New York City
Department of Environmental Protection

2004 Watershed Water Quality Annual Report

Prepared by the Division of Drinking Water Quality Control

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Acknowledgments

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1. Introduction

1.1 What is the purpose and scope of this report?

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of the City's drinking water. It is an annual report that provides the public with a general overview of the City's water resources, their condition during 2004, and compliance with regulatory standards or guidelines during this period. It is complementary to another report entitled "NYC Drinking Water Supply and Quality Report" that is distributed to consumers annually to provide information about the quality of the City's tap water. However, the focus of this report is different in that it addresses how the City protects its drinking water sources upstream of the distribution system. The report also describes the efforts of the New York City Department of Environmental Protection (DEP) to evaluate the effectiveness of watershed protection and remediation programs, and to develop and use predictive models. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through our website at http://www.nyc.gov/dep (Figure 1.1).

Figure 1.1 The DEP website.

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

The Bureau of Water Supply (BWS) is responsible for operating, maintaining, and protecting New York City's upstate water supply system to ensure delivery of high quality drinking water. BWS is currently comprised of 14 separate Divisions (Figure1.1), which perform various functions to meet the Bureau's mission. Each of the 14 BWS Divisions and their functions are described below.

West-of-Hudson Operations Division

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

    31 water supply facilities

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

East-of-Hudson Operations Division

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

  Maintenance and control of 6 Aqueducts (3 systems)
  New Croton Aqueduct (24 miles), 10 Structures
  Catskill North and South (>50 miles), 73 Structures
  Delaware North, Central, and South (>50 miles), 17 Structures
  9 Water Treatment Facilities (chlorine, fluoride, alum, sodium hydroxide, sodium bisulfite)
  2 Wastewater Treatment Plants
  16 Reservoirs and Controlled Lakes
  Maintenance of 181 Facilities
  DEC Reservoir Release Program – 12 Reservoirs
  2.8 billion dollars in design and construction from 1991–2011

Drinking Water Quality Control

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

Engineering

- Ensures that new development complies with the Watershed Regulations.
- Enforces Watershed Regulations for new and existing development to maintain protection of water quality.
- Coordinates with local health departments and the Catskill Watershed Corporation on various onsite wastewater treatment programs.

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

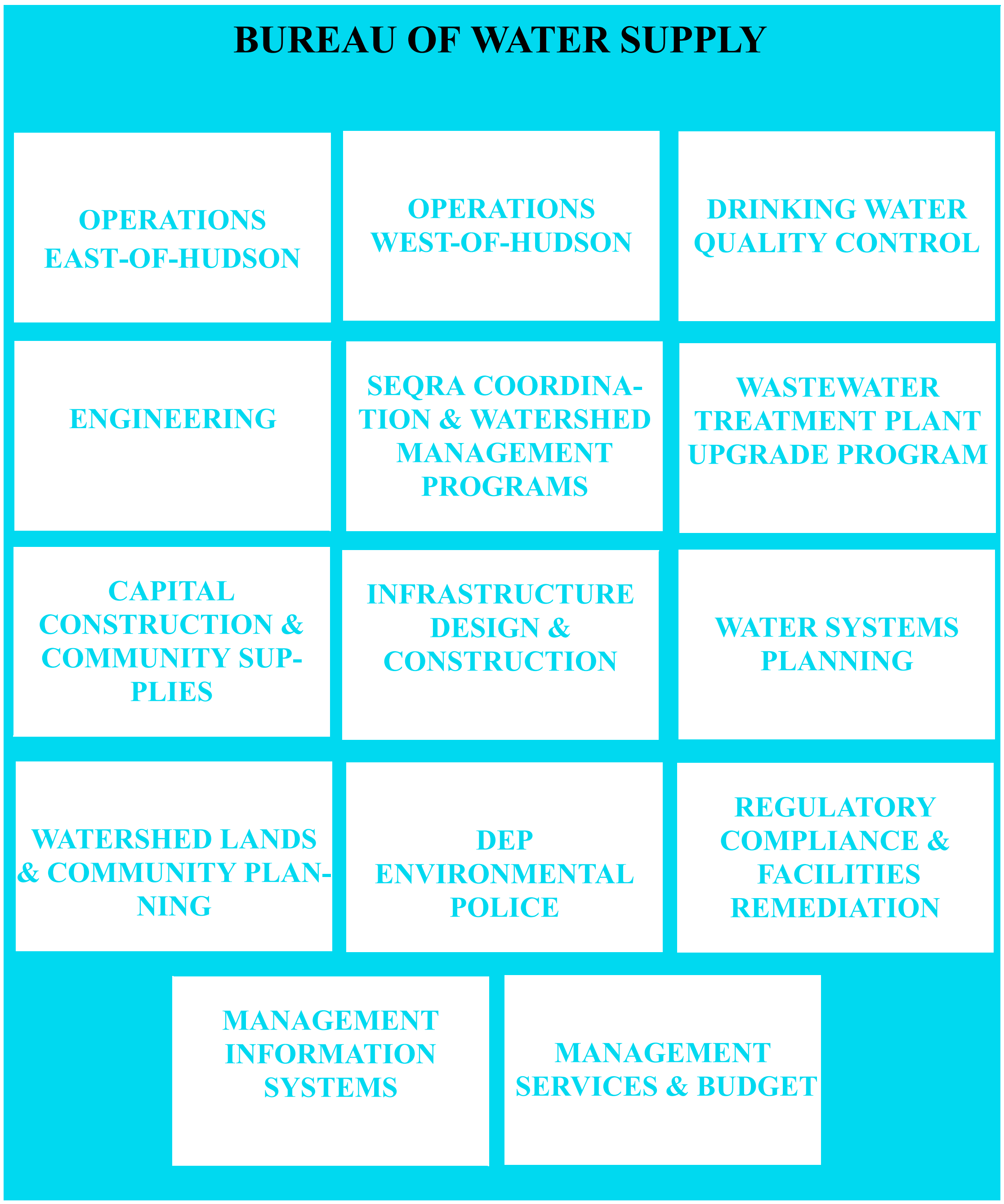

Figure 1.2 The 14 separate Divisions of the Bureau of Water Supply.

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

- Ensures the timely, thorough, and consistent application of SEQRA in the watershed and serves as the primary BWS contact for City sponsored, and funded, projects subject to SEQRA.
- Develops and implements FAD mandated East-of-Hudson Nonpoint Management Plan.
- Conducts stream restoration and management projects in East-of-Hudson watershed, and coordinates practices and strategy with Land Management and Community Planning for related programs in West-of-Hudson watershed.
- Oversees development and implementation of the Kensico Water Quality Control Program.
- Develops, designs, constructs, and maintains stormwater management practices to reduce fecal coliform bacteria, turbidity, and various pollutants in the Catskill/Delaware System.

Wastewater Treatment Plant Upgrade Program

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

Capital Projects Coordination & Community Supplies Engineering

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

Infrastructure Design and Construction

- Responsible for managing consulting engineer activities with respect to the design and construction of facilities throughout the BWS to meet operating infrastructure needs of BWS Divisions such as Operations and Drinking Water Quality Control, and for coordination with projects underway by the Bureau of Environmental Engineering.
- Provides overall construction management services including full resident inspection services on selected projects.
- Prepares budget estimates on BWS projects consisting of engineering and construction costs for incorporation into BWS capital and expense budget plans.

Water Systems Planning

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

Watershed Lands and Community Planning

- Assists in community planning and environmental infrastructure through the Catskill Watershed Corporation (CWC), Westchester/Putnam Counties, and the NYS Environmental Facilities Corporation.

- Evaluates and designs appropriate farm and forest activities in cooperation with the Watershed Agricultural Council (WAC).
- Acquires new lands through fee and conservation easement acquisition and partnerships with WAC, land trusts, counties, and New York State.
- Manages City-owned land for watershed protection purposes, providing appropriate public access and recreation, forestry activities, land use permits and agreements, and reservoir and watershed lands patrol.
- Manages streams through stream management plans, stream restorations, research, and public education.

DEP Environmental Police

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

Regulatory Compliance and Facilities Remediation

- Ensures compliance with all applicable Federal, State, and local environmental health and safety rules and regulations, and DEP procedures implemented to address them.
- Provides guidance and assistance to other BWS Divisions with environmental health and safety rules and regulations, and in relations with Agency Management, other DEP Bureaus, and outside regulatory agencies.
- Provides emergency spill response and remediation of hazardous materials throughout the upstate watershed.
- Provides supervision of contractors utilized for emergency spill response, hazardous waste/materials remediation, and disposal.
- Provides environmental, and health and safety training to BWS personnel.

Management Information Systems

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

Management Services and Budget

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

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

The condition of the water supply is monitored by the Division of Drinking Water Quality Control (DWQC). DWQC has a staff of approximately 260 who are responsible for monitoring and maintaining high water quality for the entire (upstate watershed and downstate distribution system) water supply, with over half within the upstate operations. This report is specifically about the upstate watersheds and, in particular, the Field and Laboratory Operations.

DWQC's Watershed Operations are now divided into five sections: Watershed Field Operations, Watershed Laboratory Operations, Information Management and Reporting, Process Control and Remote Monitoring, and Health and Safety.

The Watershed Field Operations Section consists of five groups: Limnology, Hydrology, Wildlife Studies, Watershed Management Studies (including Natural Resources), and Water Quality Impacts Assessment. These staff are responsible for: i) designing scientific studies, ii) collecting environmental samples for routine and special investigations, iii) submitting these samples to the Laboratory Operations (or contracted lab) for analysis, iv) organizing and interpreting data, v) documenting findings, and vi) making recommendations for effective watershed management. Field Operation staff members are located in all three water supply Systems (Catskill, Delaware, and Croton). Extensive monitoring of a large geographic network of sites to support reservoir operations and watershed management decisions are the top priority of the Field Operations Section.

DWQC's Watershed Laboratory Operations Section consists of five water quality laboratories located in the Delaware, Catskill and Croton Systems. This Section also includes Quality Assurance and Technical Operations Units. Watershed Laboratory Operations includes laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, scientists, technical specialists, and administrative staff. The laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for over 100 environmental analyses in the non-potable water and potable water categories. These analyses include physical parameters (e.g., pH, turbidity, color, conductivity), chemical parameters (e.g., nitrates, phosphates, chloride, chlorine residual, alkalinity), microbiological parameters (e.g., total and fecal coliform bacteria, algae), trace metals (e.g., lead, copper, arsenic, mercury, nickel), and organic parameters (e.g., organic carbon). Daily monitoring of water quality at critical "keypoint" monitoring sites for rapid detection and tracking of any changes in water quality is one of the top priorities of the Watershed Laboratory Operations Section.

For the 2004 reporting period covered in this report, DWQC staff performed 209,530 analyses on 21,514 samples from 627 different sampling locations.

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

2. Water Quantity

2.1 What is NYC's source of drinking water?

New York City's water supply is provided by a system consisting of 19 reservoirs and three controlled lakes with a total storage capacity of approximately 2 billion cubic meters (550 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (Figure 2.1). The system is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs in each of three watershed systems, the Catskill, Delaware, and Croton Systems. The first two are located West-of-Hudson (WOH) and the Croton System is located East-of-Hudson (EOH) (Figure 2.2). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the pollutant loads and hydraulic residence time, which in turn directly influence the reservoir's water quality and productivity.

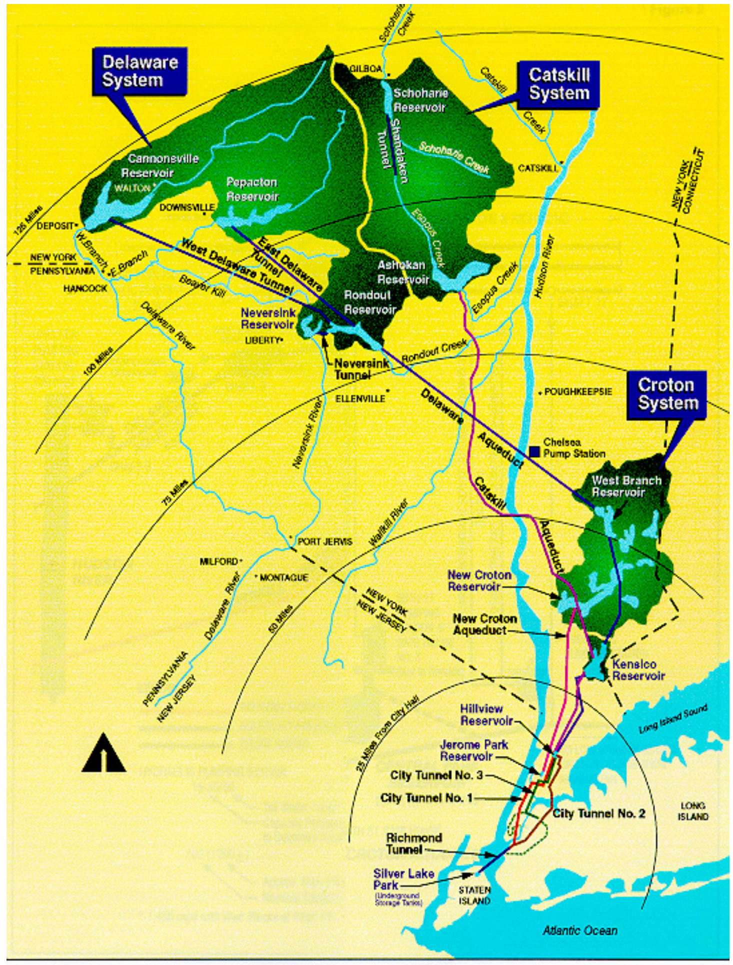

Figure 2.1 New York City water supply watershed.

2.2 How much precipitation fell in the watershed in 2004?

The average precipitation for each basin was determined from a network of precipitation gauges located in or near the watershed that collect readings daily. The total monthly precipitation for each watershed is based on the average readings of the gauges located in the watershed. The 2004 monthly precipitation total for each watershed is plotted along with the historical monthly average (Figure 2.3).

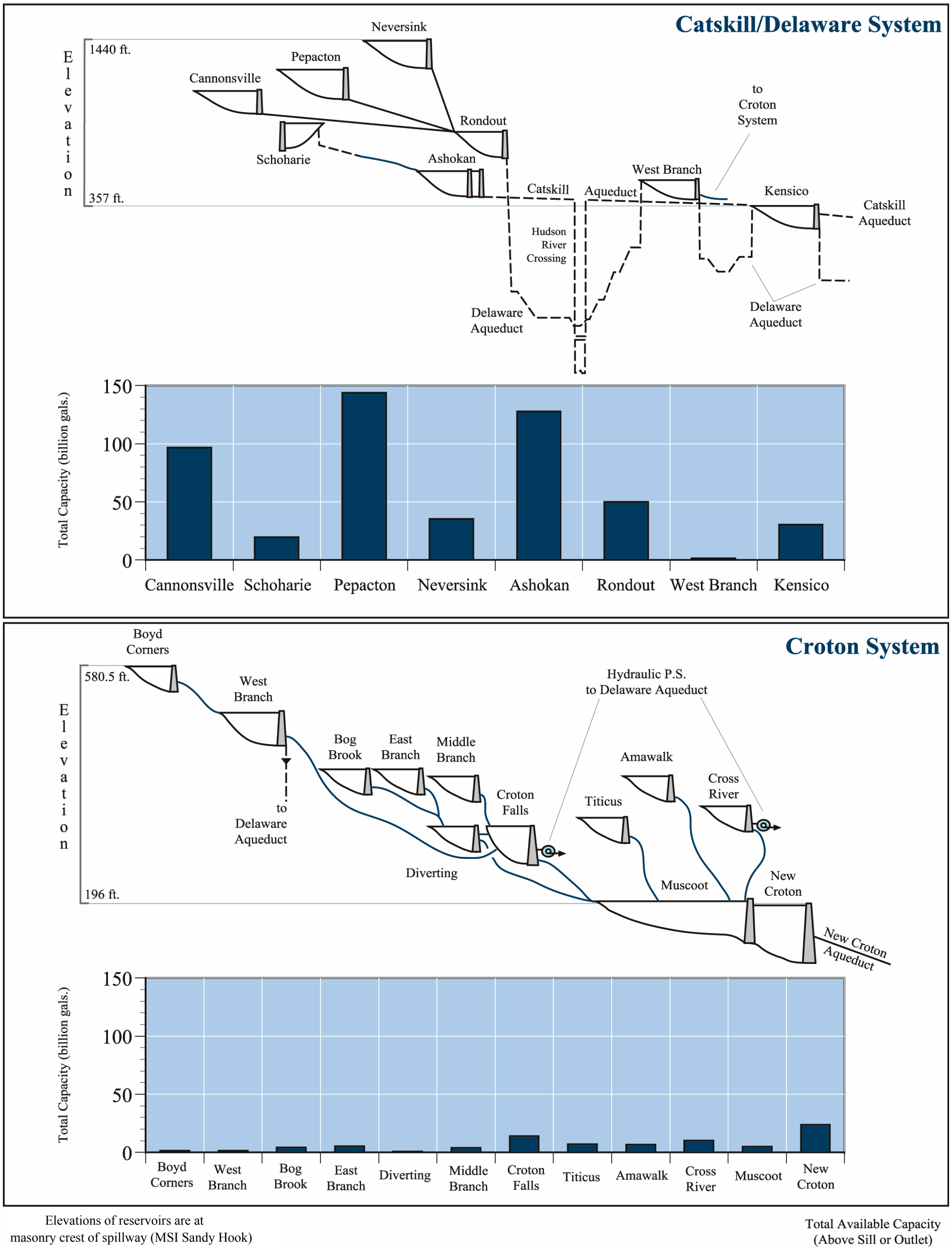

Figure 2.2 NYC water supply reservoirs and their available storage capacities.

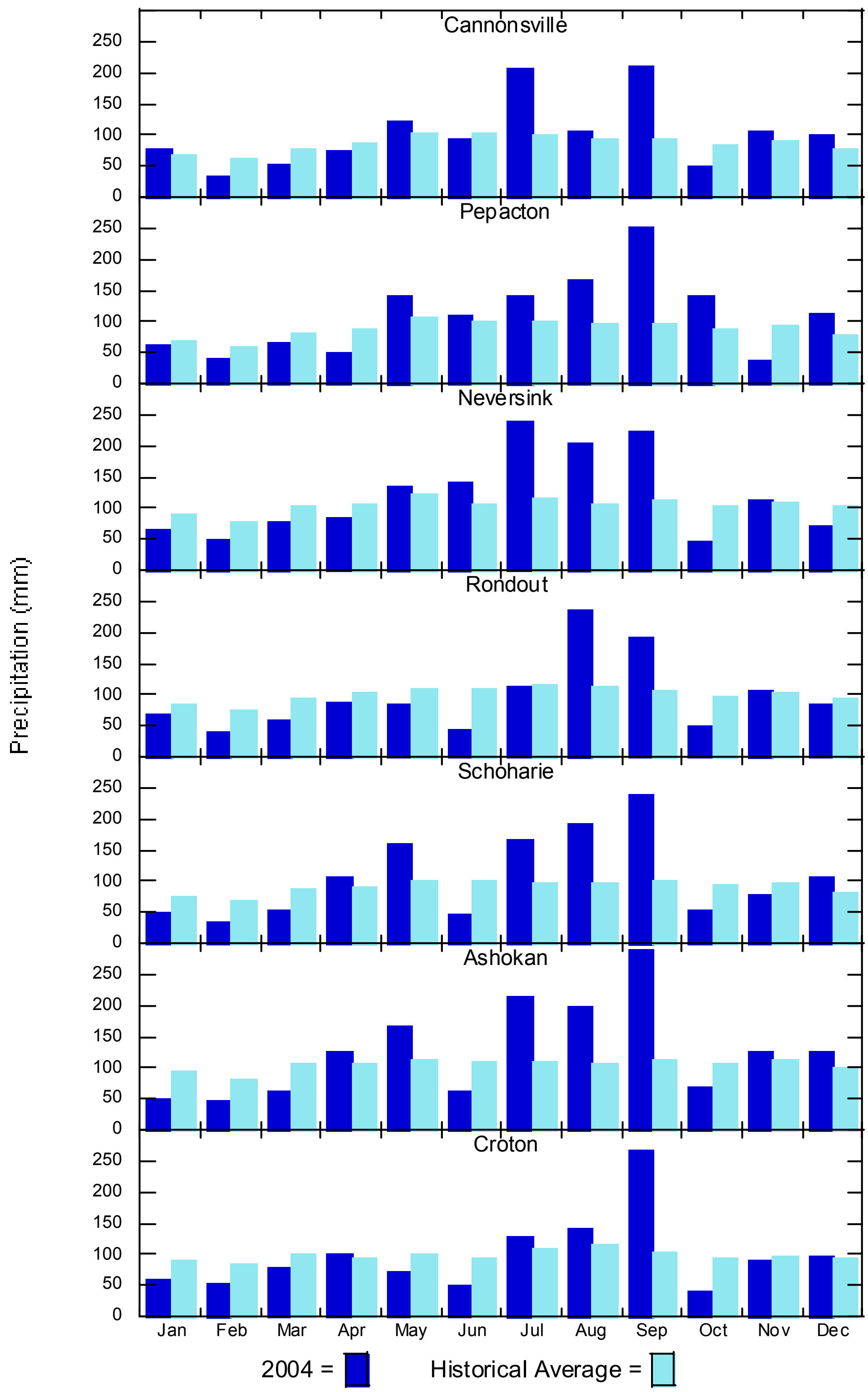

Figure 2.3 Monthly rainfall totals for NYC watersheds, 2004 and historical values.

The total monthly precipitation figures show that in general precipitation was about average or slightly below normal for January through April 2004. In May 2004 the precipitation was generally about average or slightly above average for most watersheds, while in June 2004 the precipitation was about average or somewhat below average for most watersheds. July, August, and September all had greater than average precipitation. In October all watersheds, except Pepacton, had less than average precipitation. November and December's precipitation totals were about average. Overall the total precipitation in the watershed for 2004 was 1,309 mm (51.5 in.), which is 170 mm (6.7 in.) above normal. The bulk of this excess occurred in the summer.

2.3 How and why does DEP collect meteorological data?

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

Recognizing that, in addition to the precipitation data that have been historically collected (see Section 2.2), meteorological data were valuable in meeting the Division's mission of providing high-quality drinking water through environmental monitoring and research, DWQC installed a network of 26 Remote Automated Weather Stations (RAWS) that covers both the EOH and WOH watersheds (Figure 2.4). Each station measures air temperature, relative humidity, rainfall, snow depth, solar radiation, wind speed, and wind direction. A reading is taken every minute, and values are summarized hourly (summed or averaged). Most of the stations utilize radio telemetry to transmit data in near real-time. In addition to being used by DEP, these data are shared with the National Weather Service (NWS) to help them make more accurate and timely severe weather warnings for watershed communities. These data are also important as input for DEP's hydrologic and water quality models (Chapter 5).

Figure 2.4 Remote Automated Weather Station.

The ongoing coordination efforts between DEP and NWS resulted in several valuable products for DEP in 2004. NWS began providing deterministic river forecasts for selected DEP storm event water quality monitoring sites. These forecasts estimate the timing and magnitude of peak flow for pending storm events, thus helping ensure significant events are not missed with regard to sampling. NWS also revised the Headwater Guidance product to make it more useful to DEP. (Headwater Flood Guidance estimates how much rain is needed to bring selected headwater streams to flood in a given amount of time.). DEP meteorological data were incorporated into the MesoEast web page (http://www.erh.noaa.gov/er/aly/obs/mesoEast/). MesoEast displays meteorological data from numerous sites around the northeastern US in a map-based display.

DEP meteorological data were used for a large and diverse array of projects in 2004. DEP's Project Review Group used rainfall data in a review of a proposed development in the Croton watershed. The DWQC Modeling Program used meteorological data to support its Filtration Avoidance-mandated modeling efforts. Atmospheric Information Services, Inc. used DEP data in a cooperative project with the NWS to calibrate Doppler radar rainfall estimates. USGS used the data in a river temperature modeling project commissioned by the Flow Management Technical Advisory Committee of the Delaware River Basin Commission. The Upstate Freshwater Institute (UFI) used meteorological data in a model to support management of turbidity and temperature in Schoharie Reservoir and Esopus Creek. The Town of Denning requested data for a study of wind power feasibility in the Town. Rainfall data were provided to the Natural Resources Conservation Service (NRCC) to assist its reporting on a high-intensity rainfall/runoff event in the Rondout and Neversink watersheds in July 2004. Researchers at the Institute for Ecosystem Studies in Millbrook, NY used DEP meteorological data for several ongoing biogeochemical research projects they are conducting in the Catskills. Finally, an automated program takes the near-real-time (NRT) data, generates daily summaries of precipitation and other meteorological variables, and emails them to staff in DWQC and the Division of Operations to keep them apprised of conditions in the watershed. This is in addition to the NRT sharing of data with the NWS for their use in forecasting, warnings, and related activities.

2.4 Does DEP monitor the amount of water in the snowpack?

DEP participates in the statewide snow survey program coordinated by the Northeast Regional Climate Center (NRCC). DEP measured the amount of water in the snow (snow water equivalent, or SWE) at 92 sites in 2004. Snow surveys were conducted every other week, beginning the first week in January and ending once the snow melted, following the schedule set by the NRCC. Snow data are used by the Division of Operations to facilitate reservoir operations, and by DWQC in planning storm event water quality monitoring. DEP shares the snow data with outside agencies, including the National Operational Hydrologic Remote Sensing Center (NOHRSC, part of the NWS) for use in its National Snow Analysis program.

2.5 How much runoff occurred in 2004?

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 statistic is a useful statistic to compare the runoff between watersheds. It is calculated by dividing the annual flow volume by the drainage basin area. The total annual runoff is the depth to which the drainage area would be covered if all the runoff for the year were uniformly distributed over the basin. This statistic allows comparisons to be made of the hydrologic conditions in watersheds of varying sizes.

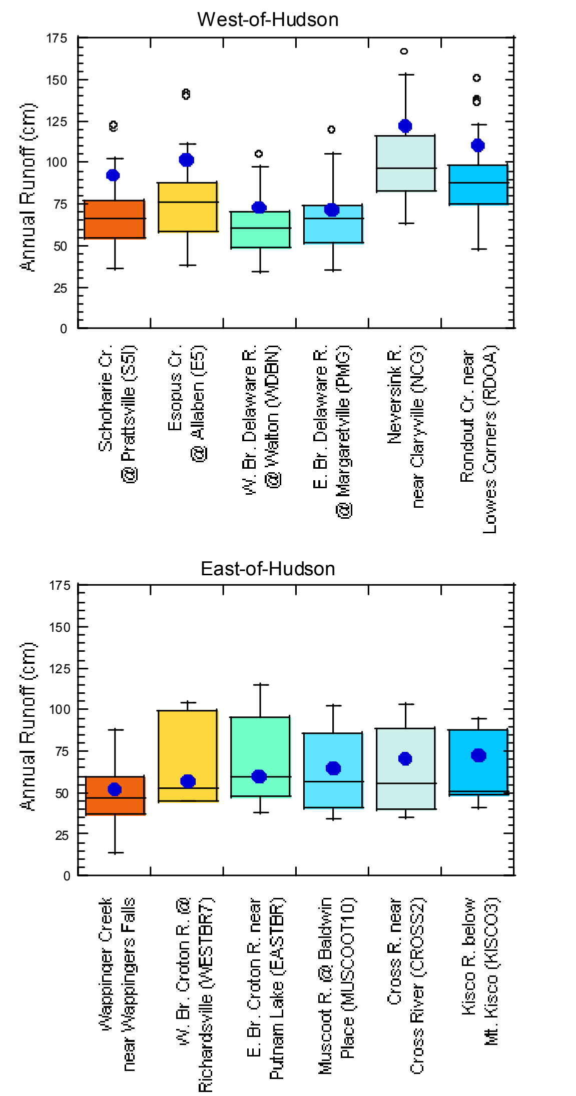

Figure 2.5 Historical annual runoff (cm) as box plots for the WOH and EOH watersheds with the values for 2004 displayed as a dot.

The USGS data collected after Sept. 30, 2004 are provisional.

Selected United States Geological Survey (USGS) stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.5). The total annual runoff from both the WOH and EOH watersheds were almost all above historical normals due to the precipitation excess for the year.

2.6 What was the storage history of the reservoir system in 2004?

The total available percent capacity (Actual) in 2003-2004 is compared to the monthly long-term average (Normal) in Figure 2.6. The long-term average was determined by calculating the monthly percent capacity during 1993–2002. Seasonal patterns are readily discernible.

Capacity normally ranges from a high of 95 percent in the spring to about 70 percent in the fall. During the 2003–2004 period, however, capacity was generally at or near 100 percent, up to 30 percent greater than the historic norm. Starting in late October of 2002 and continuing through 2004, rain and snowfall amounts were consistently elevated resulting in much higher than normal storage capacity during this time period.

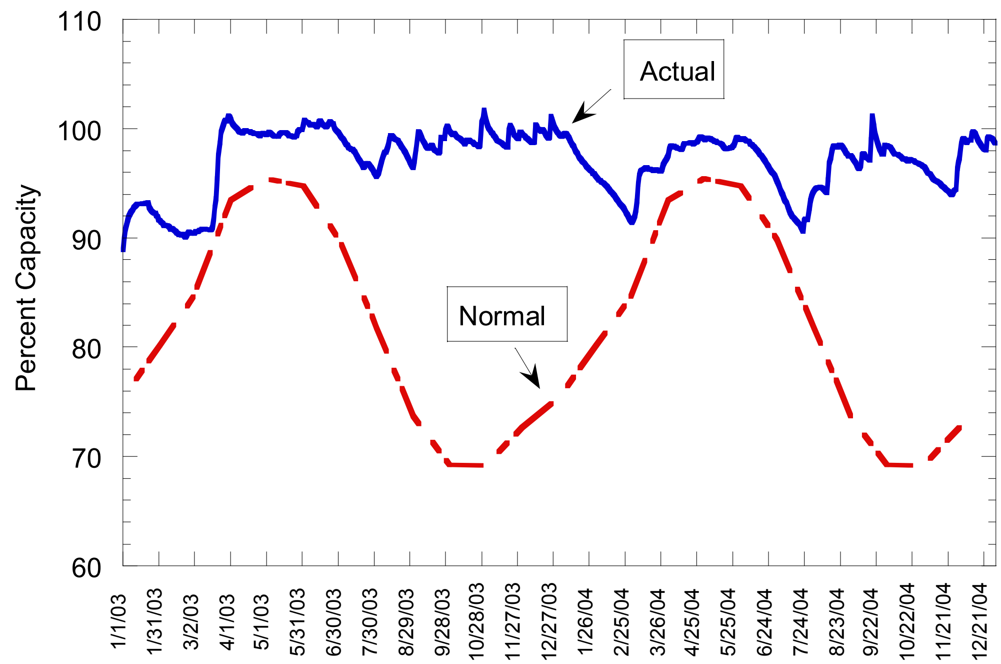

Figure 2.6 Total available percent capacity in 2003–2004 (Actual) compared to long-term (1993–2002) average (Normal) storage.

3. Water Quality

3.1 How did DWQC Watershed Operations help to ensure the delivery of the highest quality water from upstate reservoirs in 2004?

DWQC scientists worked closely with the Bureau's Division of Operations to determine the best operational strategy for delivering the highest quality water to NYC consumers.

DWQC Watershed Operations continued its extensive Aqueduct and Limnological Monitoring Programs with the collection and analysis of samples from reservoirs, reservoir intakes, tunnel outlets, and aqueducts within the Catskill, Delaware, and Croton Systems. In 2004, 116,000 physical, chemical, and microbiological analyses were performed on 11,000 samples that were collected from 150 different reservoir and aqueduct monitoring locations.

In addition, the Process Control Remote Monitoring (PCRM) Section continued to operate water quality monitoring stations at key locations, providing real-time water quality information for operational decision making and compliance reporting. In 2004, DEP added three new stations to the system. Coverage was expanded in the Delaware System with the addition of monitoring stations at both the West Delaware and the Neversink Tunnel Outlets. These stations will allow DWQC to closely monitor the quality of the water being diverted into Rondout Reservoir from Cannonsville and Neversink Reservoirs. Coverage was also expanded in the Croton System with the addition of a monitoring station at Shaft 14 (CRO14), located 15.6 miles from New Croton Reservoir on the New Croton Aqueduct (see Figure 3.1). This station will enhance DEP's ability to monitor chlorine levels as water travels from New Croton Reservoir to the Jerome Park Reservoir, allowing DEP to optimize chlorine dosing in an attempt to minimize the formation of disinfection by-products in the Distribution System. In 2004, DEP was successful in utilizing reservoir and aqueduct design to optimize the quality of water distributed through the system. Other than routine disinfection and fluoridation, no blending or watershed treatment operations were required. Watershed operational strategies for 2004 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. For example, when the color, turbidity, and manganese levels within Croton System began to increase in the fall, DEP stopped diverting water from New Croton Reservoir. Instead, more water was diverted from the Catskill/Delaware System where water quality was superior.

- Selective Withdrawal

  DEP continued to monitor water quality at different elevations within the reservoirs and used that information to determine the optimal level of withdrawal. For example, when the effects of Hurricane Ivan led to increased turbidity in the middle elevation of Pepacton Reservoir, an intake elevation change was made. By moving the level of withdrawal from the middle to the bottom of the reservoir, DEP was able to optimize the quality of the water being sent through the East Delaware Tunnel and into Rondout Reservoir.

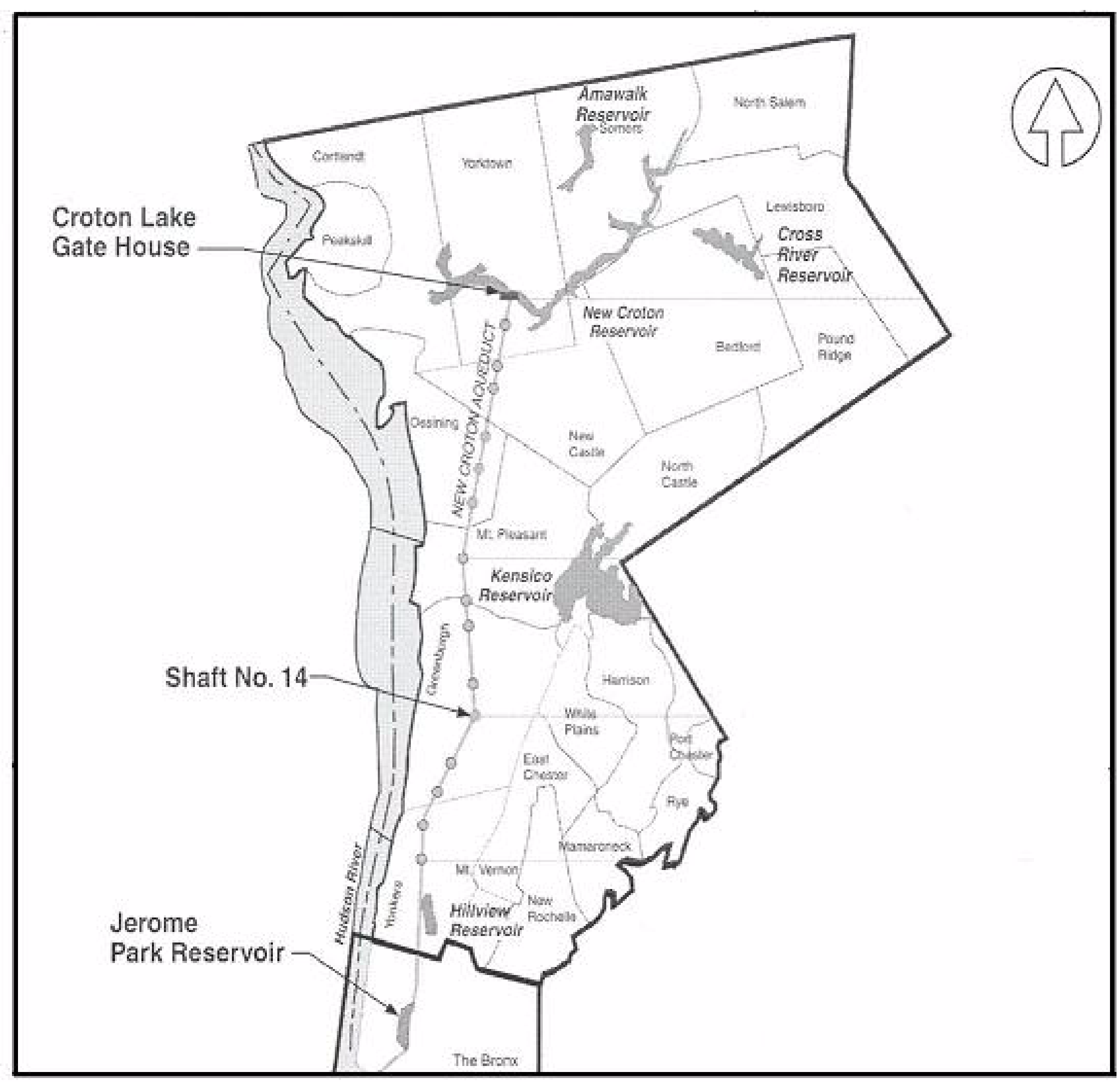

Figure 3.1 Location of Shaft 14 on the New Croton Aqueduct.

3.2 What concentrations of *Cryptosporidium* and *Giardia* and human enteric viruses were found in source waters and in the watershed in 2004?

DEP staff collected and analyzed over 1,000 samples for protozoan analysis in the watershed during 2004. Under routine operations, "source waters" are the waters in the influent and effluent chambers of Kensico Reservoir (four chambers altogether, one of each for both the Catskill and Delaware aqueducts) and the effluent chamber of New Croton Reservoir. The 50 liters of water sampled weekly from these five sites are analyzed using USEPA Method 1623 (USEPA 2001a). Results from monitoring these source waters are posted weekly on the DEP web site www.nyc.gov/html/dep/html/pathogen.html. To provide some perspective, the number of source water samples collected comprised 32% of all samples, second only to the number of stream samples collected (49%) (Figure 3.2) throughout the 125 mile radius watershed (Figure 3.3). Upstate reservoir releases and effluents, wastewater treatment plants, and storm events made up the remaining 19% of monitoring, with the exception of special projects.

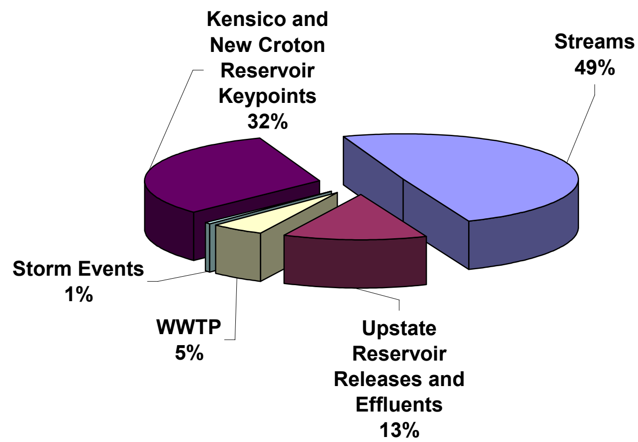

Figure 3.2 Distribution of the number of samples (including enhanced monitoring) per category of sampling sites, January 1 to December 31, 2004.

Kensico Influent Source Water

Concentrations of *Giardia* entering Kensico Reservoir differed between the Catskill and Delaware aqueducts. The mean concentration of *Giardia* at the Catskill influent aqueduct was 1.58 cysts $50L^{-1}$, and while still very low compared to any level of concern, the equivalent data from the Delaware influent aqueduct was approximately four times higher at 4.46 cysts $50L^{-1}$ (Table 3.1). These data showed a positive detection for *Giardia* of 65% and 87%, with maximum concentrations of 9 and 19 cysts $50L^{-1}$ for the Catskill and Delaware sites, respectively. Conversely, *Cryptosporidium* concentrations were much lower than *Giardia* at the influents to Kensico Reservoir, with comparable results at both locations. The Catskill influent results for 2004 produced a mean *Cryptosporidium* concentration of 0.29 oocysts $50L^{-1}$ and the equivalent Delaware data resulted in a mean concentration of 0.21 oocysts $50L^{-1}$. Results indicated a 19% and 21% positive rate for samples collected, with maximum concentrations of 3 and 1 oocyst(s) $50L^{-1}$ for the Catskill and Delaware sites, respectively.

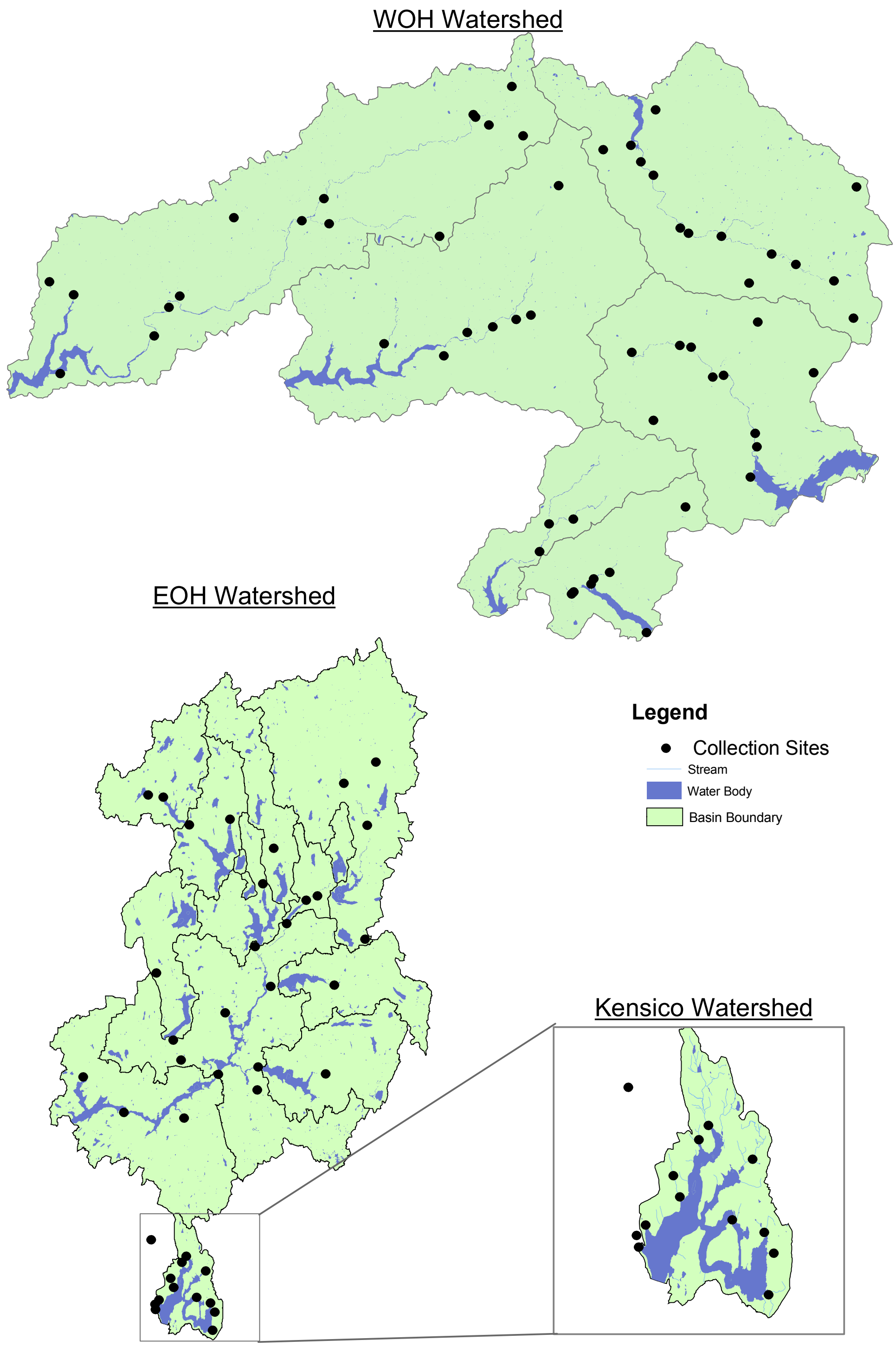

Figure 3.3 Locations of pathogen collection sites. The location outside the Kensico Watershed is CATALUM.

Table 3.1: Summary of *Cryptosporidium* and *Giardia* weekly monitoring results at NYC source waters January 1 to December 31, 2004.

Keypoint	Protozoan	Number of Samples	Number of Positive Samples	Percent Positive	Mean Concentration ($50L^{-1}$)	Maximum Concentration ($50L^{-1}$)
Catskill Influent Chamber	Total *Giardia*	52	34	65.4%	1.58	9
	Total *Cryptosporidium*		10	19.2%	0.29	3
Delaware Influent Chamber	Total *Giardia*	52	45	86.5%	4.46	19
	Total *Cryptosporidium*		11	21.2%	0.21	1
Catskill Effluent Chamber	Total *Giardia*	52	41	78.8%	2.78	11
	Total *Cryptosporidium*		12	23.1%	0.32	2
Delaware Effluent Chamber	Total *Giardia*	52	45	86.5%	2.02	14
	Total *Cryptosporidium*		15	28.8%	0.46	2
New Croton Reservoir Effluent	Total *Giardia*	52	31	59.6%	3.04	10
	Total *Cryptosporidium*		19	36.5%	0.33	3

Human enteric viruses (HEV) were detected in 50% and 35% of the Kensico influent samples at the Catskill and Delaware aqueducts, respectively (Table 3.2). Mean and maximum concentrations of HEV were 2.09 and 18.18 $100L^{-1}$ at the Catskill aqueduct, and 1.10 and 9.27 $100L^{-1}$ at the Delaware location.

Table 3.2: Summary of human enteric virus weekly monitoring results at NYC source waters January 1 to December 31, 2004.

Keypoint	Number of Samples	Number of Positive Samples	Percent Positive	Mean Concentration MPN* ($100L^{-1}$)	Maximum Concentration MPN* ($100L^{-1}$)
Catskill Influent Chamber	52	26	50.0%	2.09	18.18
Delaware Influent Chamber	52	18	34.6%	1.10	9.27
Catskill Effluent Chamber	52	25	48.1%	1.54	44.30
Delaware Effluent Chamber	52	17	32.7%	0.70	5.75
New Croton Reservoir Effluent	52	14	26.9%	0.64	8.54

* MPN - Most Probable Number.

Kensico Effluent Source Water

The waters leaving Kensico Reservoir at the Catskill and Delaware effluent aqueducts had very similar *Giardia* concentrations. The Catskill effluent aqueduct resulted in a mean concentration of 2.78 cysts $50L^{-1}$, and the Delaware effluent aqueduct had a mean of 2.02 cysts $50L^{-1}$. This relationship to each other, and to the influent data, supports the possible mixing, diluting, settling, and predation processes expected to be occurring in the reservoir. The maximum concentrations of the effluents also support these potential reservoir processes, with 11 cysts $50L^{-1}$ maximum at the Catskill effluent, and 14 cysts $50L^{-1}$ maximum at the Delaware effluent, which falls between the influent maximum results of 9 and 19, respectively. *Cryptosporidium* concentrations at the effluents of Kensico Reservoir were a little higher than at the influents in 2004. Mean concentrations $50L^{-1}$ were 0.32 and 0.46 for the Catskill and Delaware effluents, respectively, which is slightly higher than the 0.29 and 0.21 $50L^{-1}$ values for the influent waters.

Human enteric virus results for the Kensico effluents indicated a 48% and 33% positive sample rate for the Catskill and Delaware effluent system samples. Overall mean and maximum HEV concentrations were 1.54 and 44.30 $100L^{-1}$ for the Catskill effluent. This 44.30 value was an outlier for the year since removing it from the data produces a much lower maximum result of 3.25 $100L^{-1}$. The Delaware mean and maximum values were 0.70 and 5.75 $100L^{-1}$.

New Croton Effluent Source Water

New Croton Reservoir protozoan data are comparable to the Kensico Reservoir data. Mean concentrations of *Giardia* were 3.04 cysts $50L^{-1}$, while the *Cryptosporidium* mean was 0.33 oocysts $50L^{-1}$. The percent of samples positive for *Giardia* and *Cryptosporidium* were 60% and 37%, with maximum concentrations of 10 and 3 $50L^{-1}$ for cysts and oocysts respectively.

New Croton HEV data for 2004 are similar to those of the Delaware System. New Croton results indicate that 27% of the samples collected were positive for HEV. Mean and maximum concentrations were 0.64 and 8.54 $100L^{-1}$, respectively.

Watershed

For the purposes of this report, watershed samples were divided into four different categories: streams, storm events, upstate reservoir releases and effluents, and wastewater treatment plant effluents. Stream samples collected in 2004 had the highest mean *Giardia* concentration compared to the other categories, with a mean of 39.66 cysts $50L^{-1}$. Stream samples also had the second highest *Cryptosporidium* mean of 1.26 oocysts $50L^{-1}$. The highest *Cryptosporidium* and the second highest *Giardia* mean concentrations were recovered from stormwater samples collected in the watershed, 2.33 oocysts $50L^{-1}$ and 14.66 cysts $50L^{-1}$, respectively. This is not surprising since it is well documented that protozoa can be transported to waterbodies during precipitation events. Releases and effluents of upstate reservoirs resulted in a *Giardia* mean concentration of approximately 8 cysts $50L^{-1}$, while the mean *Cryptosporidium* value was 0.29 oocysts $50L^{-1}$. Wastewater treatment plant samples are collected at the effluents of the plants, post-treatment, in order to aid in monitoring the effectiveness of the plant processes. In 2004, treatment plant samples remained low for protozoan pathogens, with mean concentrations of 1.25 *Giardia* and 0.11 *Cryptosporidium* $50L^{-1}$ samples.

3.3 How did protozoan concentrations compare with regulatory levels in 2004?

Currently, there are no New York State, or Federal, regulations established for *Giardia* or *Cryptosporidium* in source water. There is, however, a proposed rule for *Cryptosporidium* submitted by the US Environmental Protection Agency (USEPA) called the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2001b), which may be promulgated within the next year. The proposed rule requires that samples will be analyzed using an approved USEPA Method 1623 laboratory and it is anticipated that the rule will provide for increased protection against microbial pathogens in drinking water. The DEP Pathogen Laboratory was approved for use of this method in August of 2001, and DEP began analyzing source water samples with Method 1623 later that year, providing DEP with approximately three and a half years of data at this time. Three source water sites are covered by LT2, one for each system—the Catskill and Delaware effluent chambers at Kensico Reservoir and the New Croton Reservoir effluent chamber. Data from all three sites for 2003 through 2004 are presented below compared to the proposed LT2 threshold for *Cryptosporidium* (Figure 3.4). Results for this year once again fell below the proposed regulatory levels for the LT2, as they did for 2002 and 2003.

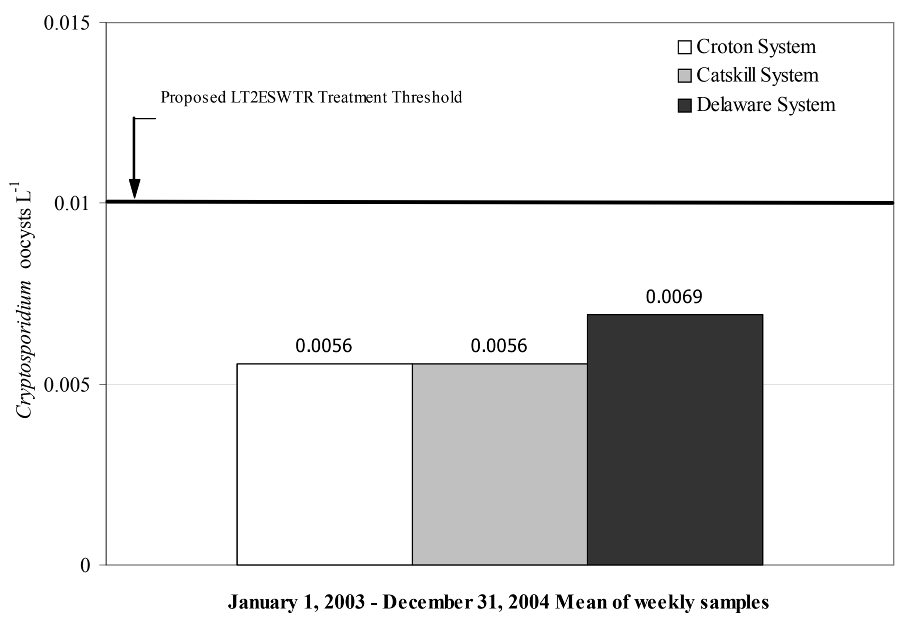

Figure 3.4 Comparison between the proposed LT2 treatment threshold and averages of 104 weekly *Cryptosporidium* analyses at each of the NYC source water effluent sites – January 1, 2003 to December 31, 2004.

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

The Surface Water Treatment Rule (SWTR) (40CFR171.71(a)(1)) requires that water at a point just prior to disinfection not exceed thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at "keypoints" just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF, and the Delaware System at DEL18). Figures 3.5 and 3.6 depict fecal coliform and turbidity data for 1992-2004. Both figures include a horizontal line marking the SWTR limit.

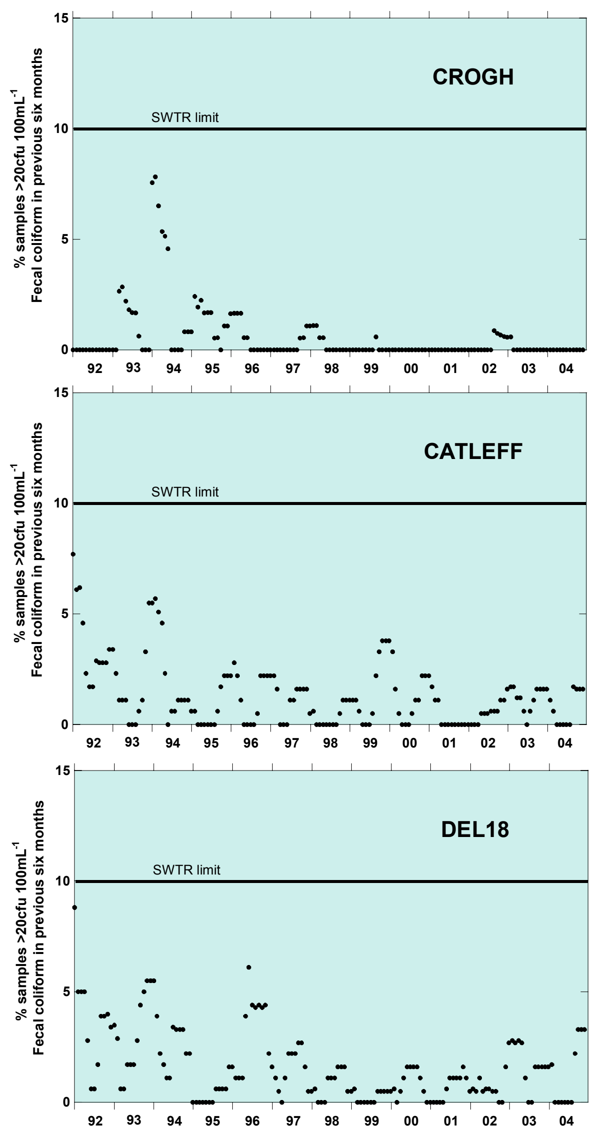

Figure 3.5 Temporal plots of fecal coliform (% of daily samples > 20 CFU $100mL^{-1}$ in the previous six months) compared with Surface Water Treatment Rule limit.

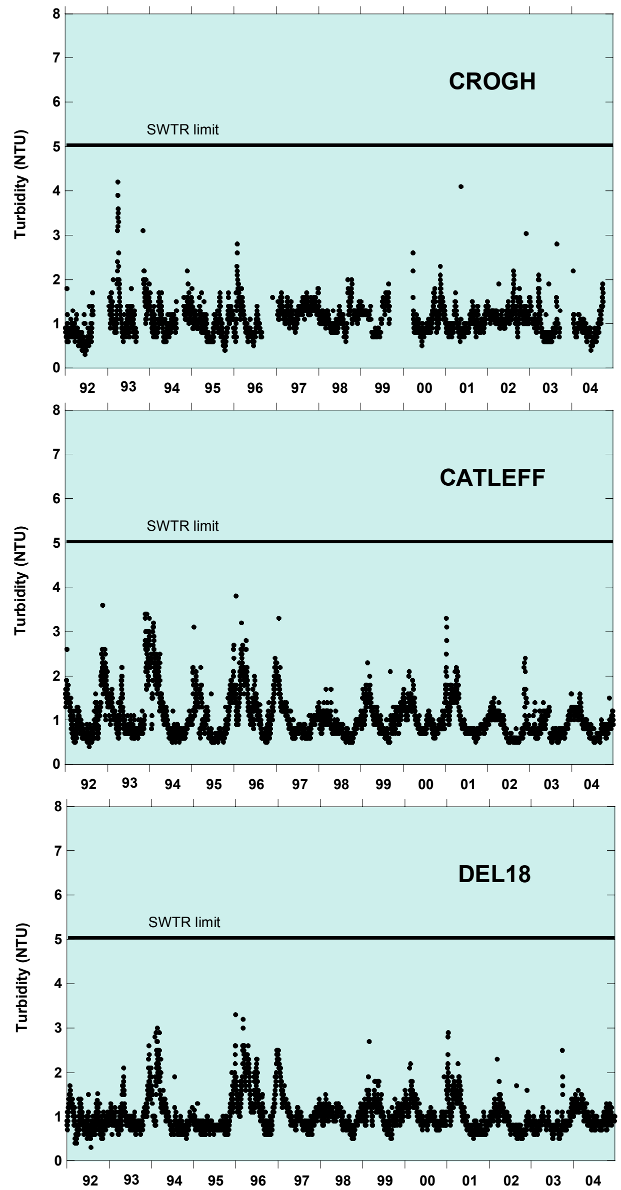

Figure 3.6 Temporal plots of turbidity (daily samples) compared with Surface Water Treatment Rule limit.

As indicated in Figure 3.5, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; for 2004, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below the 10% limit set by the SWTR standard. For 2004, for raw water samples taken at the three keypoints CROGH, CATLEFF, and DEL18, the mean and median fecal coliform concentrations ($100mL^{-1}$) were 0.3 and 0, 1.8 and 1, and 2.6 and 1, respectively.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.6, all three effluent waters were consistently well below this limit in 2004. For the three keypoints CROGH, CATLEFF, and DEL18, the mean and median turbidity values (NTU) were 0.9 and 0.9, 0.9 and 0.8, and 1.0 and 0.9, respectively.

3.5 What was the water quality in 2004 in the streams that represent the major flow into NYC's reservoirs?

The stream sites used in this report are presented in Table 3.3 and shown pictorially in Figure 3.7. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/ Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds.

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

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

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

The results presented (Figure 3.8) are based on grab samples generally collected twice a month. The figures compare the 2004 median values against historic median annual values for the previous ten years (1994-2003). However, several of the East-of-Hudson (EOH) sites have shorter sampling histories. These include: WESTBR7 (1995-present), KISCO3 (1999-present), and HUNTER1 (1998-present).

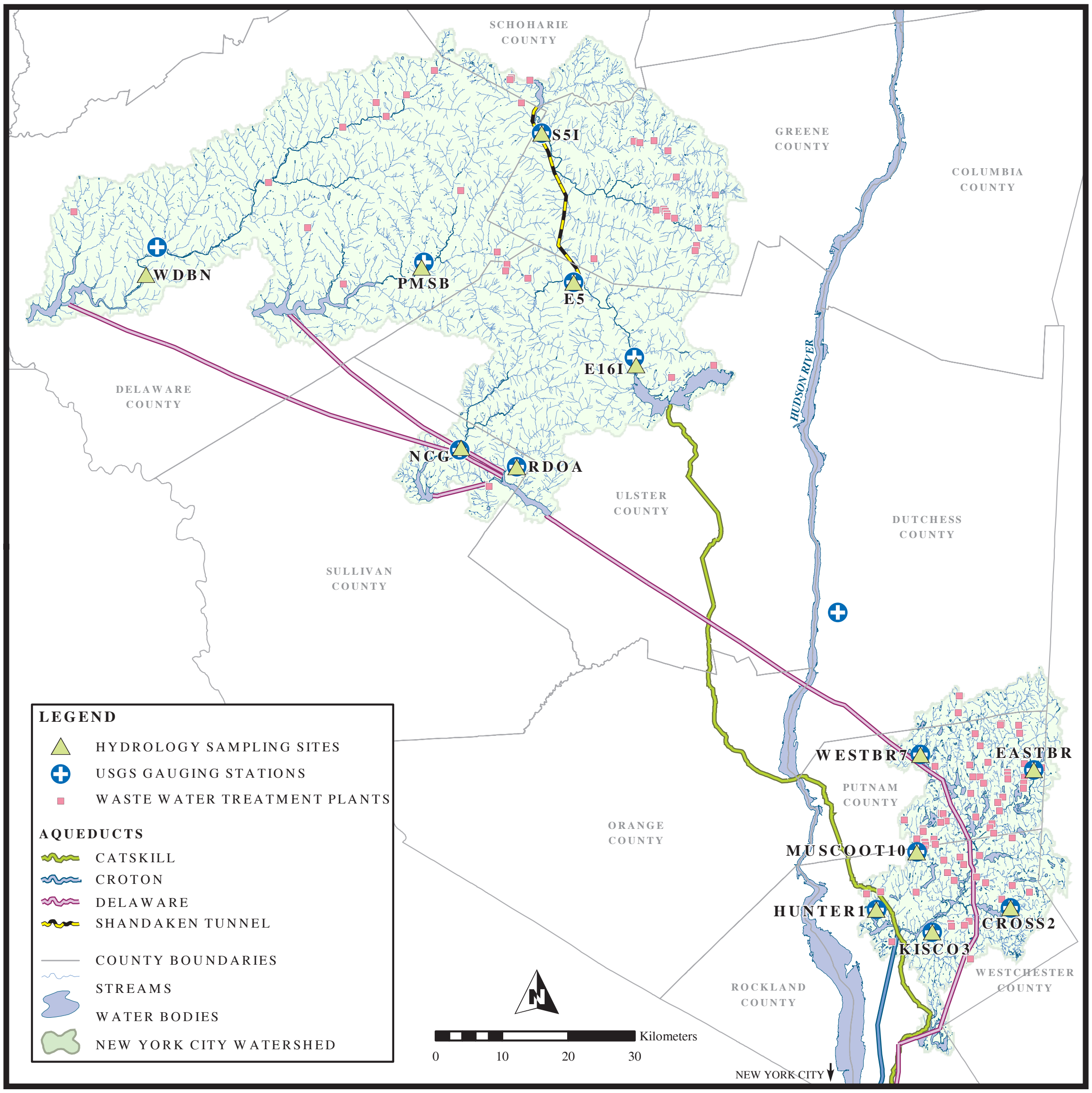

Figure 3.7 Locations of sampling sites and USGS stations.

Turbidity

The turbidity levels for 2004 were generally near “normal’ values (Figure 3.8a) with only the inflow to Amawalk (MUSCOOT10) showing a somewhat elevated median turbidity value for 2004.

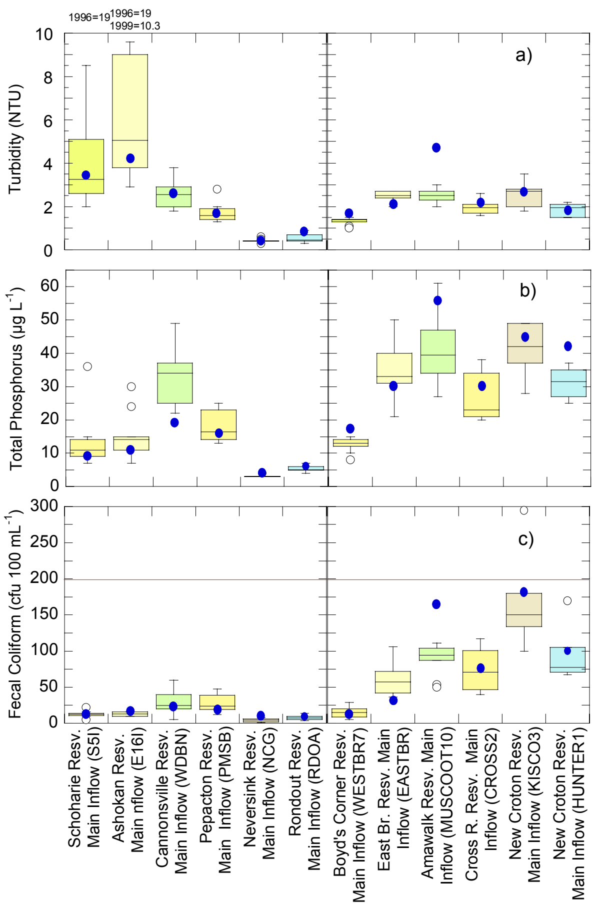

Figure 3.8 Boxplot of annual medians (1994–2003) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2004 displayed as a dot.

Total Phosphorus

In the Catskill/Delaware System, the 2004 total phosphorus levels (Figure 3.8b) were for the most part near typical historical values. In the Croton System total phosphorus values (Figure 3.8b) were generally slightly above historical values.

Fecal Coliform

The 2004 coliform levels (Figure 3.8c) in the Catskill/Delaware and Croton Systems were generally near the typical historical levels. Again, only the Amawalk Reservoir inflow showed a somewhat elevated median value for 2004.

A fecal coliform benchmark of 200 cfu $100mL^{-1}$ is shown as a solid line on Figure 3.8c. 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 coliforms. The 2004 median values for all streams shown here lie below this value.

3.6 How did the snowmelt and increased precipitation affect turbidity in the reservoirs?

Turbidity in reservoirs is caused by organic (e.g., plankton) and inorganic (e.g., clay, silt) particulates suspended in the water column. Turbidity may be generated within the reservoir itself (e.g., plankton, sediment re-suspension) or it may be derived from the watershed by erosional processes (storm runoff in particular). In 2004 the median turbidity decreased (or stayed the same) through much of the system as compared to the annual medians of the past 10 years (Figure 3.9). This occurred despite increased runoff from snowmelt and precipitation for the year. Perhaps the precipitation and runoff events were not of sufficient intensity to cause major turbidity events. Another factor was that full reservoir elevations decreased the shoreline sediments' exposure to erosion. Notable exceptions to the decreased turbidity observed in 2004 include Bog Brook and East Branch Reservoirs. Throughout 2004 these reservoirs were "drawn down" in order to perform dam repairs. The exposed sediments and/or the small water volume may explain the relatively large increases in turbidity compared to past years. However, caution should be used when comparing 2004 data from Bog Brook, East Branch, Middle Branch, Boyd Corners, Diverting, and Croton Falls to historic data. Medians in 2004 are based on a very limited number of samples and may not be an accurate representation of the year. Although these sites are not displayed in Figure 3.6, data analysis was conducted at the three controlled lakes, Kirk, Gilead, and Gleneida. The median turbidity during 1996–2003 for Kirk, Gilead, and Gleneida was 3.1, 1.3, and 1.5 NTU, respectively. In 2004, the median turbidity was 2.1, 1.4, and 2.1 NTU, similar to past levels.

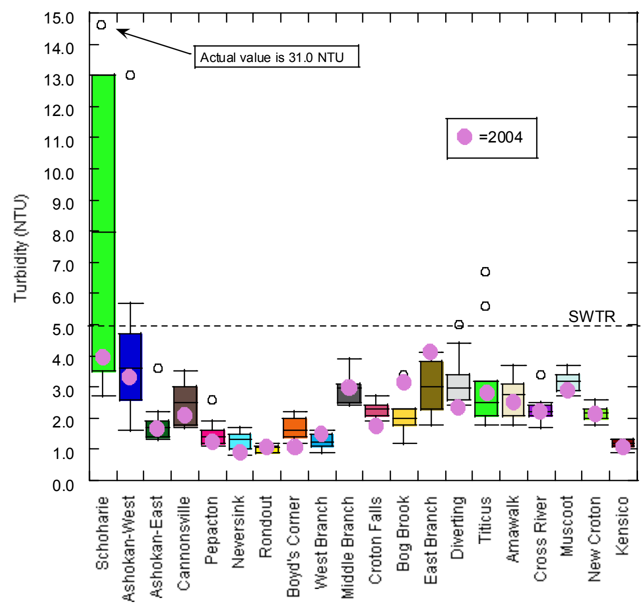

Figure 3.9 Annual median turbidity in NYC water supply reservoirs (2004 vs. 1994–2003).

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

3.7 Were the total phosphorus concentrations in the reservoirs affected by the precipitation and runoff in 2004?

Phosphorus is an important nutrient for plant growth. Main sources of phosphorus in reservoirs include: soil erosion carried by inflowing streams, atmospheric deposition, sewage, and internal recycling from sediments. With the exceptions of Schoharie and Cannonsville, most Catskill and Delaware System reservoirs have relatively low long-term (1994-2003) concentrations of total phosphorus (TP) (Figure 3.10). Relatively high concentrations can occur in Schoharie because its river channel is highly susceptible to erosion. The long-term elevated TP concentration at Cannonsville may have been caused by agricultural and nonpoint runoff and wastewater treatment plants. Many of these inputs either have been, or are currently being, addressed (see Chapter 4). In 2004, the annual median TP concentrations at all Catskill and Delaware System reservoirs were near or well below the annual median concentration of the past 10 years. One possible explanation was that this was the second consecutive year with above average precipitation. The rainfall fell with moderate intensity during the year and the basins were not severely impacted by powerful storms. The contrast in phosphorus concentration, between these "wet" years and previous years of drought, may be caused by a dilution effect from the low intensity, above-average precipitation.

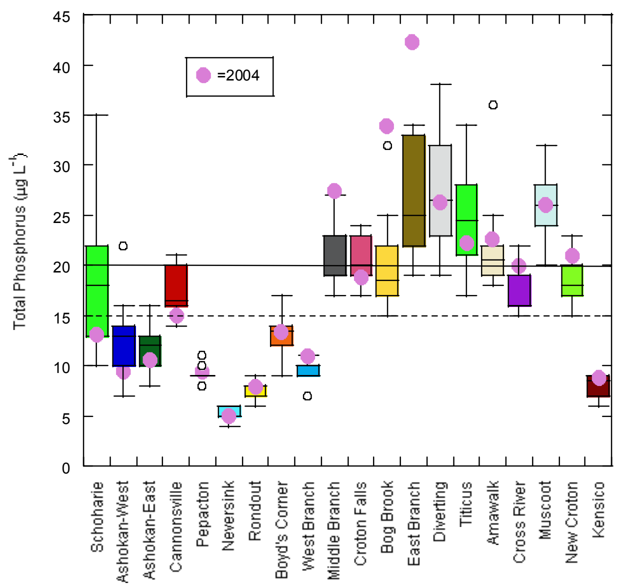

Figure 3.10 Annual median total phosphorus concentrations in NYC water supply reservoirs (2004 vs. 1994–2003).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Caution should be used when comparing 2004 data from Middle Branch, Boyd's Corner, Diverting, Bog Brook, East Branch, and Croton Falls to historic data. Medians in 2004 are based on a very limited number of samples and may not be an accurate representation of the year.

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

TP concentrations in the Croton System reservoirs are normally noticeably higher than in the Catskill and Delaware Systems due primarily to development pressure. There are 60 wastewater treatment plants scattered throughout the Croton watershed. Septic systems are also prevalent. In 2004, TP concentrations were especially high in Middle Branch, Bog Brook, and East Branch Reservoirs. The elevated concentrations were probably due to draw down in 2004 to repair dams (East Branch and Bog Brook) or to repair roadways (Middle Branch). Less water was therefore available for dilution. Another complicating factor was that these reservoirs were not sampled frequently in the spring months. Since reservoir access was limited to later in the season, the TP may be biased high due to anoxia and internal loading that typically occurs in late summer. Of the remaining Croton System reservoirs, four were at or below the annual median concentration of past years. The exceptions include West Branch, Amawalk, Cross River, and New Croton Reservoirs, which were above the long-term median concentration. The 2004 data may be reflective of conditions in these impoundments that are prevalent during years of elevated precipitation.

The Catskill System reservoirs had 2004 median TP values that continue to be well below those found in the long-term statistics. This probably occurred because the long-term box plots include data from 1996 and 1999, both of which had severe storms that had a short-term deleterious effect on the Catskill reservoirs. We believe that the effect of these storms on the watershed may be waning. Phosphorus concentrations for Kirk, Gilead, and Gleneida lakes in 2004 (data not provided in Figure 3.10) were consistent with past data. In 2004 the median TP for Kirk, Gilead, and Gleneida was 23, 20, and 18 $\mu g\ L^{-1}$, respectively.

3.8 Which basins are phosphorus-restricted?

The phosphorus-restricted basin status was derived from two, consecutive assessments (1999–2003, 2000–2004) using the methodology stated in Appendix C. Table 3.4 lists the annual growing season geometric mean phosphorus concentration for each of the City reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.11 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2004 geometric mean for the phosphorus concentration.

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

- Cannonsville Reservoir continues its non-restricted status and the geometric mean of total phosphorus concentration for 2004 continues to decline. All other Delaware District reservoirs remained non-restricted.
- The Catskill System showed a slight decrease in the five-year 2000-2004 assessment as compared to the 1999-2003 assessment. The annual average of 13.3 $\mu g\ L^{-1}$ for Schoharie in 2004, however, increased over the 2003 average, probably as a result of heavy precipitation during the year (Appendix C), but the overall assessment was lower due to the passage from the assessment range of the 1999 dataset, which contained elevated phosphorus concentrations. Similar results were found for the East and West basins of Ashokan.
- Croton System reservoir assessments revealed that restriction status remained unchanged. New Croton Reservoir continues its phosphorus-restricted status. Amawalk, Bog Brook, Boyd Corners, and West Branch had a 2004 geometric mean that was similar to the two previous time periods. Cross River and East Branch increased in 2004 relative to the two five-year averages, while the remaining Croton System reservoirs decreased in 2004. Reservoir access issues (e.g., drawdown, bridge work, dam rehabilitation) limited the number of months that were used for these calculations on Bog Brook, Boyd Corners, Croton Falls, Diverting, and East Branch Reservoirs.

- The assessment could not be calculated for Kirk Lake since three years out of five are required to run the five-year mean. Lake Gleneida and Middle Branch Reservoir did not fulfill the data requirement of three complete surveys during the growing season in 2004 because of access issues as stated above, so the annual average is not included in Figure 3.11.

Table 3.4: Phosphorus-restricted reservoir basins for 2004.

Reservoir Basin	99 - 03 Assessment (mean + S.E.) (μg L^{-1})	00-04 Assessment (mean + S.E.) (μg L^{-1})	Phosphorus-Restricted Status
Delaware System			
Cannonsville Reservoir	18.0	17.8	Non-Restricted
Pepacton Reservoir	9.4	9.5	Non-Restricted
Neversink Reservoir	5.4	5.4	Non-Restricted
Rondout Reservoir	9.0	9.1	Non-Restricted
Catskill System			
Schoharie Reservoir	19.6	16.1	Non-Restricted
Ashokan-West Reservoir	11.1	9.5	Non-Restricted
Ashokan-East Reservoir	10.8	10.5	Non-Restricted
Croton System			
Amawalk Reservoir	28.1	28.9	Restricted
Bog Brook Reservoir	26.9	28.8	Restricted
Boyd Corners Reservoir	14.9	15.0	Non-Restricted
Cross River Reservoir	17.8	19.1	Non-Restricted
Croton Falls Reservoir	23.5	23.6	Restricted
Diverting Reservoir	34.1	34.6	Restricted
East Branch Reservoir	33.8	39.6	Restricted
Middle Branch Reservoir	29.5	30.7	Restricted
Muscoot Reservoir	32.5	32.5	Restricted
Titicus Reservoir	32.8	29.8	Restricted
West Branch Reservoir	12.1	12.4	Non-Restricted
Lake Gleneida	29.2	31.0	Restricted
Lake Gilead	35.0	34.6	Restricted
Source Water			
Kensico Reservoir	8.5	8.7	Non-Restricted
New Croton Reservoir	22.2	22.8	Restricted

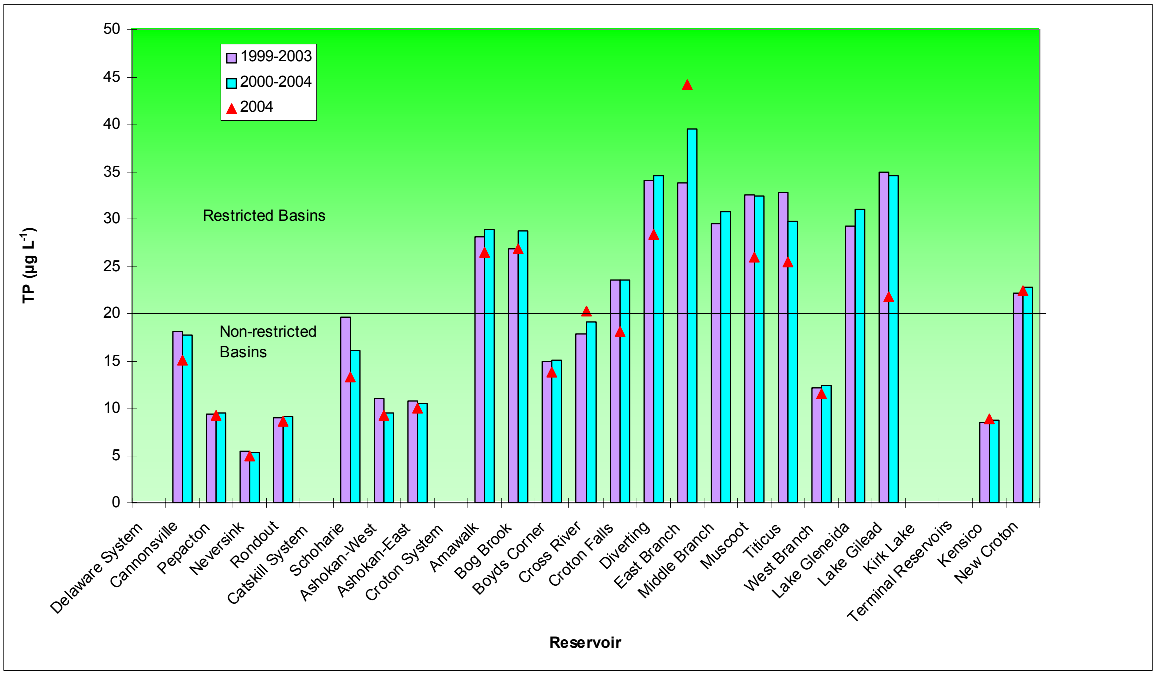

Figure 3.11 Phosphorus-restricted basin assessments with the current year (2004) geometric mean phosphorus concentration displayed for comparison.

The bars represent the mean of the five-year periods, not the range.

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

Coliform bacteria include total coliform and fecal coliform counts, which are regulated in source waters by the Safe Drinking Water Act (SDWA) at levels of 100 CFU mL^{-1} and 20 CFU 100 mL^{-1}, respectively. Both are used as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals. Figure 3.12 shows that the long-term (1994-2003) annual median values of total coliform have exceeded 100 CFU 100 mL^{-1} at only two reservoirs, Diverting and Muscoot. In 2004, East Branch, Diverting, and Muscoot had a median that exceeded this level. Limited samples collected from East Branch and Diverting due to draw-down may have skewed these medians. Bog Brook and Middle Branch may have been similarly affected, although the medians for 2004 were below 100 CFU 100 mL^{-1}. The Catskill reservoirs were all above their long-term medians in 2004. Increased precipitation may have driven the elevated levels of total coliforms. If the precipitation in 2004 was indeed the cause, then the reason for all the Delaware reservoirs having low annual median levels of total coliform in 2004 is unclear. Although not shown in the plots, the controlled lakes (Gilead, Gleneida, and Kirk) all continued to have elevated medians for 2004.

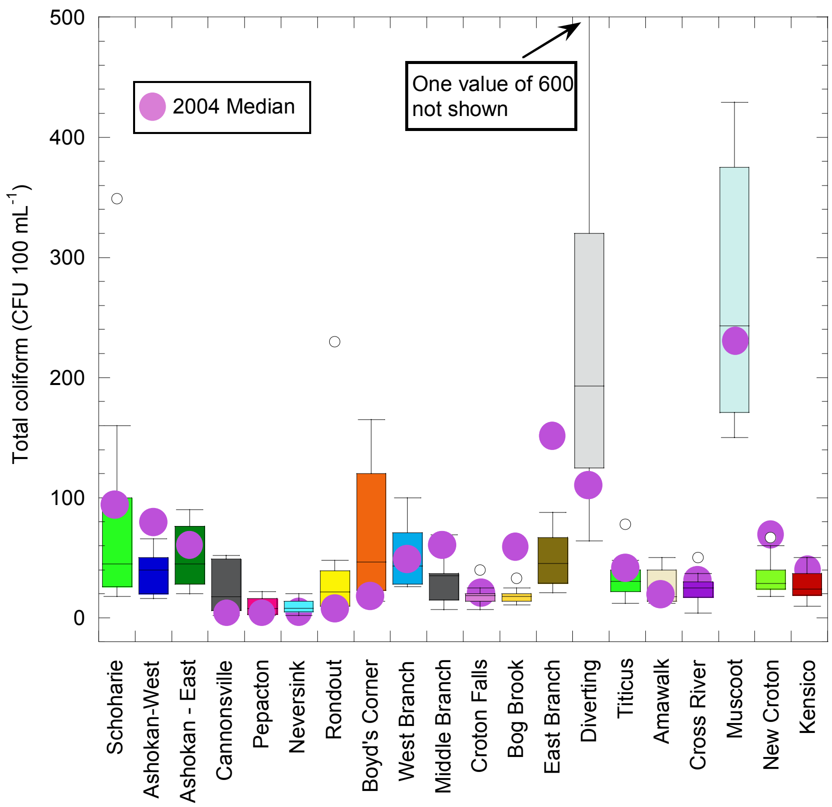

Figure 3.12 Annual median total coliform concentrations in NYC water supply reservoirs (2004 vs. 1994–2003).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Caution should be used when comparing 2004 data from Middle Branch, Boyd's Corner, Diverting, Bog Brook, East Branch, and Croton Falls to historic data. Medians in 2004 are based on a very limited number of samples and may not be an accurate representation of the year.

Figure 3.13 shows that the long-term annual medians for fecal coliform never exceeded 20 CFU 100 mL^{-1} for any of the reservoirs. Muscoot and Diverting were among the reservoirs having the highest long-term levels, although both reservoirs had decreased levels in fecal coliform as compared to previous years. East Branch was the only reservoir that had a marked increase in fecal coliform in 2004, but again, this may have been skewed by limited data as a result of drawdown. Diverting had a low median for 2004, but this result may have been affected by limited data in the same way as East Branch. The controlled lakes all had median levels of fecal coliform in 2004 that were comparable to past data. All of the West-of-Hudson (WOH) reservoirs continued to have uniformly low levels of fecal coliform in 2004, as demonstrated by the medians in Figure 3.13.

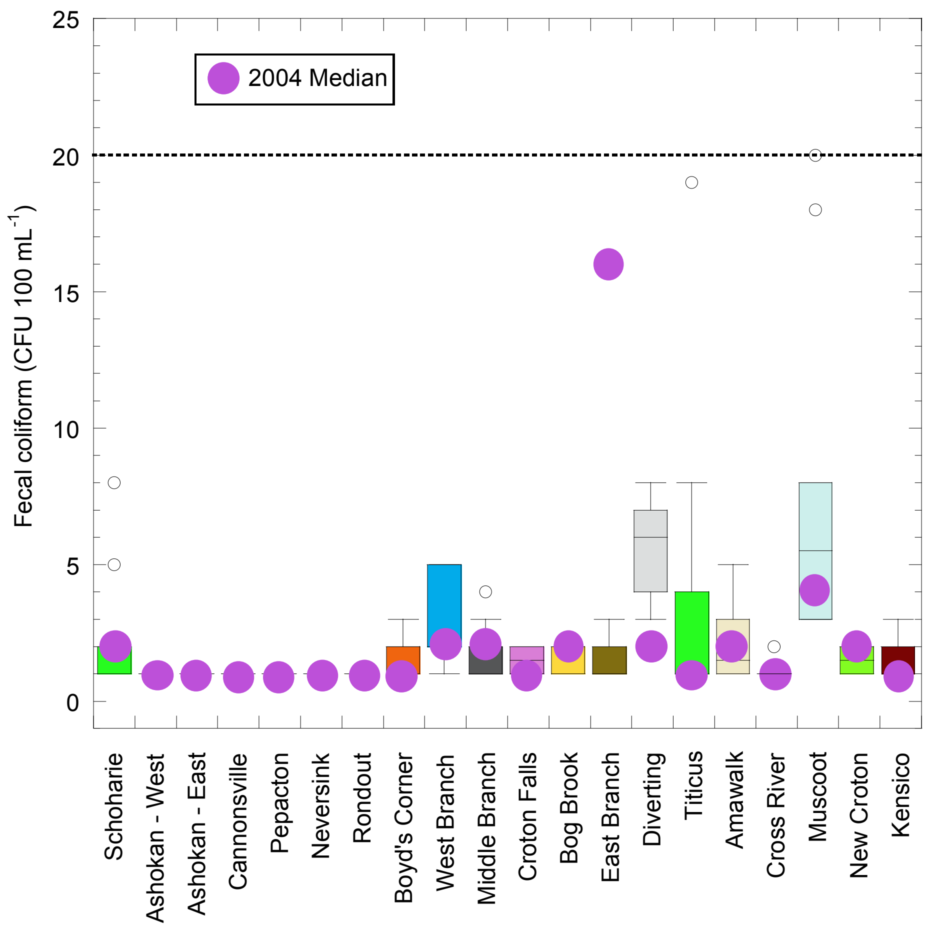

Figure 3.13 Annual median fecal coliform concentrations in NYC water supply reservoirs (2004 vs. 1994–2003).

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

3.10 Which basins are coliform-restricted?

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

With respect to the five terminal basins, an assessment has been made for 2004 under Section 18-48 (b)(1) using fecal coliform data at the effluent keypoints (Table 3.5). Currently, coliform restriction assessments are made using data from a minimum of five samples each week over two consecutive six-month periods. The threshold for fecal coliform is 20 CFU $100mL^{-1}$. If 10% of the effluent samples measured had values ≥ 20 CFU $100mL^{-1}$, and the cause was determined to be from anthropogenic (man-made) sources, the associated basin would be deemed a "coliform-restricted" reservoir. If < 10 % of the effluent keypoint samples measured ≥ 20 CFU $100mL^{-1}$, then the associated reservoir would be "non-restricted" in regards to coliform bacteria.

With respect to non-terminal basins, the water quality standard is for total coliform only and this poses several problems for reservoir basin designation. Total coliform come from a variety of natural and anthropogenic sources, so using total coliform alone will not meet the spirit of the regulation. The draft methodology developed by DEP for determining coliform-restricted basins for these non-terminal reservoirs will use the total coliform standard as an initial assessment, but will also go further to consider other microbial data to determine whether the source is anthropogenic. DEP is awaiting approval to proceed with the new methodology before conducting the analysis; therefore, coliform-restricted basins have not been determined for the non-terminal reservoirs for 2004.

Table 3.5: Coliform-restricted basin status as per Section 18-48 (b)(1) for 2004.

Reservoir Basin	Effluent Keypoint	2004 Assessment
Kensico	CATLEFF and DEL18	Not Restricted
New Croton	CROGH	Not Determined*
Ashokan	EARCM	Not Restricted
Rondout	RDRRCM	Not Restricted
West Branch	DEL10	Not Determined**

* While CROGH data from January through June supported an assessment of no coliform restriction during that six-month period, the remainder of the year was only represented from July through October 7 due to shutdown of the Croton Aqueduct. Therefore, a complete assessment could not be made.

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

3.11 How did source water quality compare with standards in 2004?

Table 3.6 represents reservoir-wide median values for a variety of physical, biological, and chemical analytes for the four source water reservoirs: Kensico, New Croton, Ashokan (East Basin), and Rondout. Appendix A gives additional statistical information on these and other reservoirs in the system. There are several noticeable differences in New Croton Reservoir compared to the other three. The pH tends to be higher because of the underlying geology and because of primary production, which at times can cause an excursion above the 8.5 pH units in the water quality standard. Low alkalinity in the WOH reservoirs provides little buffering of acidic precipitation, causing some readings to be lower than the standard of 6.5 pH units at times. Limited anion and cation data were available for comparison in the EOH reservoirs in 2004, but these ion concentrations were generally higher, as were the consequent variables—alkalinity, hardness, and conductivity. Chloride levels continued to increase in New Croton, but remained well below the 250 mg L^{-1} standard. Appendix A shows the chloride levels for all other EOH reservoirs which have had similar increases.

Typically, higher nutrient inputs caused higher chlorophyll *a* and phytoplankton levels in New Croton, which at times caused the phytoplankton to exceed the DWQC internal limit of 2000 standard areal units (SAU). Similarly, TP data summary demonstrates that TP exceeded the DEC guidance value of 15 mg L^{-1}, which applies to source waters. Other reservoirs in the Croton System also exceeded this value in 2004 (Appendix A). The increased productivity also caused higher turbidity levels and lower Secchi disc transparency. There were also higher levels of discoloration and organic carbon in New Croton. At times, water quality standards for these variables were exceeded (with the exception of organic carbon, for which there is no standard). In contrast, Kensico's water quality is reflective of the large majority of very high quality water it receives from Rondout and Ashokan reservoirs.

Table 3.6: Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the four source water reservoirs for 2004.

ANALYTES	Standard	Kensico	New Croton	East Ashokan Basin	Rondout
PHYSICAL					
Temperature (°C)		12.3	12.4	9.8	9.8
pH (units)	6.5-8.5[1]	6.89	7.4	6.99	6.36
Alkalinity (mg/L)		10.9	62	8.5	7.4
Conductivity (µS/cm)		65	371	51	49
Hardness (mg/L)		22	101	15	15
Color (Pt-Co units)	(15)	12	25	9	15
Turbidity (NTU)	(5)	1.1	2.2	1.7	1.1
Secchi Disk Depth (m)		4.8	2.8	4.1	4.9
BIOLOGICAL					
Chlorophyll *a*	7 [2]	3.3	11.78	8.34	3.8
Total Phytoplankton (SAU)	2000 [2]	180	325	170	200
CHEMICAL					
Dissolved Organic Carbon (mg/L)		1.6	3.1	1.7	1.4
Total Phosphorus (µg/L)	15 [2]	9	21	11	8.3
Total Nitrogen (mg/L)		0.275	0.51	0.25	0.356

continued...

Table 3.6: Reservoir-wide median values for a variety of physical, biological, and chemical analytes for the four source water reservoirs for 2004.

ANALYTES	Standard	Kensico	New Croton	East Ashokan Basin	Rondout
Nitrate+Nitrite-N (mg/L)	10 [1]	0.176	0.284	0.142	0.265
Total Ammonia-N (mg/L)	0.7-35 [1,3]	0.017	0.027	0.025	0.006
Iron (mg/L)	0.3 [1]	0.03	0.03	0.02	0.04
Manganese (mg/L)	(0.05)	0.038	0.03	0.007	0.018
Lead (µg/L)	50 [1]	0.3	0.3	0.5	0.3
Copper (µg/l)	200 [1]	0.7	1.2	2.5	1
Calcium (mg/L)		6.1	26.4	4.6	4.4
Sodium (mg/L)		5.7	35.1	3.0	3.5
Chloride (mg/L)	250 [1]	8.6	69	5.0	5.3

Note: See Appendix A for Water Quality Standards footnotes.

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

Trophic state indices (TSI) are commonly used to describe the productivity of lakes and reservoirs. Three trophic state categories (oligotrophic, mesotrophic, and eutrophic) are used to separate and describe water quality conditions. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters on the other hand are high in nutrients, high in algal growth, and low in water clarity (Figure 3.14). Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use three commonly measured variables (chlorophyll *a*, total phosphorus, and Secchi disk) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

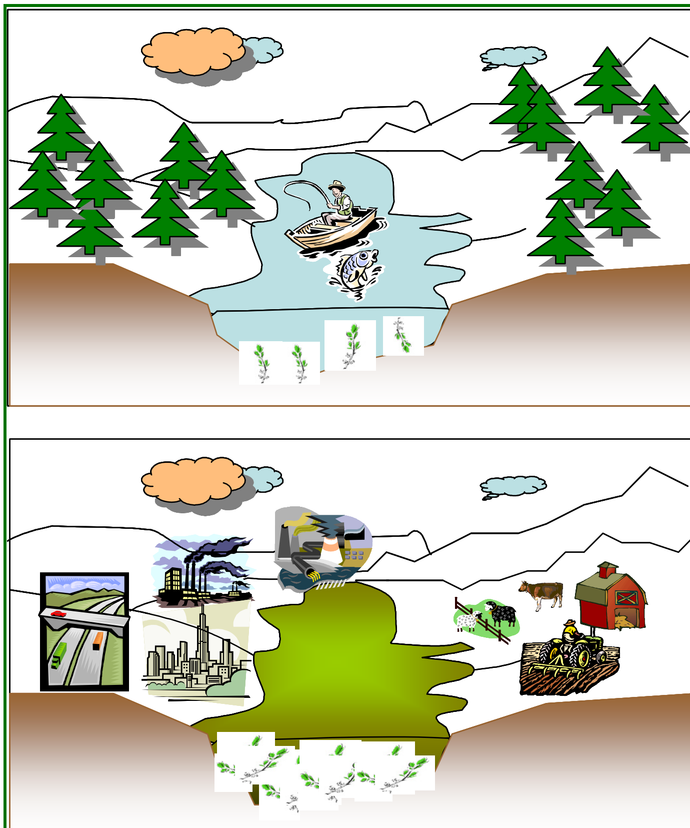

Figure 3.14 a) Pristine watershed produces water of high quality (oligotrophic). b) Disturbed watersheds produce water of low quality (eutrophic).

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

where CHLA is the concentration of chlorophyll *a*

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

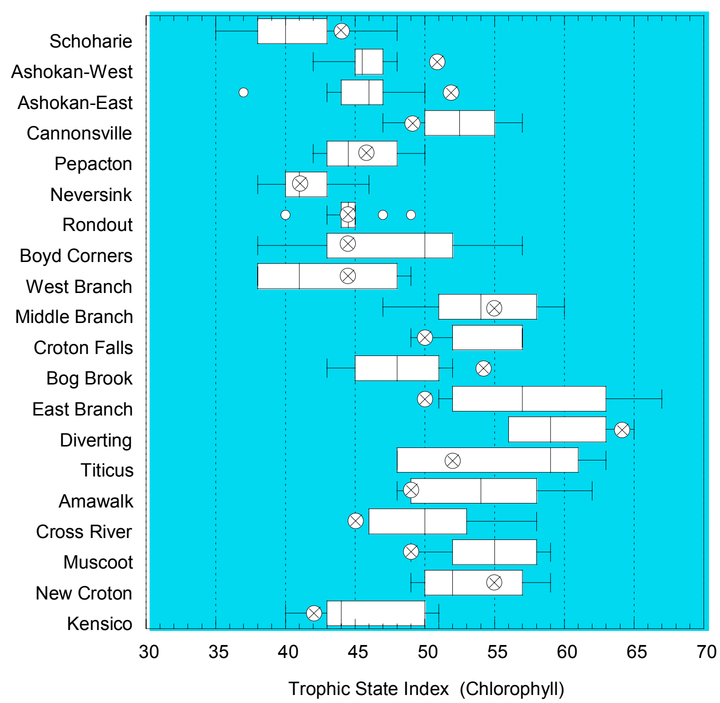

Figure 3.15 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2004 vs. 1994–2003 for most reservoirs).

In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies (1 or 2x per month) from May through October. Caution should be used when comparing 2004 data from Middle Branch, Boyd Corners, Diverting, Bog Brook, East Branch, and Croton Falls to historic data. Medians in 2004 are based on a very limited number of samples and may not be an accurate representation of the year. TSI is based on Chlorophyll *a* concentration.

Past (1994-2003 for most reservoirs) annual median TSI based on chlorophyll *a* concentration is presented in box plots in Figure 3.15. The 2004 annual median TSI appears in the figure as a circle containing an "x". This analysis usually shows a split between WOH reservoirs, which generally fall into the mesotrophic category, and EOH reservoirs, which are typically classified as eutrophic. The exceptions to these generalities are Cannonsville, which is usually considered eutrophic, and West Branch, which is considered mesotrophic due to the incoming water from Rondout Reservoir.

In 2004, the median TSIs for the Catskill reservoirs were elevated compared to past data, possibly due to improved light transparency. The Delaware reservoirs had 2004 medians that were similar to the long-term data, except for Cannonsville, which was lower in 2004. This may be a favorable result of the decrease that was also seen in total phosphorus. EOH reservoirs that had a substantial decrease in the 2004 TSI include Muscoot, Amawalk, Cross River, and Titicus. Perhaps because of the increased precipitation in 2004, nutrients were flushed through the system more rapidly resulting in limited algal growth. West Branch and New Croton Reservoirs both had slight increases in 2004 TSI, relative to past data. The increase at West Branch may be explained by operational changes, which resulted in more eutrophic water entering West Branch from Boyd Corners Reservoir relative to past years. The reason for the increase at New Croton is not clear.

3.13 How did the reservoir water conductivity in 2004 compare to previous years?

Specific conductance (conductivity) is the measurement of the ability of water to conduct an electrical current. It varies as a function of the amount and type of ions that the water contains. The ions which typically contribute most to reservoir conductivity include: calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), potassium (K^{+1}), bicarbonate (HCO_3^{-1}), sulfate (SO_4^{-2}), and chloride (Cl^{-1}). Dissolved forms of iron, manganese, and sulfide may also make significant contributions to the water's conductivity given the right conditions (i.e., anoxia). Background conductivity of waterbodies is a function of both the bedrock and surficial deposits, which comprise the watershed, as well as the topography of the watershed. For example, watersheds underlain with highly soluble limestone deposits will produce waters of high conductivity compared with watersheds comprised of relatively insoluble granite. If the topography of a watershed is steep-sided, deposits tend to be thin and water is able to pass through quickly, thus reducing the ability of the water to dissolve substances, and producing 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 2004 (Figure 3.16). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits, which produce relatively low conductivities in the 50 to 100 $\mu S\ cm^{-1}$ range. Because West Branch and Kensico generally receive most of their water from the Catskill and Delaware reservoirs, the conductivities of West Branch and Kensico are usually in the 50 to 100 $\mu S\ cm^{-1}$ range as well.

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 deposits (i.e., marble and/or limestone) within the watershed. However, most of the reservoirs have displayed steady increases in conductivity since the early 1990s, most likely associated with development pressure in the watershed (e.g., increased use of road salt). In 2004, conductivity in the Croton System reservoirs increased from 12 to 42 percent compared to the historic 10-year median. However, caution should be used when comparing 2004 data from Middle Branch, Boyd Corners, Diverting, Bog Brook, East Branch, and Croton Falls to historic data. Medians in 2004 are based on a very limited amount of samples and may not be an accurate representation of the year.

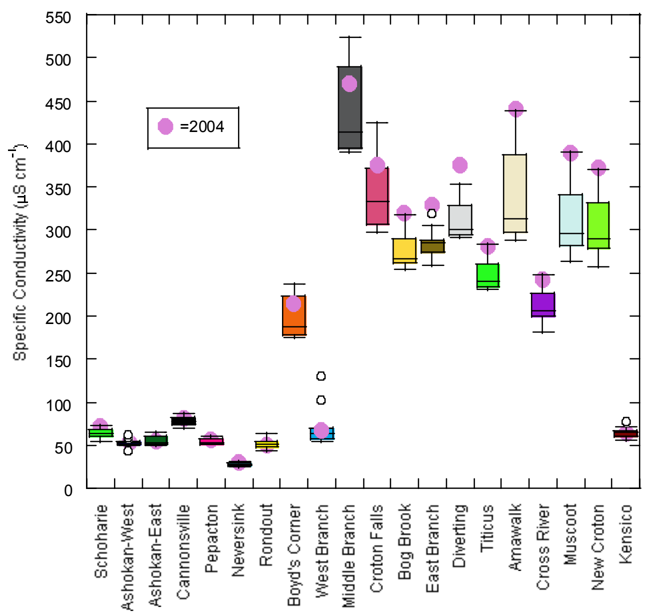

Figure 3.16 Annual median specific conductivity in NYC water supply reservoirs (2004 vs. 1994–2003).

In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Caution should be used when comparing 2004 data from Middle Branch, Boyd's Corner, Diverting, Bog Brook, East Branch, and Croton Falls to historic data. Medians in 2004 are based on a very limited number of samples and may not be an accurate representation of the year.

Conductivity also increased in the controlled lakes of the Croton System (not shown in Figure 3.16). At Gilead Lake and Lake Gleneida conductivity was measured from 1995-2004. The median conductivity increased from 148 in the past (1995-2003) to 184 µS cm $^{-1}$ in 2004 at Gilead and from 300 to 355 µS cm $^{-1}$ at Gleneida. The 2004 median conductivity at Kirk Lake is 333 µS cm $^{-1}$ compared to a median of 206 µS cm $^{-1}$ determined from samples collected from1995-2003 (no samples were collected in 2000 or 2001).

3.14 What are disinfection by-products, and what were their concentrations in the distribution system in 2004?

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

DEP monitors two important groups of DBPs: trihalomethanes and haloacetic acids. Trihalomethanes (TTHM) are a group of chemicals that includes chloroform, bromoform, bromodichloromethane, and chlorodibromomethane, of which chloroform is the main constituent. Haloacetic acids (HAA) are a group of chemicals that includes mono-, di- and trichloroacetic acids and mono- and dibromoacetic acids. USEPA has set limits on these groups of DBPs.

In January 2002, the Stage 1 Disinfectant/Disinfection By-Products (D/DBP) rule took effect, lowering the Maximum Contaminant Level (MCL) for TTHM to 80 $\mu g\ L^{-1}$ and establishing a new MCL for five haloacetic acids (HAA5) of 60 $\mu g\ L^{-1}$. The Stage 1 Rule requires monitoring to be conducted quarterly from designated sites in the distribution system. The MCL is calculated as a running annual average based on quarterly samplings over a 12-month period. The 2004 annual running quarterly averages are presented in Table 3.7 and show system compliance for TTHM in both the Catskill/Delaware and Croton Systems but an MCL violation of HAA5 for the first quarter of 2004 in the Croton System.

Table 3.7: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations ($\mu g\ L^{-1}$) for 2004.

	Catskill/Delaware		Croton	
2004 Quarter	TTHM	HAA5	TTHM	HAA5
1st	37	51	52	**66**
2nd	39	51	53	60
3rd	41	51	52	59
4th	40	49	56	55
MCL	80	60	80	60

Note: Averages in bold face indicate MCL violations.

4. Watershed Management

4.1 How can watershed management improve water quality?

Figure 4.1 Wetland in the NYC watershed.

There is a close relationship between activities within a drainage basin and the quality of its water resources (Figure 4.1). This is the underlying premise of all watershed management programs. DEP has a comprehensive watershed protection program which 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 future degradation of water quality from land use changes. The water quality benefits will be demonstrated in the future by showing the maintenance of high quality water. Remedial programs are directed at reducing existing sources of impairment.

In most cases, the beneficial water quality impacts of specific management programs are difficult to demonstrate. In the West-of-Hudson (WOH) watersheds, this is partly due to the decentralized nature of some of the programs (e.g., Septic Rehabilitation Program), and partly due to the existing high water quality. Improving excellent water quality is hard to achieve, let alone measure. The best way to evaluate the success of a watershed management program as a whole is to continuously assess the water quality in the receiving reservoirs and assess the progress of the individual management programs.

This chapter deals largely with some of the protective and remedial programs in each System. More information on the management programs can be found in the 2004 Filtration Avoidance Determination Annual Report (NYCDEP, 2005a). Information on the future direction of research programs in the watershed can be found in the 2004 Research Objectives Report (NYCDEP, 2005b).

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

The Catskill System consists of the Ashokan and Schoharie basins. While several management programs are active in these watersheds, this report will update only those programs which were discussed in last year's 2003 Watershed Water Quality Annual Report (NYCDEP, 2004).

Wastewater Treatment Plant Upgrade Program

The vast majority of the wastewater flows in the Catskill System (77%) come from NYC-owned facilities, all three of which were upgraded by the end of 1998 (Figure 4.2). Only seven percent of the currently permitted wastewater flow in the Catskill System remains in the process of upgrading.

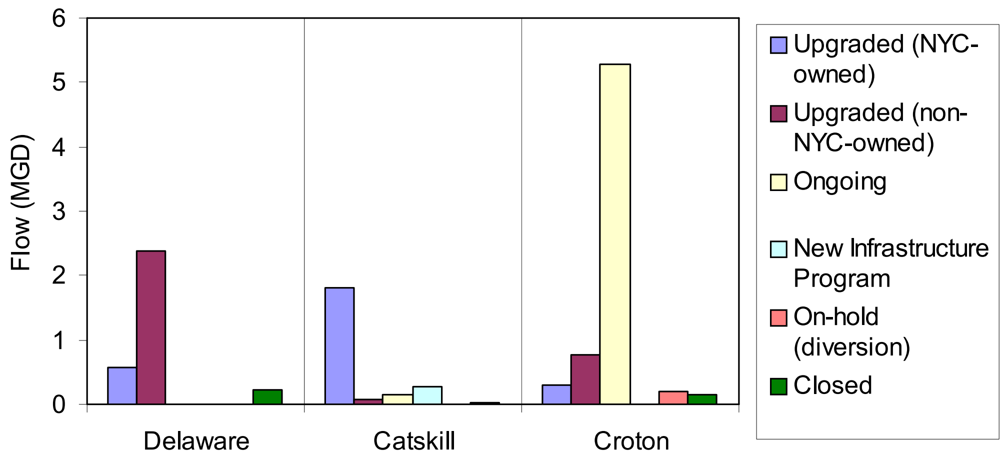

Figure 4.2 The status of the Wastewater Treatment Plant Upgrade Program through 2004.

Septic System Rehabilitation Program

DEP has committed $28.6 million in funding to rehabilitate, replace, and upgrade septic systems serving single or two-family homes in the City's WOH watersheds (Figure 4.3). The Septic System Rehabilitation and Replacement Program is managed by the Catskill Watershed Corporation (CWC), a local not-for-profit organization created to manage Watershed Partnership and Protection Programs. The program consists of several sub-programs: the Priority Area Program, the Hardship Program, the Safe Drinking Water Act–Septic Monitoring Program, and the Reimbursement Program.

Figure 4.3 Septic tank repair in progress.

In 2004, CWC identified 15 home owners as being eligible for funding under the Hardship Program and funded the repair or replacement of a total of 129 septic systems in the WOH watershed. The total number of septic systems repaired, replaced or managed under all CWC Septic Programs since the program inception is now 1,925.

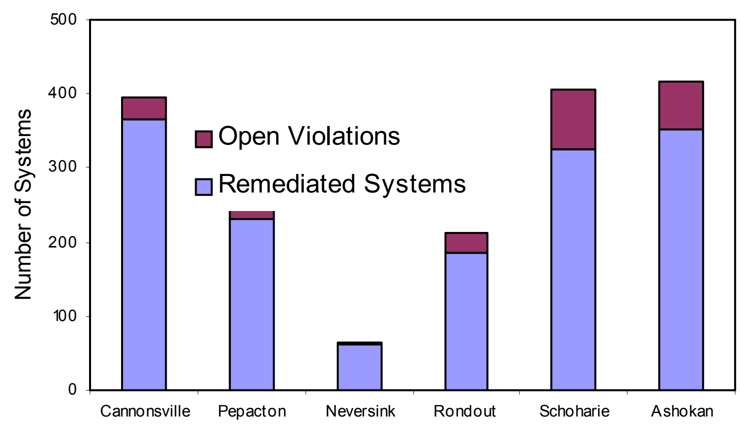

Figure 4.4 The number of remediated septic systems and open violations, 1997–2004.

In addition to the CWC Septic Program, DEP continues to identify failing septic systems and work with home owners to remediate the problem. In the Catskill watershed, an additional 11 systems were remediated in 2004, bringing the total to 676 systems remediated since the inception of this program (Figure 4.4).

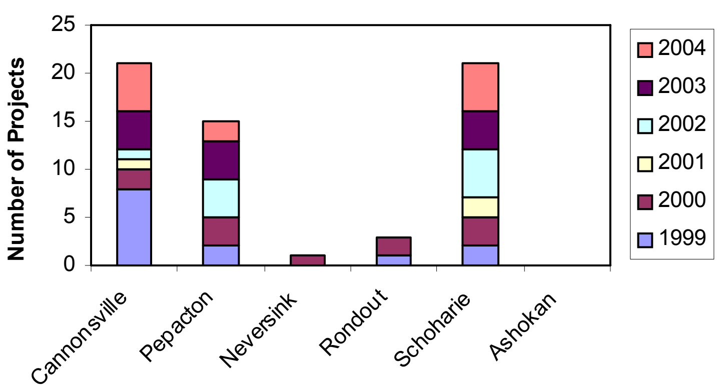

Figure 4.5 The number of completed stormwater retrofit projects through 2004.

Stormwater Retrofit Program

Five additional stormwater retrofit projects were completed in 2004 for a total of 21 projects, all located in the Schoharie Reservoir watershed (Figure 4.5). Eight new grants have been awarded for planning and assessment of stormwater retrofit projects. Two of those grants went to projects in the Ashokan Reservoir watershed. This program is managed by the CWC in conjunction with DEP.

Watershed Agricultural Program

The Watershed Agricultural Program is a voluntary partnership between the City and farms in the watershed. Thirty-seven farms located in the Catskill System are currently participating in the program. Implementation has commenced on 35 farms and is substantially complete on 24 of them (Figure 4.6). This program is administered by the Watershed Agricultural Council (WAC).

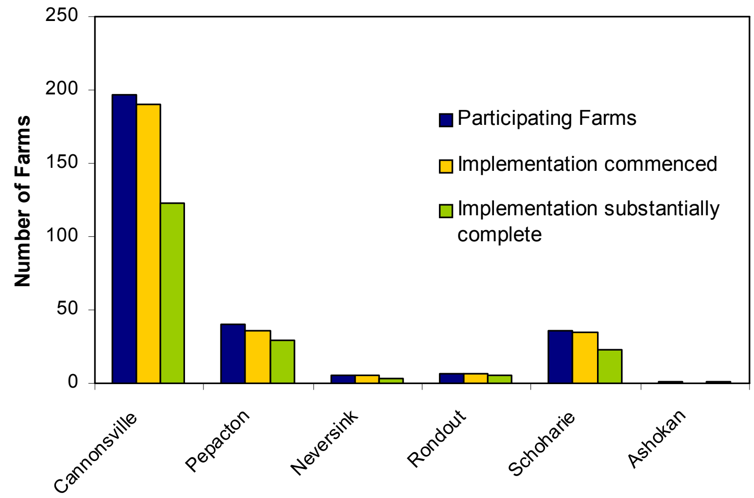

Figure 4.6 The status of the Watershed Agricultural Program through 2004.

Watershed Forestry Program

In 2004, 21 landowners in the Catskill watershed completed WAC forest management plans (Figure 4.7). These 21 plans represent 4,091 acres. In addition, eight Best Management Practices (BMP) projects involving properly installed or repaired forest access roads were conducted in the Catskill watershed.

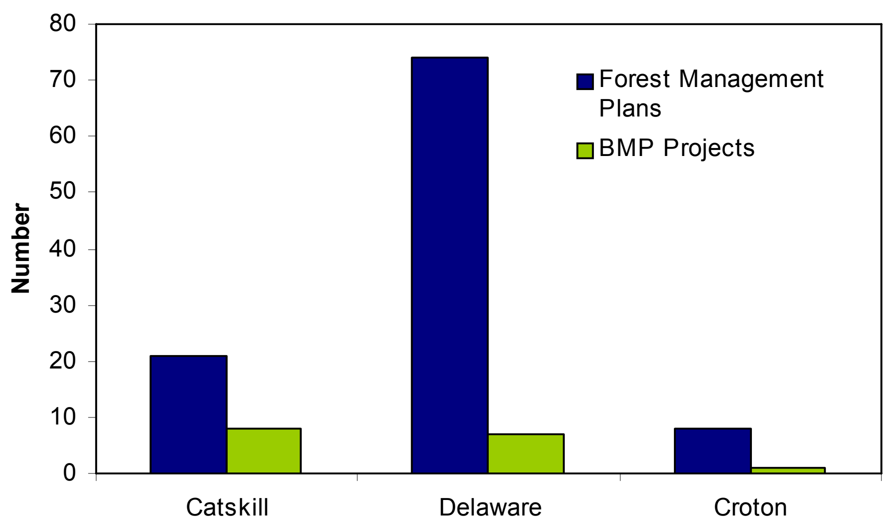

Figure 4.7 Watershed Forestry Program additions in 2004.

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

The Delaware District consists of the Cannonsville, Pepacton, Neversink, and Rondout basins. While numerous management programs are active in these basins, the status of a few key programs are given below.

Wastewater Treatment Plant Upgrade Program

Only 0.2% of the permitted wastewater flow in the Delaware System remains to be upgraded (Figure 4.2). The rest of the wastewater treatment plants have either been upgraded, closed or opted to go subsurface.

Septic System Rehabilitation Program

In addition to the CWC Septic Program discussed previously, 12 systems were remediated in the Delaware watershed in 2004 bringing the total to 844 systems remediated since the inception of this program (Figure 4.4).

Stormwater Retrofit Program

The total number of completed stormwater retrofit projects rose to 40 at the end of 2004 (Figure 4.5). Two new grants for planning and assessment of future projects were awarded in the Cannonsville and Pepacton watersheds. A new DEP/CWC Partnership monitoring program to assess the effectiveness of stormwater retrofits in Roxbury, Margaretville, and Walton is underway.

Watershed Agricultural Program

Two hundred forty-eight farms are currently participating in the Watershed Agricultural Program in the Delaware System, and implementation of plans is substantially complete on 160 of them (Figure 4.6). Throughout the entire WOH watershed, the WAC has identified 335 commercial farms (those earning more than $10,000 in gross annual agricultural sales), and 285 of those, or 85%, are participating in the program.

Watershed Forestry Program

In 2004, 74 landowners in the Delaware watershed completed WAC forest management plans (Figure 4.7). These 741 plans represent nearly 18,000 acres. In addition, 7 BMP projects involving properly installed or repaired forest access roads were conducted in the Delaware watershed.

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

The watershed management programs are designed differently in the Croton System from those in the Catskill and Delaware Systems. Instead of explicitly funding separate management programs (e.g., Stormwater Retrofit Program), DEP provided funds to Putnam and Westchester Counties to develop a watershed plan (“Croton Plan”) and to support water quality investment projects in the Croton watershed. In addition, DEP has worked closely with the New York State Department of Environmental Conservation (DEC) to develop Phosphorus Total Maximum Daily Loads (TMDLs) for the Croton reservoirs. Implementation of these TMDLs is a significant multi-stakeholder watershed management program for the Croton System.

Croton Plan and Water Quality Investment Program

In the Croton System, DEP provided funds to Putnam and Westchester Counties to develop a watershed plan to protect water quality and guide the decision making process for the Water Quality Investment Program (WQIP) funds. In 2004, both counties worked to address DEP comments on the draft Croton plans and finish incomplete tasks in the workplan. Distribution of the WQIP funds has continued and a few notable projects for 2004 are given below.

Peach Lake Study — The Peach Lake Study was completed and concluded that the basin is not suitable for a high density of septic systems. The study recommended a centralized waste-water system at an estimated cost of $21 million. Both Putnam and Westchester have reserved WQIP funds for this project and are currently seeking additional sources of funding.

Putnam County Septic Repair Program — A draft Septic Repair Program Plan has been prepared and the Putnam County Legislature has authorized $3.3 million for the high priority areas within the 60-day travel time. The program has an anticipated start date of July 2005.

Putnam County Stormwater — Putnam County authorized nearly $800,000 for several stormwater improvements to improve drainage and reduce stormwater velocity and volume (Figures 4.8 and 4.9). Additionally, $20,000 has been allocated for a stream restoration/education program. The stream is located on the Mahopac High School property and students will be involved in the restoration.

Figure 4.8 New stormwater collection system installed along Barrett Hill Road in Carmel prior to discharge to Lake Carmel.

Figure 4.9 Planned site of a streambank stabilization project in Brewster.

Putnam County Highway Maintenance — Putnam County authorized $211,000 for computerized metering devices to minimize and track application of road salt on county trucks. This program is likely to reduce sediment, chloride, and phosphorus to the reservoirs.

Westchester County Septic Program — Westchester County continues to track septic repairs and license septic contractors.

TMDL Implementation

Phase II TMDLs for the NYC reservoirs were approved by USEPA in October 2000. All of the reservoirs that require nonpoint source reductions in phosphorus load are located in the Croton System. DEC requested technical assistance in developing an implementation plan from the NYC Watershed Protection and Partnership Council's Technical Advisory Committee (TAC). In April 2004, after more than a year of technical meetings, TAC released a report titled, "Recommendations to the NYSDEC for the Development of its Phase II TMDL Implementation Plan". The recommendations rely heavily on the County Croton Plan, the DEP Watershed Strategy, and the Phase II Stormwater Regulations for Municipal Separate Stormwater Systems ("MS4s"). DEC is expected to release its TMDL Implementation Plan in 2005.

Wastewater Treatment Plant Upgrade Program

While the Croton System has a large number of wastewater treatment plants, most of these are small (64% with flows < 100,000 gallons per day) and serve schools, individual developments or commercial properties. Seven non-City-owned facilities, comprising 12% of the total permitted wastewater flow in the System, have completed their upgrades. Most of the plants are in the process of being upgraded (Figure 4.2). Upgrade plans for eight facilities are on hold pending decisions on diversion to existing plants or out of the Croton watershed entirely.

Watershed Agricultural Program

The farms in the Croton System tend to be smaller and more focused on equestrian-related activities, and the EOH Watershed Agricultural Program has been specially tailored to address these issues. This program has signed up 23 farms in the Croton System, and all have approved Whole Farm Plans. Fourteen of these farms have commenced implementation of BMPs, and seven of the farms are substantially complete (Figure 4.6).

Watershed Forestry Program

Even though the EOH watershed is generally considered urbanized, it does contain forest lands and DEP has an active Forestry Program in the Croton System. In 2004, 8 landowners completed WAC forest management plans (Figure 4.7). These 8 plans represent 726 acres. In addition, one BMP project involving properly installed or repaired forest access roads was conducted in the Croton watershed.

4.5 How is DEP assessing the distribution, characteristics, and water quality functions of watershed wetlands?

Wetlands are important for maintaining the high quality of surface waters in New York City's water supply system. Wetlands moderate peak runoff and improve water quality through sedimentation, chemical transformations, and biotic uptake. Wetlands also recharge groundwater and maintain baseflow in watershed streams. Recognizing these important functions, DEP has developed a Wetlands Protection Strategy for the NYC water supply watersheds. DWQC is conducting a number of wetland inventory, tracking, and research projects to support DEP's protection programs.

National Wetland Inventory (NWI) update — The US Fish and Wildlife Service (USFWS) is currently under contract to update the NWI data for the EOH and WOH watersheds using 2003 and 2004 aerial photography in order to provide current information on the distribution and types of wetlands.

Trend Analysis for the EOH watersheds — USFWS is currently updating a previous wetland assessment on losses, gains, and cover type changes for 1968–1984 and 1984–1994 with data for the period from 1994–2004. This project will enable DEP to identify the causes and spatial distribution of wetland losses in order to assess and direct its wetland protection programs.

Wetland Characterization and Functional Assessment — USFWS completed a Wetland Characterization and Preliminary Functional Assessment for the watershed in 2004. For this project USFWS enhanced the NWI data with descriptors of landscape position, landform, and water flow path for each wetland. Since these descriptors identify a wetland's position in the watershed, they permit a preliminary, watershed-scale functional assessment.

Figure 4.10 A reference wetland currently being monitored in the Schoharie Basin.

Reference Wetland Monitoring Program — DEP is conducting a reference wetland monitoring program to determine water quality, soils, and vegetation characteristics of wetlands among the various classes identified by USFWS (Figure 4.10). The monitoring data will enable DEP to compare baseline characteristics of wetlands among various settings that will lay the groundwork for developing wetland biological and functional assessment methods that will assist DEP in its regulatory review of proposed wetland impacts and mitigation.

4.6 Why is DEP conducting forest research and what projects are currently being done?

Figure 4.11 Soil moisture and temperature and light conditions being monitored in silvicultural treatment plots.

Forest research provides a better understanding of the existing forest's role in water quality regulation, its health, and its potential for improvement. The data collected is used to assess whether forest management activities are meeting stated goals (e.g., improving tree regeneration and reducing impacts of deer herbivory and invasive plants on the function of forest ecosystems). In addition, long-term monitoring studies are needed to enable development of forest growth projection models that will assist in management planning. Active projects in 2004 include:

- Forest Ecosystem Health Assessment Phase II: Continuous Forest Inventory—provides long-term information regarding forest health, mortality, and recruitment and enables development of growth and yield equations.
- Effects of Silvicultural Treatment on Forest Ecosystem Health—helps determine whether current forest thinnings are achieving their goals of increased numbers of tree seedlings and

reduced invasive plant species (Figure 4.11).

- Deer Herbivory Impacts on Forest Regeneration:

  Deer Exclosure Studies—provides a way of observing direct deer impacts by excluding deer from small, fenced areas.

  Before and After Hunting on Watershed Lands—follows the changes in forest understory vegetation over time as deer populations are brought under management.

- Cannonsville Salvage Regeneration Study—follows the development of the forest following salvage logging in the aftermath of a major wind event in the Cannonsville basin.

4.7 What are the components of DEP's Fisheries Program?

The DEP Fisheries Program consists of three main components: the Stream Reclassification Program, the Hydroacoustics Program, and Fish Kill Investigations.

Stream Reclassification Program

Streams in New York State are regulated by DEC based on existing or anticipated best use classifications. The purpose of the Stream Reclassification Program is to enhance the protection of water supply source tributaries under the New York State Codes, Rules, and Regulations (NYCRR) Title 6, by upgrading stream classifications to include trout and trout spawning. Enhanced regulatory criteria and standards for dissolved oxygen, ammonia, ammonium, discharge temperature, and volume for watershed streams supporting trout and trout spawning provide greater water quality protection and strengthen compliance criteria permitted under any regulated action.

Figure 4.12 DWQC staff and interns conduct a survey for the stream reclassification program.

To date, streams in the watersheds of the Kensico, West Branch, New Croton, Rondout, Neversink, Ashokan, and Schoharie Reservoirs have been inventoried (Figure 4.12), and petitions submitted to DEC for final determination of classification upgrades. In 2004, surveys were conducted in the Pepacton watershed. These surveys will be completed in 2005.

Hydroacoustics Program

DWQC recently acquired a hydroacoustic system to assess potential fish impacts associated with chemical treatment and to guide reservoir operations to minimize fish entrainment in the aqueducts. A hydroacoustic system essentially sends pulses of sound waves into the water. The sound waves bounce off solid objects, such as fish, and are reflected back to a receiver on the boat. A computer-based echo processor translates these signals into estimates of fish density, biomass, and size. Gill nets are used during the hydroacoustic surveys to validate species composition.

Hydroacoustic surveys will be conducted to determine annual population levels and distribution patterns, and may be used to evaluate any impacts to the fishery if chemical treatment is required. Permanent survey transects are established with a Geographic Positioning System (GPS) to allow for identical pre- and post-treatment surveys. In addition, acoustic survey information can be used as necessary to identify where fish are in the reservoirs. This allows Operations to adjust intake elevations to minimize fish entrainment and subsequent elevations in fecal coliform from concentrations of foraging birds. During 2004, the equipment was field tested in two reservoirs and the standard methodology refined.

Fish Kill Investigations

Fish kills in both streams and reservoirs are indicators of potential water quality impairment. Although the vast majority of fish kills are the result of natural causes, such as low dissolved oxygen in late summer, DEP investigates all fish kills to protect water quality and human health (Figure 4.13). Fish kill investigations are generally a multi-group collaborative effort within DEP. Also involved may be DEP Police, Cornell University, and DEC. DWQC collects and interprets chemical, physical, and biological data to determine the cause of the kill and the potential damage to the environment.

Figure 4.13 Fish kill at the Cannonsville Reservoir in June/July 2004.

4.8 How do environmental project reviews help protect water quality?

DWQC 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 the last six months of 2004, DWQC staff reviewed over 50 SEQRA actions, ranging from simple Environmental Assessment Forms to full Environmental Impact Statements.

In addition to projects in the SEQRA process, DWQC staff review other projects upon request. DWQC 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. Some specific types of projects are:

- DEP construction and remediation projects for the Bureau of Environmental Engineering and the Office of Environmental Planning and Assessment;
- Development projects undergoing regulatory review with Engineering;
- Terrestrial restoration and mitigation plans, and planting lists; and
- Wetland mitigation plans for the Watershed Lands and Community Planning Group.

More than 25 projects were reviewed and commented on by DWQC in 2004. Many of those projects are large, multi-year projects with ongoing review.

4.9 What "Special Investigations" were conducted in 2004?

Figure 4.14 DEP staff collecting a sample for E. coli ribotyping after a sewage spill in Mount Kisco, March 1, 2004.

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

In 2004, 18 SIs were conducted and reported on (cf. eight in 2003) (Figure 4.14). The increased number of recorded environmental incidents in the water supply watershed probably reflects greater efficiencies in response and documentation than an actual increase in incidents.

More investigations were conducted EOH (14) than WOH (4) and more involved the investigation of actual or possible sewage discharges from sewer collection systems (5 SIs) than any other potential incident. This suggests that potentially harmful environmental pollution incidents may be more likely to occur in the more densely populated EOH watersheds, where there are many more communities served by sewage collection systems and other infrastructure associated with urbanization, than in the WOH watershed.

Figure 4.15 Overturned fuel truck on Rt. 52 in Carmel on June 10, 2004 (Croton Falls watershed).

None of the investigations conducted in 2004 identified a pollution problem that was considered an immediate threat to consumers of the water supply, but some incidents recorded environmental damage that will likely last for several weeks or months (e.g., oil tanker truck spill on June 10, Figure 4.15). Below is a list of reservoir watersheds in which investigations occurred in 2004, with dates and a brief description of each investigation. Individual reports are not provided here, but are available upon request.

Kensico Reservoir

- February 25, possible sewage spill to tributary E10, later determined unlikely.
- August–September, several small oil spills reported from regular boat usage. Absorbent booms were installed to limit affected area.

New Croton Reservoir

- January 8, sewage overflow from manhole in Yorktown Heights.
- March 1, sewage overflow from manhole in Mt. Kisco.

Muscoot Reservoir

- April 25, turbid discharge from a water filtration plant to the Muscoot River below the Amawalk Reservoir release.
- July 22, probable spill of hypochlorite to tributary of Hallocks Mill Brook.
- December 15, erosion and turbid discharge to Hallocks Mill Brook from work on a water supply line.

Cross River Reservoir

- April 11, in response to an observation of several dead frogs and turtles at the reservoir shore, pesticide and SOC samples were collected in the area. The samples had no detections.

Croton Falls Reservoir

- April 19, possible sewage spill from break in collection system pipe, no evidence of discharge to watercourse observed.
- June 10, tanker truck accident spills 11,000 gallons of home heating oil.

Diverting Reservoir

- March 23, septage in domestic sump pump discharge in Brewster.

East Branch Reservoir

- July 27, unusual bacterial/algal growth on the water during dam rehabilitation.

West Branch Reservoir

- November 5, discovery of soil with elevated PAH concentrations during installation of stormwater conduit.
- December 13, sewage overflow from failed pumping station.

Ashokan Reservoir

- March 8, evaluation of quality of discharge from sump serving a bakery/restaurant.

Rondout Reservoir

- June 23, disinfection failure at NYC-owned wastewater treatment plant.

Cannonsville Reservoir

- May 5, septage in domestic sump pump discharge in Bloomville.
- June 25, fish kill in reservoir found to be caused by bacterial infection.

4.10 How can watershed monitoring protect the water supply?

In 1999, DEP was made aware of a large scale resort being planned for Belleayre Mountain in the Catskills, on lands that are currently largely forested. DEP scientists determined that the proposal presented a good opportunity to study the effects of such a land use change and document water quality pre-, during, and post-construction until the site stabilized. A program to gather such data was designed and implemented beginning in August 2000. A map of the area with monitoring sites is presented in Figure 4.16, and photographs of one of these sites (BELLETOD) are presented in Figure 4.17.

This monitoring project was used to verify the developer's description of pre-development conditions in the Draft Environmental Impact Statement (DEIS). The DEIS reported results from the WinSLAMM model for export of pre- and post-development pollutants such as total phosphorus and total suspended solids, and the model HydroCAD was used to estimate stormwater volumes. When modeled estimates of pre-development conditions were compared with DEP's data from tributaries draining the site, DEP found that the DEIS substantially overestimated pre-development pollutant export and peak stream discharges during storm events. Overestimation of pre-development conditions minimized the changes in pollutant loading and hydrology in modeled post-development conditions. In fact, the DEIS reported that post-development loads of some pollutants would be reduced over pre-development conditions.

DEP challenged the permits and acceptance of the DEIS and an Issues Conference on the validity of these challenges by DEP and others was held during the summer and early fall of 2004. Data from DEP's program to monitor tributaries draining Belleayre Mountain strengthened DEP's contention that the DEIS was inaccurate. A decision by the Administrative Law Judge on whether or not concerns regarding the DEIS are sufficiently substantive to warrant a full adjudicatory hearing has not yet been rendered.

An important finding is that several of the assumptions built into models typically used to assess land use change impacts for environmental impact statements may not accurately reflect the excellent water quality of the forested headwater streams.

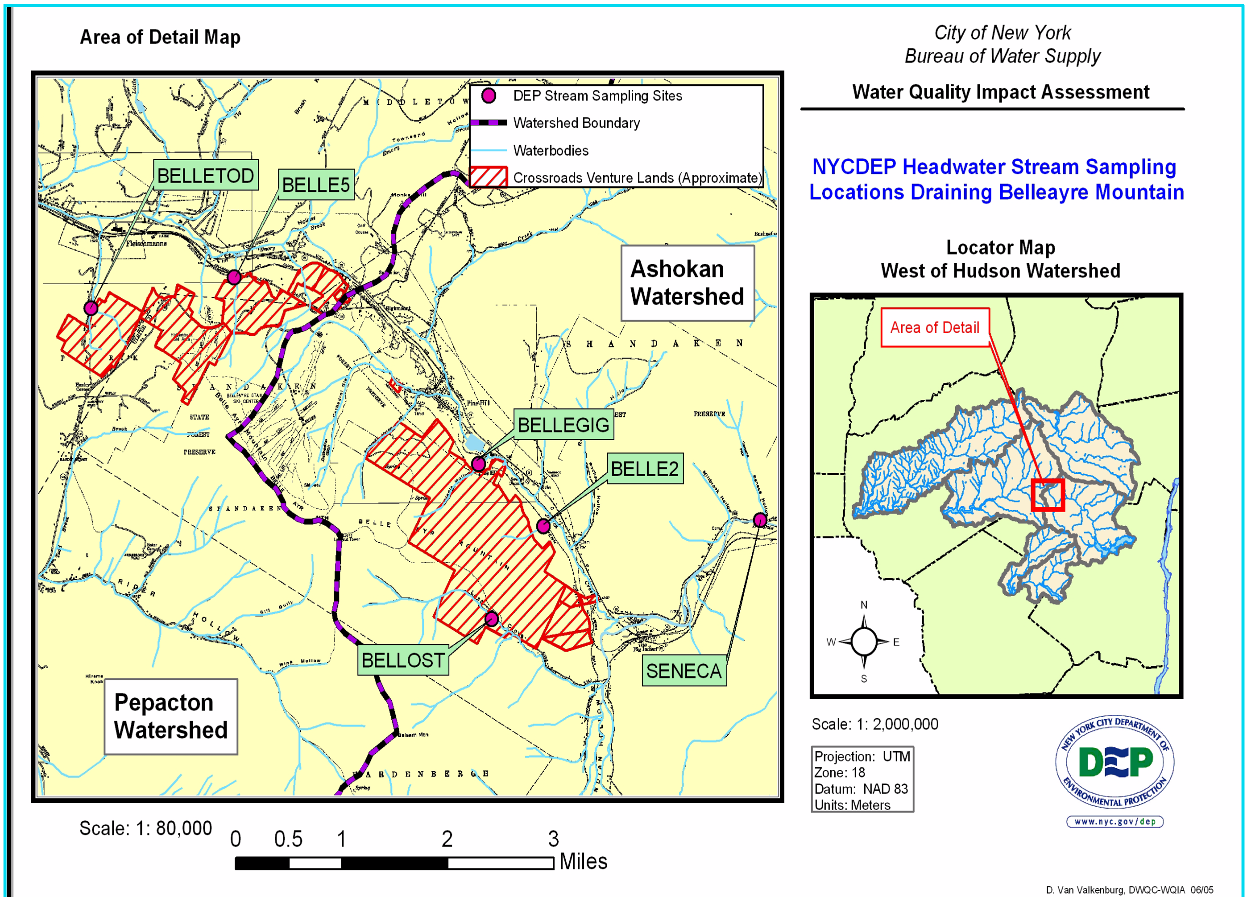

Figure 4.16 Map of Bellearye Mountain tributaries monitored to develop pre- and post-development water quality characteristics.

Figure 4.17 a) Site BELLETOD on May 14, 2004, approximately 18 hours after the peak stage associated with the May 13, 2004 flash flood event. b) Site BELLETOD on July 6, 2004 during normal low flow conditions.

4.11 What is the status of WWTP TP loads in the watershed?

Figure 4.18 displays the sum of the annual total phosphorus (TP) loads from all surface-discharging wastewater treatment plants (WWTPs) by district for the period 1999–2004. 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.

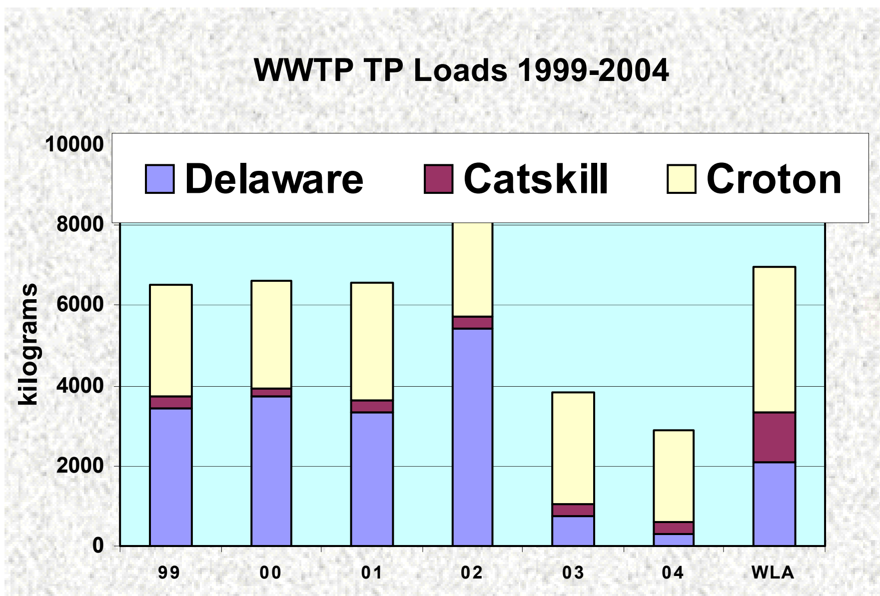

Figure 4.18 Wastewater Treatment Plant TP loads, 1999–2004.
The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

Upgrades to WWTPs include phosphorus removal and microfiltration to make the plants comply with the Watershed Rules and Regulations. All NYC-owned WWTPs in the watershed have been upgraded with the exception of the Brewster WWTP, which will be transferred to the Village of Brewster when its upgrade is complete. In 2004, upgrades were completed at Roxbury Run (Pepacton watershed), Camp L'man A'chai (Pepacton watershed), West Delaware BOCES (Cannonsville watershed), Reed Farm Condos (Cross River watershed), and Clear Pool Camp (West Branch Croton watershed).

Another major wastewater management program funded by New York City is the New Infrastructure Program (NIP). The NIP builds new WWTPs in communities previously relying on individual septic systems. Since many of the older septic systems in village centers such as

Andes, Roxbury, Windham, Hunter, and Fleischmanns could not be rehabilitated to comply with current codes, this program seeks to reduce potential nonpoint source pollution by collecting and treating wastewater with compliant systems. In 2004, the Village of Andes NIP began operation, and the villages of Windham and Hunter are expected to begin early in 2005.

Although WWTP TP loads in 2004 are lower than they were in 2003, as new NIPs are completed and sewer districts expand to their full capacities, eventually TP loads are expected to approach the WLAs for the respective Systems.

4.12 What effects do stream channel improvement projects have on resident fish assemblages?

A program was implemented by DEP and the United States Geological Survey (USGS) to assess resident fish population response to stream channel restorations. Fish populations in five Catskill Mountain streams were surveyed annually from 1999–2005, 1 to 2 years before and 1 to 4 years after natural-channel-design techniques were used to restore unstable project reaches (Figure 4.19a and 4.19b). Population and community responses to the restorations were assessed using Before-After-Control-Impact (BACI) analyses, which standardize changes in community characteristics at the various treatment (restored) reaches to normal year-to-year changes observed at unaltered stable "control" reaches.

Figure 4.19a Broadstreet Hollow before restoration.

Note the presence of a turbidity-inducing clay lens exposure in the stream channel.

Figure 4.19b Broadstreet Hollow after restoration.

Population and community indexes responded to restoration differently among streams due to unique initial habitat conditions. BACI analyses showed that natural-channel-design restorations did not affect total community density, but tended to increase community richness (Figure

4.20a) and Biomass Equitability—an index of evenness in biomass among species (Figure 4.20b). Community biomass was consistently dominated by sculpin or dace, or solely populations of sculpin, before restoration, and by trout populations (combinations of brown, brook, and rainbow) following restoration. The number of trout species and life stages as well as the total number and biomass of trout populations generally increased in all restored project reaches. These findings demonstrate that natural-channel-design restorations being implemented by DEP appreciably improve the ability at Catskill Mountain streams to support well-balanced trout populations and fish communities.

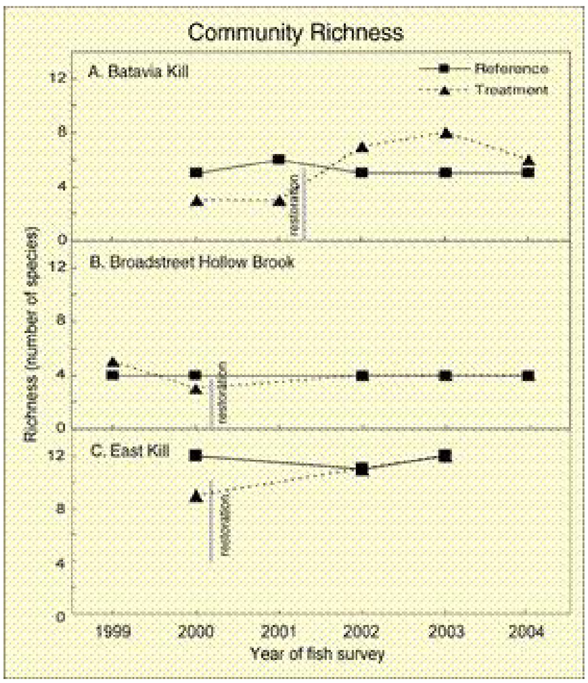

Figure 4.20a Community richness for fish in Catskill Mountain streams before and after stream restoration.

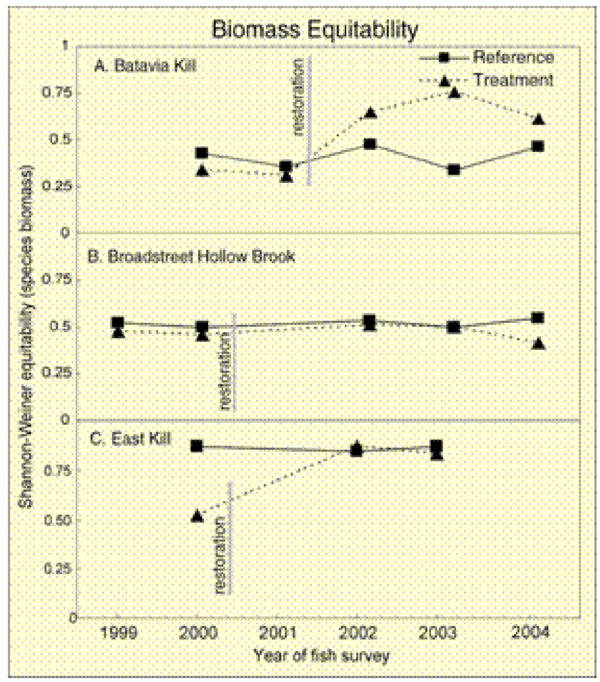

Figure 4.20b Biomass equitability for fish species in Catskill Mountain streams before and after stream restoration.

5. Model Development and Applications

5.1 Why are models important?

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

Watershed simulations provide guidance for watershed management and planning. By providing information on flow pathways and loading sources, watershed management and planning can be focused on the critical land uses and flow pathways that influence loads to reservoirs. Coupling simulated loading estimates to reservoir models allows the timing and sources of loads to be examined in relation to simulated changes in reservoir status.

5.2 How are watershed models being improved to better guide long-term watershed management?

The Generalized Watershed Loading Functions (GWLF) watershed model is used by DEP to simulate water, sediment, and nutrient loadings from the landscape as a function of weather, watershed physiography (soils, topography), land use, and watershed management. Storm runoff is the primary transport mechanism for many pollutants that accumulate on or near the ground surface, and is thus a major focus of watershed management. The effectiveness of GWLF as a tool to guide long-term watershed management thus depends on its ability to accurately predict runoff source area locations as well as storm runoff volumes from the source areas.

GWLF, like many nonpoint source pollutant loading models, utilizes the Soil Conservation Service (SCS) curve number (CN) equation to predict storm runoff when rainfall intensity exceeds the rate at which water can infiltrate the soil (infiltration-excess runoff). In the NYC watersheds, however, rainfall intensity rates have been shown to rarely exceed soil infiltration rates, and runoff typically occurs when soils become saturated from below due to a rising water table (saturation-excess runoff on variable source areas—VSAs). Since the factors that control soil infiltration rates differ from the factors that control VSAs, models that assume infiltration-excess as the primary runoff producing mechanism will depict the locations of runoff source areas differently than models that assume saturation-excess.

To improve the ability of GWLF to accurately predict the locations of storm runoff production, DEP, in collaboration with the Cornell University Dept. of Biological and Environmental Engineering, re-conceptualized the SCS-CN equation for saturation-excess VSAs, and incorporated it into the GWLF model. The revised model, called GWLF-VSA, simulates the watershed runoff response to rainfall using the standard SCS-CN equation, but spatially distributes the runoff response according to a soil wetness index. Figure 5.1 depicts runoff predictions in April and July, for an example sub-area of Town Brook in the Cannonsville watershed, using GWLF and GWLF-VSA. While both models simulate similar runoff volumes from the total area, the spatial distribution of runoff predicted by the two models is strikingly different.

The spatial distribution of runoff has important consequences for watershed management, because correctly predicting the coincidence of runoff generation and pollutant sources is critical to simulating non-point source pollution transported by runoff. For example, the GWLF simulations suggest that nutrient management should be focused entirely on corn fields (Figure 5.1a, c). However, GWLF-VSA, which we believe better represents the spatial hydrological patterns, indicates that control of nutrients from areas near streams might be more logical locations to focus water quality protection efforts. Surprisingly, in this case grasslands that occupy wet areas constitute a potentially important land use to manage (Figure 5.1b, d). More importantly, GWLF-VSA provides a more complex picture of intra-watershed processes and constitutes a more reliable tool for predicting pollutant loads in NYC watersheds.

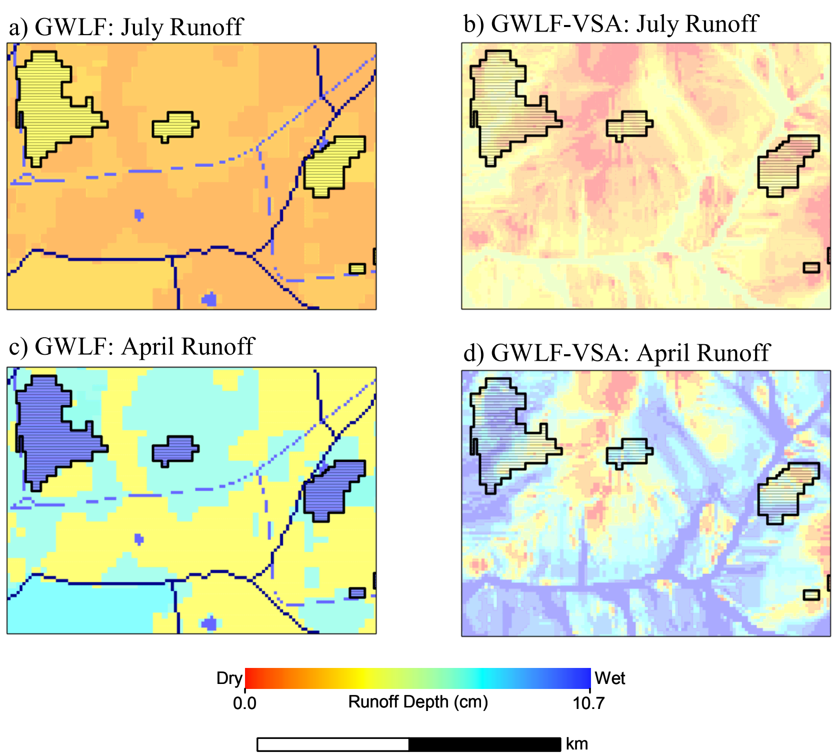

Figure 5.1 Maps, for an example sub-area of Town Brook watershed, of: (a) Mean July runoff (1998–2001) predicted by GWLF; (b) Mean July runoff predicted by GWLF-VSA; (c) Mean April runoff (1998–2001) predicted by GWLF; (d) Mean April runoff predicted by GWLF-VSA. Corn fields are outlined in heavy black lines.

5.3 What can models tell us about flow pathways and the effect of 2004's weather on nutrient loads to reservoirs?

To better understand 2004 nutrient loads to the reservoirs versus long-term flow and loading patterns, DEP updates its watershed model applications annually to include the current year highlighted in the annual report. Using the GWLF model results, annual results for 2004 can be placed in an appropriate historical context that accounts for the effects of natural meteorological variability on water quality. This variability is the background within which watershed management operates, and provides an important context for judging the effects of watershed management.

Watershed modeling of streamflow and nutrient loads provides insight into the flow paths that water and nutrients take in the watershed. Total streamflow is comprised of direct runoff and groundwater flow. Direct runoff is water that moves rapidly on or near the land surface, as opposed to much slower-moving baseflow. Section 5.5 discusses how the model is calibrated to correctly account for the direct runoff and baseflow portions of streamflow.

Direct runoff has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Figure 5.2 depicts the annual streamflow, direct runoff, and dissolved nutrient loads simulated by the model for 2004 in relation to long-term simulated annual statistics. These box plots show that 2004 was a wet year with high streamflow and direct runoff and correspondingly high dissolved nutrient loads to the reservoirs. In general, comparison of 2004 and long-term annual total dissolved nitrogen (TDN) loads follows a similar comparison for annual streamflow, while the relationship between the 2004 and long-term annual total dissolved phosphorus (TDP) loads closely follows comparisons of direct runoff. These results have important consequences for watershed management, suggesting that management of nonpoint sources of dissolved P in direct runoff can be particularly effective in controlling TDP loads, to which algal growth in the reservoirs is particularly sensitive.

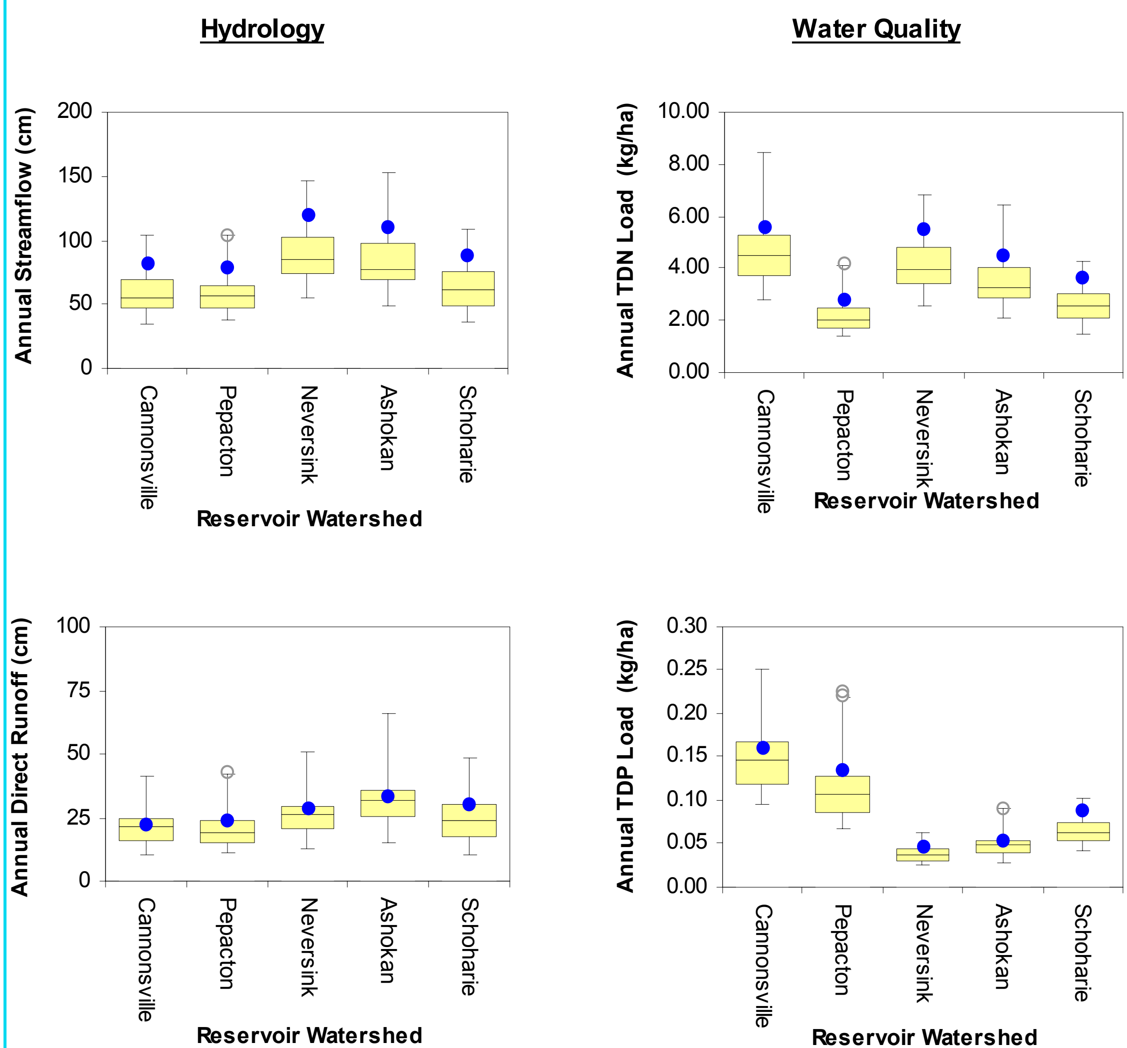

Figure 5.2 Annual streamflow, overland flow, and dissolved nutrient loads simulated by the GWLF model for 2004 in relation to long-term simulated annual statistics. Box plots show long-term statistics. Blue dots show 2004 results.

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

The watershed models explicitly simulate overland flow and nutrient loads by land use and watershed source. The relative contribution of different watershed land uses and sources to total nutrient loads is an important consideration in watershed management. Figure 5.3 depicts the relative simulated contributions of point and nonpoint sources to TDP and particulate phosphorus loads to the reservoirs based on long-term model runs. These findings support DEP's emphasis on point source reductions and on agricultural Best Management Practices (BMPs) to reduce agricultural loads, particularly in the Cannonsville watershed.

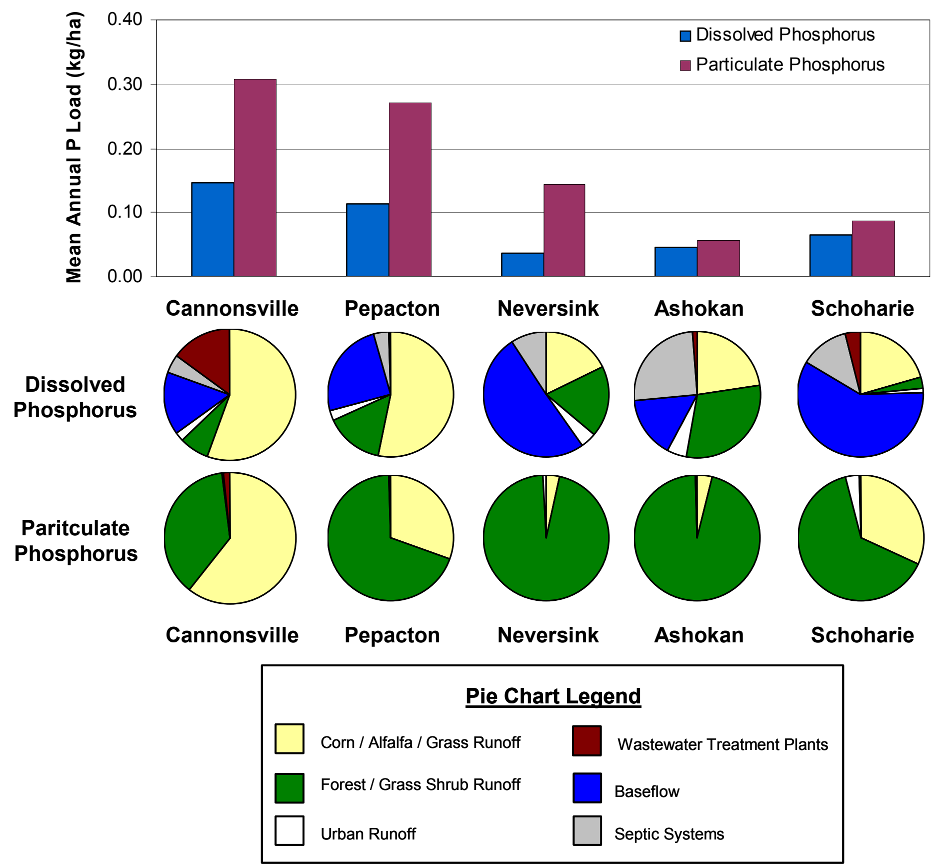

Figure 5.3 Long-term simulated relative contribution of various nonpoint source land uses and point sources to total dissolved and particulate phosphorus loads to reservoirs. Land use data based on 1992 satellite imagery; point source loads based on 2001–2003 data.

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

Watershed pollutant loading models are typically calibrated and tested for hydrology by comparing modeled and measured streamflow at the watershed outlet. These models predict pollutant loads by associating pollutant concentrations with streamflow components, especially runoff and baseflow; therefore, calibration and validation to ensure accurate simulation of flow components is just as important as accuracy of total streamflow predictions. To ensure accuracy of flow component predictions, DEP has developed and applied a methodology for calibrating the SCS-CN parameters that control runoff and baseflow in the GWLF Watershed Model, using baseflow-separated streamflow data.

Thirty-one watersheds in the Catskill and Delaware Systems, ranging between 2 and 900 sq. kilometers, were calibrated and tested. These watersheds are gauged by the United States Geological Survey (USGS) (Figure 5.4) and have at least 4 years of continuous daily streamflow data. For each basin, the streamflow hydrograph was separated into runoff and baseflow daily time series, using the widely-used baseflow separation method of Arnold et. al. (1995). Baseflow-separated data were subsequently used to calibrate SCS-CN parameters for each gauged watershed.

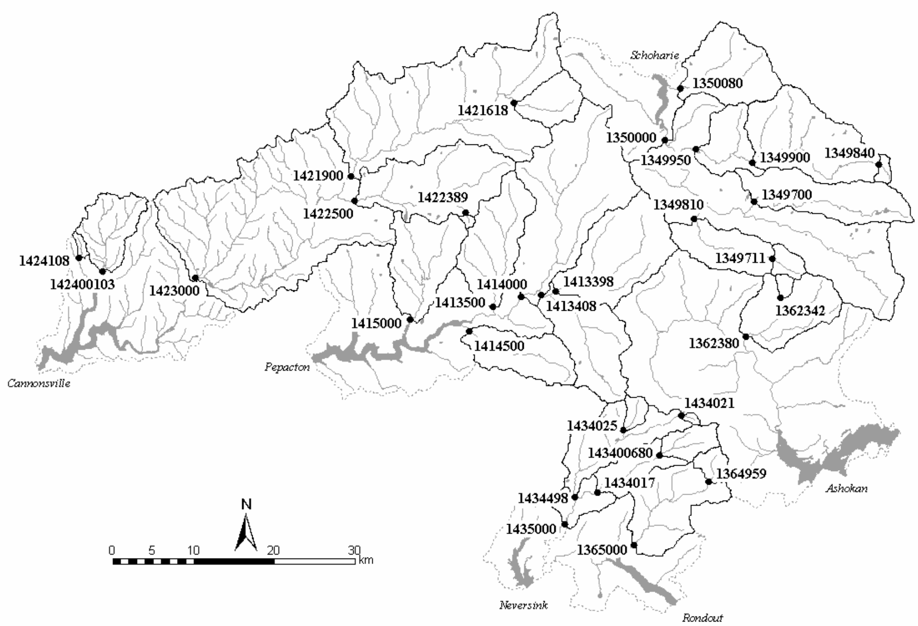

Figure 5.4 USGS-gauged watersheds in the WOH watersheds.

Comparison of modeled runoff using uncalibrated SCS-CN parameters with baseflow-separated runoff revealed significant (>50%) underestimation of modeled runoff for both growing season and dormant season storms. Use of calibrated SCS-CN parameters improved runoff estimation, with 80% of the watersheds within 20% of baseflow-separated runoff estimates. Nash-Sutcliffe R^2 and bias error statistics for the 31 gauged watersheds (Figure 5.5) demonstrate that the SCS-CN method in GWLF produces good estimates of storm event runoff when CN parameters are calibrated.

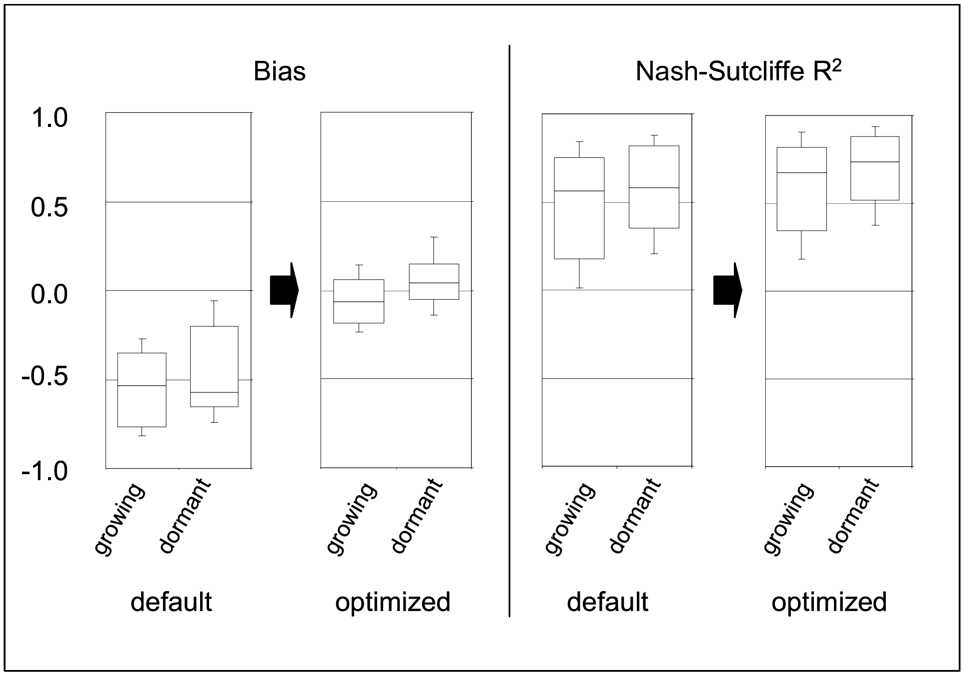

Figure 5.5 Bias and Nash-Sutcliffe R^2 statistics for modeled vs. baseflow-separated runoff during growing and dormant seasons, using default vs. optimized SCS-CN parameters.

Bias is a measure of average difference between modeled and observed values; zero bias is best. Nash-Sutcliffe R^2 measures goodness of fit of modeled and observed values, with $R^2 = 1$ indicating a perfect fit. Box and tails depict minimum, 10 percentile, median, 90 percentile, and maximum.

5.6 How does DEP use models to follow the movement of suspended solids through the reservoir system?

The Catskill portion of the water supply is comprised of the Schoharie and Ashokan reservoirs, which are connected via the Shandaken Tunnel and Esopus Creek (Figure 5.6). The Ashokan reservoir is divided into East and West Basins, and water from Ashokan usually flows from the East basin into Kensico Reservoir, where it mixes with Delaware System water, before moving into the NYC distribution system. A recurring problem with Catskill System water is that it can become turbid as a result of erosion of clay and fine sediments from a number of sources in both reservoir watersheds. Turbidity has always been a problem in the Catskill System; because of this, the system was designed to attenuate turbidity by dividing the Ashokan Reservoir into two basins, which permits greater settling of the turbidity-causing solids.

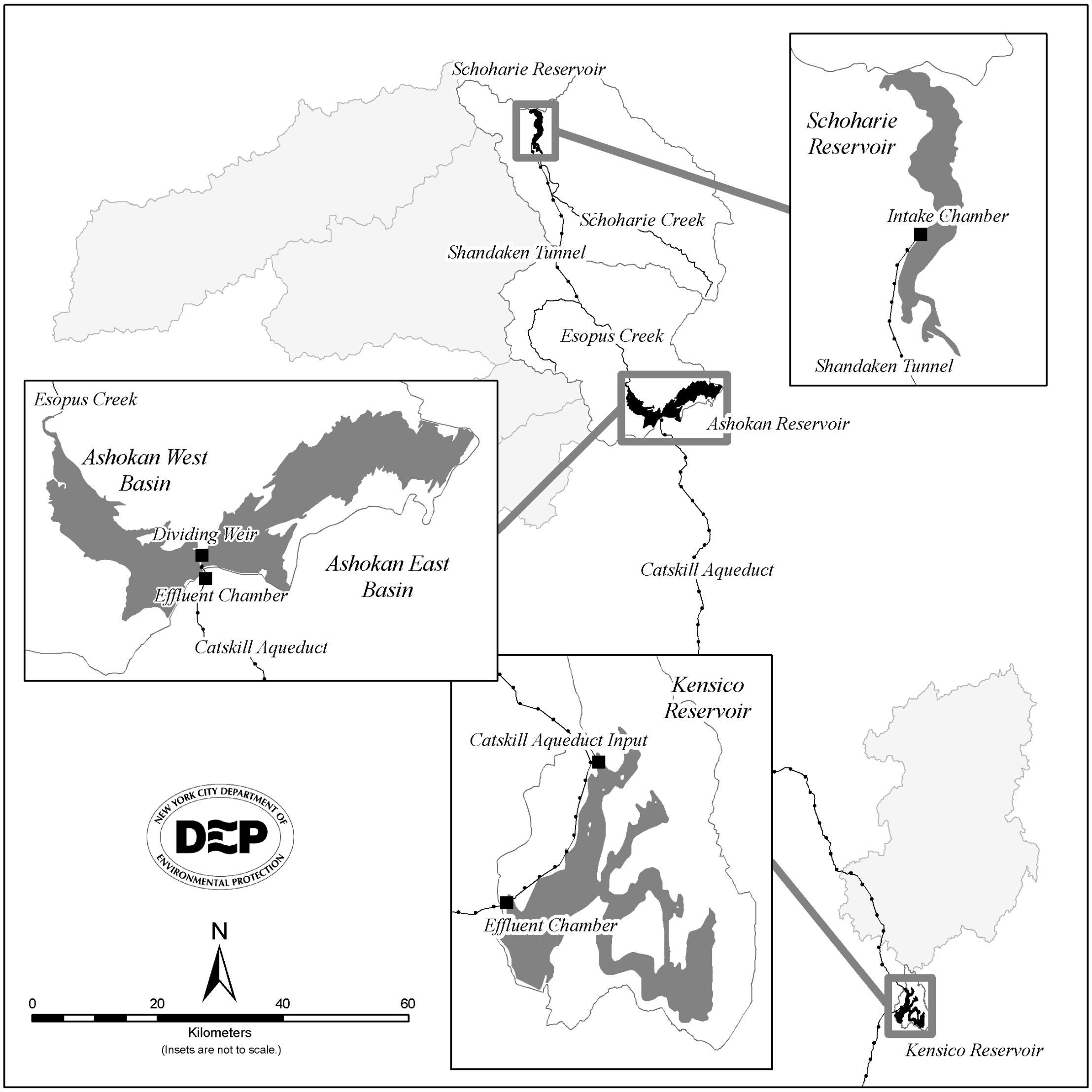

Figure 5.6 Map showing the Catskill reservoir system, its connection to Kensico Reservoir, and the key locations in Figure 5.7.

In order to develop more effective management practices to mitigate the effects of turbidity, DEP is examining the response of the reservoir system to sediment inputs from varying sources. However, it is difficult to examine the consequences of sediment inputs from any one source by analyzing reservoir measurements, since multiple sediment sources usually contribute simultaneously in response to system-wide storm events. Models can trace the movement through the Catskill-Kensico reservoir system in a way that is not possible under actual storm conditions. To illustrate how DEP makes use of its models to follow the movement of suspended sediments, a large input ("spike") of total suspended solids (TSS) was simulated to enter Schoharie Reservoir from Schoharie Creek over a three-day period. The mean daily TSS concentrations were 5,000 mg L^{-1} on the first day, 10,000 mg L^{-1} on the second day, and 5,000 mg L^{-1} on the final day (Figure 5.7). This TSS input was assigned a sinking rate of 0.2 m d^{-1}, and all other TSS sources to the Schoharie and other reservoirs were set to zero. This simulation was designed to demonstrate the ability of models to track the movement and attenuation of a well defined and large TSS input through the Catskill System and Kensico Reservoir. The scenario is not physically realistic as such patterns of TSS input are never observed.

The TSS spike added to Schoharie Creek provided a distinct signal to the Schoharie Reservoir that was transferred to Esopus Creek and Ashokan West Basin, even though the TSS concentration was reduced by a factor of about 6 as the TSS laden water moved between the two reservoirs. In this case, the attenuation of TSS was large, since the TSS spike was added at a time of low discharge, which allowed for effective settling of the TSS in Schoharie before discharge to the Shandaken Tunnel. Transfer from the West to East Basin of Ashokan further reduced TSS concentrations by a factor of more than 10, and by the time the TSS spike reached the dividing weir there was a greater dispersion of the peak. The attenuation of the turbidity peak continued as the water moved to the Catskill aqueduct, and this was followed by even more dilution in Kensico Reservoir due to large inputs of TSS free water from the Delaware aqueduct.

In the first three reservoir basins TSS rich water was colder than the reservoir water, which led to the TSS laden water plunging to the bottom of the reservoirs (isopleth plots, Figure 5.7). However, dispersion of the TSS peak delayed input to Kensico Reservoir until after onset of thermal stratification, which caused TSS to be transported along the thermocline, resulting in elevated epilimnetic concentrations.

Overall, this simulation showed that during the movement of the TSS peak from Schoharie Reservoir to Kensico Reservoir, more than a 1,000-fold decrease in TSS concentration occurred and that the peak became dispersed over a 200-day period. Even though this simulation was based on an unrealistic TSS input scenario, it demonstrates a number of important principles regarding the attenuation and movement of TSS: significant TSS dilution; temporal dispersion of peak TSS concentration; and the transport and distribution of TSS being dependent on reservoir thermal structure.

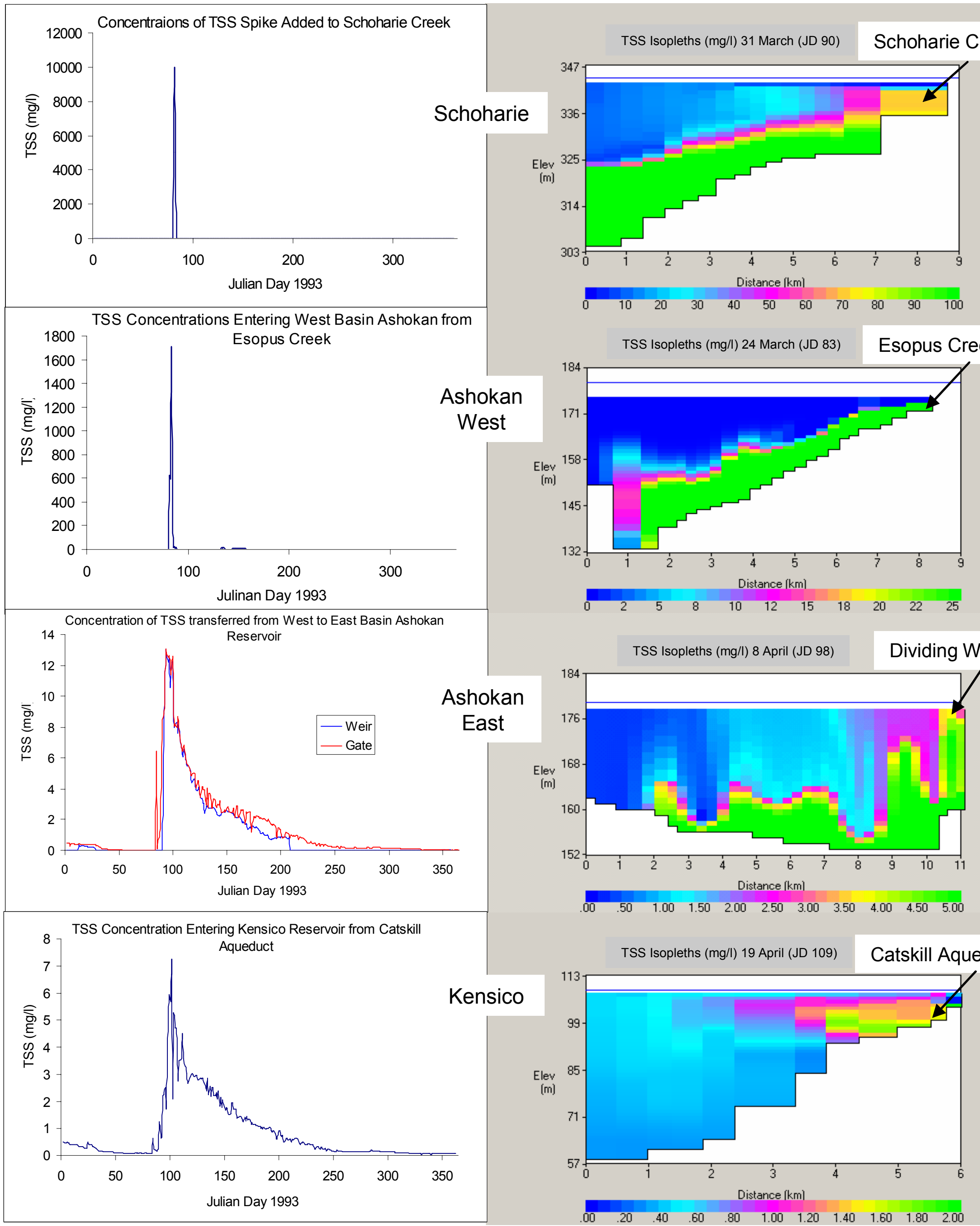

Figure 5.7 TSS concentration vs. time plots (left) at keypoints in the Catskill System, and TSS isopleth diagrams (right) for the main branch of each reservoir for dates that show representative TSS distributions.

Note that there are large changes in the TSS scaling between reservoirs.

5.7 How does DEP plan to simulate the effects of future climate change on reservoir water quality?

Variations in the weather, over time scales ranging from days to years, lead to important variations in water and nutrient inputs to the NYC drinking water reservoirs, and to the growth of phytoplankton in the reservoirs. DEP uses its Nutrient Management Eutrophication Modeling System (NMEMS), a linked set of watershed and reservoir models, to define current rates of nutrient loading, reservoir nutrient levels, and reservoir chlorophyll concentration. Using NMEMS long-term simulations (10-30 years) allows for predictions that define both the normal level, and the expected variability, in measurements of reservoir trophic status. Variability in these can in turn be attributed to natural levels of climatic variation.

If changes in the climate occur, that will have effects on the hydrology and biogeochemistry of the watersheds supplying water to the NYC reservoirs, and on the limnology of the reservoirs themselves. Climate change could lead to changes in water availability, and water quality, and also influence the background variability against which the effects of management programs must be judged. It is imperative that DEP have the capability to simulate the potential influence of climate change, so that these potential impacts can begin to be examined. While DEP has developed NMEMS, it does not presently have the climate data needed to drive simulations under future climate conditions.

To examine the effects of climate change on the NYC reservoir system, DEP has formed a Climate Change Task Force and has entered into a contract with the Columbia University Center for Climate Systems Research (CU-CCSR) to develop two datasets that can be used to drive the NMEMS:

- a control dataset covering the period of 1990–1999
- a future climate dataset covering the period 2050–2059

Both datasets will contain the data necessary to drive the NMEMS (e.g., air temperature, precipitation, wind speed). Data will be provided at a daily time step in a gridded 36 km x 36 km format that will encompass the entire NYC reservoir system. Data from both time periods will be derived from General Climate Model (GCM) simulations available to CU-CCSR staff. A critical component in this work is to correctly downscale the coarse resolution GCM data (360 km x 400 km), since the average climate of the large GCM grid cells is not usually representative of the climate in a specific reservoir watershed (Moore et al., in press).

The groundwork for this contract was laid by a previous contract to CU-CCSR which was funded by DEP and the United States Environmental Protection Agency (USEPA) (Rosenzweig and Solecki, 2001), in which CU-CCSR used both GCM and regional scale models to examine potential changes in summer climate (Figure 5.8) and related effects on the NYC water supply. In the climate modeling that is presently underway, CU-CCSR will expand upon its past work so that two continuous decade-long periods (as opposed to summer only) will be simulated using a daily time step. Such data are required by DEP's models, and would allow DEP to evaluate potential climate impacts on water quantity and quality in a manner consistent with NMEMS simulations that have already been made to examine long-term changes in watershed management and land use.

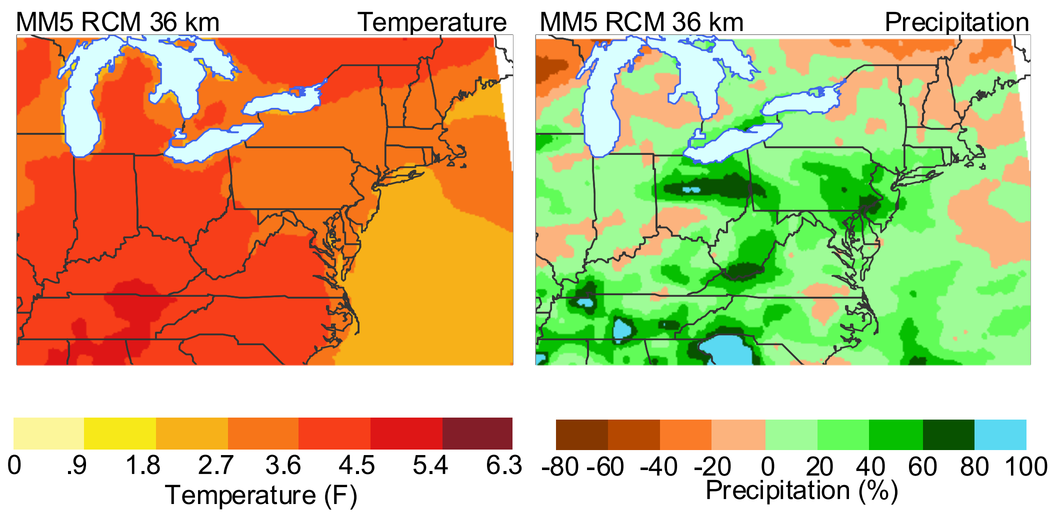

Figure 5.8 Changes in Northeast United States summer air temperature and precipitation based on downscaled GCM simulations of control and future climate scenarios, as reported in Roenzweig and Solecki, 2001. Present work by CU-CCSR will provide DEP with similar downscaled data for a continuous 10-year control and 10-year reference period.

5.8 How is robotic monitoring helping with model development?

The Upstate Freshwater Institute (UFI) is under contract to DEP to develop and test deterministic, dynamic, scientifically credible models for temperature and turbidity for Schoharie and Ashokan Reservoirs and Esopus Creek. These models will be capable of supporting the evaluation and design of reservoir rehabilitation technologies to abate the turbidity problems of this system, and simultaneously meet specified temperature goals for Esopus Creek. This work is supported by integrated programs of field measurements, sampling, laboratory analyses, and process studies. Part of the field program includes robotic measurement in reservoirs and streams.

In 2004, UFI continued a comprehensive monitoring program of Schoharie Creek, Schoharie Reservoir, and Esopus Creek that featured elements of robotic monitoring technology, as well as manual efforts.

Robotic stream monitoring

Stream sampling units (Robohuts—Figures 5.9 and 5.10) specially fabricated for this effort have been placed along streams to collect continuous stream data. Robohuts were installed on Schoharie and Esopus Creeks just upstream of Schoharie and Ashokan Reservoirs in 2003 and operated successfully during most of 2004. A third Robohut was installed on Esopus Creek, above the Shandaken Tunnel outfall, in late 2003. This unit, delayed because of permitting issues, will commence collecting data in 2005.

Figure 5.9 The Robohut located on Schoharie Creek at Prattsville (site S5I) adjacent to the USGS gauging station (green)—outside view.

Figure 5.10 The Robohut located on Schoharie Creek at Prattsville (site S5I)—inside view. This shows (from left to right) the water inflow pipe, the tank in which the measurements are made, the probes, and the sampling/refrigeration unit (above which are the telemetering electronics).

Water is pumped from the stream into the huts where measurements are made using probes situated in a tank (Figure 5.10). Measurements are made at 15-minute intervals for the key analytes: temperature, turbidity, conductivity, and beam attenuation coefficient. (See Figure 5.11 for the 2004 data series for Schoharie Creek.) The huts also contain sampling/refrigeration units so that storm samples can automatically be taken for later laboratory analysis to enhance model development. Flow data are obtained from nearby USGS gauges. Data from the huts are automatically telemetered to UFI where they are used as input for model development; those data are also available to assist DEP in optimizing reservoir operations.

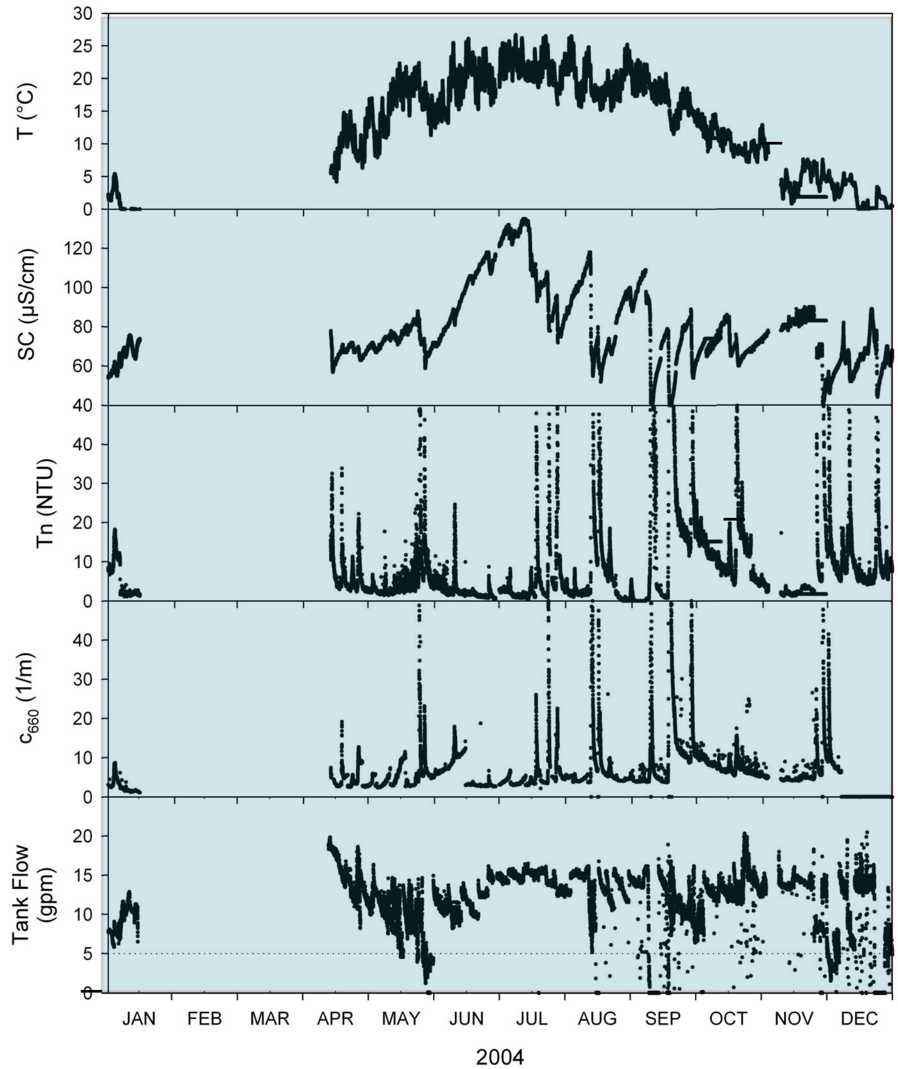

Figure 5.11 Continuous time-series of data collected by the Robohut on Schoharie Creek at Prattsville in 2004, just upstream from Schoharie Reservoir. The winter data gap was caused by ice interference. Here turbidity is referred to as Tn.

Robotic reservoir monitoring

Remote Underwater Sampling Station (RUSS) units (Figures 5.12 and 5.13) have been installed on Schoharie Reservoir to allow for continuous data collection at key locations. A single RUSS unit was tested in 2002 near the intake (site 3). Two other units were deployed in May 2003, one near the dam (site 1) and one approximately midway between the intake and the dam (site 2). These three robotic units were deployed in 2004 (April–November) at sites 2 and 3, and at a site about halfway between the dam and site 2 (at site 1.5). These sites were more in keeping with modeling requirements. The units are removed during winter because they cannot operate successfully during ice-on periods.

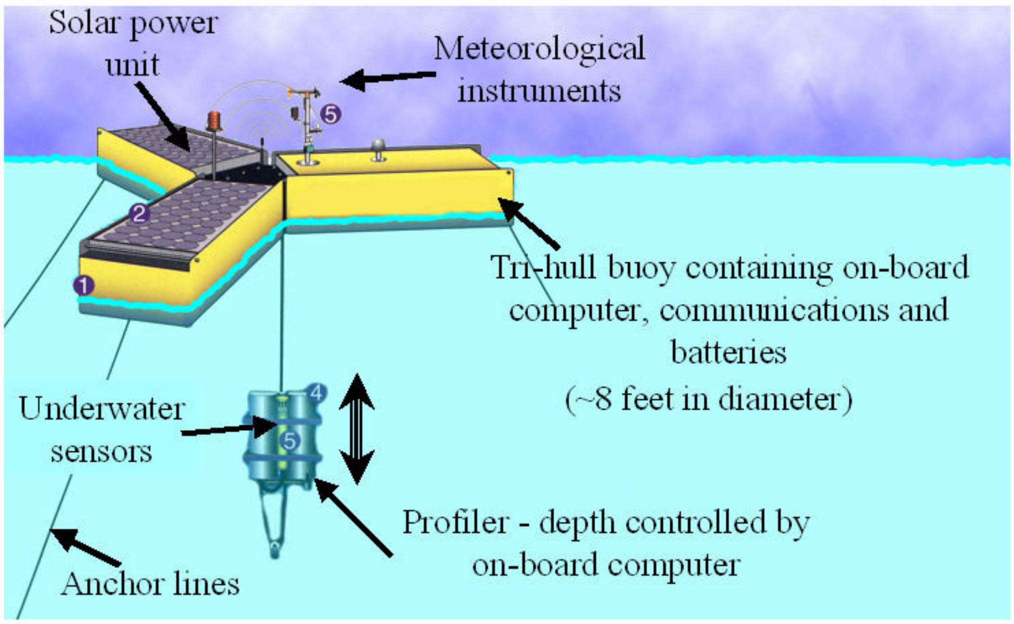

Figure 5.12 Schematic of the RUSS unit located on Schoharie Reservoir.

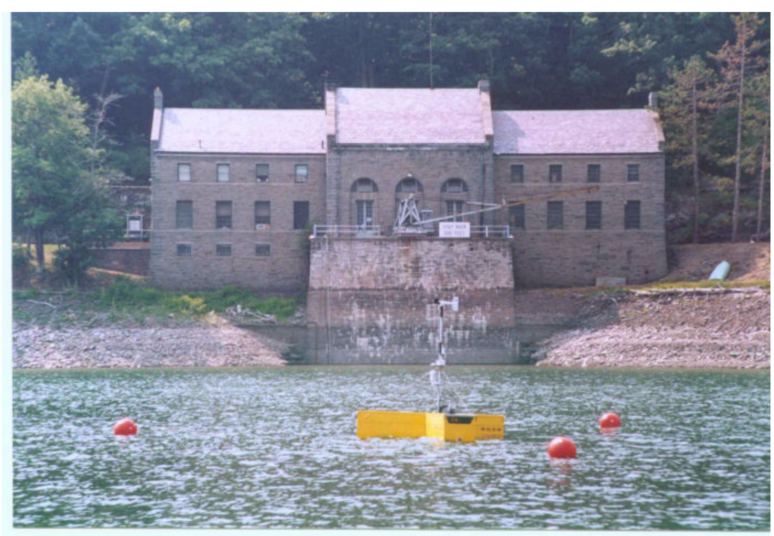

Figure 5.13 The RUSS unit located on Schoharie Reservoir (site 3).

The RUSS units automatically send measurement probes up and down the water column twice a day and measure temperature, conductivity, turbidity, and depth. One (at site 3) also has its own weather station on board (Figure 5.12). Data (see Figure 5.14 for the 2004 continuous time-series data) from the RUSS units are automatically telemetered to UFI where they are used as input for model simulations and provide independent data for model calibration and verification; they are also available to assist DEP in reservoir management.

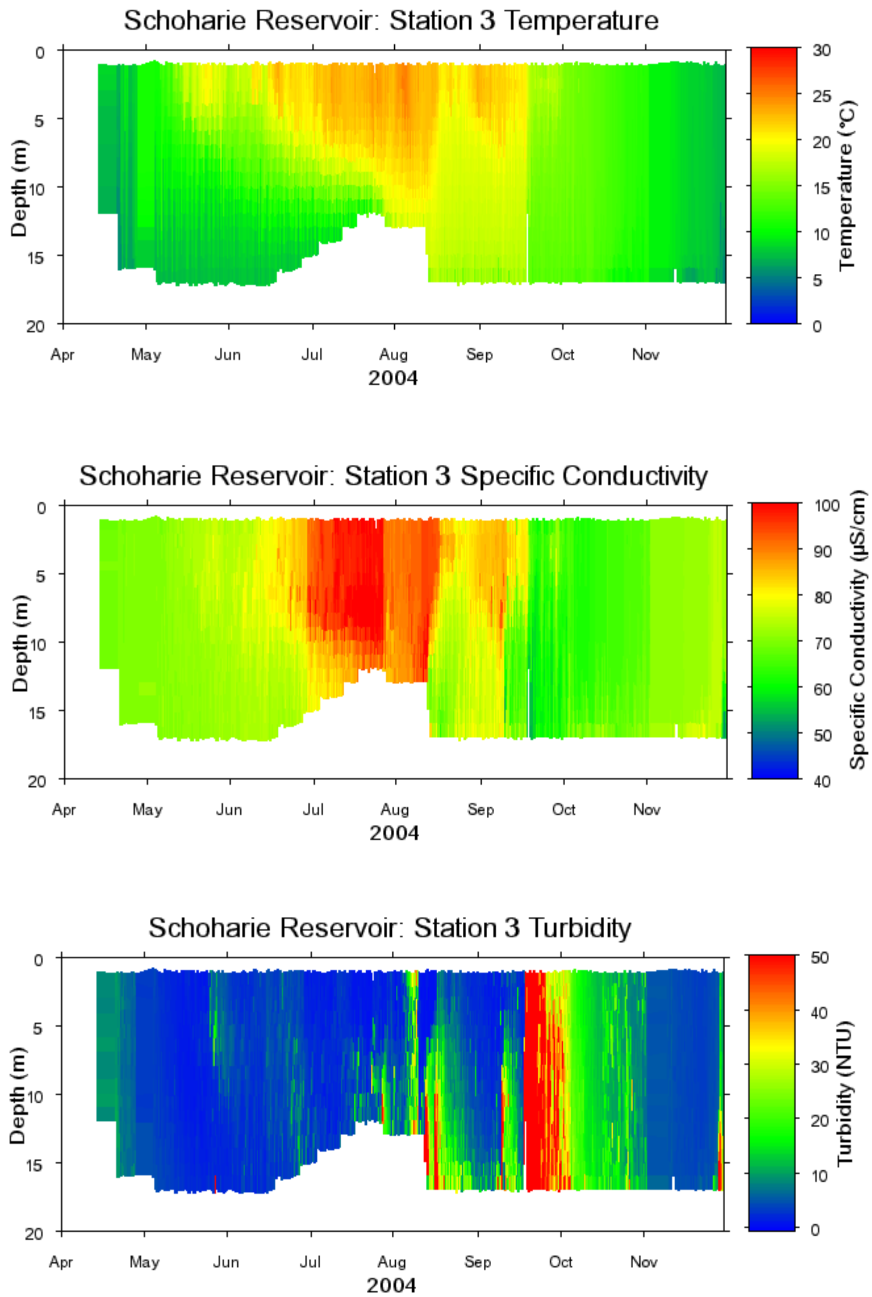

Figure 5.14 Continuous time-series of temperature, conductivity, and turbidity from the RUSS unit in Schoharie Reservoir at Station (limnology site) 3 (near the current intake) in 2004.

(All figures in this section were provided by UFI.)

6. Further Research

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

DEP extends its capabilities through grants and contracts. To date, Safe Drinking Water Act (SDWA) grants (contracted to DEP through the New York State Department of Environmental Conservation (DEC)) have supported a number of DEP projects devoted to guiding watershed management. These grants have totalled approximately $4,600,000, and additional SDWA funds will be earmarked for the NYC watershed for future work. Such projects have typically allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. In addition, contracts are needed to support the work of DWQC.

6.2 What DEP projects are supported through SDWA grants?

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

Table 6.1: DEP's current projects supported by SDWA grants.

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

continued...

Table 6.1: DEP's current projects supported by SDWA grants.

Project Category	Projects Supported
Modeling	
	Croton System Modeling Kensico Model Enhancement
Data Analysis	
	Water Quality Data Analysis and Communication GIS Infrastructure Upgrade and Geodatabase Development

6.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 6.2. The primary types of contracts are: i) Operation and Maintenance, ii) Monitoring, and iii) Research and Development. The Operations and Maintenance contracts are typically renewed each year because they are devoted to supporting the ongoing activities of the Laboratory and Field Operations. The Monitoring contracts are devoted to handling some of the laboratory analyses that must be done to keep up-to-date on the status of the water supply. Research and Development contracts typically answer questions that allow DEP to implement effective watershed management and plan for the future.

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

Contract Description	Contract Term
Operation and Maintenance	
Operation and Maintenance of DEP's Hydrological Monitoring Network (Stream Flow)	10/1/03–9/30/06
Operation and Maintenance of DEP's Hydrological Monitoring Network (Water Quality)	10/1/03–9/30/06
Waterfowl Management at Kensico Reservoir	10/1/03–9/30/06
SAS software contract	6/24/03–6/30/08
Monitoring	
Monitoring of NYC reservoirs for viruses	1/30/04–1/28/07
Monitoring of NYC's reservoirs for zebra mussels	7/1/05–6/30/07
Monitoring of NYC residences for lead and copper	1/1/03–12/31/05
Organic Analysis Laboratory Contract	3/1/04–2/28/07
Analysis of Stormwater at Beerston Cannonsville watershed	11/1/04–10/31/05
Research and Development	
Design of Controls for Zebra Mussels in NYC's Water Supply System	1/5/94–12/31/06
Croton Watershed Management	12/7/0–09/30/04
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–11/25/06

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Glossary

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

Anthropogenic – Man-made.

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

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

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

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

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

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

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

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

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

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

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

Giardia – A protozoan that causes the disease giardiasis.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Kensico			New Croton			East Ashokan Basin			Rondout		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		307	4.67 – 22.66	12.28	295	3.06 – 24.83	12.44	117	3.77 – 23.06	9.76	197	3.8 – 20.71	9.78
pH (units)	6.5–8.5[1]	235	5.72 – 7.67	6.89	246	6.55 – 9.03	7.4	117	5.95 – 8.31	6.99	197	5.17 – 7.88	6.36
Alkalinity (mg/L)		12	9.4 – 12	10.85	24	58.5 – 71.5	61.95	9	7.7 – 10.4	8.5	9	5.96 – 9.76	7.44
Conductivity (µS/cm)		307	47 – 80	65	287	309 – 402	371	117	46.4 – 65	50.6	197	36.6 – 57	49
Hardness (mg/L)		7	20.59 – 23.32	21.86	17	94.2 – 103.84	101.06	9	14.53 – 16	15.08	8	13.13 – 18.58	15.34
Color (Pt–Co units)	(15)	307	7 – 20	12	294	10 – 60	25	120	5 – 20	9	197	8 – 18	15
Turbidity (NTU)	(5)	307	0.5 – 1.9	1.1	294	0.8 – 5.8	2.2	120	0.6 – 4.95	1.7	197	0.5 – 3.3	1.1
Secchi Disk Depth (m)		109	3.1 – 5.9	4.8	98	1.4 – 3.7	2.8	32	2.4 – 5.3	4.1	54	2.8 – 5.4	4.9
Chlorophyll *a*	7[2]	45	0.71 – 7.9	3.3	39	1.6 – 22.65	11.78	18	6.21 – 17.51	8.34	17	2.8 – 7.7	3.8
Total Phytoplankton (SAU)	2000[2]	148	10 – 480	180	130	10 – 1200	325	80	2.5 – 615	170	118	2.5 – 840	200
Dissolved Organic Carbon (mg/L)		168	1.1 – 1.9	1.55	142	2.1 – 3.6	3.1	66	1.3 – 2	1.7	80	1.13 – 2.215	1.37
Total Phosphorus (µg/L)	15[2]	168	1.5 – 15	9	152	9 – 42	21	96	3 – 35	11	150	3.7 – 16.6	8.25
Total Nitrogen (mg/L)		168	0.02 – 0.4	0.275	142	0.2 – 0.79	0.51	48	0.13 – 0.31	0.25	90	0.274 – 0.457	0.3555
Nitrate+Nitrite–N (mg/L)	10[1]	168	0.037 – 0.285	0.1755	152	0.005 – 0.563	0.2835	72	0.011 – 0.241	0.1415	90	0.132 – 0.368	0.265
Total Ammonia–N (mg/L)	0.7–35[1,3]	168	0.005 – 0.037	0.017	152	0.005 – 0.361	0.0265	72	0.01 – 0.13	0.025	90	0.002 – 0.025	0.0055
Iron (mg/L)	0.3[1]	4	0.025 – 0.05	0.025	7	0.025 – 0.07	0.025	8	0.02 – 0.15	0.02	8	0.02 – 0.06	0.04
Manganese (mg/L)	(0.05)	4	0.025 – 0.12	0.0375	7	0.025 – 0.32	0.03	8	0.007 – 0.148	0.007	8	0.007 – 0.067	0.018
Lead (µg/L)	50[1]	8	0.25 – 0.25	0.25	34	0.25 – 0.25	0.25	8	0.5 – 0.5	0.5	8	0.3 – 0.3	0.3
Copper (µg/L)	200[1]	8	0.25 – 1.32	0.72	34	0.25 – 1.38	1.18	8	2.5 – 2.5	2.5	8	1 – 2	1
Calcium (mg/L)		7	5.74 – 6.42	6.05	17	24.2 – 27.03	26.38	9	4.45 – 4.99	4.61	8	3.66 – 5.38	4.395
Sodium (mg/L)		7	5.06 – 6.54	5.66	17	32.7 – 38.74	35.11	9	2.91 – 3.11	3.01	8	3.06 – 4.31	3.49
Chloride (mg/L)	250[1]	14	7.3 – 10.5	8.6	9	65.7 – 71	69.4	72	4.3 – 5.5	4.95	6	4.93 – 7.53	5.315

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Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Amawalk			Bog Brook			Boyd’s Corner			Croton Falls		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		63	5.8 – 24.42	11.33	24	6.56 – 24.44	20.445	27	9.4 – 21.4	15.9	85	5.38 – 24.42	12.3
pH (units)	6.5–8.5[1]	60	6.8 – 9.08	7.625	12	7.66 – 8.82	7.865	27	6.4 – 7.8	7.2	82	6.66 – 9.36	7.6
Alkalinity (mg/L)		9	65.3 – 87	73.8	3	67.5 – 72.2	70	3	28.9 – 29.7	29.5	12	40.1 – 65.3	58.1
Conductivity (µS/cm)		57	296 – 468	443	24	313 – 330.5	320.35	27	203 – 228	216	85	247 – 529	379
Hardness (mg/L)		4	115.1 – 120.4	118.6	0	. – .		3	48.9 – 58.2	50.1	6	92.3 – 101.9	97.3
Color (Pt–Co units)	(15)	65	14 – 80	25	21	12 – 45	30	27	17 – 50	25	85	9 – 35	17
Turbidity (NTU)	(5)	65	1.2 – 5	2.5	21	0.7 – 9.5	3.2	27	0.6 – 2.2	1.1	85	0.6 – 6.7	1.8
Secchi Disk Depth (m)		22	1.8 – 3.2	2.45	12	1.3 – 5.8	1.6	10	1.8 – 5.6	3.9	31	1.3 – 5.2	3.7
Chlorophyll *a*	7[2]	11	1.73 – 22.53	6.6	7	2.1 – 21.38	11.3	4	1.5 – 13.7	4.3	16	2.3 – 64.5	6.9
Total Phytoplankton (SAU)	2000[2]	16	40 – 2400	405	5	240 – 2000	990	3	85 – 1100	94	23	65 – 1200	660
Dissolved Organic Carbon (mg/L)		63	2.7 – 4.1	3.6	21	3 – 4.5	4	27	2.2 – 5.2	2.9	80	2.1 – 4	2.75
Total Phosphorus (µg/L)	15[2]	65	12 – 121	23	21	11 – 54	34	27	10 – 20	13	83	7 – 33	19
Total Nitrogen (mg/L)		61	0.24 – 0.92	0.48	21	0.2 – 0.5	0.31	26	0.16 – 0.33	0.23	82	0.17 – 0.87	0.485
Nitrate+Nitrite–N (mg/L)	10[1]	63	0.005 – 0.405	0.079	21	0.005 – 0.16	0.005	27	0.005 – 0.118	0.048	84	0.005 – 1.08	0.31
Total Ammonia–N (mg/L)	0.7–35[1,3]	63	0.005 – 0.796	0.028	21	0.005 – 0.12	0.021	27	0.014 – 0.057	0.021	84	0.005 – 0.173	0.026
Iron (mg/L)	0.3[1]	3	0.06 – 0.1	0.06	0	. – .		0	. – .		0	. – .	
Manganese (mg/L)	(0.05)	3	0.06 – 0.55	0.06	0	. – .		0	. – .		0	. – .	
Lead (µg/L)	50[1]	7	0.25 – 0.25	0.25	0	. – .		3	0.25 – 1.1	0.54	6	0.25 – 0.25	0.25
Copper (µg/L)	200[1]	7	0.25 – 1.38	1.0111	0	. – .		3	0.94 – 1.07	1.00	6	1.01 – 1.11	1.05
Calcium (mg/L)		4	28.84 – 30.4	29.7	0	. – .		3	12.2 – 15.5	12.5	6	23.1 – 25.8	24.6
Sodium (mg/L)		4	43 – 44.6	43.55	0	. – .		3	22.5 – 22.9	22.9	6	36.6 – 40.5	37.4
Chloride (mg/L)	250[1]	3	82.3 – 83.03	83	0	. – .		5	39.4 – 40.7	39.9	5	67.2 – 74.3	69.1

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Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Cross River			Diverting			East Branch			Lake Gilead		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		68	5.03 – 24.81	9.435	23	8.19 – 23.86	18.19	17	5.6 – 23.33	14.71	35	4.32 – 24.46	7.6
pH (units)	6.5–8.5[1]	65	6.34 – 8.77	7.19	14	7.26 – 8.71	7.83	13	6.81 – 8.82	7.48	27	6.66 – 8.5	7.22
Alkalinity (mg/L)		9	41.4 – 56	45.4	5	75.5 – 85.3	76.5	4	73.5 – 94.7	87.2	9	40.7 – 50.7	41.4
Conductivity (μS/cm)		62	229 – 266	243	23	342 – 403	377	17	251 – 353	331	35	176 – 199	184
Hardness (mg/L)		4	69.75 – 72.38	71.895	3	107.05 – 110.77	108.99	0	. – .		3	57.91 – 61.6	58.24
Color (Pt–Co units)	(15)	68	10 – 100	25	21	20 – 40	30	16	32 – 70	40	12	10 – 25	15
Turbidity (NTU)	(5)	68	1 – 20	2.2	21	1.5 – 8.9	2.3	16	2.4 – 10.3	4.05	12	0.8 – 2.8	1.35
Secchi Disk Depth (m)		23	2.1 – 4.6	3.3	9	1 – 4.8	2.9	8	1.1 – 2.7	1.9	12	2.8 – 5.1	4.65
Chlorophyll *a*	7[2]	12	1.3 – 10.88	4.2	5	2 – 112.4	29.78	5	3.5 – 53.65	7.3	3	2.4 – 5.8	5.1
Total Phytoplankton (SAU)	2000[2]	15	35 – 2400	410	4	300 – 2100	810	4	180 – 1100	475	4	106 – 500	325
Dissolved Organic Carbon (mg/L)		65	2.5 – 3.7	3	21	2.5 – 4.5	3.5	16	3.9 – 6.3	4.85	12	2.6 – 3.4	3.05
Total Phosphorus (μg/L)	15[2]	68	14 – 49	20	21	16 – 43	26	16	30 – 58	42	12	11 – 268	19.5
Total Nitrogen (mg/L)		63	0.19 – 1.13	0.29	21	0.28 – 0.53	0.36	16	0.31 – 0.53	0.43	12	0.21 – 0.82	0.295
Nitrate+Nitrite–N (mg/L)	10[1]	68	0.005 – 0.273	0.016	21	0.005 – 0.317	0.114	16	0.022 – 0.121	0.065	12	0.005 – 0.284	0.009
Total Ammonia–N (mg/L)	0.7–35[1,3]	68	0.005 – 0.893	0.0245	21	0.016 – 0.082	0.024	16	0.014 – 0.15	0.0795	12	0.005 – 0.608	0.0156
Iron (mg/L)	0.3[1]	1	0.27 – 0.27	0.27	0	. – .		0	. – .		0	. – .	
Manganese (mg/L)	(0.05)	1	0.8 – 0.8	0.8	0	. – .		0	. – .		0	. – .	
Lead (μg/L)	50[1]	5	0.25 – 0.83	0.25	3	0.25 – 0.25	0.25	0	. – .		1	0.25 – 0.25	0.25
Copper (μg/L)	200[1]	5	0.75 – 1.08	0.94	3	1.28 – 1.48	1.2945	0	. – .		1	0.25 – 0.25	0.25
Calcium (mg/L)		4	19.28 – 19.8	19.55	3	27.5 – 28.2	27.9	0	. – .		3	14.4 – 15.5	14.6
Sodium (mg/L)		4	18.7 – 20.03	19.55	3	25 – 26.1	25.9	0	. – .		3	12.5 – 12.8	12.5
Chloride (mg/L)	250[1]	3	39.4 – 40.5	40.1	3	50.9 – 51.4	51.3	0	. – .		3	23.9 – 24.4	24.3

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Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		20	5.2 – 23.5	7.1	26	6.8 – 24.1	22.34	56	6.4 – 21.9	14.75	16	8.5 – 21.3	12.6
pH (units)	6.5–8.5[1]	20	6.84 – 8.65	7.585	21	6.71 – 8.68	8.18	56	6.6 – 8.4	7.4	16	7.3 – 8.7	7.65
Alkalinity (mg/L)		6	64.8 – 75.9	65.3	5	52.8 – 54.1	53.5	6	65.2 – 73.4	70.55	2	60.6 – 61	60.8
Conductivity (μS/cm)		20	343 – 411.5	354.5	26	304 – 349	333.5	56	302 – 451	385	16	463 – 519	464
Hardness (mg/L)		3	91.4 – 95.5	93.73	3	92.0 – 94.5	92.5	2	104.1 – 108.58	106.34	0	. – .	
Color (Pt–Co units)	(15)	6	10 – 25	10	6	20 – 35	25	56	20 – 60	32	16	20 – 100	26
Turbidity (NTU)	(5)	6	1 – 2.8	2.1	6	1.8 – 3	2.1	56	0.9 – 8.3	2.85	16	2.3 – 6.7	2.95
Secchi Disk Depth (m)		6	3.6 – 5.1	4.8	18	2.6 – 4.1	2.8	33	1.7 – 4	2.9	7	2.1 – 3	2.3
Chlorophyll *a*	7[2]	1	3.1 – 3.1	3.1	2	5.6 – 8.71	7.155	23	1.6 – 15.24	5.44	4	10.4 – 12.2	11.6
Total Phytoplankton (SAU)	2000[2]	2	68 – 530	299	2	820 – 1800	1310	24	60 – 1400	400	4	95 – 720	440
Dissolved Organic Carbon (mg/L)		6	2.8 – 3.3	2.95	6	2.2 – 4.7	3.7	56	2.2 – 4.4	3.5	16	2.2 – 3.8	3.65
Total Phosphorus (μg/L)	15[2]	6	9 – 274	17.5	5	12 – 25	23	55	13 – 43	26	16	21 – 45	27
Total Nitrogen (mg/L)		6	0.24 – 0.89	0.265	6	0.22 – 0.65	0.265	55	0.3 – 1.07	0.49	16	0.25 – 0.79	0.38
Nitrate+Nitrite–N (mg/L)	10[1]	6	0.005 – 0.089	0.005	5	0.005 – 0.509	0.016	55	0.019 – 0.61	0.252	16	0.005 – 0.345	0.068
Total Ammonia–N (mg/L)	0.7–35[1,3]	6	0.011 – 0.705	0.014	5	0.013 – 0.06	0.026	55	0.005 – 0.195	0.034	16	0.005 – 0.519	0.052
Iron (mg/L)	0.3[1]	0	. – .		0	. – .		2	0.07 – 50.5	25.285	0	. – .	
Manganese (mg/L)	(0.05)	0	. – .		0	. – .		2	0.05 – 3.96	2.005	0	. – .	
Lead (μg/L)	50[1]	1	0.25 – 0.25	0.25	1	0.25 – 0.25	0.25	4	0.25 – 0.25	0.25	1	0.25 – 0.25	0.25
Copper (μg/L)	200[1]	1	0.93 – 0.93	0.93	1	0.25 – 0.25	0.25	4	0.25 – 1.37	0.80	1	0.25 – 0.25	0.25
Calcium (mg/L)		3	22.8 – 23.8	23.6	3	23 – 23.4	23.3	2	26.5 – 27.7	27.1	0	. – .	
Sodium (mg/L)		3	33.3 – 34.7	34.7	3	29.3 – 29.8	29.8	2	33 – 34.5	33.75	0	. – .	
Chloride (mg/L)	250[1]	3	64.7 – 66.2	65.9	3	61.7 – 63.3	62.8	3	3.8 – 66.9	66	0	. – .	

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Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Titicus			West Branch			West Ashokan Basin			Pepacton		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		63	6.06 – 25.5	11.5	138	4.06 – 20.7	12.7	177	4.11 – 22	10.34	278	3.7 – 22.14	8.18
pH (units)	6.5–8.5[1]	60	6.65 – 8.875	7.58	127	6.1 – 7.8	7.1	177	6.04 – 7.6	6.86	261	5.93 – 8.47	6.6
Alkalinity (mg/L)		6	64.7 – 67.8	65.3	12	9.7 – 28.2	18.6	12	6.9 – 10.5	8.45	21	9.92 – 13.3	10.7
Conductivity (µS/cm)		57	265 – 298	279	138	53 – 152	73	177	39 – 57.8	50	278	52.4 – 62	56.2
Hardness (mg/L)		3	92.95 – 95.73	94.74	4	19.11 – 48.29	33.54	12	14.08 – 17.67	15.43	21	18.15 – 21.46	19.45
Color (Pt–Co units)	(15)	58	10 – 60	25	144	9 – 28	15	177	5 – 17	10	233	8 – 18	12
Turbidity (NTU)	(5)	58	1.3 – 16	2.7	144	0.8 – 2.8	1.6	180	1.1 – 11	3.4	265	0.5 – 5.4	1.3
Secchi Disk Depth (m)		22	0.8 – 3.4	2.9	55	2.3 – 5.6	4.1	48	0.5 – 4.8	2.75	82	0.9 – 5.5	4.3
Chlorophyll *a*	7[2]	13	0.82 – 105	9.1	17	0.74 – 9.1	3.58	24	2.26 – 14.86	8.345	41	2.6 – 7.4	4.9
Total Phytoplankton (SAU)	2000[2]	15	130 – 2000	460	79	28 – 1200	270	100	2.5 – 875	115	104	2.5 – 520	125
Dissolved Organic Carbon (mg/L)		48	2.3 – 3.8	3.15	69	1.2 – 2.9	1.8	87	1.1 – 2.2	1.4	164	0.96 – 1.87	1.28
Total Phosphorus (µg/L)	15[2]	62	15 – 61	22.5	73	6 – 26	12	143	3 – 19	10	269	1.5 – 23.4	9.2
Total Nitrogen (mg/L)		48	0.2 – 0.63	0.31	73	0.13 – 0.38	0.28	71	0.21 – 0.43	0.39	136	0.171 – 0.467	0.3625
Nitrate+Nitrite–N (mg/L)	10[1]	62	0.005 – 0.413	0.0415	73	0.005 – 0.292	0.184	95	0.102 – 0.471	0.351	164	0.011 – 0.4	0.285
Total Ammonia–N (mg/L)	0.7–35[1,3]	62	0.005 – 0.313	0.02	73	0.005 – 0.034	0.016	96	0.01 – 0.03	0.01	164	0.002 – 0.013	0.004
Iron (mg/L)	0.3[1]	1	0.21 – 0.21	0.21	2	0.025 – 0.05	0.0375	8	0.02 – 0.14	0.095	8	0.01 – 0.04	0.02
Manganese (mg/L)	(0.05)	1	0.51 – 0.51	0.51	2	0.025 – 0.06	0.0425	8	0.007 – 0.124	0.0285	8	0.004 – 0.091	0.0435
Lead (µg/L)	50[1]	5	0.25 – 0.25	0.25	5	0.25 – 0.25	0.25	8	0.5 – 0.5	0.5	8	0.3 – 0.3	0.3
Copper (µg/L)	200[1]	5	0.25 – 1.05	0.82	5	0.25 – 1.05	0.25	8	2.5 – 2.5	2.5	8	1 – 1	1
Calcium (mg/L)		3	24.19 – 24.6	24.4	4	5.23 – 12.2	8.65	12	4.32 – 5.41	4.695	21	5.24 – 6.4	5.71
Sodium (mg/L)		3	18.9 – 19.48	19.1	4	5.12 – 17.3	11.115	12	2.69 – 3.63	2.91	21	3.27 – 3.95	3.57
Chloride (mg/L)	250[1]	3	37.5 – 37.8	37.7	4	7.8 – 34.6	20.8	95	2.6 – 6.6	5.2	21	5.05 – 6.5	5.48

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Appendix Table A.1: Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes for 2004.

Analytes		Neversink			Schoharie			Cannonsville		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median
Temperature (°C)		194	4.13 – 21.54	8.83	184	3.55 – 22.16	9.54	240	3.14 – 22.48	11.48
pH (units)	6.5–8.5[1]	194	5.15 – 6.5	5.755	184	6.31 – 7.63	6.98	223	6.09 – 8.87	6.7
Alkalinity (mg/L)		9	1.86 – 2.96	2.3	9	7.5 – 17.2	10.8	27	12.3 – 18	15.7
Conductivity (µS/cm)		194	22.2 – 29.6	27.4	173	39 – 92	69.8	240	72.9 – 94.05	81.15
Hardness (mg/L)		9	8.03 – 8.92	8.72	11	16.33 – 24.68	20.35	24	22.7 – 27.49	25.735
Color (Pt–Co units)	(15)	180	7 – 20	14	116	8 – 28	14	205	10 – 22	15
Turbidity (NTU)	(5)	195	0.4 – 1.9	0.9	184	0.7 – 18	4.45	226	0.5 – 8.1	2.15
Secchi Disk Depth (m)		62	3.8 – 8.3	5.65	58	0.7 – 6.2	2.55	76	1.6 – 6.4	3.8
Chlorophyll *a*	7[2]	22	0.5 – 4.9	2.85	24	0.5 – 24.85	3.645	54	1.7 – 21.8	6.9
Total Phytoplankton (SAU)	2000[2]	91	2.5 – 440	65	61	2.5 – 430	31	108	2.5 – 2600	305
Dissolved Organic Carbon (mg/L)		96	1.16 – 2.39	1.45	73	1.6 – 3.4	2	172	1.13 – 4.6	1.665
Total Phosphorus (µg/L)	15[2]	189	1.5 – 10.8	5.3	153	3 – 32	14	229	5.6 – 40.8	16.2
Total Nitrogen (mg/L)		96	0.238 – 0.441	0.365	73	0.17 – 0.56	0.43	119	0.222 – 0.82	0.627
Nitrate+Nitrite–N (mg/L)	10[1]	96	0.093 – 0.351	0.302	73	0.031 – 0.482	0.322	183	0.011 – 0.699	0.492
Total Ammonia–N (mg/L)	0.7–35[1,3]	96	0.002 – 0.037	0.0085	64	0.01 – 0.04	0.02	183	0.002 – 0.048	0.008
Iron (mg/L)	0.3[1]	8	0.03 – 0.07	0.045	4	0.1 – 0.17	0.13	8	0.02 – 0.1	0.08
Manganese (mg/L)	(0.05)	8	0.009 – 0.039	0.029	4	0.032 – 0.139	0.044	8	0.005 – 0.104	0.021
Lead (µg/L)	50[1]	8	0.3 – 2.4	0.3	4	0.5 – 0.5	0.5	8	0.3 – 0.3	0.3
Copper (µg/L)	200[1]	8	1 – 7.7	1	4	2.5 – 2.5	2.5	8	1 – 2.1	1
Calcium (mg/L)		9	2.34 – 2.55	2.46	11	5.12 – 7.74	6.42	24	6.27 – 7.76	7.14
Sodium (mg/L)		9	1.43 – 1.94	1.75	11	4.11 – 5.83	4.93	24	5.63 – 6.74	6.18
Chloride (mg/L)	250[1]	9	2.13 – 3.1	2.69	73	5 – 10.4	8.9	18	8.78 – 12.2	9.195

Notes for Appendix A:

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

Water Quality Standards:

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

[2] DEP target values are listed for chlorophyll *a,* total phosphorus, and total phytoplankton. The total phosphorus target value of 15 $\mu g\ L^{-1}$ applies to source water reservoirs only and has been adopted by DEC in the TMDL Program.

[3] Dependent upon pH and temperature.

( ) The turbidity, color, and manganese standards in parentheses are only applicable to keypoint and treated water, but are supplied to provide context for the reservoir data.

Abbreviations:

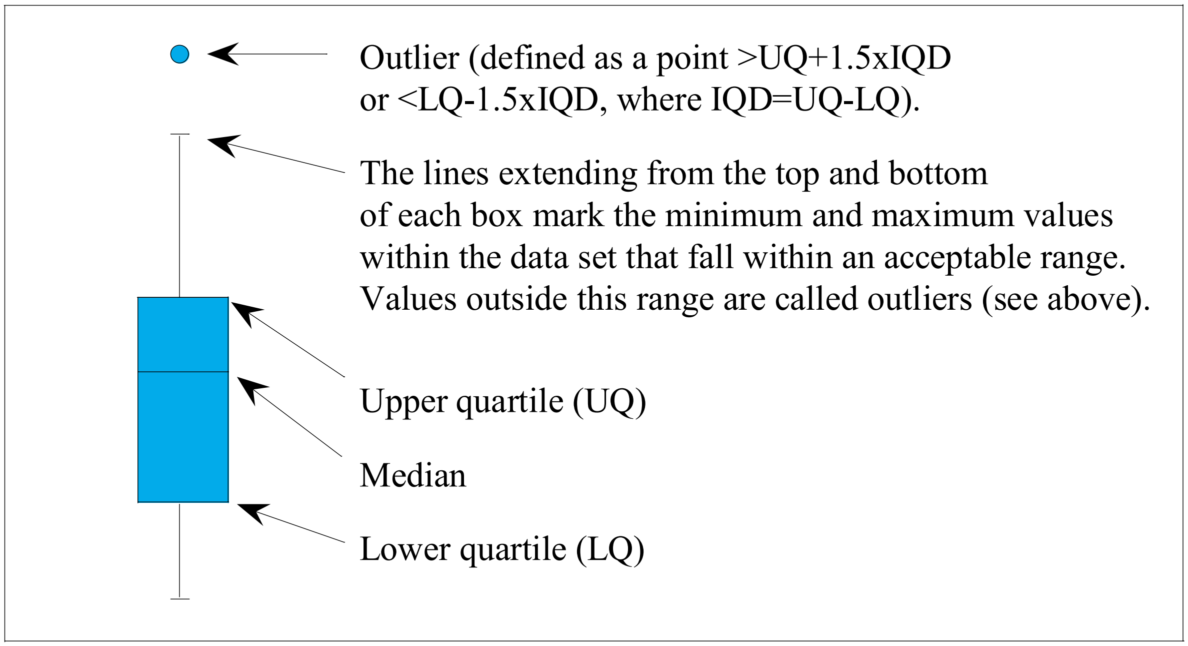
N = number of samples
range = minimum to 95%–ile (to avoid the occasional outlier in the dataset)
ND = non detect
SAU = standard areal units

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

Methods:

All EOH data are provisional at this time.
Chlorophyll *a* for 2004 represents the time period May–October; however, EOH data were limited due to limited access from dam rehabilitation and other work.
Chlorophyll *a* results were obtained through use of spectrophotometer or fluorometer method from 1991–2000, and by HPLC from 2001–2004.
TP results were obtained using the Valderamma method (1980) from 1991–1999, and by APHA (1992, 1998) from 2000–2004.
Secchi transparency results were obtained on the shady side of the boat using the naked eye from 1991–1998, and by use of a viewer box on the sunny side of the boat 1999–2004, which produced slightly higher results (Smith and Hoover, 1999; Smith, 2001).

Appendix B Key to Box Plots



Appendix C Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Rules and Regulations as “the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D.” The designation of a reservoir basin as phosphorus restricted has two primary effects: 1) new or expanded wastewater treatment plants with surface discharges are prohibited in the reservoir basin, and 2) stormwater pollution prevention plans required by the Watershed Rules and Regulations must include an analysis of phosphorus runoff, before and after the land disturbance activity, and must be designed to treat a 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 “Methodology for Determining Phosphorus-Restricted Basins” (NYCDEP, 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 DEP laboratories, and typically ranges between 2-5 μg L^{-1}. Phosphorus concentration data for the reservoirs approaches a lognormal distribution; therefore, the geometric mean is used to characterize the annual phosphorus concentrations (see Appendix Table C.1).

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, that annual average may or may not be representative of the reservoir, and the data for the under-sampled year is removed from the analysis. In addition, each five-year assessment must incorporate at least three years of data.

To provide some statistical assurance that the five-year arithmetic mean is representative of a basin’s phosphorus status, given the interannual variability, the five-year mean plus the standard error of the five-year mean is compared to the NYS guidance value of 20 μg L^{-1}. A basin is **unrestricted** if the five-year mean plus the standard error is below the guidance value of 20 μg L^{-1}, and phosphorus restricted if it is equal to or greater than 20 μg L^{-1}, unless 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	1999 mg L^{-1}	2000 mg L^{-1}	2001 mg L^{-1}	2002 mg L^{-1}	2003 mg L^{-1}	2004 mg L^{-1}
Delaware System						
Cannonsville Reservoir	17.27	17.20	19.3	17.9	15.4	15.1
Pepacton Reservoir	8.93	8.10	8.6	10.4	9.1	9.2
Neversink Reservoir	5.13	5.26	5.8	4.7	5.2	5.0
Rondout Reservoir	7.65	10.40	7.4	9.2	6.8	8.6
Catskill System						
Schoharie Reservoir	25.92	21.31	15.2	11.7	7.5	13.3
Ashokan-West Reser-	14.23	9.56	9.4	9.6	6.1	9.3
Ashokan-East Reservoir	11.00	10.60	7.7	12.4	7.0	10
Croton System						
Amawalk Reservoir	22.12	38.63	19.8	22.2	19.6	26.5
Bog Brook Reservoir	18.01	34.73	21.4	*	16.9	26.8
Boyd Corners Reservoir	12.61	16.00	13.6	15.9	12.4	13.8
Cross River Reservoir	10.85	17.15	14.8	20.3	17.9	20.2
Croton Falls Reservoir	16.54	26.09	22.3	24.1	20.4	18.1
Diverting Reservoir	22.95	30.02	31.8	41.7	28.8	28.3
East Branch Reservoir	19.47	39.01	33.3	*	26.5	44.2
Middle Branch Reser-	23.18	32.42	27.7	31.2	23.7	*
Muscoot Reservoir	26.46	35.00	29.7	33.9	29.5	26.0
Titicus Reservoir	37.31	33.58	28.7	26.9	27.3	25.4
West Branch Reservoir	7.12	13.29	11.5	12.9	10.2	11.5
Lake Gleneida	22.00	30.36	31.6	*	22.8	*
Lake Gilead	28.07	34.89	38.4	*	28.5	21.8

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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	1999 mg L^{-1}	2000 mg L^{-1}	2001 mg L^{-1}	2002 mg L^{-1}	2003 mg L^{-1}	2004 mg L^{-1}
Kirk Lake	*	*	*	*	30.8	*
Source Water						
Kensico Reservoir	5.80	9.11	8.5	8.4	7.6	8.8
New Croton Reservoir	15.88	22.68	21.9	23.9	19.5	22.4

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