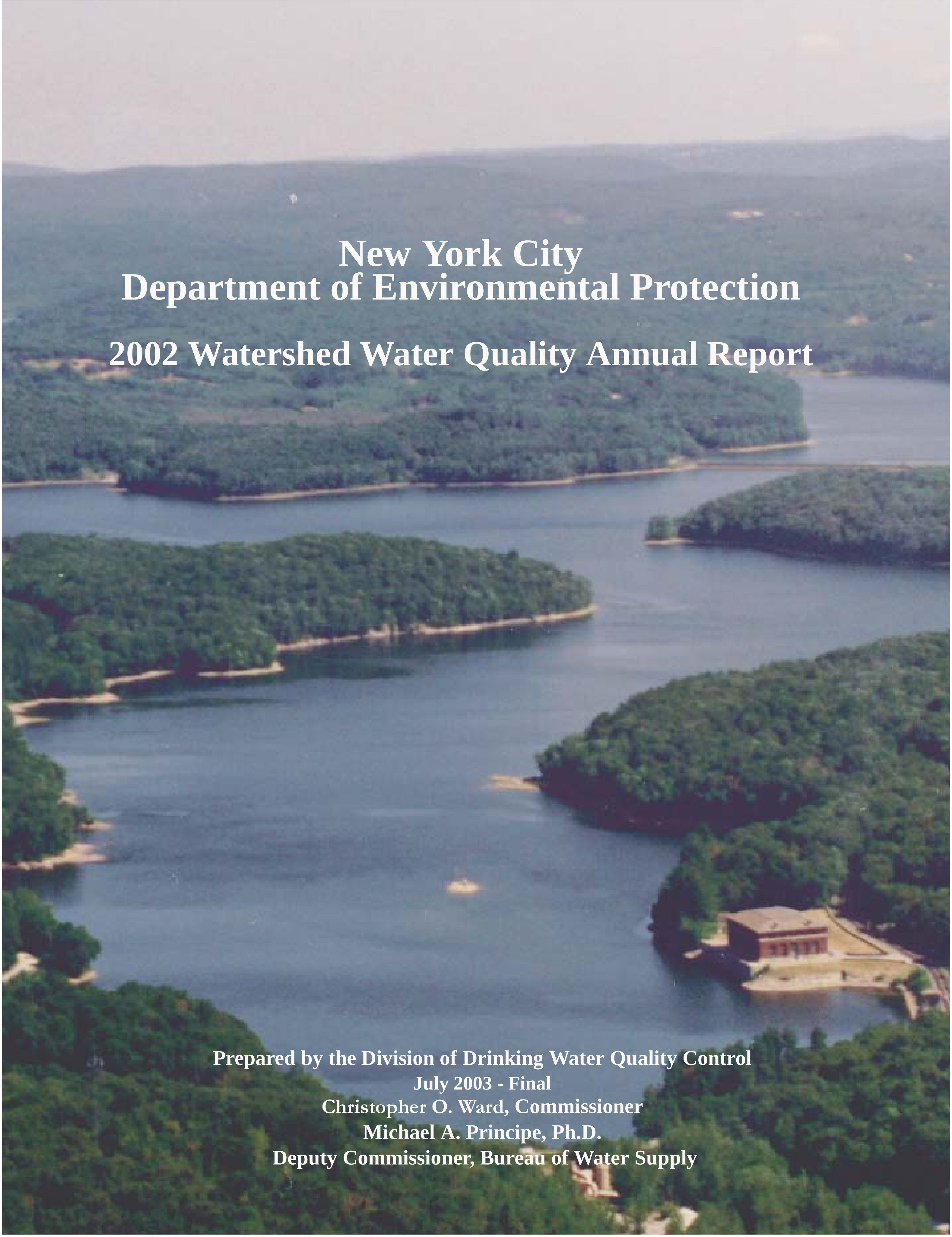

New York City
Department of Environmental Protection

2002 Watershed Water Quality Annual Report

Prepared by the Division of Drinking Water Quality Control

July 2003 - Final

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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 disc (cf. Secchi disk).

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

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

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

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

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

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

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

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

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

***Giardia* –** A protozoan that causes the disease giardiasis.

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

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

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

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

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

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

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

Nutrients – Substances necessary for the growth of all living things, such as nitrogen, carbon, potassium, and phosphorus. High concentrations of nutrients in 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 or a form of an organism produced either in response to environmental conditions or as a normal part of the life cycle of the organism. It is characterized by a thick and environmentally resistant cell wall. *Cryptosporidium* are shed as oocysts.

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

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

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

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

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

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

Protozoa – Single cell organisms. Pathogenic intestinal protozoa can cause diarrhea or gastroenteritis of varying severity.

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

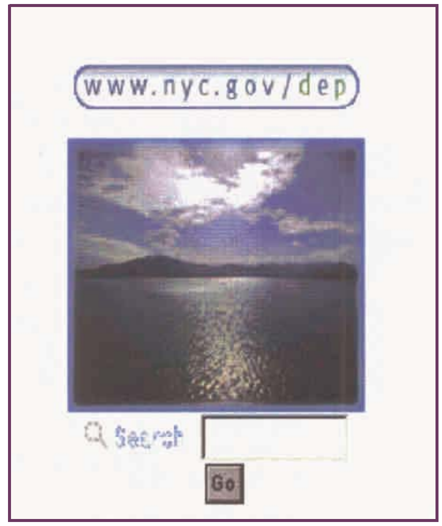
Acknowledgments

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

General guidance in the activities of the Division was provided by Dr. Michael Principe, Deputy Commissioner of the Bureau of Water Supply, and Dr. David Lipsky, Acting Director of DWQC. Mr. Steven Schindler and Dr. Lorraine Janus were responsible for management of the Division's Upstate Laboratory and Field Operation sections, respectively. The original outline of this report was presented in NYC's 2001 Watershed Protection Program Summary, Assessment, and Long-term Plan (issued December 2001). Subsequently, DWQC Supervisors and their staff produced the detailed versions of each chapter. Leading roles in authorship and editing were taken by Dr. Lorraine Janus, Ms. Lori Emery, Mr. Andrew Bader, Dr. David Smith, Mr. James Mayfield, Mr. Gerard Marzec, Dr. Kimberlee Kane, Mr. Charles Olson, Dr. Yves Mikol, Ms. Kerri Alderisio, Dr. Elliot Schneiderman, and Mr. Mark Zion. Special mention of sub-section authors goes to Ms. Salome Freud, Mr. Christopher Nadareski, Mr. Guillermo Mendoza, Mr. Todd Echelman, Mr. Richard Van Dreason, Mr. Martin Rosenfeld, Mr. Bryce McCann, and Mr. Gerald Pratt. Thanks also go to Ms. Kelly Seelbach, Mr. Jeff Mantus, and Mr. Steven Adamec for additional graphics or information. Finally, Ms. Patricia Girard is acknowledged for her expert consolidation and formatting of the many text and graphics files that comprise this report. Her ability to remain organized and cheerful through seemingly endless “additions” and “corrections” is remarkable and much appreciated by all.

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 2002, and compliance with regulatory standards or guidelines during this period. It is complementary to another report entitled "NYC Drinking Water Supply and Quality Report" that is distributed to consumers annually to provide information about the quality of the City's tap water. However, the focus of this report is different in that it addresses how the City protects its drinking water sources upstream of the distribution system. The report also describes DEP's efforts to evaluate the effectiveness of watershed protection and remediation programs, and to develop and use predictive models. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through our website at http://www.nyc.gov/dep.

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

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

Operations

- Operates and maintains the City's reservoirs, tunnels, aqueducts, shafts, chambers and other facilities
- Responsible for delivery of sufficient high quality water to the City and outside communities
- Responsible for the operation & maintenance of ~175 facilities, 19 reservoirs, 4 treatment facilities, ~70 miles of roads, bridges and 8 wastewater treatment plants (WWTPs) & sewer collection systems
- Provides support to other Bureau Divisions as needed

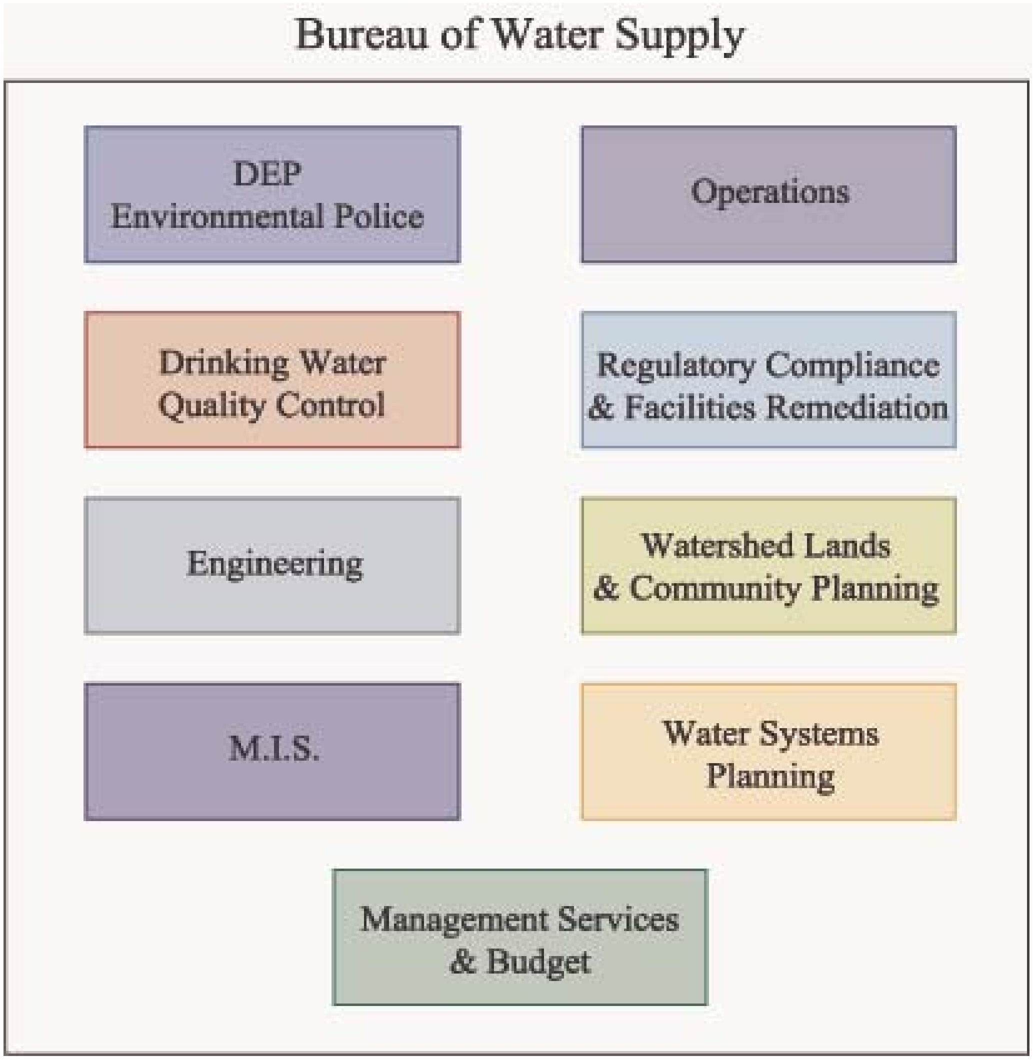


Figure 1.1 Organization of the Bureau of Water Supply.

Drinking Water Quality Control

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

Engineering

- Ensures that new development complies with the Watershed Regulations
- Ensures existing development does not jeopardize water quality

- Inspects all WWTPs in the watershed to ensure proper operation
- Provides engineering support to other BWS units, including WWTP Upgrade Program
- Oversees Community Water Supplies

Watershed Lands and Community Planning

- Assists in community planning through Catskill Watershed Corporation (CWC), New Infrastructure, Sewer Extensions, Westchester/Putnam Counties
- Evaluates and designs appropriate farm and forest activities in cooperation with the Watershed Agricultural Council (WAC)
- Acquires new lands through fee and conservation easement acquisition & partnerships with WAC, Land Trusts, Counties, State/Real Estate Services
- Manages land to ensure appropriate public access and recreation, forestry activities through land use agreements (hay, maple syrup, community partnerships), reservoir and watershed lands patrol, and acquisition support
- Manages streams through stream management plans, stream restorations, research and public education

Water Systems Planning

- Develops plans for security enhancement of water supply system (*e.g.*, physical hardening of infrastructure and building of new police precincts)
- Implements emergency contracts (*e.g.*, drought)
- Performs long-term planning for water supply system in coordination with other Bureaus
- Performs water resource management activities including the monitoring of storage, consumption, diversions, releases and hydrologic conditions to optimize storage

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 rules and regulations regarding the environment and employee health and safety
- Provides emergency spill response and remediation
- Provides supervision of contractors hired for hazardous waste/materials remediation and disposal
- Provides environmental, health and safety training to BWS personnel

MIS

- 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 & Budget

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

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

The condition of the water supply is monitored by the Division of Drinking Water Quality Control (DWQC). DWQC has a staff of more than 300 who are responsible for monitoring and maintaining high water quality for the entire (upstate watershed and downstate distribution system) water supply. This staff is evenly divided between the distribution system in the City and the upstate watershed. This report is specifically about the upstate watersheds and the staff devoted to conducting the Field Operations, Laboratory Operations, and Administration.

DWQC's Watershed Field Operations Section consists of seven groups that are devoted to a variety of disciplines, including: Hydrology, Limnology, Pathogens, Geographic Information Systems, Modeling, Watershed Management, and Reporting. These staff are responsible for: i) designing scientific studies; ii) collecting environmental samples for routine and special investigations; iii) submitting these samples to the Laboratory Operations for analysis; iv) organizing and interpreting data; v) documenting findings; and, vi) making recommendations for effective watershed management. Field Operations' staff members are located in all three water supply Systems (Catskill, Delaware, and East of Hudson). Extensive monitoring of a large geographic network of sites to support reservoir operations and watershed management decisions are the top priority of the Field Operations Section.

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

DWQC's Watershed Laboratory Operations Section consists of 5 water quality laboratories located in the Delaware, Catskill and East-of-Hudson Watershed Systems. This Section also includes a Technical Support Unit and a Research Microbiology Unit. Laboratory Operations includes laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, scientists, and technical specialists. The laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for over 100 environmental analyses in the non-potable water, potable water, and solid and hazardous waste 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, pigments, THMs, PCBs). In addition, this Section operates a Pathogen Laboratory that analyzes water samples for the protozoan pathogen's *Cryptosporidium spp*. and *Giardia spp*. Daily monitoring of water quality at a few critical "Keypoint" monitoring sites for rapid detection and tracking of any changes in water quality is one of the top priorities of the Laboratory Operations Section.

Figure 1.3 The five DEP laboratories process approximately 25,000 samples each year.

For the 2002 reporting period covered in this report, DWQC staff performed approximately 310,000 analyses on approximately 25,000 samples from 500 different sampling locations.

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 drained by the system is approximately 5,100 square kilometers (1,972 square miles) (see Figure 2.1). The flow pattern and relative size of the reservoirs is shown in Figure 2.2. The system is dependent on precipitation (rainfall and snow melt) and subsequent runoff to supply the reservoirs in each of three watershed systems, the Catskill, Delaware, and Croton Systems. The first two are located West-of-Hudson (WOH) and the Croton System is located East-of-Hudson (EOH). As the water drains from the watershed, it is carried via streams, groundwater, and rivers to the reservoirs. The water is then directed through a series of aqueducts to source water reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the pollutant loads and hydraulic residence time, which in turn directly influence the reservoirs' water quality and productivity.

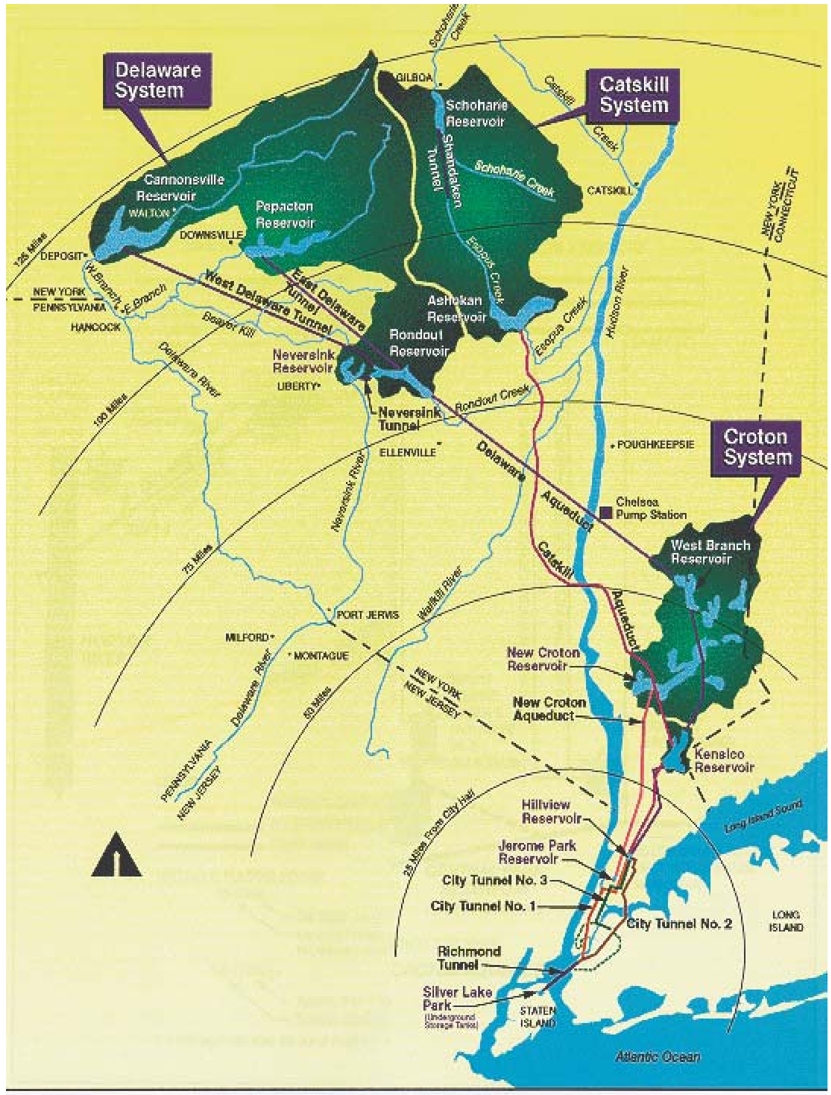


Figure 2.1 New York City water supply watershed.

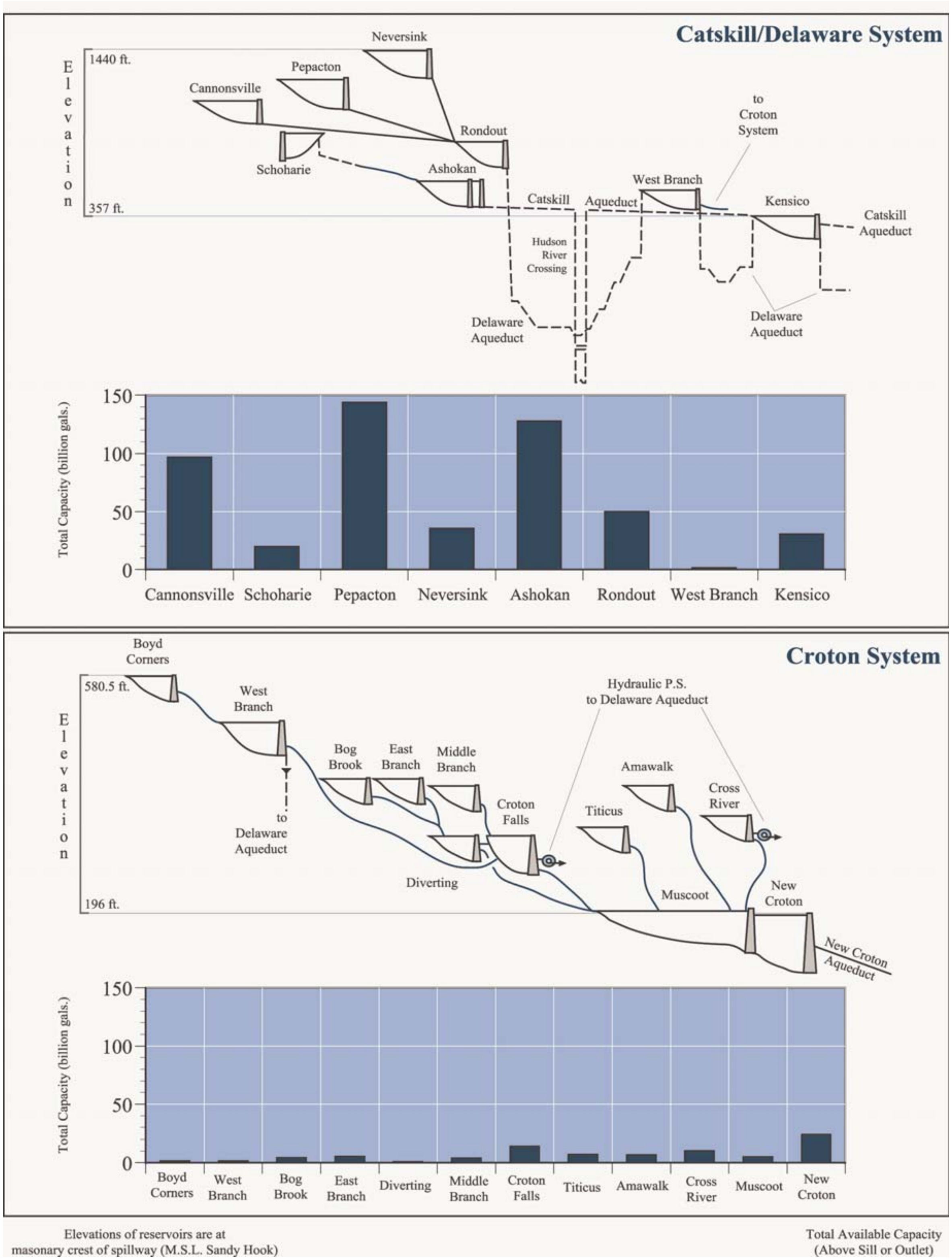


Figure 2.2 NYC water supply reservoirs and their available storage capacities.

2.2 How much precipitation fell in the watershed in 2002?

The average precipitation for each basin was determined from a network of precipitation gauges that collect readings daily and is located in or near the watershed. The total monthly precipitation for each watershed is based on the average readings of the gauges located in or near the watershed. The 2002 monthly precipitation total for each watershed is plotted along with the historical monthly average (see Figure 2.3).

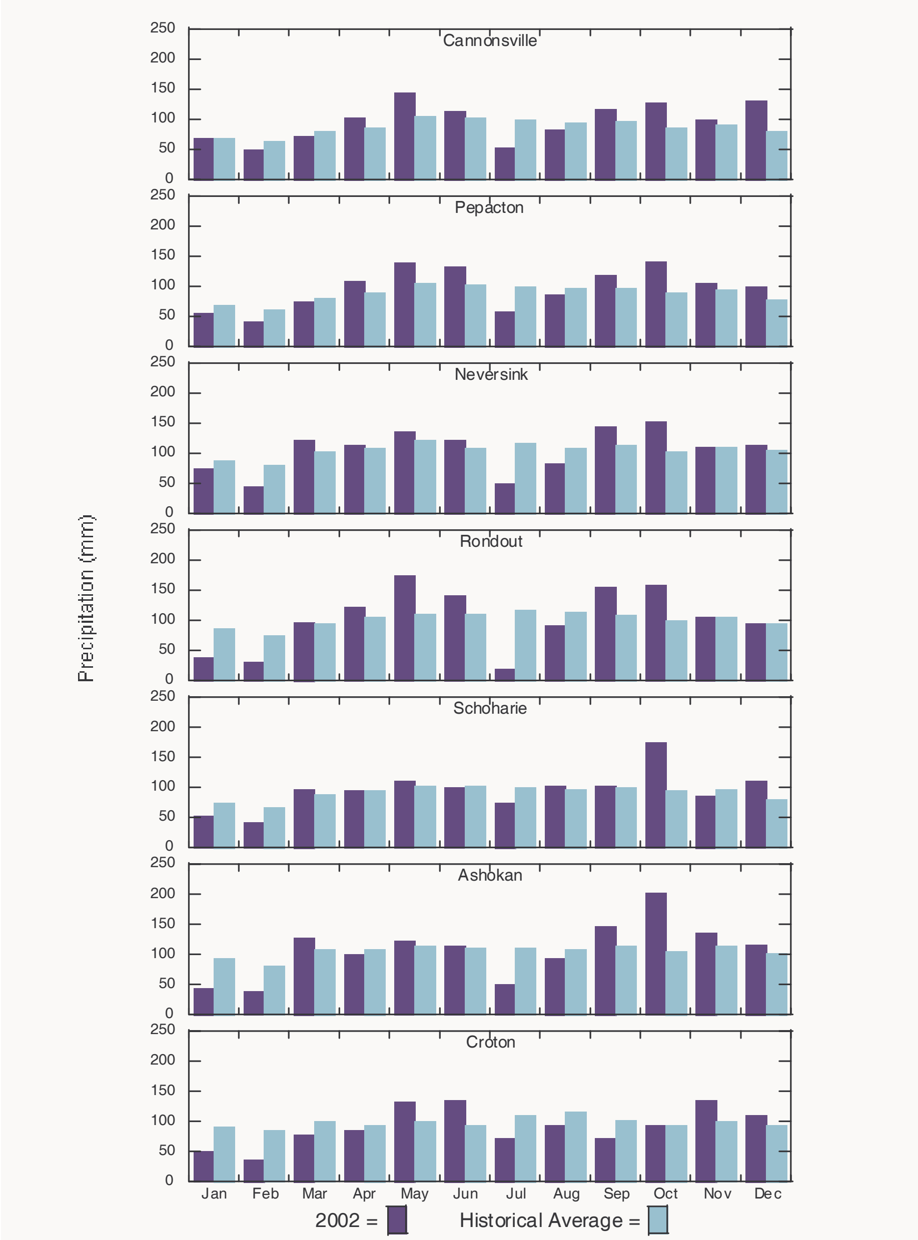


Figure 2.3 Monthly rainfall totals for NYC watersheds, 2002 and historical values

The total monthly precipitation figures show that in general precipitation was below normal for January and February 2002. The spring months of March, April, May, and June 2002 had precipitation values greater than normal, followed by two more months of below average precipitation. The last four months of the year had greater than average precipitation, which eventually ended the drought.

2.3 How much runoff occurred in 2002?

Runoff is defined as the part of the precipitation and snowmelt that appears in streams and rivers, *i.e.* "natural" flow. The runoff from the watershed can be affected by meteorological factors such as: type of precipitation (rain, snow, sleet, etc.), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, antecedent precipitation and resulting soil moisture. The physical characteristics of the watersheds also affect runoff. These include: land use, vegetation, soil type, drainage area, basin shape, elevation, slope, topography, direction of orientation, drainage network patterns, and ponds, lakes, reservoirs, sinks, etc. in the basin which prevent or alter runoff. 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, analogous to the estimations for inches of rainfall for the year. This statistic allows comparisons to be made of the hydrologic conditions in watersheds of varying sizes.

Selected United States Geological Survey (USGS) stations (Figure 2.4) were used to characterize annual runoff in the different NYC watersheds. The total annual runoff from the WOH watersheds was about normal or slightly less due to the drought conditions in the early part of the year, while runoff from the EOH watersheds were all well below normal due to the precipitation deficit.

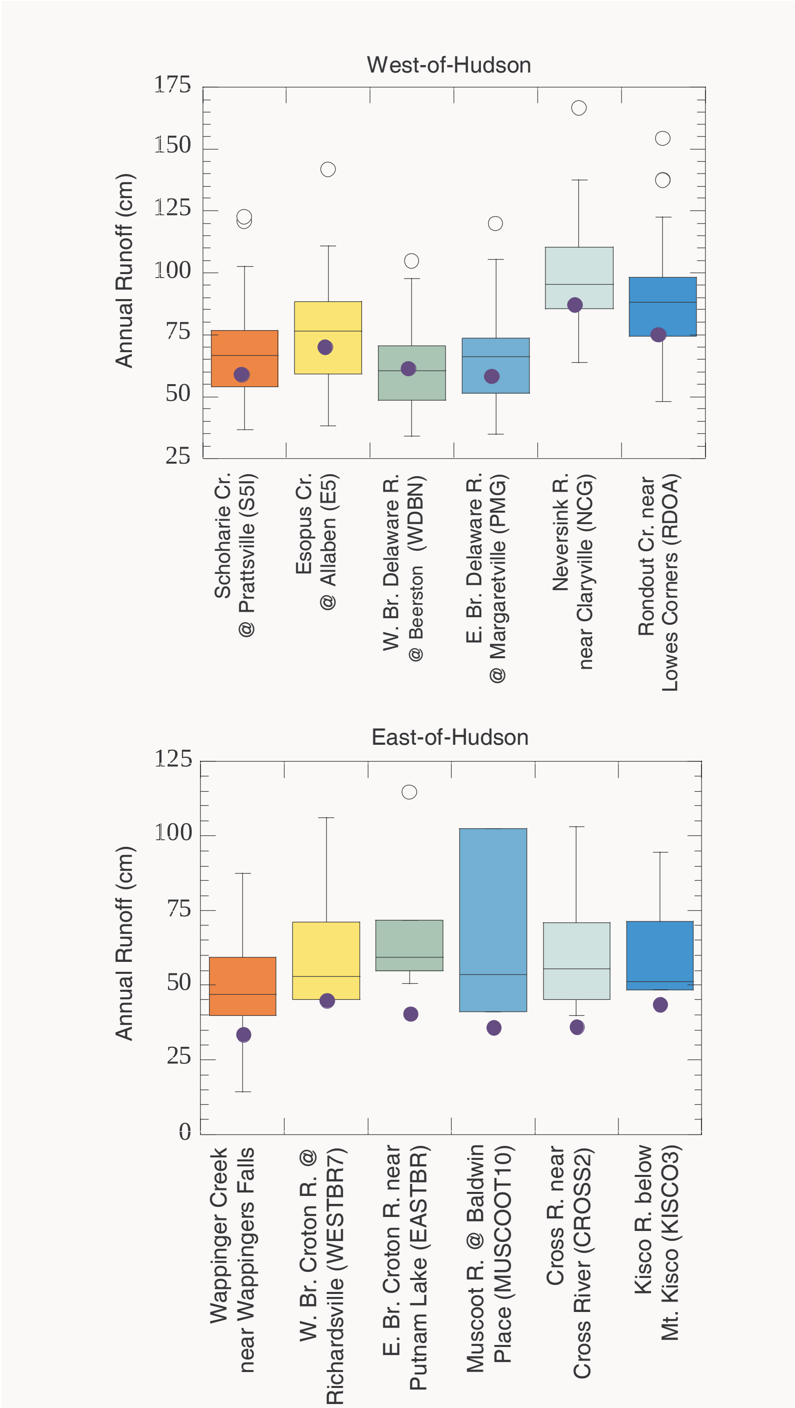


Figure 2.4 Historic annual runoff (cm) as box plots for the WOH and EOH watersheds with the values for 2002 displayed as a dot.

The USGS data collected after Sept. 30, 2001 are provisional.

2.4 What was the storage capacity of the reservoir system in 2002?

The total available percent capacity (Actual) in 2001-2002 is compared to the monthly long-term average (Normal) in Figure 2.5. The long-term average was determined by calculating the monthly percent capacity during 1991-2000. Departure from the long-term average is apparent from 9/28/01-6/25/02 when total capacity was up to 40 percent less than "Normal" capacity. For the remainder of the year rainfall increased and percent capacity returned to approximately normal levels.

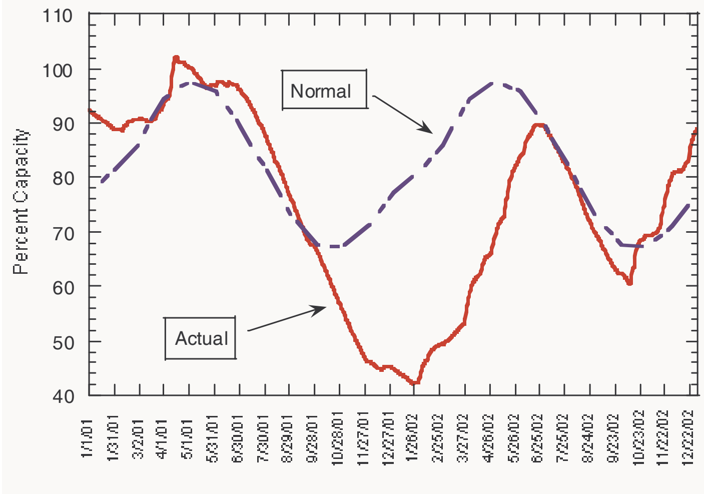


Figure 2.5 Percent usable storage in 2001-2002 (Actual) compared to long-term (1991-2000) average (Normal) storage.

2.5 How does flow affect reservoirs and their water residence times?

Residence time is an estimate of the average time water resides in a reservoir, or may be thought of as a replacement rate. The annual residence times are estimated by dividing the average reservoir storage by the total outflow for each month and taking the average. In 2002, the residence times for several reservoirs were longer than they had been since 1995. The primary reason for this was the low-flow, drought conditions of 2002. Box plots of annual residence time are presented in Figure 2.6. The time period represented for Catskill and Delaware System reservoirs, including Kensico and West Branch, is 1992-2002. Residence times for 1995-2002 (recent years) are presented in the box plots of the Croton System Reservoirs. The residence times for Pepacton and Neversink were much longer than recent years because total outflow was less in 2002 compared to past years. Less outflow occurred for two reasons: 1) less water was diverted into the aqueduct in an effort to conserve supply during the drought, and 2) in 2002 reservoir elevations were always below their spillway elevations so that no water could leave via the spillway. Less spillage in 2002 compared to past years also occurred at several Croton System Reservoirs (*i.e.*, Croton Falls, Titicus, Amawalk and New Croton). Since spillway releases normally account for a large portion of annual output in these reservoirs, the decrease in spillway releases in 2002 resulted in an increase in residence time. The residence time at West Branch was also longer than in past years. Here the longer residence time resulted from diverting less water from the reservoir into the aqueduct in an effort to conserve water or avoid water quality problems. It should also be noted that dam rehabilitation projects occurred at Cross River from 1996-1998, and at Titicus and Amawalk from 1997-1999. During portions of this time the reservoirs were lowered to accommodate repairs on the dams. The decrease in spillway releases and varied storage volumes during the dam rehabilitation years explains the broad range of residence times observed in the box plots for these reservoirs. Finally, the residence time of Boyd Corners also appears to be longer than normal. This may not be the case, however, since it appears that outflows from this reservoir have been overestimated by weir equations resulting in underestimates of the residence time prior to 2002. In 2002, a USGS gauge was installed allowing outflow to be measured directly. At Bog Brook/East Branch Reservoirs, extreme drawdown during the drought resulted in the shortest residence time observed for these reservoirs since 1995.

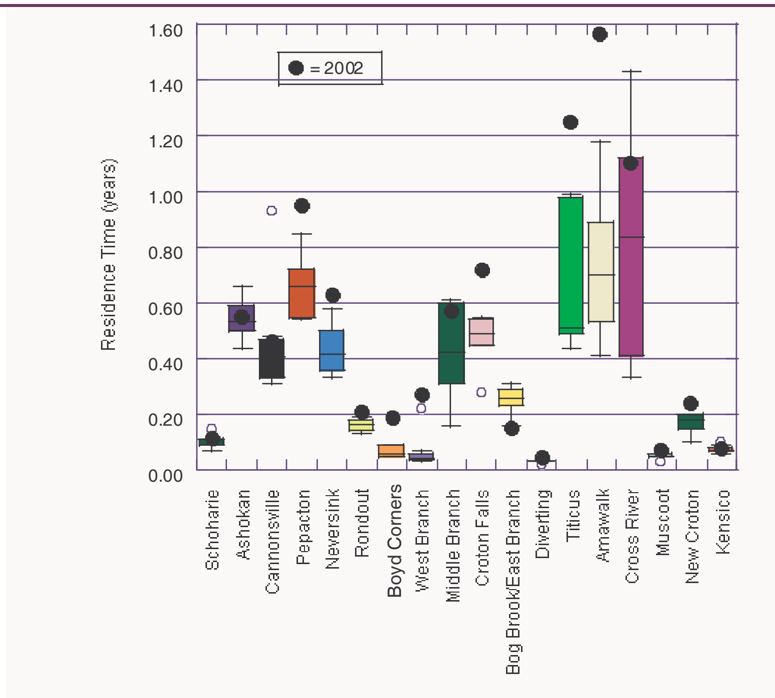


Figure 2.6 Annual residence time for NYC water supply reservoirs (2002 *vs.* 1992-2001 for Catskill and Delaware System Reservoirs including West Branch and Kensico, 2002 *vs.* 1995-2001 for Croton System Reservoirs).

Residence times for Catskill and Delaware System Reservoirs were calculated using total storage volume. Total storage is not available for Kensico, West Branch and the Croton System Reservoirs so available storage was used instead.

2.6 How did DEP cope with the drought?

At the beginning of 2002 NYC was still under an official Drought Watch for the City's Water Supply System that had been declared in December 2001. On January 27, 2002 the system moved from a Watch into a Drought Warning. On April 1, 2002 a Stage I Drought Emergency was declared. In a Stage I Drought Emergency, mandated prohibitions are placed on water use. Although Spring 2002 had rainfall amounts slightly above normal, this did not compensate completely for the drought conditions of the previous nine months, so on June 1, 2002 the reservoirs were only at 82.5% of their capacity instead of the normal 100% capacity on that date. Precipitation was above normal during the last four months of the year. This allowed the Drought Emergency to be reduced to a Drought Watch on November 1, 2002, which was in effect for the remainder of the year.

3. Water Quality

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

DWQC Watershed Laboratory Operations has an extensive Aqueduct Monitoring Program that involves the daily collection and analysis of samples from reservoir intakes, tunnel outlets and aqueducts in the Catskill, Delaware and Croton Systems. In 2002, over 60,000 physical, chemical and microbiological analyses were performed on 10,000 samples that were collected from 65 different key aqueduct locations. DWQC also operates and maintains continuous monitoring stations (Figure 3.1) at several of these locations to provide real-time water quality data. Scientists from DWQC review data from the aqueduct and limnology programs on a continuous basis, and work closely with the Bureau's Division of Operations to determine the best operational strategy for delivering the highest quality water to NYC consumers.

The design of the reservoirs and aqueducts in the Catskill, Delaware and Croton Watersheds provides DEP with numerous options for optimizing the quality of water that is diverted through the system. Common operational strategies include:

Selective Diversion

Water is delivered to NYC consumers through a series of reservoirs and aqueducts from the Catskill, Delaware and Croton Watersheds that ultimately lead to the distribution system. DEP maximizes the flow from reservoirs with the best water quality and minimizes the flow from reservoirs with inferior water quality. If water quality in a reservoir declines, DEP can take the reservoir "off-line" or bypass the reservoir to prevent negative impacts downstream in the system.

Figure 3.1 Continuous Monitoring Station at the Catskill Lower Effluent Chamber.

Selective Withdrawal

Many of the City's reservoirs have water withdrawal points at multiple elevations, and water quality can vary significantly between these different depths. An example of an intake structure with multiple withdrawal points is shown in Figure 3.2. DEP monitors water quality data from different elevations within the reservoirs, and gate-like devices called stop shutters can be used to control the elevation from which that water is withdrawn. This technique is particularly effective during the summer months when the reservoirs are stratified due to thermal variations.

Figure 3.2 West Branch Reservoir upper intakes.

Blending Operations

The Water Supply System is designed to allow DEP to blend water from a combination of intake levels and locations within individual reservoirs, and to blend water between different watershed systems to improve water quality. In 2002, water from two different locations in the New Croton Reservoir was blended with water from the Ashokan Reservoir to effectively decrease color levels in the Croton System.

Treatment Operations

If the above options fail to adequately address water quality problems such as turbidity, bacterial events and algal blooms, DEP has the ability to implement various treatment operations. Elevated levels of turbidity can be treated through the addition of aluminum sulfate (alum). Alum causes particles in the water to coagulate and settle out before they can impact water quality in downstream reservoirs. Likewise, elevated levels of bacteria and algae can be treated through the addition of chlorine. While chlorine is routinely added immediately before diversion to the distribution system for disinfection, it can also be added to upstate aqueducts to provide preliminary treatment to minimize the effects of bacterial and algal blooms on downstream reservoirs. Selective diversion, selective withdrawal and blending operations were highly effective in 2002, and no treatment operations were required.

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

The Surface Water Treatment Rule (SWTR) (40CFR171.71(a)(1)) requires that water at a point just prior to disinfection ("raw water") not exceed thresholds for fecal coliform bacteria

(Figure 3.3) and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at “keypoints” just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF and the Delaware System at DEL18). Figures 3.4 and 3.5 depict fecal coliform and turbidity data for 1992-2002. Both figures include a horizontal line marking the SWTR limit.

As indicated in Figure 3.4, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; for 2002, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below the 10% limit set by the SWTR standard. For 2002, for raw water samples taken at the three keypoints CROGH, CATLEFF, and DEL18, the mean and median fecal coliform concentrations (cfu 100 mL^{-1}) were 1.8 and 1, 2.5 and 1, and 2.3 and 1, respectively.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.5, all three effluent waters were consistently well below this limit in 2002. For the three keypoints CROGH, CATLEFF, and DEL18, the mean and median turbidity values (NTU) were 1.2 and 1.2, 0.9 and 0.9, and 0.9 and 0.9, respectively.

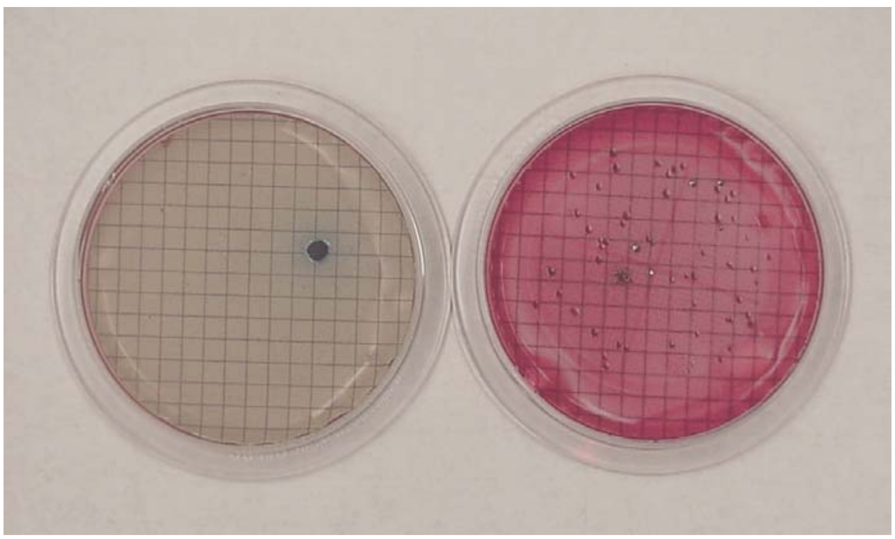


Figure 3.3 Typical fecal and total coliform agar plates.

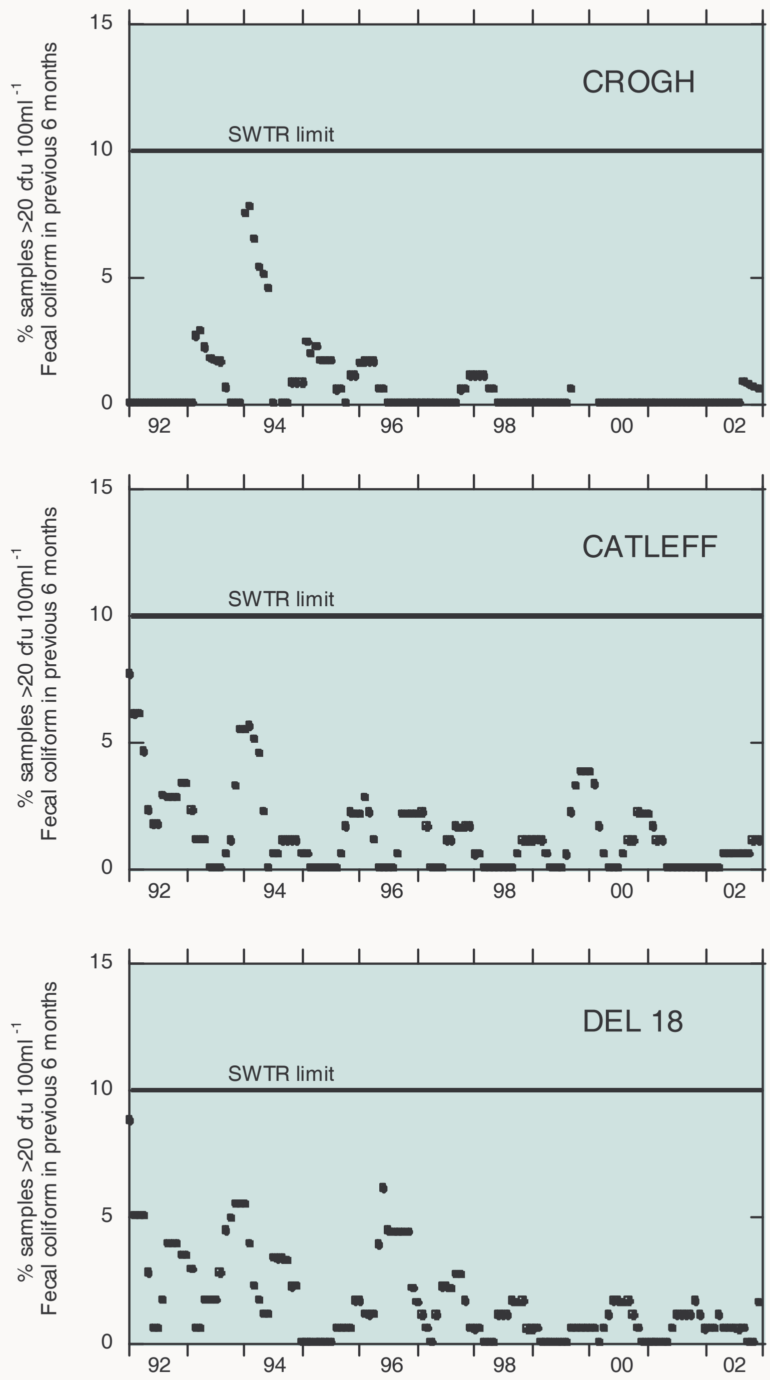


Figure 3.4 Temporal plots of fecal coliform (% of daily samples > 20 cfu 100 mL^{-1} in the previous six months) compared with Surface Water Treatment Rule limits.

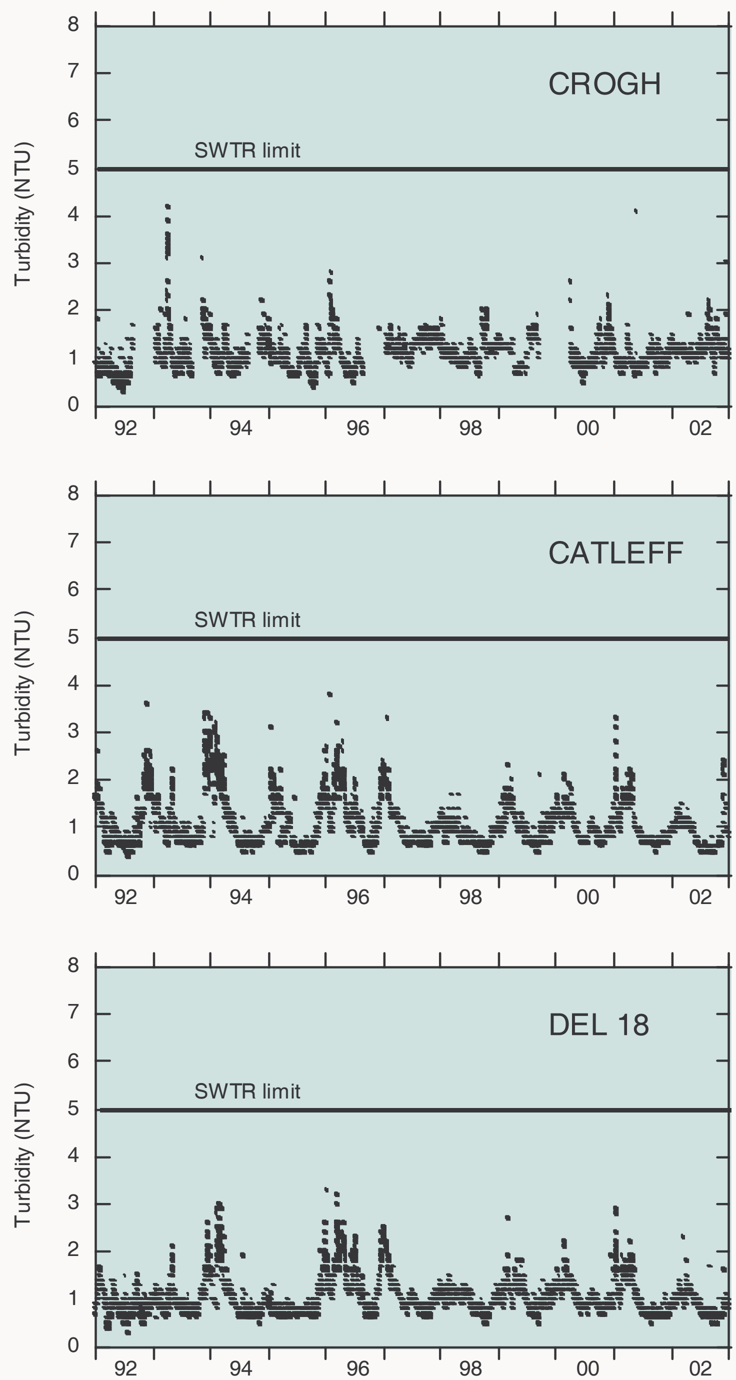


Figure 3.5 Temporal plots of turbidity (daily samples) compared with Surface Water Treatment Rule limits.

3.3 What levels of protozoan pathogens are found in the source waters and watershed?

DEP began monitoring for the protozoan pathogens *Cryptosporidium* and *Giardia* at Kensico Reservoir's effluents in 1992. Monitoring was extended in 1993 to include additional reservoir keypoints, other sites throughout the watershed, and human enteric viruses at selected sites. In 2002, 743 samples from 47 sites were collected and analyzed for *Cryptosporidium* and *Giardia,* and 287 samples from 15 sites for human enteric viruses. Weekly results are posted on the DEP web site (http://www.nyc.gov/html/dep/html/pathogen.html) and presented in semi-annual reports.

Concentrations of pathogens in streams and reservoirs are very low. Sampling methods require the filtration of large volumes of water (50 liters for protozoans and 100 liters for viruses) to recover a few organisms (Figure 3.6). All samples collected and analyzed for protozoans in 2002 used USEPA Method 1623 (USEPA, 2001a). Fixed frequency sampling locations include source water, keypoints, streams (including major influents to reservoirs), and wastewater treatment plants. These locations are represented on Figures 3.7 to 3.9. Keypoints are major influents and effluents of reservoirs, either major stream inputs or aqueducts entering or leaving the reservoirs. Stream locations measure non-point sources and can represent various types of land use and land cover.

Figure 3.6 Pathogen sampling requires filtration of large (50 to 100 L) volumes.

Source water keypoints are sampled at least once a week. A total of 156 weekly samples were collected at the two Kensico Reservoir effluents and New Croton Reservoir effluent. *Cryptosporidium* was found in 13 samples from each of the two Kensico Reservoir effluents and 10 samples from New Croton Reservoir (Figure 3.10). *Giardia* was found more often than *Cryptosporidium* (73 in the Kensico Reservoir effluents and 23 in the New Croton Reservoir effluent). Similarly, *Cryptosporidium* detection in Kensico Reservoir influents (14 out of 104 samples) is less frequent than *Giardia* (46 out of 104 samples). Human enteric viruses were not found in any of the 156 samples collected at New York City's three source water effluents or in 104 samples collected at Kensico Reservoir's influents.

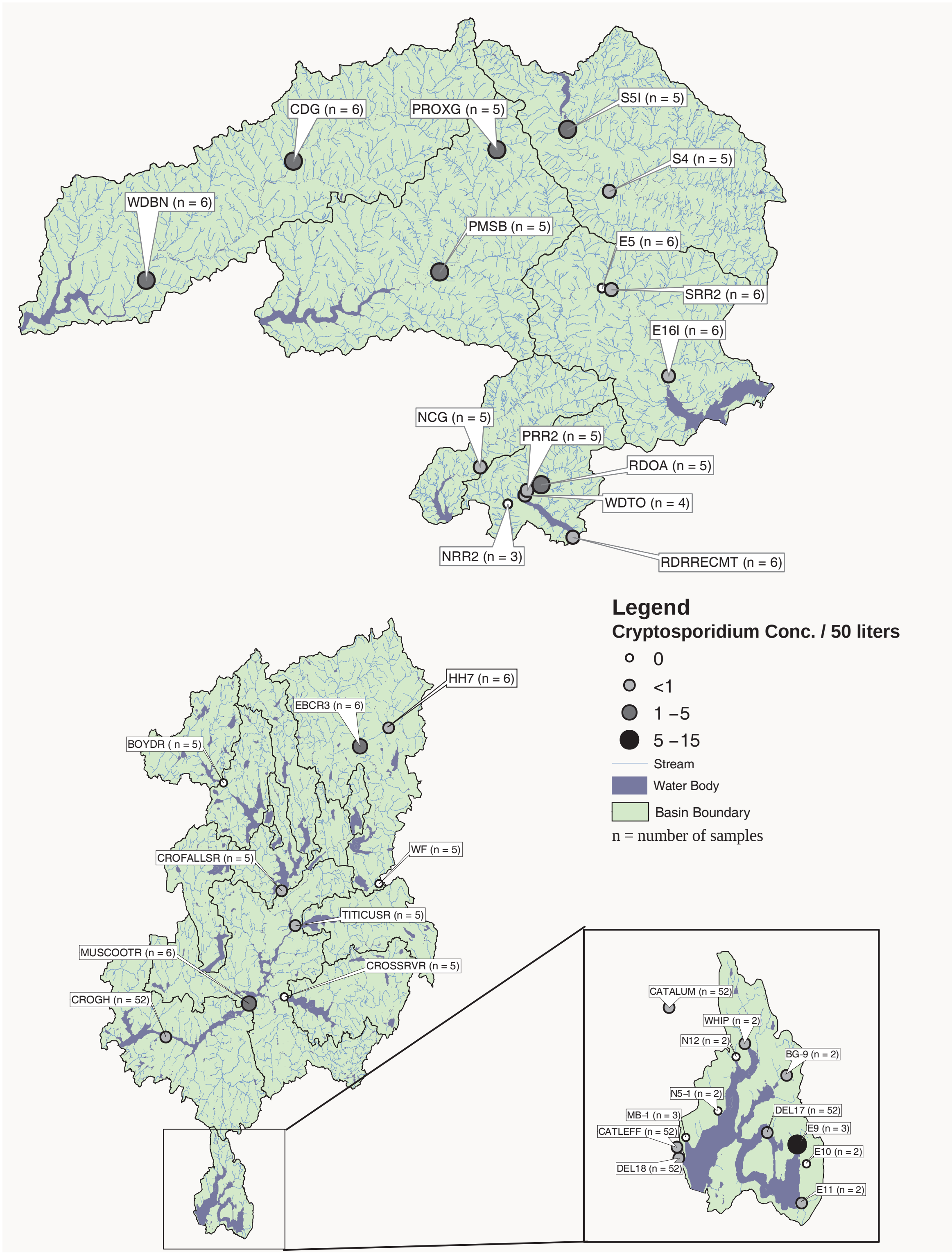


Figure 3.7 2002 Average *Cryptosporidium* concentrations in streams and upstate reservoir effluents

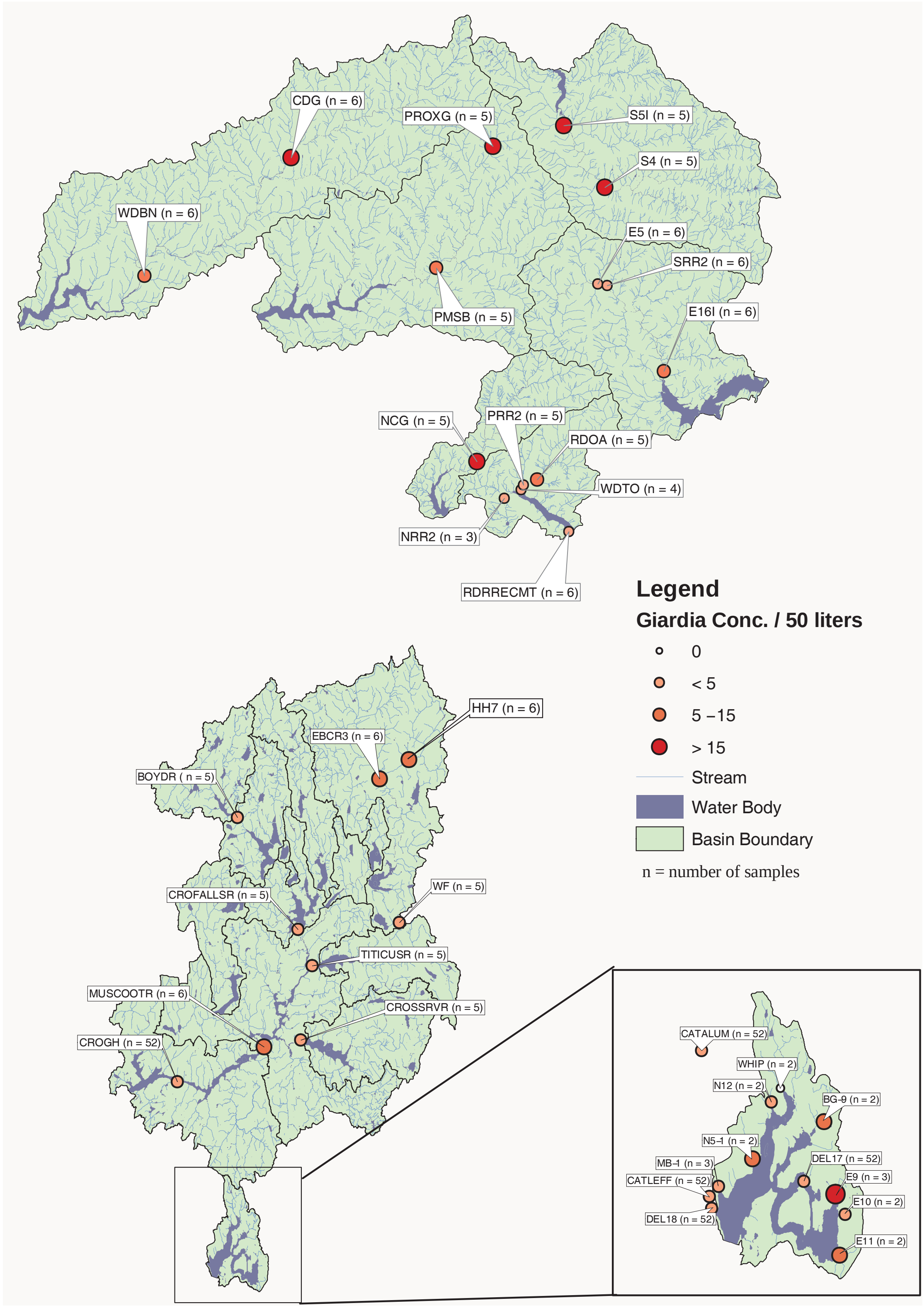


Figure 3.8 2002 Average *Giardia* concentrations in streams and upstate reservoir effluents

Fixed-frequency sampling of *Cryptosporidium* and *Giardia* from upstream reservoir effluents and streams feeding these reservoirs is summarized in Figures 3.7 and 3.8. The figures present the distribution of the sampling locations across the New York City Watershed. *Giardia* is found more frequently than *Cryptosporidium*.

Nineteen wastewater treatment plant effluents were collected from July to December 2002 at nine upgraded plants located West-of-Hudson and one plant located East-of-Hudson (Brewster) (not shown). One *Cryptosporidium* was found in two samples and *Giardia* in five samples (Figure 3.9). Human enteric viruses were not found at upgraded WWTPs but were found in four of 12 samples at the Brewster plant which is scheduled for an upgrade.

All upgrades for New York City-owned WWTPs were completed in 1997. Among non-City owned WWTPs whose upgrades were completed in 2002, the villages of Delhi, Walton and Stamford added dual sand filtration, and the village of Hobart added microfiltration to its treatment process. One *Cryptosporidium* in a 50 liter sample was found once at Pine Hill WWTP and once at Brewster WWTP. *Giardia* was found at four of the nine West-of-Hudson WWTPs sampled during the year and once at Brewster WWTP. Human enteric viruses were not found at any of the West-of Hudson upgraded plants. The Brewster WWTP was sampled monthly. Low concentrations of viruses were found in four of the 12 samples (concentrations ranging from 1 to 7.5 virus per 100 liters).

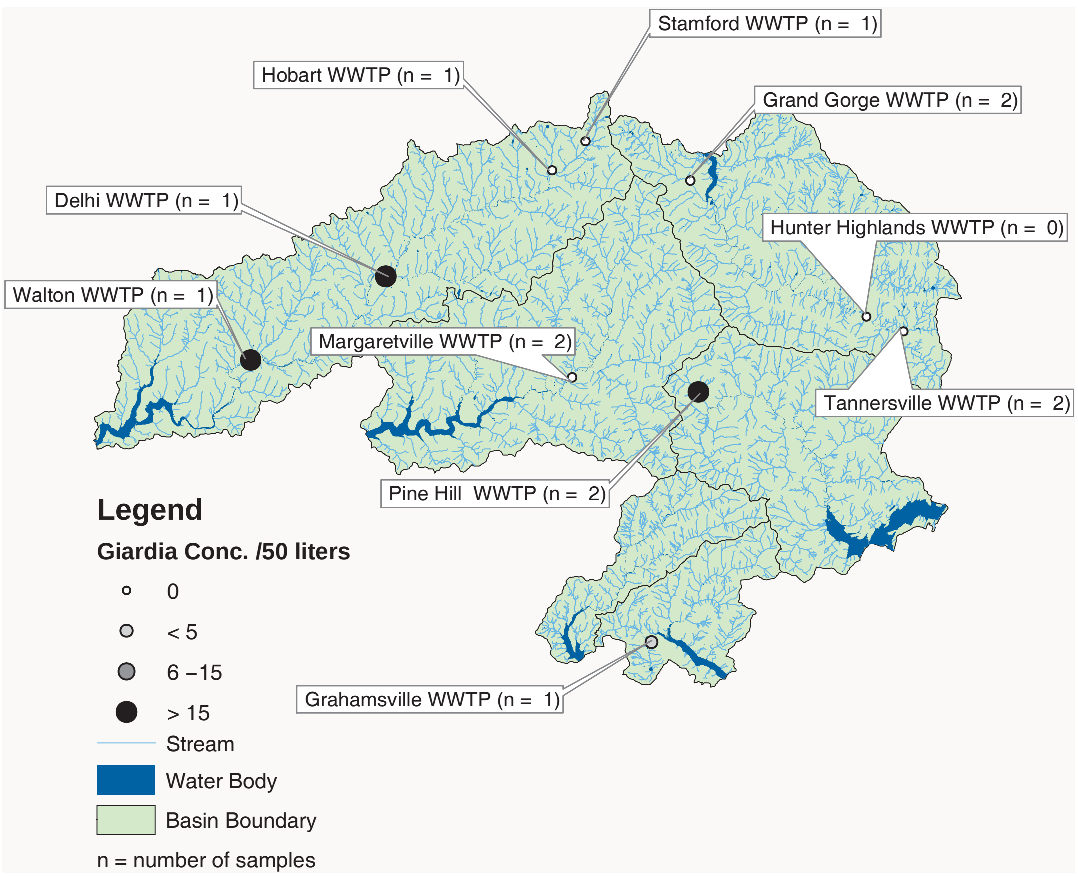


Figure 3.9 2002 Average *Giardia* found at West-of-Hudson wastewater treatment plants.

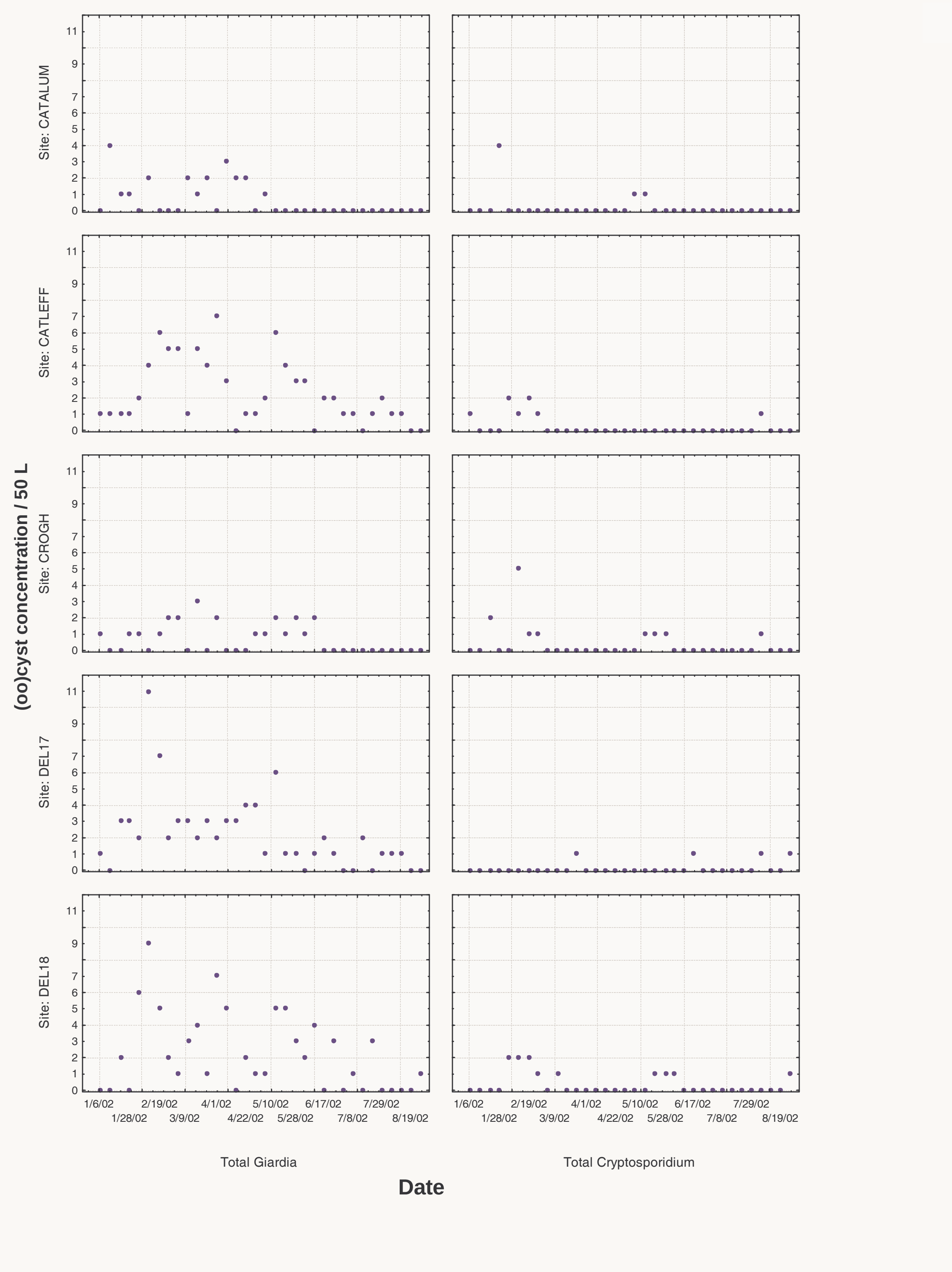


Figure 3.10 Temporal plots of *Giardia* and *Cryptosporidium* concentrations at Kensico and New Croton Reservoirs during 2002.

DEP also conducted event-based monitoring. Samples are collected as a result of spills or during significant rainstorms sufficient to produce runoff. Autosamplers are used during storm events to (a) compare oocyst concentrations during fixed-sampling base flow monitoring and storm event sampling, and (b) conduct genotype studies (see Section 3.5). Results from the event-based monitoring are reported in semi-annual reports (NYCDEP, 2003a).

3.4 How do protozoan concentrations compare with regulatory levels and results from previous years?

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

Method 1623HV is more sensitive than methods previously used (ASTM, ICR), so higher concentrations and occurrences of protozoans are expected. However, since these methods (a) use different sampling and analytical procedures, and (b) have different levels of detection, results are not directly comparable between the methods. Higher concentrations and more frequent detections reported by the laboratory do not necessarily reflect changes in water quality. Some general observations comparing historical data and the current reporting period (2002) suggest that current results are similar to previously reported results. On average, fixed-frequency results from source water keypoints are the lowest in protozoan concentrations (Figure 3.10). Data from upstream keypoint sites (*i.e.*, NRR2, PRR2, RDRRECMT, WDTO, and SRR2) show that (a) *Giardia* was found at more locations than *Cryptosporidium* (4 and 5, respectively), and (b) *Giardia* was found in greater numbers than *Cryptosporidium* (2.14 $50L^{-1}$ and 1.36 $50L^{-1}$, respectively). Fixed frequency results from stream sites also show (a) *Giardia* was found at more locations than *Cryptosporidium* (21 and 15, respectively) and (b) *Giardia* was found in greater numbers than *Cryptosporidium* (26.6 $50L^{-1}$ and 1.48 $50L^{-1}$, respectively). *Cryptosporidium* and *Giardia* are more likely to be found in higher numbers in stream sites, because those locations are closer to sources of these protozoans, and lower at keypoints which represent larger bodies of water where *Cryptosporidium* and *Giardia* are likely to be diluted.

3.5 Does the DEP know where the low levels of *Cryptosporidium* in NYC's unfinished water supply originate?

The DEP has been working with the Centers for Disease Control and Prevention (CDC) on methods to improve the detection and characterization of *Cryptosporidium* oocysts from environmental samples since late 1998. After detection, oocysts have been analyzed using a small-subunit rRNA-based diagnostic and genotyping tool. This is a Polymerase Chain Reaction (PCR) method that analyzes the DNA of the oocysts to identify the species and host origin of the protozoa. Since base flow water samples in our system normally result in no detection of oocysts, these studies have been conducted only on stream samples collected during storm events where there is increased runoff and overland flow in the upstate watershed.

Cryptosporidium genotypes studied during 2002, which are mostly from samples collected at Malcolm Brook, a tributary to Kensico Reservoir, indicate that 88% of the known genotypes recovered during that year originated from non-human sources. More specifically, the DNA sequencing indicates that the animal hosts of these oocysts were wild animals, and not farm animals or domestic animals. Nearly a third of the oocysts studied this year have not yet been matched with known sources; however, their genetic patterns suggest that they are not from human sources, and are also likely from wildlife. The exception was in March of 2002 on Malcolm Brook, when some human types were discovered along with the wildlife types. Interestingly, DEP has continued to sample Malcolm Brook since that time and no detection of human types has been repeated there for the past 15 months. Figure 3.11 illustrates the sources of *Cryptosporidium* oocysts found in Malcolm Brook from December 2001 – June 2003.

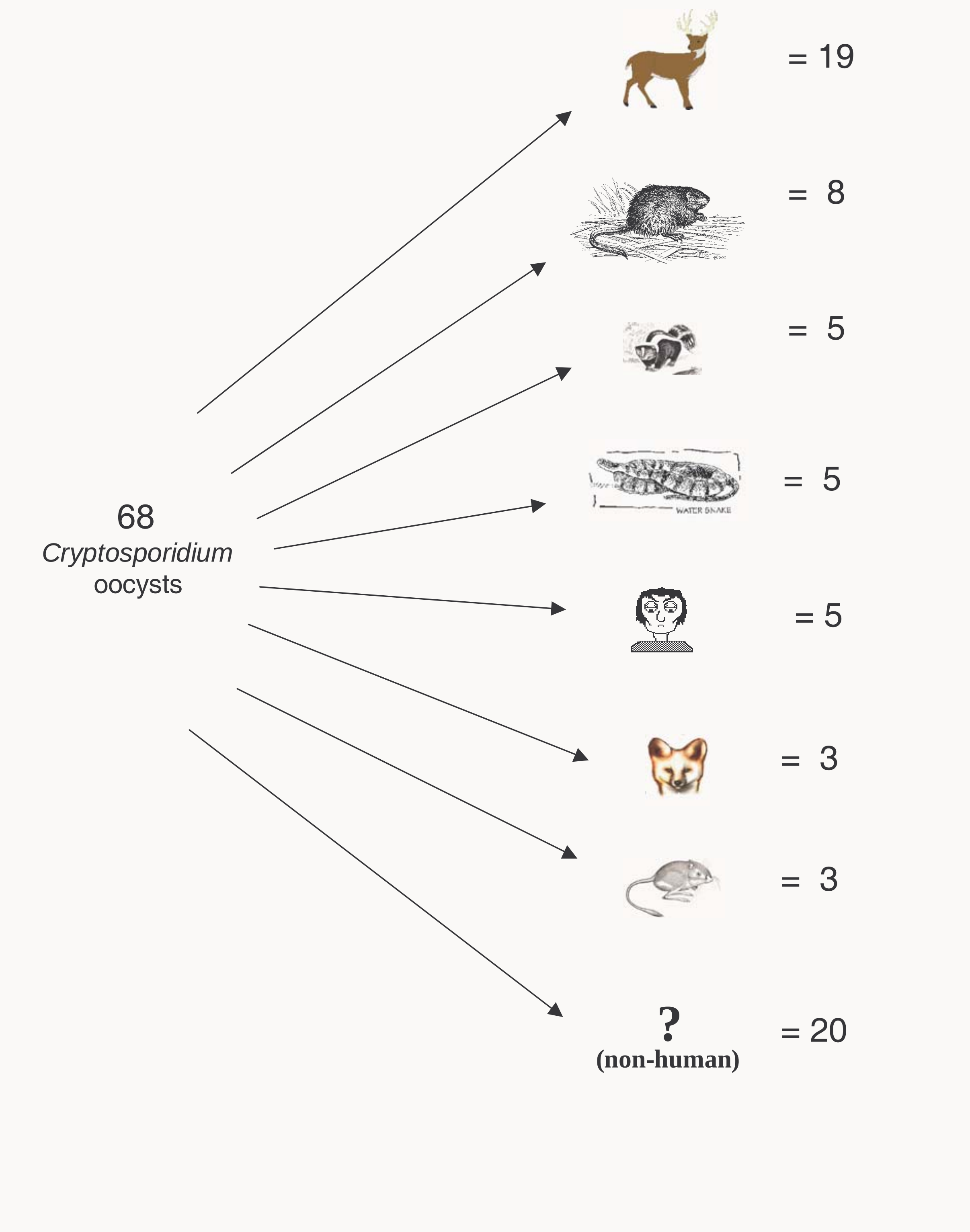


Figure 3.11 Sources of *Cryptosporidium* oocysts found in Malcolm Brook between Dec. 2001 and June 2003 using SSU rRNA PCR technique.

3.6 Why is the origin of pathogens important?

The species of *Cryptosporidium* and type of animal that it comes from is important since, like many illnesses, *Cryptosporidiosis* is a species specific ailment. In other words, not all *Cryptosporidium* oocysts can cause illness in humans, and those most likely to infect humans (*i.e.*, those originating from other humans) have not been routinely detected in the upstate watershed. A summary listing of all the streams and storm events studied for oocyst genotypes is presented in Table 3.1.

Table 3.1: Stream storm samples analyzed for *Cryptosporidium* genotypes, Jan.-Dec. 2002.

Stream	# Storm Events	# Oocysts genotyped	Known genotypes
Malcolm Brook	18	48	5 human*, 43 non-human
N5	3	6	6 non-human
E9	2	2	2 non-human

* All human types occurred in March 2002 and have not been repeated in past 15 months.

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

The stream sites used in this report are presented in Table 3.2 and shown pictorially in Figure 3.12. 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 5 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 3.2: 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 Boyds Corner Res.
EASTBR	East Branch Croton River, above East Branch Res.
MUSCOOT10	Muscoot River, above Amawalk Res.
CROSS2	Cross River, above Cross River Res.
KISCO3	Kisco River, input to New Croton Res.
HUNTER1	Hunter Brook, input to New Croton Res.

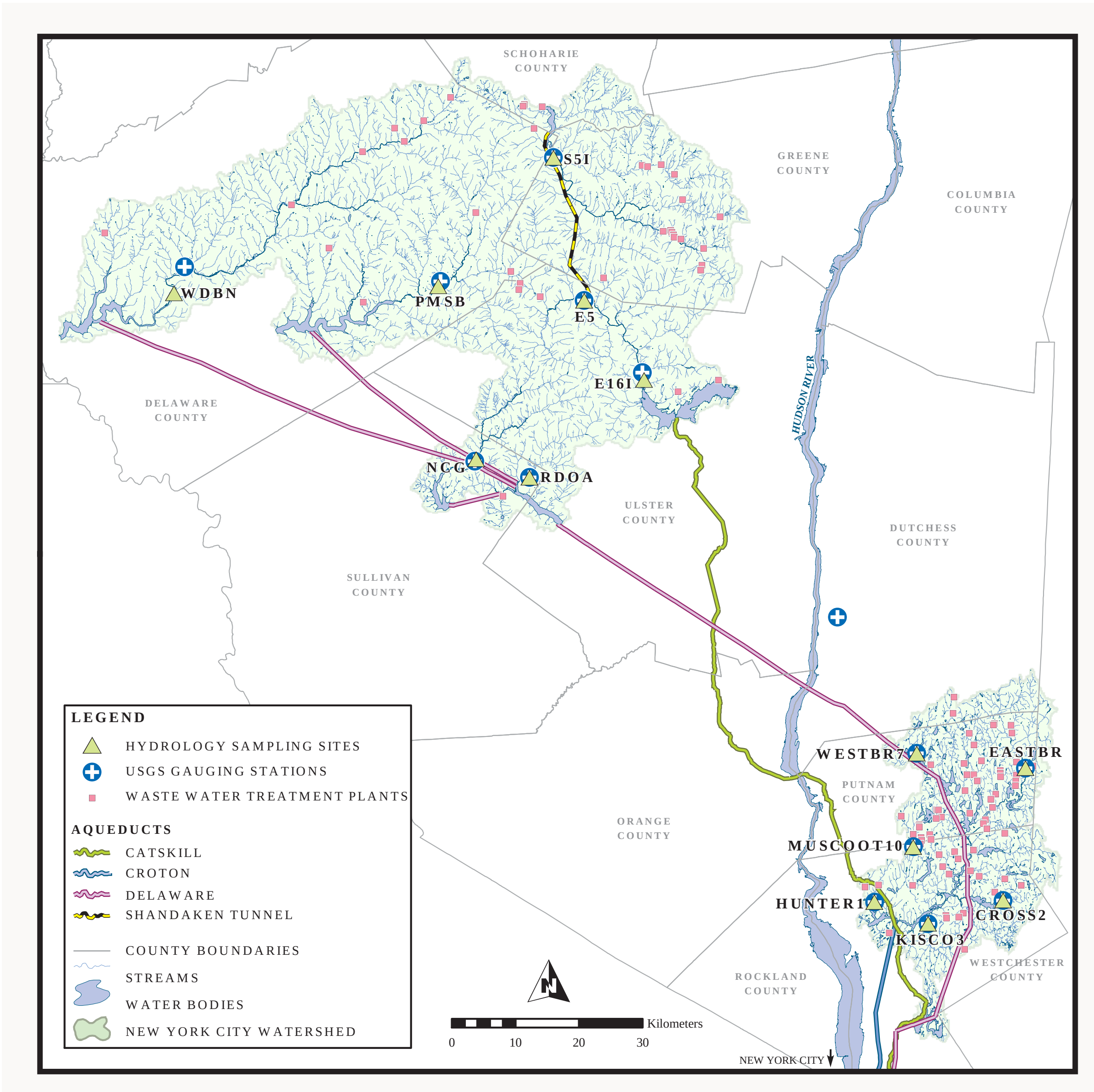


Figure 3.12 Locations of sampling sites and USGS stations discussed in this report.

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

The results presented are based on grab samples generally collected twice a month. The figures compare the 2002 median values against historic median annual values for the previous ten years (1992-2001). However, several of the EOH sites have shorter sampling histories. These include: WESTBR7 (1995-present), KISCO3 (1999-present), and HUNTER1 (1998-present).

Turbidity in Streams

The turbidity levels for 2002 were generally near “normal” values (Figure 3.13a). This includes the inflow to the Schoharie and Ashokan Reservoirs and indicates improvement in the turbidity levels of the Schoharie watershed (see Section 3.8).

Total Phosphorus

In the Catskill/Delaware System, the 2002 total phosphorus levels (Figure 3.13b) were for the most part near or slightly below typical historical values. In the Croton System total phosphorus values (Figure 3.13b) were either near or slightly above historical values.

Coliforms (fecal and total)

The 2002 coliform levels (Figure 3.13c and d) in the Catskill/Delaware and Croton Systems were generally near the typical historical levels.

A fecal coliform benchmark of 200 cfu 100 mL^{-1} is shown as a solid line in Figure 3.13c. This benchmark relates to the NYS Environmental Conservation Rules and Regulations water quality standard (expressed as a monthly geometric mean of five samples, the standard being <200 cfu 100 mL^{-1}) for fecal coliforms. The 2002 median values for all streams shown here lie well below this value.

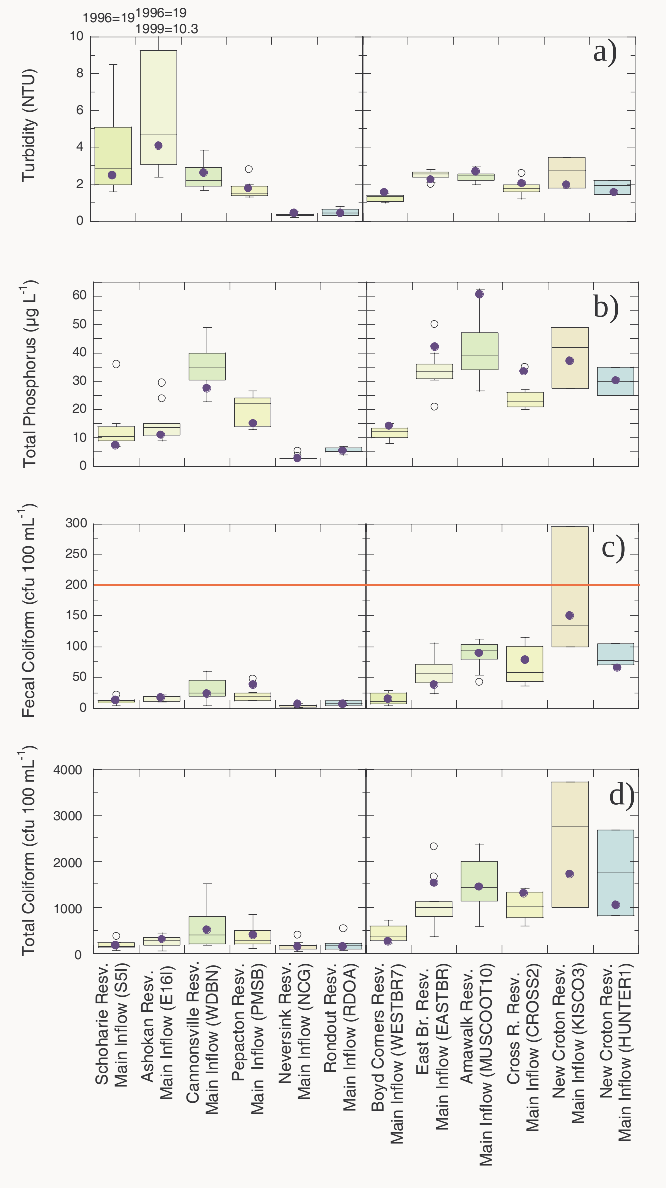


Figure 3.13 Box plot of annual medians (1992-2001) for a) turbidity b) total phosphorus c) fecal coliforms d) total coliforms for selected stream (reservoir inflow) sites with the value for 2002 displayed as a dot.

3.8 What was the turbidity of water in NYC's reservoirs?

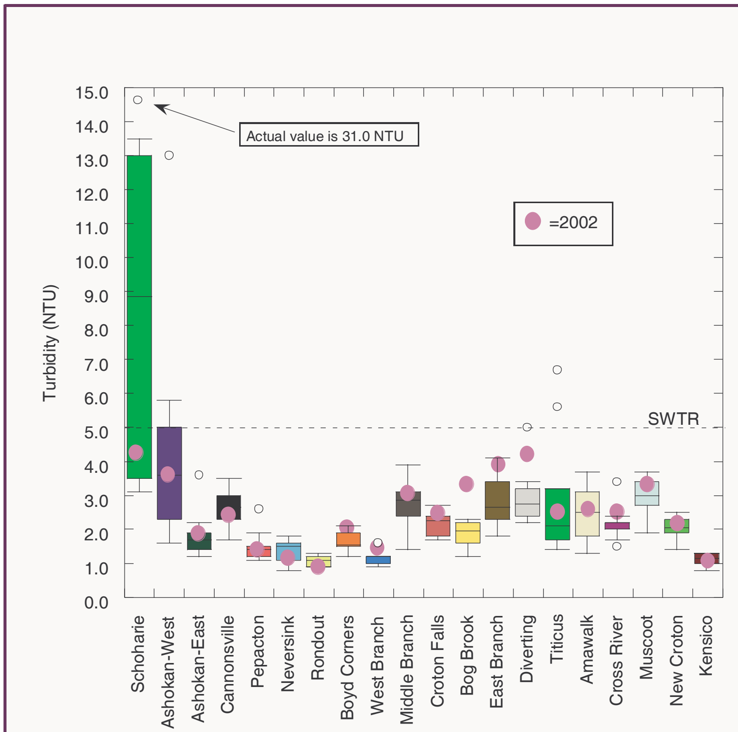


Figure 3.14 Annual median turbidity in NYC water supply reservoirs (2002 *vs.* 1992-2001).

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.

Turbidity in reservoirs is caused by organic and inorganic particulates (*e.g.*, clay, silt, plankton) suspended in the water column. Turbidity may be generated within the reservoir itself (*e.g.*, plankton, sediment re-suspension) or it may be derived from the watershed by erosional processes (*i.e.*, storm run-off). In 2002, the median turbidity in Catskill and Delaware System Reservoirs was near or below the annual medians of the past 10 years (Figure 3.14). Less storm induced runoff compared to past years is one reason for the low turbidity values observed in 2002. Conserving water during the drought also helped to reduce turbidity. By keeping reservoir elevations as high as possible, less of the shoreline sediments were exposed to erosion. However, at two Croton System Reservoirs (Bog Brook, East Branch) demand for water caused water levels to drop severely. The ratio of exposed sediments to water volume increased, resulting in higher turbidity values for Bog Brook and East Branch. Because Diverting Reservoir receives most of its water from Bog Brook and East Branch its turbidity was also elevated relative to past years. At the remaining Croton System Reservoirs drawdown was much less severe. Subsequently the 2002 median turbidities were very similar to past levels. Several small lakes—Kirk, Gilead and Gleneida—are also part of the Croton Reservoir System (not shown in Figure 3.14). The median turbidity during the time period 1995-2001 for Kirk, Gilead and Gleneida was 3.5, 1.4 and 1.4 NTU, respectively. In 2002 the median turbidity was 3.1, 1.0 and 1.6 NTU, very similar to past levels.

3.9 What was the total phosphorus concentration in NYC's reservoirs?

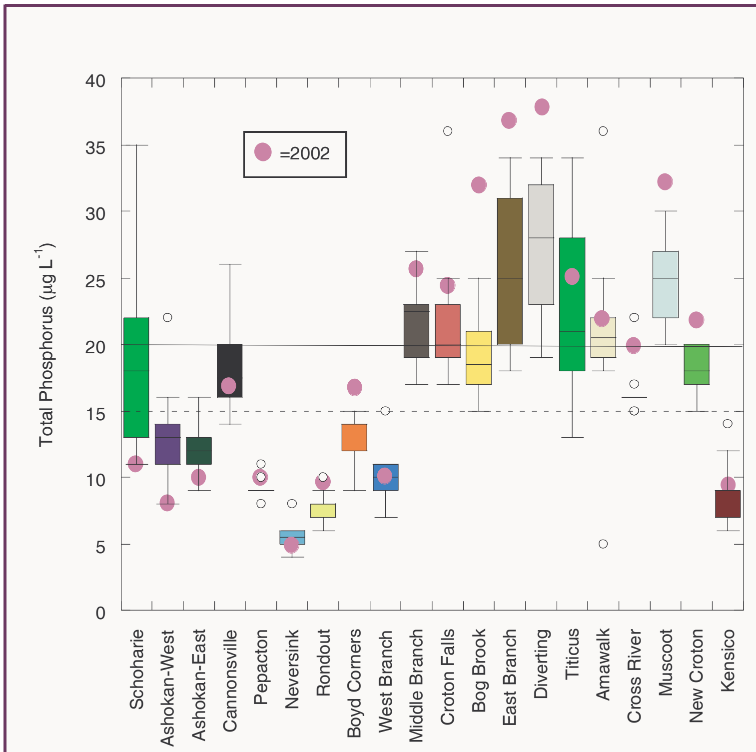


Figure 3.15 Annual median total phosphorus concentrations in NYC water supply reservoirs (2002 *vs.* 1992-2001).

Phosphorus is an important nutrient for plant growth. Main sources of phosphorus in reservoirs include: soil erosion carried by inflowing streams, atmospheric deposition, WWTPs and internal recycling from sediments. Phosphorus concentrations (as total P) for all reservoirs for 2002 are compared with the previous ten years in Figure 3.15. Data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads (TMDL) guidance value based on epilimnetic samples collected bi-weekly from June-September. This guidance value is appropriate for source waters. The horizontal solid line at 20µg L^{-1} refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs). With the exceptions of Schoharie and Cannonsville most Catskill and Delaware System Reservoirs have relatively low long-term concentrations of total phosphorus. Relatively high concentrations can occur at Schoharie because its watershed is very large and highly susceptible to soil erosion. Elevated phosphorus at Cannonsville is likely due to agricultural runoff and five waste water treatment plants that are located within the watershed. In 2002, the annual median phosphorus concentrations at all Catskill and Delaware System reservoirs were near or well below the annual median values of the past 10 years. Due to the lack of storm runoff and because the reservoirs were kept as full as possible to conserve water during the drought, erosional inputs of phosphorus were minimized.

Total phosphorus concentrations in the Croton System Reservoirs are noticeably higher than in the Catskill and Delaware Systems due primarily to development pressure. To serve the population, approximately 60 WWTPs are scattered throughout the Croton watershed. Septic systems are also prevalent. In 2002, the annual median total phosphorus concentrations at most Croton Reservoirs were higher compared to past years. Drought induced drawdown may be responsible. When a reservoir's outflow exceeds its inputs less water is available to dilute phosphorus inputs. Drawdown also increases the exposure of shoreline sediments making them more susceptible to erosion. Phosphorus concentrations for Kirk, Gilead and Gleneida lakes in 2002 (data not provided in Figure 3.15) were consistent with past data. In 2002 the median total phosphorus for Kirk, Gilead and Gleneida was 32, 18 and 18 µg L^{-1}, respectively.

3.10 Which basins are phosphorus-restricted?

The phosphorus restricted basin status was derived from two consecutive assessments (1997 - 2001; 1998 - 2002) using the methodology set forth in Appendix C. Table 3.3 lists the annual summer geometric mean phosphorus concentration for each of the City reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.16 graphically depicts the phosphorus restriction status of the NYC Reservoirs and the year 2002 phosphorus concentration.

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

- In September1999, Schoharie Reservoir was impacted by flooding, as a result of Tropical Storm Floyd, which brought in large amounts of suspended material and resulted in higher phosphorus concentrations. Since this event is unusual and unpredictable and did not result in eutrophication of the reservoir, the Department is utilizing its best professional judgment and is not designating Schoharie basin as phosphorus restricted at this time.
- Bog Brook Reservoir, East Branch Reservoir, Lake Gleneida, and Lake Gilead had insufficient phosphorus data in 2002, due to laboratory error, field error, or inaccessibility, to fulfill the data requirement of three complete surveys during the growing season. The assessment was thus performed on the previous four years of data (1998-2001).
- Cannonsville Reservoir continued in its second year of non-restricted status.

The 1998-2002 assessment showed that New Croton is above the 20 µg L^{-1} criterion. If the trend continues in the upcoming 1999-2003 assessment, the reservoir will become phosphorus restricted.

Table 3.3: Phosphorus restricted reservoir basins for 2002.

Reservoir Basin	97 - 01 Assessment (mean + S.E.) (µg L^{-1})	98 – 02 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus Restricted Status
Delaware System			
Cannonsville Reservoir	19.2	18.2	
Pepacton Reservoir	8.5	9.2	
Neversink Reservoir	5.3	5.3	
Rondout Reservoir	8.55	9.0	
Catskill System			
Schoharie Reservoir	21.7	21.0	
Ashokan-West Reservoir	13.6	12.6	
Ashokan-East Reservoir	12.2	11.8	
Croton System			
Amawalk Reservoir	28.5	28.7	Restricted
Bog Brook Reservoir	25.1	27.3	Restricted
Boyd Corners Reservoir	13.1	14.7	
Cross River Reservoir	16.4	17.5	
Croton Falls Reservoir	22.5	23.4	Restricted
Diverting Reservoir	30.5	35.0	Restricted
East Branch Reservoir	33.1	34.9	Restricted
Middle Branch Reservoir	27.9	29.8	Restricted
Muscoot Reservoir	30.7	32.5	Restricted
Titicus Reservoir	26.6	35.2	Restricted
West Branch Reservoir	10.3	11.7	
Lake Gleneida	28.0	29.0	Restricted
Lake Gilead	32.5	34.6	Restricted
Source Water			
Kensico Reservoir	7.6	8.2	
New Croton Reservoir	19.9	21.8	

Note: Each assessment consists of a five year arithmetic average (plus one standard error of the mean) of the annual geometric mean phosphorus concentrations during the growing season. The previous two assessment periods are compared, and if both assessments exceed the guidance value then the basin is designated phosphorus restricted.

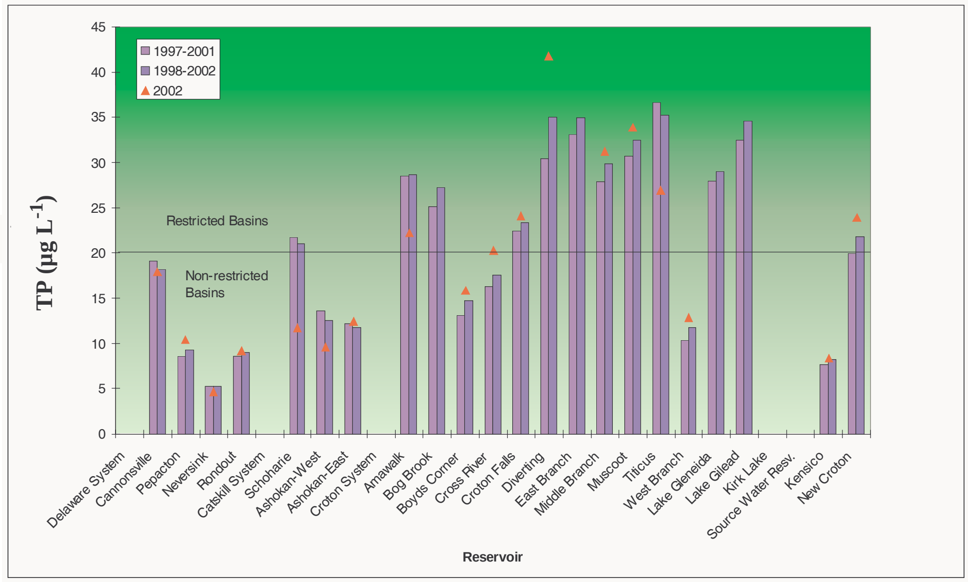


Figure 3.16 Phosphorus restricted basin assessments with the current year (2002) geometric mean phosphorus concentration displayed for comparison.

3.11 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 100 mL^{-1} and 20 cfu 100 mL^{-1}, respectively. Both are used as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals. Figure 3.17 shows that, in the long-term (1993-2001), annual median levels of total coliform have exceeded 100 cfu 100 mL^{-1} at times in Schoharie, Diverting and Muscoot reservoirs. In 2002, only Diverting and Muscoot had a median that exceeded this level. Some basins had a 2002 median higher than the long-term range. Cannonsville, both basins of Ashokan and Middle Branch reservoirs fell into this category. From a review of temporal data (not

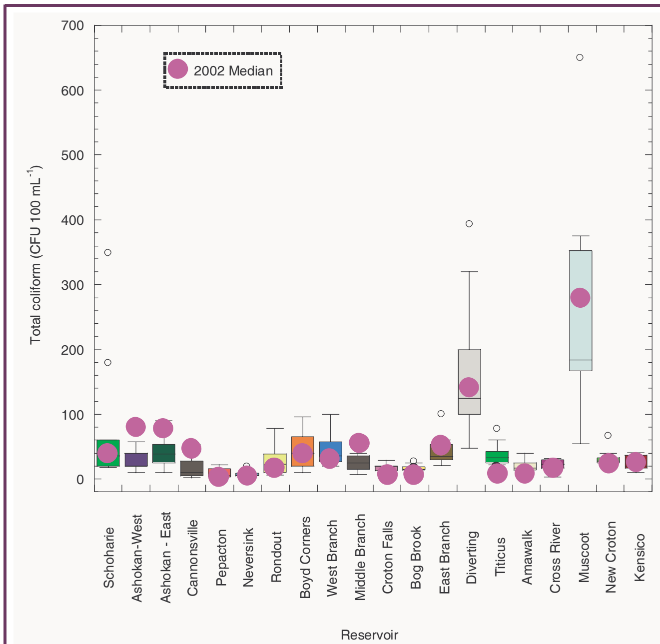


Figure 3.17 Annual median total coliform in NYC water supply reservoirs (2002 *vs.* 1993-2001).

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

shown), Ashokan appears to have an upward trend, while Cannonsville and Middle Branch had a one year increase in total coliform counts. East Branch was also elevated for 2002, but this was due to a minimal number of samples collected during low elevations. Although not shown in the plots, the controlled lakes (Gilead, Gleneida and Kirk) all had elevated medians for 2002 as compared to previous years.

Figure 3.18 shows that the long-term annual medians for fecal coliform have never exceeded 20 cfu 100 mL^{-1} for any of the reservoirs. Muscoot and Diverting are among the reservoirs having the highest levels. Diverting had an increase in fecal coliform as compared to previous years; however, Muscoot remained below its long-term median. East Branch and Bog Brook had a small number of samples, due to low elevations. In 2002, the medians were at the low end of the long-term range for many of the other East-of-Hudson reservoirs. There are many possible causes, but one contributing factor may have been the reduced precipitation and run-off during part of the year. The controlled lakes all had median levels of fecal coliform in 2002 that were comparable to past data.

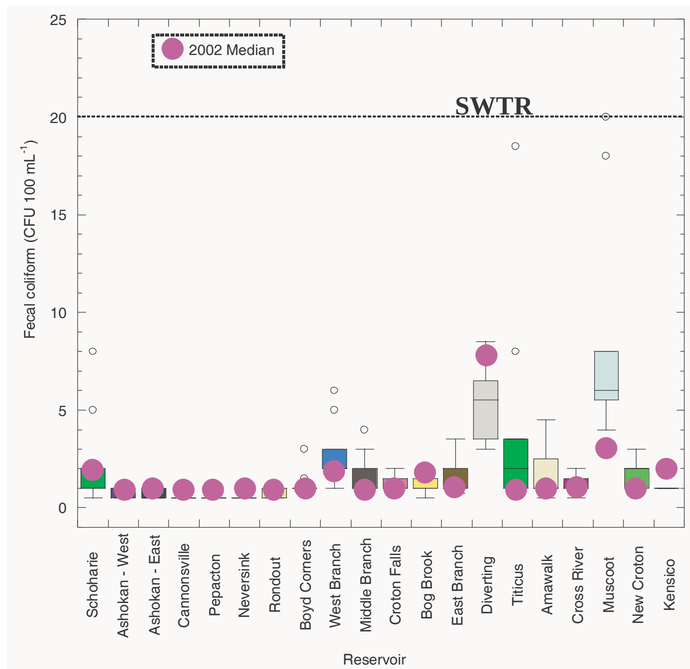


Figure 3.18 Annual median fecal coliform in NYC water supply reservoirs (2002 *vs.* 1993-2001).

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

3.12 Which basins are coliform-restricted?

New York City's revised Watershed Rules and Regulations (WRRs) (NYCDEP, 1996) prohibit new or expanded wastewater treatment plants with surface discharges from being located within coliform-restricted basins, and call for analysis of coliform runoff as part of the stormwater prevention plan in coliform restricted basins. A coliform restricted basin is the drainage basin of a reservoir or controlled lake in which the coliform standards are exceeded as determined by the Department in its annual review. The Regulations specify two sets of coliform standards that drive coliform restricted basin determinations: the total coliform 6 NYCRR Class AA standard, and a fecal coliform standard similar to that in the Surface Water Treatment Rule (NYSDEC, 1991).

The standards used for AA waters are that the monthly median value for **total coliforms** (number 100 mL^{-1}) shall not exceed 50, and no more than 20% of the samples from a minimum of five examinations shall exceed 240 cfu 100 mL^{-1}. Currently 6NYCRR provides no fecal coliform standard for Class AA waters. In addition, the WRRs provide that the **fecal coliform** concentrations measured at locations within 500 feet of the aqueduct effluent chamber located at a terminal reservoir (Kensico, West Branch, New Croton, Ashokan and Rondout) shall be less than 20 cfu 100mL^{-1} in at least 90% of the measurements over any consecutive six-month period. A minimum of 5 samples per week must be taken from each reservoir, with fecal coliform results taking precedence over total coliform results. (This coliform standard is similar to the filtration avoidance fecal coliform requirements set forth in the Surface Water Treatment Rule.) The WRRs also specify that where the Department determines that any exceedances of the above standards are due to "a non-perennial, non-anthropogenic source, such exceedances shall not be included in calculating whether a violation of these rules and regulations has occurred."

The coliform-restricted basin methodology is currently under discussion. The 6NYCRR Class AA standard is problematic in that it is exclusively a total coliform standard, and makes no reference to either fecal coliforms or *E. coli*. In recent years, as better information and analytical technology developed, fecal and *E. coli* have replaced total coliforms as the indicator of choice for fecal contamination. In fact in 1990, when the Surface Water Treatment Rule was developed, that Rule specified that when both fecal and total coliforms are monitored, the fecal findings take precedence. More recent writings emphasize the fact that fecal coliform bacteria (or *E. coli*) most accurately reflect fecal contamination. For this reason further development of the methodology is a consideration for the future.

A revised methodology for determining the coliform restricted status of non-terminal basins, with associated changes to the WRRs, is under consideration. With respect to terminal basins, based on the most recent assessment and utilizing the methodology in Section 18-48(b) of the WRR, the following evaluations have been made:

Table 3.4: Coliform-restricted basin status as per Section 18-48 (b) (1) for 2002

Terminal Reservoir Basin	2002 Assessment
Kensico	Not Restricted
New Croton	Not Restricted
Ashokan	Not Restricted
Rondout	Not Restricted*
West Branch	Not Determined**

* Due to a valve malfunction at keypoint RDRR, 2002 assessment of fecal coliform data from Rondout included samples collected from RDRR, RR1 and RDRRECMT.

** Due to complications of operational changes (between flow-through, float, and bypass) data were inconclusive in defining the status of West Branch Basin.

3.13 What was the conductivity in NYC's reservoirs?

Conductivity is a measure of the ability of water to conduct an electrical current and varies with the amount and type of ions that water contains. This measurement can sometimes be used to differentiate wastewater from other, more naturally occurring waters, or to distinguish waters originating from different geological settings. Ions which typically contribute most to reservoir conductivity include: calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), potassium (K^{+1}), bicarbonate (HCO_3^{-1}), sulfate (SO_4^{-2}) and chloride (Cl^{-1}). Dissolved forms of iron, manganese and sulfide may also make significant contributions to the water's conductivity given the right conditions (*e.g.*, anoxia). Background conductivity of 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. This type of terrain will also produce waters of low conductivity. Such is the case with NYC's water supply reservoirs.

Catskill and Delaware System Reservoirs display uniformly low median conductivities in the past as well as in 2002 (Figure 3.19). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits which produce extremely low conductivities in the 50 to 100 $\mu S\ cm^{-1}$ range. Because West Branch and Kensico receive virtually all their water from the Catskill and Delaware reservoirs, the conductivities of West Branch and Kensico are also in this range.

Reservoirs of the Croton System have higher conductivities than those of the Catskill and Delaware Systems. In part this is due to the flatter terrain of the Croton watershed as well as to the occurrence of easily soluble deposits (*i.e.*, marble and/or limestone) within the watershed. Anthropogenic sources of ions, such as road salt, also impact the Croton Reservoirs. Most of the reservoirs have displayed steady increases in conductivity since the early 1990s. The reason for the increase in 2002, however, may in part be due to the drought (*i.e.*, less water for dilution). For similar reasons conductivity also increased in the controlled lakes of the Croton System (not shown in Figure 3.19). At Gilead Lake and Lake Gleneida conductivity was measured from 1995-2002. The past (1995-2001) median conductivity increased from 145 to 157 $\mu S\ cm^{-1}$ in 2002 at Gilead and from 300 to 315 $\mu S\ cm^{-1}$ at Gleneida. The 2002 median conductivity at Kirk Lake is 315 $\mu S\ cm^{-1}$ compared to a median of 199 $\mu S\ cm^{-1}$ determined from samples collected from 1995-1999 (no samples were collected in 2000 or 2001).

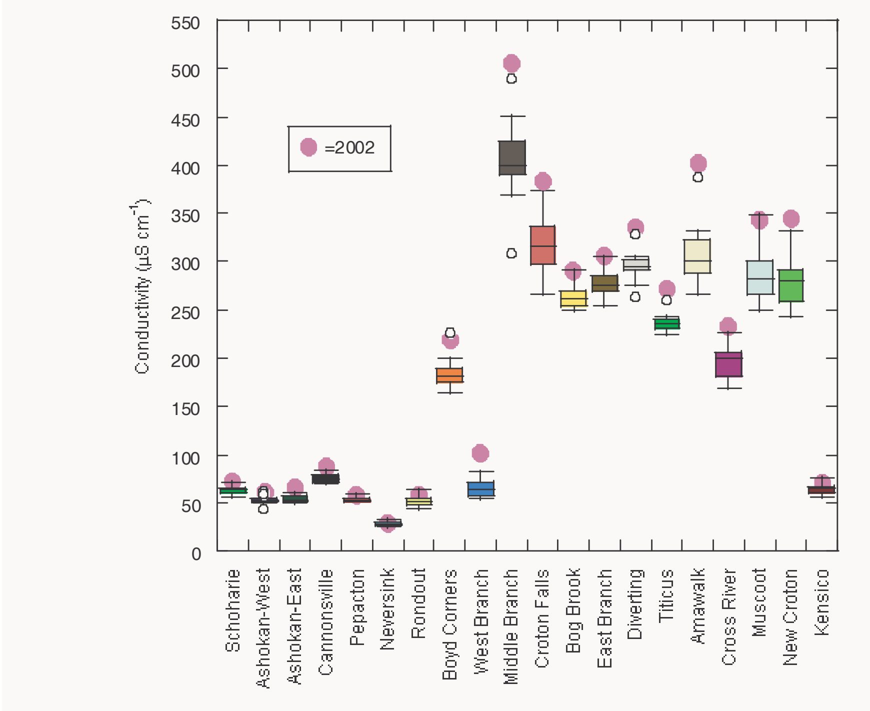


Figure 3.19 Annual median conductivity in NYC water supply reservoirs (2002 *vs.* 1992-2001).

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

3.14 How did source water quality compare to standards?

Table 3.5 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 as compared to the other three. The major cations are higher, as are the consequent variables - alkalinity, hardness and conductivity. Higher nutrient inputs cause New Croton to have greater primary production than the other three reservoirs, as indicated by the chlorophyll *a* and phytoplankton medians. The increased production causes higher turbidity levels and lower Secchi disk transparency. There are also higher levels of discoloration, iron, manganese and organic carbon in New Croton. In contrast, Kensico's water quality is reflective of the large majority of water it receives from Rondout and Ashokan reservoirs.

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

ANALYTES:	Water Quality Standard	Kensico Reservoir	New Croton Reservoir	East Ashokan Basin	Rondout Reservoir
PHYSICAL					
Temperature (°C)		13.4	14.6	14.2	10.4
pH (units)	6.5 - 8.5†	7.1	7.8	7.2	6.9
Alkalinity (mg L^{-1})		12.6	66.3	11.3	9.4
Conductivity (µS cm^{-1})		71	340	66	64
Hardness (mg L^{-1})		19	89	20	20
Color (Pt-color units)	(15)	10	18	11	12
Turbidity (NTU)	(5), *	1.2	2.1	1.9	1
Secchi disk depth (m)		4.9	3.3	3.9	4.3
BIOLOGICAL					
Chlorophyll *a* (µg L^{-1})	7‡	6.8	14.7	5	5
Total Phytoplankton (SAU)	2000‡	485	1200	490	350
CHEMICAL					
Dissolved organic carbon (mg L^{-1})		1.6	3.5	1.5	1.7
Total phosphorus (µg L^{-1})	15‡	9	22	10	9
Total nitrogen (mg L^{-1})	*	0.35	0.544	0.25	0.468
Nitrate + nitrite - N (mg L^{-1})	10†	0.175	0.15	0.09	0.281
Total ammoniacal - N (mg L^{-1})	2†	0.018	0.03	0.02	0.007
Iron (mg L^{-1})	0.3†	ND	0.13	0.06	0.02
Manganese (mg L^{-1})	(0.05)	ND	0.055	ND	0.046
Lead (µg L^{-1})	50†	0.3	1.1	ND	ND
Copper (µg L^{-1})	200†	1	2.8	ND	1
Calcium (mg L^{-1})		5.7	23	6.3	5.7
Sodium (mg L^{-1})		4.5	28	4.2	4.3
Chloride (mg L^{-1})	250†	7.3	61	8.5	6.6

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

3.15 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 biological 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 (Figure 3.20). Eutrophic waters on the other hand are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (*i.e.*, chlorophyll *a*, total phosphorus, and Secchi disk) to designate the trophic state of a water body. TSI based on chlorophyll *a* (CHLA) concentration is calculated as:

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

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 state 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 correlation between the variables is greatest. Water supply managers prefer reservoirs of a lower trophic state to avoid the need for chemical treatments and to produce better water quality at the tap.

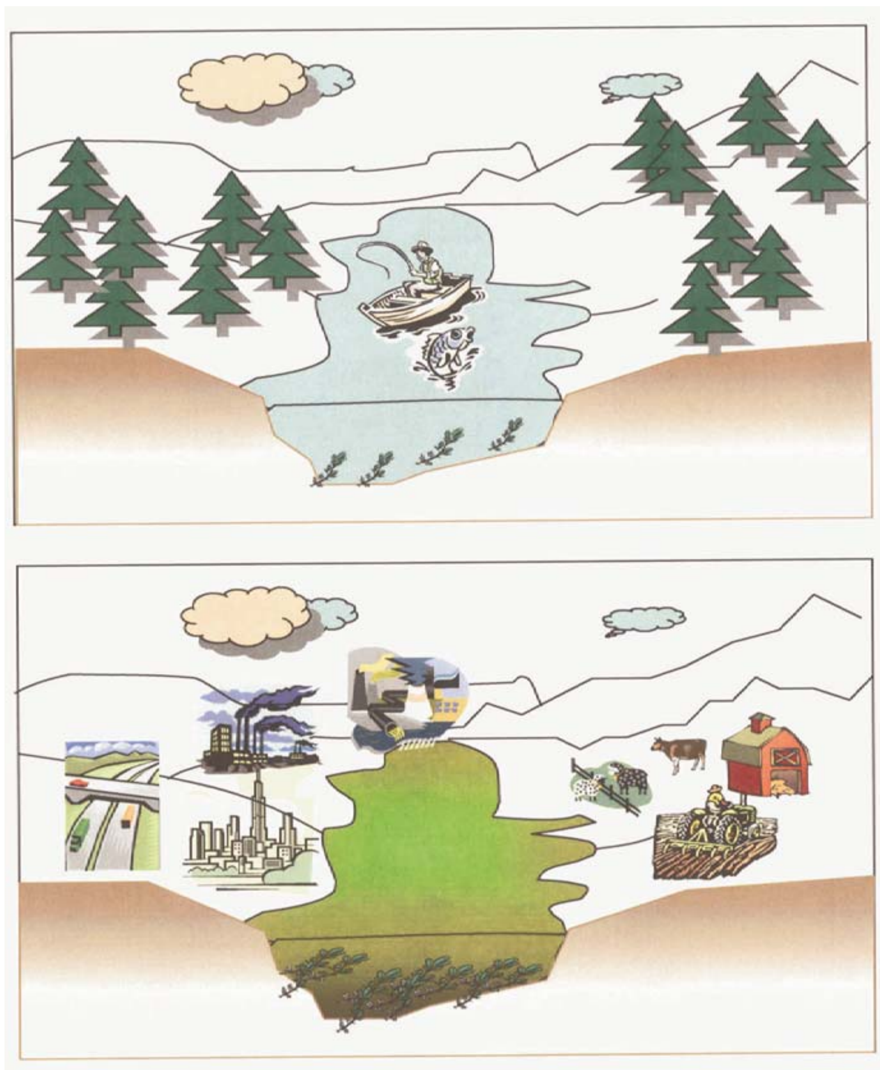


Figure 3.20 a) Pristine watershed produces water of high quality (oligotrophic).
b) Disturbed watersheds produce water of low quality (eutrophic).

Past (approximately 1992-2001) annual median TSI based on chlorophyll *a* concentration is presented in box plots for all reservoirs in Figure 3.21. The 2002 annual median TSI for Catskill and Delaware System Reservoirs appears in the figure as a circle containing an "x". In 2002, median TSI for several Catskill and Delaware Reservoirs appears to be significantly less than past years. This is due to hydrology and nutrient control programs. (Notably, the data presented for 2002 are from a depth of 3 meters rather than integrated photic zone samples; however, statistical comparison of the two methods showed no significant difference.)

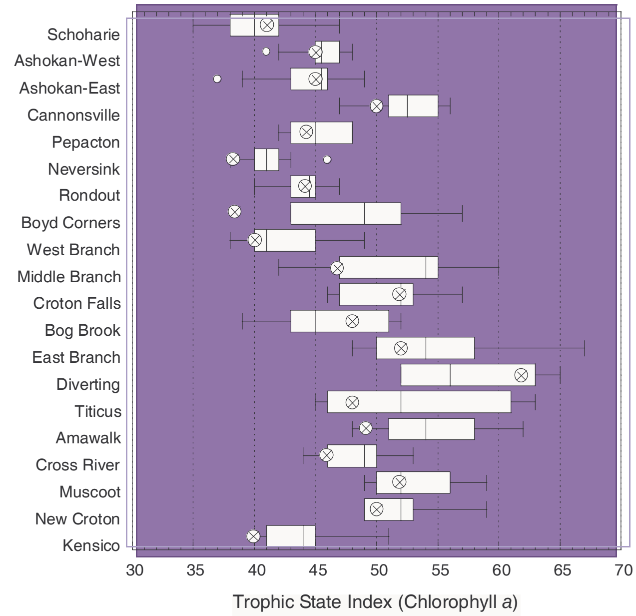


Figure 3.21 Trophic State Index (TSI) for New York City Reservoirs in 2002 based on chlorophyll *a* concentration (May - October).

Cannonsville, East Branch, Diverting, Muscoot, Titicus, Amawalk, Croton Falls, and New Croton can be classified as eutrophic in most years. The remaining reservoirs are typically classified as mesotrophic.

3.16 If DEP can reduce phosphorus in reservoirs, will that result in reduced levels of algae and a lower trophic state?

Research on northern temperate zone lakes has shown that chlorophyll *a* (Chl *a*) is positively correlated with total phosphorus (TP) (Vollenweider and Kerekes, 1982). This relationship is also apparent for NYC reservoirs (Figure 3.22). In general, reservoirs from the Catskill and Delaware Systems (including Kensico and West Branch) are low in nutrient concentration (as measured by total phosphorus) and low in algae response (as indicated by Chl *a*) while reservoirs of the Croton System tend to have high nutrient concentrations and high algal levels. Cannonsville Reservoir is similar in trophic status to the eutrophic reservoirs of the Croton System. Schoharie reservoir is an outlier indicating that the Chl *a* response to TP in this reservoir is different from the other NYC reservoirs. Apparently the low light transmission of Schoharie interferes with the algal response to the growth potential set by the phosphorus concentration; as a result, Schoharie has a low trophic status in spite of moderately high total phosphorus concentrations.

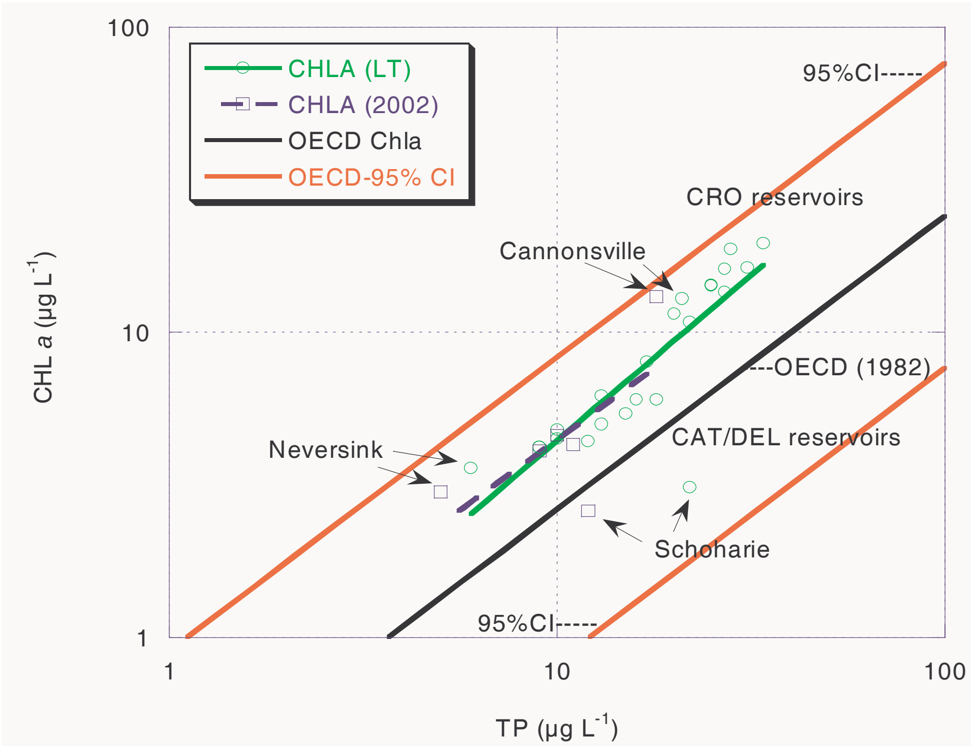


Figure 3.22 Mean chlorophyll *a vs.* total phosphorus concentration in samples collected in the photic zone during the growing season (May through October) in NYC reservoirs over a 10 year period (1992-2001) (LT) and for 2002.

The relationships (TSI based on chlorophyll *a*, Chl *a vs.* TP, and Chl *a vs.* Z_{SD} (Secchi depth transparency)) can be used to provide a valuable diagnostic framework for the reservoirs. Terminal reservoirs (closer to distribution) tend to be at a lower trophic state than outlying reservoirs. The high TSI values suggest that reservoirs like Cannonsville, Croton Falls, Diverting, East Branch, and Muscoot are clearly eutrophic, and blue-green algae frequently dominate. Algal growth is driven by TP for most reservoirs and, in general, algae limit transparency. Non-algal particulates usually dominate light attenuation in Schoharie indicating that nutrient and algal control will not improve transparency in Schoharie because of the overwhelming effect of silt. With the exceptions of Cannonsville and Schoharie, the Catskill and Delaware System reservoirs have deeper Secchi transparency, less phosphorus and less chlorophyll *a* than the Croton System reservoirs.

3.17 If phosphorus, and subsequently algae, in reservoirs is reduced through watershed management, will water transparency improve?

In the case of most reservoirs, yes. NYC reservoirs generally conform to the behavior of other northern temperate water bodies (as depicted by the OECD relationship in Figure 3.23; Vollenweider and Kerekes, 1982). That is to say that as lakes and reservoirs receive higher nutrient loads, algal levels rise, transparency decreases, and trophic status increases. The two reservoirs that show variation from this relationship are Cannonsville and Schoharie reservoirs. Cannonsville was more transparent in 2002 than one would expect, given its chlorophyll *a* levels. This was due to a combination of factors, including low runoff and silt load from the watershed during the first half of the year, the colonial (rather than single-celled) algal species composition, and the change to a more sensitive analytical method of measuring chlorophyll *a*. Nonetheless, Cannonsville transparency is related to chlorophyll *a* levels and watershed management would be expected to result in improved Secchi transparency. In contrast, Schoharie Reservoir transparency is very low despite very low levels of chlorophyll *a*. This indicates that other suspended matter (not related to the algal biomass) determines Schoharie Reservoir transparency. Therefore, further reduction of the already low biomass would not be expected to result in any greater transparency in Schoharie Reservoir. Notably, the lack of runoff and accompanying silt load during the first half of 2002 resulted in improved Secchi transparency for Schoharie, as well as most other reservoirs.

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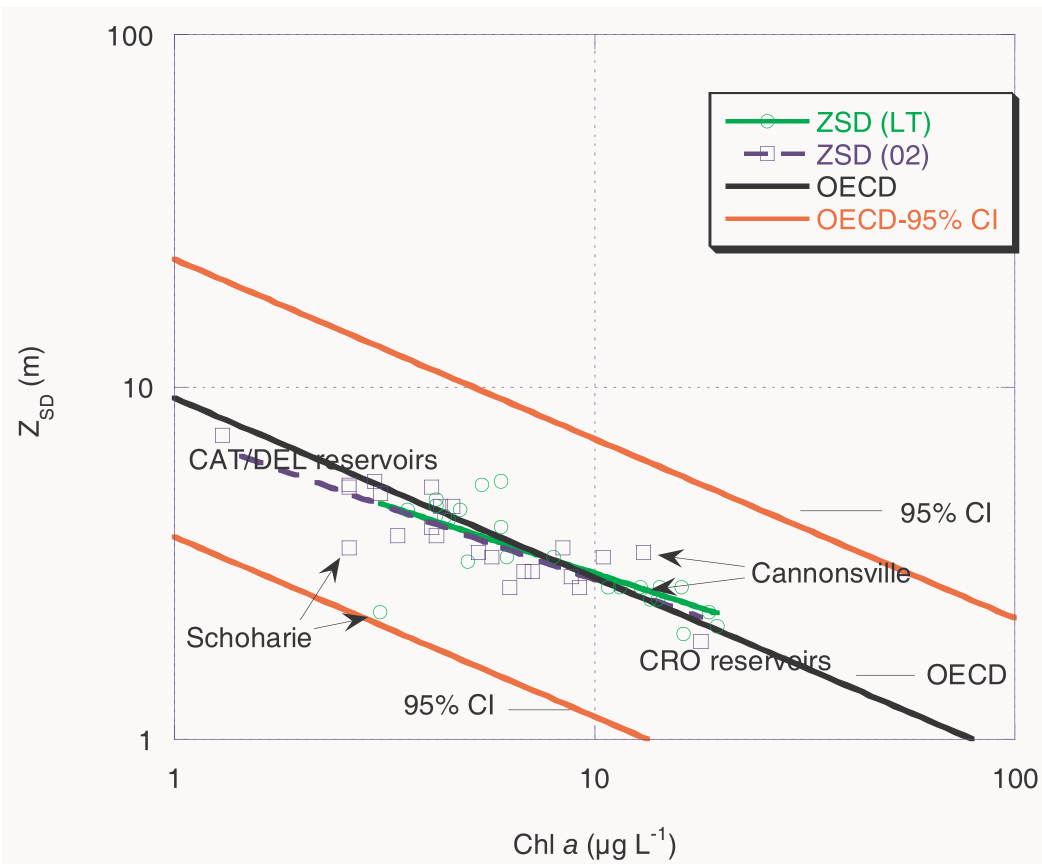

Figure 3.23 Mean chlorophyll *a* (Chl *a*) *vs.* Secchi depth transparency (Z_{SD}) in samples collected in the photic zone during the growing season (May through October) in NYC reservoirs over a 10 year period (1992-2001) (LT) and for 2002.

3.18 What are disinfection by-products, where do they come from, and how do current levels compare with regulatory limits?

Disinfection by-products (DBPs) are compounds that are formed when organic matter in raw water reacts with chlorine during the disinfection process. DEP monitors the two most important groups of DBPs: total trihalomethanes (TTHM), of which chloroform is the main constituent, and haloacetic acids (HAAs). The USEPA has set limits on these DBPs.

In January 2002, the new 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 four quarterly samplings, so the first results for the Rule could not be calculated until the fourth quarter of 2002. The first set of results under the new regulation is presented in Figure 3.24 and shows system compliance for both the Catskill/Delaware and Croton systems.

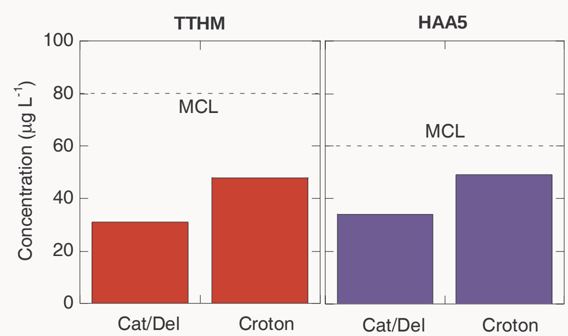

Figure 3.24 Stage 1 distribution system DBP concentrations ($\mu g\ L^{-1}$) for the fourth quarter of 2002.*

*annual running quarterly average

3.19 Have turbidity conditions improved in the Schoharie watershed since the 1996 flood?

On January 18-19, 1996 heavy rains fell on a substantial snow pack, which, along with unseasonably mild temperatures, resulted in widespread flooding in New York. The most severely affected region was within and surrounding the Catskill Mountains. This event had a major impact on water quality. In the Schoharie watershed, turbidity levels remained elevated compared to pre-flood levels (Figure 3.25), whereas turbidity returned to pre-flood levels in the Esopus watershed relatively quickly.

The storm apparently damaged the Schoharie watershed resulting in an enhanced ability to entrain turbidity-causing material. This enhanced ability to mobilize turbidity-causing material under all flow conditions in the Schoharie watershed resulted in the sustained elevated turbidity levels observed in the Schoharie Reservoir and the Shandaken Tunnel. It would appear that beginning in 2001 and continuing into 2002, the turbidity levels in the Schoharie watershed have returned to pre-1996 levels as indicated by the Schoharie Creek at Prattsville. The 2002 data for the reservoir and tunnel show that these downstream locations are responding to the lower turbidity values from the upstream watershed.

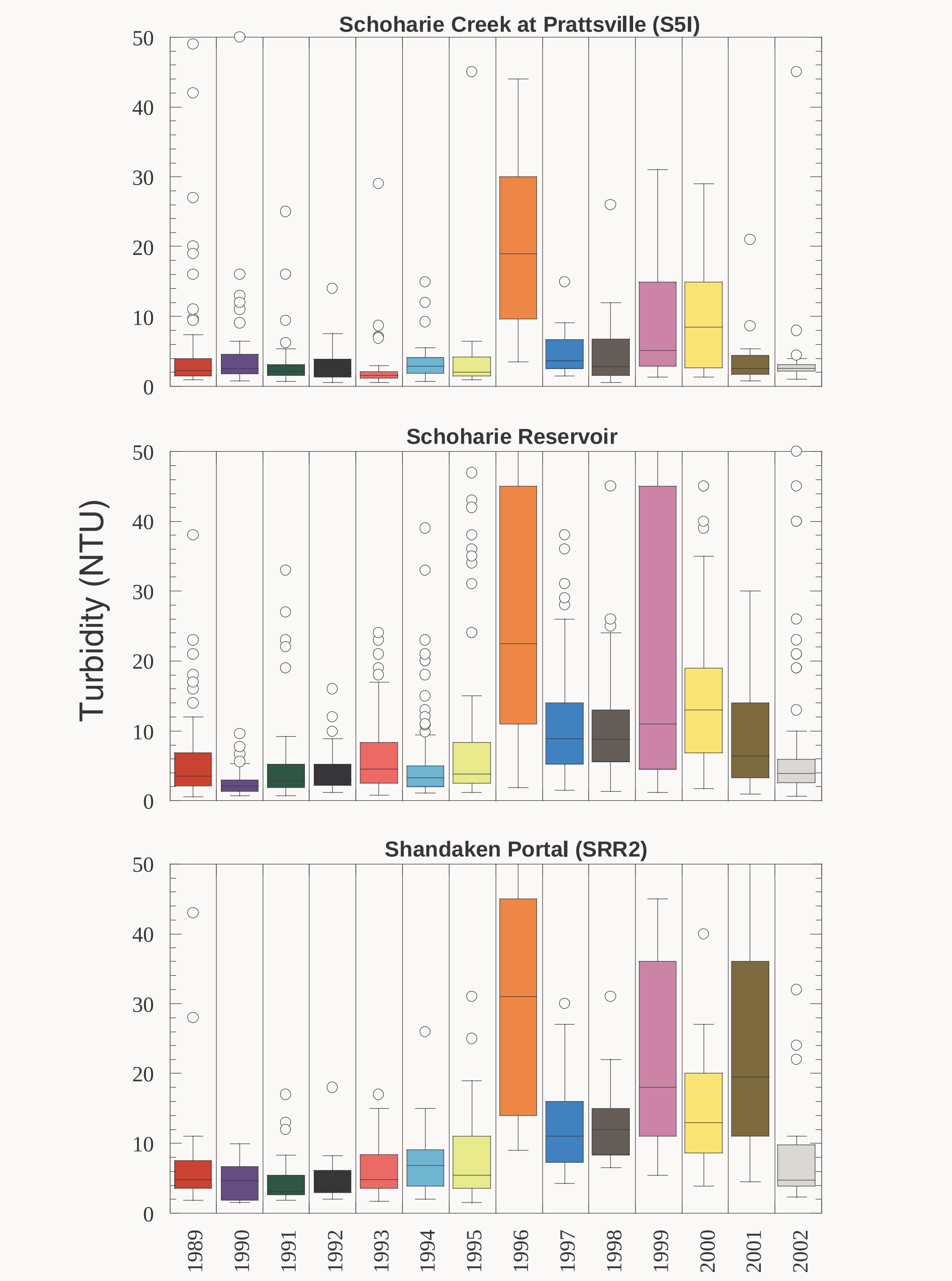

Figure 3.25 Box plot of turbidity values by year (1989-2002) for a) Schoharie Creek at Prattsville (S5I) b) Schoharie Reservoir c) Shandaken Portal (SRR2).

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

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

3.21 Does the Shandaken Tunnel have an impact on macroinvertebrate water quality scores of the Esopus Creek?

Beginning in 1999, paired sites were located above and below the Shandaken Tunnel outfall to Esopus Creek and sampled annually to develop a long-term assessment of the Tunnel's impact. While final water quality scores, based on a non-parametric statistical test, appear to be lower below the tunnel, water quality at the below-tunnel site remains excellent, as is demonstrated by its mean water quality score of 7.59 (Table 3.6). Other Esopus Creek samples taken in 1996 and 1997, mostly from below the tunnel, are consistent with that result. Out of 15 assessments along the Creek since 1996, only two scores—both 7.4—fell below the non/slightly-impaired threshold value of 7.5. While the differences in the final scores of these two sites appears to be statistically significant, it is not clear that lower water quality scores below the tunnel reflect significant impairment to either water quality or the macrobenthic community.

In terms of actual sample composition (the data to support this are not presented here but are available from DEP) the macrobenthic community above the tunnel appears to contain greater numbers of sensitive mayflies than the site below. Generally speaking, however, taxa present above the tunnel are present below it as well. Moreover, the possibility exists that differences in species composition between the two sites may be related to differences in discharge volume, which is much greater below the tunnel than above. The photographs depict the stream at the sampling sites above (Figure 3.26) and below (Figure 3.27) the tunnel. DEP plans to visit sites above and below the tunnel annually, and will continue to track community structure variation.

Table 3.6: Converted (normalized) metric and final water quality scores from biomonitoring sites in Esopus Creek located above and below the Shandaken Tunnel, and the results of Wilcoxon Rank Sum tests* for years 1999 - 2002.

Metric	mean above (n=5)	mean below (n=5)	2-sided *p*-value of Wilcoxon Rank Sum test
Species richness	7.27	6.35	0.28
EPT richness	9.70	8.95	0.11
Biotic index	8.20	7.25	0.07
Percent model affinity	7.57	7.82	0.55
Final Water Quality score	8.19	7.59	0.03

* For this test, H_o = no difference between sites.

Figure 3.26 Biomonitoring site on Esopus Creek above the Shandaken Tunnel.

Figure 3.27 Biomonitoring site on Esopus Creek below the Shandaken Tunnel.

3.22 Has the invertebrate habitat improved as a result of Streambank Stabilization Projects in the Schoharie Reservoir Watershed?

In 1996, DEP initiated biomonitoring of streambank stabilization projects (BMPs) being implemented in the Schoharie Reservoir watershed. The first stabilization project was on Schoharie Creek in the Town of Lexington in 1997. Only one pre-project sample was collected at this site, and the sample collected in 1997 was taken only three weeks after the project had been completed. The other four sites discussed here, Maier Farm, Brandywine, Farber Farm, and Broadstreet Hollow were completed in 1999, 1999-2000, 2000, and 2001, respectively.

Table 3.7 presents the water quality scores from the 1996-2001 period. Shaded cells indicate the first post-implementation sample, and the final right-hand column lists scores found at upstream control sites. Generally, all sites were found to have excellent water quality exhibiting scores above the 7.5 non-impaired/slightly impaired threshold. The one farm site, however, consistently yielded low water quality scores, due largely to reduced numbers of EPT taxa and low similarity to the DEC's ideal stream macrobenthic community. The data below encompass too short a time span to be able to fully reflect potential improvements in the macrobenthic community that may be realized by the BMPs, but macrobenthic community data gathered by the USGS under contract to DEP may help to identify broader trends when all results are considered.

Table 3.7: Water quality scores at sites of DEP streambank stabilization projects. Shaded cells indicate first post-implementation sample.

Project	1996	1997	1998	1999	2000	2001	Upstream Control 2000
Lexington	7.6	7.3	9.1	6.9	8.1	7.7	n.d.
Maier Farm	n.d.	n.d.	7.6	7.9	7.9	7.7	n.d.
Brandywine	n.d.	n.d.	7.6	7.3	8.2	7.3	8.6
Farber Farm	n.d.	n.d.	5.1	7	7.2	6.4	8.2
Broadstreet Hollow	n.d.	n.d.	n.d.	7.7	7.8	7.5	8.3

n.d.= no data

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

DEP began biomonitoring of Schoharie Creek at Prattsville, immediately upstream of Schoharie Reservoir, in 1995. Water quality scores at this site have historically been low for the Catskills Region, with a mean score of 7.3 over the 1995-2002 period, which places the site just below the 7.5 non-impaired/slightly impaired threshold. DEP's other primary long-term site on Schoharie Creek, located near the Hunter-Jewett Town line just over 20 kilometers upstream, has a mean water quality score of 8.4 for the 1994-2002 period, well into the non-impaired region. DEP had no explanation for the differences between these two average scores, as land use remains relatively constant throughout the reach and there are no point-source discharges to Schoharie Creek between these two sites. In an effort to narrow the search for the reach where water quality scores appear to change, DEP sampled a seven-site transect on the Creek between Prattsville and Elka Park in 2001 and 2002.

Figure 3.28 displays the species richness ("S"), EPT ("E"), biotic index ("H"), and percent model affinity ("P"), as well as the final score (•) for each site and each year. On Figure 3.28, sites are numbered (#1 - #7) in increasing order as they are located away from the Reservoir, so site #1 is in Prattsville, and site #7 is upstream in Elka Park. From the figure, it can be seen that species richness (the total number of taxa identified in the 100 count subsample) is substantially lower at site #1, and this pulls the overall water quality score down at that site relative to all other sites on the Creek. DEP plans to review these data using DEC's Impact Source Determination models in an effort to determine the causes for differences observed.

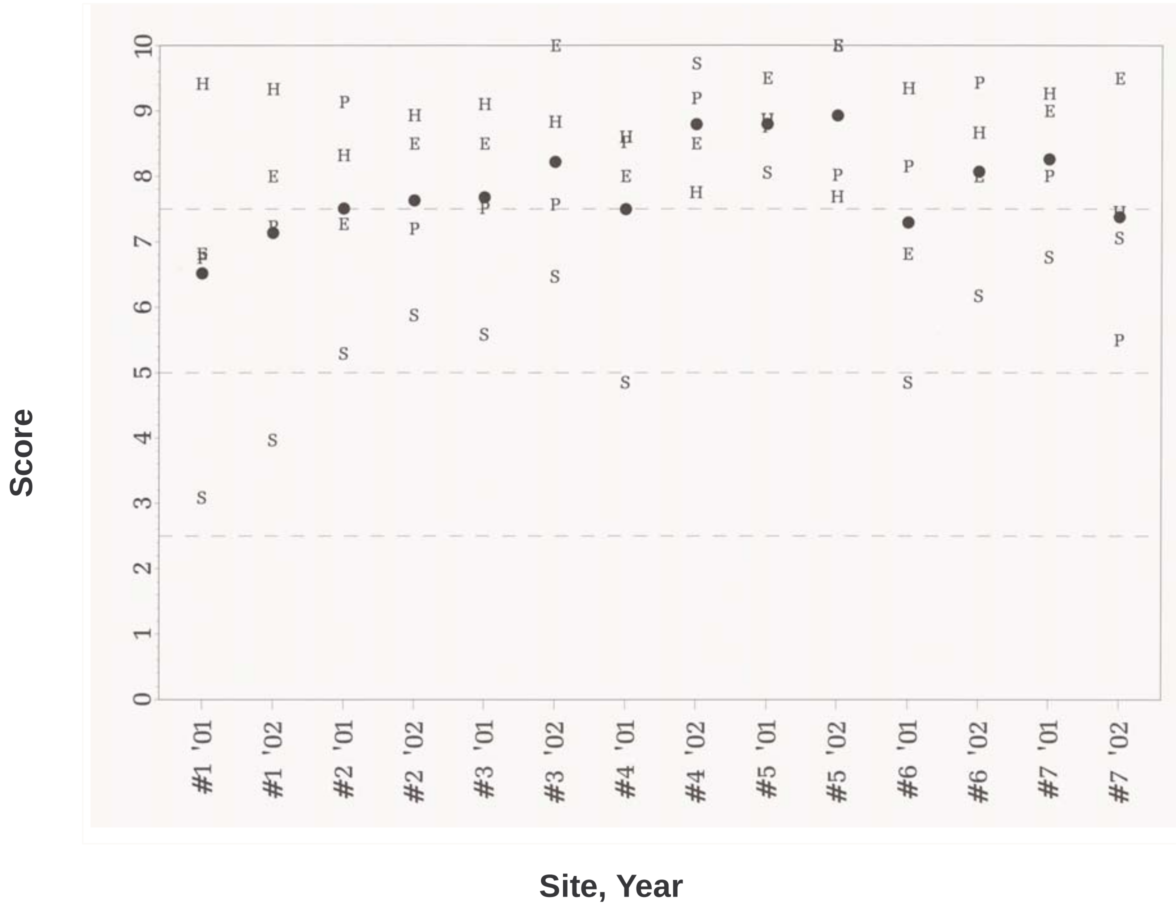

Figure 3.28 Individual metric (S,E,H,P) and final water quality scores (•) of seven sites sampled along Schoharie Creek in 2001 and 2002.

4. Watershed Management

4.1 How can watershed management improve water quality?

Many scientific studies demonstrate the connection between the activities within a drainage basin and the quality of its water resources. Water quality is adversely impacted when management practices are lacking and contaminants are simply washed off the landscape by rain or melting snow, or released directly into streams, and flow into the water supply. The essence of watershed management is to remove or prevent contaminants from reaching the natural flow-path of water.

DEP has a comprehensive watershed protection program which focuses on implementing both protective (anti-degradation) 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 realized in the future by maintaining the current high quality water. Remedial programs are directed at existing sources of impairment. The water quality benefit of some remedial programs, such as the WWTP Upgrade program, can be easily quantified and a case study is provided later on in this chapter.

One way to evaluate the success of the watershed management program as a whole is to continuously assess the water quality in the receiving reservoirs and the management programs that are planned or in place across the watershed. This is a long-term evaluation, since natural variations in water quality and the response time of reservoirs can mask reductions in watershed loadings. In the following sections, a summary of several key remedial management programs is provided along with a summary of water quality for each System. More information on the management programs in the NYC watershed can be found in the 2002 FAD Annual Report (NYCDEP, 2003d); more information on the research programs can be found in the 2002 Research Objectives Report (NYCDEP, 2003b). Management programs that are ongoing in the Kensico basin are described in the Annual Kensico Report.

4.2 What is the link between watershed management and water quality in the Catskill System?

The Catskill System consists of the Ashokan and Schoharie basins. While numerous management programs are active in these basins, the status of a few key programs is as follows:

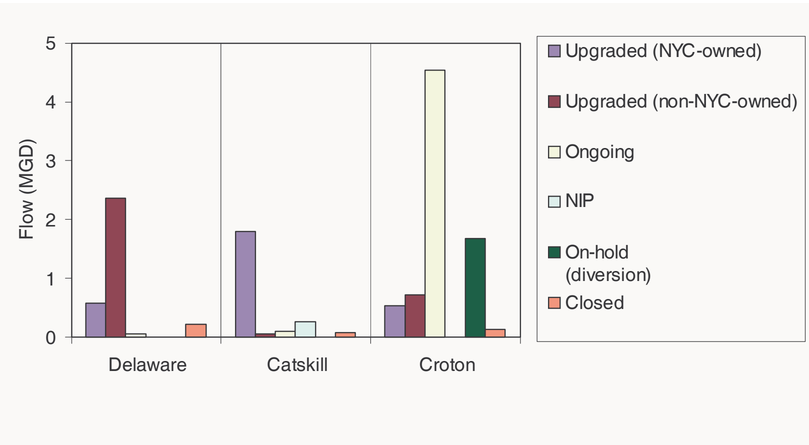

Figure 4.1 The status of the Wastewater Treatment Plant Upgrade Program through 2002.

Wastewater Treatment Plant Upgrade Program – The NYC-owned plants, comprising 78% of the wastewater flow in the system, have all been upgraded to tertiary treatment; seven facilities will be incorporated into new facilities constructed as part of the New Infrastructure Program; another 5% of the wastewater flow is currently in the process of being upgraded (Figure 4.1).

Septic System Rehabilitation Program – A total of 705 septic systems have been remediated or replaced in the Catskill System (Figure 4.2). This program is managed by the Catskill Watershed Corporation in conjunction with DEP.

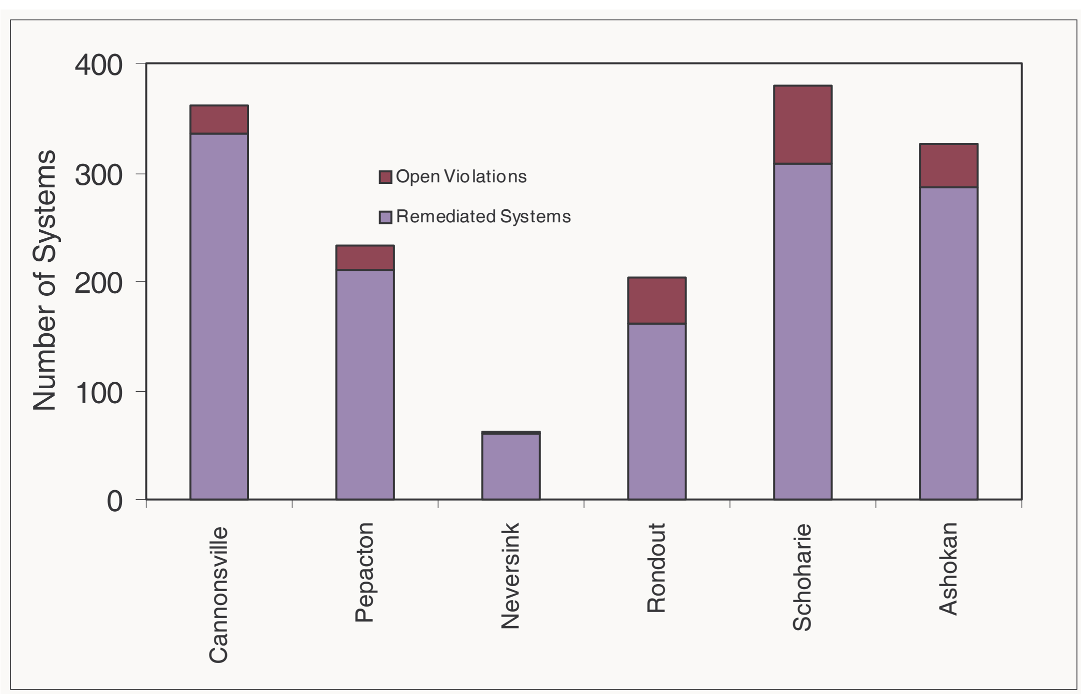

Figure 4.2 Remediated septic systems or systems with open violations since the inception of the program; 1997 – 2002.

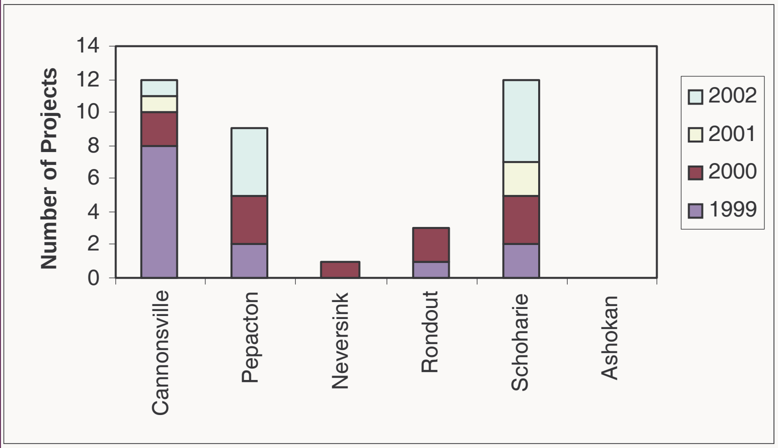

Figure 4.3 The number of approved stormwater retrofit projects by year.

Stormwater Retrofit Program – A total of 12 stormwater projects have been funded in the Catskill System (Figure 4.3). This program is managed by the Catskill Watershed Corporation in conjunction with DEP.

Watershed Agricultural Program – A total of 33 farms are participating in the Catskill System; implementation of Whole Farm Plans has commenced on 31 of them and 20 farms are substantially complete (Figure 4.4). The Watershed Agricultural Program is a voluntary partnership between the City and the farms. It is administered by the Watershed Agricultural Council.

Water quality in the Catskill System remains very good. As mentioned previously, the beginning of 2002 found storage in all the water supply systems very low. When normal rainfall volumes returned in the spring, storage recovered to average levels by July 2002. The onset of the spring rains fortunately did not bring unusually high turbidity in the Catskill System, a common situation in the Catskills. Median fecal coliform bacteria were slightly higher than average in Schoharie Reservoir, but overall the Catskill System's median fecal coliform concentration remained well below 20 CFU 100 mL $^{-1}$ for the year.

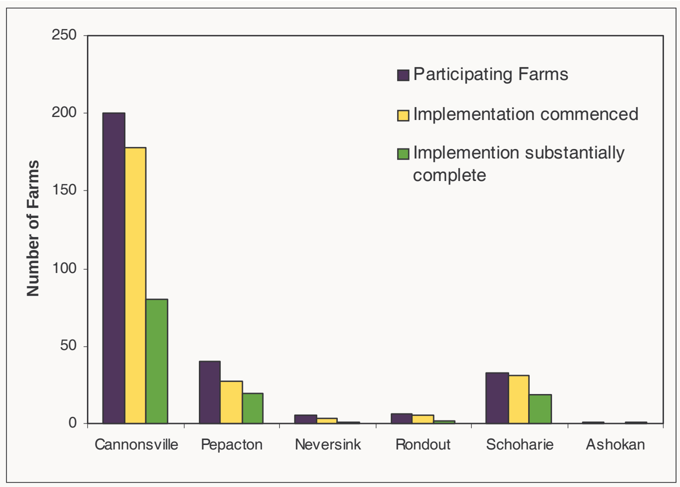

Figure 4.4 The number of farms participating in the Whole Farm Program and the farms, implementation status per reservoir basin through 2002.

4.3 What is the link between watershed management and water quality in the Delaware System?

The Delaware System 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 is as follows:

<u>Wastewater Treatment Plant Upgrade Program</u> – Over 90% of the wastewater flow in the Delaware System has been upgraded, the vast majority at private/municipal facilities; only 2% of the flow (5 facilities) is still in the process of upgrading (Figure 4.1). Two facilities have closed or the flow was diverted to a nearby facility. Except for one NYC-owned WWTP in the Rondout basin, all these facilities are in the Cannonsville and Pepacton basins.

Figure 4.5 Grahamsville Wastewater Treatment Plant.

<u>Septic System Rehabilitation Program</u> – A total of 860 septic systems have been remediated or replaced in the Delaware System (Figure 4.2).

<u>Stormwater Retrofit Program</u> – A total of 25 stormwater projects have been funded in the Delaware System (Figure 4.3).

<u>Watershed Agricultural Program</u> – A total of 251 farms are participating in the Delaware System; implementation has commenced on ~85% of the farms with ~40% substantially complete (Figure 4.4).

Water quality remains excellent throughout the Delaware System. Cannonsville Reservoir continues to display the highest average concentration of total phosphorus in the WOH District, while Neversink Reservoir continues to display the lowest concentration. Overall, the Delaware System tends to have lower total phosphorus concentrations than the Catskill System. Conductivity appears to be a bit higher than for the general record, but fecal coliform bacteria and turbidity remained very low for the year.

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

The Memorandum of Agreement (MOA) watershed management programs are designed differently in the Croton System from 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 support water quality investment projects in the East-of-Hudson watershed. The counties have reserved the majority of these funds awaiting completion and agreement of the Croton Plan and final assessment of diversion options in Westchester County. Putnam County has spent and/or allocated approximately 25% of its funds on projects such as land acquisition, stormwater BMPs, and various wastewater projects.

DEP is also developing a comprehensive strategy to address potential nonpoint pollution sources in the Catskill/Delaware basins located east of the Hudson River. This program will include mapping of stormwater and sanitary sewer systems and remedial stormwater management projects. At this time, the strategy is still in the planning phases.

The Wastewater Treatment Plant Upgrade Program is active in the Croton System although progress on select WWTPs awaits final determinations with regard to WWTP consolidation or WWTP diversions (Figure 4.1). At this time, a total of eight facilities (22% of the total flow) have their upgrade plans on hold until final decisions are made regarding either WWTP consolidation or diversion of wastewater off the watershed. One NYC-owned facility has been upgraded (Mahopac WWTP) and the other will be rebuilt and turned over to the village to operate (Brewster WWTP). Several private and/or municipal facilities have completed their upgrades and the majority are currently in the process of upgrading.

The East-of-Hudson Watershed Agricultural Program started in 2002 and already has ten farms signed up for the program. Implementation will commence in 2003 on four of the farms.

Water quality in the Croton System is generally good. Total phosphorus concentrations and conductivity appeared a bit higher in 2002 than for the general record of the reservoirs in the Croton System. Middle Branch Reservoir in particular appears to have an upward trend in conductivity. Fecal coliform bacteria concentrations are still appropriately low in 2002, and turbidity values were normal for the period of record.

4.5 What information can case studies provide?

DEP funds numerous management projects to improve and protect water quality in the water supply watershed. Typically these projects are targeted at controlling pollutant inputs from the dominant anthropogenic sources in a given basin. Case studies can demonstrate the direct result of these remedial projects on water quality. For example, in the Cannonsville Reservoir watershed where agriculture dominates land use, DEP funds the Watershed Agricultural Program. Research at one of these farms has documented reductions in nutrient export after a series of farm management activities were implemented (see: http://h2osparc.wq.ncsu.edu/319/2001rept/pdf-Files/NY-01.pdf). In the more urban watershed of Kensico Reservoir, extended detention basins to improve stormwater quality have been installed at key locations (see: “Kensico Watershed Management Plan Annual Report”, NYCDEP, 2003c). Other management programs with direct measurable impacts on water quality include the WWTP upgrade program, and the waterbird management program, discussed below.

WWTP Upgrade Program and Phosphorus Reductions

The Watershed Rules and Regulations (WRRs) require that surface-discharging WWTPs upgrade their treatment processes to include phosphorus removal and microfiltration for removal of pathogenic protozoans. While these upgrades are currently in progress at some WWTPs, upgrades at the City-owned facilities are complete. Figure 4.6 displays annual loads from City-owned WWTPs WOH for the period 1996 – 2002. Following WWTP upgrades, dramatic reductions in the loads can be seen. Based on these data, DEP expects that WWTPs will be minor sources of phosphorus after the upgrade program is completed.

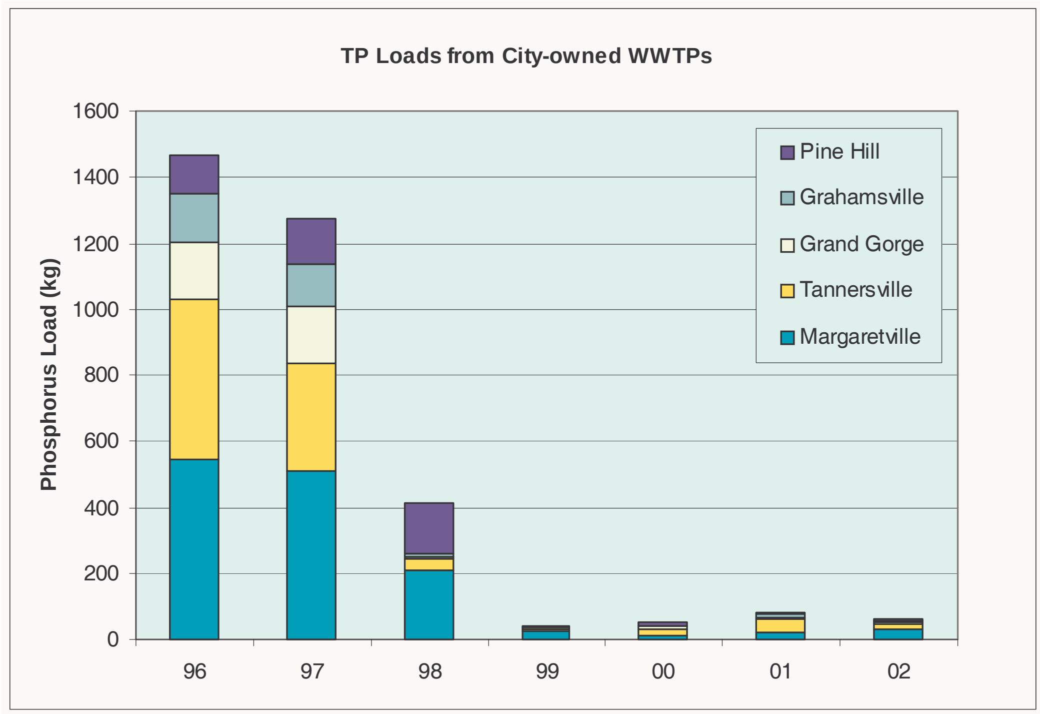

Figure 4.6 Phosphorus loads from City-owned WOH Wastewater Treatment Plants (1996 – 2002). Upgrades at these facilities took place between 1997 – 1999.

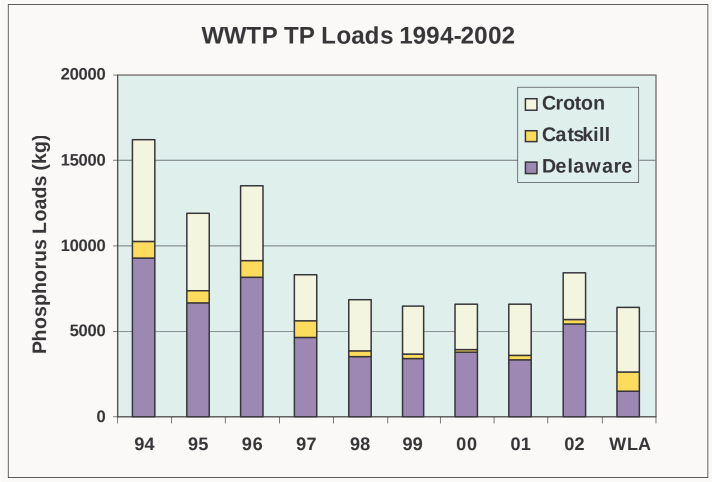

Figure 4.7 Phosphorus Loads from WWTPs by System (1994 – 2002). The Phase II TMDL Wasteload Allocation (WLA), summed for the entire watershed, is shown for comparison.

As part of its overall water quality monitoring and protection program, DEP staff inspect each of the surface-discharging WWTPs quarterly, and sample their effluents twice-monthly during their period of operation (city-owned plants are monitored weekly). Phosphorus is an important analyte that is monitored since this nutrient is a limiting factor for algal biomass in the reservoirs. DEP calculates total phosphorus loads using DEP sample data and the facility's self-reported data where available. DEP load calculations indicate that phosphorus from WWTPs has been decreasing since the mid 1990s (Figure 4.7). One anomaly was an increase in phosphorus load to the Delaware System in 2002. This was caused by the addition of an industrial wastestream to the Delhi Village WWTP. This caused the plant's flow to increase prior to the upgrade being completed. Upgrade of the Delhi WWTP has since been completed, and it is expected that the plant's effluent phosphorus load for 2003 will be reduced to well below 2001 levels. Also included in Figure 4.7 is a bar showing the Wasteload Allocation (labeled WLA) for each system, which is the final allowable phosphorus load from surface-discharging WWTPs as recorded in the Phase II TMDLs.

Much of the watershed-wide load reduction can be attributed to involvement by DEP staff. When a WWTP regularly violates its SPDES permit, Compliance Assistance Conferences between DEP and the WWTP owners can lead to plant upgrades, increased or improved maintenance, and/or increased use of certified operators. WWTP operators may also implement suggestions made by DEP staff in quarterly inspection reports without requiring Compliance Conferences or consent orders. Since nutrient removal is more difficult than removal of solids and oxygen demanding substances, the phosphorus load reductions generally correlate with improved plant performance overall.

Waterbird Management Program and Coliform Reductions

Not all management programs target anthropogenic sources. In response to seasonal increases in fecal coliform bacteria concentrations in Kensico Reservoir, DEP's Wildlife Studies Group began implementation of a waterbird management program in 1993. The goal of the program was to keep waterbirds from roosting on the Reservoir, and to conduct activities to help control waterbird fecundity. The success of the program in reducing the seasonal fecal coliform bacteria concentrations in Kensico has been well documented in previous reports (see: "2001 Watershed Water Quality Annual Report", NYCDEP, 2002).

As part of the November 2002 FAD Report (NYCDEP, 2003d), waterbird management will be expanded to include five additional reservoirs on an "as needed" basis. The criteria which define the "as needed" actions include water quality results and the spatial distribution of water-birds in relation to the water intake structures. Additional measures using overhead wires to prevent waterbirds from landing on the reservoir were implemented at Hillview and Jerome Reservoirs with continued success. Occasionally, elevated fecal coliform levels have been detected and attributed to roosting waterbirds at other reservoirs; in such cases, emergency (as needed) short-term harassment measures have been implemented. Figure 4.8 shows the results of such a situation at Rondout Reservoir during the months of December 2002 and January 2003. Waterbird management produced an immediate response in Rondout similar to those repeatedly documented in Kensico.

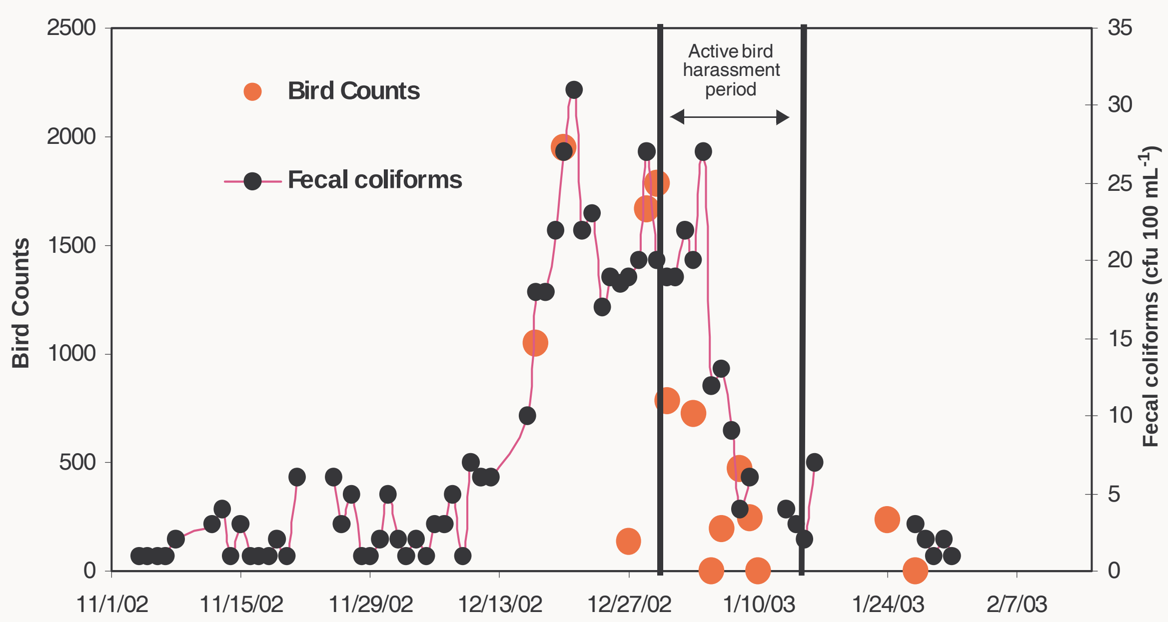

Figure 4.8 Fecal coliform bacteria concentrations and bird counts at Rondout Reservoir.

4.6 What types of long-term watershed protection programs are in place?

DEP has a comprehensive watershed protection program which contains both protective and remedial programs. These are described in more detail in the NYC 2001 Long Term Watershed Protection Program Summary (NYCDEP, 2001). A vital component of good watershed management is sound scientific research and watershed-specific information. DEP has a wide variety of ongoing research programs to supply this type of information for the NYC watershed. These programs range from monitoring stormwater BMP effectiveness to investigations of the water quality functions of wetlands. More information on DEP research programs can be found in the 2003 Research Objectives Report (NYCDEP, 2003b).

4.7 How does DEP develop watershed management plans?

Watershed management plans can be narrow and address a single issue, or they can be broad and address a comprehensive set of problems. DEP completed a comprehensive watershed strategy for the Croton System in 2002 that evaluated several key water quality variables (phosphorus, total suspended sediments, pathogens, toxics and pesticides) from a host of point and non-point sources. The watershed analysis was conducted for both existing and future buildout conditions, and was used as the basis for determining watershed management priority areas for programs that address stormwater, wastewater, roadway runoff, agriculture and open space preservation. The Croton Watershed Strategy project also provided DEP with GIS-based management tools to continue to update and refine this management plan in the future.

4.8 What special investigations were conducted during 2002?

Special investigations as discussed here refer to non-routine collections of environmental samples in response to a specific concern or event. DEP conducts special investigations for many reasons including illegal discharges of sewage, fish kills, discovery of previously unknown facility outfalls, and transportation accidents resulting in discharges to waters of the State. Three investigations conducted in 2002 which involved sample collection and for which reports were written are summarized below.

Sewage spill to the Muscoot River, January 11, 2002

At approximately 7:00 am on January 11, operators at the Yorktown Heights WWTP noticed that a lift pump failure had resulted in spillage from the trickling filter to a drainage swale and into Hallocks Mill Brook, a tributary of Muscoot Reservoir. Facility personnel estimated the volume of the spilled primary treated wastewater to be approximately 230,000 gallons. Later in the morning, DEP collected samples to help assess the threat to water quality at the Croton Lake Gatehouse. Samples were collected from the Muscoot River at Woods Ave., approximately 2 miles downstream of the WWTP, from the Muscoot Reservoir at the crossing of Route 100, and from the Kisco River at routine sampling site KISCO3. Samples from the Muscoot River and the Muscoot Reservoir were presumably within the spill's flowpath. Sampling of the Kisco River was included to provide a baseline reference. A review of routine stream sampling data from 1999-2000 for the Hallocks Mill (MUSCOOT5) and Kisco River (KISCO3) sites found that the fecal coliform concentrations detected during this special sampling effort were within the historic ranges. No fecal coliform bacteria were detected in the sample collected from the Muscoot Reservoir, which indicated that the spill did not appear to have an impact on the Reservoir.

Investigation into Possible Sources of Elevated Concentrations of *Cryptosporidium* and *Giardia* in Kensico Tributary E9

A routine sample for enteric pathogens collected from Kensico tributary E9 on September 25, 2002 found unusually high levels of *Cryptosporidium* and *Giardia* for a sample that was not influenced by a storm event. Follow-up sampling again found unusually high concentrations of *Cryptosporidium* and *Giardia*. These samples triggered a month-long investigation into potential sources of the pathogens. The investigation involved video surveillance of a nearby culvert, dye testing of a nearby sewer line, dye testing of a nearby WWTP subsequently determined to be discharging outside the Kensico watershed into waters within the State of Connecticut, and thorough field investigations of wetlands within the E9 sub-basin. Sampling for pathogens and other water quality parameters continued throughout this investigation. Genotyping of the *Cryptosporidium* determined the source to be non-human. When *Cryptosporidium* and *Giardia* concentrations appeared to decline, the investigation was discontinued with the belief that the source was most likely an animal.

Response to Overflow of Upper Bronx Valley Sewer Extension Line, November 27, 2002

Blockage in a sewer extension line maintained by the Westchester County Department of Environmental Facilities led to a spill of untreated sewage to Kensico Reservoir. The blockage was cleared and the immediate site of the spill was cleaned up on Thanksgiving Day, November 28, 2002. DEP personnel began sample collection within the Reservoir on the evening of November 28. Over the next 10 days, 45 special investigation samples were collected from various locations in an effort to detect an impact to Kensico Reservoir. The Reservoir itself was by-passed on December 1 to avoid any threat to public health from this spill.

DEP's Pathogen Laboratory analyzed 26 samples for *Cryptosporidium* and *Giardia* during the course of this investigation. Concentrations of *Giardia* never exceeded historic levels. For *Cryptosporidium* one 10L sample collected from the Reservoir contained 3 *Cryptosporidium* oocysts, whereas aqueduct keypoint sampling had never recovered more than 2 *Cryptosporidium* oocysts prior to this event. This may have been a result of the spill. Ribotypes of 5 (*of*) *E. coli* collected from the Reservoir in the vicinity of the spill site matched ribotypes of human *E. co*li in DEP's library indicating that this spill reached the reservoir, but that impacts were low.

5. Model Development and Applications

5.1 Why are models important?

The NYC Water Supply Reservoirs and watersheds constitute a complex environmental system. Water quality and quantity in the system depend on biological, geological, chemical, and human interactions that vary in both time and space. Management of watershed land uses and activities and reservoir operations within the context of varying weather and environmental conditions requires understanding the key processes and interactions that control generation and transport of water and chemical constituents in the watersheds and reservoirs. Watershed and reservoir simulation models provide a framework for understanding these interactions and for quantifying their effects on water quality and quantity in the system.

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

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

DEP's linked watershed-reservoir eutrophication models have been used for evaluating the effectiveness of watershed management in controlling nutrient loading and eutrophication in Catskill and Delaware System Reservoirs. These model applications involve long-term (>30 years) simulations of watershed loads and reservoir algal growth incorporating various watershed management strategies. This type of analysis makes possible the prediction of changes in the frequency and quantity of summer reservoir algal growth due to implementation of proposed watershed management programs.

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

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

DEP is updating its watershed model applications annually to include the current year. This provides DEP the capability to estimate flows and nutrient loads from different watershed land uses and sources to the reservoirs for the current year, in relation to long-term historical conditions. Current year model results viewed against long-term statistical flow and loading patterns are placed in an appropriate historical context that accounts for the effects of natural meteorological variability on water quality. This variability is the background within which watershed management operates, and provides an important context for guiding watershed management.

Watershed modeling of streamflow and nutrient loads provides insight into the flow paths that water and nutrients take in the watershed. Total streamflow is comprised of overland flow and groundwater flow. Overland flow is water that moves rapidly on or near the land surface, as opposed to much slower-moving groundwater flow. Overland flow has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Figure 5.1 depicts the annual streamflow, overland flow, and dissolved nutrient loads simulated by the model for 2002 in relation to long-term simulated annual statistics. Comparison of annual nutrient loads to annual hydrology shows that whereas the relationship of 2002 to long-term annual total dissolved nitrogen (TDN) loads follows annual streamflow, the relationship of 2002 to long-term annual total dissolved phosphorus (TDP) loads follows annual overland flow. For example, in the Cannonsville watershed, both annual TDN and streamflow for 2002 were above long-term average, whereas annual TDP and overland flow for 2002 were below average. These results have important consequences for watershed management, suggesting that management of overland flow in the watershed can be particularly effective in controlling TDP loads, to which algal growth in the reservoirs is particularly sensitive. Hence the importance of stormwater control.

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

The watershed models explicitly simulate overland flow and nutrient loads by land use and watershed source. The relative contributions of different watershed land uses and sources to total nutrient loads is an important consideration in watershed management. Figure 5.2 depicts the relative simulated contributions of point and non-point sources to TDP loads to the reservoirs for 2002 in relation to long-term simulated annual statistics. These findings support DEP's emphasis on point source reductions and on agricultural BMPs to reduce agricultural loads, particularly in Cannonsville watershed.

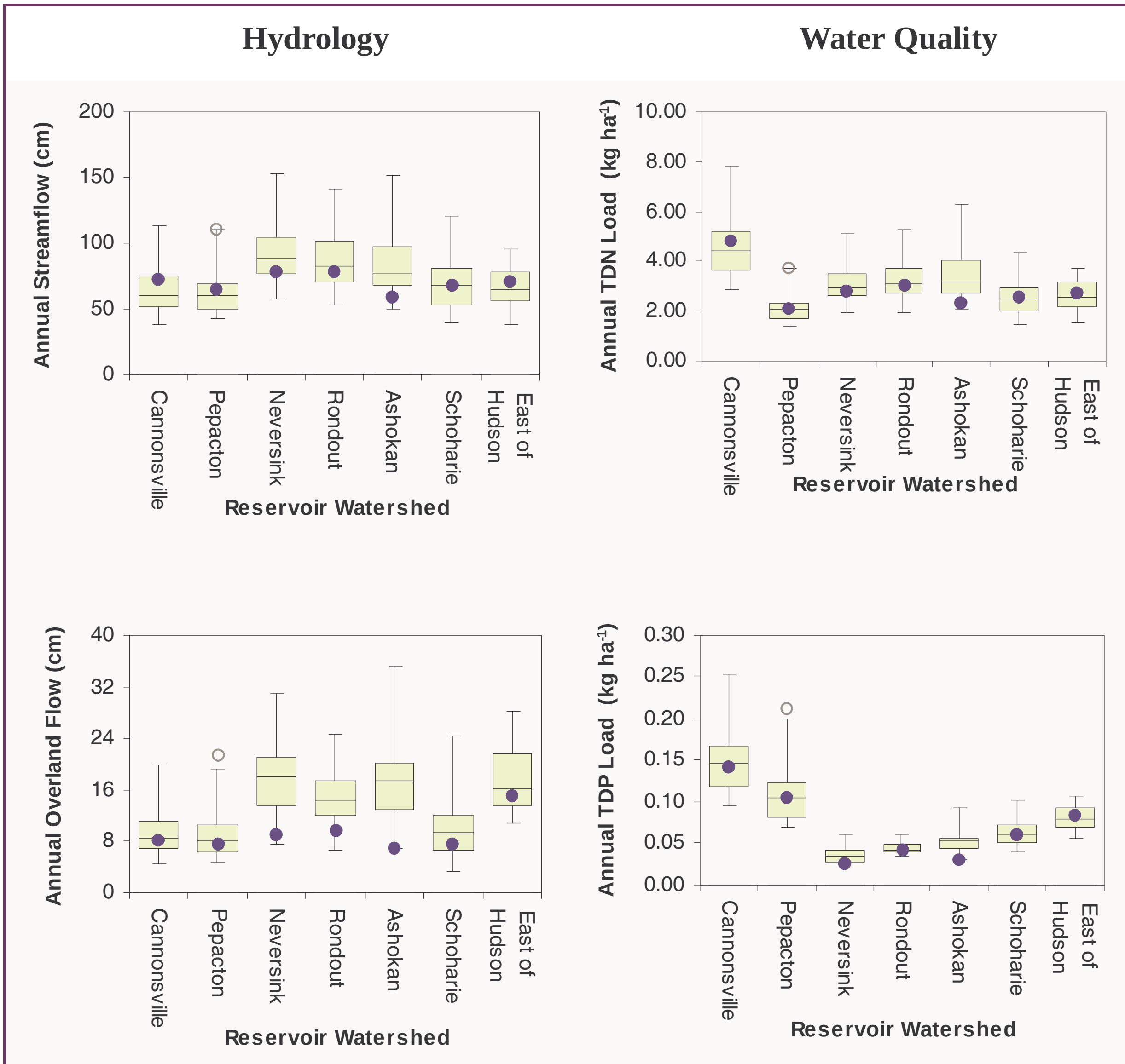

Figure 5.1 Annual streamflow, overland flow, and dissolved nutrient loads simulated by the GWLF model for 2002 in relation to long-term simulated annual statistics. Box plots show long term statistics. Blue dots show 2002 results.

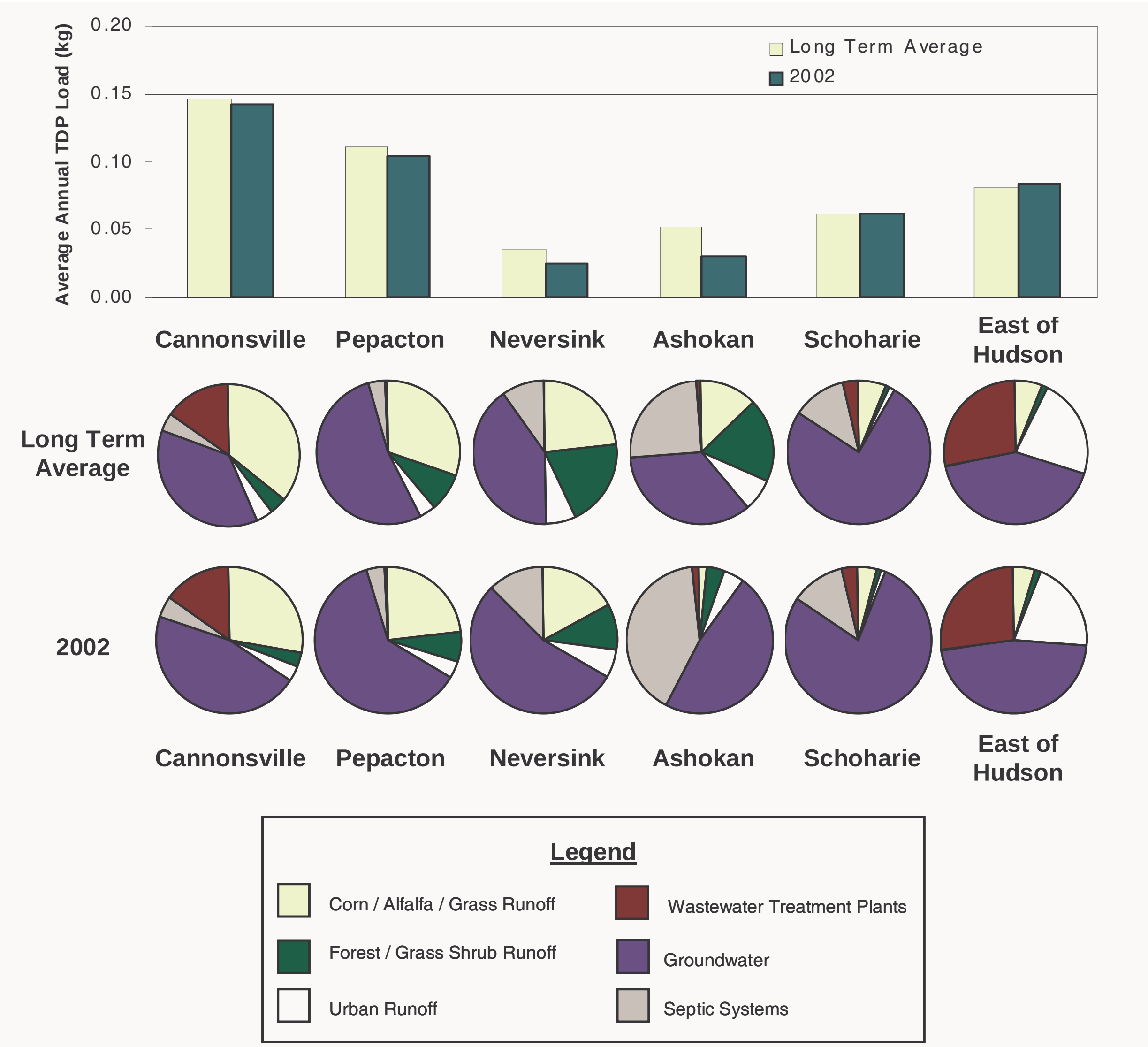

Figure 5.2 Relative simulated contributions of various non-point source land uses and point sources to TDP loads to the reservoirs for 2002 in relation to long-term simulated annual statistics.

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

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

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

These monthly loading data can be compared to results for the GWLF model. Figure 5.3 shows comparisons to GWLF model results for dissolved phosphorus, dissolved nitrogen, particulate phosphorus and total suspended sediment for the East Branch of the Delaware River watershed for 1996-1999. The estimated monthly loads are shown with the red triangles and the corresponding black circles show the GWLF results. The line shows the GWLF results for months between comparison data points. One measure of the performance of the model is the Nash-Sutcliff coefficient of model efficiency. This coefficient, referred to as r^2, measures the goodness of fit of model-predicted *versus* measured data, and can range from –infinity to 1, with 1 indicating a perfect fit. If r^2 is less than zero the model-predicted values are worse than simply using the observed, long-term mean. The Nash-Sutcliff coefficient values, shown in Figure 5.3, are well above 0.60, showing that the model is performing well in simulating the loads for these constituents.

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

Model improvement is an ongoing process as better data, research findings, and improved understanding of conceptual processes are obtained. As a result, modeling capabilities have been improved for both DEP's terrestrial and reservoir models.

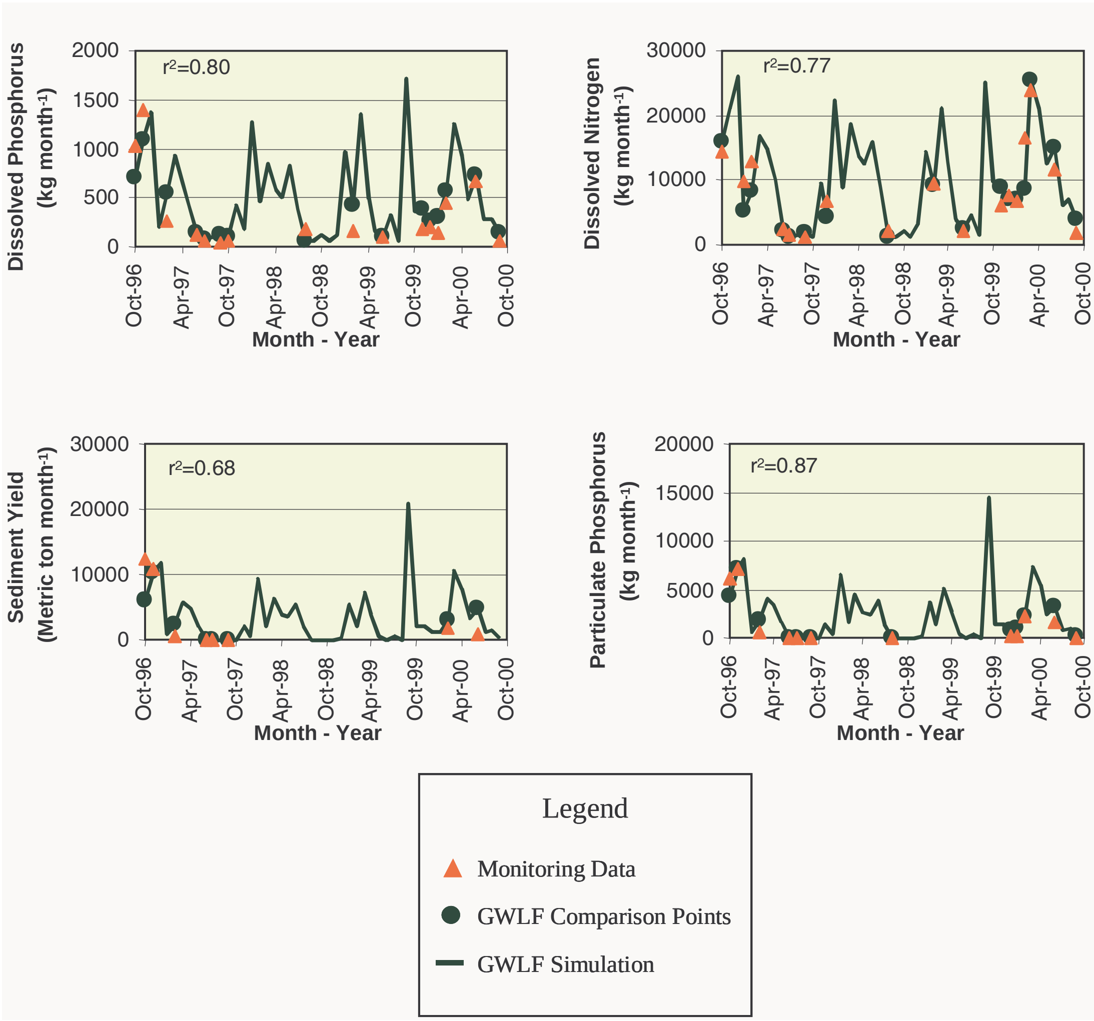

Figure 5.3 Comparison of loads estimated from stream monitoring data (red triangles) *versus* GWLF model results (dark circles) for East Branch of the Delaware River in Pepacton Watershed.

The GWLF hydrology and water quality modules have been extensively calibrated and verified for the Cannonsville watershed. The hydrology module has been calibrated and verified for the other Catskill/Delaware System watersheds consisting of the Pepacton, Neversink, Rondout, Schoharie, Ashokan and West Branch watersheds. During 2002, DEP set forth a schedule for the completion of the calibration and verification of the GWLF water quality modules for the remaining Catskill/Delaware System watersheds. As part of this schedule, water quality calibration for the Pepacton Watershed was updated using monitoring data collected through 2000.

A number of new parameters were added to the current GWLF model to improve the integration of GWLF with the reservoir management models. The GWLF model for Cannonsville Watershed was updated to simulate total dissolved nitrogen, instead of dissolved inorganic nitrogen. Existing monitoring data were further analyzed to develop a relationship between total dissolved nitrogen and dissolved inorganic nitrogen, thus enabling the updated GWLF model calibration and application. Dissolved organic carbon simulation was also added to the Catskill/Delaware System GWLF models.

DEP has begun developing a GWLF model application for the Town Brook Watershed. Application of GWLF to Town Brook, an agricultural sub-basin of Cannonsville watershed that the NYC Watershed Agricultural Council has designated as a research watershed, will provide a testing ground for improving agricultural phosphorus loading coefficients and refining runoff generation mechanisms for GWLF terrestrial model applications. During 2002, DEP began efforts on calibrating GWLF for the Town Brook Watershed. The calibration process focused on refining meteorological inputs to obtain more realistic forcing data for this local watershed application.

During 2002, a paper by the DEP modeling group entitled “Modeling the Hydrochemistry of the Cannonsville Watershed with GWLF” was published in the October 2002 issue of the Journal of the American Water Resources Association (Schneiderman et al., 2002). The paper documents the model changes that NYCDEP has made to the original GWLF model, calibration and verification methods, parameter sensitivity analyses, and the application of the revised and calibrated model to the Cannonsville watershed.

NYCDEP has developed and tested (and continues to test) mechanistic nutrient-phytoplankton water quality models for the Catskill/Delaware reservoirs. It has been established that the reservoirs of the Catskill/Delaware Systems have unusually high levels of inanimate particles (tripton) relative to concentrations of phytoplankton. Presently, the effects of tripton and resuspension are not predicted in these models. The Cannonsville sediment resuspension study was designed to assess the potential impact of incorporating tripton into the Catskill/Delaware water quality models. This study involves extensive field and laboratory analytical programs, including data collected by remote field instrumentation (RUSS units, sediment traps and wave gages), in addition to other data acquisition and analysis. Wind fetches and bioavailability of tripton were determined. The 1-D and 2-D hydrothermal reservoir model codes were revised to accommodate a wave submodel (including fetch), a bottom shear stress submodel, and resuspension of total suspended solids (TSS). Model input files were developed, and preliminary simulations of TSS were performed in both 1-D and 2-D models.

In accordance with the FAD deliverable to “incorporate a mechanistic sub-model for THM precursors into the existing Cannonsville eutrophication model framework,” DEP and the American Water Works Association Research Foundation (AWWARF) co-sponsored an extensive study of THM precursors in lakes and reservoirs. This work produced a mechanistic model for predicting THM precursors in lakes and reservoirs. A manuscript entitled “Origins, behavior, and a mechanistic model for THM precursors in lakes and reservoirs” will be published by AWWARF. The most relevant sections of this manuscript were submitted to EPA as the December 2002 FAD deliverable.

DEP is developing a modeling software interface through an SDWA funded contract with Par Government Systems Corporation. The software consists of two main sub-programs: the Modeling Support Tool System (MSTS) and the Scenario Support Tool System (SSTS). The MSTS will combine tools for terrestrial and reservoir models with data, calibration/verification, and visualization tools in an integrated software package. The SSTS will link the MSTS with a database of watershed management program implementation and effectiveness measures to provide support for evaluating the effectiveness of watershed management and BMPs in maintaining reservoir water quality. During 2002, progress was made on the specification of model software requirements and software programming began.

The Catskill/Delaware Management Model framework was finalized. This model links and integrates the eight individual 1-D reservoir models into an integrated multiple-reservoir management tool. The linked reservoir model (LINKRES) framework was also finalized, and integrates the eight individual 2-D reservoir models into a single management tool, but was produced without a user-friendly graphical user interface (GUI). A second version of LINKRES was developed, which incorporates a Kensico reservoir 2-D hydrothermal model (without nutrient-phytoplankton calibration) into the LINKRES framework, and also includes a GUI. This second version of LINKRES is currently undergoing DEP final review.

6. Further Research

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

DEP extends its capabilities through grants and contracts. In recent years, the appropriation of approximately $20 million under the Safe Drinking Water Act (SDWA), earmarked for the NYC Watershed, has supported a number of DEP projects devoted to guiding watershed management. This funding also supports projects conducted by other organizations such as the New York State Department of Conservation (NYSDEC), United States Geological Survey (USGS), United States Department of Agriculture (USDA), Cornell University, Delaware County, Stroud Water Research Center, and others. These projects have typically allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. Contracts are also used to support the work of the Division. The activities carried out through grants and contracts are described below.

6.2 What DEP projects are supported through SDWA grants?

DEP's SDWA projects are listed in Table 6.1. They fall into four major categories: i) Monitoring and Evaluation, ii) Watershed Management, iii) Modeling, and iv) Data Analysis. The research conducted under these grants has enhanced DEP's ability to document the existing conditions of the watershed including the role of wetlands, 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, streambank stabilizations, and forest management. Several projects have also been devoted to model development. Models allow DEP to extrapolate the effects of watershed management both into the future and throughout the nearly 2000 square miles of NYC's water supply watershed. Models are of increasing importance because they guide decisions affecting watershed protection and remediation. Finally, data analysis and communication are receiving attention to ensure that information is available in a timely manner.

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 since they are devoted to supporting the ongoing activities of the Lab and Field Operations Section. The "Monitoring" contracts are devoted to handling some of the laboratory analyses that must be done to keep up-to-date on the status of the water supply. "Research and Development" contracts typically answer questions that allow DEP to implement effective watershed management and plan for the future.

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

Project Category	Projects Supported
Monitoring and Evaluation	
	Ambient Surface Water Monitoring*
	Wetland Water Quality Functional Assessment*
	Pathogen Fate, Transport, and Source Identification
	Identification of Watershed Sources of E. coli
	Genotyping of Cryptosporidium oocysts (Ribotyping: Effects of Septics *vs.* Sewers)
	USGS Forest Health and Soil Nutrient Status
Watershed Management	
	Stream Management: A.Calibrating USGS Gages* B.Reference Reach Design* C.Monitoring BMP Effectiveness* D.Erosion and Scour Study
	TP Tracking System
	Stormwater BMP Monitoring Demonstration
Modeling	
	1-D Croton System Model
	Croton System Modeling
	Kensico Model Enhancement
Data Analysis	
	Water Quality Data Analysis and Communication
	MIS support

*Projects continued from previous grant

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

Contract Description	Contract Term
Operation and Maintenance	
Operation & Maintenance of DEP's Hydrological Monitoring Network	10/1/01-9/30/02
Waterfowl Management at Kensico Reservoir	8/1/01-5/31/02
The Removal of Hazardous Waste from DEP's laboratories	5/20/02-5/19/04
SAS software contract	11/5/01-11/4/02
Monitoring	
Development of an Enhanced Hydrologic Gage Network throughout NYC's 3 watersheds	
Monitoring of NYC reservoirs for pathogens	7/1/00-7/1/04
Monitoring of NYC reservoirs for viruses	11/2/00-11/2/03
Monitoring of NYC's reservoirs for zebra mussels	4/23/01-4/23/03
Monitoring of NYC residences for lead and copper	1/1/02-12/31/02
Organic Analysis Laboratory Contract	11/6/00-11/6/03
Laboratory Analysis of Wetlands and Storm Runoff in the NYC Watersheds	3/1/00-8/31/02
Analysis of Stormwater at Beerston –Cannonsville watershed	11/1/01-10/31/02
Research and Development	7/1/95-12/31/02
Design of Controls for Zebra Mussels in NYC's Water Supply System	1/5/94-10/3/03
Croton Watershed Management	12/5/00-12/4/02
Mapping Update of WOH Watershed Wetlands & Wetland Trend Analysis in EOH Watershed Wetlands	6/15/02-6/14/03
Wetland Functional Analysis Contract for all 3 Upstate Watersheds	3/1/02-3/1/04
The Development of 6 West of Hudson Reservoir Models	4/8/97-6/30/03
Croton Process Study	4/1/99-12/31/01
Development of Geographic Information Management System	7/1/95-9/30/02

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Appendix A - Comparison of Reservoir-wide Median Values of Selected Analytes

Appendix A: Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality Standard	Kensico N	Kensico Range	Kensico Median	New Croton N	New Croton Range	New Croton Median	East Ashokan Basin N	East Ashokan Basin Range	East Ashokan Basin Median	Rondout N	Rondout Range	Rondout Median
PHYSICAL													
Temperature (°C)		534	4.1 - 26.3	13.4	562	2.6 - 28.9	14.6	155	5.5 - 26.7	14.2	239	4.0 - 24.7	10.4
pH (units)	6.5 - 8.5†	500	6 - 8.6	7.1	516	6.7 - 9.4	7.8	150	6.3 - 8.9	7.2	225	6.0 - 8.9	6.9
Alkalinity (mg/l)		24	11.3 - 15.1	12.6	23	57.8 - 83.9	66.3	7	10.7 - 12.7	11.3	3	9.22 - 9.54	9.4
Conductivity (µS/cm)		512	60 - 91	71	554	307 - 419	340	155	56 - 94	66	239	50 - 72	64
Hardness (mg/l)		13	18 - 20	19	10	83-94	89	7	17-28	20	3	0	20
Color (Pt-color units)	(15)	339	6 - 50	10	411	9 - 200	18	108	Mar-33	11	180	8 - 27	12
Turbidity (NTU)	(5), *	339	0.5 - 4.6	1.2	411	1 - 17	2.1	109	0.6 - 20	1.9	180	0.5 - 4.4	1
Secchi transparency (m)		16	4.2 - 6.3	4.9	20	2 - 4.9	3.3	12	2.65 - 7.1	3.9	13	2.4 - 6.1	4.3
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7‡	131	0.64 - 10.5	2.69	165	0.21 - 21.53	6.21	36	0.65 - 20.94	4.95	46	1.7 - 14.1	4.75
Total Phytoplankton (SAU)	2000‡	400	10 - 9600	485	416	ND - 8400	1200	127	ND - 3300	490	179	ND - 4300	350
CHEMICAL													
Dissolved organic carbon (mg/l)		57	1.2-2.8	1.6	125	2.6-8.9	3.5	74	1.1-2.7	1.5	68	1.4-2.2	1.7
Total phosphorus (µg/l)	15‡	160	4 - 16	9	214	11 - 281	22	96	ND - 157	10	120	3.5 - 22	9
Total nitrogen (mg/l)	*	159	0.231 - 0.56	0.35	180	0.343 - 2.133	0.5435	56	0.1 - 0.5	0.25	38	0.373 - 0.574	0.468
Nitrate + nitrite - N (mg/l)	10†	181	0.028 - 0.429	0.175	235	ND - 0.523	0.15	79	ND - 0.31	0.09	78	0.086 - 0.422	0.281
Total ammoniacal - N (mg/l)	2†	178	ND - 0.205	0.018	246	ND - 1.808	0.03	77	0.01 - 0.49	0.02	78	ND - 0.062	0.007
Iron (mg/l)	0.3†	9	ND - 0.04	ND	7	0.09 - 4.57	0.13	6	0.02 - 0.3	0.06	6	ND - 0.03	0.02
Manganese (mg/l)	(0.05)	9	ND - 0.86	ND	14	ND - 2.86	0.055	6	ND - 0.575	ND	6	0.008 - 0.089	0.046
Lead (µg/l)	50†	15	0.1 - 5.3	0.3	7	0.8 - 3.3	1.1	6	0	ND	6	ND	ND
Copper (µg/l)	200†	16	0.8 - 8.6	1	7	2 - 4.2	2.8	6	ND	ND	6	ND - 1.9	1
Calcium (mg/l)		6	5.49 - 5.95	5.69	17	19.8 - 26	23	9	5.36 - 6.49	6.29	3	5.62 - 5.68	5.68
Sodium (mg/l)		6	4.32 - 4.62	4.5	17	24.6 - 30.5	28	9	3.65 - 4.38	4.18	3	4.23 - 4.4	4.33
Chloride (mg/l)	250†	21	6.4 - 8.3	7.3	26	5 - 67.2	60.8	77	6.7 - 10.6	8.5	9	5.45 - 7.1	6.6

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Appendix A *Continued:* Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality Standard	Amawalk			Bog Brook			Boyd Corners			Croton Falls		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		47	6.7 - 26.7	12.3	22	14.7 - 26.4	20.3	43	6.1 - 25.6	18.5	133	6.8 - 26.6	17.5
pH (units)	6.5 - 8.5†	47	6.9 - 9.2	7.9	22	7.2 - 9.2	8.3	34	6.6 - 7.9	7.3	133	6.7 - 9.8	8
Alkalinity (mg/l)		8	66.1 - 82.4	76	2	70.3 - 71.9	71.1	4	31.6 - 33.2	32.9	13	51.5 - 77.6	57.6
Conductivity (µS/cm)		47	384 - 410	398	22	280 - 308	289	43	204 - 246	222	133	269 - 520	386
Hardness (mg/l)		7	83 - 115	107	2	89 - 90	90	4	36-50	44	7	79-112	96
Color (Pt-color units)	(15)	33	11 - 30	17	16	15 - 45	28	28	25 - 50	35	90	9 - 80	17
Turbidity (NTU)	(5), *	33	1.8 - 4.2	2.6	16	1.9 - 4.8	3.4	28	0.8 - 12	2.2	90	1.3 - 17	2.5
Secchi transparency (m)		5	2.1 - 3.3	2.8	3	2.6 - 3.6	3	3	2.5 - 5	4.4	6	2.9 - 5.5	4.3
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7‡	18	1.42 - 22.4	5.04	11	1.31 - 11.05	4.56	15	0.97 - 7.31	2.07	51	0.59 - 35.45	6.98
Total Phytoplankton (SAU)	2000‡	32	91 - 4100	1450	17	230 - 13000	1100	31	20 - 2600	980	52	81 - 12000	1200
CHEMICAL													
Dissolved organic carbon (mg/l)		15	1.2-6.5	4.4	4	4.2-4.9	4.6	4	4.0-4.5	4.4	36	2.9-5.5	3.9
Total phosphorus (µg/l)	15‡	28	15 - 37	22	10	19 - 137	32	22	11 - 27	17	61	10 - 85	24
Total nitrogen (mg/l)	*	32	0.396 - 0.754	0.541	17	0.488 - 0.937	0.543	28	0.33 - 0.658	0.401	89	0.284 - 1.84	0.51
Nitrate + nitrite - N (mg/l)	10†	32	ND - 0.38	0.019	16	ND - 0.018	ND	28	ND - 0.101	0.036	89	ND - 1.127	0.031
Total ammoniacal - N (mg/l)	2†	32	ND - 0.286	0.037	16	ND - 0.52	0.024	28	ND - 0.166	0.026	89	ND - 0.645	0.033
Iron (mg/l)	0.3†	2	0.1 - 0.16	0.13	2	0.08 - 0.7	0.39	2	0.11 - 0.23	0.17	3	0.05 - 0.36	0.27
Manganese (mg/l)	(0.05)	5	ND - 0.52	ND	2	ND - 0.19	0.105	2	ND - 0.09	0.055	3	ND - 0.16	0.15
Lead (µg/l)	50†	2	0.8 - 1	0.9	2	0.5 - 0.6	0.6	2	1.4 - 2.3	1.9	7	0.3 - 1.7	0.3
Copper (µg/l)	200†	2	ND - 2	ND	2	1.1 - 1.8	1.5	2	1.7 - 2	1.9	7	1.1 - 2	1.3
Calcium (mg/l)		6	22.7 - 28.9	26.9	2	22.2 - 22.7	22.4	2	9.62 - 12.2	10.9	3	25.4 - 29.3	27.9
Sodium (mg/l)		5	33 - 34	33.3	2	17.5 - 17.7	17.6	2	16.1 - 20.4	18.3	3	39.8 - 41.6	40.5
Chloride (mg/l)	250†	8	68.3 - 75.3	72.3	2	40.7 - 41.2	41	4	39.1 - 45	41.9	11	49.3 - 80.2	59.5

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Appendix A *Continued:* Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality Standard	Cross River			Diverting			East Branch			Lake Gilead		
		N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		67	5.3 - 26.5	12.4	41	6.3 - 23.9	16.1	25	4.7 - 26.5	20.3	20	4.7 - 27.1	10.3
pH (units)	6.5 - 8.5†	67	6.6 - 9.1	7.6	35	7.2 - 9	8.2	22	7 - 9.1	8.2	20	6.5 - 8.5	7.7
Alkalinity (mg/l)		10	44.9 - 55.9	48.1	7	73.2 - 83.3	77.8	5	61.5 - 88.7	80.6	9	39.5 - 50.3	40.8
Conductivity (µS/cm)		67	220 - 245	235	35	304 - 386	340	25	242 - 347	294	20	155 - 177	157
Hardness (mg/l)		10	63-71	67	2	96-98	97	3	99-102	100	0		
Color (Pt-color units)	(15)	52	10 - 80	18	25	22 - 100	35	18	23 - 70	40	9	7 - 13	9
Turbidity (NTU)	(5), *	52	1.1 - 24	2.5	25	2.9 - 24	4.4	18	1.3 - 8.4	3.8	9	0.7 - 2	1
Secchi transparency (m)		7	2.3 - 4.6	3.3	7	1.7 - 2.6	1.9	4	1.6 - 3.2	2.5	4	7 - 8.4	7.6
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7‡	22	0.8 - 13.73	4.91	19	1.06 - 33.95	15.67	10	0.02 - 14.96	7.40	6	1.24 - 4.5	1.51
Total Phytoplankton (SAU)	2000‡	39	230 - 3100	1400	33	91 - 5600	2400	17	91 - 14000	3200	9	ND - 2700	740
CHEMICAL													
Dissolved organic carbon (mg/l)		19	3.1-6.6	3.6	12	4.5-5.8	4.7	6	4.8-5.3	5.2	3	2.7-3.4	3
Total phosphorus (µg/l)	15‡	40	Nov-36	20	22	30 - 138	38	13	26 - 74	41	9	7 - 423	12
Total nitrogen (mg/l)	*	46	0.275 - 1.14	0.396	25	0.561 - 0.969	0.673	18	0.469 - 0.745	0.579	9	0.283 - 1.029	0.327
Nitrate + nitrite - N (mg/l)	10†	46	ND - 0.21	ND	25	ND - 0.21	0.108	18	ND - 0.107	ND	9	ND - 0.107	ND
Total ammoniacal - N (mg/l)	2†	46	ND - 0.962	0.022	25	0.015 - 0.292	0.029	18	ND - 0.282	0.022	9	0.013 - 0.76	0.028
Iron (mg/l)	0.3†	5	0.04 - 1.95	0.11	2	0	0.43	3	0.12 - 0.96	0.7	0	-	
Manganese (mg/l)	(0.05)	7	ND - 1.56	ND	2	0.11 - 0.12	0.115	3	ND - 0.38	0.19	0	-	
Lead (µg/l)	50†	6	ND - 1.2	ND	2	0.6 - 0.9	0.75	3	0.5 - 1	0.6	3	ND	ND
Copper (µg/l)	200†	6	0.7 - 0.9	0.8	2	1 - 1.2	1.1	3	1 - 2.1	1.1	3	0	0.5
Calcium (mg/l)		7	18 - 19.3	18.6	2	23.9 - 24.5	24.2	3	24.7 - 25	24.8	0	-	
Sodium (mg/l)		7	15 - 16.1	15.9	2	17.7 - 18.2	18	3	17.1 - 17.8	17.2	0	-	
Chloride (mg/l)	250†	9	37.8 - 39.1	38.4	7	40.5 - 69.1	52.6	3	38.9 - 40.5	40.2	9	7.4 - 19.5	18

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Appendix A *Continued:* Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality	Lake Gleneida			Kirk Lake			Muscoot			Middle Branch		
	Standard	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL													
Temperature (°C)		19	5.2 - 26.9	14	12	14.1 - 26.8	21.2	94	5.6 - 25.5	13.8	58	7.7 - 26.6	12.2
pH (units)	6.5 - 8.5†	19	6.6 - 9.2	8.1	12	7.3 - 8.4	8.2	94	6.9 - 9.3	7.6	58	6.7 - 9.3	7.5
Alkalinity (mg/l)		9	61.7 - 76	66.8	3	52.4 - 56.7	52.4	7	64.4 - 81	68	8	58.1 - 80.1	59.9
Conductivity (µS/cm)		19	310 - 338	315	12	305 - 322	313	94	261 - 479	342	58	456 - 545	506
Hardness (mg/l)		0			0			2	96-100	98	3	91-101	96
Color (Pt-color units)	(15)	9	8 - 20	11	3	21 - 25	25	60	18 - 120	30	38	12 - 120	21
Turbidity (NTU)	(5), *	9	1.3 - 2.7	1.6	3	2.7 - 3.5	3.2	60	2.2 - 13	3.4	38	1.7 - 24	3.1
Secchi transparency (m)		5	3.5 - 6	5.6	4	1.7 - 3.6	2.9	8	1.6 - 3.5	2.5	8	1.9 - 5.9	3
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7‡	6	2.42 - 12.27	2.89	2	10.51 - 15.17	12.84	32	1.82 - 19.92	8.33	21	0.74 - 15.82	5.41
Total Phytoplankton (SAU)	2000‡	9	ND - 1200	170	4	1400 - 3700	2450	67	60 - 5600	1500	40	140 - 5600	1200
CHEMICAL													
Dissolved organic carbon (mg/l)		3	2.7-2.9	2.8	2	4.6-4.7	4.7	32	1.3-6.6	3.9	19	3.0-6.1	3.6
Total phosphorus (µg/l)	15‡	9	9 - 321	17	3	18 - 42	38	58	19 - 92	32	38	17 - 257	25.5
Total nitrogen (mg/l)	*	9	0.33 - 0.869	0.394	3	0.483 - 0.528	0.494	59	0.471 - 2.021	0.686	38	0.396 - 1.794	0.511
Nitrate + nitrite - N (mg/l)	10†	9	ND - 0.084	0.01	3	ND	ND	59	ND - 1.363	0.183	38	ND - 0.119	0.018
Total ammoniacal - N (mg/l)	2†	9	0.012 - 0.633	0.019	3	0.014 - 0.03	0.03	59	0.011 - 1.108	0.05	38	ND - 1.46	0.126
Iron (mg/l)	0.3†	0	-		0	-		0	-		2	0.12 - 0.31	0.22
Manganese (mg/l)	(0.05)	0	-		0	-		0	-		2	ND - 0.49	0.255
Lead (µg/l)	50†	3	ND - 1.4	0.8	2	0.6 - 1.1	0.9	4	0.5 - 1.9	0.8	5	0.3 - 7.1	0.6
Copper (µg/l)	200†	3	1.9 - 2	2	2	1.3 - 3	2.15	4	1.4 - 2.1	1.6	5	0.3 - 12.8	0.3
Calcium (mg/l)		0	-		0	-		2	24.3 - 25.2	24.8	3	22.8 - 25.3	23.8
Sodium (mg/l)		0	-		0	-		2	26.6 - 27.9	27.3	3	50.3 - 55.8	54.3
Chloride (mg/l)	250†	8	34.5 - 57.3	53.4	3	50.5 - 57.1	56.6	14	53.7 - 84.9	61.3	12	91.1 - 122.8	106.4

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Appendix A *Continued:* Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality Standard	Titicus N	Titicus Range	Titicus Median	West Branch N	West Branch Range	West Branch Median	West Ashokan Basin N	West Ashokan Basin Range	West Ashokan Basin Median	Pepacton N	Pepacton Range	Pepacton Median
PHYSICAL													
Temperature (°C)		47	6 - 26.8	12.2	255	2.3 - 24.9	14.8	335	4.9 - 26.0	12.8	363	1.1 - 24.8	10.1
pH (units)	6.5 - 8.5†	47	6.8 - 9.3	8	223	6.4 - 8.2	7.3	335	6.3 - 8	7.2	363	6.1 - 9.1	7.1
Alkalinity (mg/l)		10	66.1 - 76.3	72.6	15	0.338 - 25	17.4	13	10.1 - 13.9	10.9	7	10.5 - 11.1	10.7
Conductivity (µS/cm)		47	255 - 287	271	225	65 - 205	104	327	47 - 82	63	363	52 - 74	60
Hardness (mg/l)		8	88-94	91	15	25-37	29	9	17-20	19	7	20-22	21
Color (Pt-color units)	(15)	35	12 - 49	22	162	1 - 40	12	260	6 - 23	11	218	6 - 28	12
Turbidity (NTU)	(5), *	36	1.4 - 12	2.5	162	0.5 - 8	1.5	268	1 - 42	2.8	269	0.5 - 26	1.6
Secchi transparency (m)		7	2.3 - 4.3	2.9	17	2.8 - 7.4	5.1	10	2.3 - 5.4	3	9	2.9 - 6.3	3.7
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7‡	31	0.23 - 16.65	3.82	57	0.19 - 15.71	2.74	27	1.92 - 8.09	4.20	86	1 - 21.2	4.50
Total Phytoplankton (SAU)	2000‡	48	30 - 5800	820	198	8.3 - 9700	885	222	ND - 5100	210	207	ND - 2200	260
CHEMICAL													
Dissolved organic carbon (mg/l)		19	1.3-6.1	4.2	38	1.5-4.0	2.2	85	1.0-2.4	1.5	110	1.2-8.8	1.5
Total phosphorus (µg/l)	15‡	31	14 - 197	25	76	7 - 49	11	153	ND - 37	9	212	3 - 76.2	10.3
Total nitrogen (mg/l)	*	36	0.304 - 0.815	0.453	88	0.221 - 0.696	0.34	86	0.1 - 0.43	0.26	69	0.176 - 0.496	0.396
Nitrate + nitrite - N (mg/l)	10†	36	ND - 0.207	0.014	88	ND - 0.262	0.111	100	ND - 0.31	0.16	138	ND - 0.393	0.2215
Total ammoniacal - N (mg/l)	2†	36	ND - 0.703	0.047	88	ND - 0.568	0.019	102	0.01 - 0.04	0.02	138	ND - 2.06	0.006
Iron (mg/l)	0.3†	4	0.07 - 0.27	0.13	6	0.06 - 0.38	0.08	6	0.02 - 0.39	0.13	6	ND - 0.09	0.04
Manganese (mg/l)	(0.05)	5	ND - 0.47	ND	6	ND - 0.4	0.055	6	ND - 0.204	0.041	6	0.005 - 1.52	0.084
Lead (µg/l)	50†	3	ND - 0.5	ND	6	ND - 2.9	1.05	6	0	ND	6	ND	ND
Copper (µg/l)	200†	3	0.5 - 0.6	0.6	6	0.9 - 1.5	1	6	ND	ND	6	ND - 2.1	ND
Calcium (mg/l)		5	21.6 - 24.2	23.5	11	6.73 - 9.2	7.43	9	5.2 - 6.17	5.96	7	5.78 - 6.26	6.05
Sodium (mg/l)		5	14.5 - 15.3	14.8	10	5.62 - 10.4	8.02	9	3.5 - 4.14	3.92	7	3.39 - 3.72	3.67
Chloride (mg/l)	250†	9	35.1 - 37.1	35.8	16	12 - 22.8	14.6	97	5.6 - 10.5	7.8	14	4.45 - 5.85	5.08

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Appendix A *Continued:* Reservoir-wide median values for a variety of physical, biological and chemical analytes.

Analytes	Water Quality Standard	Neversink			Schoharie			Cannonsville		
		N	Range	Median	N	Range	Median	N	Range	Median
PHYSICAL										
Temperature (°C)		223	4 - 32.1	10.8	180	4.2 - 24.2	10.6	319	4.0 - 26.3	12.4
pH (units)	6.5 - 8.5†	190	5.6 - 8.5	6.5	180	6.4 - 8.4	7.3	319	6.1 - 10	7.3
Alkalinity (mg/l)		3	2.3 - 2.4	2.36	5	12.4 - 13.1	12.7	9	12.6 - 14.3	13.3
Conductivity (µS/cm)		207	25 - 34	31	169	55 - 124	72	301	67 - 120	87
Hardness (mg/l)		3	9.3-9.7	9.6	8	21-24	22	9	25-27	25
Color (Pt-color units)	(15)	150	6 - 20	12	99	7 - 27	12	205	8 - 40	15
Turbidity (NTU)	(5), *	155	0.5 - 3	1.1	131	0.6 - 50	3.9	223	0.6 - 26	2.4
Secchi transparency (m)		12	2.7 - 6.7	5.1	7	0.3 - 7.6	2.7	15	2 - 5.5	3.2
BIOLOGICAL										
Chlorophyll *a* (µg/l)	7‡	45	1.2 - 7.5	3.20	15	1.34 - 5.82	3.61	96	0.9 - 64.1	8.00
Total Phytoplankton (SAU)	2000‡	165	ND - 3800	300	94	ND - 820	84	207	ND - 15000	880
CHEMICAL										
Dissolved organic carbon (mg/l)		63	1.2-3.4	1.5	42	1.4-3.9	2	156	1.5-6.1	2
Total phosphorus (µg/l)	15‡	116	ND - 18.9	5	126	ND - 43	11	181	5.4 - 88.5	17.7
Total nitrogen (mg/l)	*	46	0.203 - 0.363	0.315	52	0.14 - 0.5	0.32	64	0.273 - 1.1	0.771
Nitrate + nitrite - N (mg/l)	10†	72	ND - 0.3	0.186	62	ND - 0.34	0.205	155	ND - 0.96	0.381
Total ammoniacal - N (mg/l)	2†	72	ND - 0.06	0.006	62	0.01 - 0.07	0.02	155	ND - 0.368	0.017
Iron (mg/l)	0.3†	4	0.03 - 0.1	0.08	6	0.08 - 0.29	0.15	9	0.05 - 0.27	0.11
Manganese (mg/l)	(0.05)	4	0.012 - 0.149	0.099	6	0.012 - 0.289	0.051	9	0.009 - 0.236	0.021
Lead (µg/l)	50†	4	ND	ND	6	0	ND	9	0	ND
Copper (µg/l)	200†	4	ND	ND	6	ND - 5	ND	9	0.6 - 3.7	0.6
Calcium (mg/l)		3	2.66 - 2.77	2.75	8	6.57 - 7.61	6.86	9	6.97 - 7.73	7.15
Sodium (mg/l)		3	1.78 - 1.8	1.8	8	4.06 - 5.44	4.98	9	5.65 - 6.71	6.21
Chloride (mg/l)	250†	3	2.35 - 2.4	2.4	62	0.3 - 11.8	9.3	20	7.4 - 10.5	8.75

Notes for Appendix A:

Sites: For most parameters, the data for each reservoir represent a statistical summary of all samples, taken at all sites and depths, for 2002. Chlorophyll *a* statistics were calculated from photic zone samples only. Secchi disk depth statistics were calculated from reservoir sampling site (near the dam) only.

Water Quality Standards:

* Narrative water quality standards.

† Numeric water quality standards, from 6NYCRR, Part 703.

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

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

Abbreviations:

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

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

Methods:

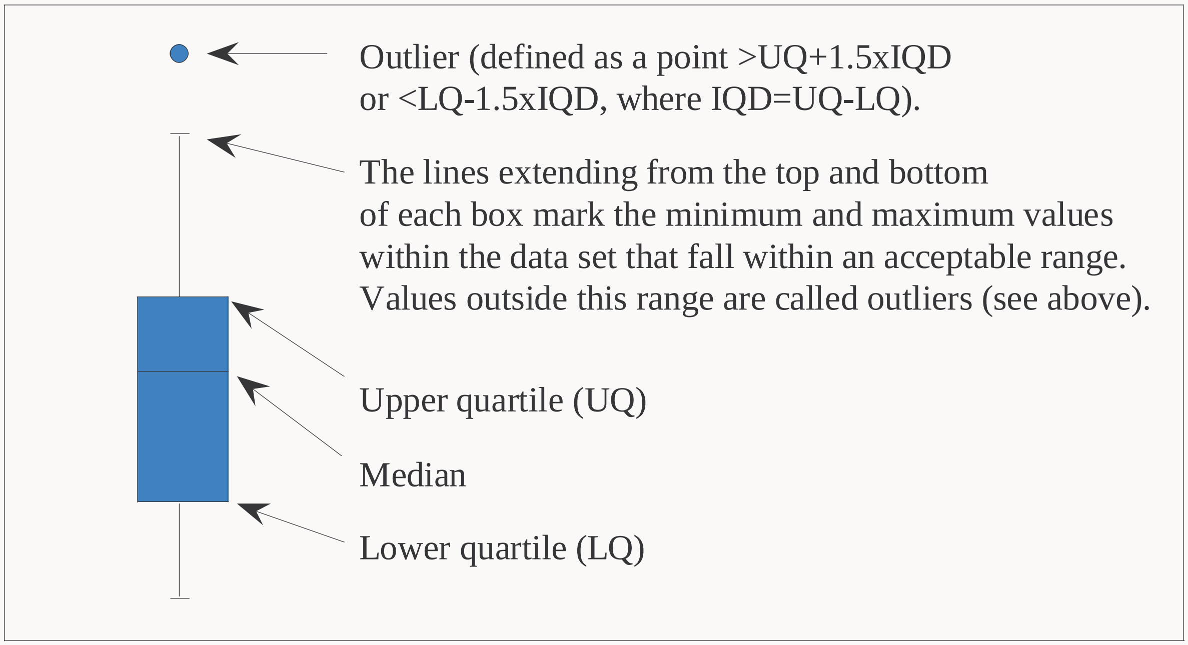
Chlorophyll *a* for 2002 represents the time period May - October; however, EOH data are provisional.

Chlorophyll *a* results were obtained through use of spectrophotometer or fluorometer method from 1991-2000, and by HPLC 2001-2002.

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

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 1999-2002, 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 Regulations as "the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D." The designation of a reservoir basin as phosphorus restricted has two primary effects: 1) new or expanded wastewater treatment plants with surface discharges are prohibited in the reservoir basin, and 2) stormwater pollution prevention plans required by the Watershed Regulations must include an analysis of phosphorus runoff, before and after the land disturbance activity, and must be designed to treat the 2-year, 24-hour storm. A summary of the methodology used in the phosphorus restricted analysis will be given here; the complete description can be found in “Methodology for Determining Phosphorus Restricted Basins” (NYCDEP, 1997).

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

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

To provide some statistical assurance that the five year arithmetic mean is representative of a basin’s phosphorus status, given the interannual variability, the five year mean plus the standard error of the five year mean is compared to the NYS guidance value of 20 $\mu g\ L^{-1}$. A basin is **unrestricted** if the five year mean plus standard error is below the guidance value of 20 $\mu g\ L^{-1}$, and phosphorus **restricted** if it is equal to or greater than 20 μg L^{-1}, unless the 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.

Reservoir Basin	**1997** μg L^{-1}	**1998** μg L^{-1}	**1999** μg L^{-1}	**2000** μg L^{-1}	**2001** μg L^{-1}	**2002** μg L^{-1}
Delaware System						
Cannonsville Reservoir	21.02	17.06	17.27	17.20	19.3	17.9
Pepacton Reservoir	8.16	7.85	8.93	8.10	8.6	10.4
Neversink Reservoir	5.06	3.29	5.13	5.26	5.8	4.7
Rondout Reservoir	6.33	7.59	7.65	10.40	7.4	9.2
Catskill System						
Schoharie Reservoir	18.44	18.71	25.92	21.31	15.2	11.7
Ashokan-West Reservoir	14.48	14.23	14.23	9.56	9.4	9.6
Ashokan-East Reservoir	13.73	12.65	11.00	10.60	7.7	12.4
Croton System						
Amawalk Reservoir	21.11	23.52	22.12	38.63	19.8	22.2
Bog Brook Reservoir	14.13	19.83	18.01	34.73	21.4	*
Boyd Corners Reservoir	5.06	8.74	12.61	16.00	13.6	15.9
Cross River Reservoir	*	16.83	10.85	17.15	14.8	20.3
Croton Falls Reservoir	19.76	19.59	16.54	26.09	22.3	24.1
Diverting Reservoir	23.11	33.42	22.95	30.02	31.8	41.7
East Branch Reservoir	25.11	31.55	19.47	39.01	33.3	*
Middle Branch Reservoir	18.92	25.97	23.18	32.42	27.7	31.2
Muscoot Reservoir	23.31	29.34	26.46	35.00	29.7	33.9
Titicus Reservoir	*	38.13	37.31	33.58	28.7	26.9
West Branch Reservoir	5.55	6.56	7.12	13.29	11.5	12.9
Lake Gleneida	24.00	21.34	22.00	30.36	31.6	*
Lake Gilead	21.51	23.21	28.07	34.89	38.4	*
Source Water						
Kensico Reservoir	5.37	5.34	5.80	9.11	8.5	8.4
New Croton Reservoir	15.00	15.76	15.88	22.68	21.9	23.9

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