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: Site codes and site descriptions of the stream sample locations discussed in Section 3.3.

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

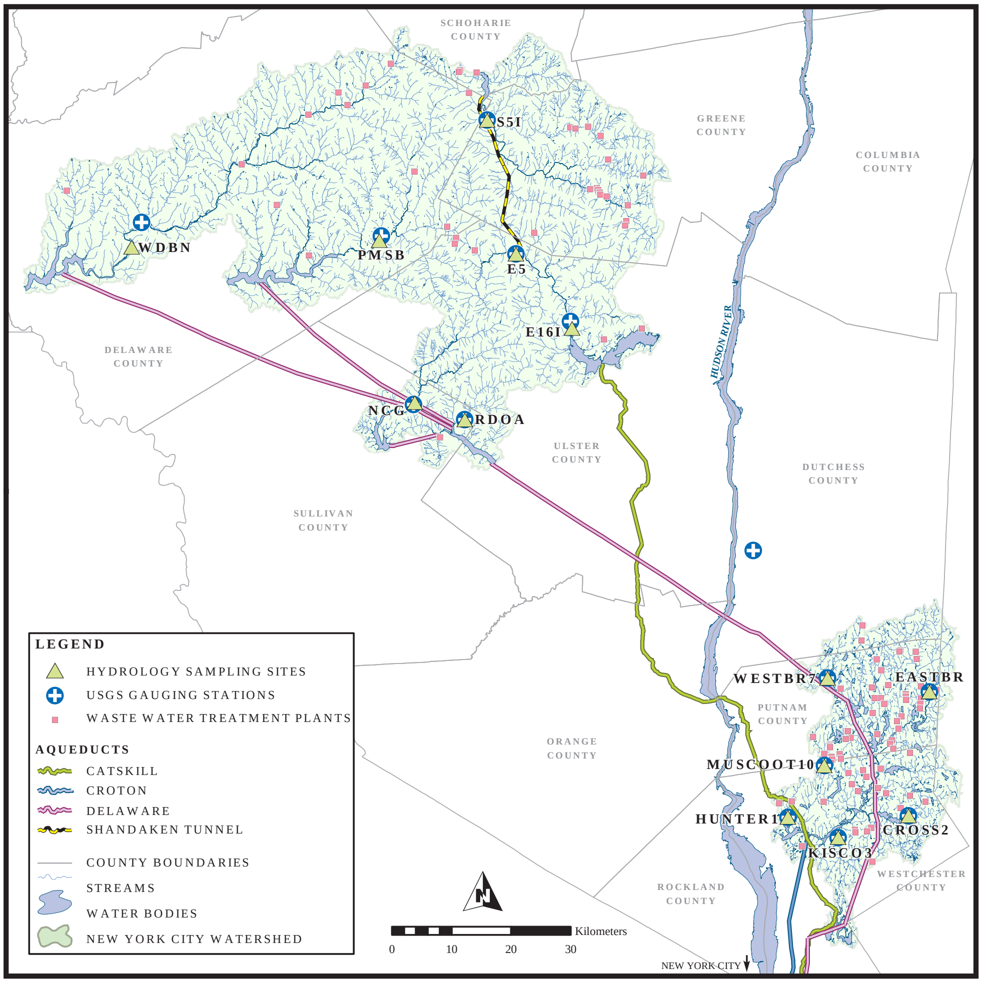


Figure 3.8 Locations of sampling sites discussed in Section 3.3 and USGS stations used to calculate the runoff values presented in Section 2.4.

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 the SWTR limit), total phosphorus (nutrient/eutrophication issues), and fecal coliform bacteria (values may not exceed SWTR limits).

The results presented in Figure 3.9 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 2008 median values against historical median annual values for the previous 10 years (1998–2007). However, one of the EOH sites, KISCO3, has a shorter sampling history (1999–present).

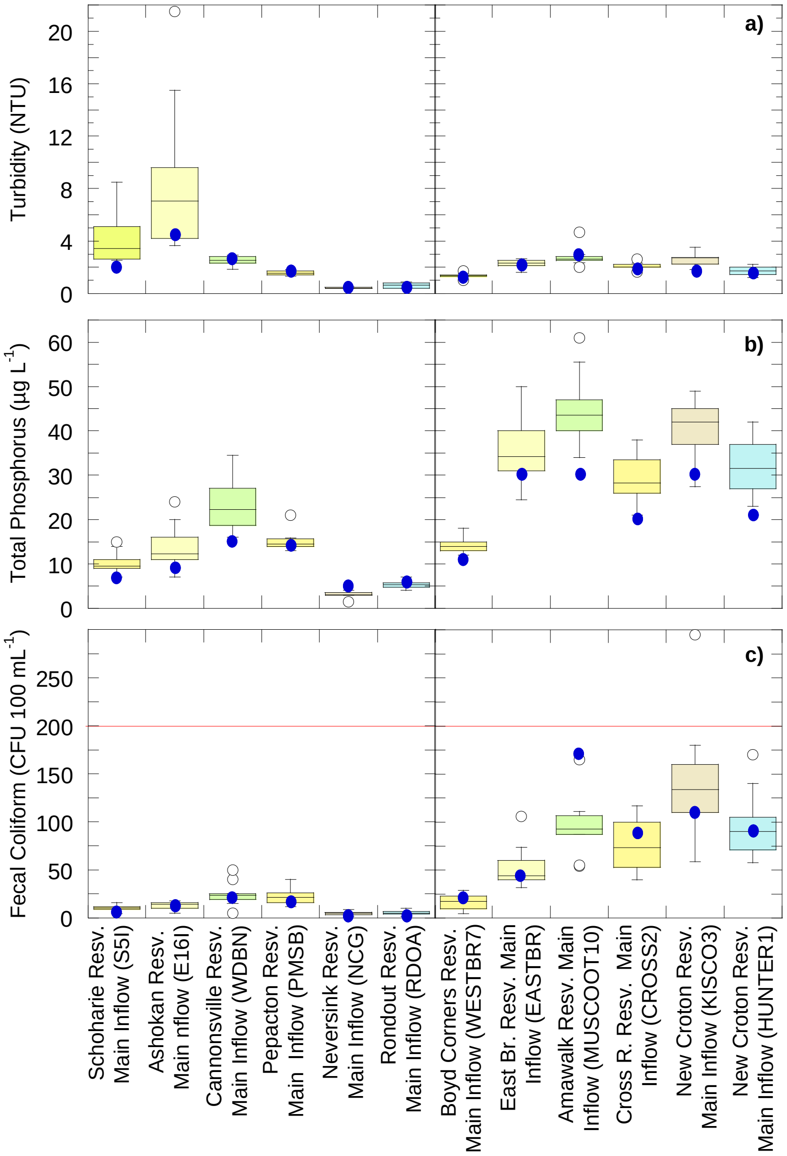


Figure 3.9 Boxplot of annual medians (1998–2007) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2008 displayed as a dot.

Turbidity

The turbidity levels for 2008 were generally near “normal” values (Figure 3.9a) with the 2008 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 2008 median turbidity values in the Kisco River was also less than the historical median for the previous 10 years.

Total Phosphorus

In the Catskill and Delaware Systems, the 2008 median total phosphorus (TP) levels (Figure 3.9b) were for the most part near typical historical values. As with turbidity, the annual total phosphorus median for 2008 for the inflows to Ashokan and Schoharie were somewhat less than the historical median for the previous 10 years. Also, the TP value in Cannonsville in 2008 remained below the historical median, perhaps reflecting the influence of improvements in agricultural practices and wastewater treatment plant (WWTP) upgrades. The 2008 TP medians in the Croton System were all less than historical values.

Fecal Coliform Bacteria

The 2008 median fecal coliform bacteria levels (Figure 3.9c) in the Catskill, Delaware, and Croton Systems were generally near the typical historical levels. Only MUSCOOT10, the inflow to Amawalk Reservoir, showed an elevated median value of fecal coliform in 2008. A fecal coliform benchmark of 200 CFU $100mL^{-1}$ is shown as a solid line in Figure 3.9c. 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 2008 median values for all streams shown here lie below this value.

3.4 How does drawdown affect water quality?

Numerous studies of NYC watersheds and other watersheds throughout the nation have been conducted on the impact of water level fluctuations on reservoirs. These fluctuations may be due to natural events, such as drought, or human-induced by variations in the withdrawal. Water level drawdown has been used as a reservoir management technique to control certain aquatic plants, manage fish populations, and carry out repairs or improvements to reservoir structures (Cooke et al. 1986). The fluctuations in water level may impact biological, chemical, and physical processes within the reservoir due to effects of drawdown on the reservoir’s thermal structure, light environment, and sediment exposure (Furey et al. 2004). The magnitude of impacts from a seasonal drawdown is dependent on factors including reservoir-specific hydrology and morphometry, as well as interannual climatic conditions (Nowlin et al. 2004).

Studies within the NYC watershed have demonstrated the impacts that drawdown can have on a reservoir. In 1995 a major drawdown occurred at Cannonsville Reservoir. Data from that year and long-term data were examined by Effler and Bader (1998). During the drawdown, sediment resuspension was at least in part responsible for introducing particles into the water column. These (non-phytoplankton) particles are referred to as tripton. As a result of the resuspension, the TP levels increased and the Secchi depth decreased. There was also a decrease in the duration of stratification. The resuspension of sediments led to the development of a benthic nepheloid layer (a bottom layer of turbid water) that eventually extended 10 meters above the bottom of the reservoir at one point. The increased tripton in the upper waters led to an increase in turbidity (Effler et al. 1998). Effler and Matthews (2004) showed that higher levels of inorganic tripton were generally observed in the years of greater drawdown. Tripton has an impact on the optical properties of a reservoir, and contributes to turbidity levels. Sediment resuspension can also enhance phytoplankton growth by release of phosphorus from decaying plankton to the productive (euphotic) layers of the reservoir and by desorption from suspended sediment. Resuspension of sediments can also have a negative effect on phytoplankton growth if shading interferes with light penetration. In Cannonsville Reservoir, resuspension is likely promoted by the drawdown of the water surface (Effler et al. 1998).

To further study the impact of drawdown on water quality, case studies of specific periods of drawdown, such as those in 2008 for Ashokan and West Branch, were examined (DEP 2009). Model simulations show that measured turbidity levels in the West Basin of Ashokan were affected by sediment resuspension during drawdown. Similar effects would be expected to occur in the East Basin and this could impact use of Ashokan water. Close monitoring of West Branch turbidity during a 2008 Delaware Aqueduct shutdown also indicated increased turbidity during drawdown. In this case, increases in turbidity were relatively small, but these could impact Kensico Reservoir, which is subject to the most stringent regulatory criteria.

A basic tenet of limnology is that water quality is influenced by reservoir or lake morphometry and watershed hydrology. The combination of these factors determines both nutrient loading and water residence times. Together, nutrient loading and water residence times determine biological productivity. Operation of the reservoir system imparts different elevation histories and water residence times to headwater versus terminal reservoirs and this was used to characterize reservoirs. An analysis of 20 years of data on reservoirs was conducted to demonstrate how water quality has responded to drawdown in the past (DEP 2009). Time series plots, scatter plots, and correlations were used to identify the strongest relationships between water quality and reservoir elevation. An interesting feature of these data was that in many cases, the relationship between drawdown and water quality parameters became stronger once water levels fell below a critical elevation.

3.5 What factors contributed to the turbidity patterns observed in the reservoirs in 2008?

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 resuspension) or it may be derived from the watershed by erosional processes (storm runoff in particular).

In 2008, turbidity in the Catskill System was lower than normal (Figure 3.10). Precipitation was high in February and March, which required the Shandaken Tunnel to be shut down; much of the turbid water from Schoharie was spilled to the Mohawk River. Turbid water entering Ashokan Reservoir via Esopus Creek was released to the waste channel from the West Basin, minimizing its impacts to Ashokan, especially the East Basin. Although July was wetter than normal, elevated turbidity was only observed at Schoharie Reservoir during this month. The operational changes and the relative absence of any additional runoff events during the year are the likely factors explaining such low turbidities in the Catskill System.

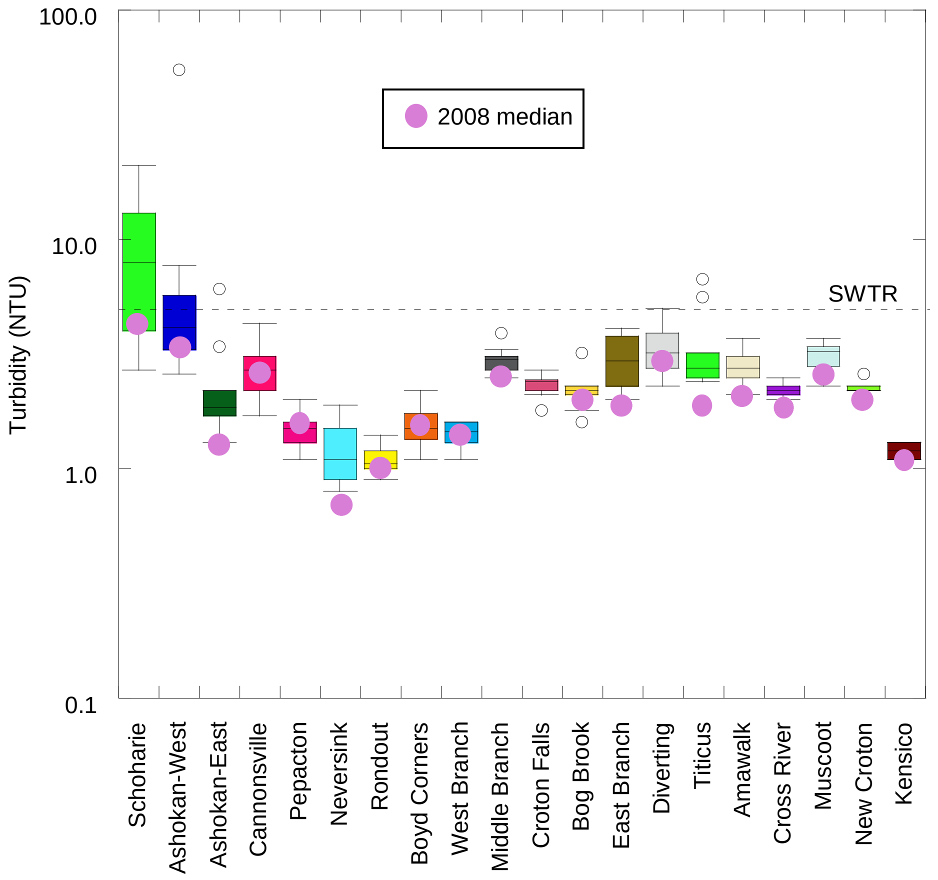


Figure 3.10 Annual median turbidity in NYC water supply reservoirs (2008 vs. 1998–2007). The dashed line at 5 NTU represents the SWTR criterion that considers 2 consecutive days > 5 NTU a violation in source water reservoirs.

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 2008 for Croton Falls Reservoir due to insufficient data.

Unlike the Catskill reservoirs, most Delaware reservoirs were very close to their long-term median turbidity levels in 2008. Runoff events in February and March caused above average turbidities that lasted from April to June in Cannonsville. In Pepacton Reservoir the turbidity levels fell after the month of April. Pepacton also experienced elevated turbidity from late July to early August caused by locally heavy rain. Turbidity in Neversink, unlike the other Delaware reservoirs, was at its lowest level in the last 11 years. Despite 13.1 inches of rain that fell in February and March, Neversink showed little effect from the runoff since turbidity levels were near the median in April and below the median from May to November. Rondout, which receives most of its water from Cannonsville, Pepacton, and Neversink, was just below the long-term median turbidity for the year.

West Branch Reservoir, a blend between Rondout and Boyd Corners water, had slightly lower turbidity than its long-term median. Kensico Reservoir had lower than normal turbidity in 2008, reflecting the low turbidities of its primary inputs—Rondout, West Branch, and Ashokan Reservoirs.

Most of the Croton System reservoirs were close to or less than their long-term median turbidity levels. A relative absence of large rain events in 2008 is the likely cause. Although precipitation was high in February and March, the effect of this early runoff produced only low to median spring turbidity levels in all reservoirs except Boyd Corners. Low amounts of precipitation in April, May, and August also contributed to the low annual medians in all the other Croton reservoirs. Turbidity samples were only collected in August and late October for Lakes Gilead, Gleneida, and Kirk (results not shown in Figure 3.10). Turbidity levels were near the median for Gilead and Gleneida (1.4 and 1.6 NTU, respectively) and about 30% lower than normal for Kirk (3.3 NTU).

3.6 How were the total phosphorus concentrations in the reservoirs affected by precipitation and runoff in 2008?

Precipitation and runoff 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, and internal recycling from reservoir sediments.

In 2008, median TP levels in all Catskill and Delaware System reservoirs were at or near their lowest concentrations since 1997 (Figure 3.11). Monthly TP concentrations were especially low in April, May, and June. An early snowmelt from February to early March, along with operational increases in reservoir releases and spills in headwater reservoirs, were largely responsible for the low spring TP concentrations. Infrequent large storms (i.e., total rainfall greater than 1 inch) during the remaining months helped ensure a low TP year. Additional factors were apparent at Cannonsville Reservoir where monthly TP concentrations were lower in all months except June. Efforts to reduce TP loads (e.g., continued construction of agricultural BMPs and WWTP upgrades) and a continuing decline in dairy farming are likely factors contributing to these low TP values.

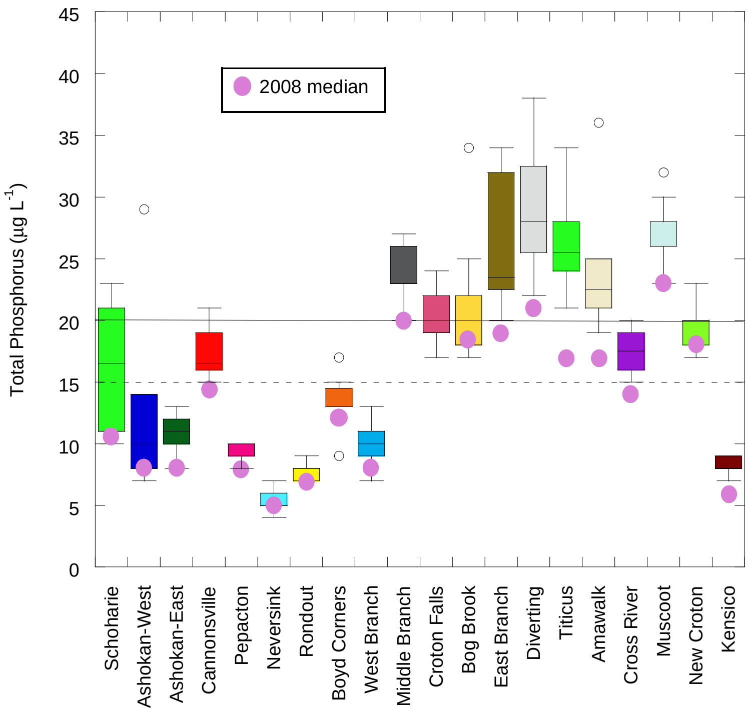


Figure 3.11 Annual median total phosphorus in NYC water supply reservoirs (2008 vs. 1998–2007). The horizontal dashed line at 15 µg L^{-1} represents the NYC TMDL guidance value for source waters (in the NYC water supply system, New Croton and Kensico Reservoirs, but see note below). The horizontal solid 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 2008 for Croton Falls Reservoir due to insufficient data.

The terminal reservoirs are Kensico, New Croton, Rondout, Ashokan East, Ashokan West, and West Branch.

West Branch Reservoir is a blend of Rondout water from the Delaware System and of Boyd Corners water from the Croton System. TP concentrations in these inputs were both below the median and resulted in below median TP in West Branch in 2008.

Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, had a low TP median in 2008, largely due to the low TP concentrations of its inputs.

As shown in Figure 3.11, TP concentrations in the Croton System reservoirs 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 2008 TP concentrations are low relative to past concentrations for all Croton reservoirs and Kirk Lake (Figure 3.11 and Table 3.2). Lake Gleneida was slightly elevated compared to the 10-year historical median but the lake was only sampled in August and September in 2008.

Table 3.2: Total phosphorus summary statistics for NYC controlled lakes (µg L^{-1}).

Lake	Median Total Phosphorus (10-year)	Median Total Phosphorus (2008)
Gilead	20	20
Gleneida	18	21
Kirk	29	26

Data for Croton Falls were very limited in 2008 due to continuing dam rehabilitation work that necessitated the drawdown of this impoundment. Although accurate representative medians could not be calculated for 2008, the distribution of past annual medians is provided in Figure 3.11.

Several factors may be responsible for the nearly system-wide low TP concentrations. Reduced concentrations in April and May were probably a result of the early “flushing” of TP from the watersheds by unusually heavy rainfall in February and March. Reduced summer drawdown due to above average rainfall in July and September was another factor. At more typical drawdown levels, resuspension of exposed sediments can be an important source of TP to the reservoirs.

3.7 Which basins were phosphorus-restricted in 2008?

Phosphorus-restricted basin status is presented in Table 3.3 and was derived from two consecutive assessments (2003–2007 and 2004–2008) using the methodology stated in Appendix C. Table C.1 in Appendix C lists the annual growing season geometric mean phosphorus concentration for NYC reservoirs. Reservoir basins that exceed the guidance value for both assessments are classified as restricted. Figure 3.12 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2008 geometric mean phosphorus concentration.

Table 3.3: Phosphorus-restricted reservoir basins for 2008.

Reservoir Basin	03–07 Assessment (mean + S.E.) (µg L^{-1})	04–08 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus Restricted Status
Delaware System			
Cannonsville	18.2	18.0	Non-Restricted
Pepacton	9.9	9.8	Non-Restricted
Neversink	6.5	6.4	Non-Restricted
Rondout	8.2	8.1	Non-Restricted
Catskill System			
Schoharie	16.1	16.3	Non-Restricted
Ashokan-West	15.7	15.8	Non-Restricted
Ashokan-East	9.8	9.9	Non-Restricted
Croton System			
Amawalk	24.3	24.2	Restricted

Table 3.3: (Continued) Phosphorus-restricted reservoir basins for 2008.

Reservoir Basin	03–07 Assessment (mean + S.E.) (μg L^{-1})	04–08 Assessment (mean + S.E.) (μg L^{-1})	Phosphorus Restricted Status
Bog Brook	22.9	23.5	Restricted
Boyd Corners	15.9	15.8	Non-Restricted
Cross River	19.1	18.9	Non-Restricted
Croton Falls	19.9	18.7	Restricted*
Diverting	Insufficient data	Insufficient data	Restricted
East Branch	33.7	33.1	Restricted
Middle Branch	27.9	28.8	Restricted
Muscoot	27.9	27.2	Restricted
Titicus	27.0	25.8	Restricted
West Branch	12.2	12.1	Non-Restricted
Lake Gleneida	Insufficient data	Insufficient data	Restricted
Lake Gilead	31.1	32.2	Restricted
Kensico	8.6	8.5	Non-Restricted
New Croton	20.0	19.5	Restricted

* Croton Falls Reservoir was only sampled in the main basin in 2008. Since this basin receives water primarily from West Branch Reservoir, the 2008 geometric mean and the subsequent five-year analysis were biased low. For this reason, Croton Falls Reservoir remains restricted.

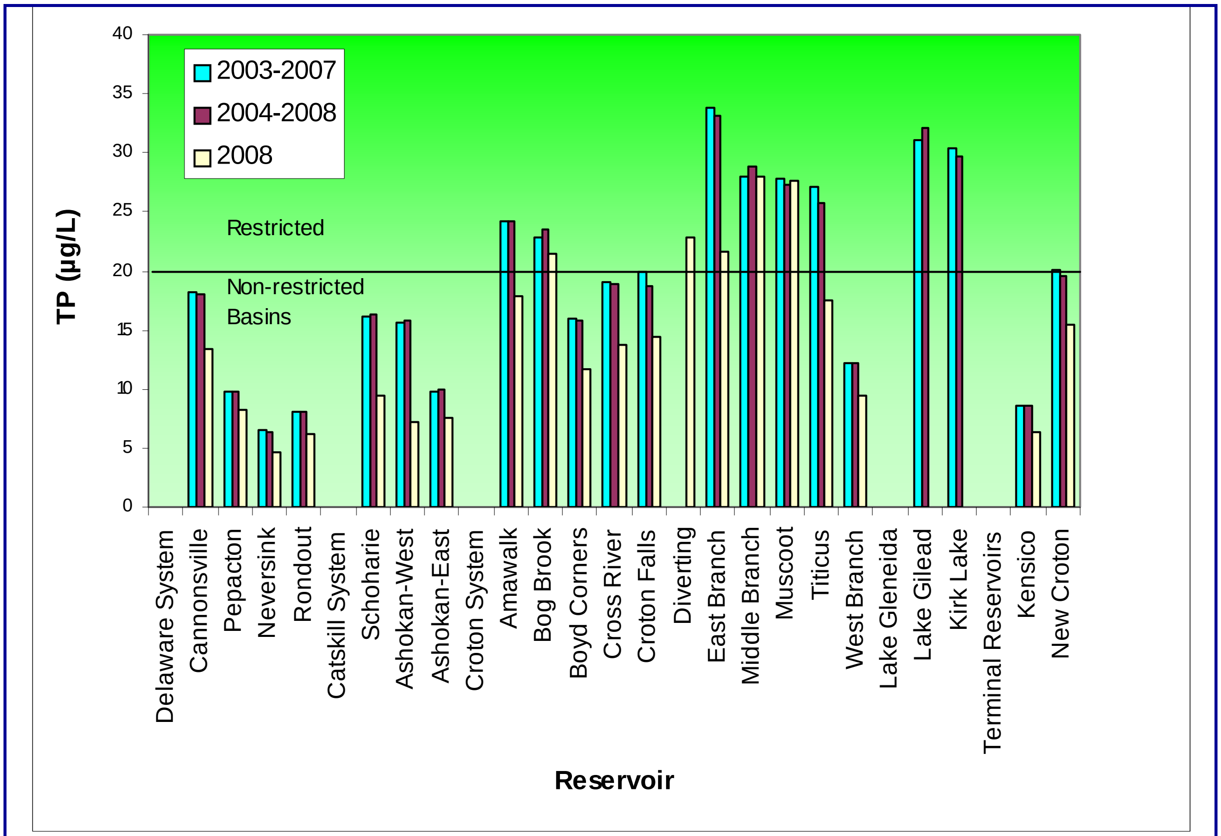


Figure 3.12 Phosphorus-restricted basin assessments, with the current year (2008) geometric mean phosphorus concentration displayed for comparison. The horizontal solid line at 20µg L^{-1} represents the DEC ambient water quality guidance value appropriate for reservoirs other than source waters.

Some notes and highlights regarding phosphorus-restricted basin status in 2008 are listed below:

- The Delaware System reservoirs remained non-restricted with respect to TP. Figure 3.12 shows that the 2008 geometric mean was lower than the mean for the two five-year assessments for all four reservoirs.
- The Catskill System reservoirs were also non-restricted since the two five-year assessment periods were well below 20 µg L^{-1}. The 2008 geometric mean was lower in all reservoirs compared to the two assessments.
- The Croton System reservoirs had some differences from previous assessments. In general, the geometric means of the TP concentrations for 2008 were lower than in previous years (Appendix C). The three controlled lakes were only sampled twice for TP during 2008 so their geometric mean couldn't be included in Figure 3.12. Lakes Gilead and Kirk had sufficient data in previous years to calculate the five-year assessments and their status remained restricted. Since insufficient data were available to change the status of Lake Gleneida, it also

remained restricted. Boyd Corners, Cross River, and West Branch Reservoirs remained non-restricted. Croton Falls Reservoir dropped below 20 µg L^{-1} for the 2004–2008 assessment. Upon closer examination, it was found that the 2008 mean concentration was unusually low because only the main basin, which has the best water quality, was sampled. Since the other sites were not sampled, an assessment could not be made, because any assessment that failed to include all the sites would not have been truly representative of the reservoir. The basin remains restricted until additional data confirm a decrease in 2009.

- Kensico Reservoir TP levels continue to be well below 20 µg L^{-1} for each of the last two assessments, and the basin remains unrestricted. New Croton Reservoir continues to show a decreasing geometric mean TP since 2004 (Table C.1 in Appendix C). As a result, the last five-year assessment dropped below 20 µg L^{-1}. If this trend continues, New Croton could be removed from TP-restricted status next year.

3.8 Are eutrophication patterns in NYC reservoirs comparable to those of other northern temperate water bodies?

Eutrophication is defined as a process where water bodies receive excess nutrients that stimulate excessive algal growth. 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 (1998–2007) mean and the annual mean for 2008 were compared to the regression line developed by the OECD program (Figure 3.13). Upper and lower 95% confidence intervals are also shown in the figure. The shift in the NYC regression line 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 methods used to develop the OECD relationships in 1981 (fluorometric or spectrophotometric analysis).

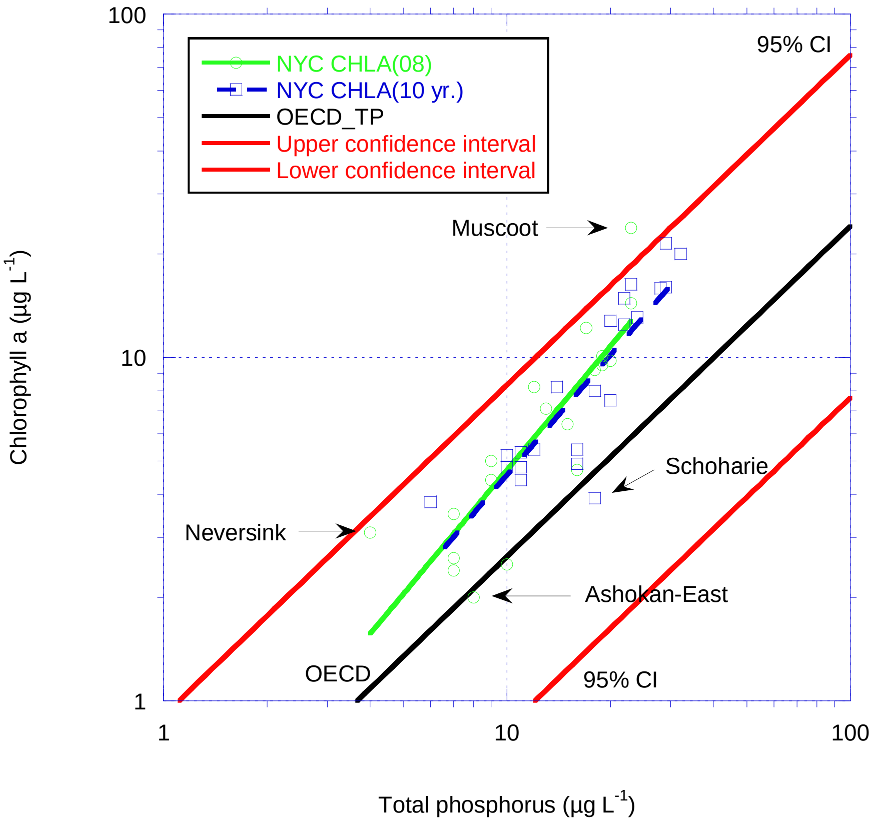


Figure 3.13 Mean chlorophyll *a* vs. total phosphorus concentration in NYC reservoirs compared to OECD Eutrophication Program lakes. For NYC reservoirs, samples were collected in the photic zone during the growing season (May–October) over a 10-year period (1998-2007) and in 2008.

Note: Chl *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, NYC reservoirs achieved a greater algal response (as indicated by chl *a*) for each unit of nutrient concentration increase (as measured by TP) than the OECD water bodies. Reservoirs of the Catskill and Delaware systems mostly had lower nutrient levels as exemplified by Neversink Reservoir and Ashokan's East Basin in the plot. Reservoirs of the Croton System tended to have higher nutrient concentrations and higher chl *a*. Muscoot Reservoir is a notable example of this—its annual growing season mean TP and chl *a* were above the 95% confidence interval compared to the OECD water bodies. The long-term data for Schoharie Reservoir are shown below the OECD line, 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. This effect was not as apparent in the 2008 data for Schoharie, and indeed several reservoirs had lower TP and chl *a* in 2008 as compared to the long-term data.

NYC reservoirs 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 3.14). The long-term regression line for NYC reservoirs is clustered about the OECD line, while the 2008 data show a lower slope than either the long-term or OECD regression lines. Most reservoirs had lower TP values in 2008, which could explain the lower chl *a* values in this plot.

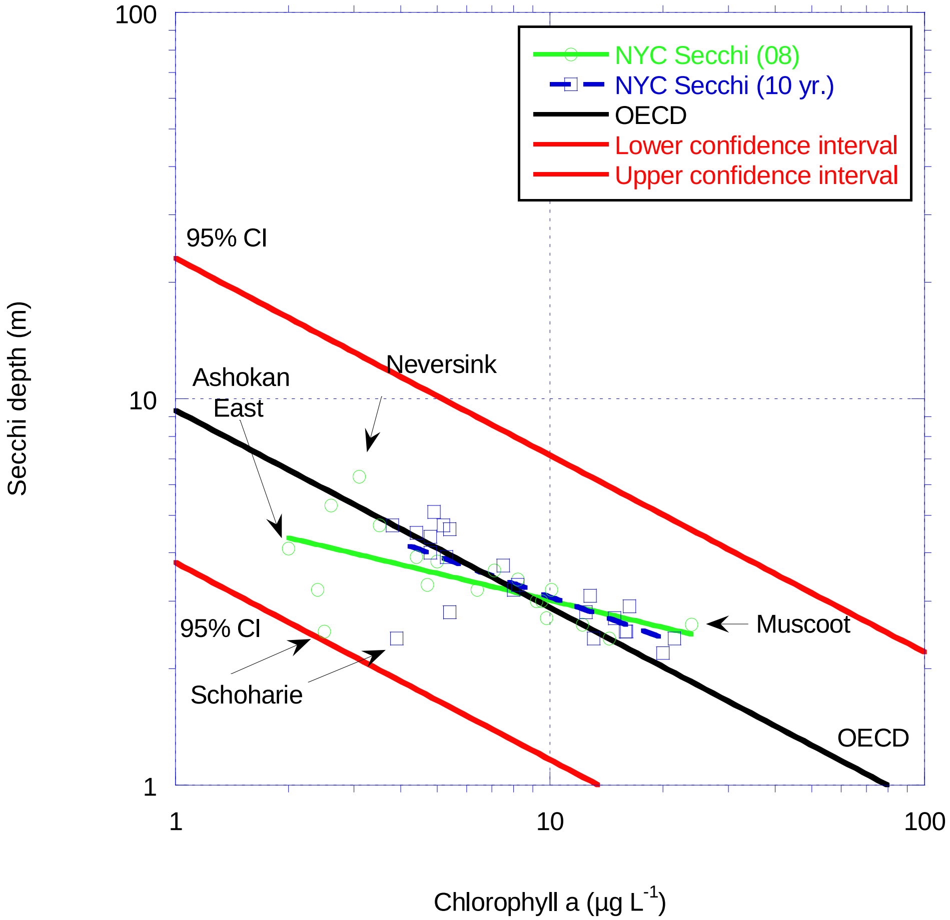


Figure 3.14 Mean chlorophyll *a* vs. Secchi transparency (Z_{SD}) in samples collected in the photic zone during the growing season (May–October) in NYC reservoirs over a 10-year period (1998–2007) and for 2008.

Note: Chl *a* results were obtained through the use of a spectrophotometer or fluorometer from 1998–2000, and by HPLC thereafter. Z_{SD} results were obtained on the shady side of the boat using the naked eye in 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 have lower chl *a* levels and deeper Secchi transparency as compared to East of Hudson impoundments. Neversink, Muscoot, and Ashokan's East Basin are noted on the plot as examples. Schoharie Reservoir stands out because of its relatively low transparency and low chl *a* concentrations compared to other NYC reservoirs and OECD water bodies. The departure of Schoharie from the "standard" Secchi-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. Interestingly, the 2008 chl *a* mean was lower than the long-term value, but the Secchi values remained similar for the two periods.

The combination of three plots (chl *a* vs. TP, chl *a* vs. Z_{SD}, and Trophic State Index (TSI) (Section 3.9) can be used to provide valuable information about the reservoirs. For example, algal growth is driven by TP for most reservoirs and, 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. Typically, blue-green algae are likely to dominate in these impoundments. The plots also show that the primary cause of light attenuation in Schoharie and Ashokan's West Basin is the presence of non-algal particulates, and the terminal receiving water reservoirs (closer to the distribution system) 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, lower phosphorus concentrations, and lower chl *a* than the Croton System reservoirs.

3.9 What was the trophic status of each of the City's 19 reservoirs and why is this important?

The trophic state index (TSI) is 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*, TP, and Secchi transparency) to delineate the trophic state of a body of water. TSI based on chl *a* concentration is calculated as:

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

where CHLA is the concentration of chlorophyll *a* in $\mu g\ L^{-1}$.

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 most highly correlated. DEP water supply managers prefer reservoirs of a lower trophic state, because such reservoirs 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.

Historical (1998–2007) annual median TSI based on chl *a* concentration is presented in boxplots for all reservoirs in Figure 3.15. The 2008 annual median TSI appears in the figure as a circle containing an “x”. This analysis usually shows a split between West of Hudson reservoirs, which usually fall into the mesotrophic category, and East of Hudson 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 Reservoir; and Kensico, which is considered mesotrophic due to inputs from Rondout (usually via West Branch) and from the East Basin of Ashokan.

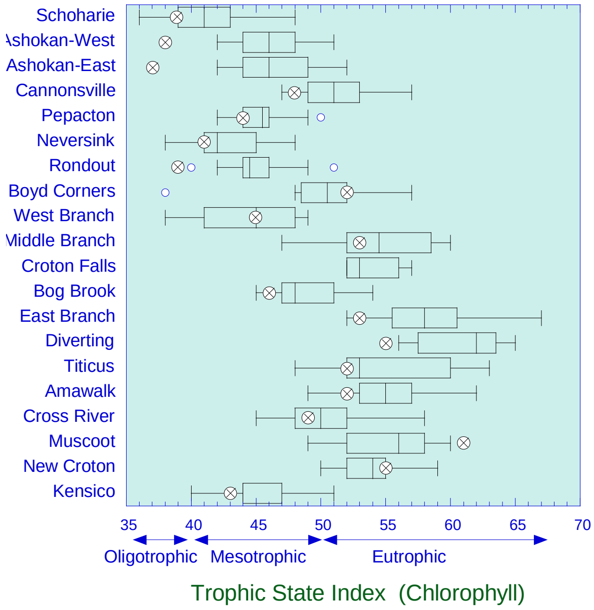


Figure 3.15 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2008 vs. 1998–2007).

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 chl *a* concentration.

In 2008, TSI was low in both the Catskill and Delaware Systems. In fact, TSI calculations for the three Catskill reservoirs placed them all in the oligotrophic range for the first time in the same year (Figure 3.15). It is likely that phytoplankton populations were limited by a scarcity of nutrients from April to June, presumably due to the early flushing of phosphorus through the systems in February to March, followed by an absence of runoff events in April and May. High turbidity levels in June and July at Schoharie and in August at Ashokan-West reduced light availability to algae and is an additional factor explaining low plankton counts in these reservoirs.

For headwater Delaware reservoirs, lesser quantities of nutrients were available in the summer of 2008. These reservoirs experienced less drawdown than usual so nutrient inputs from resuspension were probably reduced in 2008. Rondout, the terminal reservoir of the Delaware System, had its lowest TSI in the last 11 years.

TSI in West Branch, a blend of Rondout and Boyd Corners reservoirs, was equivalent to its historical median level, approximately halfway between the TSI levels of its inputs. In 2008, Kensico received most of its water from Rondout and Ashokan-East and, to a lesser extent, West Branch. Although Kensico's TSI was slightly lower than its historical median it was about 5 TSI units higher than its primary inputs, perhaps an indication of local primary production.

TSI patterns were not consistent for the Croton System reservoirs but most were close to their historical medians or significantly lower (Figure 3.15). Sampling was insufficient to calculate representative medians at Croton Falls and the controlled lakes Kirk, Gilead, and Gleneida. The reservoirs that showed lower TSI in 2008 were associated with reduced phosphorus concentrations attributable to the very mild drawdown of these reservoirs in 2008.

TSI was higher than usual at three Croton System reservoirs: Boyd Corners, New Croton, and Muscoot. Productivity in Boyd Corners was up because of blooms in July and August, apparently brought on by rain events. New Croton had higher TSI in 2008 because its main input, Muscoot, had a high TSI. Reasons for Muscoot's productivity increase are not clear. Four of the five major inputs to Muscoot (Amawalk, Diverting, Titicus, and Cross River) were all lower in TSI than their respective long-term medians, with the highest TSI of 55 recorded at Diverting. Normally the receiving water in a cascading system will show less productivity than its inputs due to die off of algae and settling of algae and TP. This was not the case for Muscoot where, in 2008, a TSI of 61 was observed, much higher than any of these four inputs and the highest at Muscoot in the last 11 years. Potentially, elevated flow inputs from Croton Falls may be a factor. In recent years releases from Croton Falls to Muscoot have greatly increased to facilitate dam and pump repairs. These increased releases tend to keep water levels lower in Croton Falls, which, in general, tends to increase productivity. Unfortunately, the low water levels have also prevented samples from being collected at Croton Falls, so this possible source of productivity can not be verified. The morphometry of Muscoot may also be partly responsible. Most of the reservoir is shallow so the water is warm and the likelihood of nutrient resuspension due to storm events is increased. Finally, the dendritic morphometry of Muscoot's shoreline creates many backwater areas with abundant macrophyte growth, which greatly restrict flow. All of these factors tend to promote algal growth.

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

Total coliform and fecal coliform bacteria are regulated at raw water intakes by the SWTR at levels of 100 CFU 100 mL^{-1} and 20 CFU 100 mL^{-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.

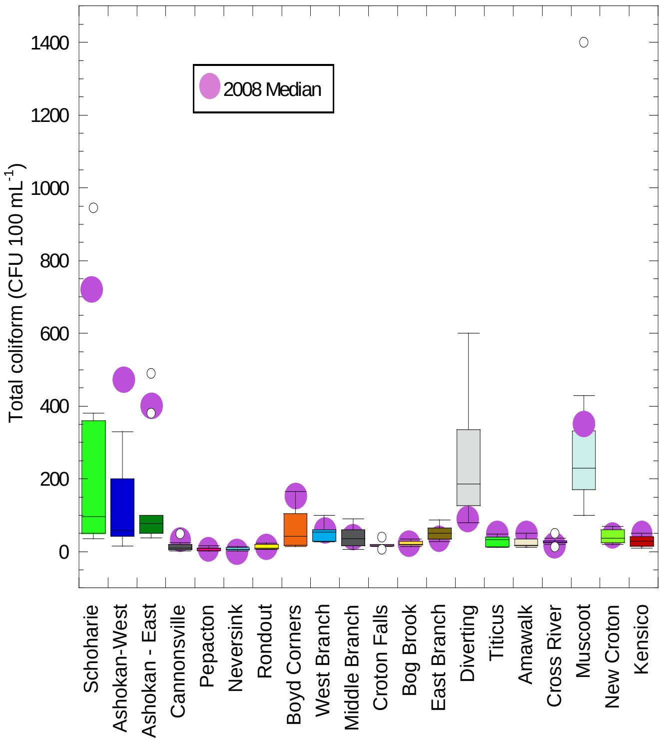


Figure 3.16 Annual median total coliform in NYC water supply reservoirs (2008 vs. 1998–2007).

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 2008 for Croton Falls Reservoir due to insufficient data.

Figure 3.16 shows that the long-term (1998–2007) annual median levels of total coliform usually exceed 100 CFU 100mL^{-1} in Diverting and Muscoot Reservoirs. This situation does not occur in any of the other Croton System reservoirs. Muscoot is much shallower than the other Croton System reservoirs and is susceptible to wind driven resuspension events, which may distribute bacteria and detritus into the water column. The shallow depths are also conducive to warm temperatures, which allow many types of coliforms to survive. Diverting is deeper, but has a small volume, and rapid flow through this reservoir may influence total coliform levels. Although the broad Y-axis scale of Figure 3.16 makes it difficult to discern changes, the 2008 data showed that some Croton reservoirs had large increases compared to their long-term medians. These include: Amawalk at 182%, Boyd Corners at 231%, Muscoot at 34%, and Titicus at 47%. For all Croton reservoirs, the highest coliform counts occurred during summer months and were very often associated with rainfall. Decreases were also apparent, most notably at Diverting and Cross River. Their median total coliform counts were down 39% and 20%, respectively. Reasons for the decrease are not clear, but may be related to the 2008 dam construction, which resulted in very low water levels and consequently fewer samples being collected. The remaining Croton reservoirs were very close to their long-term annual medians. In 2008, insufficient data exist from Croton Falls to accurately estimate the median.

Results for the controlled lakes—Gilead, Gleneida and Kirk—are provided in Table 3.4 below. The higher total coliforms observed at Kirk as compared to the other two lakes were probably due to sediment resuspension events common in shallow water bodies like Kirk, where mean depth is 2 meters.

Table 3.4: Coliform summary statistics for NYC controlled lakes (CFU $100mL^{-1}$).

Lake	Median Total Coliform (1998–2007)	Median Total Coliform (2008)	Median Fecal Coliform (1998–2007)	Median Fecal Coliform (2008)
Gilead	25	25	<1	<1
Gleneida	10	10	<1	<1
Kirk	86	40	<1	<1

In 2008, the Catskill reservoirs continued to have annual median total coliform levels that were above their long-term medians. Extensive periods of elevated coliform counts occurred in all Catskill basins during the 2005–2007 period and elevated coliform levels were usually observed during summer and fall. Research has shown that total coliforms commonly adhere to soil particles. Some of the bacteria have previously been determined to be of terrestrial origin. The Catskill System is underlain with glacial lacustrine clays that are easily mobilized during large storm events. Coliforms were probably transported to the reservoirs during runoff events by adsorption to the easily erodible clay particles common in the Catskill watersheds.

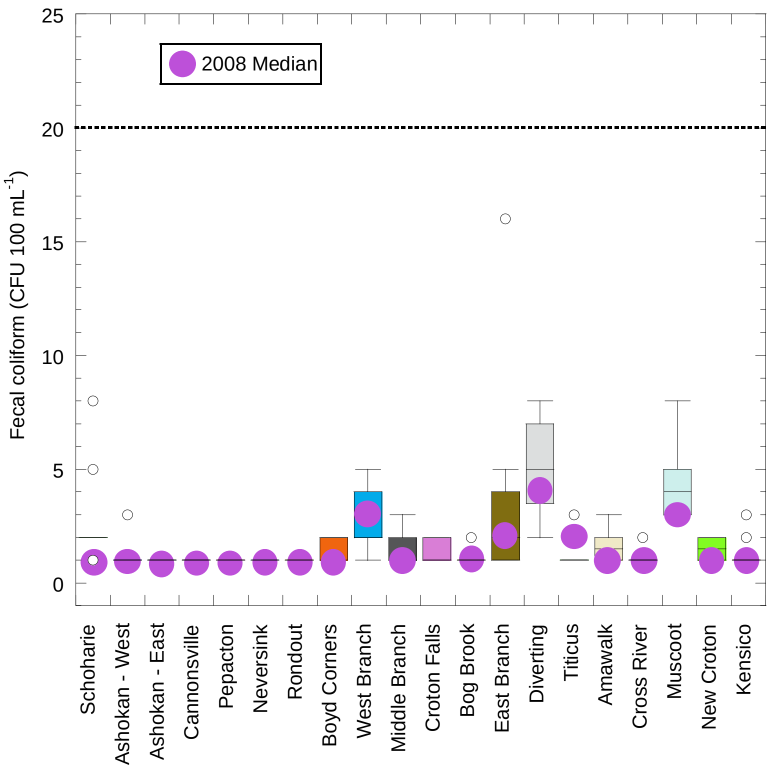


Figure 3.17 Annual median fecal coliform in NYC water supply reservoirs (2008 vs. 1998–2007). The dashed line represents the SDWA standard for source waters.

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 2008 for Croton Falls Reservoir due to insufficient data.

In contrast, all the Delaware reservoirs had medians near their long-term levels. Because stream banks and beds 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 3.17 compares the long-term (1998–2007) annual fecal coliform medians with the current (2008) annual median. Not enough data were collected in 2008 to estimate an accurate median for Croton Falls Reservoir. Fecal counts in the Croton reservoirs and controlled lakes were at or below the long-term median, and all were well below 20 CFU 100mL^{-1} (the SWTR limit for source waters). Reasons for the low counts are not clear although there was a scarcity of runoff events from September through November.

Fecal counts in the Catskill and Delaware Systems (including Kensico and West Branch) were very close to or lower than their historical long-term levels in 2008. West Branch did experience a brief spike in December coinciding with drawdown and elevated bird counts.

3.11 Which basins were coliform-restricted in 2008?

Coliform bacteria are used by water suppliers as 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 be given “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.

Terminal basin assessments. In 2008, assessments were made for all five terminal basins, and none received a restricted assessment (Table 3.5). Currently, coliform-restriction assessments are made using data from a minimum of five samples each week over two consecutive six-month periods. The threshold for fecal coliform is 20 CFU 100mL^{-1}. If 10% or more of the effluent samples measured have values ≥ 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 ≥ 20 CFU 100mL^{-1}, the associated basin is deemed "non-restricted".

Table 3.5: Coliform-restricted basin status as per Section 18-48 (b) (1) for terminal reservoirs in 2008.

Reservoir Basin	Effluent Keypoint	2008 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

* The site CROGH was only sampled from June through October due to shutdown of the Croton Aqueduct. Therefore, site CRO1T (at the intake near the dam—sampled daily) was used for this assessment.

Non-terminal basin assessments. Section 18-48(a)(1) requires that non-terminal basins be assessed according to 6NYCRR Part 703 for total coliform. These New York State regulations are specific to the class of the reservoir. A minimum of five samples must be collected per month on each basin. Both the median value and >20% of the total coliform counts for a given month need to exceed the values ascribed to the reservoir class to exceed the standard. Table 3.6 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. A detailed listing of these calculations is provided in Appendix D.

Table 3.6: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated values for a reservoir to exceed the standard.

Reservoir	Class	Standard monthly median/>20% (CFU 100mL^{-1})	Number of months that exceeded the standard/ Number of months of data
Amawalk	A	2400/5000	0/8
Bog Brook	AA	50/240	0/8
Boyd Corners	AA	50/240	3/8
Croton Falls	A/AA	50/240	1/4
Cross River	A/AA	50/240	1/8
Diverting	AA	50/240	2/3
East Branch	AA	50/240	1/8
Lake Gilead	A	2400/5000	0/8
Lake Gleneida	AA	50/240	0/8
Kirk Lake	B	2400/5000	0/7
Muscoot	A	2400/5000	0/8
Middle Branch	A	2400/5000	0/8
Titicus	AA	50/240	2/8
Pepacton	A/AA	50/240	0/8
Neversink	A	50/240	0/8
Schoharie	A	50/240	7/8
Cannonsville	A/AA	50/240	1/8

Note: The reservoir class is defined in 6NYCRR Parts 815, 862, 864, and 879. For those reservoirs that have dual designations, the higher standard was applied.

There were nine reservoirs that never exceeded the Part 703 standard for total coliform in 2008. These include Amawalk, Bog Brook, Lake Gilead, Lake Gleneida, Kirk Lake, Middle Branch, Muscoot, Pepacton, and Neversink. Schoharie Reservoir, however, exceeded the standard for seven out of eight months. The remaining reservoirs exceeded the standard for one to three months of the sampling season.

Total coliform originate from a variety of natural and anthropogenic sources. Therefore, it is not possible to utilize total coliform counts alone to perform non-terminal basin assessments. The NYC Watershed Rules and Regulations state that the source of the total coliforms must be proven to be anthropogenic to receive coliform-restricted status. Since other microbial tests for identification of potential sources were not performed on these samples, these results are only presented as an initial assessment of total coliform for the non-terminal basins in 2008.

3.12 How did reservoir water conductivity in 2008 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 have displayed uniformly low median conductivities in the past as well as in 2008 (Figure 3.18). 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. Urbanization pressure 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.

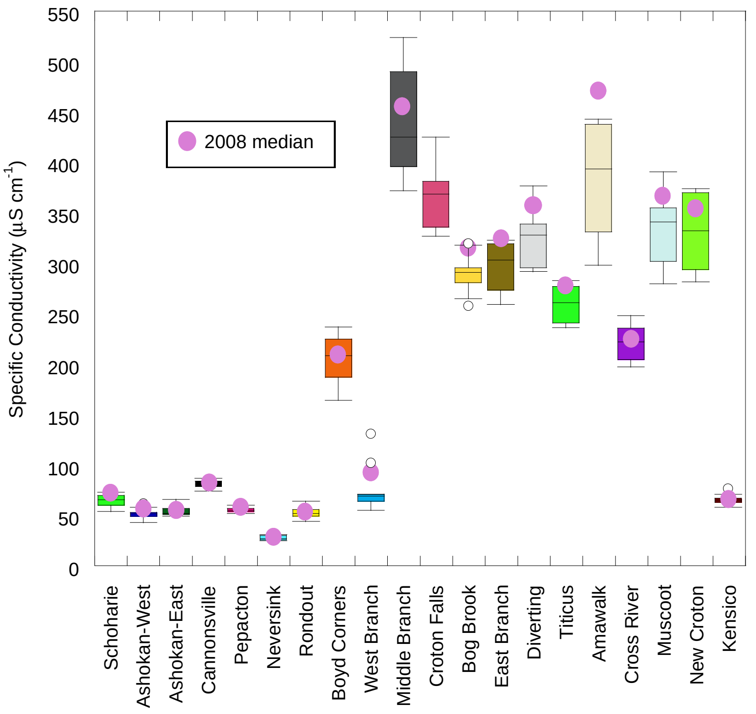


Figure 3.18 Annual median specific conductivity in NYC water supply reservoirs (2008 vs. 1998–2007).

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 2008 for Croton Falls Reservoir due to insufficient data.

With the exception of West Branch, conductivity in all Catskill and Delaware System reservoirs (including Kensico) were all very close to their historical median levels. Conductivity in West Branch, however, increased 33% compared to its historical median. West Branch is typically a blend of Rondout and the more conductive Boyd Corners Reservoir. However, in 2008, the Delaware Aqueduct was occasionally shut down and West Branch was often in “float” mode. This led to a greater contribution from Boyd Corners, causing an increase in conductivity. Similar situations occurred in 2002 and 2003 as indicated by the two outliers associated with the West Branch boxplot in Figure 3.18.

Conductivity median values in the Croton System were higher for most reservoirs in 2008 as compared to the past 10 years (Figure 3.18). Sufficient data were not available to report on Croton Falls and the controlled lakes. Bog Brook, East Branch, Diverting, Titicus, and Muscoot were close to their long-term maxima, while Amawalk exceeded its previous maximum of 443 µS cm^{-1} by 27 µS cm^{-1}. The increase in conductivity corresponds to an increase in chloride concentrations. Major sources of chloride include salt for de-icing roads, salt from water softener discharge, and even deposition from coastal storms. Additional investigation of weather patterns, de-icing operations, and other factors are necessary before these Croton System conductivity trends can be explained.

3.13 How did water quality in terminal reservoirs compare with regulatory standards in 2008?

The NYC reservoirs and water supply system are subject to the federal SWTR standards, NYS ambient water quality standards, and DEP's own target values. In this section these standards are compared with 2008 sampling data encompassing a variety of physical, biological, and chemical analytes for the terminal reservoirs (reservoirs that serve, or potentially serve, as source waters—Kensico, New Croton, Ashokan, Rondout and West Branch). Note that these standards are not necessarily applicable to the individual samples and medians described herein. Placing the data in the context of these standards assists in understanding the robustness of the water system and water quality issues.

Table 3.7 shows the 2008 median reservoir sampling values along with the standard for each of the physical, chemical, and biological analytes. Appendix A gives additional statistical information for the four reservoirs investigated here and on other reservoirs in the system. During the review of the summary statistics, the full data set was also reviewed to determine the extent to which the standards were exceeded (data not shown).

Table 3.7: Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the five terminal reservoirs in 2008.

ANALYTES	Standards	Kensico	New Croton	Ashokan East Basin	Ashokan West Basin	Rondout	West Branch
PHYSICAL							
Temperature (C)		11.4	10.9	10.5	9.5	10.4	13.8
pH (units)	6.5-8.5[1]	7	7.5	7.1	6.7	7	7.2
Alkalinity (mg/l)		10.6	60	9.9	10.1	6.5	17.9
Conductivity		67	353	56	55	53	95
Hardness (mg/l)[2]		19	88	16	18.1	14	22.1
Color (Pt-Co units)	-15	10	20	9	12	12	15
Turbidity (NTU)	(5) [3]	1.1	2	1.6	3.6	0.9	1.4
Secchi Disk Depth (m)		4.8	2.6	4.2	3.1	5.3	3.6

Table 3.7: (Continued) Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the five terminal reservoirs in 2008.

ANALYTES	Standards	Kensico	New Croton	Ashokan East Basin	Ashokan West Basin	Rondout	West Branch
BIOLOGICAL							
Chlorophyll a (µg/l)	7[4]	4.3	12	1.9	2.18	2.3	4.45
Total Phytoplankton (SAU)	2000[4]	260	540	170	180	155	440
CHEMICAL							
Dissolved Organic Carbon (mg/l)		1.5	2.9	1.5	1.3	1.5	2.0
Total Phosphorus (µg/l)	15[4]	6	14	8	8	7	9
Total Nitrogen (mg/l)		0.29	0.48	0.29	0.30	0.34	0.26
Nitrate+Nitrite-N (mg/l)	10[1]	0.19	0.21	0.18	0.222	0.26	0.131
Total Ammonia-N (mg/l)	2[1]	<0.01	0.04	0.02	<0.02	<0.02	<0.010
Iron (mg/l)	0.3[1]	0.02	0.07	0.03	0.05	0.02	0.06
Manganese (mg/l)	-0.05	na	na	na	na	na	na
Lead (µg/l)	50[1]	<1	<1	<1	<1	<1	<1
Copper (µg/l)	200[1]	<3	<3	<3	<3	<3	<3
Calcium (mg/l)		5.4	23	5	5.5	4.1	5.8
Sodium (mg/l)		5.4	33	3.8	3.79	3.6	8.80
Chloride (mg/l)	250[1]	9	67	6.7	6.6	6.9	19.0

Note: See Appendix A for water quality standards footnotes.

New Croton Reservoir water quality was noticeably different from the other terminal reservoirs. The median pH in New Croton was higher, as is often the case owing to its underlying geology and greater primary production. The latter can at times cause the pH to rise above the water quality standard of 8.5, especially in the upper waters during summer blooms. The median pH readings in WOH reservoirs were circumneutral. As a result of low alkalinity, however, readings can drop below the standard of 6.5, which they occasionally did in 2008. Alkalinity provides a buffer for acidic precipitation. Another factor contributing to lower pH values at depths below the thermocline is the acidifying effect of respiration.

Color readings in New Croton were approximately double that of the other terminal reservoirs and virtually all samples collected in 2008 exceeded the color standard of 15 units. Background color in New Croton is high, due in part to a relatively high percentage of wetlands compared to the WOH watersheds. The highest color readings were observed in bottom samples during summer, when iron and manganese were released from sediments and further discolored the water.

Median turbidity levels in all terminal reservoirs were well below the standard of 5.0 NTU. Relatively few turbidity values surpassed the standard in 2008. In New Croton, turbidity greater than 5 NTU mostly occurred in summer when hypolimnetic waters released metals from the sediments. Turbidity readings in Ashokan surpassed the standard in the spring and during rain events in October. Only one excursion was observed at Kensico in 2008 and it was associated with a minor October turbidity event originating in Ashokan. Rondout had no samples above 5.0 NTU.

The Croton System typically has greater nutrient inputs than the WOH reservoirs, which results in higher phytoplankton counts and chlorophyll *a* levels. Although the median phytoplankton count did not exceed the WQ guidance value in 2008, New Croton Reservoir had several events in the spring and summer where samples exceeded a total phytoplankton count above the 2000 SAU standard. Chlorophyll *a* for New Croton was usually above 7 $\mu g\ L^{-1}$ all year, although it was a relatively low productivity year as reflected in the trophic status plot (Figure 3.15). Rondout and Ashokan Reservoirs did not exceed 5.2 $\mu g\ L^{-1}$ of chlorophyll *a* while Kensico exceeded 7 $\mu g\ L^{-1}$ in April and just surpassed this criterion in October and November. These three reservoirs did not exceed 2000 SAU for phytoplankton in 2008. West Branch Reservoir infrequently exceeded 2000 SAU, primarily in the Site 4 basin which is influenced more from local streams rather than from Rondout.

Median total phosphorus was lower than the water quality guidance value of 15 $\mu g\ L^{-1}$ for each source water reservoir in 2008. There were no observations that surpassed this value in Rondout for 2008. Kensico exceeded the standard in 4 samples that were mostly associated with one local runoff event in late November. The East Basin of Ashokan exceeded the guidance value in 3 bottom samples, probably the result of anoxic sediments during late summer. None of the samples in the West Basin exceeded the TP guidance value. West Branch Reservoir infrequently exceeded the guidance criteria, again, primarily in the Site 4 basin. Nitrate was uniformly low in all reservoirs with no samples approaching the standard of 10 $mg\ L^{-1}$. Ammonia was very low for WOH terminal reservoirs and no excursions above the standard were evident. Although concentrations did not exceed the 2 $mg\ L^{-1}$ health standard at New Croton, there were occasions when ammonia exceeded 1 $mg\ L^{-1}$ in anoxic bottom samples.

No excursions for lead or copper were observed at any of the terminal reservoirs in 2008. Most samples were below the instrument detection limit.

Chloride levels in New Croton were approximately 10 times those observed in the WOH reservoirs. However, the highest, 69 $mg\ L^{-1}$, was still much lower than the standard of 250 $mg\ L^{-1}$. mocline is the acidifying effect of respiration.

3.14 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. This is 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 2008 sampling season, DEP had established 162 sampling sites in streams throughout the water supply watershed, with the greatest number in the Catskill System, followed by Croton and Delaware. 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-or-better record that were sampled in 2008 were examined, to reduce the chances that short-term variation, or aberrant samples, might cloud the analysis. (For sites with a five-year-or-better record not sampled in 2008, see DEP 2007a.) Twenty-seven (27) sites met the 5-year criterion, 11 in the Croton System, 9 in Catskill, and 7 in Delaware (Fig. 3.19). Of these, all but three were routine sites (generally, major tributaries to receiving reservoirs).

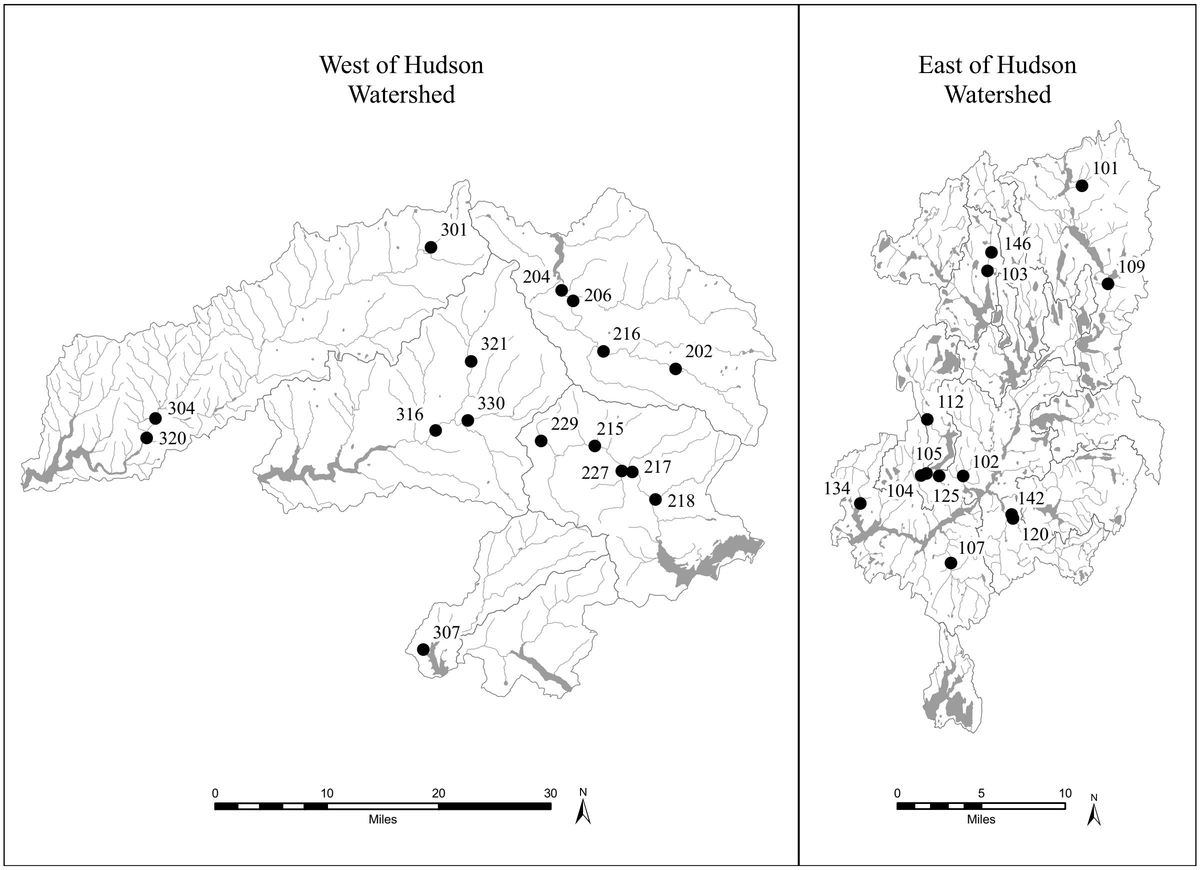


Figure 3.19 Stream biomonitoring sites with a 5-year-or-better record.

The data are plotted in Figures 3.20 and 3.21 for the East of Hudson and West of Hudson watersheds, respectively. With the exception of sites on Hallocks Mill Brook, located above and below the recently-upgraded Yorktown Heights wastewater treatment plant (see Section 3.15 for details), long-term changes to the macroinvertebrate community were not observed. At Site 109 on the East Branch of the Croton River, the upward trend in scores characterized by two non-impaired assessments in the previous three years (2005 and 2007) did not continue. The 2008 score, however, while resulting in a slightly impaired assessment, was nevertheless the third highest score ever recorded at the site. The return of the tolerant caddisfly *Cheumatopsyche* sp. to the high levels observed from 1995-2004 was largely responsible for the lower score and assessment in 2008. The reason for these fluctuations in *Cheumatopsyche* numbers is not known.

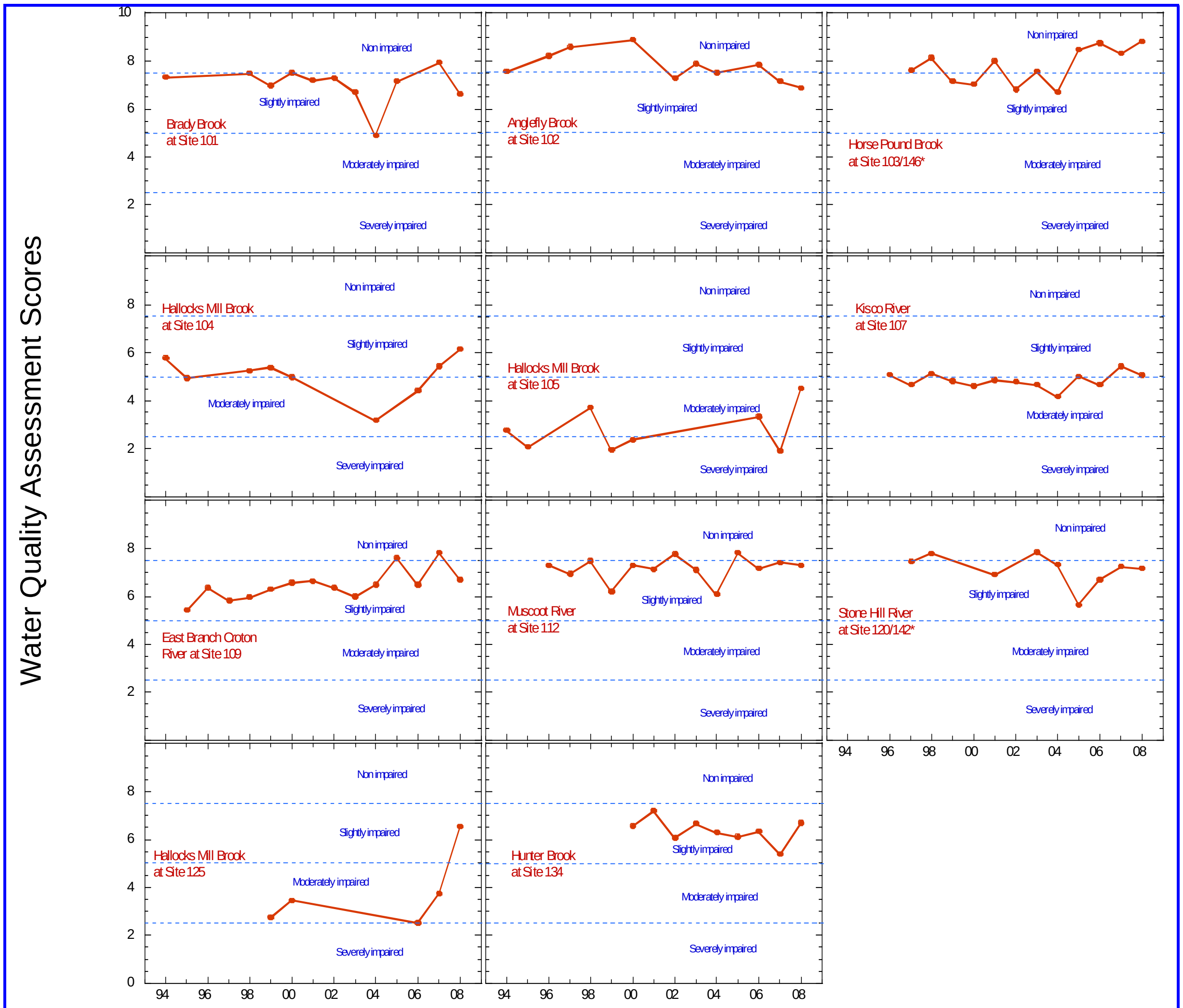


Figure 3.20 Water Quality Assessment Scores based on stream biomonitoring data for East of Hudson streams with a 5-year-or-better record.

*The Horse Pound Brook site was moved from Site 103 to Site 146 in 2004. The Stone Hill River site was moved from Site 120 to Site 142 in 2003. In both cases, data for the combined sites are plotted as a single graph.

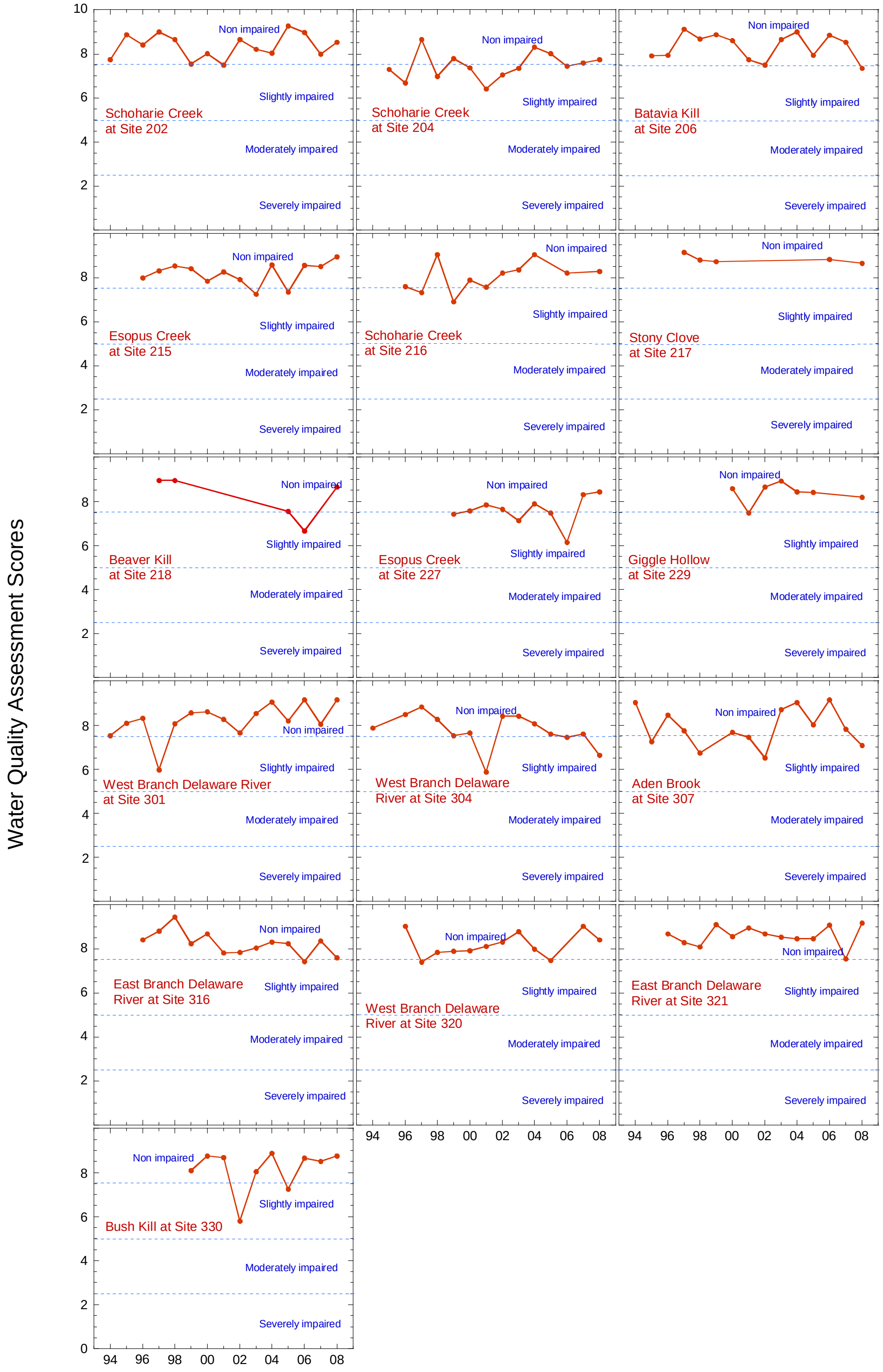


Figure 3.21 Water Quality Assessment Scores based on stream biomonitoring data for West of Hudson streams with a 5-year-or-better record.

At the Beaver Kill (a tributary to Esopus Creek in the Ashokan Reservoir watershed), the sharp decline in scores observed in recent years was reversed in 2008, after the mayfly *Acentrella turbida* returned to historical levels of abundance (43% of the total assemblage in 2006, 5.5% in 2008). The increase in *Acentrella* in 2006 depressed the taxa richness metric that year and probably the mayfly/stonefly/caddisfly richness metric as well. Spikes in *Acentrella* have occurred in Catskill streams before, often (but not always) during periods of high flows. Following such events, numbers of this mayfly usually retreat to previous levels, as they did in 2008, with concomitant increases in the two richness metrics.

3.15 What can sampling a stream's macroinvertebrate community tell us about the effectiveness of wastewater treatment plant upgrades?

Stream water quality plays a large role in the composition of benthic macroinvertebrate communities: unpolluted streams generally harbor more sensitive organisms and a more diverse assemblage than streams whose water quality is poor. Since upgrades to wastewater treatment plants often result in improved water quality to the receiving stream, the effectiveness of these enhancements can often be measured by sampling the stream's macroinvertebrate community and noting any changes that might indicate improved community composition. Chief among these would be an increase in the water quality assessment score, derived from applying protocols used by the NYS Stream Biomonitoring Unit (DEC 2002). Other critical measures include an increase in the number of sensitive organisms, like mayflies, caddisflies, and stoneflies, and in the number of total taxa.

In 2008, DEP gathered data providing strong evidence that wastewater treatment plant improvements at the Yorktown Heights wastewater treatment plant in Westchester County, NY, resulted in an improved biotic community in the receiving stream, Hallocks Mill Brook. For many years, the plant's discharge was characterized by high levels of ammonia, a substance which has been shown to cause mortality in a wide range of benthic invertebrates. From 1994-2007, for example, the annual concentration of ammonia, based on DEP's monitoring of the plant's discharge, averaged 21.7 mg L^{-1}. Although the average recorded in Hallocks Mill Brook at DEP's downstream monitoring site during the same period was lower (4.4 mg L^{-1}), it was still far higher than the NYS ambient water quality standard, which ranges from 0.007-0.050 mg L^{-1}, depending on pH and temperature. Concentrations of ammonia in the stream have generally been highest in summer/fall and lowest in winter, with a maximum during the 13-year period of 23.7 mg L^{-1} in October 1998 and a minimum of 0.09 mg L^{-1} in December 1996.

DEP began sampling Hallocks Mill Brook in 1994 to assess the impacts to the macroinvertebrate community of discharges from the treatment plant. Initially (1994, 1995, 1998), sampling was conducted at the DEP water quality monitoring sites above and below the plant (HMILL7 and HMILL4, respectively; biomonitoring Sites 104 and 105). In 1999 and 2000, three sites downstream of Site 105 were added (Sites 125, 126, and 127) in order to complete a longitudinal transect of the stream (Fig. 3.22). In the last three years (2006-2008), samples have been collected at Sites 104, 105, and 125.

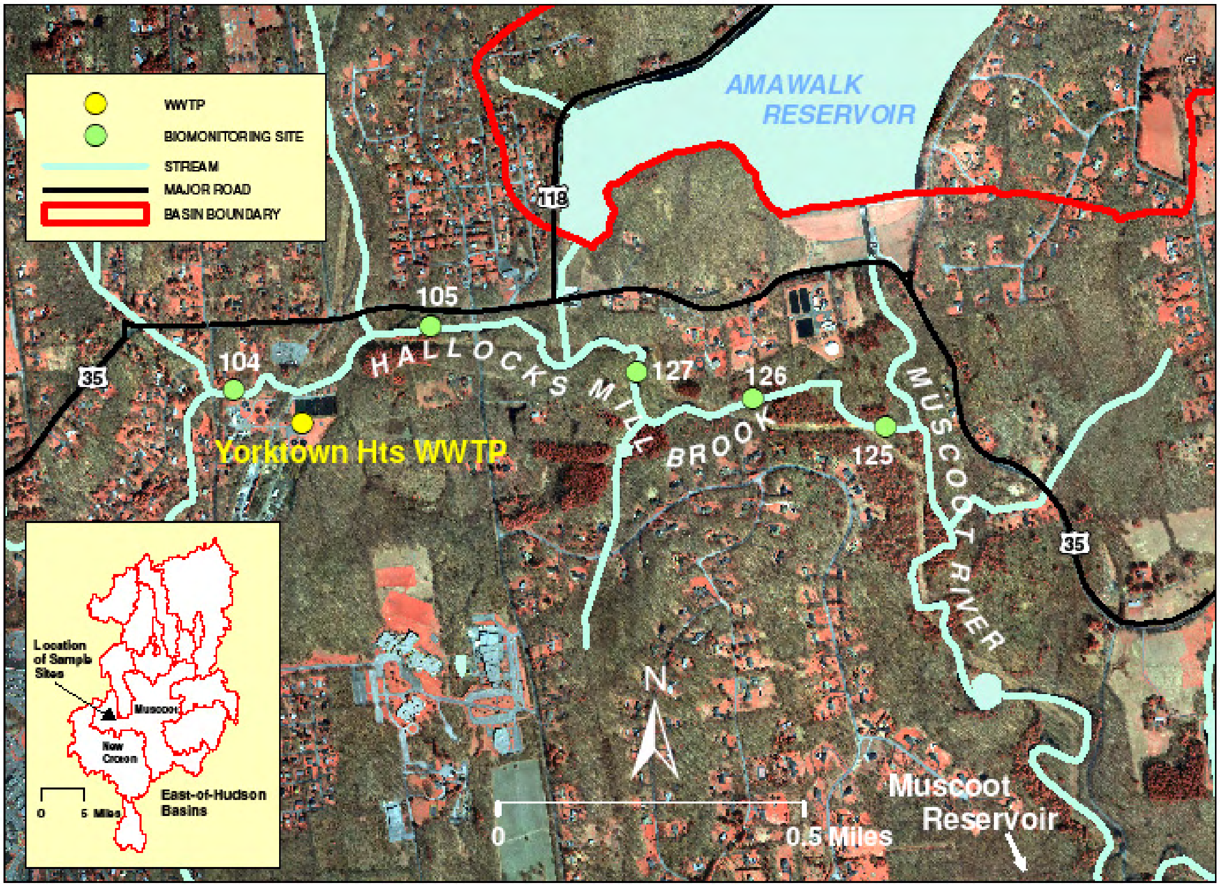


Figure 3.22 Location of Yorktown Heights wastewater treatment plant and biomonitoring sampling sites on Hallocks Mill Brook.

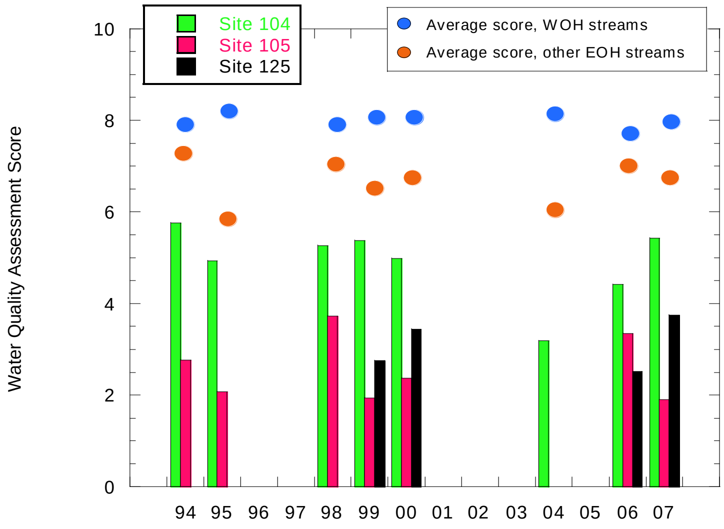


Figure 3.23 Water quality assessment scores at Hallocks Mill Brook biomonitoring sites 104, 105, and 125 compared to average scores for other NYC water supply watershed streams, 1994-2007.

Taken together, the biological assessments at the various sites on Hallocks Mill Brook indicate that, through 2007, it was the most seriously impacted stream in the entire New York City water supply watershed, with scores well below the average for other streams both East and West of Hudson (Fig. 3.23). During this period, no site below the treatment plant ever assessed higher than moderately impaired (the second worst category of impairment), while in the seven years it was sampled, the site directly below the plant (Site 105) assessed as seriously impaired (the worst rating) four times. The benthic community consisted almost entirely of midges and worms, two of the most tolerant macroinvertebrate groups. Only two mayfly individuals were ever collected, one from Site 105 in 1994 and one from Site 126 in 1999. The only other sensitive organism recorded, a glossossomatid caddisfly, was found at Site 105 in 1998.

In September 2007, new equipment was installed to reduce the levels of ammonia in the plant’s discharge. The result was dramatic. Between October 1 and November 1, 2007, effluent concentrations dropped from 17 mg L^{-1} to 5.6 mg L^{-1}, eventually reaching 1 mg L^{-1} by April 1 of the following year. In Hallocks Mill Brook, ammonia levels at the biomonitoring site below the treatment plant’s outflow (Site 105) showed similar declines—from 8.65 mg L^{-1} in October 2007 to 0.165 mg L^{-1} the following month. By August of the following year, ammonia levels were down to 0.112 mg L^{-1}. At the farthest site downstream (Site 125), data are available for only one pre- and post-reduction month, but the results are similar: 4.056 mg L^{-1} in August 2007 versus 0.012 mg L^{-1} in August 2008.

Figure 3.24 An ephemerellid mayfly, collected from Hallocks Mill Brook in May 2009.

The impact of these changes on the benthic macroinvertebrate community is clearly demonstrated by the biomonitoring samples collected in August 2008, particularly at the site farthest downstream, Site 125. The water quality assessment score at that location rose from 3.74 the previous year to 6.52, placing it in the slightly impaired category (the second highest) for the first time (Fig. 3.20). All four metrics used to calculate the score also improved substantially (Fig. 3.25). Perhaps most remarkable, almost 10% of the sample consisted of ephemerellid mayflies (Fig. 3.24). These organisms, uncommon in any East of Hudson stream, are extremely sensitive to pollution, with a tolerance value of 1 on a scale of 0-10, 0 being the most sensitive. Another 20% of the sample consisted of baetid mayflies. Baetids are more tolerant than ephemerellids, but are nevertheless sensitive organisms. Together, mayflies made up about one-third of the sample, even though none had ever been recorded at the site before (Fig. 3.25). Mayflies, along with caddisflies and stoneflies, are generally considered the best macroinvertebrate indicators of clean water.

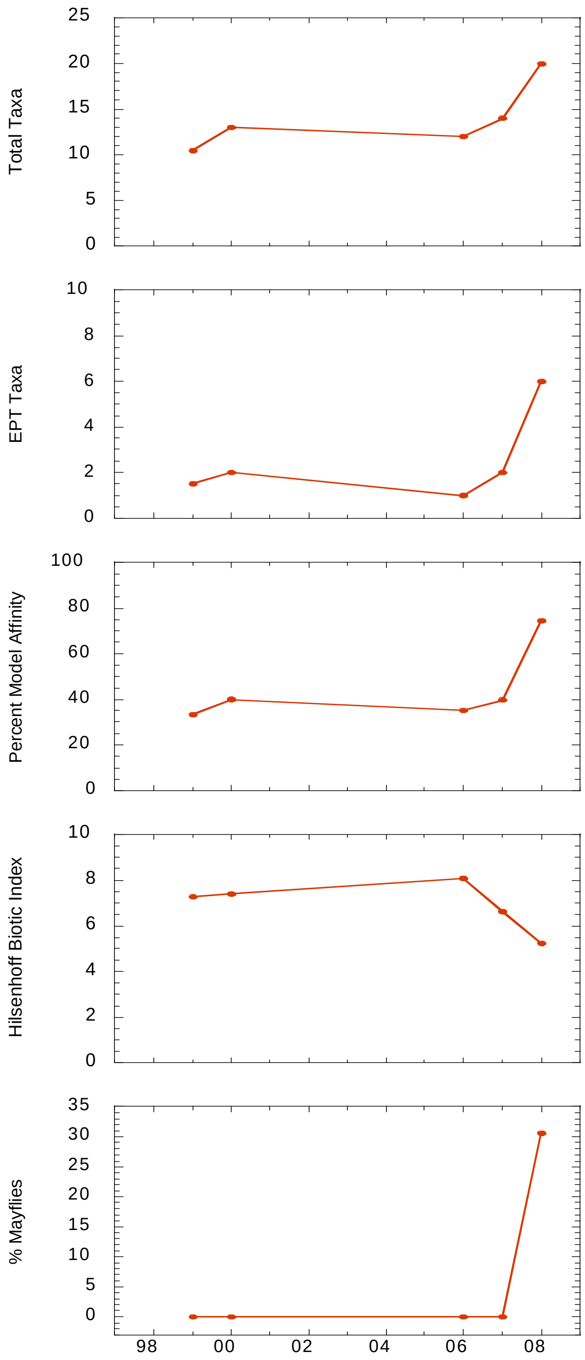


Figure 3.25 Metric scores and percent mayflies recorded at Site 125 on Hallocks Mill Brook, 1998-2008. Total taxa is the total number of taxa present; EPT taxa is the total number of mayflies, stoneflies, and caddisflies; Percent Model Affinity is a measure of the community's similarity to a model non-impacted community as defined by the NYS Stream Biomonitoring Unit; the Hilsenhoff Biotic Index is a measure of organic pollution, with low values indicative of clean water conditions.

DEP went back to the site in May 2009 to determine if these organisms were actually living in Hallocks Mill Brook or had accidentally been washed upstream from the nearby Muscoot River, to which Hallocks Mill is a tributary. Ten late instar ephemerellids were found, indicating they had been living, and growing, in the stream since the previous August, when only early instars had been collected. The continuous presence of these larvae over a period of nine months is strong evidence of the improvement to water quality that has occurred in the stream as a result of modifications to the wastewater treatment plant.

Site 105, the site closest to the plant's discharge, assessed as moderately impaired in 2008 but nevertheless had a record high score of 4.38. No sensitive organisms, however, were found. DEP will return to this site and to Site 125 in 2009 to see if the improved community at the latter site persists and to determine whether sensitive insects like mayflies colonize farther upstream in the wake of the stream's improved water quality.

3.16 What are disinfection by-products, and did organic concentrations in source waters allow DEP to meet compliance standards in the distribution system in 2008?

Disinfection by-products (DBPs) form when naturally occurring acids from decomposing vegetative matter (such as tree leaves, algae, and macrophytes) reacts with chlorine during chlorination of drinking water. The quantity of DBPs in drinking water varies 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. Drinking water is disinfected by public water suppliers to kill bacteria and viruses that could cause disease. Chlorine is the most commonly used disinfectant in New York State. For this reason, disinfection of drinking water by chlorination is beneficial to public health.

DEP monitors two important groups of DBPs: trihalomethanes (TTHM) and haloacetic acids (HAA). TTHM are a group of chemicals that includes chloroform, bromoform, bromodichloromethane, and chlorodibromomethane, of which chloroform is the main constituent. HAA are a group of chemicals that includes mono-, di- and trichloroacetic acids and mono- and dibromoacetic acids. USEPA has set limits on these groups of DBPs under the Stage 1 Disinfectant/Disinfection By-Products Rule. The Maximum Contaminant Level (MCL) for TTHM is 80 $\mu g\ L^{-1}$ and the MCL for the five haloacetic acids covered the rule (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 2008 annual running quarterly averages are presented in Table 3.8 and show system compliance for TTHM and HAA5 in both the Catskill/Delaware and Croton Distribution Areas of New York City.

Table 3.8: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations (µg L^{-1}) for 2008.

	Catskill/Delaware		Croton	
2008 Quarter	TTHM	HAA5	TTHM	HAA5
1st	37	38	46	41
2nd	39	38	49	42
3rd	38	37	46	40
4th	37	38	49	45
MCL	80	60	80	60

4. Pathogens

4.1 How many samples did DEP collect for *Cryptosporidium*, *Giardia* and human enteric viruses in 2008, and what were the occurrences and concentrations in the "source waters"?

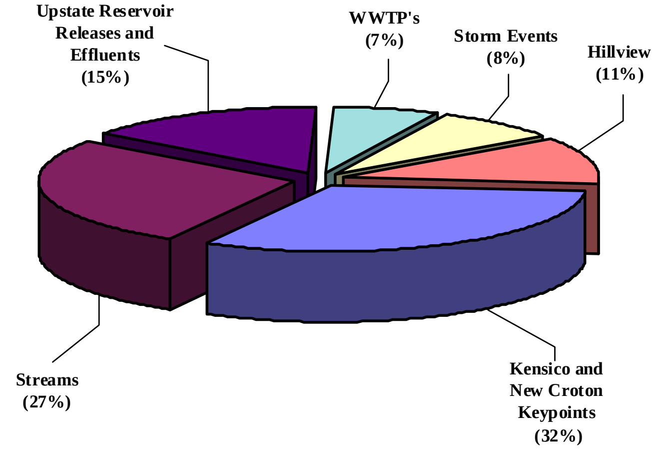


Figure 4.1 DEP sample type distribution for 2008 (includes routine and enhanced monitoring samples).

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 781 routine samples for protozoan analysis during 2008, which does not include 78 additional samples related to special projects. DEP collected 317 HEV samples in 2008. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2008 sampling effort, accounting for 31.5% of the samples, followed by stream samples, which were 27.4% of the sample load. Upstate reservoir effluents, wastewater treatment plants (WWTPs), storm events, and Hillview Reservoir sampling made up the remaining 41.1% of samples (Figure 4.1).

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 HEVs. The effluent results are posted weekly on DEP's website (DEP 2006c), monthly in the Croton Consent Decree and USEPA reports, and semi-annually in the Filtration Avoidance Determination reports (DEP 2006d,e)**.**

Catskill Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at CATALUM (Catskill influent to Kensico Reservoir) were low, with a mean of 0.13 oocysts 50L^{-1} and 7 positive detections out of 52 samples (13.5%) (Table 4.1). The *Cryptosporidium* results at CATLEFF (Catskill effluent of Kensico Reservoir) were also very low, although slightly greater than at CATALUM, with a mean of 0.23 oocysts 50L^{-1} and 10 positive detections out of 52 samples (19.2%).

The *Giardia* cyst concentration at CATALUM had a mean of 0.71 cysts $50L^{-1}$ with 20 positive detections out of the 52 samples (38.5%) (Table 4.1). Mean *Giardia* concentrations at CATLEFF were higher than those at CATALUM, with a mean of 2.01 cysts $50L^{-1}$ and 46 positive detections (88.5%).

Table 4.1: Summary of *Giardia*, *Cryptosporidium*, and HEV compliance monitoring data at the five DEP keypoints for 2008 (includes enhanced monitoring samples).

	Keypoint Location	# of samples	# of positive samples	Mean***	Max
Cryptosporidium oocysts $50L^{-1}$	Catskill Influent	52	7	0.13	1.00
	Catskill Effluent	52	10	0.23	2.00
	Delaware Influent*	52	6	0.15	1.98
	Delaware Effluent	52	1	0.02	1.00
	New Croton Effluent**	56	8	0.21	3.00
Giardia cysts $50L^{-1}$	Catskill Influent	52	20	0.71	5.00
	Catskill Effluent	52	46	2.01	7.00
	Delaware Influent *	52	26	1.02	5.00
	Delaware Effluent	52	39	1.69	8.00
	New Croton Effluent **	56	26	0.73	4.00
Human Enteric Viruses $100L^{-1}$	Catskill Influent	52	11	0.42	7.06
	Catskill Effluent	52	3	0.19	5.75
	Delaware Influent*	52	14	0.50	5.76
	Delaware Effluent	52	7	0.16	2.13
	New Croton Effluent **	52	6	0.21	4.46

*Includes alternate sites sampled to best represent DEL17 during “off-line” status.
**Includes alternate sites sampled to best represent CROGH during “off-line” status.
***Zero value is substituted for non-detect values when calculating mean.

Concentration and detection frequency of HEVs at CATALUM were low in 2008 with a mean concentration of 0.42 MPN $100L^{-1}$ and 11 positive detections out of 52 samples (21.2%) (Table 4.1). Similar to previous years, HEV results were somewhat lower at CATLEFF than at CATALUM during 2008, with 0.19 MPN $100L^{-1}$ and 3 positive detections (5.8%) continuing to suggest that the reservoir acts as a sink for viruses.

Delaware Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at DEL17 (Delaware influent to Kensico Reservoir) were low, with a mean of 0.15 oocysts $50L^{-1}$ and 6 positive detections out of 52 samples (11.5%) (Table 4.1). *Cryptosporidium* concentrations at DEL18

(Delaware effluent of Kensico Reservoir) were very low, with a mean of 0.02 oocysts 50L^{-1} and only 1 positive detection out of 52 samples (1.9%). The mean concentration and detection frequency at DEL18 remain unchanged from 2007 levels.

The *Giardia* cyst concentration at DEL17 had a mean of 1.02 cysts 50L^{-1} with 26 positive detections out of the 52 samples (50.0%) (Table 4.1). Mean *Giardia* concentration and detection frequency at DEL18 were higher than those at DEL17, with a mean concentration of 1.69 cysts 50L^{-1} and 39 positive detections out of 52 samples (75.0%).

HEV concentration and detection frequency at DEL17 were 0.50 MPN 100L^{-1} and 14 positive detections out of 52 samples (26.9%) (Table 4.1). Much like the Catskill Aqueduct and similar to results from previous years, HEV results were somewhat lower at DEL18 than at DEL17 during 2008, with a mean concentration of 0.16 MPN 100L^{-1} and 7 positive detections out of 52 samples (13.5%).

New Croton Aqueduct

Protozoan sample results at CROGH (New Croton Reservoir effluent) for 2008 had a mean *Cryptosporidium* concentration of 0.21 oocysts 50L^{-1} and 8 positive detections out of 56 samples (14.3%) (Table 4.1). CROGH had a mean *Giardia* concentration of 0.73 cysts 50L and 26 positive detections out of 52 samples (50.0%).

Results for HEV sampling at CROGH were low, with a mean of 0.20 MPN 100L^{-1} and 6 positive detections out of 52 samples (11.5%).

As in prior years, a seasonal variation could be detected for *Giardia* at all influent and effluent sites in 2008, with winter and spring having higher concentrations and more frequent occurrences than summer and fall (Figure 4.2). Some seasonality can be seen for *Cryptosporidium* at Kensico Reservoir’s Delaware influent and Catskill effluent, as well as at the New Croton Reservoir effluent. In general, *Giardia* occurrences were much more frequent and at higher concentrations than *Cryptosporidium* at the source water sites.

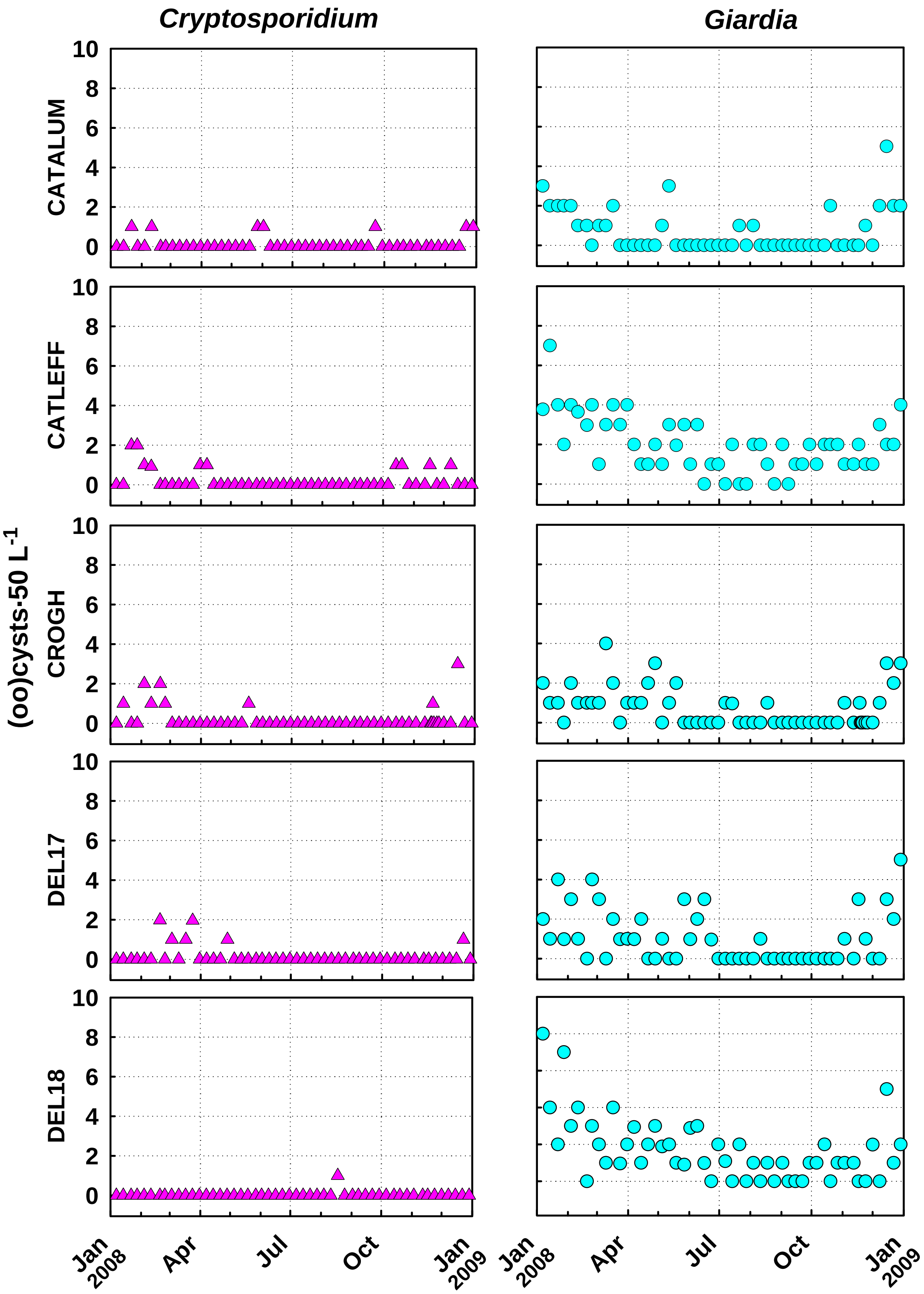


Figure 4.2 Routine weekly source water keypoint monitoring results for 2008.

4.2 How did protozoan concentrations compare with regulatory levels in 2008?

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) (USEPA 2006) requires that utilities conduct monthly source water monitoring for *Cryptosporidium* over a two-year period, though a more frequent sampling schedule may be used. The LT2 requires all unfiltered public water supplies to "provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*." If the average source water concentration exceeds 0.01 oocysts per liter based on the LT2 monitoring, "the unfiltered system must provide at least 3-log (i.e., 99.9 percent) inactivation of *Cryptosporidium.*" The average concentration is determined by calculating the mean monthly results for two years, and then calculating the mean of those monthly means. For perspective, results have been calculated here using data from the most recent two-year period (January 1, 2007 to December 31, 2008), including all routine and non-routine samples (Table 4.2).

Table 4.2: Number and type of samples used to calculate the average *Cryptosporidium* concentration under the LT2ESWTR from January 1, 2007 to December 31, 2008.

Aqueduct	# of routine samples	# of non-routine samples	Total N
Croton	105	4	109
Catskill	105	4	109
Delaware	105	2	107

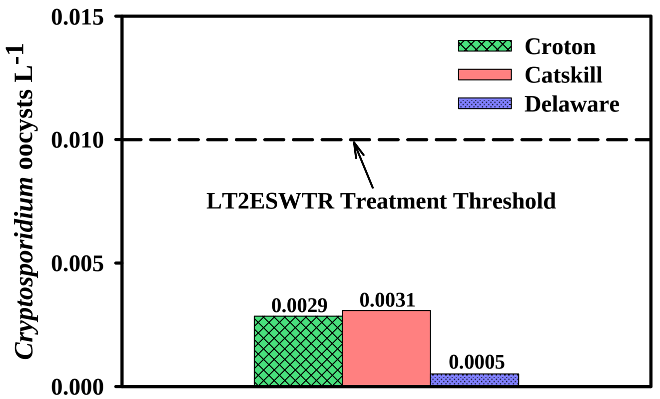


Figure 4.3 The 2007–2008 LT2ESWTR calculated means for *Cryptosporidium* at DEP's three source waters—Croton, Catskill, and Delaware.

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) classification level. Unfiltered systems that do not meet this requirement are required to provide at least 3-log inactivation of *Cryptosporidium*. The averages, as shown in Figure 4.3, are as follows: 0.0029 oocysts L^{-1} at the Croton effluent, 0.0031 oocysts L^{-1} at the Catskill effluent, and 0.0005 oocysts L^{-1} at the Delaware effluent.

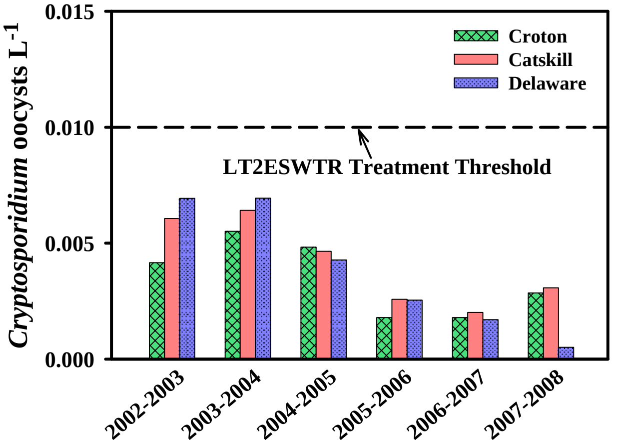


Figure 4.4 The 2002–2008 LT2ESWTR calculated means for *Cryptosporidium* since the start of Method 1623 at DEP's three source waters—Croton, Catskill, and Delaware.

Compared to the previous two-year period (2006–2007), the 2007–2008 Croton and Catskill means were greater, although still lower than the first three two-year calculation periods using Method 1623 (Figure 4.4). Conversely, the Delaware Aqueduct LT2ESWTR means have been decreasing steadily since the 2002–2003 period. The current Delaware LT2ESWTR mean is about 30% of the previous period's mean value.

In addition to calculating the LT2ESWTR means in a given two-year period, a more in-depth investigation of the possibility of operational changes explaining a greater or lesser mean was performed for the Delaware System. For the current two-year period, there were two significant shutdown periods (2/19/2008–3/04/2008 and 10/25/2008–11/25/2008), which may have affected the source water going through the Delaware Aqueduct. Upon comparing the *Cryptosporidium* results during the same periods in previous years, there were no differences (all results during these time periods were non-detects), suggesting that the shutdown did not significantly affect *Cryptosporidium* means for the current two-year period. Other possible reasons for the decline in *Cryptosporidium* over the last several years in the Delaware System may include improvements in upper watershed land use or upgrades of WWTPs, suggesting a positive effect of the Watershed Management Plan**.** As for the slight increase of *Cryptosporidium* in the Croton and Catskill Aqueducts, no notable operational changes were made that would provide an explanation. The current two-year mean remains well below the means observed from 2002–2005 (Figure 4.4). These slight increases or decreases may ultimately be due to natural variability of oocyst load and weather patterns within the watershed in the studied timeframe.

4.3 How do 2008 source water concentrations compare to historical data?

DEP's source water monitoring is conducted at five sites in the EOH System, four of which represent the Catskill and Delaware influents and effluents of Kensico Reservoir, with New Croton Reservoir's effluent being the fifth site. Water quality can vary at the source water sites depending on several factors in their respective watersheds, such as stormwater runoff, environmental impacts from land use, and the effects of other ecological processes, such as algal blooms. Each source water site has been sampled weekly, using EPA's Method 1623HV since October 2001. This has given DEP a large dataset with several years of samples for the detection of seasonal patterns and long-term changes in protozoan concentrations with respect to public health concerns and risk assessment.

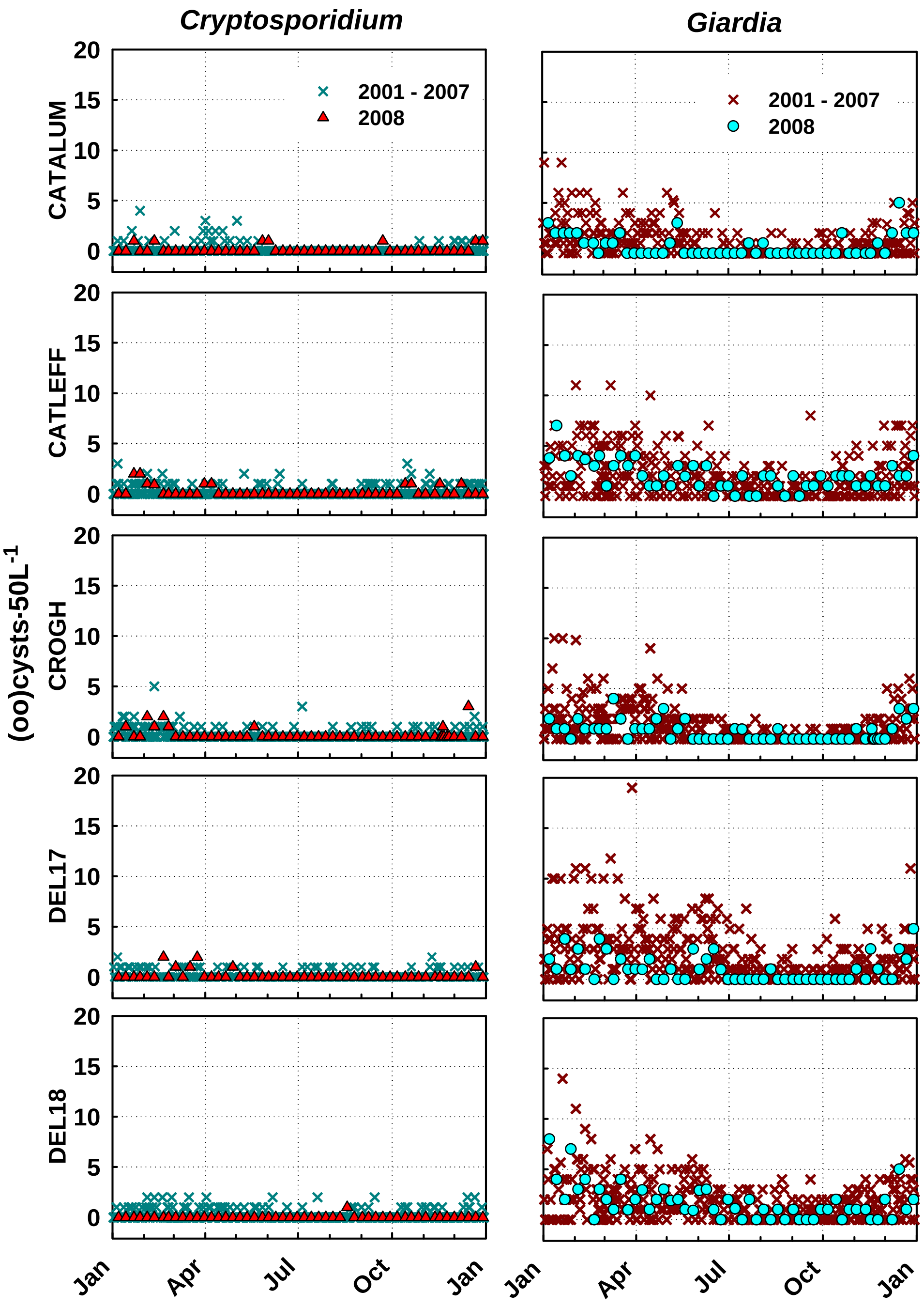


Figure 4.5 Source water keypoint weekly sampling results from October 2001–December 2008. For *Cryptosporidium*, the red triangles represent 2008 and the blue "x"s represent 2001–2007 data (left). For *Giardia*, the blue circles represent the 2008 data, while the red "x"s represent the 2001–2007 data (right).

Pathogen sample data collected in 2008 indicate that concentrations of *Giardia* and *Cryptosporidium* remained relatively low for most of the source water sites. When compared to data collected from 2001 to 2007 at the same sites, the Delaware Aqueduct influent and effluent and the Catskill influent at Kensico Reservoir exhibited lower or similar mean concentrations for both *Giardia* and *Cryptosporidium* in 2008, with a marked drop in the occurrence of *Cryptosporidium* at the Delaware effluent (Figure 4.5). Sampling in 2008 at New Croton Reservoir's effluent showed only slight differences in the occurrence rates and mean concentrations for either protozoan when compared to 1623HV data from all previous years. The Catskill Aqueduct effluent data showed only very slight increases in the mean concentrations for both pathogens compared to the previous years of 1623HV data and only a slight increase in *Giardia* occurrence.

A seasonal pattern is evident for *Giardia* at all source water sites in 2008; however, this seasonal pattern is much less clear, or absent, for *Cryptosporidium*, due to a heavy predominance of non-detects and detects at low concentrations. To more clearly illustrate the presence or absence of this seasonal trend at the different source water sites, a locally weighted scatterplot smooth (LOWESS) curve was plotted through the data points (Figures 4.6 and 4.7). A suggestion of seasonality occurs with *Cryptosporidium* data; however, the events are sporadic and are not statistically significant due to the high number of non-detects. LOWESS curves for *Giardia* sampling show increasing concentrations of cysts generally in the fall and winter months and decreasing concentrations in the spring and summer months. There is some disturbance to this seasonal pattern caused by a change of methods in 2005–2006, during which time a different USEPA-approved stain was used for laboratory analysis.

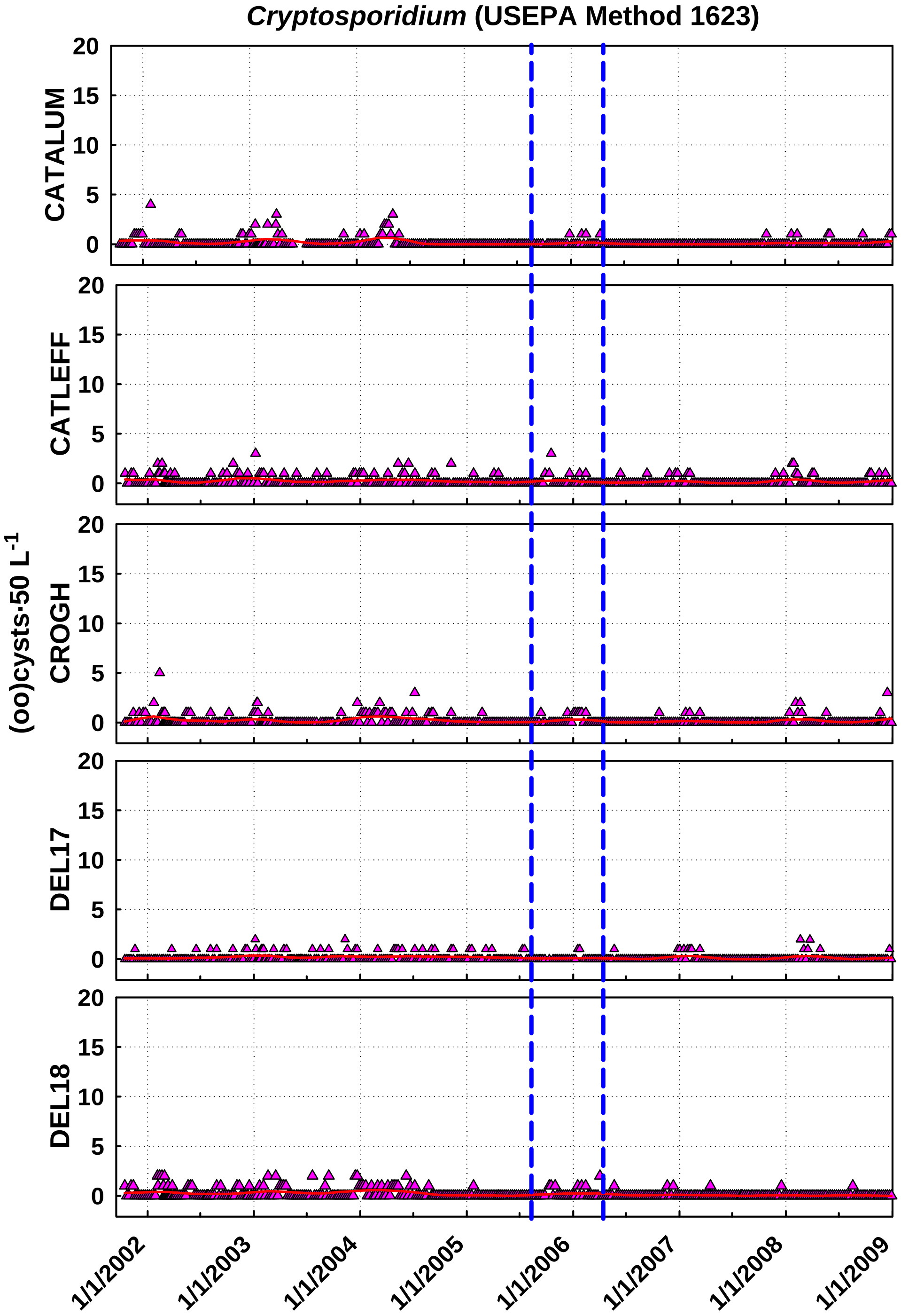


Figure 4.6 Weekly routine source water keypoint results for *Cryptosporidium* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2008. The area between the blue dotted lines indicates the period during which the DEP laboratory temporarily switched to a different USEPA-approved stain (Method Change).

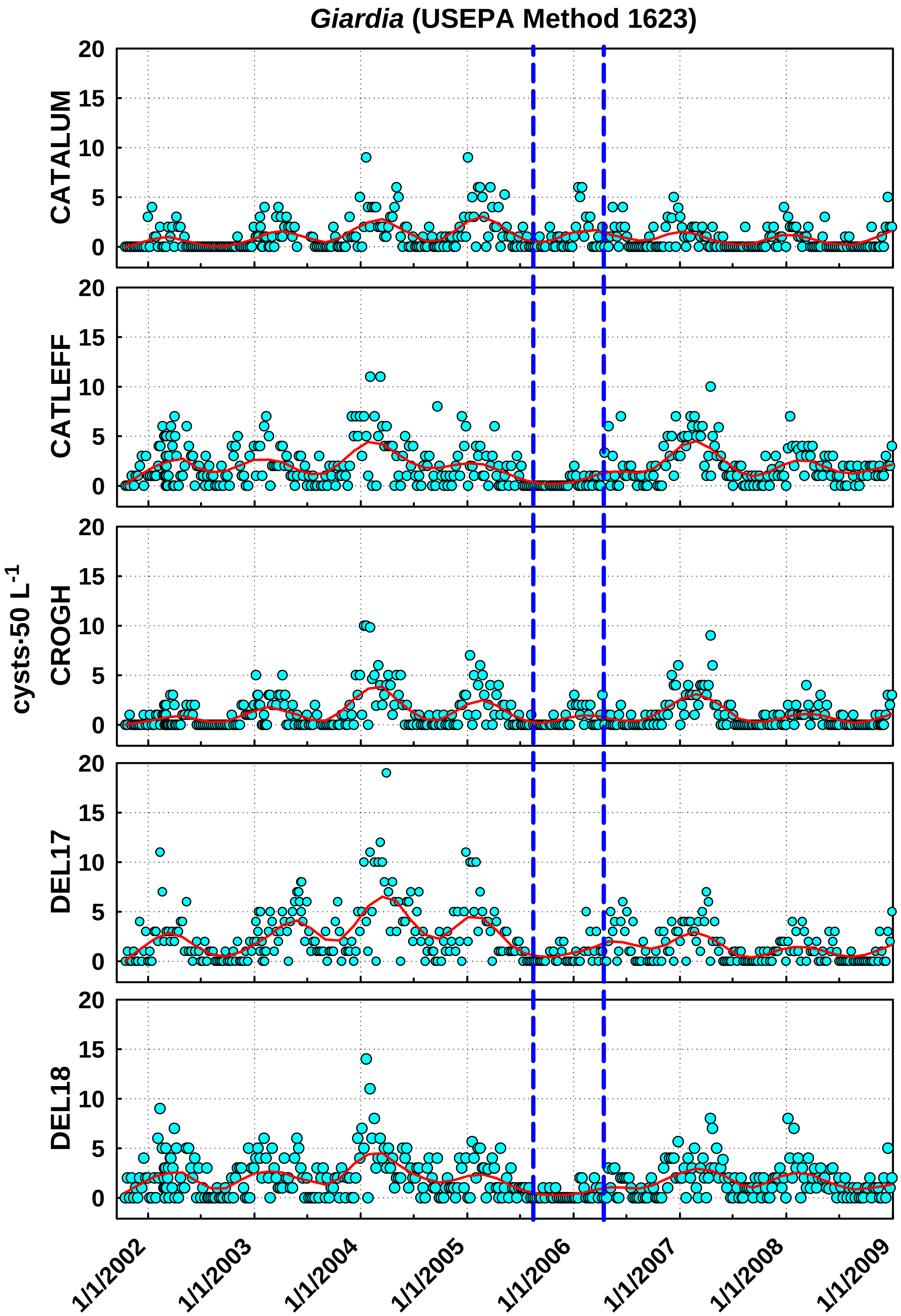


Figure 4.7 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2008. The area between the blue dotted lines indicates the period during which the DEP laboratory temporarily switched to a different USEPA- approved stain (Method Change). Note the absence of a seasonal peak during that period.

4.4 What concentrations of *Cryptosporidium* and *Giardia* were found in the various NYC watersheds in 2008?

The NYC Watershed covers 1972 square miles and includes several sub-watersheds, which empty into 19 reservoirs and three controlled lakes. As part of the objectives outlined in the Integrated Monitoring Report (IMR) (DEP 2003a), DEP has monitored the major tributaries and reservoir releases of the various reservoirs to assess and compare the relative pathogen concentrations at each of the watersheds. The various IMR objectives have included both fixed-frequency and event-based pathogen monitoring.

Fixed-frequency Sampling

The monthly fixed-frequency monitoring results indicate very low concentrations of *Cryptosporidium* in the WOH Watershed in 2008 (Figure 4.8). Sites CDG1 and PMSB, which are part of the Cannonsville and Pepacton Reservoir watersheds, respectively, had relatively higher means compared to the other sites, with mean oocyst concentrations of 3.6 and 7.5 50L^{-1}, respectively (Figure 4.8). Aside from these two sites, results were similar to 2007 data. The aforementioned sites are among those that have been identified for further monitoring in the new Watershed Water Quality Monitoring Plan (which succeeds the IMR) (DEP 2008a); hence DEP will continue to monitor these sites.

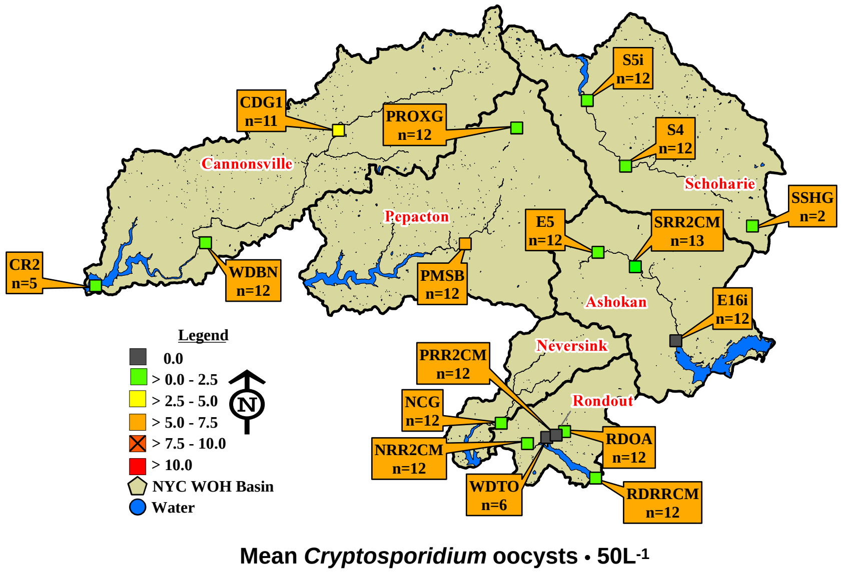


Figure 4.8 Fixed-frequency *Cryptosporidium* monitoring results in the WOH watershed in 2008 (n = sample size).

The 2008 WOH watershed *Giardia* concentrations were consistently higher at WDBN, CDG1, PROXG, and S5i, and resulted in mean values of 70.5, 73.4, 52.0, and 32.0 cysts 50L^{-1}, respectively. These sites are located in the Cannonsville, Pepacton, and Schoharie Reservoir watersheds, respectively, and the results are similar to the 2007 findings. Accordingly, these sites have been identified as locations for future monitoring in the new Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2008a), and will continue to be sampled. The *Giardia* concentrations at the remaining sites range from very low to moderate and are similar to the 2007 results.

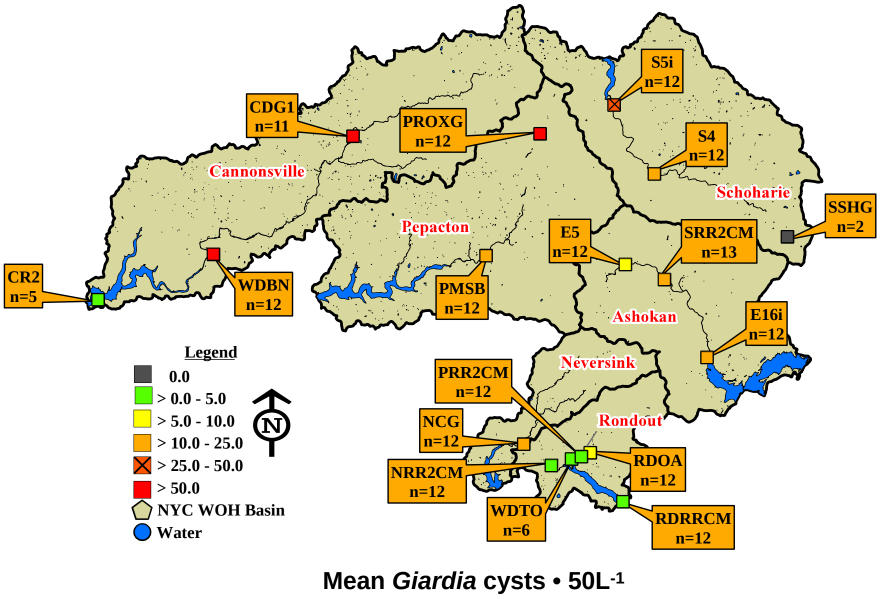


Figure 4.9 Fixed-frequency *Giardia* monitoring results in the WOH watershed in 2008 (n = sample size).

Only 11 of the 12 scheduled monthly samples were obtained at sites CDG1 and CR2/WDTO due to samples freezing while being transported to the laboratory in February. Since the original samples were taken at the end of the month, no resampling was able to be performed before March. In addition to their monthly samples, sites SRR2CM and RDRRCM had one and two enhanced samples, respectively. The SRR2CM resample was in response to the 12/04/08 sample, which had 79 *Giardia*. The resample, performed on 12/30/08, had 58 *Giardia*. Further investigation revealed that operational flow had increased just prior to the time the original sample (79 cysts) was taken, and that surface runoff had been very high around the time of the resample (58 cysts). Results from subsequent sampling returned close to mean levels at this site. It is likely that flow management and precipitation were associated with these elevated results.

Regarding site RDRRCM, in August 2008 the Bureau of Water Supply (BWS) reconfigured the sample collection piping at the Rondout Effluent Chamber keypoint site by extending the piping from the lower valve chamber up to the basement level. This modification was made to address sampler safety concerns. This change did not affect the location of water withdrawal; it only affected the location of the sample collection point. BWS did not consider this a sample site change; however, to confirm that the new piping had no effect on results, a side-by-side comparison was performed at the upper and lower locations. The results of these paired samples are shown in Table 4.3. Sampling officially began at the new tap location in October of 2008. It should be noted that the new sample collection point is only used for pathogen sampling at this time; all other keypoint sampling is being performed at the original location in the lower valve chamber.

Table 4.3: Side-by-side *Cryptosporidium* and *Giardia* results obtained to verify the equivalence of the existing sample site and the proposed sample site at RDRRCM. RDRR = proposed sample site. MS = Matrix Spike Sample.

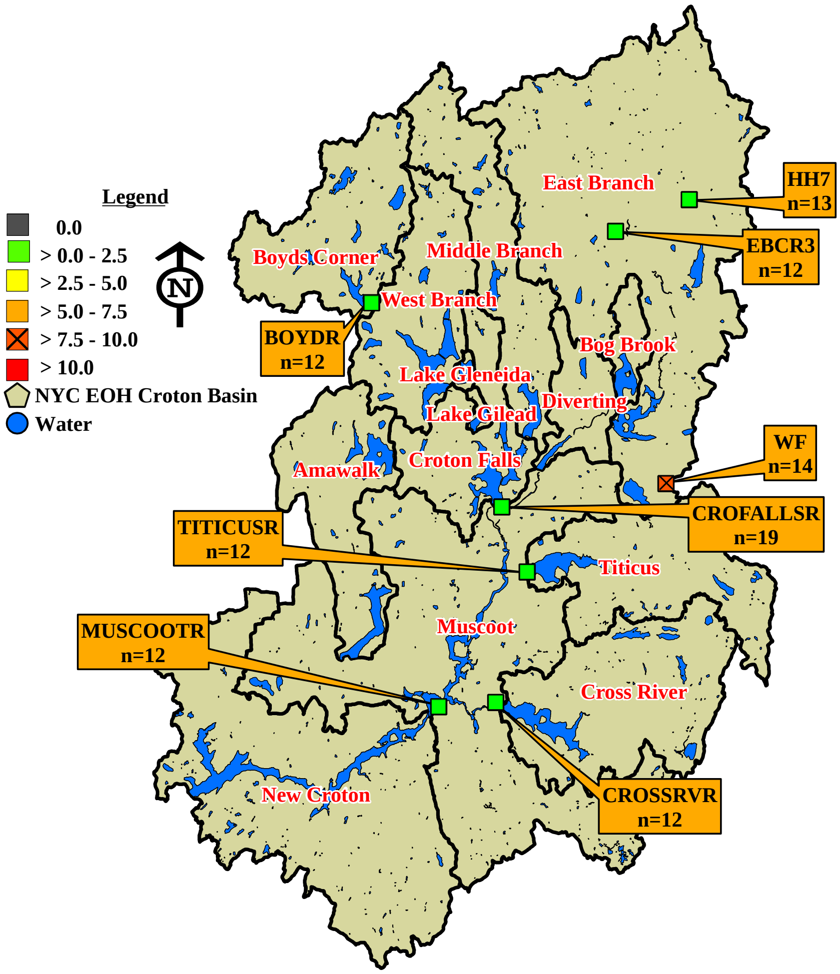
Date	Site	*Cryptospordium* oocysts $50L^{-1}$	*Giardia* cysts $50L^{-1}$
8/27/08	RDRRCM	0	0
8/27/08	RDRR	0	0
9/29/08	RDRRCM	1	0
9/29/08	RDRR	0	0
9/29/08	RDRR-MS	57%	59%

Sample site SSHG was only sampled twice in 2008. This site was sampled as part of a storm water monitoring project, and these data were part of the baseline sampling component.

Sample sites in the Croton watershed were sampled monthly. Mean *Cryptosporidium* concentrations were found to be very low, except for the Willow Farm (WF) site , which is located in the East Branch watershed (Figure 4.10). This site had a moderate mean *Cryptosporidium* concentration of 8 oocysts $50L^{-1}$. Two especially high sample results were obtained on 6/10/08 and 11/21/08 (29 and 54 oocysts $50L^{-1}$, respectively). The WF site is sampled pursuant to the Croton Consent Decree and will continue to be monitored in the future.

Mean *Giardia* concentrations were found to be very low to low, except for sites HH7 and EBCR3, which had mean *Giardia* concentrations of 40.5 and 31.3 cysts $50L^{-1}$, respectively (Figure 4.11). These are both located in the East Branch watershed. One especially high *Giardia* result (exceeding the 95th percentile) was obtained at both HH7 and EBCR3 in 2008 (188 and 193 cysts $50L^{-1}$, respectively).

Enhanced sampling occurred at HH7, WF, and CROFALLSR this year. The extra sample at HH7 was a resample following the 188 *Giardia* cysts found on 8/12/08. The resample was collected on 8/29/08 and yielded 20 cysts. Site WF was resampled twice in 2008. The first was on 6/17/08, following 29 *Cryptosporidium* oocysts discovered on 6/10/08. Protozoan results for this resample were 8 oocysts and 31 cysts. The second WF resample in 2008 was on 12/3/08 after 54 oocysts and 28 cysts were recovered on 11/21/08. Results of this resample were 4 oocysts and 21 cysts. Contrary to HH7and WF, enhanced sampling at CROFALLSR this year was not a result of following up on elevated counts of cysts or oocysts. Seven enhanced samples were taken from CROFALLSR as a result of an operational change which resulted in the utilization of the release hydraulic pump at CROFALLSR. The enhanced sampling results were all very low: only one *Cryptosporidium* oocyst was found on 11/03/08 and one *Giardia* cyst on 10/27/08 and 12/08/08.



Mean *Cryptosporidium* oocysts • 50L^{-1}

Figure 4.10 Fixed-frequency *Cryptosporidium* monitoring results in the Croton watershed in 2008 (n = sample size).

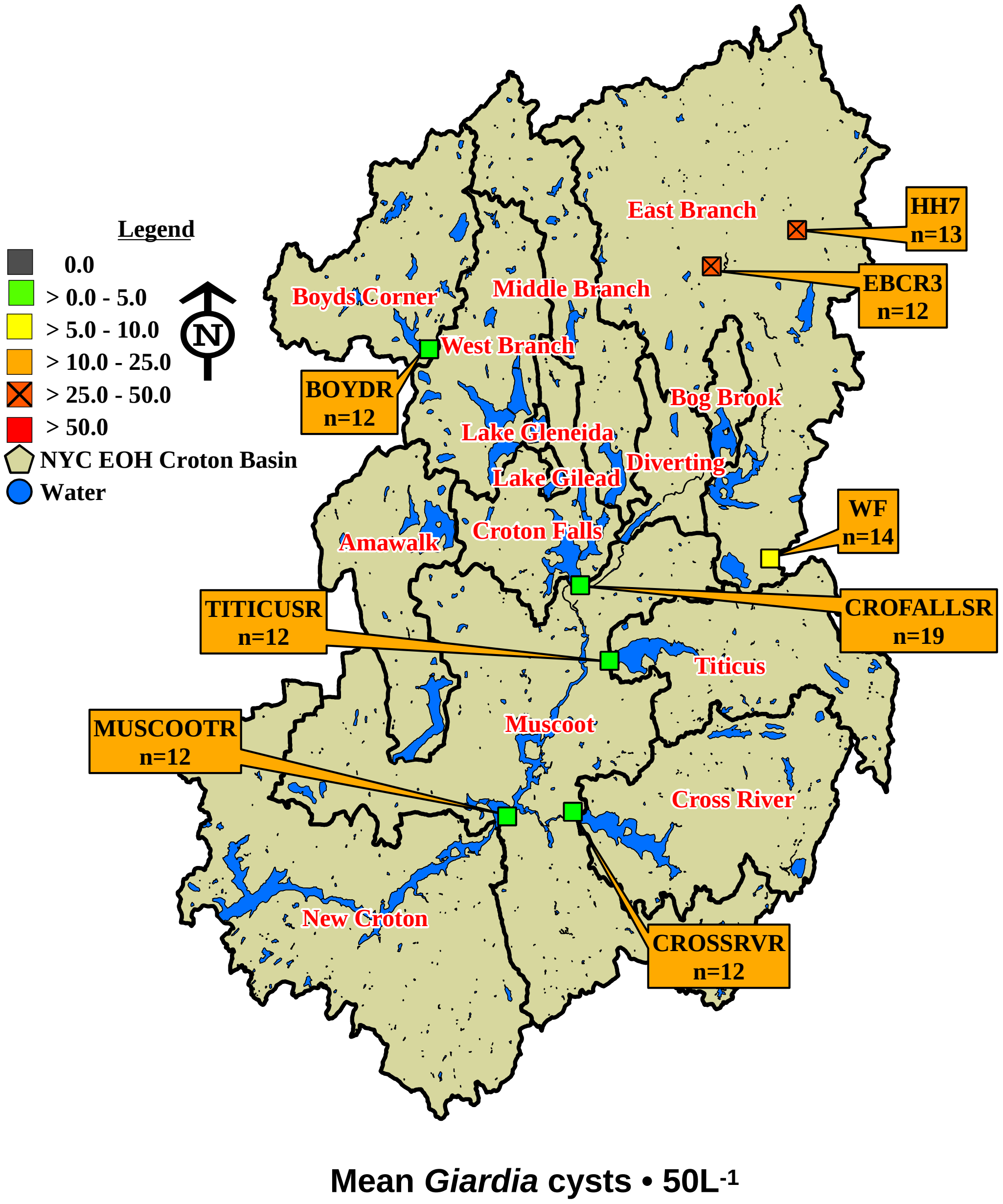


Figure 4.11 Fixed-frequency *Giardia* monitoring results in the Croton watershed in 2008 (n = sample size).

The Kensico watershed stream sites are sampled bi-monthly, except for site MB-1, which is sampled monthly due to its proximity to the Catskill Aqueduct. Mean *Cryptosporidium* concentrations were found to be very low at all sites. These results are similar to those obtained in 2007 (Figure 4.12).

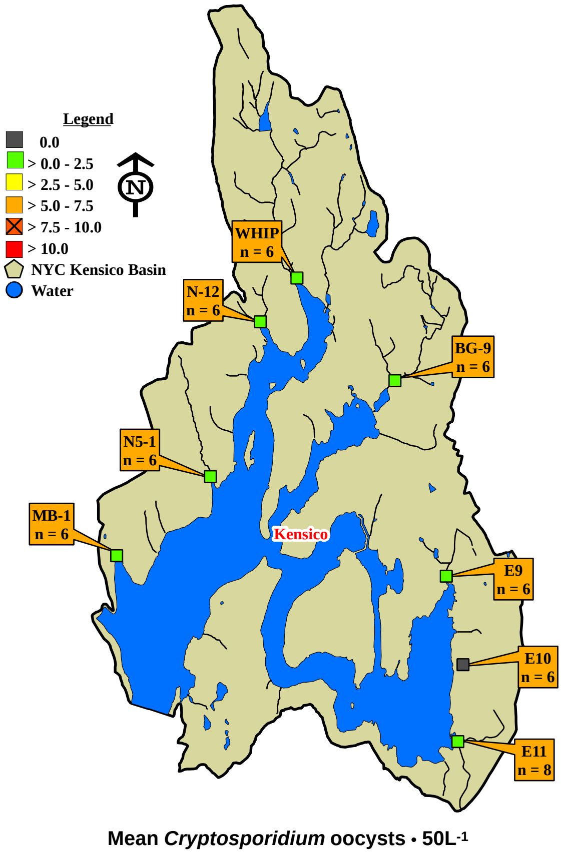


Figure 4.12 Fixed-frequency *Cryptosporidium* monitoring results in the Kensico watershed in 2008 (n = sample size).

Mean *Giardia* concentrations were found to be very low to moderate, except for site E11, which had a mean *Giardia* concentration of 112.2 cysts 50L^{-1}(Figure 4.13). While the 2008 mean was much higher, E11 also had the highest mean *Giardia* concentration in 2007. For the other sites, the 2008 mean *Giardia* concentrations were similar to, or lower than, the 2007 results.

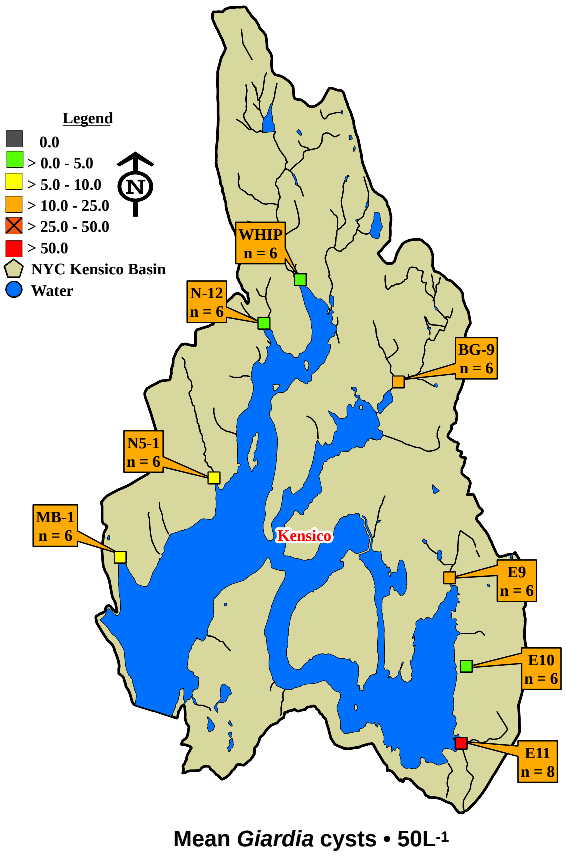


Figure 4.13 Fixed-frequency *Giardia* monitoring results in the Kensico watershed in 2008 (n = sample size).

The high mean at site E11 can be attributed to one extremely high count of 590 cysts 50L^{-1} found in a sample taken on 6/03/08. The E11 sample site is a BMP effluent located in the southeast portion of the Kensico watershed between I-684 and Westchester County Airport. Enhanced samples were subsequently obtained at the BMP influent and effluent sites (E11, E11 N1, and E11 S1) as well as from the sediment of the BMP inlet and main basin (Table 4.4). The enhanced sample results were low at all locations, and did not suggest any chronic environmental contamination.

Table 4.4: Enhanced monitoring results at E11 in response to an elevated result.

Sample Date	Site	Sample Volume (L)	*Cryptosporidium* (# oocysts)	*Giardia* (# cysts)
11-Jun-08	E11	50	0	26
	E11N1	50	1	4
	E11S1	50	0	3
26-Jun-08	E11*	n/a	0	0

Table 4.4: (Continued) Enhanced monitoring results at E11 in response to an elevated result.

Sample Date	Site	Sample Volume (L)	*Cryptosporidium* (# oocysts)	*Giardia* (# cysts)
	E11 MAIN*	n/a	0	0
	E11N INLET*	n/a	0	0
	E11	30	1	0
	E11N1	50	0	7
	E11S1	50	0	6

* Sediment samples.

According to the WWQMP, all Kensico streams will be sampled monthly (rather than bi-monthly) to be consistent with sampling at MB-1, which is already sampled monthly. These results will be included in future reports.

Event-based sampling

As per the 2003 IMR objective outlining event-based monitoring strategies for reservoirs, DEP performed storm event sampling at three WOH sites (SSHG, S4, and S5i) and 5 EOH sites (E10, MB-1, N5-1, N5-1 Main, and N5-1 Trib) in 2008. The WOH sites are located along Schoharie Creek, which empties into Schoharie Reservoir, and the EOH sites are located on tributaries to Kensico Reservoir. The EOH sites represent two pre-BMP stream sites (N5-1 Main and N5-1 Trib) and two post-BMP stream sites (N5-1 and MB-1), in addition to a site on an unmodified stream system (E10).

In general, *Cryptosporidium* concentrations were very low to low, except at N5-1 (Table 4.5). This mean concentration is much higher than the fixed-frequency sampling results and is consistent with previous results**,** which found that event-based monitoring pathogen concentrations were consistently higher than baseline results.

Mean *Giardia* concentrations were low to moderate except for N5-1, which was high (Table 4.5). N5-1 is the BMP outlet, which is fed by N5-1 Main and N5-1 Trib. Previous results suggest that the current in-line BMP design does not always attenuate protozoan pathogen concentrations and this N5-1 result is consistent with this finding.

As suggested in previous findings, event-based (oo)cyst concentrations at the WOH sites along Schoharie Creek, which begin at the headwaters (SSHG), showed notably higher mean concentrations at the mid-tributary site, S4 (Table 4.5); however, this result is based on a sample size of only 2. Previous sampling results indicate that (oo)cyst concentrations tend to increase with increased distance downstream.

Table 4.5: Event-based *Cryptosporidium* and *Giardia* monitoring mean results per 50L.

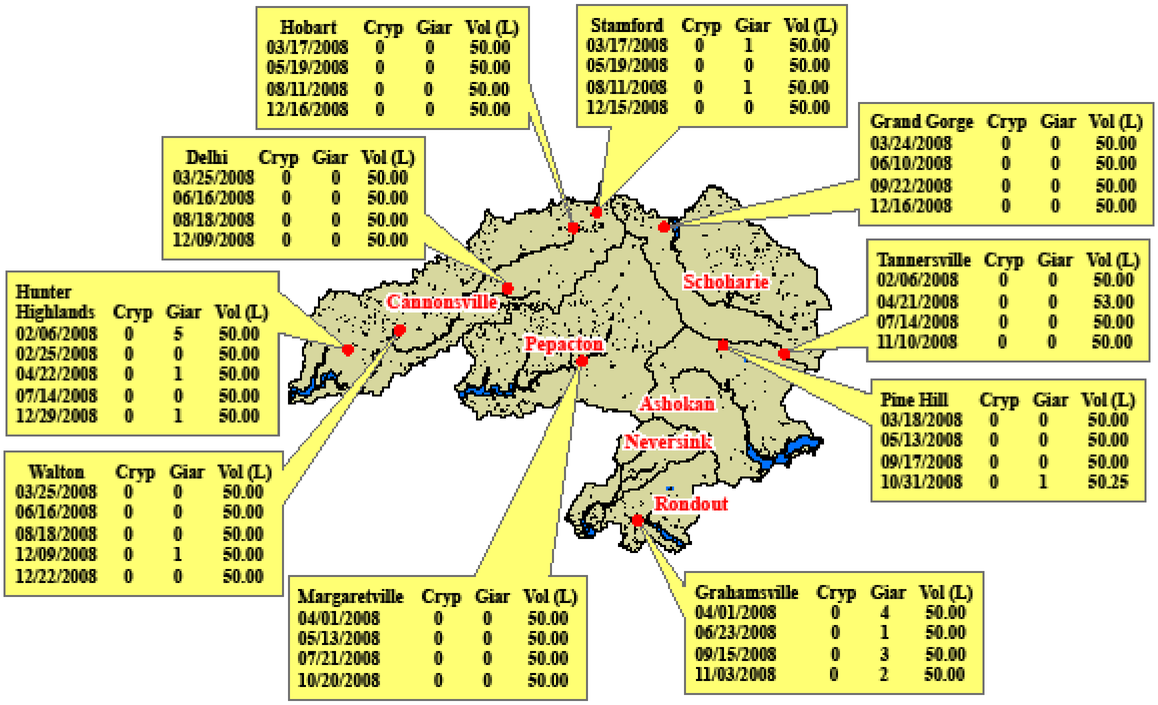
Watershed	Site	N	*Cryptosporidium* oocysts $50L^{-1}$	*Giardia* cysts $50L^{-1}$
Kensico (EOH)	E10	13	0.7	10.8
Kensico (EOH)	MB-1	11	0.8	17.2
Kensico (EOH)	N5-1	12	11.7	37.8
Kensico (EOH)	N5-1MAIN	13	0.0	12.5
Kensico (EOH)	N5-1TRIB	11	4.8	18.5
Schoharie (WOH)	S5I	2	0.0	2.8
Schoharie (WOH)	S4	2	2.0	20.4
Schoharie (WOH)	SSHG	2	0.0	0.0

4.5 What levels of protozoa and HEVs were found in WWTP effluents?

DEP began monitoring pathogens and HEVs at 10 WOH WWTPs in July 2002 as part of the IMR. Since then sampling at each plant’s final effluent has been conducted a minimum of four times annually. As in 2007, the WWTPs sampled in 2008 were Hunter Highlands, Delhi, Pine Hill, Hobart, Margaretville, Grahamsville, Grand Gorge, Tannersville, Stamford, and Walton (Figure 4.14). In addition, the East of Hudson Brewster Sewage Treatment Plan (BSTP) was sampled monthly for *Cryptosporidium* and *Giardia* and bimonthly for HEVs to satisfy the requirements of the Croton Consent Decree (CCD).

West of Hudson

A total of 42 *Cryptosporidium* and *Giardia* samples were taken at the 10 WOH WWTP sites. Of these, 40 were routine samples and two were enhanced follow-up samples based on routine sample results. Of the 42 samples taken, none (0.0%) were positive for *Cryptosporidium* and 11 (26.2%) were positive for *Giardia*. A total of two enhanced samples were taken, one at Hunter Highlands on 2/25/08 and one at Walton on 12/22/08. Over the years of sampling WWTPs, there has been evidence that positive results at some of the sites could be attributed to wildlife at uncovered chlorine contact tanks or grates. Consequently, sites of this design with a history of positive detects do not automatically warrant a resample for concentrations that are within the low to mid range of historical data. For example, Grahamsville has been documented as having issues with *Cryptosporidium* or *Giardia* detection. It is hypothesized that the source is from an open chlorine contact tank prior to the sample point, which is susceptible to use by wildlife, and wildlife have been observed at this location. Since the results were within the range of historical data, no follow-up enhanced sampling was conducted at this site. However, at the Walton WWTP, no wildlife exposure was initially suspected, hence an additional sample was taken when one *Giardia* cyst was detected in a 50L sample. However, in retrospect, this resample would not have been collected at this concentration because it has now been determined that wildlife may have access to this site. The other resample, which occurred at the Hunter Highlands WWTP, was in response to a *Giardia* result that was on the higher end of the spectrum of historical results, and taken despite the suspected exposure to wildlife (Figure 4.14). In both enhanced follow-up samples, no *Giardia* or *Cryptosporidium* were detected. As part of the monitoring under the WWQMP, sampling will be conducted prior to the point of potential wildlife exposure at the Grahamsville WWTP, which has had the greatest issue with protozoan pathogen detection.



Hobart	Cryp	Giar	Vol (L)
03/17/2008	0	0	50.00
05/19/2008	0	0	50.00
08/11/2008	0	0	50.00
12/16/2008	0	0	50.00

Stamford	Cryp	Giar	Vol (L)
03/17/2008	0	1	50.00
05/19/2008	0	0	50.00
08/11/2008	0	1	50.00
12/15/2008	0	0	50.00

Grand Gorge	Cryp	Giar	Vol (L)
03/24/2008	0	0	50.00
06/10/2008	0	0	50.00
09/22/2008	0	0	50.00
12/16/2008	0	0	50.00

Delhi	Cryp	Giar	Vol (L)
03/25/2008	0	0	50.00
06/16/2008	0	0	50.00
08/18/2008	0	0	50.00
12/09/2008	0	0	50.00

Tannersville	Cryp	Giar	Vol (L)
02/06/2008	0	0	50.00
04/21/2008	0	0	53.00
07/14/2008	0	0	50.00
11/10/2008	0	0	50.00

Hunter Highlands	Cryp	Giar	Vol (L)
02/06/2008	0	5	50.00
02/25/2008	0	0	50.00
04/22/2008	0	1	50.00
07/14/2008	0	0	50.00
12/29/2008	0	1	50.00

Pine Hill	Cryp	Giar	Vol (L)
03/18/2008	0	0	50.00
05/13/2008	0	0	50.00
09/17/2008	0	0	50.00
10/31/2008	0	1	50.25

Walton	Cryp	Giar	Vol (L)
03/25/2008	0	0	50.00
06/16/2008	0	0	50.00
08/18/2008	0	0	50.00
12/09/2008	0	1	50.00
12/22/2008	0	0	50.00

Margaretville	Cryp	Giar	Vol (L)
04/01/2008	0	0	50.00
05/13/2008	0	0	50.00
07/21/2008	0	0	50.00
10/20/2008	0	0	50.00

Grahamsville	Cryp	Giar	Vol (L)
04/01/2008	0	4	50.00
06/23/2008	0	1	50.00
09/15/2008	0	3	50.00
11/03/2008	0	2	50.00

Figure 4.14 2008 *Cryptosporidium* and *Giardia* sample results for Catskill and Delaware System WOH WWTPs.

A total of 40 HEV samples were taken at the 10 WWTPs, which satisfies the minimum set at each site. In addition, two resamples were taken, one at DTP on 6/24/08 and one at SGE, also on 6/24/08. The DTP resample was taken because the chlorine residual exceeded the 0.09 mg L^{-1} upper limit set by the DEP Field Standard Operating Procedure for the ICR HEV sampling method. The SGE resample was attributed to an issue with shipping, which caused the sample to arrive at the contract analytical lab beyond the 4-day hold time.

None of the samples taken for any of the WWTPs were positive for HEVs, which is consistent with the 2007 data. HEV will continue to be monitored at the WWTPs selected as part of the new 2009 WWQMP.

East of Hudson

In addition to the WOH WWTP sites, DEP monitors the EOH Brewster Sewage Treatment Plant monthly for *Cryptosporidium* and *Giardia* and bimonthly for HEVs as required by the CCD. In total, 12 *Cryptosporidium* and *Giardia* and 7 HEV samples were taken (Table 4.6). Only one sample was positive for *Giardia*. One virus resample was collected on 01/22/08 because a scheduled QC sample was not collected on the 1/08/08 sample run.

Table 4.6: Monitoring results for *Cryptosporidium*, *Giardia*, and HEV results at Brewster Sewage Treatment Plant in 2008.

Date	*Cryptosporidium* oocysts $50L^{-1}$	*Giardia* cysts $50L^{-1}$	HEVs MPN $100L^{-1}$
08-Jan-08	0	0	0
22-Jan-08	nsr	nsr	0
12-Feb-08	0	0	nsr
11-Mar-08	0	0	0
08-Apr-08	0	1	nsr
13-May-08	0	0	0
17-Jun-08	0	0	nsr
08-Jul-08	0	0	0
12-Aug-08	0	0	nsr
09-Sep-08	0	0	**
14-Oct-08	0	0	0
10-Nov-08	-110	-110	-110
21-Nov-08	0	0	0
10-Dec-08	0	0	nsr

nsr = no sample required.

-110 = field error, sample frozen.

** = sample was inadvertently omitted from the schedule.

Since 2008 was the fifth and final year under the 2003 IMR, certain sample sites have changed according to the long term WWTP monitoring objectives set forth in the 2009 WWQMP. In addition, the issue of potential wildlife exposure causing pathogen contamination after membrane filtration has been addressed with the relocation of certain sample sites to after membrane filtration, but prior to the end of the treatment train, to reduce the potential wildlife issue. These data will be covered in the next annual report.

4.6 What concentrations of *Cryptosporidium* and *Giardia* were found at the effluents of various NYC reservoirs in 2008?

DEP's pathogen monitoring program provides for sampling at upstate reservoirs and streams in the NYC watershed to help identify the sources of potential protozoan contamination and to assist with estimation of the variability of concentrations between watersheds. Sampling at the upstate reservoir outlets also helps to evaluate the effect of each reservoir and its role in reduction of pathogen concentrations as water flows to terminal reservoirs.

In 2008, *Cryptosporidium* levels remained very low in the WOH watersheds, with all WOH reservoir outlets showing mean concentrations below 0.2 oocysts 50 L^{-1} (Figure 4.15). EOH reservoir *Cryptosporidium* levels remained low, with Boyd Corners and Croton Falls mean concentrations also below 0.2 oocysts 50 L^{-1}. Three of the five EOH reservoirs sampled (Cross River, Muscoot, and Titicus) had slightly higher mean concentrations; however, all averaged under 0.7 oocysts 50 L^{-1}. The mean *Cryptosporidium* concentration at Titicus Reservoir rose in 2008, from zero in 2007 (n=12), to six in 2008 (n=12). In the fall of 2008, nine additional samples were taken at the release of Croton Falls Reservoir when water was being pumped from this reservoir into the Delaware Aqueduct to supplement the system during a shutdown of the Rondout-West Branch Tunnel. Two of these nine samples froze during transport and both were re-sampled within two days.

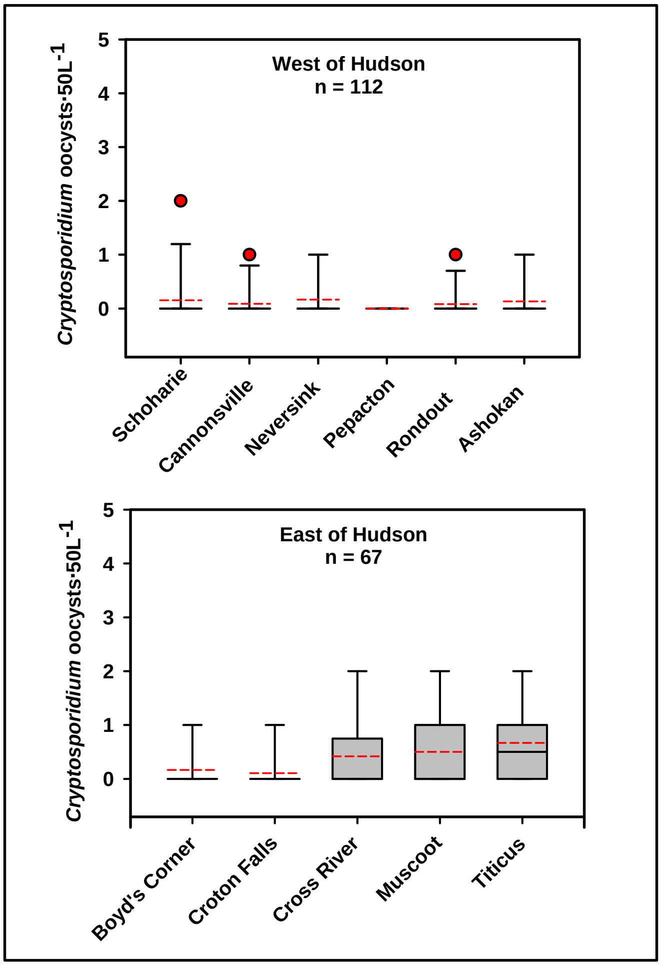


Figure 4.15 2008 summary of *Cryptosporidium* distribution among WOH and EOH watersheds (--- Mean, ___ Median, ● outliers).

Giardia concentrations at WOH reservoirs remained low during 2008, with most sites averaging below 1.3 cysts 50 L^{-1}, with the exception of Schoharie Reservoir (Figure 4.16). Schoharie had a mean *Giardia* concentration of 15.1 cysts 50 L^{-1}, mainly driven by two high results on December 4 and 30 of 79 and 58 cysts 50 L^{-1}, respectively. Mean *Giardia* concentrations for 2008 at reservoir effluents in the EOH watershed remained below 2.7 cysts 50 L^{-1}, with the exception of Muscoot Reservoir, which averaged 5 cysts 50 L^{-1}. Mean *Giardia* concentrations were higher than those of *Cryptosporidium* at most locations, sometimes by as much as two orders of magnitude (e.g., SRR2CM, 15.08 and 0.15 (oo)cysts 50 L^{-1}, respectively). Both *Giardia* and *Cryptosporidium* concentrations were slightly higher in the EOH watershed in 2008 than they were West of Hudson (Figure 4.17).

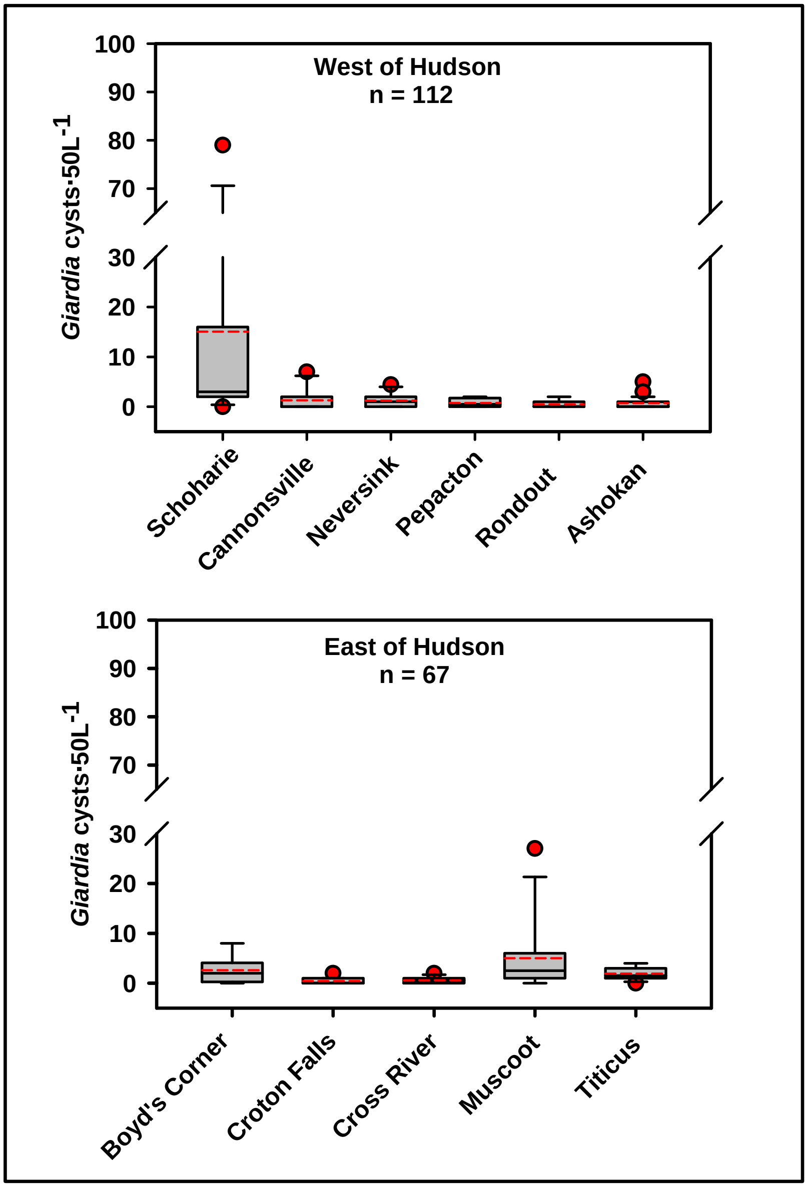


Figure 4.16 2008 summary of *Giardia* distribution among WOH and EOH watersheds (--- Mean, ___ Median, ● outliers).

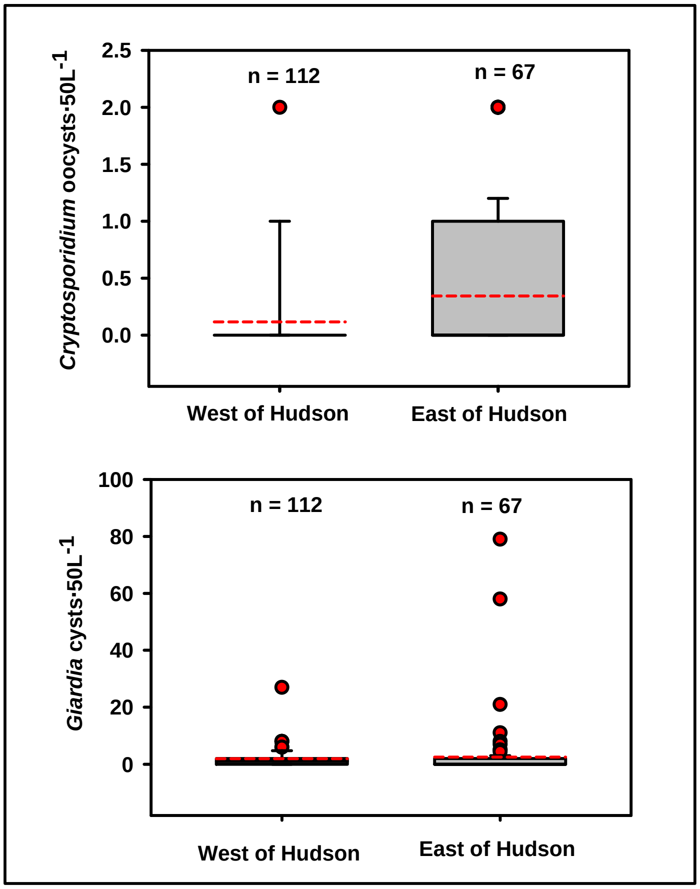


Figure 4.17 Comparison of WOH and EOH *Cryptosporidium* and *Giardia* concentrations $50L^{-1}$.

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

The LT2ESWTR contains a mandate requiring systems with an uncovered finished water storage facility to either 1) cover the uncovered finished water storage facility, or 2) treat the discharge to achieve inactivation and/or removal of at least 4-log removal for viruses, 3-log removal for *Giardia lamblia*, and 2-log removal for *Cryptosporidium*.

Hillview Reservoir (Figure 4.18), part of NYC's water supply located in Yonkers, New York, fits the description of an uncovered finished water storage facility under the LT2, and as a result, NYC was required to respond to the rule's mandate to cover the reservoir or treat the discharge. To that end, DEP initiated a study in September of 2006. The sampling scheme included sites along both the Catskill and Delaware Aqueducts, which flow through and bypass Hillview Reservoir, respectively. Sample collection was carried out in two sampling periods: September 12, 2006–September 29, 2007 and March 4–August 28, 2008.

Figure 4.18 Aerial view of Hillview Reservoir.

The primary objective of this study was to collect and analyze samples along both the Catskill and Delaware Aqueducts, prior to and following Hillview Reservoir, to see if there was a significant difference in the occurrence of *Giardia* spp. or *Cryptosporidium* spp. at these locations. The focus of this work was to assess whether there are outside sources of pathogens entering the uncovered reservoir after the inlet, yet prior to the outlet to determine if the data supported the LT2ESWTR requirement. Sampling was performed at four keypoints surrounding Hillview Reservoir, as follows:

Site 1 - Uptake No. 1, the Catskill Uptake at Hillview Reservoir.
Site 2 – Uptake No. 2, the Delaware Uptake at Hillview Reservoir.
Site 3 – Downtake No. 1, the Catskill Downtake at Hillview Reservoir.
Site 58 – Downtake No. 2, the Delaware Downtake at Hillview Reservoir.

The first sampling period demonstrated that the Delaware Aqueduct system showed no increase in protozoa from Site 2 to Site 58, which was not unexpected considering that this aqueduct routinely bypasses the reservoir basin. For the Catskill Aqueduct sites, additional matrix spike and duplicate sampling was necessary to provide a clearer picture of all factors possibly influencing the results in order to properly test whether a higher occurrence of protozoa was exiting Hillview Reservoir. Traditional parametric and nonparametric analyses indicated a possible significant increase depending on the test used (sign test p=0.048; sign-ranked test p=0.051). However, the dataset was highly censored (many zeroes) with several tied data pairs; therefore, traditional paired parametric testing was inappropriate due to the inability to correct for normality. Moreover, traditional paired nonparametric statistics could not provide a fair assessment of the outcome because a high percentage of the data (i.e., 82% tied data pairs for *Cryptosporidium* at Site 1 and Site 3) was excluded from the analysis, which could lead to an over-inflation of the Type I error and false positive results (Fong et al. 2003).

Therefore, the effort during the second sampling period was focused on Catskill Site 1 and Site 3 only, with increased matrix spike samples and the addition of sample duplicates. This sampling scheme was designed to help clarify whether the possible difference (if any) was attributed to recovery differences or inherent variability. In addition, DEP contracted a statistician to determine whether a more appropriate analysis was available to deal with censored datasets with many tied pairs. A nonparametric test proposed by Fong et al. (2003) (modified sign test), which incorporated tied data pairs in the analysis, resulted in no statistically measurable difference in the occurrence of *Cryptosporidium* or *Giardia* (oo)cysts from the influent (Site 1) to the effluent (Site 3) of Hillview Reservoir (Table 4.7).

Table 4.7: Results from the comparison of Catskill Site 1 and Site 3.

Parameter	statistical question	proportion of ties	sign test, ties excluded (*p*-value)	sign-ranked test, ties excluded (*p*-value)	modified sign test, corrected for ties (*p*-value)
Cryptosporidium	Site 3 > Site 1?	80/98	0.048	0.051	0.5
Giardia	Site 3 > Site 1?	54/98	0.913	0.975	0.5

Note: Statistical significance $p<0.05$.

Additionally, enhanced MS recovery data, duplicate data, and supporting water quality do not provide support for, or against, significantly greater protozoan concentrations at Hillview Reservoir effluents than at the influents.

In summary, the data do not support the idea that Hillview Reservoir is a significant source of protozoa (DEP 2008c).

5. Watershed Management

5.1 What watershed management programs are required for filtration avoidance and how do they protect the water supply?

Several of DEP's watershed management programs are described in the 2007 Filtration Avoidance Determination (USEPA 2007) and summarized below.

Waterfowl Management

The Waterfowl Management Program includes three activities: avian population monitoring, avian harassment activities (motorboats, air boats, and pyrotechnics) and avian deterrence (depredation of nests and eggs, bird exclusion wires, and netting at critical intake chambers.) The objective of the program is to minimize the fecal coliform loading to the reservoirs that result from roosting birds during the migratory season.

Land Acquisition

The Land Acquisition Program seeks to prevent future degradation of water quality by acquiring sensitive lands to ensure that undeveloped, environmentally-sensitive watershed lands remain protected and that the watershed continues to be a source of high quality drinking water to the City and upstate counties.

Land Management

The responsibilities of the Land Management Program include property management, natural resources management, implementing/administering the recreational use program, monitoring water supply lands, monitoring and enforcing conservation easements, maintaining a watershed land information system (GIS), and developing a forest management plan.

Watershed Agricultural Program

The overall objective of the Watershed Agricultural Program is to prevent pollution and improve water quality by reducing pollutants leaving farms through the implementation of best management practices (BMPs).

Watershed Forestry Program

The Watershed Forestry Program is a voluntary partnership between New York City and the forestry community that supports and maintains well-managed forests as a beneficial land use in the watershed. The primary objective of the program is to maintain unfragmented forested land and promote the use of management practices to prevent nonpoint source pollution during timber harvests. The program provides resources for logger training, forest management planning, implementation of management practices, research, demonstration projects, and educational opportunities.

Stream Management

The objective of the Stream Management Program is to protect and restore stream stability through the development and implementation of stream management plans and demonstration projects, and the enhancement of long-term stream stewardship through increased community participation resulting from partnerships, education, and training. Stabilizing stream reaches provides multiple environmental benefits including overall water quality improvement and turbidity reduction through decreased streambank erosion.

Riparian Buffer Protection

The Riparian Buffer Protection Program represents a new initiative under the 2007 FAD, committing the City to continue its riparian buffer protection efforts through existing programs (e.g., Land Acquisition, Watershed Agricultural, Stream Management, and Forestry programs) as well as initiating selected program enhancements. The enhancements focus on improving riparian buffer protections along privately-owned stream reaches. For example, within the context of the Stream Management Program, DEP is strengthening its landowner agreements by acquiring enhanced management agreements for the protection of riparian buffers for all current and future stream restoration projects. In addition, riparian landowners have access to technical assistance targeted to their needs. Specifically, enhanced education and training focus on proper streamside management, including development and design assistance with plans for riparian plantings.

Wetlands Protection

The Wetlands Protection Program includes research and mapping programs, such as the National Wetlands Inventory (NWI), wetland status and trends, and wetland monitoring and functional assessment. All of these support protection programs such as wetland permit review, land acquisition, and watershed agricultural programs. Wetlands play a major role in watershed protection because of their ability to maintain good surface water quality in watercourses and reservoirs and to improve degraded water. Wetlands also moderate peak runoff, recharge groundwater, and maintain baseflow in watershed streams.

East of Hudson Non-Point Source Pollution Control Program

DEP has developed a comprehensive nonpoint source program for the West Branch, Boyd Corners, Croton Falls, and Cross River Reservoir basins located east of the Hudson. Program elements in these basins include an agricultural program, forestry program, new septic and stormwater initiatives, and cooperative planning efforts by the City and Westchester and Putnam Counties. These efforts provide for integrated watershed management to protect and improve water quality in the West Branch, Boyd Corners, Croton Falls, and Cross River Reservoir basins. In addition, DEP addresses many concerns in the East of Hudson watersheds through the aggressive implementation of the Watershed Rules and Regulations and continued increased involvement in project reviews, as well as through a grant program to assist stormwater districts or municipalities reduce stormwater pollutant loading to the Croton Falls and Cross River basins.

Kensico Water Quality Control

Because Kensico Reservoir provides the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, protection of this reservoir is critically important to maintaining filtration avoidance for the City. Since the early 1990s, DEP has prioritized watershed protection in the Kensico watershed. FADs (USEPA 1997, 2002) built a foundation of expanded watershed protection and pollution prevention initiatives for the Kensico watershed. Under the 2007 FAD, DEP is instituting new watershed protection and remediation programs designed to ensure the continued success of past efforts while providing for new source water protection initiatives that are specifically targeted toward stormwater and wastewater pollution sources.

Catskill Turbidity Control

The Catskill Turbidity Control Program includes analysis and implementation of engineering, structural, and operational alternatives to address elevated turbidity in the Catskill Watershed.

5.2 How can watershed management improve water quality?

The close relationship between activities in a drainage basin and the quality of its water resources forms the underlying premise for all watershed management programs. As discussed above, 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, such as the Wastewater Treatment Plant (WWTP) Upgrade Program and the Streambank Stabilization Program, 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 2006f). 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.

5.3 What are DEP's watershed management efforts in the Catskill/Delaware Systems?

- *Watershed Agricultural Program*. Since 1992, the Watershed Agricultural Program has developed pollution prevention plans (also known as Whole Farm Plans), on more than 390 small and large farms in the Catskill, Delaware, and Croton watersheds. To date, more than 94.4% of the 307 large farms in the Catskill/Delaware watersheds have Whole Farm Plans. Of these, 97% have commenced implementation and 86.9% have substantially completed implementation. The Conservation Reserve Enhancement Program (CREP) has protected more than 185 stream miles with riparian forest buffers.

- *Land Acquisition*. Between 1997 and the end of 2008, the City secured more than 91,000 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 Catskill/Delaware systems under City ownership for purposes of protecting drinking water to over 126,000 acres, which is 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, 97.8% emanates from plants that have so far been upgraded.
- *New Infrastructure Program (NIP)*. Five new WWTPs and one collection system/force main project have been completed in communities with failing or likely-to-fail septic systems. In 2008, the addition of the Hubbell’s Corners collection system to the Roxbury collection system/force main NIP project transitioned from the study phase to the design phase. Construction on the Hubbell’s Corners collection system is to commence in 2009. A wastewater treatment facility for the Hamlet of Phoenicia in the Town of Shandaken was still under consideration by the Town in 2008.
- *Partnership Programs*. Partnering with DEP, the Catskill Watershed Corporation administers a number of watershed protection and partnership programs, including the Septic Program, the Community Wastewater Management Program, and the Stormwater Retrofit Program (Figure 5.2). The Septic Program funded the remediation of 258 failing septic systems in 2008. (Since 1997, more than 2,864 failing septic systems have been repaired or replaced.) Through the Community Wastewater Management Program, one community (DeLancey) has established a septic maintenance district, while another (Bovina) has completed a community septic system. In addition, 2008 saw construction proceed on two additional community septic systems (Hamden and DeLancey), and two other communities (Boiceville and Ashland) continued work on design plans for WWTPs. Over 60 stormwater retrofit projects have been funded through 2008 by the Catskill Watershed Corporation, resulting in the construction and implementation of stormwater BMPs throughout the WOH Watershed. In addition, 30 facilities that store road deicing materials have been upgraded.

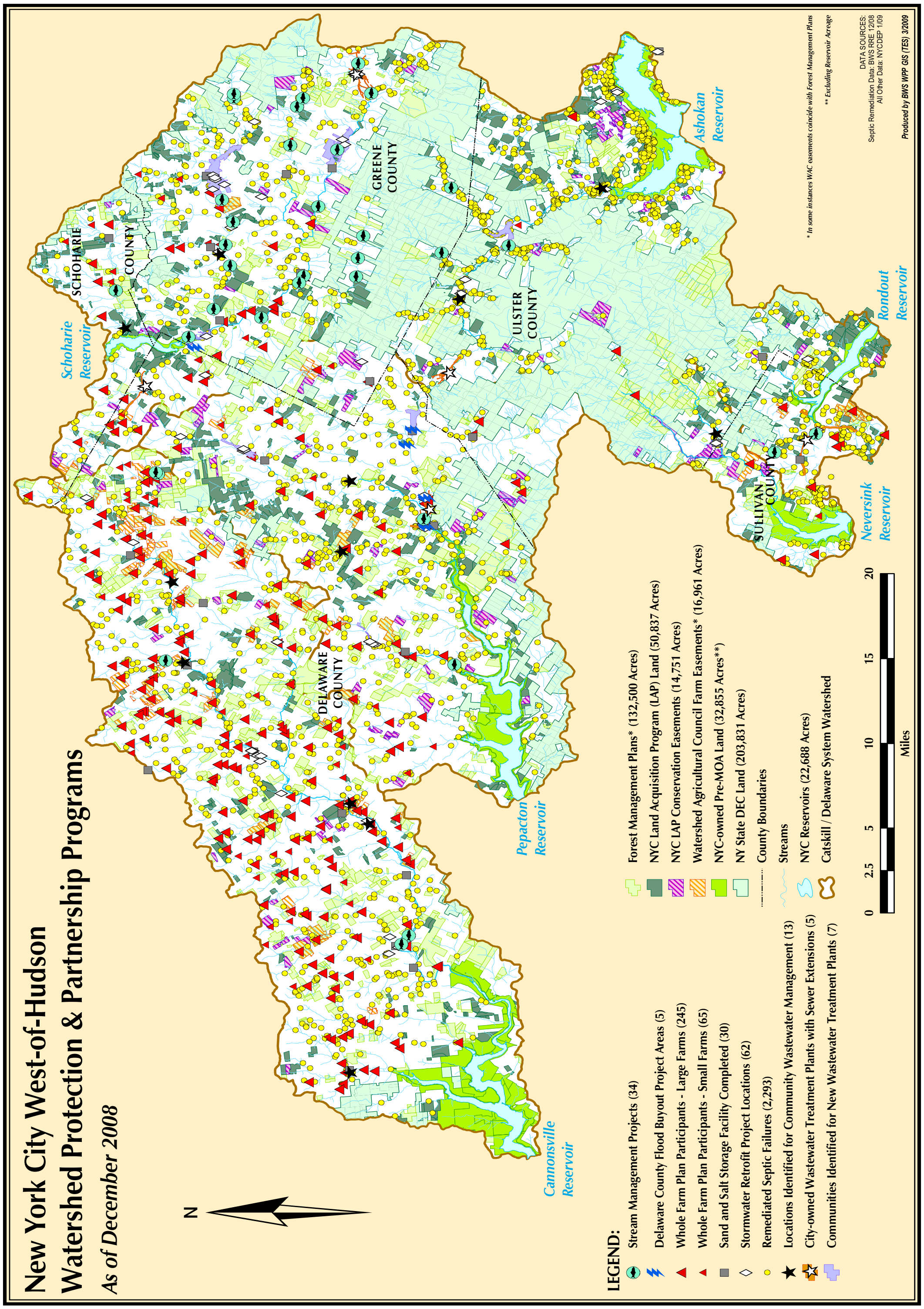


Figure 5.2 New York City West of Hudson Watershed Protection and Partnership Programs as of December 2008.

5.4 How has DEP tracked water quality improvements in the Catskill/ Delaware Systems?

Water quality has been and continues to be excellent in the Catskill and Delaware Systems. From1993–2008, many improvements in water quality have been observed. The most dramatic change has been the reduction in phosphorus in the Catskill/Delaware watersheds due to WWTP upgrades. As an example, Figure 5.3 shows phosphorus loads and flows from WWTPs in the Cannonsville watershed. The reduction in total phosphorus loads between 1994 and 1999 can be attributed 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 Reservoir was taken off the phosphorus-restricted basin list in 2002.

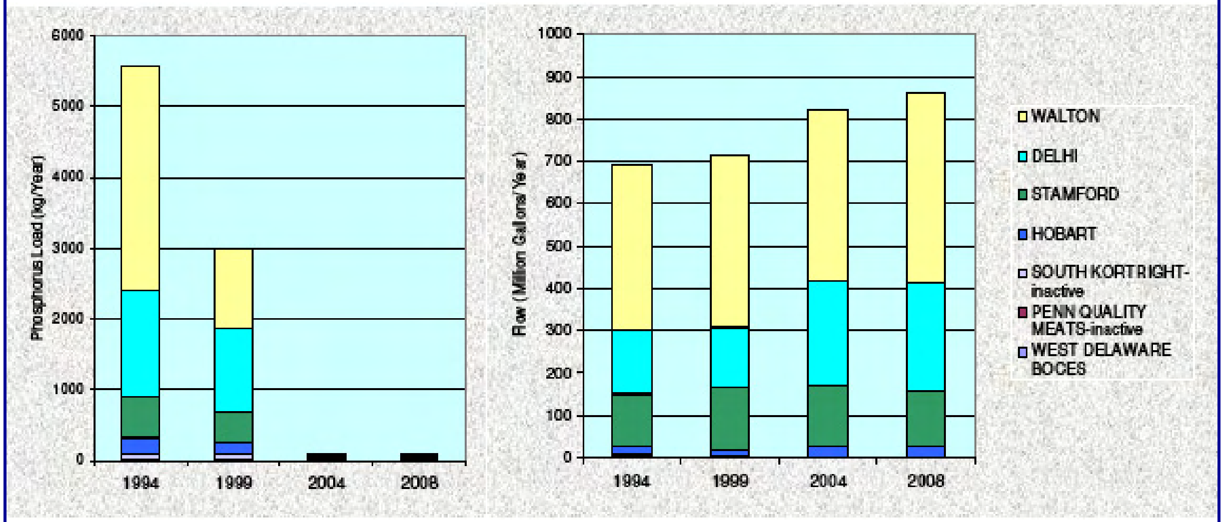


Figure 5.3 Wastewater Treatment Plant TP loads and flow in the Cannonsville watershed, 1999–2008.

5.5 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 and municipalities, DEP has implemented an East of Hudson Nonpoint Source Pollution Control Program to address specific watershed concerns (e.g., stormwater retrofits). Other DEP management programs (e.g., the Wastewater Treatment Plant Upgrade Program, the Watershed Agricultural Program) operate similarly in all systems.

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 sum of used and remaining WQIP funds exceeds $100 million. A few notable projects for 2008 are described below.

- *Putnam County Septic Repair Program (SRP)*. Putnam County continued to fund and implement the Septic Repair Program in high priority areas and has repaired over 100 systems to date. Since the program’s start, the county has allocated over $4.6 million to rehabilitate systems in close proximity to water bodies.
- *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 pump-outs as well as train 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 70 non-City-owned WWTPs located EOH, 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 watersheds (totaling 1.36 million gallons per day). Sixty-two of the 70 (88.6%) non-City-owned WWTPs located EOH have flows of less than 100,000 gallons per day. Twenty-nine of the 70 WWTPs (80.6% of the permitted flow) have completed their upgrades as of December 2008 and are either ready to start up or have already done so. An additional 38 WWTPs either have commenced construction of the upgrades or are in the design phase. Upgrade plans for three remaining EOH WWTPs (1.5% of the permitted flow) are on hold pending decisions on diversion to existing plants or out of the Croton watershed.

Thirty-three of the 70 non-City-owned WWTPs located EOH are located within the 60-day travel time (57.4% of the permitted flow) and 13 of these (48% of the permitted flow) have completed their upgrades. The flow from the 13 WWTPs equates to 83.7% of the permitted flow within the 60-day travel time. The three WWTPs that are on hold are within the 60-day travel time.

East of Hudson Watershed Agricultural Program

The farms in the EOH District tend to be smaller and more focused on equestrian-related activities than 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 BMPs, and a total of 277 BMPs have been installed.

Nonpoint Source Management Program

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 are 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:

- Stormwater remediation projects continue to be identified and implemented. Small remediation projects are completed annually. The designs and permitting necessary for the larger remediation projects are currently underway.
- Completed the development of a Stormwater Prioritization Assessment, including the establishment of criteria to be used to locate potential future stormwater retrofits in the EOH FAD basins.
- Design, permitting, and survey work were completed for 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.

5.6 What are the water quality impacts from waterbirds (Canada geese, gulls, cormorants, and other waterfowl) and how is the problem mitigated?

Following several years of waterbird population monitoring, DEP's scientific staff, consisting of wildlife biologists and microbiologists, identified birds as a significant source of fecal coliform at several NYC reservoirs (e.g., Kensico Reservoir, Figure 5.4). In response, DEP developed and implemented a Waterfowl Management Plan (WMP) using standard bird management techniques (approved by the United States Department of Agriculture, Wildlife Services (USDA) and the New York State Department of Environmental Conservation (DEC)) to reduce or eliminate the waterbird populations inhabiting the reservoir system (DEP 2002b). DEP has also acquired depredation permits from the United States Fish and Wildlife Service (USFWS) and DEC to implement some management techniques.

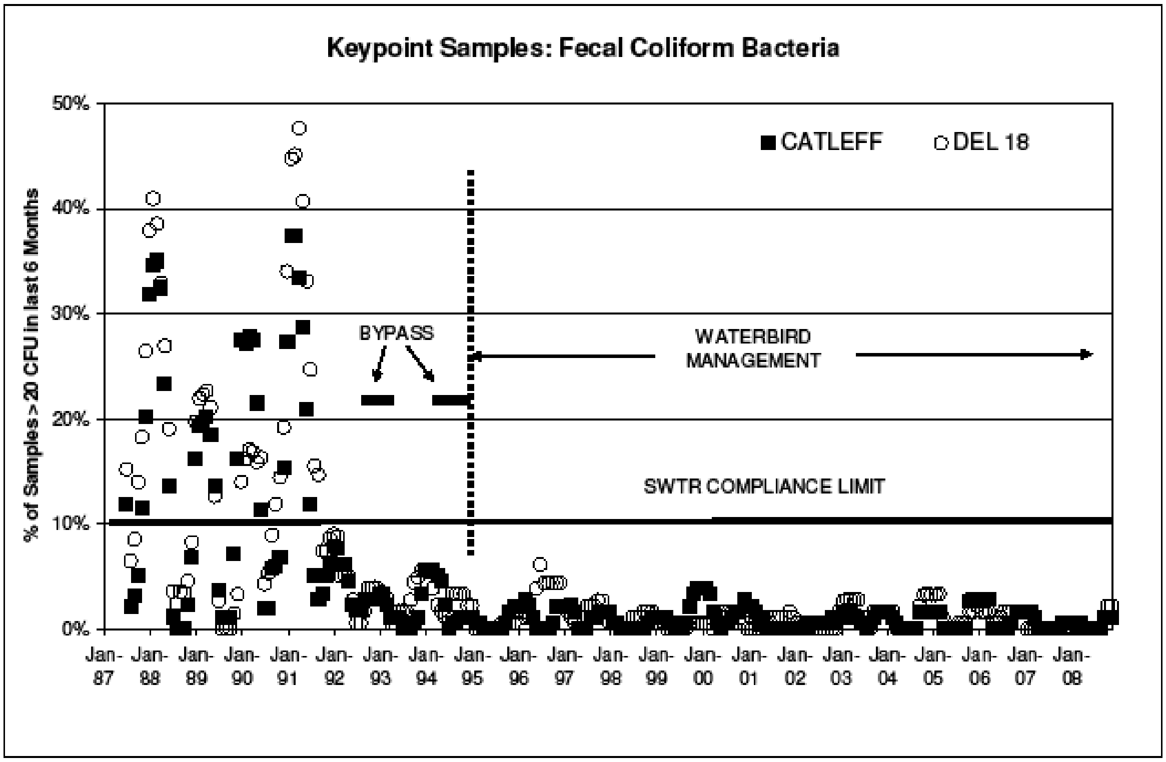


Figure 5.4 Keypoint fecal coliforms at Kensico Reservoir effluents before and after initiation of waterbird management.

Migratory populations of waterbirds utilize NYC reservoirs as temporary staging areas and wintering grounds and therefore significantly contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These migrant waterbirds generally roost nocturnally and occasionally forage and loaf diurnally on the reservoirs; however, it has been determined that most of the feeding activity occurs away from the reservoir. Fecal samples collected and analyzed for fecal coliform bacteria concentrations from both Canada geese (*Branta canadensis*) and Ring-billed Gulls (*Larus delawarensis*) revealed that fecal coliform concentrations are relatively high per gram of feces (Alderisio and DeLuca 1999). Water samples collected near waterbird roosting locations show that fecal coliforms have increased along with waterbird populations at several NYC reservoirs for several years (DEP 2002b, 2003b, 2004, 2005, 2006g, 2007c, and 2008d). Thus, DEP has determined that waterbirds contributed the most important fecal coliform bacteria load seasonally to Kensico Reservoir and to other terminal reservoirs (West Branch, Rondout, Ashokan) and potential source reservoirs to distribution (Croton Falls and Cross River).

Figure 5.5 Canada geese nesting on the roof of a DEP laboratory building after nest depredation under federal permit.

Bird deterrence measures, which include waterbird reproductive management, shoreline fencing, bird netting, overhead deterrent wires, and meadow management, continued to reduce local breeding opportunities around water intake structures, and eliminate fecundity.

Monitoring the effects that bird dispersal measures have on each reservoir can be achieved through continued routine population surveys and by expanding research that identifies sources of bacteria. Survey results provide inferences about the potential effect of the birds' fecal matter through the spatial and temporal aspects of the birds, and also makes it possible to evaluate the effectiveness of the dispersal measures. DEP will continue implementation of the WMP indefinitely to help ensure the best possible water quality water.

5.7 How has DEP tracked the status and trends of wetlands in the West of Hudson Watersheds?

The DEP contracted the USFWS to conduct a status and trends analysis for wetlands and ponds in the West of Hudson Watershed for two time periods, from the mid-1980s to the mid-1990s, and from the mid-1990s to 2004. The USFWS superimposed 2004, and then mid-1980s National Wetlands Inventory (NWI) data, on mid-1990s aerial photography to identify gains, losses, and cover type changes in vegetated wetlands and ponds over the two time periods (Tiner 2008). Changes in non-vegetated wetlands were annotated separately from vegetated wetlands because their functions differ in many respects. The rate of vegetated wetland loss declined over the two time periods. Pond construction was extensive and accounted for the majority of vegetated wetland losses in both time periods, though the rate of pond construction declined from the 1990s to 2004. From the mid-1980s to the mid-1990s, there was a net loss of approximately 87 acres of vegetated wetlands in the West of Hudson watershed. This represents less than 1% of the West of Hudson wetland base acreage. In addition, there was a net increase of 527 acres of non-vegetated wetlands (ponds). Approximately 94% of the total loss of vegetated wetlands was due to pond construction. From the mid-1990s to 2004, a loss of 15.25 acres of vegetated wetlands was recorded along with a gain of 18.75 acres, resulting in a net gain of 3.5 acres of vegetated wetlands. Much of the gain in vegetated wetlands was due to re-vegetation of ponds. Non-vegetated wetlands (ponds) showed a net increase of approximately 109 acres. Eleven percent of the new ponds were constructed in wetlands, mostly in palustrine emergent systems, accounting for 90% of the loss of vegetated wetlands.

The decreased rate of vegetated wetland loss, coupled with significant, though declining, rates of pond construction, are consistent with findings from prior studies in the Croton watershed (Tiner et al. 1999, Tiner et al. 2005) and from national studies (Dahl 2006). The replacement of vegetated wetlands with ponds represents a shift in wetland function, as ponds do not provide the same range of functions as vegetated wetlands. While this analysis was completed through remote sensing, and, therefore, likely underestimates loss of small wetlands, forested wetlands, and temporarily or seasonally saturated wetlands, it does allow for a cumulative assessment of local, state, and federal wetland protection programs. It also enables wetland managers to target specific geographic regions or activities, such as pond construction, that are impacting vegetated wetlands.

5.8 What is the status of the Forest Science Program's Continuous Forest Inventory and how is it contributing to development of DEP's Forest Management Plan?

The Forest Science Program collects data on forest ecosystems located on water supply lands. For over 10 years, efforts have 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—tree growth, recruitment of young seedlings into the forest stand, and mortality of older or more susceptible species or stands of trees. In 2008, Continuous Forest Inventory (CFI) plots were established and measured in the Pepacton Reservoir watershed. Only the Cannonsville Reservoir watershed remains to be surveyed for baseline data.

Methods used in data collection have served as the testing ground for the U. S. Forest Service inventory of watershed lands that begins in 2009. The forest scientist is able to help troubleshoot and answer questions related to the Northeast Decision model (NED) software being used in that inventory. In addition, data from the CFI plots has been used to compare tree diameter and height relationships built into the software against locally-collected information. CFI plot data will contribute to development of modeling/forecasting tools, ground-truthing of forest stand types mapped from aerial photos, and tracking progress and results of applied management activities over time. This and other analyses will help DEP and the Forest Service as they develop the Forest Management Plan.

5.9 How did trout spawning affect stream reclassification in the East of Hudson Watersheds?

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 suitable 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). 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.

In 2008 streams in the EOH watersheds were surveyed for the presence of trout or trout spawning. No trout and no evidence of trout spawning were found in 2008. Therefore, no petitions to stream upgrades will be submitted to DEC.

5.10 How do environmental project reviews help protect water quality and how many were conducted in 2008?

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 2008, DEP staff reviewed a total of 109 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 96 of these projects were reviewed and commented on by DEP in 2008. Many of these projects were large, multi-year efforts with ongoing reviews, while 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 2008, approximately 31 wetland permit applications were reviewed and commented on.

5.11 What was the status of WWTP TP loads in the watershed in 2008?

Figure 5.6 displays the sum of the annual total phosphorus (TP) loads from all surface-discharging WWTPs by system from 1999–2008. The far right bar displays the calculated wasteload allocation (WLA) for all these WWTPs, which is the TP load allowed by the State Pollutant Discharge Elimination System (SPDES) permits—in other words, the maximum permitted effluent flow multiplied by the maximum permitted TP concentration. Overall, the TP loads from WWTPs remain far below the WLA. The fact that loads in the Delaware and Catskill Systems remain so far below their respective WLAs reflects the effect of the WWTP upgrade program, which is largely complete WOH. More recently, upgrades of WWTPs in the Croton System are reducing TP loads to levels well below the EOH WLA.

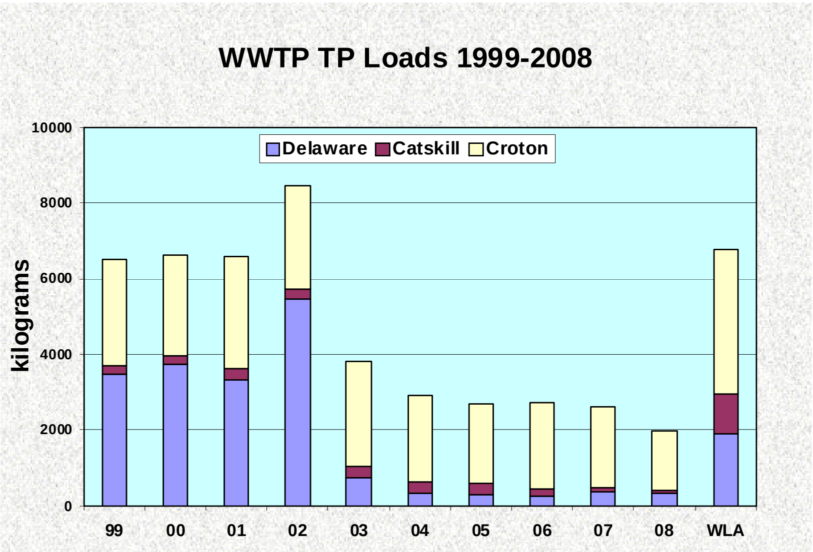


Figure 5.6 Wastewater Treatment Plant TP loads, 1999–2008. The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

Upgrades to WWTPs include phosphorus removal and microfiltration to enhance compliance with the Watershed Rules and Regulations. 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 new plants in the New Infrastructure Program (NIP).

The New Infrastructure Program is another major wastewater management program funded by DEP. The NIP builds new WWTPs in communities previously relying on individual septic systems. Since many of the older septic systems in village centers such as Andes, Roxbury, Windham, Hunter, 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 new NIPs are completed and sewer districts expand to their full capacities, TP loads are expected to approach the WLAs for the respective systems.

5.12 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 this mollusk, because they can reproduce quickly and are capable of clogging pipes. This would seriously impair DEP's operations, preventing an adequate flow of water from the reservoirs to the City and those upstate communities dependent on the New York City water supply. In addition, they create taste and odor problems in the water. To protect the system from zebra mussels, DEP does the following:

- *Monitoring*. As suppliers of water to over nine million people, it is DEP's responsibility to monitor New York City's water supply for zebra mussels, since early identification of a zebra mussel problem will make it possible 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 the NYC reservoirs for any reason be inspected and thoroughly steam cleaned prior to being allowed on the reservoir (Figure 5.7). 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 steam cleaning requirement applies to all boats that will be used on the reservoirs, whether they be rowboats used by the general public, or motor boats used by DEP. Additionally, all contractor boats, barges, dredges, equipment (e.g., anchors, chains, lines), and trailer parts must be thoroughly steam cleaned inside and out. All water must be drained from boats, barges, their components (including outdrive units, all bilge water (if applicable), and raw engine cooling systems), and equipment at an offsite location, away from any NYC reservoirs or streams that flow into NYC reservoirs or lakes, prior to arrival for DEP inspection.

Figure 5.7 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 on preventing the introduction and spread of zebra mussels to bodies of water that do not have them. Fishermen can inadvertently introduce zebra mussels to a body of water through their bait buckets that may have zebra mussels in them (depending upon where the bait was obtained), or by 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. In addition, signs are put up throughout the watershed providing information as to how to prevent the spread of zebra mussels.

5.13 What "Special Investigations" were conducted in 2008?

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 2008, 5 SIs were conducted. Reports are prepared to document each incident and DEP's response and remedial actions as appropriate. All investigations in 2008 were conducted

East of Hudson. Actual or possible sewage-related problems were the most common incident investigated. Other incidents included an oil spill and an organic sheen. None of the investigations conducted in 2008 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 2008, with the date and reason for each investigation.

Muscoot Reservoir

- February 29, a diesel fuel spill adjacent to the Titicus River.

East Branch Reservoir

- August 19, *Cryptosporidium* detection in the Peach Lake watershed.
- February 27, runoff from a horse farm in Pawling, NY.

Cross River Reservoir

- April 25, septic system failure, Cross River, NY.

West Branch Reservoir

- February 2, a surface sheen near Delaware Shaft #9.

6. Model Development and Application

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

DEP uses computer simulation models to aid in short-term water system operational decisions and long-term planning and assessment of the water supply system and watershed management programs.

The DEP modeling system (Figure 6.1) 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 (GWLF-VSA) model (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 CEQUAL-W2 models) simulate the hydrothermal structure and hydrodynamics of the reservoirs, as well as the transport and concentrations of nutrient and sediment within the reservoirs. 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.

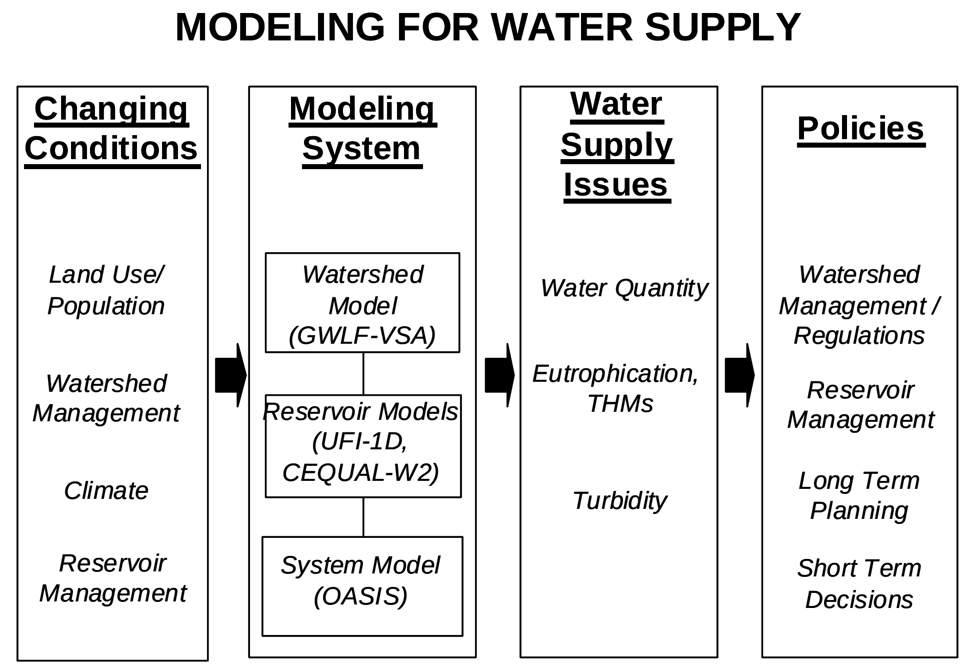


Figure 6.1 Schematic of DEP's Linked Water Supply and Water Quality Modeling System.

Two major model applications conducted during 2008 are discussed in this report. The modeling system was used to begin the first phase of a project to examine the effects of climate change on the water supply (Section 6.3), including climate change effects on turbidity in Schoharie Reservoir, eutrophication in Cannonsville Reservoir, and WOH water quantity. Simulations using the Kensico Reservoir CEQUAL-W2 model were used to recommend aqueduct flow levels so that alum treatment would not be required for a medium-sized storm event during the spring of 2008 (Section 6.4).

During previous years, the models have been used to identify major sources of turbidity and to examine alternative operational rules for use 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). Additionally, 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 2006f).

6.2 What can models tell us about the effects of 2008'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 2008 in a historical context.

Figure 6.2 depicts the annual streamflow, direct runoff, and nonpoint source (NPS) dissolved nutrient loads simulated by the GWLF-VSA model for 2008 in relation to long-term simulated annual statistics. These boxplots show that 2008 was wetter than normal with higher than normal modeled streamflow and direct runoff, especially for the Pepacton and Cannonsville watersheds. Consistent with these higher than normal flows, modeled 2008 NPS dissolved nutrient loads were also larger than normal for each of the WOH reservoir watersheds. The relationship between 2008 and long-term annual total dissolved nitrogen (TDN) loads follows a similar pattern as annual streamflow, and the relationship between the 2008 and long-term annual total dissolved phosphorus (TDP) loads closely follows direct runoff.

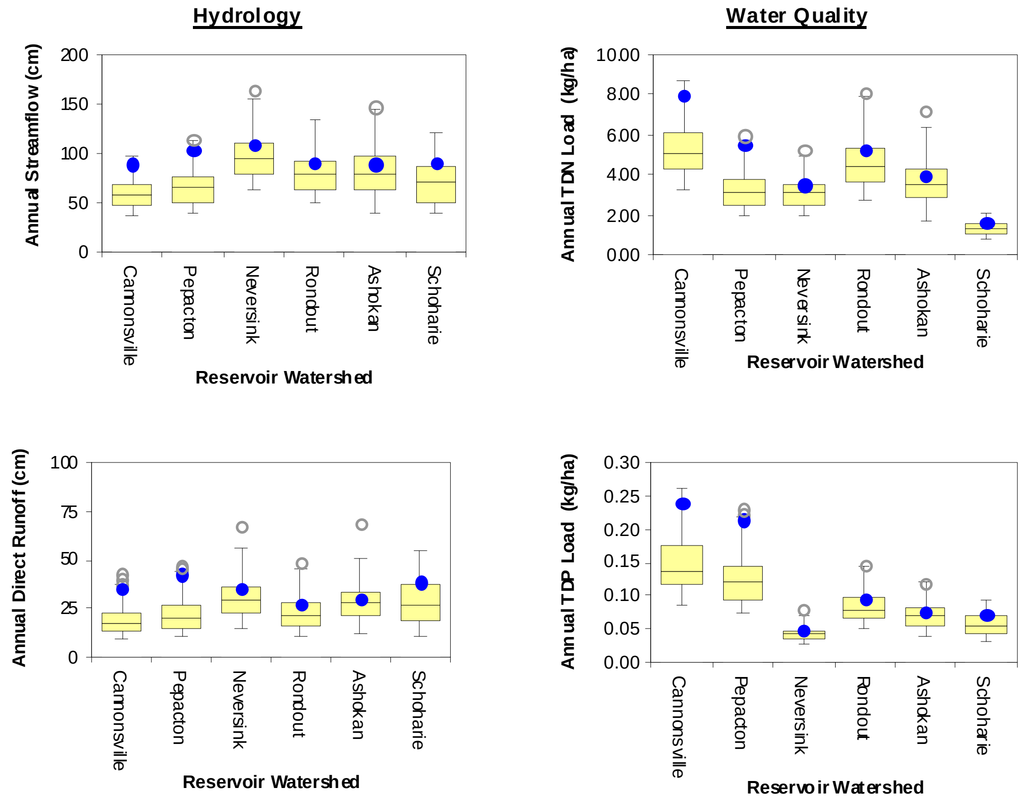


Figure 6.2 Annual streamflow, direct runoff, and nonpoint source dissolved nutrient loads simulated by the GWLF model for 2008 in relation to long-term simulated annual statistics. Boxplots show long-term statistics. Blue dots show 2008 results.

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

DEP is using a suite of simulation models to investigate the effects of climate change on water supply quantity and quality. Preliminary investigations focus on estimating future climate projections; looking 65 years and 100 years forward in the Catskill Mountain WOH watersheds; and using DEP's modeling system (Figure 6.3) to estimate the effects of future climate projections on the hydrology of the WOH watersheds, water quantity in the WOH reservoirs, turbidity in Schoharie Res-

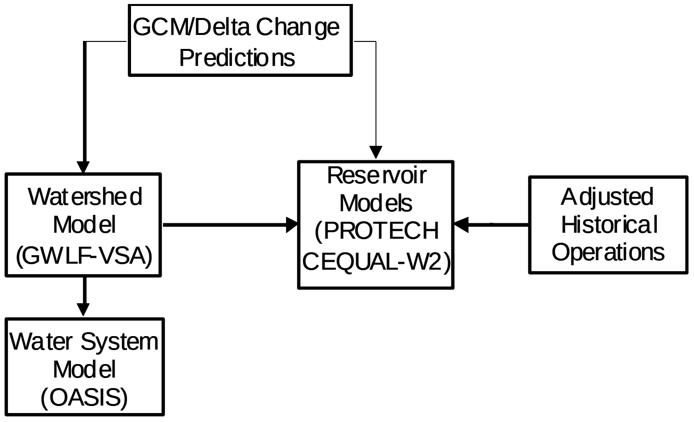


Figure 6.3 DEP's modeling system of water quality and supply system models used for preliminary climate change investigations.

ervoir, and eutrophication in Cannonsville Reservoir. The GWLF-VSA watershed model simulates the effects of future changes in meteorology on streamflow, turbidity, and nutrient inputs to the upstate water supply reservoirs; the OASIS model simulates the operation of the system of reservoirs and the storages and fluxes of water in the system as affected by changing reservoir inputs; and the CEQUAL-W2 and PROTECH reservoir models simulate the effects of changing reservoir inputs on turbidity and eutrophication, respectively, assuming conservatively-adjusted historical reservoir operations.

Future Climate Projections

Preliminary projections of future air temperature and precipitation looking 65 and 100 years forward were developed from three Global Climate Models (GCMs) (Goddard Institute for Space Studies (GISS), National Center for Atmospheric Research (NCAR), and the European Centre Hamburg Model (ECHAM)) and 3 greenhouse gas emission scenarios (A1B, A2, and B1). For each combination of GCM and emission scenario, monthly delta change factors (Figure 6.4) were derived by comparing GCM output for control (1980–2000) versus future prediction periods (2045–2065 and 2080–2100). The boxplots in Figure 6.4 display the changes in average daily air temperature and precipitation by month predicted using the various combinations of GCMs and emission scenarios. Precipitation change factors represent the ratio (unitless) of future to control average daily precipitation by month, while air temperature change factors represent the difference (^{o}C) between future and control. Note that the format of the boxplots in section 6.3 as described in the captions differs from that described in the Appendix key.

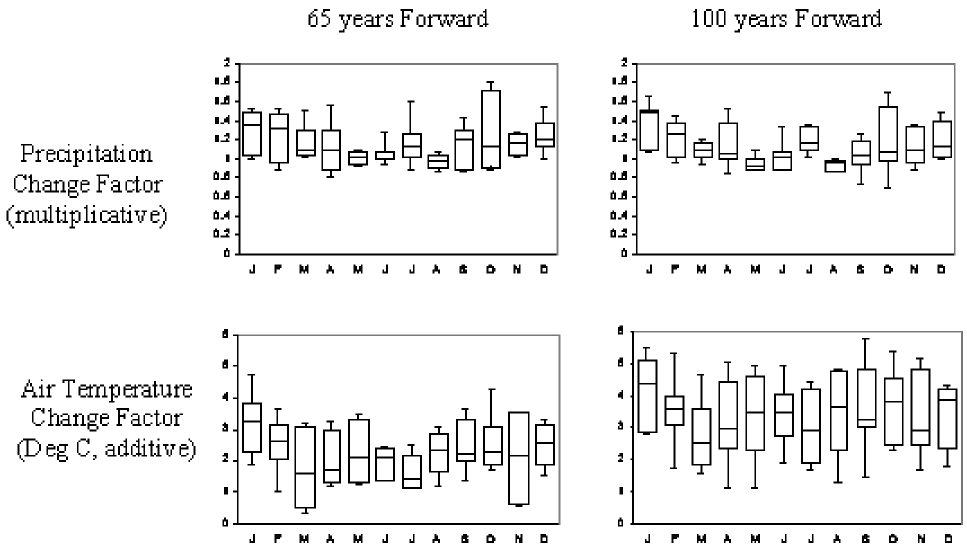


Figure 6.4 Monthly delta change factors for precipitation (unitless) and air temperature (^{o}C). The midway line in the boxes shows the median value for the climate scenarios, the extent of the boxes shows the range of the middle six scenarios, and the whiskers show the range of all scenarios.

Analysis of monthly delta changes indicates that while these GCM/emission scenarios vary somewhat in their predictions (the ranges depicted in the boxplots), there is a clear and significant predicted increase in air temperature, and a somewhat less certain predicted increase in precipitation, particularly in winter. It must be pointed out that the delta change methodology used is a first cut procedure that does not account for possible changes in the frequency and severity of storms, for which more sophisticated methods are under development.

Hydrology of WOH Watersheds

The GWLF-VSA watershed model for each WOH reservoir watershed was run for a baseline scenario representing current conditions, eight climate change scenarios looking 65 years ahead, and eight scenarios looking 100 years ahead. The baseline scenario uses historical inputs of precipitation and temperature from 1966 through 2004. The climate change scenarios were developed by applying the appropriate delta change factors—additively for air temperature and multiplicatively for precipitation—to the historical daily precipitation and temperature data to derive inputs for the watershed model.

The watershed model simulates the water balance of the watershed and the timing of streamflow, reflecting the effects of the projected changes in precipitation and air temperature due to climate change. Figure 6.5 depicts the mean daily water balance by month for the historical baseline data (solid line) and eight climate scenarios (boxes) as projected by the GWLF-VSA watershed model. Projected increases in air temperature (a) and precipitation (b) are accompanied by increased evapotranspiration (c); decreasing snowfall (d) and a much reduced snowpack (e); and a change in the timing of streamflow (f), with higher flows in the late fall and early winter, and a transfer of the traditional high snowmelt related flows of March and April to earlier in the year.

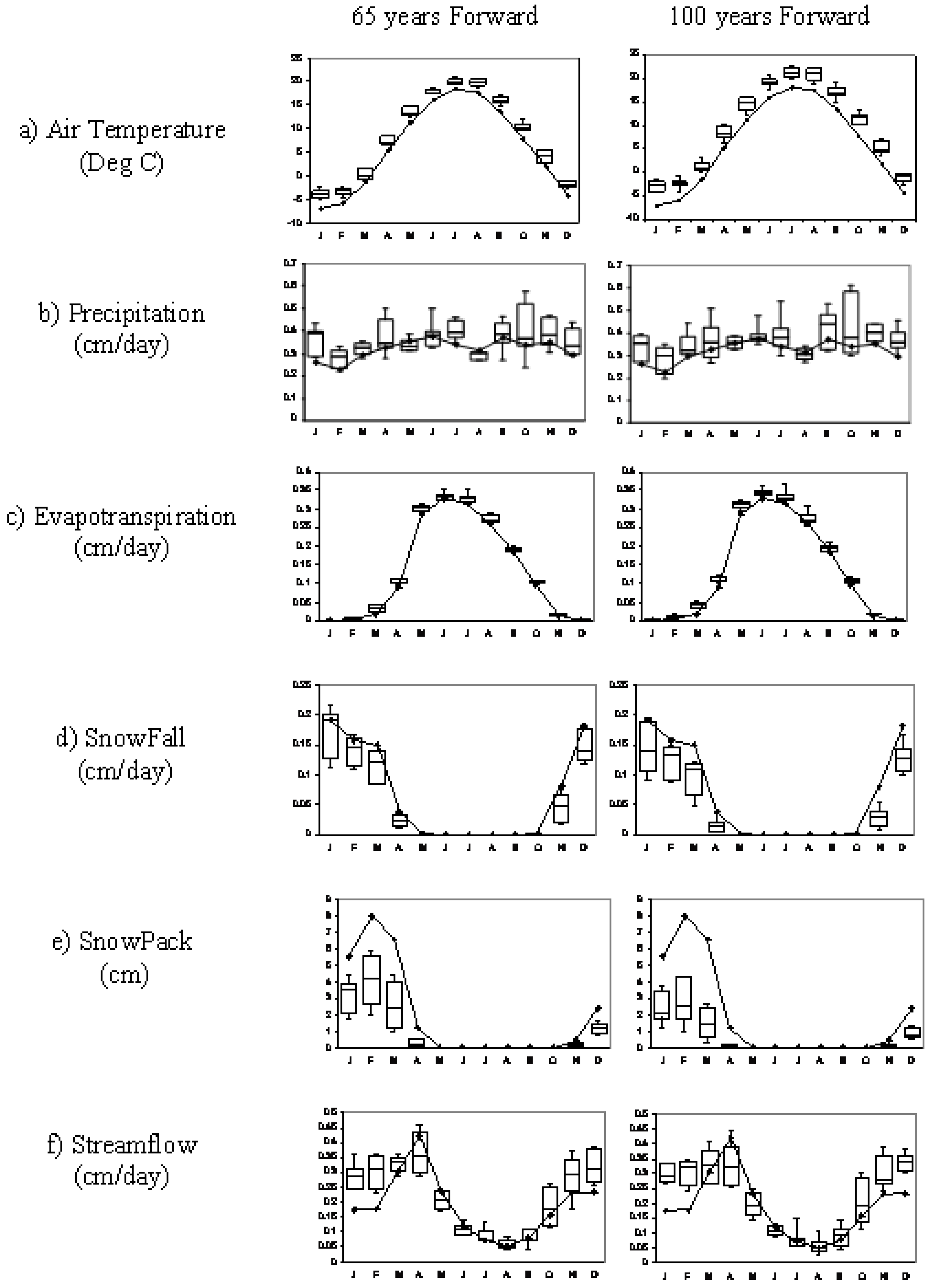


Figure 6.5 Water balance components for WOH watersheds for baseline (solid line) and eight scenarios (boxes), simulated by GWLF-VSA model. The midway line in the boxes shows the median value for the climate scenarios, the extent of the boxes shows the range of the middle six scenarios, and the whiskers show the range of all scenarios.

Water Quantity in WOH Reservoirs

The potential impact of climate change on water quantity in the WOH reservoir system was investigated by running the OASIS Water System Model driven by streamflow inputs to reservoirs as simulated by the watershed model for baseline and climate change scenarios. The OASIS model simulates water supply system operations, and provides assessments of supply status and system operating policies.

The model results for total WOH reservoir storage, releases, and spills (Figure 6.6) illustrate the effects of the changes in input streamflow. In general, the reservoirs are fuller during the late fall and early winter due to the increased input streamflow during this period. Reservoir storage during the growing season remains largely unchanged. Similarly, the reservoir releases and spills increase during the same late fall and early winter period, as the reservoirs are fuller and streamflow increases. Spills and releases during the late winter and early spring show a wide variation under varying scenarios.

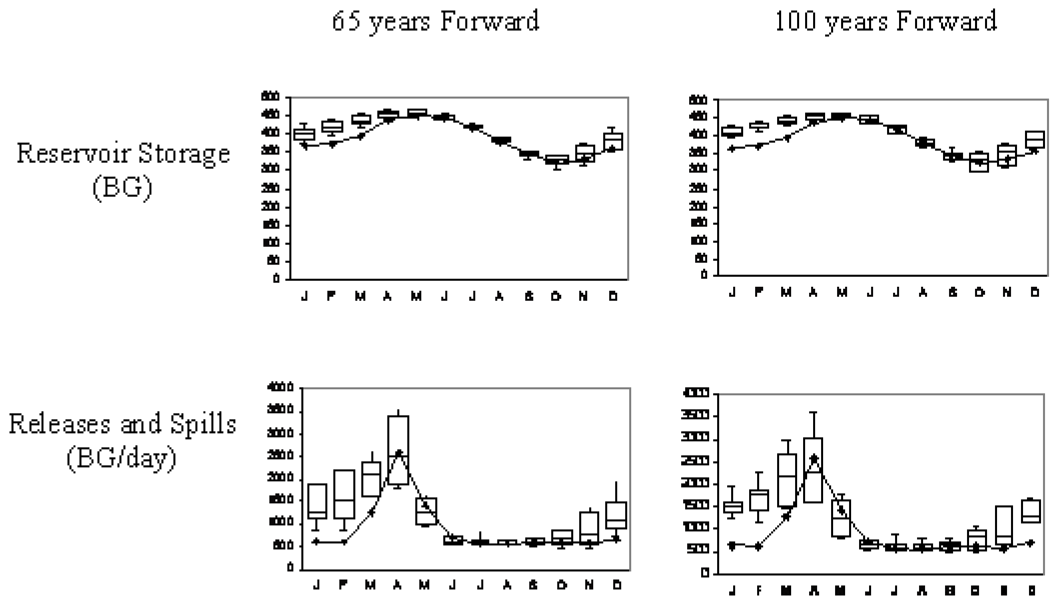


Figure 6.6 Monthly mean WOH reservoir storages (BG), releases, and spills (BG/day) for baseline and eight scenarios for the 65-year future and 100-year future scenarios. The midway line in the boxes shows the median value for the climate scenarios, the extent of the boxes shows the range of the middle six scenarios, and the whiskers show the range of all scenarios.

Turbidity in Schoharie Reservoir

The CEQUAL-W2 model was used for preliminary investigation of climate change effects on turbidity in Schoharie Reservoir. CEQUAL-W2 simulates turbidity transport within the reservoir and has been used extensively to simulate turbidity levels and to guide long-term planning.

Watershed model flow results and turbidity loads based on a turbidity rating curve were input into the CEQUAL-W2 reservoir model developed for Schoharie Reservoir. To simulate operations of the reservoir, a model preprocessor was developed. This preprocessor used Shandaken Tunnel flows from the historical record and reduced these flows when withdrawal exceeded available reservoir storage so that withdrawal levels were consistent with scenario reservoir inflows. The baseline scenario is based on an historical simulation of flows and loads for 1948 through 2004.

The mean monthly turbidity load for the baseline and climate change scenarios is shown in Figure 6.7a. Similar to the streamflow pattern (Figure 6.5f), turbidity loads increase in the late fall and early winter. Turbidity loads are especially increased in the fall, due to relatively large and variable increases in streamflow. Figure 6.7b shows the effects of the increased load on Shandaken Tunnel turbidity, with increases in late fall and early winter, and decreases in the late winter and early spring. These results are directly related to the changes in streamflow timing due to the changes in snowpack development and melting.

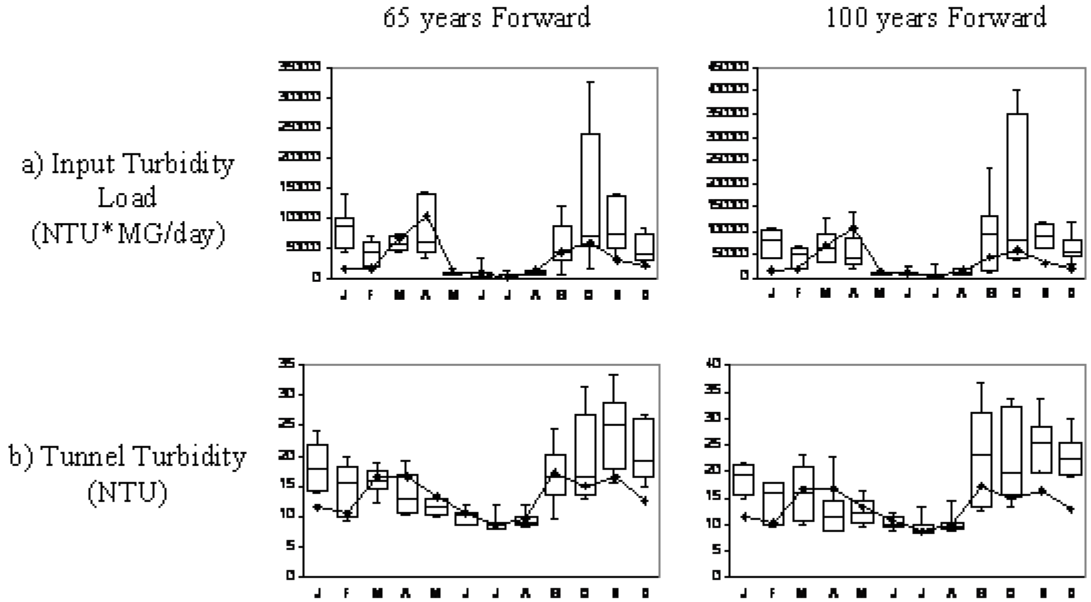


Figure 6.7 Monthly mean input turbidity load (NTU * MG/day) to Schoharie Reservoir (a), and monthly mean turbidity in the Shandaken Tunnel (NTU) (b), for baseline and eight scenarios. The midway line in the boxes shows the median value for the climate scenarios, the extent of the boxes shows the range of the middle six scenarios, and the whiskers show the range of all scenarios.

Eutrophication in Cannonsville Reservoir

Climate change effects on eutrophication in Cannonsville Reservoir were investigated using the PROTECH model. Future climate scenario watershed model flow and nutrient loads were input into the PROTECH reservoir model. In addition, the climate change scenario air temperatures were used to affect changes in thermal stratification and input stream temperatures. As with the Schoharie simulations above, the operations of the reservoir were simulated with a model preprocessor to estimate scenario aqueduct flows. The historical record was generally used for aqueduct flows, which were reduced when withdrawal exceeded available reservoir storage, to ensure that these flows were consistent with scenario reservoir inflows.

Mean monthly inputs of dissolved phosphorus are shown in Figure 6.8a. These inputs follow the patterns in streamflow with increased loads in the fall and early winter and decreased loads in the early spring. In addition to the changes in loads, the effects of temperature changes on the thermal stratification of the reservoir are shown to be important in affecting phytoplankton development. The lake temperature is increased to greatest in the fall (Figure 6.8b). This increase in temperature also coincides with a longer and more intense period of thermal stratification in the reservoir (Figure 6.9).

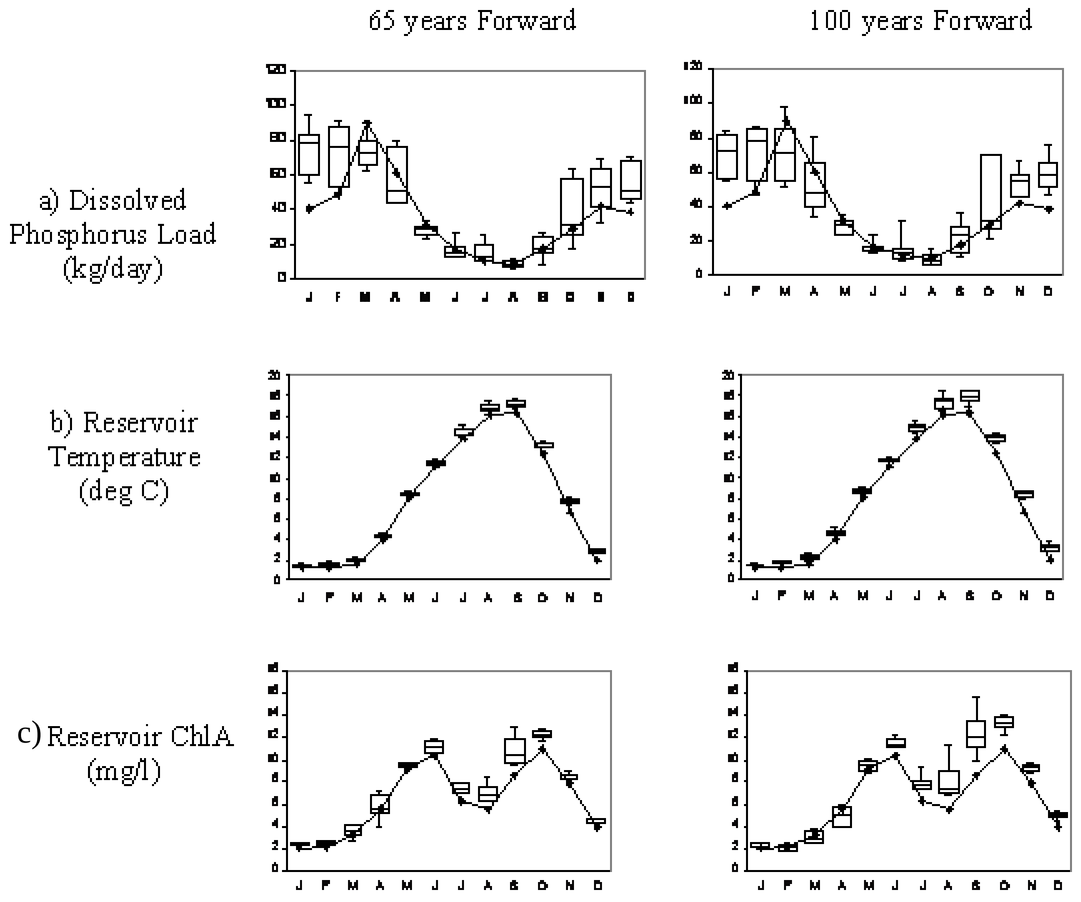


Figure 6.8 Monthly mean dissolved phosphorus (P) input (kg/day) (a), reservoir water temperature (^{o}C) (b), and chlorophyll *a* (mg/l) (c) in Cannonsville Reservoir for baseline and 8 scenarios. The midway line in the boxes shows the median value for the climate scenarios, the extent of the boxes shows the range of the middle six scenarios, and the whiskers show the range of all scenarios.

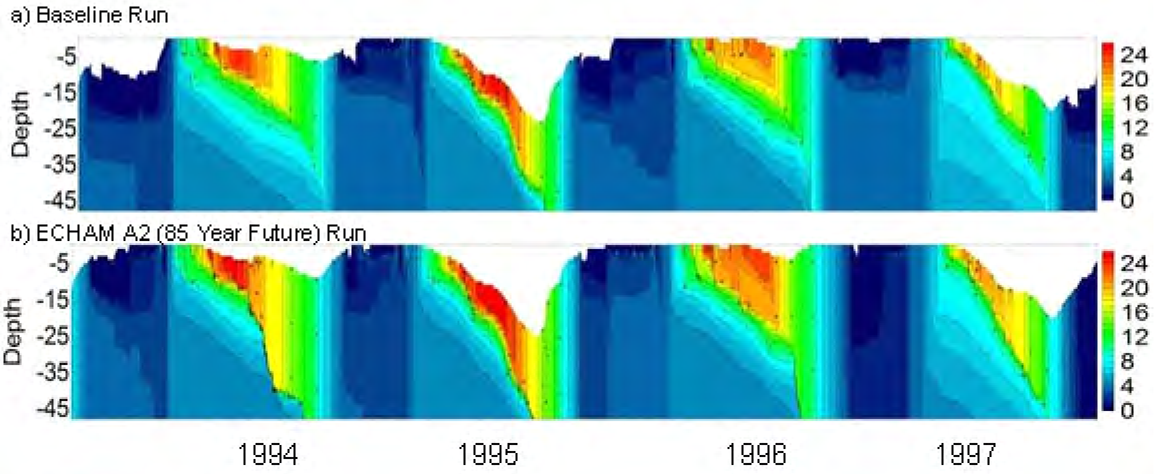


Figure 6.9 Example of time series of PROTECH model thermal profile for Cannonsville Reservoir for the baseline scenario (a) and the ECHAM A2 85 year future scenario (b). The thermal stratification starts earlier in the spring, ends later in the fall, and is more intense for the future climate scenario, as compared with the baseline scenario.

The changes in phosphorus loading and thermal stratification pattern have discernible effects on phytoplankton development (Figure 6.8c). In the baseline scenario, there are two distinct peaks in phytoplankton levels, one in the spring and one in the fall, typical of northern mid-latitude lakes. For the climate change scenarios, each of these peaks increases. In particular the fall bloom increases more intensely due to a combination of the stronger thermal stratification and the increased nutrient loads.

Summary

DEP's watershed, reservoir, and system models have been combined to perform a preliminary investigation of the effects of potential climate change on water quantity and quality in the NYC water supply. Initial results of this analysis suggest that increased air temperatures may result in less snow, more winter rain, and smaller snowpack accumulation. This may, in turn, lead to increased late fall and winter streamflows and decreased spring snowmelt. Both turbidity and nutrient loads will increase in winter due to increased flows. Additionally, reservoir thermal stratification is expected to last longer and be more intense under future conditions. The combination of increased nutrient loads and stronger thermal stratification may lead to increases in phytoplankton production, especially in the fall. Increases in turbidity loads during winter and fall will potentially lead to greater reservoir turbidity levels.

The results presented here are preliminary for a number of reasons: (1) climate change projections using delta change method do not account for possible changes in storm frequency, intensity, and spatial variability; (2) the reservoir operations adjustments need to be integrated with the OASIS system model results; (3) feedback between reservoir operations and water quality needs to be incorporated (as illustrated in the Schoharie turbidity results); (4) further model testing and sensitivity analyses are needed to understand model predictions, especially at extreme present climate and future climate conditions. These limitations will be addressed in future work.

6.4 How did DEP use model simulations in 2008 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 (Fig 6.10). Kensico Reservoir is of great importance for the water supply since it is the location where water from the WOH 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. Naturally occurring, episodic inputs of turbid water (e.g., Fig 6.11) do increase turbidity levels in Ashokan Reservoir and the Catskill System water withdrawn from it, and this water could in turn affect turbidity levels in Kensico Reservoir.

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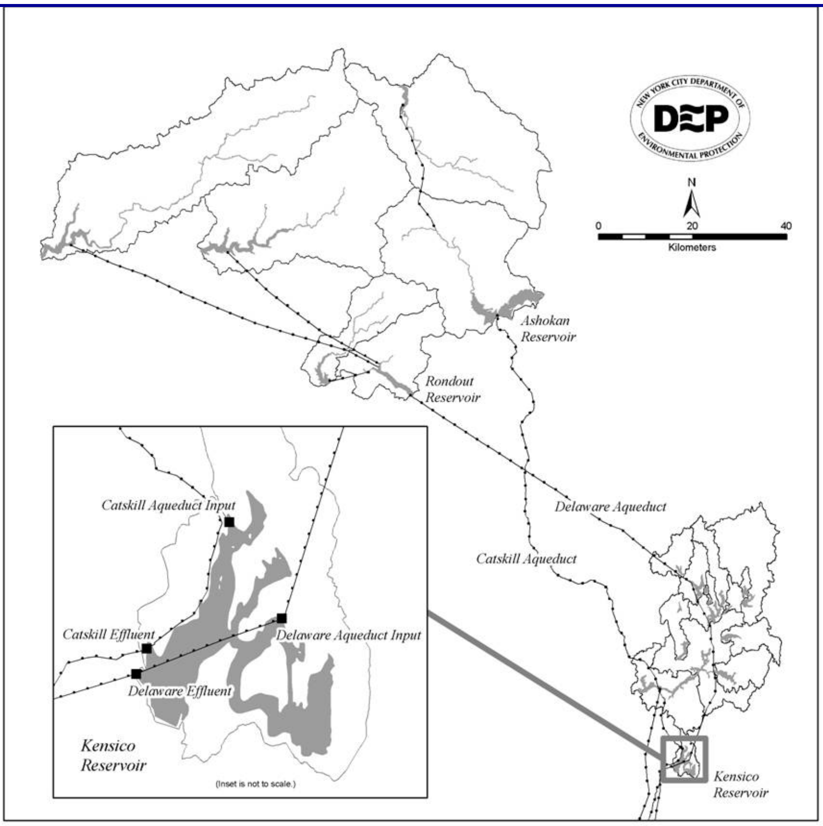


Figure 6.10 New York City water supply reservoirs. Water from the two Catskill System reservoirs enters the Catskill Aqueduct from Ashokan Reservoir, while water from the four Delaware System reservoirs enters the Delaware Aqueduct from Rondout Reservoir. Inserts show details of inflows and outflows in Ashokan and Kensico Reservoirs.

The data shown in Figure 6.11 document the only occasion during 2008 when increases in Catskill System turbidity potentially threatened Kensico Reservoir water quality. This series of storms, beginning in February 2008 and culminating in two closely spaced storm events from March 5-12, 2008, increased Ashokan Reservoir turbidity levels and the turbidity of water entering the Catskill Aqueduct. Peak turbidity levels measured in Esopus Creek, just upstream of the confluence with Ashokan Reservoir, exceeded 250 NTU, which led to an increase in Ashokan Reservoir turbidity to between 6 and 8 NTU at the Catskill Aqueduct effluent (Figure 6.11). To safeguard Kensico Reservoir water quality, Catskill Aqueduct flow was reduced during this event, while the withdrawal of low turbidity Delaware System water was increased. Model simulations were used to help define safe levels of Catskill Aqueduct flow as turbidity changed over the course of the event.

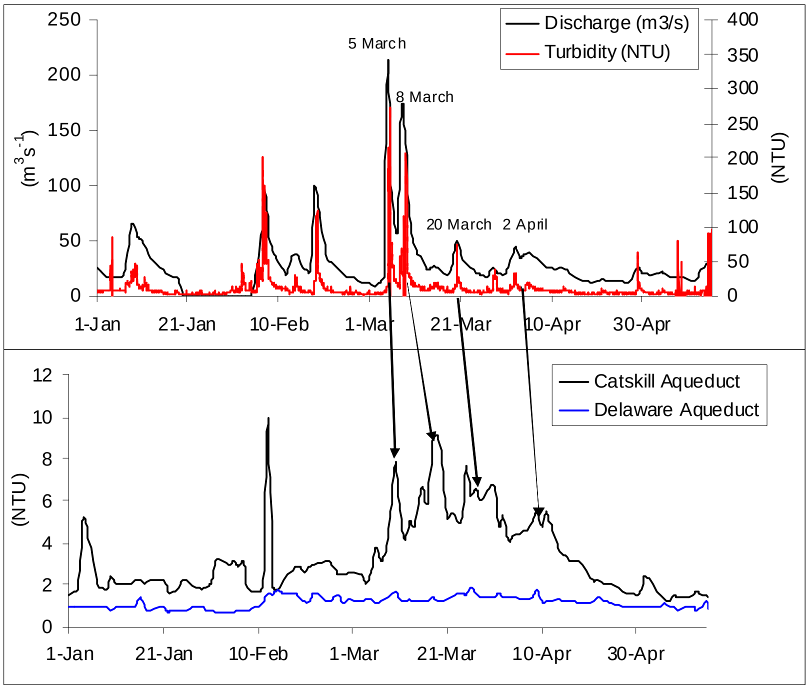


Figure 6.11 Conditions leading up to and following the March 2008 turbidity event. The top panel shows the discharge and turbidity measured in Esopus Creek near its confluence with Ashokan Reservoir. The bottom panel shows the turbidity levels measured in the Catskill and Delaware Aqueduct withdrawals from Ashokan and Rondout Reservoirs. The arrows show the correspondence between the storm event turbidity inputs to Ashokan Reservoir and the change of turbidity in the Catskill Aqueduct effluent withdrawn from the East Basin of Ashokan Reservoir.

Table 6.1: Steady state inputs used for Kensico modeling forecasts during the March 2008 turbidity event. This is a subset of a larger number of combinations of aqueduct flow and turbidity used to provide multiple forecasts during the event.

Kensico Aqueduct flows				Kensico input turbidity	
Cat In MGD	Del In MGD	Cat Out MGD	Del Out MGD	Cat In NTU	Del In NTU
600	500	400	700	15	1.5
300	800	400	700	15	1.5

An example of a model-based forecast of the turbidity levels in the water withdrawn from Kensico Reservoir is shown in Figure 6.12. This forecast was made on March 7 as the turbidity event unfolded. For these simulations the model was initially run using measured aqueduct inputs of water and turbidity to Kensico Reservoir and measured outputs of water from the reservoir. Comparison of the simulated output turbidity levels with those measured by DEP leading up to the event suggested that the model was capable of predicting the pre-event turbidity levels within the margin of error related to uncertainty in particle sinking. Following this initial “spin up” period, future inputs to the reservoir were based on the need to satisfy a demand of 1100 MGD and to maintain a mass balance of water within Kensico Reservoir. Two forecasts are illustrated here. In the first, the total demand was apportioned between the Catskill and Delaware Systems in an approximately equal manner, which would be typical of normal operating conditions, and in the second the Catskill Aqueduct flow was reduced by half, while increasing the Delaware flow. Delaware reservoir turbidity levels were assumed to be at 1.5 NTU, as was measured at the time of the event (Figure 6.11). Catskill System turbidity levels were assumed to vary between 6-20 NTU, based on the trend in Ashokan Reservoir withdrawal turbidity (Figure 6.11). For the forecast described here, a turbidity level of 15 NTU was chosen, which at the time of the simulations was a reasonable estimate of a maximum “worst case” turbidity. The forecast input levels are given in Table 6.1. These were held constant for one month into the future following the model spin up period. During the actual event multiple simulations were run using a range of input turbidity levels.

The results suggested that at a normal flow of 600 MGD Catskill Aqueduct turbidity inputs would likely lead to Kensico effluent turbidity levels exceeding the 5 NTU regulatory limit. Reducing the Catskill Aqueduct flow to 300 MGD, while increasing the Delaware Aqueduct flow by the same amount, almost completely eliminated the possibility of turbidity levels exceeding 5 NTU.

The example forecast shown in Figure 6.12 illustrates how model simulations were used to define acceptable aqueduct flow rates to Kensico Reservoir during periods of elevated Catskill System turbidity. Based on this and related simulations it was suggested that under current operating conditions Catskill input turbidity levels up to, but not exceeding, 10 NTU could be tolerated.

Further reductions in Catskill Aqueduct flow to at least 300 MGD would be required if turbidity exceeded 10-15 NTU, in order to maintain a reasonable margin of safety in approaching the 5 NTU regulatory limit. Actual Catskill Aqueduct turbidity levels remained below 10 NTU, but on a number of occasions peaked close to this value (Figure 6.11). Given that DEP had the capability to reduce the Catskill flows and that Catskill turbidity levels were approaching a level that could lead to increases in Kensico effluent turbidity, a decision was made to reduce Catskill Aqueduct flows by approximately 50 percent on March 11, 2008.

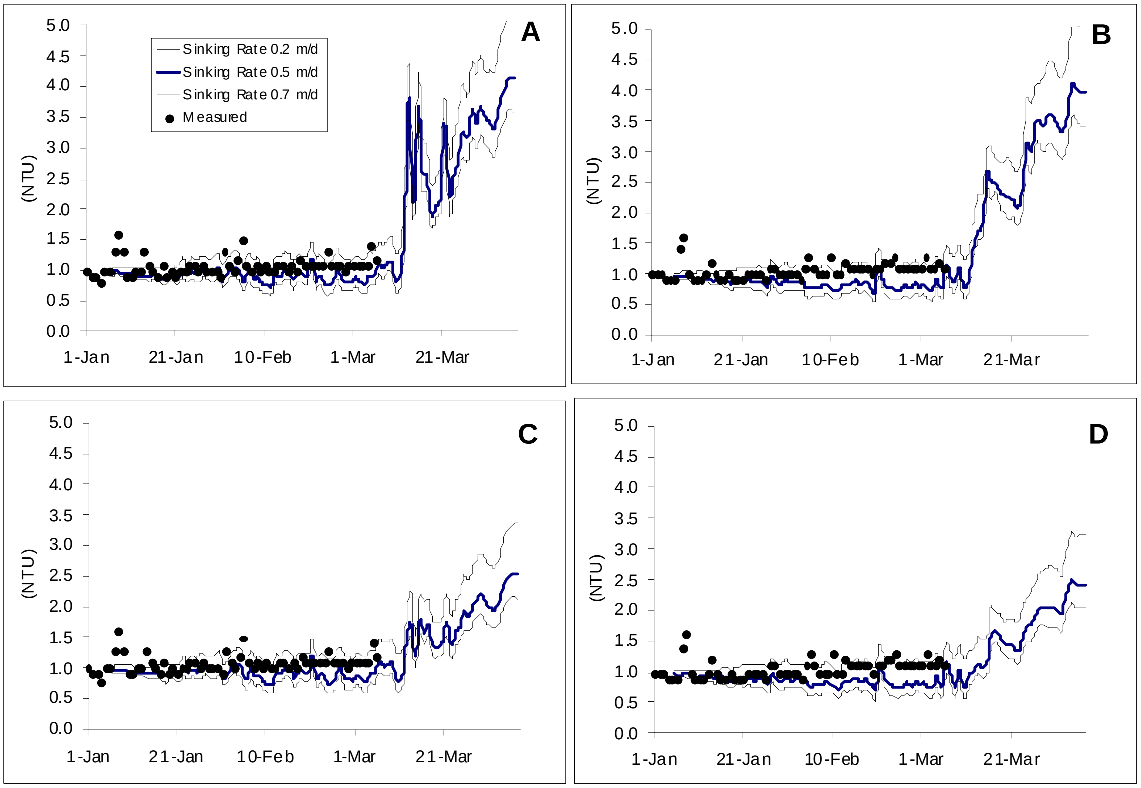


Figure 6.12 Simulated Kensico Reservoir effluent turbidity levels assuming a constant 15 NTU turbidity in the Catskill Aqueduct input to the reservoir. In the top portion of the figure the predicted turbidity at the Catskill (A) and Delaware (B) effluents are shown assuming a Catskill Aqueduct flow of 600 MGD. In the bottom portion of the figure the predicted turbidity in the Catskill (C) and Delaware (D) effluents are shown when the Catskill Aqueduct flow was reduced to 300 MGD and the Delaware Aqueduct flow was increased to 800 MGD. The three lines show a range in simulated turbidity that results from reasonable variations in the settling rate of the turbidity-causing particles. The points are measured turbidity during the period prior to the forecasts.

The March-April 2008 event described above was a moderate event that led to elevated turbidity levels in Catskill System water. Turbidity increases were not extreme enough to require alum treatment. 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 optimize reservoir operations helped DEP choose aqueduct flow rates while at the same time accounting for reservoir system turbidity levels.

6.5 How does DEP obtain and make use of future climate simulation data?

For long-term planning, DEP requires future climate simulations as inputs to an integrated suite of models (Section 6.1) to examine the potential effects of climate change on the quantity and quality of water in the NYC water supply.

Since the future climate is unknown and uncertain, future climate scenarios are simulated, and scientists around the world use a number of possible scenarios to cover the uncertainty. A number of methods are available to obtain future climate simulations. DEP uses Global Climate Model (GCMs) simulations for possible emission scenarios (called SRES A1B, SRES B1, and SRES A2). GCMs are complex mathematical models, which simulate the behavior of the global climate system, its components, and their interactions. The components include the atmosphere, the hydrosphere (liquid water), the cryosphere (ice and snow), the lithosphere (rock and soil), and the biosphere (plants and animals, including humans). Nonlinear interactions between components occur through physical, chemical, and biological processes. The GCM simulations are at global scale (40,000 km^2), so DEP processes them to get local future climate conditions at the watershed scale (2000 km^2) using various downscaling techniques. The methodologies used by DEP are widely used by policy makers, scientists, and other experts for assessing the causes of climate change and its potential impacts.

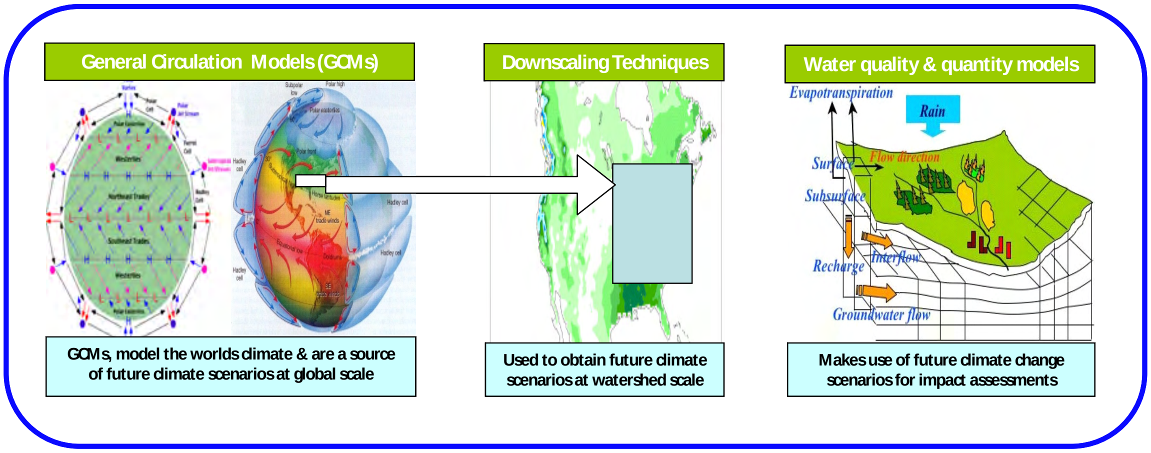


Figure 6.13 Overview of processing future climate simulation data to produce data sets that can be used with DEP's watershed and reservoir models.

7. Further Research

7.1 What research is DEP currently or prospectively engaged in that will extend its water quality monitoring capabilities?

In 2008, DEP completed studies intended to enhance understanding of pathogens during storm events and in transport at Hillview Reservoir. At the same time, DEP continued its development of models that elucidate and quantify the effects of climate, watershed management, and reservoir operations on the quality and reliability of the NYC water supply system. These projects are described more fully below.

Pathogens

Storm Water Monitoring

In 2008, DEP completed a multi-year project funded by DEP and a United States Army Corps of Engineers Water Resources Development Act (WRDA) grant. The project began in August 2005 and continued through May 2008, and included sites in the NYC watershed both east and west of the Hudson River.

Results from the project have provided more detailed information concerning pathogens and storm events in the watershed. DEP was able to develop automated systems to continuously monitor storm water flows and collect samples for pathogen analysis at multiple sites around the reservoir system, with enough flexibility to assess pathogen concentrations during different phases of the storm. DEP was also able to identify optimal pathogen sample collection time throughout the storm within the stream storm hydrograph; identify pathogen occurrence, concentration, and load during storm events from site to site; and compare pathogen concentrations and loads during storm events to available base flow conditions. Additionally, DEP studied the relationship between pathogen concentration and storm event size, as well as the effect of stream size and water resource protection projects—such as storm water retention basins—on pathogen occurrence, transport, and loading. These studies provide insight into how and when monitoring and protection of the water supply should be performed.

West of Hudson. The West of Hudson data indicate that storm events have greater pathogen concentration, loading, and weighted loading rate compared to base flow data at all sites for the two sub-basins studied, Esopus Creek in the Ashokan Reservoir watershed and Schoharie Creek in the Schoharie Reservoir watershed. Similarly, *Giardia* was consistently greater than *Cryptosporidium* for concentration (approximately 1 order of magnitude), loading (approximately 2-3 orders of magnitude), and weighted loading index (approximately 1-2 orders of magnitude). This consistency may be useful if it is found to apply to the entire NYC Watershed, since it could lead to the development of a rough estimate of *Giardia* and *Cryptosporidium* ratios during storm events.

In addition to comparing the sub-basins, the pathogen data were used to help identify whether protozoan pathogens originated from point or non-point sources. Esopus Creek—the primary tributary of Ashokan Reservoir—did not reveal any evidence of protozoan pathogen point sources, except for SRR2CM, which represents the outflow of Schoharie Reservoir via the Shandaken Tunnel. On the other hand, the Schoharie Creek sub-basin data suggest both a point and non-point origin, based on the abundance of protozoan pathogens and land use. The data indicate a relatively significant increase in both *Cryptosporidium* and *Giardia* between an upstream site (SSHG) and a midstream site (S4), while both the baseline and storm event data suggest that the abundance of *Cryptosporidium* and *Giardia* in the Schoharie Creek sub-basin is greater than in the Esopus Creek sub-basin. A comparison of land use between the sub-basins indicates that the Schoharie Creek sub-basin has significantly more livestock farming, population centers, and WWTPs than the Esopus Creek sub-basin, and that these land uses occur more frequently close to Schoharie Creek. A more detailed look at the land use between SSHG and S4 indicates that two population centers (Tannersville and Hunter) and nine WWTPs occur in close proximity to Schoharie Creek. The next step to determine the specific sources of the protozoa would be to conduct a more exhaustive land use analysis, with ground truthing and sampling at the WWTPs that are not currently monitored, for both base flow and storm events.

East of Hudson. As with data from the West, East of Hudson data indicate that storm events have greater pathogen concentration, loading, and weighted loading rate compared to base flow data at all sites for the eight sub-watersheds studied.

The project also provided valuable data relating to appropriate sampling intervals for monitoring storms East of Hudson. For the larger streams in the Kensico watershed, 30 minute sample intervals using two autosamplers (24 samples for each autosampler) seem to capture most small to moderate storms adequately. Larger storms (2 inches or greater) at these sites require additional autosampler runs, or longer sampling intervals. In general, smaller streams require a 10-30 minute sample interval depending on the size of the storm, the rainfall intensity, and consistency. DEP missed several peak flows at small streams because the interval was too long.

Differences between the timing of protozoan transport in unmodified streams and BMP-modified streams became quite apparent during DEP’s analysis. Unmodified streams exhibited the “first flush phenomenon” characteristic of basins with residential development and impervious surfaces. The highest concentrations of pathogens at unmodified streams were found in the rising limb, followed by the peak of flow. Estimates of pathogen loading were greatest in the peak of flow at unmodified streams, which can be attributed to the extremely elevated flow during this portion of the storm and its ability to mobilize particles and microbes from the landscape into the streams. BMP data suggest an attenuation of protozoa in the BMPs, with a delayed discharge of the elevated protozoa later in the storm.

In sum, the project achieved most of its goals, providing informative results and generating new questions regarding the mobilization of pathogens during storm events. A complete report discussing details of the project will be forthcoming under separate cover.

Hillview Reservoir

Hillview Reservoir, part of New York City's water supply located in Yonkers, New York, fits the description of an uncovered finished water storage facility according to the Long Term Enhanced Surface Water Treatment Rule 2 (LT2). Under this rule, NYC was required to cover the reservoir or treat its discharge in a manner the rule prescribes. In September 2006, DEP initiated a study to see if a significant difference in protozoa existed at the reservoir's effluent compared to its influent, to determine if remedial actions of this kind were warranted. The sampling scheme included sites along both the Catskill and Delaware Aqueducts, which flow through and bypass Hillview Reservoir, respectively. Sample collection was carried out in two sampling periods: September 12, 2006–September 29, 2007, and March 4–August 28, 2008. No significant difference ($p=0.5$) was detected between protozoa at the inflows and outflows of Hillview, indicating the open reservoir does not contain significant sources of these pathogens. This suggests that covering Hillview Reservoir will not significantly improve the quality of drinking water with respect to levels of protozoa (DEP 2008c).

Modeling

Two major planned advancements in DEP's modeling capability—the linkage of watershed and reservoir models to a system-wide model (OASIS) and the development of more spatially-distributed and process-based watershed models—have been undertaken to support long-term planning for climate change and watershed management that maximizes water quality in the NYC Water Supply.

A system-wide modeling approach investigates how each reservoir fits into the larger water supply system. This type of analysis would investigate the probability of exceeding (or staying below) regulatory and guidance pollutant limits at key system locations (e.g., Kensico effluents, Shandaken Tunnel portal, Rondout effluent) under various realistic scenarios of flow and loading conditions. By simulating the entire system, the effects on system operations due to improved water quality in one reservoir can be analyzed.

Spatially-distributed watershed models explicitly simulate loadings from sub-basins and route water and pollutants from their sources to each reservoir. The effects of BMP-induced pollutant load reductions on reservoir water quality may differ depending on where in the watershed the pollutant sources are being treated. These analyses would support prioritization of sub-basins (and possibly stream reaches) for watershed management.

These advances in modeling are being developed as a result of several projects to upgrade DEP’s modeling capability and evaluate the effects of climate change on the water supply. Current FAD funding over the next four years will provide the resources to develop the data, models, and tools that could subsequently be used as the basis for future model applications.

7.2 What work is supported through contracts?

DEP accomplishes several goals 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 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	6/24/03–6/30/09
Monitoring	
Monitoring of NYC Reservoirs for Viruses	7/29/08–7/28/11
Monitoring of NYC Reservoirs for Zebra Mussels	8/1/08–6/30/10
Monitoring of NYC Residences for Lead and Copper	1/1/07–12/31/09
Organic Analysis Laboratory Contract	7/1/08–6/30/11
Bulk Chemical Analysis	8/1/05–7/31/08
Analysis of Stormwater at Beerston, Cannonsville Watershed	11/1/07–10/30109
Research and Development	
Design of Controls for Zebra Mussels in NYC’s Water Supply System	1/5/94–6/30/10
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–12/31/10
Croton System Model Development and Protech	11/15/05–6/30/10
Robotic Water Quality Monitoring Network	1/1/09–12/31/11

References

Alderisio, K.A. and N. DeLuca. 1999. Seasonal enumeration of fecal coliform bacteria from the feces of Ring-billed Gulls (*Larus delawarensis*) and Canada geese (*Branta canadensis*). *Appl. Environ.l Microb*. 65:5628-5630.

American Public Health Association. 1992, 1998. Standard methods for the examination of water and wastewater. 18th and 19th editions. APHA.

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

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

Cooke, G. D., E. B.Welch, S. Peterson, P. Newroth. 1986. Lake and Reservoir Management. Butterworth Publishers. Stoneham, MA.

Dahl, T.E. 2006. Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. 112 p.

DEC [New York State Department of Environmental Conservation]. 2002. Quality Assurance Work Plan for Biological Stream Monitoring in New York State. Albany, NY. 116 p.

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

DEP. 2002a. Rules and regulations for the protection from contamination, degradation and pollution of the New York City water supply and its sources. CAPA Regulations. Valhalla, NY.

DEP. 2002b. Continue Implementation of Final Waterfowl Management Plan. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2003a. Integrated Monitoring Report. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2003b. Waterfowl Management Program. July 31, 2003. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2004. Waterfowl Management Program. July 31, 2004. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2005. Waterfowl Management Program. July 31, 2005. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2006a. New York City's 2005 Watershed Protection Program Summary, Assessment and Long-Term Plan. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2006b. 2006 Long-Term Watershed Protection Program. Valhalla, NY. 66 p.

DEP. 2006c. www.nyc.gov/html/dep/html/pathogen.html.

DEP. 2006d. DEP Pathogen Studies of *Giardia* spp., *Cryptosporidium* spp., and Enteric Viruses, January 31, 2006. Valhalla, New York.

DEP. 2006e. DEP Pathogen Studies of *Giardia* spp., *Cryptosporidium* spp., and Enteric Viruses, July 31, 2006. Valhalla, New York.

DEP. 2006f. Waterfowl Management Program. July 31, 2006. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2006g. 2006 Watershed Protection Program Summary and Assessment. Division of Drinking Water Quality Control. Valhalla, NY. 494 p.

DEP. 2007a. 2006 Watershed Water Quality Annual Report. Directorate of Water Quality. Valhalla, NY. 138 p.

DEP. 2007b. 2006 Research Objectives Report. Directorate of Water Quality. Valhalla, NY. 86 p.

DEP. 2007c. Waterfowl Management Program. July 31, 2007. Directorate of Water Quality. Valhalla, NY.

DEP. 2008a. 2009 Watershed Water Quality Monitoring Plan. Directorate of Water Quality. Valhalla, NY. 226 p.

DEP. 2008b. *Report 1: Assessment and Action Plan – A Report Based on the Ongoing Work of the DEP Climate Change Task Force*. The NYCDEP Climate Change Program. DEP with contributions by Columbia University Center for Climate Systems Research and HydroQual Environmental Engineers and Scientists, P.C. New York, NY. 100 p.

DEP. 2008c. Monitoring *Giardia* spp. and *Cryptosporidium* spp. oocysts at the Uptakes and Downtakes of Hillview Reservoir. Valhalla, NY. 51 p.

DEP. 2008d. Waterfowl Management Program. July 31, 2008. Directorate of Water Quality. Valhalla, NY.

DEP. 2009. The Impact of Drawdown on Water Quality in Catskill and Delaware Reservoirs. Valhalla, NY. 67 p. (in review).

Effler, S. W. and A. P. Bader. 1998. A limnological analysis of Cannonsville Reservoir, NY. *J. Lake Reservoir Manage*. 14:125-139.

Effler, S. W., R.K. Gelda, D.L. Johnson, and E.M. Owens. 1998. Sediment resuspension in Cannonsville Reservoir, NY. *J. Lake Reservoir Manage*. 14:225-237.

Effler, S. W. and D. A. Matthews. 2004. Sediment resuspension and drawdown in a water supply reservoir. *J. Am. Water Work Assoc.* 40: 251-264.

Fong, D.W.T., C.W. Kwan, K.F. Lam, and S.L. Karen. 2003. Use of the Sign Test for the median in the presence of ties. *Am. Stat*. 57:237-240.

Furey, P. C., R. N. Nordin, and A. Mazumder. 2004. Water level drawdown affects physical and biogeochemical properties of littoral sediments of a reservoir and a natural lake. *J. Lake Reservoir Manage*. 20:280-295.

Gannett Fleming and Hazen and Sawyer. 2007. Phase III Final Report: Catskill Turbidity Control Study. Valhalla, NY.

Janus, L. L. and R. A. Vollenweider. 1981. The OECD Cooperative Programme on Eutrophication.Summary Report. Canadian Contribution. Canada Centre for Inland Waters. Burlington,Ontario. 392 p.

Nowlin, W.H., J-M. Davies, R. N. Nordin, and A. Mazumder. 2004. Effects of water level fluctuation and short-term climate variation on thermal and stratification regimes of a British Columbia reservoir and lake. *J. Lake Reservoir Manage*. 20:91-109.

Schneiderman, E.M., T.S. Steenhuis, D.J. Thongs, Z.M. Easton, M.S. Zion., A.L. Neal, G.F. Mendoza, and M.T. Walter. 2007. Incorporating variable source area hydrology into a curve-number-based watershed model. *Hydrol. Proc.* 21: 3420-3430.

Smith, D.G. and C.M. Hoover. 1999. Use of a viewer box in Secchi disk measurements. *J. Am.*

Water Resour. Assoc. 35:1183-1189.

Smith, D.G. 2001. A protocol for standardizing Secchi disk measurements. *J. Lake Reservoir Manage*. 17:90-96.

Tiner, R., J. Swords, and S. Schaller. 1999. Wetland Trends in the Croton Watershed, New York: 1960s to 1990s. U.S. Fish and Wildlife Service, Hadley, MA. Prepared for the New York City Department of Environmental Protection, Bureau of Water Supply, Quality, and Protection, Valhalla, NY.

Tiner, R.W., J. Q. Swords, and H.C. Bergquist. 2005. Wetlands of the East of Hudson Watershed of the New York City Water Supply System: 2004 Status and Recent Trends (1994-2004). U.S. Fish and Wildlife Service, National Wetlands Inventory, Ecological Services, Region 5, Hadley, MA. Prepared for the New York City Department of Environmental Protection, Valhalla, NY.

Tiner, R.W. 2008. Wetlands of the West of Hudson Watershed of the New York City Water Supply System: 2004 Status and Trends since the Mid-1980s. U.S. Fish and Wildlife Service, National Wetlands Inventory, Ecological Services, Region 5, Hadley, MA. Prepared for the New York City Department of Environmental Protection, Valhalla, NY.

USEPA. 1997. New York City Filtration Avoidance Determination. Surface Water Treatment Rule Determination for New York City's Catskill/Delaware Water Supply System.

USEPA. 2002. New York City Filtration Avoidance Determination. Surface Water Treatment Rule Determination for New York City's Catskill/Delaware Water Supply System.

USEPA. 2006. Long Term Enhanced Surface Water Treatment Rule (LT2), 40 CFR Parts 9, 141, and 142.

USEPA. 2007. New York City Filtration Avoidance Determination. Surface Water Treatment Rule Determination for New York City's Catskill/Delaware Water Supply System.

Valderrama, J.C. 1980. The simultaneous analysis of total nitrogen and total phosphorus in natural waters. *Mar. Chem*. 10:109-122.

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, 2008.

			Kensico			New Croton			East Ashokan Basin			Rondout	
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		427	2.6 - 21.9	11.4	309	3.8 - 24.8	10.9	92	3.8 - 23.7	10.5	179	2.9 - 22.3	10.4
pH (units)	6.5-8.5[1]	362	6.3 - 7.5	7.0	256	6.9 - 8.9	7.5	92	5.9 - 8.2	7.1	149	6.0 - 8.5	7.0
Alkalinity (mg/L)		20	8.7 - 13.3	10.6	29	51.7 - 70.6	59.9	9	9.2 - 12.1	9.9	9	5.3 - 9.9	6.5
Conductivity		401	50 - 88	67	309	328 - 377	353	86	50 - 64	56	179	44 - 61	53
Hardness (mg/L)[2]		20	16.12 - 20.5	19.0	18	82.5 - 93.8	87.9	8	15.9 - 18.2	16.3	9	12.1 - 16.9	14.3
Color (Pt-Co units)	(15)	371	5 - 15	10	316	8 - 45	20	89	5 - 15	9	180	7 - 16	12
Turbidity (NTU)	(5)[3]	427	0.2 - 2.5	1.1	316	0.7 - 4.7	2.0	91	0.8 - 6.6	1.6	180	0.4 - 1.7	0.9
Secchi Disk Depth (m)		117	2.3 - 6.1	4.8	102	1.6 - 3.7	2.6	25	2.1 - 5.8	4.2	51	3.7 - 6.9	5.3
BIOLOGICAL													
Chlorophyll *a* (µg/L)	7[4]	61	<0.40 - 9.30	4.30	48	4.70 - 16.60	11.75	20	0.96 - 3.78	1.88	24	0.22 - 5.13	2.28
Total Phytoplankton (SAU)	2000[4]	159	30 - 1300	260	161	2 - 2600	540	59	5 - 870	170	106	<5 - 650	155
CHEMICAL													
Dissolved Organic Carbon (mg/L)		193	1.1 - 1.9	1.5	160	2.1 - 4.0	2.9	57	1.3 - 1.8	1.5	80	1.3 - 1.9	1.5
Total Phosphorus (µg/L)	15[4]	195	3 - 10	6	161	1.5 - 33	14	65	<5 - 13	8	100	<5 - 9	7
Total Nitrogen (mg/L)		177	0.15 - 0.44	0.29	162	0.22 - 0.80	0.48	48	0.11 - 0.40	0.29	80	0.25 - 0.47	0.34
Nitrate+Nitrite-N (mg/L)	10[1]	170	0.042 - 0.336	0.190	162	<0.010 - 0.520	0.213	42	<0.050 - 0.276	0.181	29	0.120 - 0.411	0.257
Total Ammonia-N (mg/L)	2[1]	136	<0.010 - 0.035	<0.010	138	<0.010 - 0.447	0.038	57	<0.02 - 0.05	0.02	70	<0.02 - 0.03	<0.02
Iron (mg/L)	0.3[1]	6	0.02 - 0.04	0.02	62	0.02 - 0.14	0.07	8	0.02 - 0.06	0.03	8	0.02 - 0.04	0.02
Manganese (mg/L)	(0.05)	6	na	na	69	na	na	8	na	na	8	na	na
Lead (µg/L)	50[1]	6	<1 - <1	<1	4	<1 - <1	<1	8	<1 - <1	<1	8	<1 - <1	<1
Copper (µg/l)	200[1]	6	<3 - <3	<3	4	<3 - 18	<3	8	<3 - 27	<3	8	<3 - <3	<3
Calcium (mg/L)		20	4.7 - 5.8	5.4	18	20.8 - 24.6	22.8	8	4.8 - 5.2	5.0	9	3.5 - 4.9	4.1
Sodium (mg/L)		20	4.06 - 5.95	5.41	25	28.9 - 35.3	32.90	8	3.59 - 4.09	3.75	9	3.42 - 4.17	3.64
Chloride (mg/L)	250[1]	20	7.3 - 10.9	9.0	27	60.5 - 69	66.9	27	6.3 - 7.1	6.7	25	6.4 - 8.1	6.9

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2008.

			Amawalk			Bog Brook			Boyd Corners			Croton Falls	
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		49	5.6 - 25.0	12.1	50	6.5 - 25.1	13.0	44	6.9 - 26.0	17.5	34	7.3 - 24.2	14.8
pH (units)	6.5-8.5 [1]	49	7.0 - 9.1	7.7	47	7.0 - 8.7	7.5	44	6.8 - 8.1	7.4	28	7.0 - 8.5	7.4
Alkalinity (mg/L)		9	63.2 - 79.8	69.3	9	64.3 - 78	70.6	5	23.9 - 37.1	34.5	3	44.7 - 53.6	45.8
Conductivity		49	451 - 488	470	50	308 - 329	316	44	193 - 224	209	34	251 - 409	300
Hardness (mg/L) [2]		9	98.9 - 110.0	106.2	7	92.3 - 95.7	94.1	5	40.4 - 51.2	48.3	3	65.3 - 77.6	66.0
Color (Pt-Co units)	(15)	49	12 - 35	20	48	10 - 35	18	39	15 - 30	25	24	15 - 50	21
Turbidity (NTU)	(5) [3]	49	1.0 - 4.2	2.2	48	0.9 - 5.3	2.0	40	0.7 - 3.1	1.7	24	1.5 - 18.0	2.5
Secchi Disk Depth (m)		18	2.0 - 3.9	2.9	15	2.1 - 4.4	3.3	17	2.6 - 4.3	3.6	8	2.7 - 3.6	2.9
BIOLOGICAL													
Chlorophyll *a* (µg/L)	7 [4]	18	3.10 - 22.10	9.10	14	1.40 - 34.90	5.35	18	<0.40 - 14.10	6.90	3	9.20 - 13.60	10.70
Total Phytoplankton (SAU)	2000 [4]	12	63 - 2200	310	10	250 - 3000	710	13	30 - 3300	400	8	490 - 1500	1100
CHEMICAL													
Dissolved Organic Carbon (mg/L)		47	2.7 - 4.1	3.3	45	2.8 - 4.2	3.3	40	2.2 - 4.4	3.9	13	2.1 - 2.9	2.6
Total Phosphorus (µg/L)	15 [4]	49	9 - 44	17	48	6 - 100	19	40	6 - 15	12	18	5 - 38	15
Total Nitrogen (mg/L)		49	0.24 - 0.87	0.47	41	0.18 - 0.57	0.27	37	0.15 - 0.67	0.24	13	0.26 - 1.04	0.29
Nitrate+Nitrite-N (mg/L)	10 [1]	49	<0.010 - 0.395	0.112	42	<0.010 - 0.105	0.005	38	<0.010 - 0.133	0.005	13	<0.010 - 0.210	0.095
Total Ammonia-N (mg/L)	2 [1]	42	<0.010 - 0.417	0.022	45	<0.010 - 0.292	<0.010	38	<0.010 - 0.033	<0.010	13	<0.010 - 0.843	0.027
Iron (mg/L)	0.3 [1]	3	0.05 - 0.10	0.09	3	0.06 - 0.96	0.06	4	0.07 - 0.49	0.10	0	na	
Manganese (mg/L)	(0.05)	3	na	na	3	na	na	4	na	na	0	na	na
Lead (µg/L)	50 [1]	3	<1 - 1	<1	3	<1 - <1	<1	4	<1 - <1	<1	0	na	
Copper (µg/l)	200 [1]	3	<3 - <3	<3	3	<3 - 10	<3	4	<3 - <3	<3	0	na	
Calcium (mg/L)		9	24.3 - 27.9	26.4	7	23.2 - 23.9	23.4	5	10.1 - 12.6	12.0	3	16.5 - 19.8	16.8
Sodium (mg/L)		9	44.8 - 49.8	49.00	7	23.6 - 25.5	24.50	5	20.6 - 22.5	22.10	3	28.7 - 36.3	29.00
Chloride (mg/L)	250 [1]	6	93.9 - 98.8	96.3	8	49 - 52.5	51.7	5	38 - 41.3	40.4	3	54.8 - 66.9	54.9

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2008.

			Cross River			Diverting			East Branch			Lake Gilead	
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		54	4.5 - 25.7	8.9	31	7.9 - 21.4	15.8	55	7.0 - 24.9	15.8	35	5.0 - 24.5	5.4
pH (units)	6.5-8.5[1]	54	6.7 - 9.0	7.4	29	7.3 - 8.4	7.6	52	7.1 - 8.7	7.4	20	6.8 - 8.9	7.1
Alkalinity (mg/L)		9	38.7 - 46	42.3	4	69.4 - 102.9	78.0	9	67.8 - 92.4	85.8	3	40.2 - 45.8	41.5
Conductivity		54	219 - 247	225	31	313 - 391	358	55	292 - 345	322	20	196 - 221	209
Hardness (mg/L)[2]		9	57.7 - 65.5	61.0	3	99.4 - 124.0	102.3	6	89.6 - 110.0	102.6	3	55.5 - 58.9	56.9
Color (Pt-Co units)	(15)	51	10 - 30	20	21	20 - 40	25	55	15 - 50	25	6	10 - 25	10
Turbidity (NTU)	(5)[3]	51	0.8 - 7.4	1.8	21	1.7 - 5.8	3.0	55	0.8 - 4.1	1.9	6	1.0 - 1.9	1.4
Secchi Disk Depth (m)		16	2.6 - 5.1	3.6	15	1.4 - 3.2	2.6	16	1.9 - 4.1	2.3	7	2.6 - 5.3	4.4
BIOLOGICAL													
Chlorophyll *a* (µg/L)	7[4]	14	2.10 - 16.40	7.10	11	4.20 - 35.30	10.58	17	1.50 - 21.20	10.70	2	3.00 - 5.80	4.40
Total Phytoplankton (SAU)	2000[4]	9	33 - 1700	780	6	100 - 3300	1700	10	25 - 2700	675	2	9 - 30	20
CHEMICAL													
Dissolved Organic Carbon (mg/L)		51	2.5 - 3.5	2.9	17	2.7 - 4.7	3.3	52	3.0 - 6.1	3.9	6	2.6 - 3.7	3.0
Total Phosphorus (µg/L)	15[4]	48	9 - 27	13	26	11 - 35	21	55	7 - 35	19	6	11 - 171	20
Total Nitrogen (mg/L)		51	0.11 - 0.57	0.31	14	0.28 - 0.90	0.42	49	0.18 - 0.64	0.32	6	0.23 - 0.74	0.33
Nitrate+Nitrite-N (mg/L)	10[1]	45	<0.010 - 0.327	0.025	18	<0.010 - 0.251	0.184	49	<0.010 - 0.181	0.024	6	<0.010 - 0.042	0.012
Total Ammonia-N (mg/L)	2[1]	45	<0.010 - 0.173	0.018	16	<0.010 - 0.616	0.021	52	<0.010 - 0.159	0.014	6	<0.010 - 0.452	<0.010
Iron (mg/L)	0.3[1]	3	0.05 - 0.25	0.06	2	0.24 - 0.27	0.25	3	0.05 - 0.17	0.05	3	0.02 - 0.22	0.04
Manganese (mg/L)	(0.05)	3	na	na	2	na	na	3	na	na	3	na	na
Lead (µg/L)	50[1]	3	<1 - <1	<1	2	<1 - <1	<1	3	<1 - <1	<1	3	<1 - 2	<1
Copper (µg/l)	200[1]	3	<3 - <3	<3	2	<3 - <3	<3	3	<3 - 6	<3	3	<3 - <3	<3
Calcium (mg/L)		9	15.5 - 17.8	16.6	3	25.4 - 32.2	25.9	6	22.4 - 27.4	25.5	3	13.8 - 15.1	14.2
Sodium (mg/L)		9	16.6 - 18.1	17.80	3	29.1 - 31.5	30.00	6	21.3 - 22.7	21.55	5	15.7 - 17.0	16.30
Chloride (mg/L)	250[1]	12	36.2 - 37.6	36.8	4	54 - 64.4	59.3	9	43.2 - 47.8	47.3	3	34.1 - 34.7	34.2

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2008.

		Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		35	5.0 - 24.6	5.7	24	10.5 - 27.4	21.0	58	8.3 - 23.2	15.0	45	6.7 - 24.6	10.6
pH (units)	6.5-8.5 [1]	20	7.0 - 8.8	7.4	15	7.1 - 8.8	7.6	58	7.0 - 9.0	7.6	45	7.0 - 9.0	7.4
Alkalinity (mg/L)		3	64.8 - 79.2	66.5	3	46.8 - 51.2	51.1	6	63 - 93.3	68.7	9	47.2 - 65.9	55.7
Conductivity		20	378 - 431	403	15	322 - 349	342	58	311 - 476	365	45	438 - 482	452
Hardness (mg/L) [2]		3	92.4 - 95.6	92.4	0	na		5	89.3 - 109.4	95.2	8	75.6 - 87.2	79.4
Color (Pt-Co units)	(15)	6	10 - 70	15	5	20 - 30	25	56	20 - 90	25	38	15 - 50	22
Turbidity (NTU)	(5) [3]	6	0.7 - 10.0	1.6	5	2.1 - 4.7	4.5	56	1.1 - 10.0	2.8	38	1.6 - 11.0	2.6
Secchi Disk Depth (m)		7	4.5 - 5.0	4.8	18	1.8 - 3.6	2.9	32	1.5 - 3.4	2.5	15	1.8 - 6.4	3.0
BIOLOGICAL													
Chlorophyll *a* (µg/L)	7 [4]	1	2.60 - 2.60	2.60	2	10.10 - 18.80	14.45	29	1.10 - 39.10	16.40	13	<0.40 - 21.00	9.00
Total Phytoplankton (SAU)	2000 [4]	2	50 - 200	125	2	120 - 1800	960	21	25 - 4400	1200	7	23 - 2700	900
CHEMICAL													
Dissolved Organic Carbon (mg/L)		6	2.3 - 3.0	2.8	5	4.3 - 4.5	4.4	56	1.5 - 4.9	3.7	38	2.4 - 4.2	3.1
Total Phosphorus (µg/L)	15 [4]	6	8 - 268	21	5	17 - 35	26	56	13 - 60	23	38	12 - 221	20
Total Nitrogen (mg/L)		6	0.24 - 0.95	0.26	5	0.27 - 0.56	0.31	49	0.25 - 1.35	0.48	34	0.22 - 1.39	0.45
Nitrate+Nitrite-N (mg/L)	10 [1]	3	<0.010 - <0.010	0.005	5	<0.010 - 0.045	0.005	56	<0.010 - 0.552	0.203	36	<0.010 - 0.382	0.065
Total Ammonia-N (mg/L)	2 [1]	6	<0.010 - 0.769	<0.010	5	<0.010 - 0.183	<0.010	56	<0.010 - 0.99	0.019	33	<0.010 - 0.831	0.047
Iron (mg/L)	0.3 [1]	3	0.02 - 0.86	0.04	3	0.05 - 0.11	0.09	4	0.10 - 2.35	0.16	4	0.06 - 1.22	0.12
Manganese (mg/L)	(0.05)	3	na	na	3	na	na	4	na	na	4	na	na
Lead (µg/L)	50 [1]	3	<1 - 2	2	3	<1 - 2	<1	4	<1 - <1	<1	4	<1 - <1	<1
Copper (µg/l)	200 [1]	3	<3 - <3	<3	3	<3 - 8	4	4	<3 - <3	<3	4	<3 - <3	<3
Calcium (mg/L)		3	22.9 - 24.1	22.9	0	na		5	22.7 - 27.4	24.2	8	19.3 - 22	20.4
Sodium (mg/L)		6	40.2 - 42.8	40.90	1	32.3 - 32.3	32.30	5	27.4 - 38.1	32.10	8	50.3 - 54.7	52.45
Chloride (mg/L)	250 [1]	3	79.3 - 81.6	79.4	3	64.7 - 65.4	64.7	6	58.2 - 81.1	71.1	8	96 - 103.3	99.8

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2008.

			Titicus			West Branch			West Ashokan Basin			Pepacton	
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		49	4.8 - 25.5	10.9	147	3.6 - 23.6	13.8	143	4.0 - 22.8	9.5	203	2.7 - 23.3	7.3
pH (units)	6.5-8.5 [1]	49	7.0 - 8.6	7.7	133	6.4 - 8.1	7.2	143	5.9 - 7.5	6.7	157	6.6 - 9.2	7.1
Alkalinity (mg/L)		9	58.5 - 68.3	64.3	14	9.4 - 50.5	17.9	12	6.6 - 13.9	10.1	21	9.2 - 13.5	10.5
Conductivity		49	261 - 298	275	139	59 - 165	95	105	42 - 70	55	190	54 - 67	58
Hardness (mg/L) [2]		9	76.1 - 89.8	82.6	5	19.2 - 30.2	22.1	9	12.7 - 20.0	18.1	19	16.3 - 20.3	18.2
Color (Pt-Co units)	(15)	46	10 - 35	20	147	8 - 30	15	141	6 - 18	12	197	6 - 17	12
Turbidity (NTU)	(5) [3]	46	0.8 - 4.9	1.9	147	0.7 - 3.5	1.4	144	1.3 - 9.3	3.6	197	0.4 - 9.0	1.6
Secchi Disk Depth (m)		17	2.0 - 4.6	2.7	60	0.2 - 5.0	3.6	39	1.4 - 4.5	3.1	66	0.6 - 5.1	3.9
BIOLOGICAL													
Chlorophyll *a* (µg/L)	7 [4]	17	1.40 - 18.70	8.40	28	<0.40 - 16.60	4.45	28	1.04 - 4.71	2.18	43	0.03 - 8.03	4.33
Total Phytoplankton (SAU)	2000 [4]	7	75 - 1600	640	76	21 - 2500	440	75	<5 - 610	180	61	<5 - 880	230
CHEMICAL													
Dissolved Organic Carbon (mg/L)		45	2.5 - 4.6	3.1	62	1.5 - 3.3	2.0	85	1.0 - 2.1	1.3	145	1.2 - 2.0	1.4
Total Phosphorus (µg/L)	15 [4]	42	11 - 48	17	74	5 - 19	9	105	<5 - 14	8	192	<5 - 22	8
Total Nitrogen (mg/L)		45	0.20 - 0.70	0.34	75	0.15 - 0.39	0.26	75	0.15 - 0.39	0.30	130	0.14 - 0.59	0.47
Nitrate+Nitrite-N (mg/L)	10 [1]	40	<0.010 - 0.353	0.020	76	<0.010 - 0.264	0.131	59	<0.050 - 0.301	0.222	64	<0.050 - 0.480	0.381
Total Ammonia-N (mg/L)	2 [1]	36	<0.010 - 0.431	0.023	76	<0.010 - 0.101	<0.010	85	<0.02 - 0.03	<0.02	142	<0.02 - 0.04	<0.02
Iron (mg/L)	0.3 [1]	3	0.05 - 0.42	0.08	5	0.03 - 0.96	0.06	8	0.02 - 0.50	0.05	8	0.02 - 0.04	0.03
Manganese (mg/L)	(0.05)	3	na	na	5	na	na	8	na	na	8	na	na
Lead (µg/L)	50 [1]	3	<1 - <1	<1	5	<1 - <1	<1	8	<1 - 1	<1	8	<1 - <1	<1
Copper (µg/l)	200 [1]	3	<3 - <3	<3	5	<3 - <3	<3	8	<3 - 14	<3	8	<3 - 3	<3
Calcium (mg/L)		9	19.4 - 23.1	21.0	5	5.1 - 7.9	5.8	9	3.8 - 6.2	5.5	19	4.8 - 6.1	5.3
Sodium (mg/L)		9	17.9 - 19.9	18.70	5	7.85 - 10.5	8.80	9	3.32 - 4.41	3.79	19	3.62 - 3.90	3.74
Chloride (mg/L)	250 [1]	9	39 - 41	39.8	14	9.6 - 34.3	19.0	36	5.9 - 7.6	6.6	40	6.2 - 7	6.8

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2008.

			Neversink			Schoharie			Cannonsville	
Analyte	WQS	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL										
Temperature (°C)		136	3.3 - 22.4	8.1	119	4.2 - 22.1	9.7	183	3.7 - 23.2	11.8
pH (units)	6.5-8.5[1]	136	5.6 - 7.3	6.3	119	6.3 - 7.7	6.9	166	6.5 - 9.1	7.0
Alkalinity (mg/L)		9	1.7 - 6.5	3.0	9	9.7 - 18.8	12.9	18	10.9 - 20.4	15.8
Conductivity		136	25 - 31	29	108	58 - 92	73	183	73 - 103	83
Hardness (mg/L)[2]		9	7.3 - 8.2	8.0	6	16.4 - 19.8	18.6	18	20.0 - 26.6	24.7
Color (Pt-Co units)	(15)	136	7 - 18	12	91	5 - 24	16	165	8 - 23	14
Turbidity (NTU)	(5)[3]	136	0.3 - 1.6	0.8	120	1.2 - 11.0	4.3	165	0.8 - 11.0	2.4
Secchi Disk Depth (m)		39	4.4 - 9.8	5.8	41	1.1 - 4.0	2.2	59	1.7 - 5.3	2.9
BIOLOGICAL										
Chlorophyll *a* (µg/L)	7[4]	32	0.47 - 6.00	2.65	35	0.16 - 5.67	1.63	48	1.44 - 13.27	5.07
Total Phytoplankton (SAU)	2000[4]	62	<5 - 220	41	52	<5 - 1100	56	76	5 - 4400	295
CHEMICAL										
Dissolved Organic Carbon (mg/L)		97	1.4 - 2.1	1.6	73	1.4 - 2.8	1.7	147	1.3 - 2.2	1.6
Total Phosphorus (µg/L)	15[4]	135	<5 - 8	5	104	6 - 19	10	163	5 - 19	14
Total Nitrogen (mg/L)		97	0.10 - 0.35	0.28	73	0.14 - 0.45	0.32	120	0.20 - 0.79	0.54
Nitrate+Nitrite-N (mg/L)	10[1]	46	<0.050 - 0.250	0.180	37	<0.050 - 0.350	0.180	60	<0.050 - 0.721	0.402
Total Ammonia-N (mg/L)	2[1]	96	<0.02 - 0.08	<0.02	64	<0.02 - 0.04	0.02	132	<0.02 - 0.05	0.02
Iron (mg/L)	0.3[1]	7	0.04 - 0.10	0.06	4	0.11 - 0.33	0.15	8	0.04 - 0.11	0.07
Manganese (mg/L)	(0.05)	7	na	na	4	na	na	8	na	na
Lead (µg/L)	50[1]	7	<1 - 1	<1	4	<1 - <1	<1	8	<1 - <1	<1
Copper (µg/l)	200[1]	7	<3 - <3	<3	4	<3 - <3	<3	8	<3 - 5	<3
Calcium (mg/L)		9	2.1 - 2.3	2.3	6	5.1 - 6.0	5.8	18	5.6 - 7.6	7.1
Sodium (mg/L)		9	1.69 - 1.85	1.80	6	4.57 - 5.32	5.04	18	5.94 - 7.56	6.40
Chloride (mg/L)	250[1]	21	3.1 - 3.7	3.5	28	6.8 - 11.1	9.6	32	10.3 - 12.7	11.1

Notes for Appendix A:

Footnotes:

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

2 = Hardness calculated as follows:

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

3 = Narrative water quality standards.

4 = DEP 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 keypoint and treated water, respectively, but are supplied to provide context for the reservoir data.

Abbreviations:

N = number of samples
na = not available
Range = minimum to 95%-ile (to avoid the occasional outlier in the dataset)
< = non detect; number to right of < is the detection limit
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 2008 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 2003a).

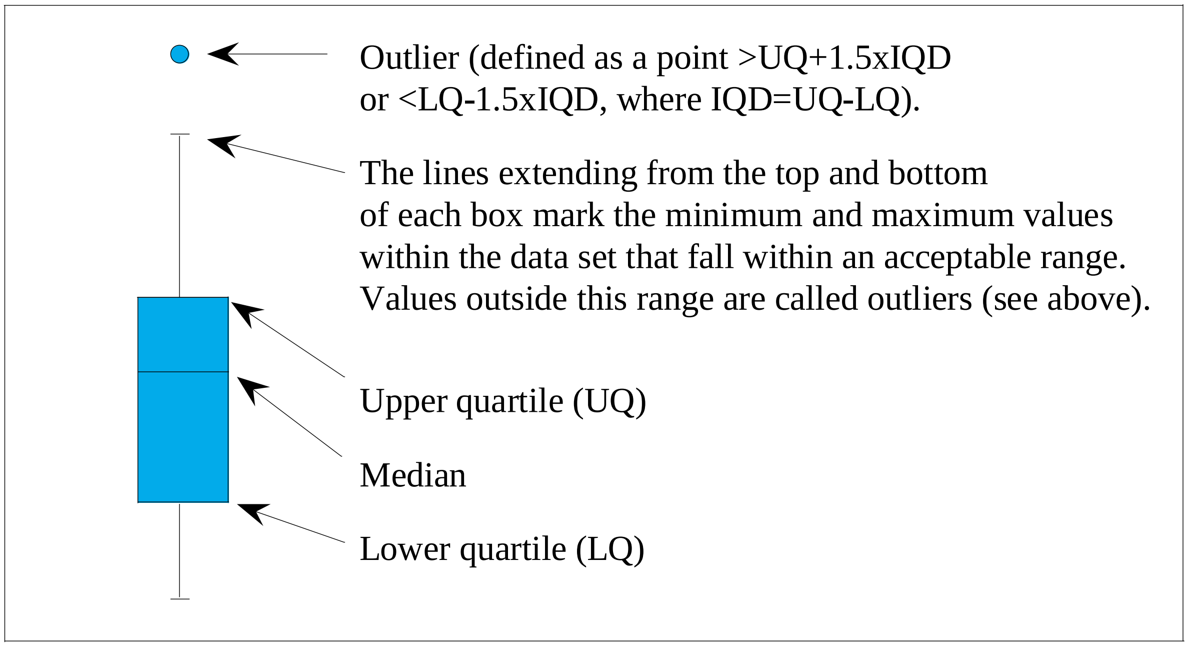
Chlorophyll *a* results are from surface samples collected at a 3-meter depth from April –November. Note that this differs from the trophic status boxplots presented in Chapter 3, which only consider photic samples collected during the growing season (May–October).

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 Boxplots



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

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

Upper quartile (UQ)

Median

Lower quartile (LQ)

Appendix C - Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Regulations as "the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D." (DEP 2002a). 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 C.1 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 µg L^{-1}, unless DEP, 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	2003 µg L^{-1}	2004 µg L^{-1}	2005 µg L^{-1}	2006 µg L^{-1}	2007 µg L^{-1}	2008 µg L^{-1}
Delaware District						
Cannonsville Reservoir	15.4	15.1	19.6	20.5	14.0	13.4
Pepacton Reservoir	9.1	9.2	8.7	10.8	9.7	8.2
Neversink Reservoir	5.2	5.0	7.3	7.3	4.7	4.7
Rondout Reservoir	6.8	8.6	7.8	8.6	7.1	6.1
Catskill District						
Schoharie Reservoir	7.5	13.3	20.6	17.4	9.7	9.5
Ashokan-West Reservoir	6.1	9.3	26.0	11.2	8.1	7.2
Ashokan-East Reservoir	7.0	10	11.0	9.9	7.3	7.5
Croton District						
Amawalk Reservoir	19.6	26.5	24.0	24.5	20.2	17.9
Bog Brook Reservoir	16.9	26.8	18.6	18.7	24.0	21.5
Boyd Corners Reservoir	12.4	13.8	*	17.4	15.6	11.6
Cross River Reservoir	17.9	20.2	18.7	18.6	17.8	13.8
Croton Falls Reservoir	20.4	18.1	*	19.2	*	14.4**
Diverting Reservoir	28.8	28.3	*	*	*	22.8
East Branch Reservoir	26.5	44.2	28.3	28.4	23.0	21.6
Middle Branch Reservoir	23.7	*	31.5	24.2	25.0	27.9
Muscoot Reservoir	29.5	26.0	26.8	27.9	25.7	27.6
Titicus Reservoir	27.3	25.4	24.6	29.6	21.6	17.5
West Branch Reservoir	10.2	11.5	14.8	10.3	9.6	9.4
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	2003 µg L^{-1}	2004 µg L^{-1}	2005 µg L^{-1}	2006 µg L^{-1}	2007 µg L^{-1}	2008 µg L^{-1}
Lake Gilead	28.5	21.8	*	30.5	33.6	*
Kirk Lake	30.8	*	*	29.7	28.6	*
Source Water						
Kensico Reservoir	7.6	8.8	9.7	7.6	7.0	6.4
New Croton Reservoir	19.5	22.4	18.2	18.1	17.7	15.5

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

**The Croton Falls mean was biased due to sampling the main basin only (for details, see Section 3.7).

Appendix D. Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008)

Appendix Table D.1: Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
CA	A	2400/5000	Apr-08	5	20	0
CA			May-08	5	45	0
CA			Jun-08	5	20	0
CA			Jul-08	5	>1600	0
CA			Aug-08	5	100	0
CA			Sep-08	5	<100	0
CA			Oct-08	5	40	0
CA			Nov-08	5	60	0
CBB	AA	50/240	Apr-08	5	<5	0
CBB			May-08	5	10	0
CBB			Jun-08	6	25	0
CBB			Jul-08	5	10	0
CBB			Aug-08	5	120	0
CBB			Sep-08	6	100	0
CBB			Oct-08	5	20	0
CBB			Nov-08	6	40	0
CBC	AA		Apr-08	6	15	0
CBC			May-08	5	20	0
CBC			Jun-08	5	440	80
CBC			Jul-08	7	<20	0
CBC			Aug-08	7	1000	100
CBC			Sep-08	7	<500	100
CBC			Oct-08	7	200	14
CCF	A/AA	50/240	Jul-08	5	900	100
CCF			Aug-08	5	<100	0

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
CCF			Sep-08	6	50	0
CCF			Oct-08	18	50	0
CCF			Nov-08	3	Insufficient Data	-
CCR	A/AA	50/240	Apr-08	6	10	0
CCR			May-08	5	<5	0
CCR			Jun-08	6	20	0
CCR			Jul-08	6	85	17
CCR			Aug-08	5	20	0
CCR			Sep-08	6	410	67
CCR			Oct-08	6	90	17
CCR			Nov-08	6	60	0
CD	AA	50/240	Apr-08	5	20	0
CD			May-08	3	Insufficient Data	-
CD			Jun-08	5	TNTC	?
CD			Jul-08	5	250	60
CD			Aug-08	5	400	60
CD			Sep-08	4	Insufficient Data	-
CEB	AA	50/240	Apr-08	5	20	0
CEB			May-08	6	50	0
CEB			Jun-08	6	120	0
CEB			Jul-08	6	20	0
CEB			Aug-08	5	60	0
CEB			Sep-08	6	215	50
CEB			Oct-08	6	30	0
CEB			Nov-08	6	65	0

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
CGD	A	2400/5000	Apr-08	5	<5	0
CGD			May-08	5	5	0
CGD			Jun-08	5	35	0
CGD			Jul-08	5	200	0
CGD			Aug-08	5	<50	0
CGD			Sep-08	5	10	0
CGD			Oct-08	5	90	0
CGD			Nov-08	5	10	0
CGL	AA	50/240	Apr-08	5	<5	0
CGL			May-08	5	5	0
CGL			Jun-08	5	5	0
CGL			Jul-08	5	<100	0
CGL			Aug-08	5	<20	0
CGL			Sep-08	5	20	0
CGL			Oct-08	5	20	0
CGL			Nov-08	5	5	0
CKL	B	2400/5000	Apr-08	5	5	0
CKL			May-08	5	10	0
CKL			Jun-08	5	30	0
CKL			Jul-08	5	100	0
CKL			Aug-08	5	100	0
CKL			Sep-08	5	60	0
CKL			Oct-08	5	200	0
CM	A	2400/5000	Apr-08	7	45	0
CM			May-08	7	160	0

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
CM			Jun-08	7	300	0
CM			Jul-08	7	200	0
CM			Aug-08	7	2300	29
CM			Sep-08	7	580	0
CM			Oct-08	7	620	0
CM			Nov-08	7	200	0
CMB	A	2400/5000	Apr-08	5	5	0
CMB			May-08	5	20	0
CMB			Jun-08	5	30	0
CMB			Jul-08	5	20	0
CMB			Aug-08	7	70	0
CMB			Sep-08	5	40	0
CMB			Oct-08	5	40	0
CMB			Nov-08	5	40	0
CT	AA	50/240	Apr-08	5	5	0
CT			May-08	5	5	0
CT			Jun-08	5	50	0
CT			Jul-08	5	200	40
CT			Aug-08	5	200	40
CT			Sep-08	5	50	0
CT			Oct-08	5	20	0
CT			Nov-08	5	40	0
EDP	A/AA	50/240	Apr-08	34	2	0
EDP			May-08	34	3	3
EDP			Jun-08	28	4	0

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
EDP			Jul-08	32	12	13
EDP			Aug-08	16	40	0
EDP			Sep-08	16	15	0
EDP			Oct-08	15	12	0
EDP			Nov-08	16	6	0
NN	AA	50/240	Apr-08	26	2.5	4
NN			May-08	25	7	0
NN			Jun-08	24	2	0
NN			Jul-08	12	4	0
NN			Aug-08	12	<10	0
NN			Sep-08	11	16	0
NN			Oct-08	11	12	0
NN			Nov-08	12	15	0
SS	AA	50/240	Apr-08	20	170	25
SS			May-08	18	90	17
SS			Jun-08	18	950	78
SS			Jul-08	9	>8000	92
SS			Aug-08	9	>16000	100
SS			Sep-08	9	>29000	100
SS			Oct-08	9	2000	100
SS			Nov-08	9	1900	100
WDC	A/AA	50/240	Apr-08	30	2	0
WDC			May-08	30	11	3
WDC			Jun-08	30	100	17
WDC			Jul-08	15	200	41

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2008). 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class	Standard (Median/ Value not > 20% of samples)	Collection Date	n	Median Total Coliform (CFU100mL^{-1})	Percentage > Standard
WDC			Aug-08	15	80	10
WDC			Sep-08	15	100	6
WDC			Oct-08	15	<10	0
WDC			Nov-08	15	35	0

Note: (1) The reservoir class is defined by 6NYCRR Parts 815, 862, 864, and 879. For those reservoirs that have dual designations, the higher standard was applied. (2) Diverting Reservoir had five samples in June that were Too Numerous To Count (TNTC). The median could not be estimated for these samples.