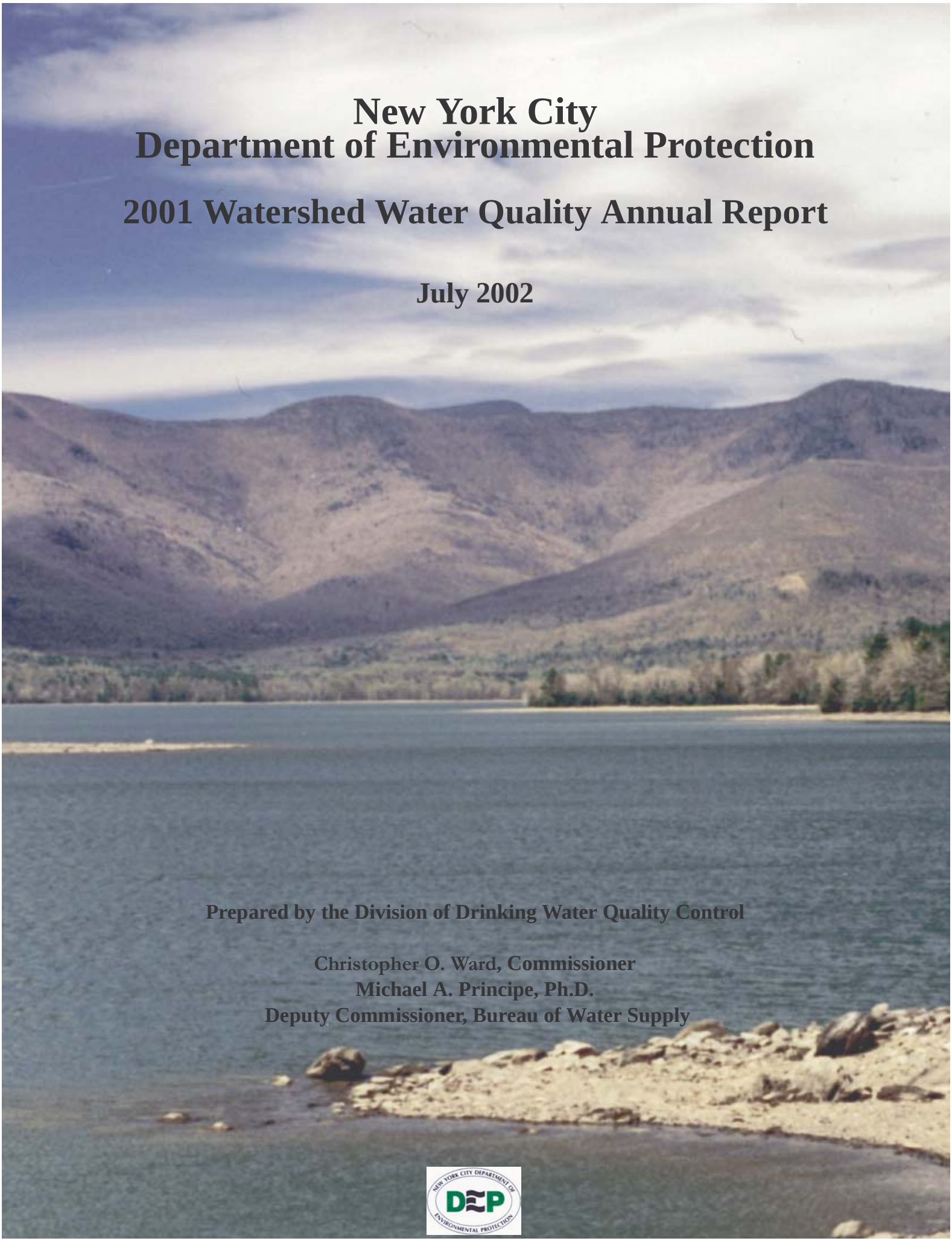


New York City Department of Environmental Protection

2001 Watershed Water Quality Annual Report

July 2002

Prepared by the Division of Drinking Water Quality Control

Christopher O. Ward, Commissioner
Michael A. Principe, Ph.D.
Deputy Commissioner, Bureau of Water Supply

Table of Contents

List of Tables iii
List of Figures v
Acronyms ix
Acknowledgments xi
1. Introduction 1
1.1 What is the purpose of this report? 1
1.2 What role does the Division of Drinking Water Quality Control play in the operation of NYC's water supply? 1
1.3 How does the City monitor the condition of its reservoirs and their watersheds? 2
2. Water Quantity 5
2.1 Where does our water come from? 5
2.2 How much water did we have in 2001? 10
2.3 How did DEP cope with the "dry" year? 10
3. Water Quality 15
3.1 How does the water quality of NYC's source waters compare with safety standards set by federal regulations 15
3.2 What levels of protozoan pathogens are found in the source waters and watershed? 18
3.3 Which basins are phosphorus-restricted? 25
3.4 Which basins are coliform-restricted? 26
3.5 What streams represent the major flow into NYC's reservoirs, and what is their water quality? 27
3.6 What is the quality of water in NYC's reservoirs? 31
3.7 What are the trophic states of the City's 19 reservoirs and why is this important? 36
3.8 What are disinfection by-products (DBPs), where do they come from, and are current levels acceptable? 40
3.9 Is water quality changing in the streams, reservoirs, and keypoints? 41
4. Watershed Management 43
4.1 How do contaminants get into the water supply? 43
4.2 How can watershed management improve water quality? 43
4.3 What kind of watershed management programs does DEP have and what are the recent accomplishments? 44
4.4 How can DEP reduce point sources of contaminants? 45
4.5 How can DEP reduce nonpoint sources of contaminants? 50
4.6 How can DEP enhance protection of the Water Supply? 55
4.7 Does DEP evaluate biological integrity? 58
5. Model Development and Applications 61
5.1 Why are models important? 61
5.2 How are models being used to guide water supply operations? 61
5.3 How are models being used to guide long-term watershed management? 63
5.4 What was accomplished in 2001 in the development of modeling capabilities? 67
5.5 Modeling milestones completed in 2001 69
6. Further Research 71

6.1 How does DEP extend its capabilities for water quality monitoring and research? 71
6.2 What DEP projects are supported through SDWA grants? 71
6.3 What work is supported through contracts? 71
Glossary List 77
Appendix A - Key to Box Plots 79
Appendix B - Routine Pathogen Program Sampling Location Codes and Descriptions 81
Appendix C - Method to Determine Phosphorus-Restricted Basins 83
Appendix D - Comparison of Reservoir-wide Mean Values of Selected Analytes 87
Appendix E - Hindcasting versus Forecasting Models 91

List of Tables

Table 2.1. Drought stages as defined in NYC's Drought Management Plan. 13
Table 3.1. Phosphorus restricted basins determination. 26
Table 3.2. Coliform-restricted status of reservoir basins based on 1996-2000 and 1997-2001 assessments 27
Table 3.3. Sites codes and site descriptions of the stream sample locations discussed in this report 28
Table 3.4. Reservoir-wide mean values for a variety of physical, biological and chemical analytes for the four source water reservoirs: Kensico, New Croton, Ashokan (east basin), and Rondout. 35
Table 4.1: DEP watershed programs and achievements. 44
Table 6.1. DEP's SDWA grants. 72
Table 6.2. DEP contracts related to water quality monitoring and research. 73
Table B.1. Pathogen sampling location codes and descriptions. 81
Table C.1. Geometric Mean Total Phosphorus Data utilized in the Phosphorus Restricted Assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit. 85
Table C.2. Phosphorus Restricted Reservoir Basins for 2001. 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. 86

List of Figures

Figure 1.1 Organization of the upstate section of DWQC. 2
Figure 1.2 The DEP limnology staff monitors water quality in the City's 19 reservoirs. 3
Figure 1.3 The five DEP laboratories process approximately 25,000 samples each year. 3
Figure 2.1 New York City Watershed. 5
Figure 2.2 NYC water supply reservoirs and their available storage capacities. 6
Figure 2.3 The Ashokan Reservoir spillway. 7
Figure 2.4 Historic total annual and monthly precipitation (mm) for the WOH and EOH Systems (1965-2001) and values for 2001 showing that nine months of the year were drier than usual. 8
Figure 2.5 Historic annual runoff (cm) as boxplots for the WOH and EOH watersheds with the values for 2001 displayed as a dot. 9
Figure 2.6 Percent usable storage in 2001 compared to the long-term average (normal) storage. 11
Figure 2.7 Total NYC Reservoir System storage (10 year average compared with 2001). Kensico Reservoir storage is not included in the calculations of total storage. 11
Figure 2.8 Annual residence times as box plot for NYC Reservoirs based on 1991-2001 data for WOH reservoirs, including West Branch and Kensico and 1995-2001 data for Croton Reservoirs 12
Figure 2.9 Cannonsville Reservoir during the drought of 2001. 13
Figure 3.1 Fecal and total coliform agar plates. 15
Figure 3.2 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. 16
Figure 3.3 Temporal plots of turbidity (daily samples) compared with Surface Water Treatment Rule limits. 17
Figure 3.4 Temporal plots of *Cryptosporidium* and *Giardia* concentrations (weekly samples). 19
Figure 3.5 Average *Cryptosporidium* concentrations in the source waters are all below the proposed treatment threshold (LT2ESWTR), despite changes in analytical methodology. 20
Figure 3.6 Average *Cryptosporidium* concentrations in the NYC watersheds. 21
Figure 3.7 Average *Giardia* concentrations in the NYC watersheds. 22
Figure 3.8 2001 Average fixed frequency pathogen sampling results in the NYC watersheds. 23
Figure 3.9 Pathogen Stormwater Autosampler. 24
Figure 3.10 Phosphorus restricted basins in 2001. 25
Figure 3.11 Phosphorus restricted basin assessments with the current year 2001 geometric mean phosphorus concentration displayed for comparison. 26
Figure 3.12 Locations of sampling sites and USGS stations. 28
Figure 3.13 Boxplot of annual medians (1991-2000) for a) turbidity b) total phosphorus c) fecal coliforms d) total coliforms for selected streams (reservoir inflow) sites with the value for 2001 displayed as a dot. 30

Figure 3.14 Annual median turbidity levels in NYC Reservoirs (2001 vs. 1991-2000). ...31
Figure 3.15 Annual median total phosphorus concentration in NYC Reservoirs (2001 vs. 1991-2000). 32
Figure 3.16 Annual median coliform levels in NYC Reservoirs (2001 vs. 1993-2000). ...33
Figure 3.17 A comparison of historic annual conductivity in reservoirs with 2001 values shown as a dot. 34
Figure 3.18 Trophic State Index of the New York City reservoirs based on chlorophyll *a* concentration. 36
Figure 3.19 Asterionella formosa, a phytoplankton species typically found in NYC's reservoirs 37
Figure 3.20 Mean chlorophyll a vs. total phosphorus concentration in samples collected in the photic zone during the growing season (May-October) in NYC reservoirs over a 10 year period (1991-2000) and for 2001. 38
Figure 3.21 Secchi depth transparency (ZSD) vs. mean chlorophyll *a* (Chl *a*) in samples collected in the photic zone during the growing season (May-October) in NYC reservoirs over a 10 year period (1991-2000) and for 2001. 39
Figure 3.22 Secchi disc measurement with a viewer box on the sunny side of the boat. ...39
Figure 3.23 Total Trihalomethanes (THM) concentrations found in the Croton and Catskill/Delaware distribution systems 1995 through 2001 plotted as quarterly running averages 41
Figure 4.1 Storm flow is responsible for the transport of non-point source contaminants from the landscape into the water supply 43
Figure 4.2 Wastewater treatment plant TP loads by district, 1994 - 2000. 46
Figure 4.3 Upgrade schedule for Delaware District WWTPs. 47
Figure 4.4 Typical waste water treatment plant reductions in average virus concentration 48
Figure 4.5 Waste water treatment plant upgrades resulted in a reduction of the average Cryptosporidium and Giardia concentrations of WWTP effluents. ...49
Figure 4.6 Map of Kensico Reservoir watershed with locations of extended detention basin BMPs. 52
Figure 4.7 BMP Facility 12 following a rain event. 52
Figure 4.8 Load reduction regressions for Facility 12 (Malcolm Brook) extended detention basins. 53
Figure 4.9 Canada geese are sometimes the cause of high bacterial levels in reservoirs. 54
Figure 4.10 The effects of waterbird management on source water fecal coliform concentrations. 55
Figure 4.11 Adult brook trout (Salvelinus fontinalis). 56
Figure 4.12 Documenting captured fish characteristics during stream reclassification surveys. 56
Figure 4.13 New Croton Reservoir proposed Stream Classification Program. 57
Figure 4.14 A lotic reference wetland located within the West Branch Reservoir Basin of the Croton Watershed. 57
Figure 4.15 *Ephemerella sp* - an example of the benthic organisms used to evaluate environmental quality. 58
Figure 4.16 Boxplots of stream biomonitoring water quality scores, 1994-2000 data. 59

Figure 5.1 Predicted time course of tracer concentrations at three water supply intakes in Cannonsville Reservoir at four water supply intakes in downstream Rondout Reservoir. 62
Figure 5.2 Sources of dissolved and particulate loads to Catskill/Delaware System Reservoirs, under baseline conditions (before implementation of watershed management programs). 63
Figure 5.3 Schematic showing the modeling framework that simulates multiple years, using a specified loading condition and historical meteorological, hydrological and operational data to provide water quality predictions in a probabilistic format. 65
Figure 5.4 Effects of dissolved and particulate phosphorus loading reductions before and after program implementation on chlorophyll *a* predictions in Cannonsville Reservoir. 66
Figure 5.5 Effects of dissolved and particulate phosphorus loading reductions on chlorophyll *a* predictions in Pepacton Reservoir. 67
Figure 5.6 Schematic showing how continued testing and application of models relates to use of management models for making informed decisions with respect to water supply protection. 68

Acronyms

ASTM – Association of Standards and Testing Materials
BMP – Best management practice
cfu – colony forming unit
Chla – chlorophyll a
cm – centimeter
CREP – Conservation Reserve Enhancement Program
DBP – Disinfection-by-products
DEP – New York City Department of Environmental Protection
DOT – New York State Department of Transportation
DRBC – Delaware River Basin Commission
DWQC – Division of Drinking Water Quality Control
ELAP – Environmental Laboratory Approval Program
EOH – East-of-Hudson
FAD – Filtration Avoidance Determination
GIS – Geographic Information System
GWLF – Generalized Watershed Loading Function
HAAs – Haloacetic acid
HPLC – High Performance Liquid Chromatography
ICR – Information Collection Rule
KWIC – Kensico Watershed Improvement Committee
L^{-1} – per liter
LT2SWTR – Long-term 2 Surface Water Treatment Rule
MCL – Maximum concentration limit
ml^{-1} – per milliliter
mm – millimeter
MOA – New York City Watershed Memorandum of Agreement
NCDC – National Climatic Data Center
NTU – Nephelometric units
NYC – New York City
DEP – New York City Department of Environmental Protection
NYCRR – New York City Rules and Regulations
NYSDEC – New York State Department of Environmental Conservation
QA – Quality assurance
SDWA – Safe Drinking Water Act

SPDES – State Pollutant Discharge Elimination System
SWTR – Surface Water Treatment Rule
THM – Trihalomethanes
THMFP – Trihalomethanes formation potential
TMDL – Total Maximum Daily Load
TOGS – NYSDEC Technical and Operational Guidance Series
TP – Total phosphorus
TSI – trophic state index
US ACOE – United States Army Corps of Engineers
USEPA – United States Environmental Protection Agency
US FWS – United States Fish and Wildlife Service
USGS – United States Geological Survey
WMP – Waterfowl Management Program
WOH – West-of-Hudson
WRR – Watershed Rules and Regulations
WWTP – Wastewater treatment plant
Z_{SD} – Secchi disk transparency depth
µg – micrograms

Acknowledgments

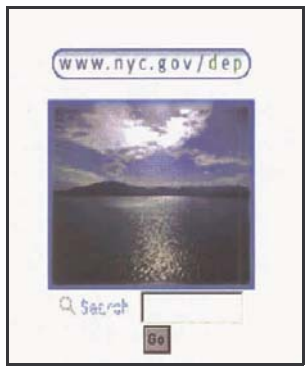
The production of this report required the scientific expertise, creativity, and cooperation of the many staff members of the Division of Drinking Water Quality Control (DWQC.) All deserve special recognition and thanks for their willing participation in the many facets of the Division's work, from sample 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 activities of the Division operating. Therefore, thanks are due to all the field and laboratory staff who collected and analyzed all the samples for the watershed monitoring programs and the administrative staff who back 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 members deserve recognition for the role they play in this production.

General guidance in all the activities of the Division was provided by Dr. Michael Principe, Deputy Commissioner of the Bureau of Water Supply (Director of DWQC in 2001) and Dr. David Lipsky, Director of DWQC (Upstate Deputy Chief in 2001.) Mr. Steven Schindler and Dr. Lorraine Janus were responsible for management of the Division’s Upstate Laboratory and Field Operation sections, respectively. In the production of this report, the original outline was composed by Dr. Lorraine Janus, Section Chief for Upstate Field Operations, and was presented in NYC's 2001 Watershed Protection Program Summary, Assessment, and Long-term Plan (issued December 2001.) Subsequent interaction with DWQC Supervisors and their staff led to the detailed versions of each chapter. Leading roles in authorship and editing were taken by Dr. Lorraine Janus, Mr. James Mayfield, Dr. David Smith, Dr. Kimberlee Kane, Dr. Carol Stepczuk, and Dr. Elliot Schneiderman. Special mention of sub-section authors goes to Mr. Andrew Bader, Dr. Yves Mikol, Mr. William Richardson, Mr. Arthur Ashendorf, Mr. Gerald Marzec, Ms. Salome Freud, Mr. Charles Cutietta-Olson, Mr. Christopher Nadareski, Mr. Thomas Baudanza, Ms. Laurie Machung, and Mr. Mark Zion. Thanks also go to Ms. Kelly Seelbach, Mr. Jeff Mantus, Mr. Raphael Hurwitz, Dr. David Stern, Mr. Gerald Pratt, and Ms. Sharon Neuman for additional graphics or information. Significant improvements were made to the final report through the editing efforts of Dr. Michael Principe, Dr. David Lipsky, Dr. Lorraine Janus, and Mr. David Warne. 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 in the face of the inevitable barrage of final 'additions' and 'corrections' is remarkable and much appreciated by all.

1. Introduction

1.1 What is the purpose 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 produced by the Division of Drinking Water Quality Control (DWQC), to provide the public with a general overview of the City's water resources, their condition during 2001, and compliance with regulatory standards or guidelines during this period. It's 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 the Division of Drinking Water Quality Control play in the operation of NYC's water supply?

DWQC provides critical information to ensure that water entering the drinking water supply is of known quality, is of the best quality possible, and complies with all Federal and State regulations. DWQC achieves this mission through extensive monitoring of the nearly 2,000 square miles of the City's watersheds, its network of streams, and 19 interconnected reservoirs.

Monitoring is done to meet the informational needs for decisions on both short-term operations and long-term watershed management and protection. The short term needs (e.g., reservoir flow adjustments to maintain high water quality, estimation of substances transported by storm events, or in rare cases, treatments), are served by high frequency (hourly, daily or weekly) monitoring at critical locations. Long-term needs (e.g., characterization of geographic coverage for extrapolation, or tracking changes over time) are served by monitoring at many other sites throughout the watershed on a less frequent (biweekly or monthly) basis. This monitoring provides comparative information on the temporal and spacial variation of water quantity and quality throughout the watershed.

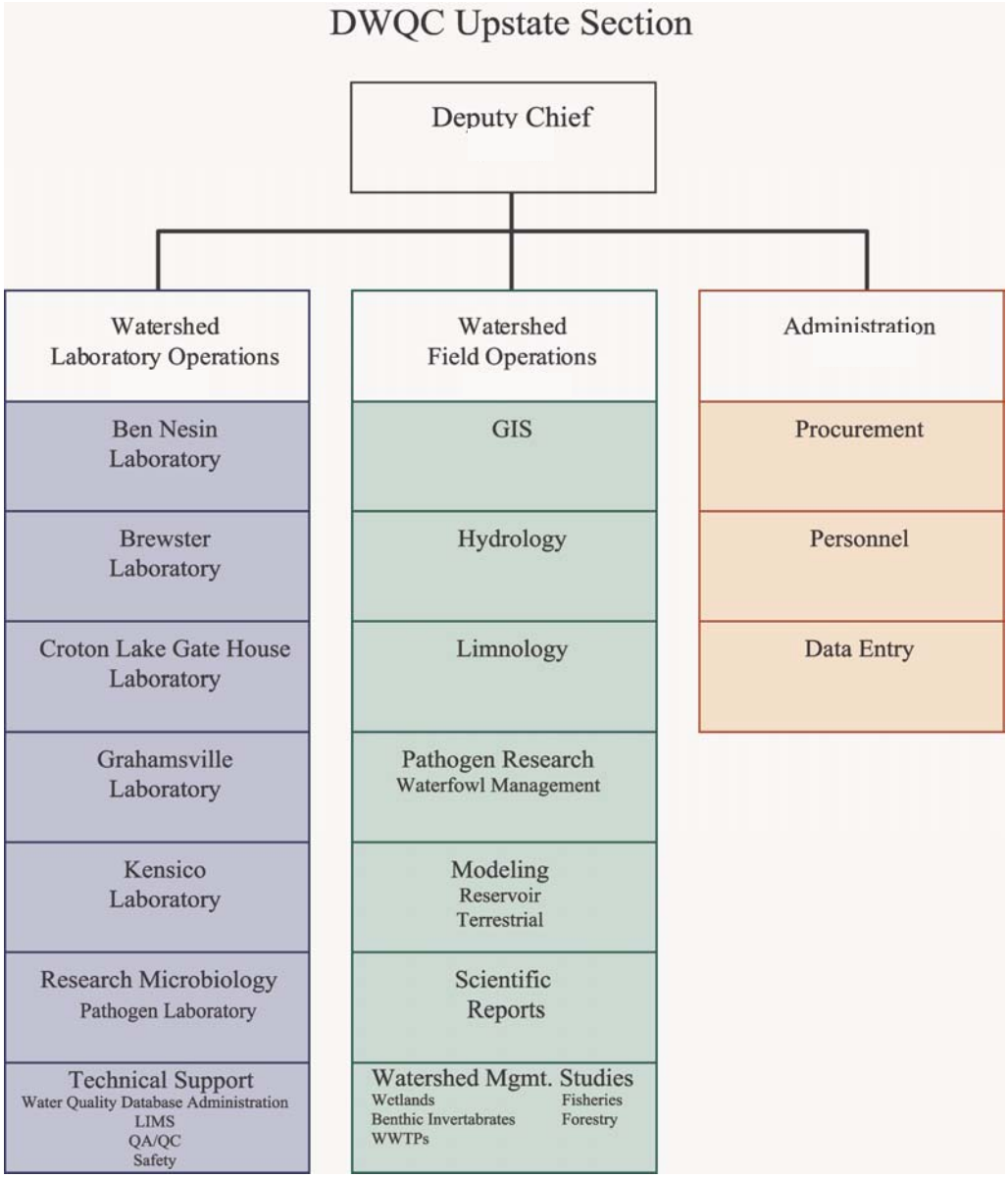


Figure 1.1 Organization of the upstate section of DWQC.

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

The Division of Drinking Water Quality Control 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 (see Figure 1.1.)

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 Districts (Catskill, Delaware, and East of Hudson.) Extensive monitoring of a vast 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 Districts. 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 oper-

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

ates a Pathogen Laboratory that analyses water samples for the protozoan pathogen *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.

For the 2001 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 Where does our water come from?

New York City's water supply is provided by a system of 19 reservoirs and three controlled lakes with a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (see Figure 2.1). The system is dependent on precipitation (rainfall and snow melt) and subsequent runoff to supply the reservoirs in each of three watershed systems, the Catskill, Delaware, and Croton Systems. The first two are located West-of Hudson (WOH) and the Croton System is located East-of-Hudson (EOH) (Figure 2.2). As the water drains from these watersheds, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the pollutant loads and hydraulic residence times, which in turn directly influence each reservoir's water quality and productivity.

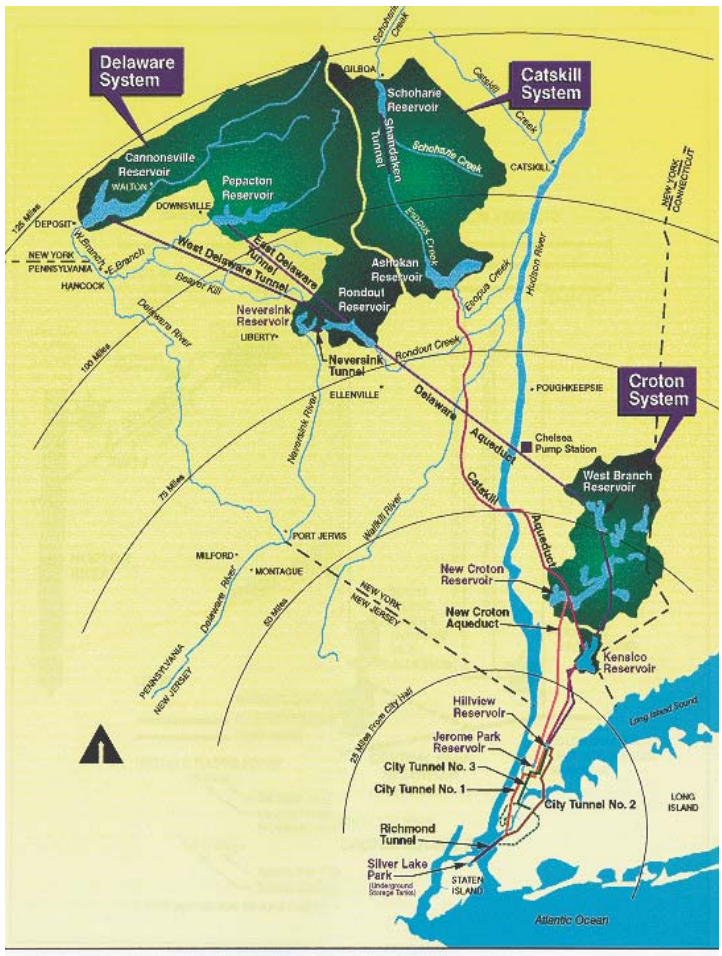


Figure 2.1 New York City Watershed.

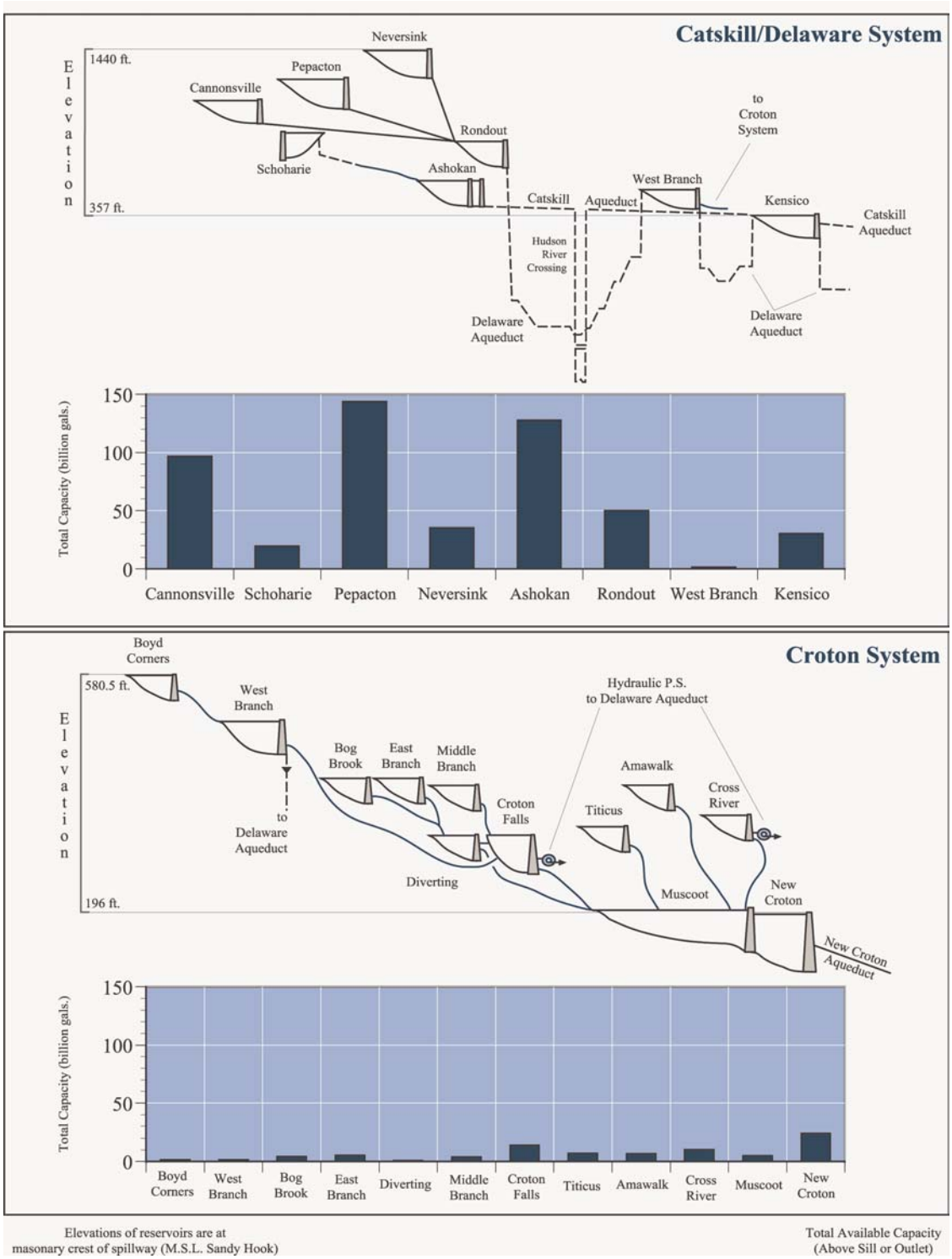


Figure 2.2 NYC water supply reservoirs and their available storage capacities.

Precipitation

Figure 2.3 The Ashokan Reservoir spillway.

The total annual and total monthly precipitation for each reservoir basin is calculated from the data provided by a network of 20 National Climatic Data Center (NCDC) precipitation gauges located in or near the watershed (Figure 2.4). Eighteen of these gauges are located WOH. These gauges collect data on a daily basis which are summed over the month or year, as appropriate. Because of substantive variations in precipitation both spatially and temporally, precipitation from each gauge must be extrapolated to a basin-wide estimate of total annual or monthly precipitation. Data are presented throughout this report as box plots and an explanation of how to read them is provided in Appendix A.

The total annual and monthly precipitation in this period 1965-2001 for EOH is shown in Figure 2.4c and d. The deficit in EOH was 266 mm (≈10.5 inches). As indicated, 2001 was the second driest year since 1965, both EOH and WOH, exceeded only by the drought year of 1965. The overall precipitation deficit for WOH in 2001 was 273 mm (≈11 inches). For both WOH and EOH, nine of the twelve months in 2001 were below the historical median monthly totals.

Runoff

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

Selected United States Geological Survey (USGS) stations (Figure 3.12) were used to characterize annual runoff in the different NYC watersheds. As indicated in Figures 2.5a and b, the annual runoff from the watersheds to the WOH and EOH reservoirs was well below historic values for 2001 because of the precipitation deficit.

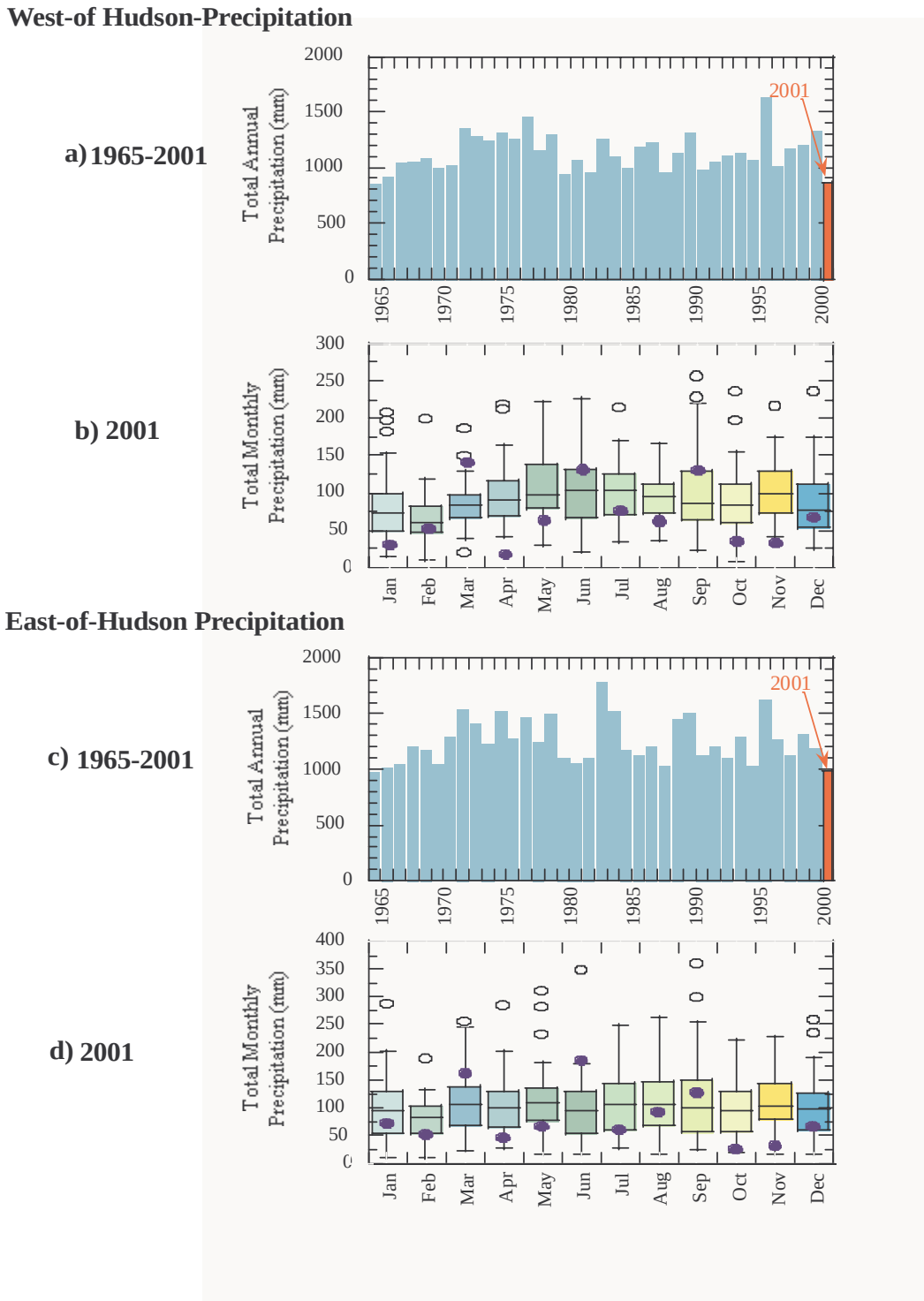


Figure 2.4 Historic total annual and monthly precipitation (mm) for the WOH and EOH Systems (1965-2001) and values for 2001 showing that nine months of the year were drier than usual.

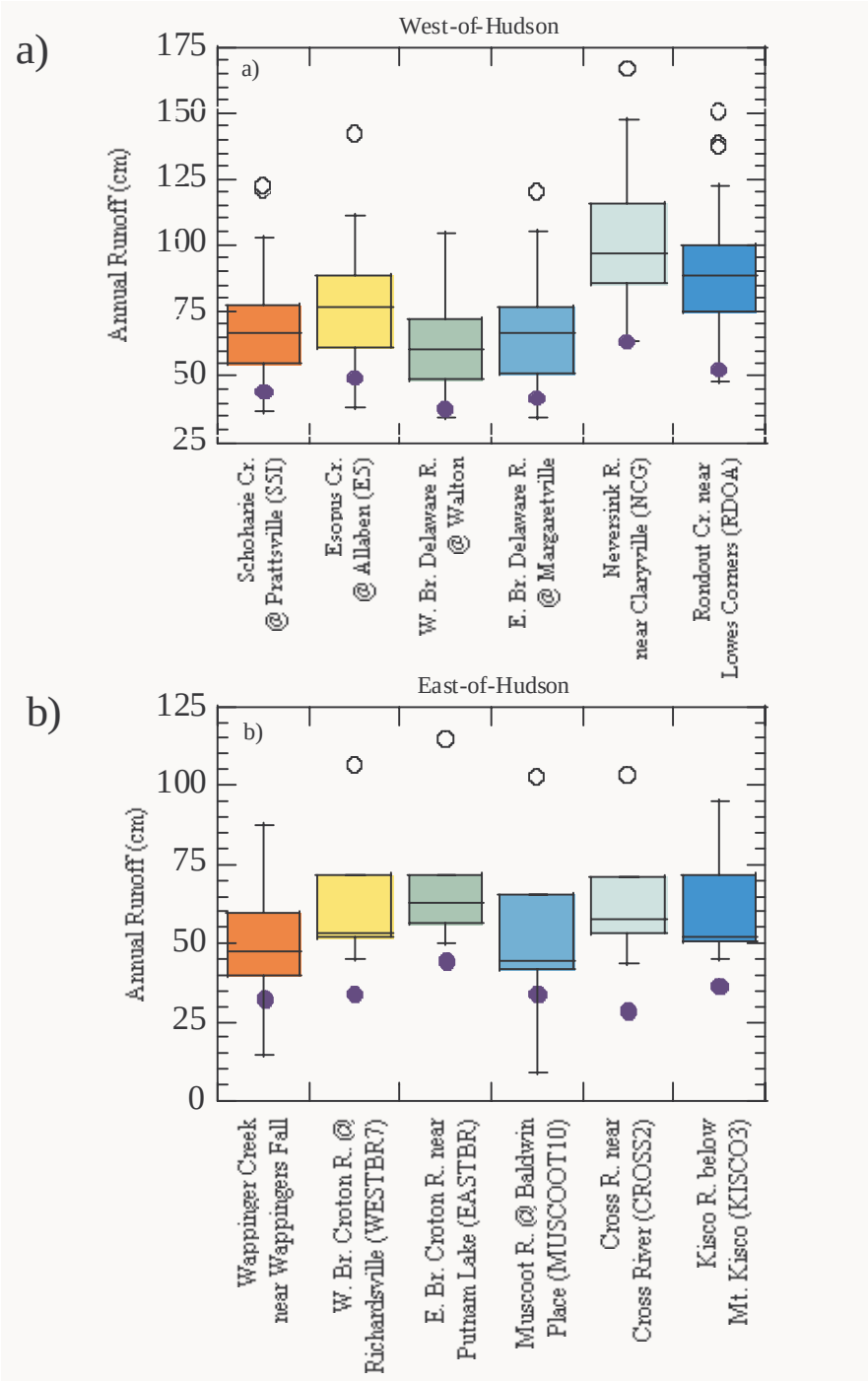


Figure 2.5 Historic annual runoff (cm) as boxplots for the WOH and EOH watersheds with the values for 2001 displayed as a dot. The USGS data collected after Sept. 30, 2000 are provisional.

2.2 How much water did we have in 2001?

The quantity of water available in 2001 as compared to the long-term average is shown in Figure 2.6 (June 1, 2001-May 31, 2002). Storage in 2001 and the beginning of 2002 was far below normal. If the data are examined on a monthly basis, NYC reservoir storage levels were above the 10-year average (1991-2000) for the first half of 2001 (Figure 2.7). During the second half of 2001, however, the combined effect of reduced rainfall and runoff (Figures 2.5 and 2.4) and normal consumption was quite evident upon the storage levels of the Catskill and Delaware systems (Figure 2.7). Storage in the Croton System was less affected by the lack of rainfall because the City's did not use Croton System water due to construction at Jerome Park Reservoir. By the end of the year, total water supply storage was less than 50% of capacity, which is about 25% below normal.

Residence time is an estimate of how fast water moves through a reservoir. From a water quality perspective, a relatively short residence time can mean less phytoplankton growth because growth-limiting nutrients (i.e. phosphorus and nitrogen) move more quickly through a reservoir allowing less nutrient uptake. Annual residence times are calculated by dividing the average reservoir available storage by the total outputs for each year. A box plot of annual residence times is presented in Figure 2.8. In 2001, the residence times for most reservoirs were within historic limits. Amawalk Reservoir had a relatively long residence time in 2001 because of a lower demand from the Village of Yorktown Heights and because less water was released downstream compared to previous years.

2.3 How did DEP cope with the "dry" year?

As discussed above there was a rainfall deficit in 2001, which was greatest during the latter part of the year. This led to below normal reservoir storage levels. As a result, a Drought Watch for the Delaware System was established on October 29, 2001 by the Delaware River Basin Commission (DRBC). This condition was upgraded to a Drought Warning shortly thereafter, on November 4, 2001. Each DRBC drought level required successively larger cutbacks in the diversion flow rates from Delaware Basin reservoirs towards NYC. During drought conditions, Delaware system reservoirs are operated according to the rule formulae established in the "Good Faith Agreement" (Supreme Court Decree 1982). NYC's Drought Management Plan (see Table 2.1 and additional information at http://www.nyc.gov/html/dep/html/droughtplan.html) is different from the DRBC drought response plan. It has three phases based upon prevailing hydrological and meteorological conditions, as well as operational considerations, and pertains to all city reservoirs (NYC-DEP 1998). Based on these conditions, DEP declared a Drought Watch for the NYC System on December 23, 2001.

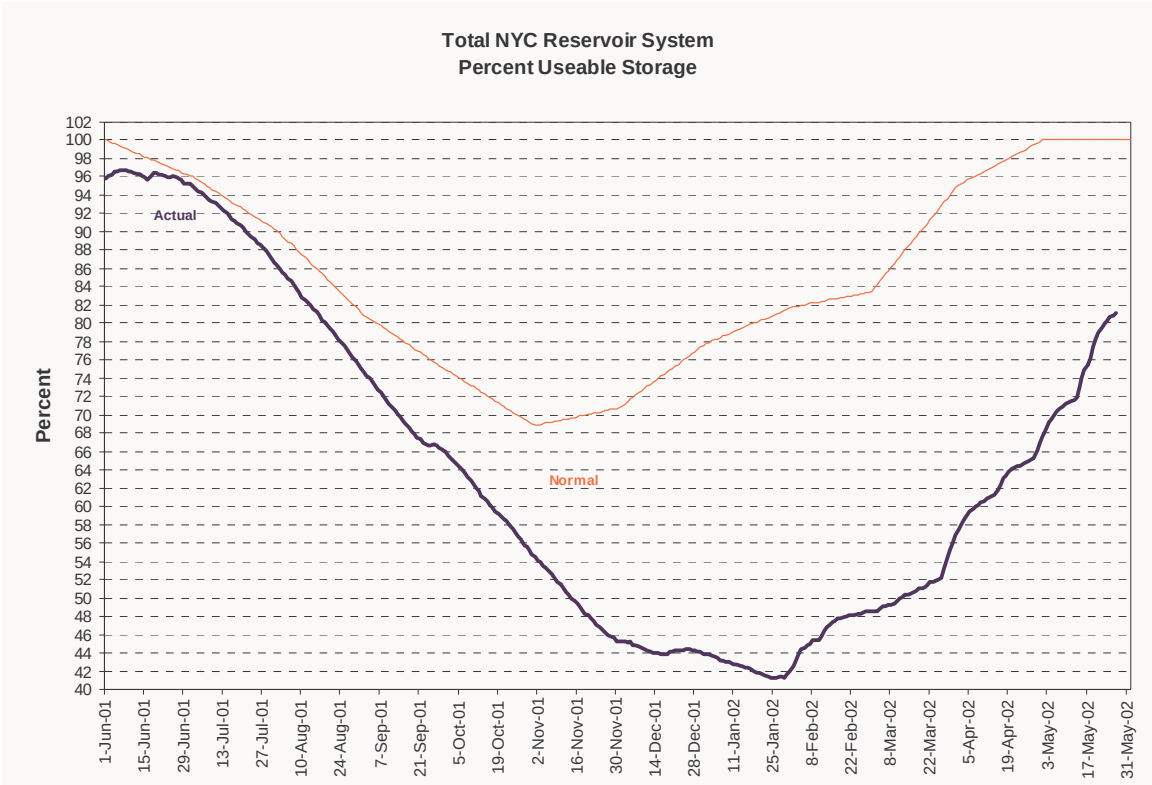


Figure 2.6 Percent usable storage in 2001 compared to the long-term average (normal) storage.

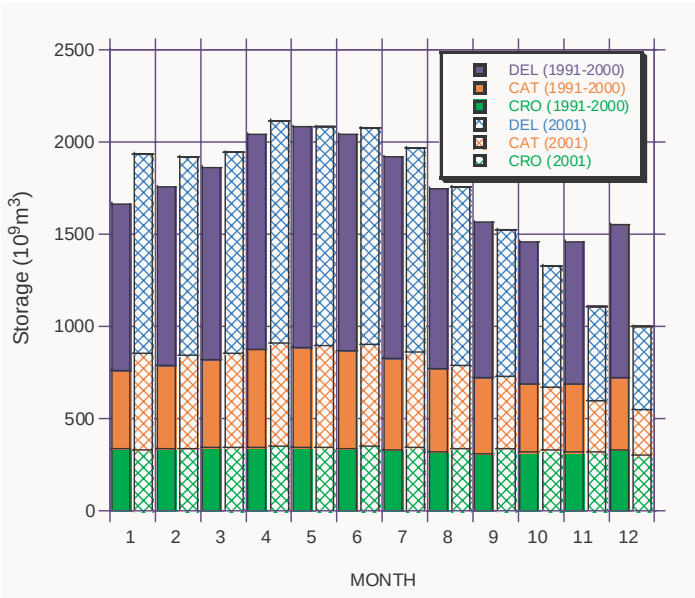


Figure 2.7 Total NYC Reservoir System storage (10 year average compared with 2001). Kensico Reservoir storage is not included in the calculations of total storage.

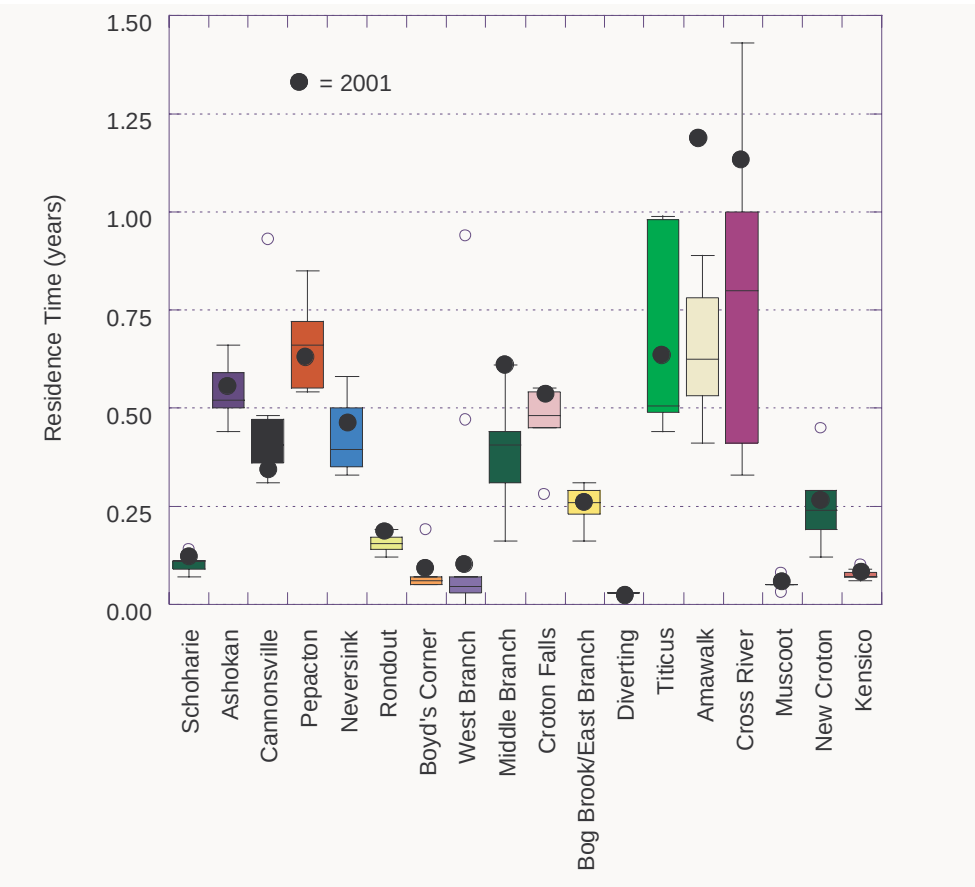


Figure 2.8 Annual residence times as box plot for NYC Reservoirs based on 1991-2001 data for WOH reservoirs, including West Branch and Kensico and 1995-2001 data for Croton Reservoirs

Figure 2.9 Cannonsville Reservoir during the drought of 2001.

Table 2.1. Drought stages as defined in NYC's Drought Management Plan.

Drought Watch	A drought watch is declared when there is less than a 50% probability that either of the two largest reservoir systems, the Delaware or the Catskill will fill by June 1 – the start of DEP's water year.
Drought Warning	A drought warning is declared when there is less than a 33% probability that either the Catskill or Delaware systems will fill by June 1.
Drought Emergency	A drought emergency is declared when there is reasonable probability that without the implementation of stringent measures to reduce consumption, a protracted dry period would cause the City's reservoirs to be drained. There are four stages of drought emergency.

3. Water Quality

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

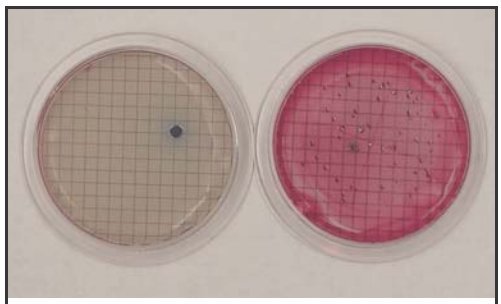


Figure 3.1 Fecal and total coliform agar plates.

The Surface Water Treatment Rule (SWTR) (40CFR171.71(a)(1)) requires that water at a point just prior to disinfection does not exceed thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at "keypoints" just prior to disinfection (the Croton system at CROGH, the Catskill system at CATLEFF and the Delaware system at DEL18). Figures 3.2 and 3.3 depict daily fecal coliform and turbidity data for 1992-2001. Both figures include a horizontal line marking the SWTR limit.

Figures 3.2 and 3.3. provide fecal coliform and turbidity data for the period 1992-2001. As indicated in the figure, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; fewer than 10% of samples had fecal coliform concentrations greater than 20 cfu 100 mL^{-1} in the previous six months of samples. For 2001, the calculated percentage for effluent waters at CROGH and CATLEFF is 0% and around 1% for the latter half of 2001 at DEL18 and this is far below the 10% limit set by the SWTR standard. For 2001, 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 1.0 and 0, 1.8 and 1, and 2.4 and 1, respectively.

For turbidity, the SWTR limit is 5 NTU. All three effluent waters are consistently well below this limit. For 2001, for the three keypoints CROGH, CATLEFF, and DEL18 the mean and median turbidity values (NTU) were 1.0 and 1.0, 1.0 and 0.8, and 1.0 and 0.8, respectively.

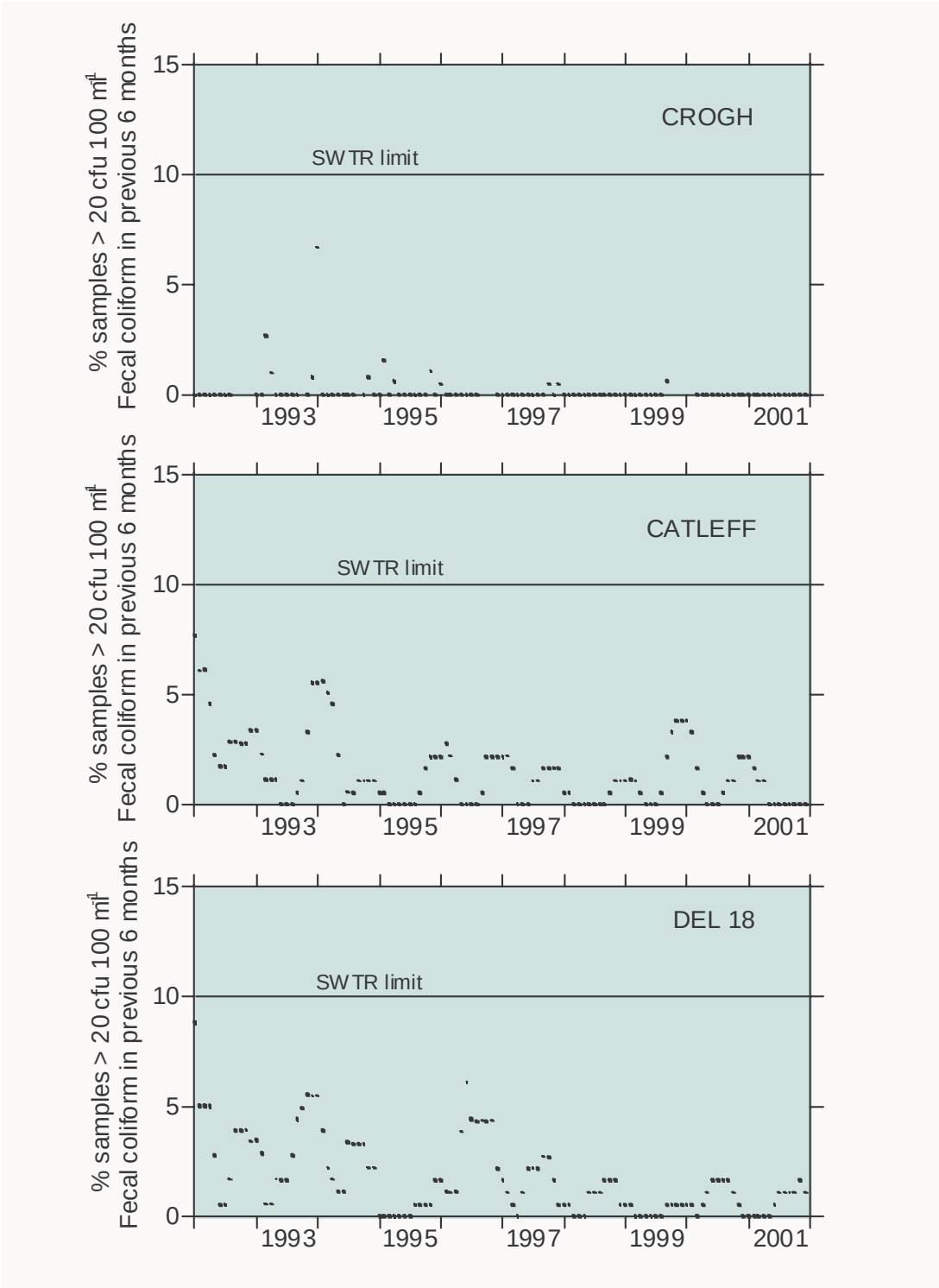


Figure 3.2 Temporal plots of fecal coliform (% of daily samples > 20 cfu 100 mL^{-1} in the previous six months) compared with Surface Water Treatment Rule limits.

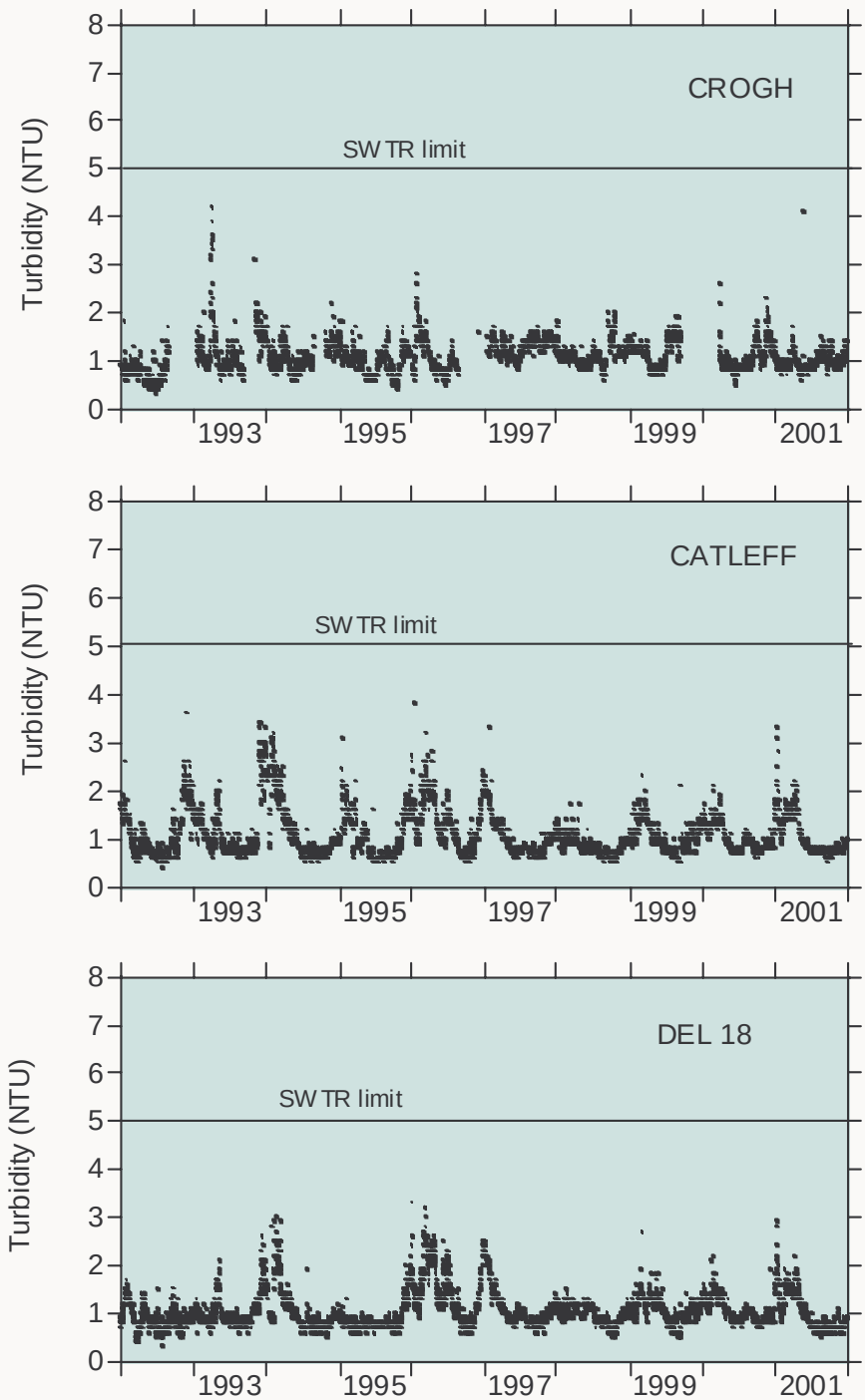


Figure 3.3 Temporal plots of turbidity (daily samples) compared with Surface Water Treatment Rule limits.

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

DEP began monitoring the protozoan pathogens *Cryptosporidium* and *Giardia* at Kensico Reservoir's keypoints (CATLEFF and DEL18) in 1992 and at Croton Reservoir's keypoint (CROGH) in 1993. Monitoring was then extended to watershed streams and reservoirs effluents. In 2001, over 900 samples were collected and analyzed for *Cryptosporidium* and *Giardia*. The sampling program has two major components: a "fixed-frequency" part where samples are collected at regularly scheduled intervals (weekly, monthly) and a "storm event " part where samples are collected during rain storms.

Methods to detect pathogens have improved since 1992, and DEP has used analytical methods successively recommended by US EPA. These methods are: ASTM, ICR and 1623HV. Because these methods (a) use different sampling and analytical methods, and (b) have different levels of detection, results are not directly comparable from one method to the other. However, results adjusted to a 50-Liter volume are presented on the same figure to provide a perspective of pathogen concentration in weekly samples from 1992 to 2001 (Figure 3.4). Results from the weekly sampling at the three keypoints are posted on DEP's website: http://www.nyc.gov/html/dep/html/pathogen.html

DEP has analyzed recent *Cryptosporidium* results in light of proposed new regulations from the USEPA. The regulations are under the Safe Drinking Water Act (SDWA), Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) and will require unfiltered water suppliers (such as NYC) to monitor their source water keypoints for two years. An average of the monitoring results will be compared with a proposed treatment threshold of 0.01 oocysts L^{-1}. USEPA will require that Method 1623 be used for *Cryptosporidium* analysis. DEP began to use Method 1623 for its source water keypoints in October 2001. The average of weekly results from October to December 2001 for each keypoint are presented in Figure 3.5. Theses averages are below the 0.01 oocysts L^{-1} proposed threshold. Previous results obtained with the ICR Method are also shown on Figure 3.5. Averages from weekly samples over a 30-month period are well below the proposed threshold.

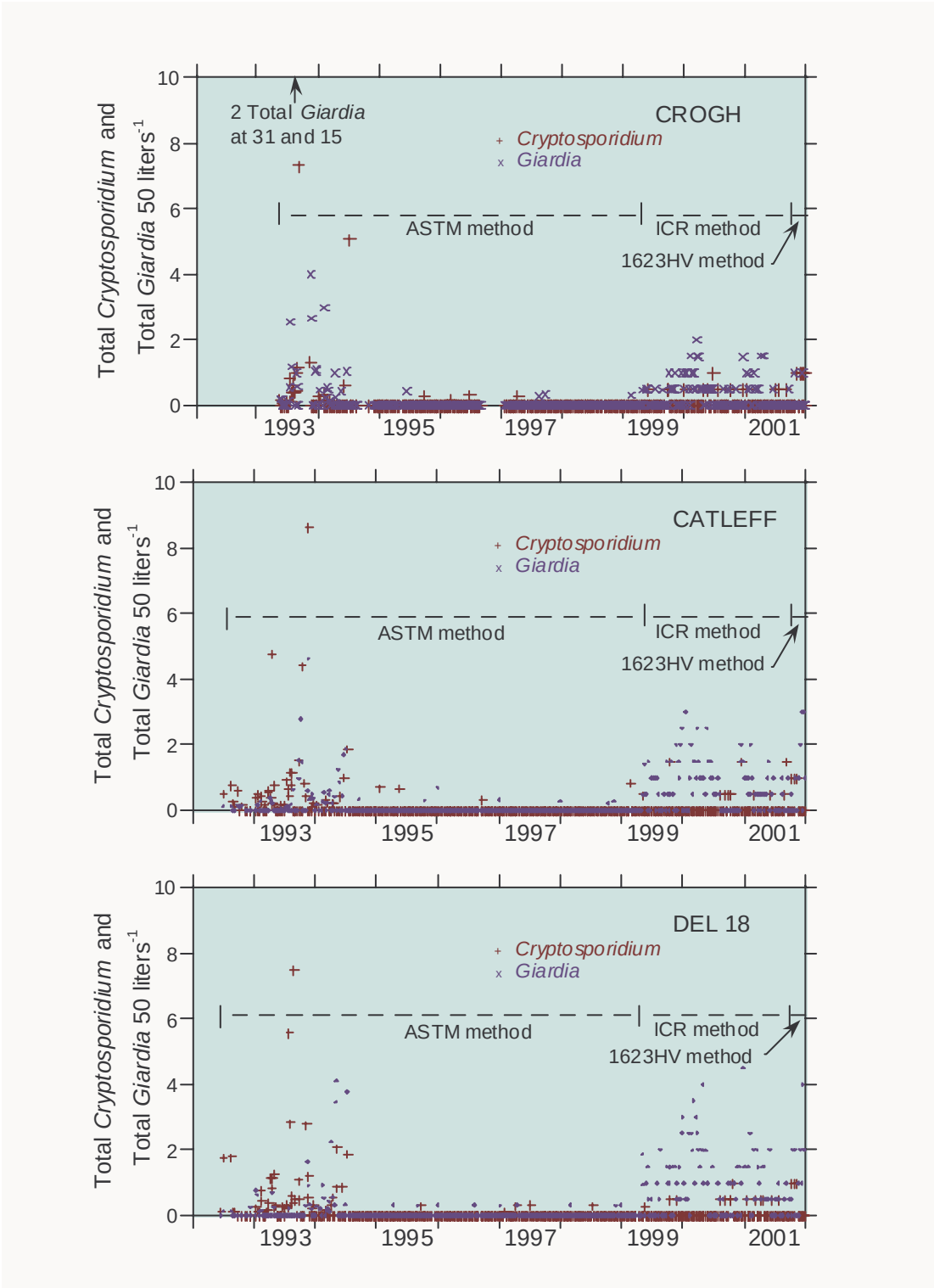


Figure 3.4 Temporal plots of *Cryptosporidium* and *Giardia* concentrations (weekly samples).

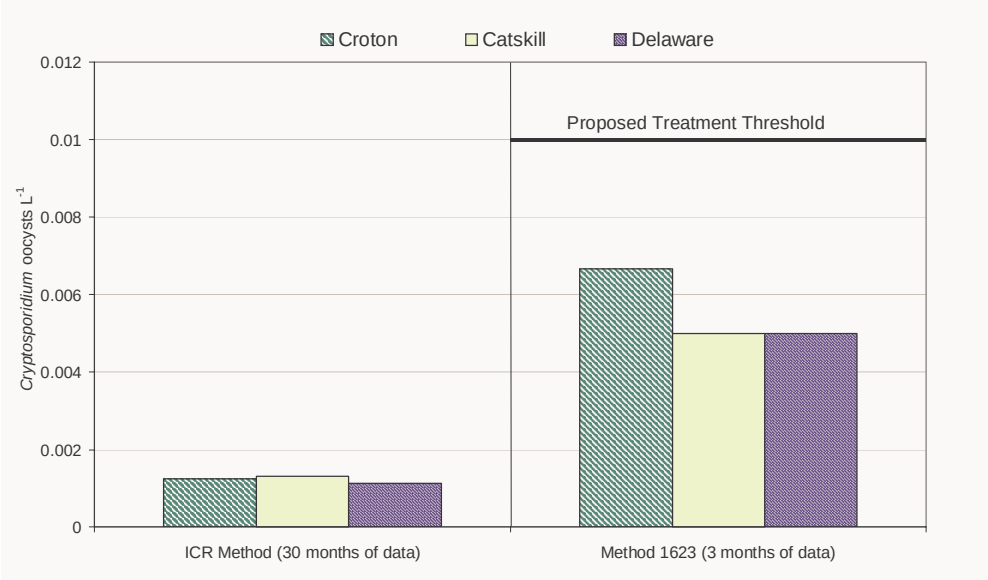


Figure 3.5 Average *Cryptosporidium* concentrations in the source waters are all below the proposed treatment threshold (LT2ESWTR), despite changes in analytical methodology.

The average concentration of the pathogens, *Cryptosporidium* or *Giardia*, at fixed-frequency sampling locations in different regions of the NYC water supply during 2001 is indicated in Figures 3.6 and 3.7. (See Appendix B for the key to pathogen site codes.) These figures use different sized dark circles to show the levels found for both organisms (white circles indicate none found). Note that these figures only include streams and reservoirs effluents locations analyzed by the ASTM Method in 2001. This allows for a relative comparison between locations. No pathogens were detected at three reservoir effluents: Ashokan (EAR), Neversink (NRR2), and Rondout (RDRR). In addition to their location, sample sites may be grouped into broad categories based on the type of water body the sample is drawn from (reservoirs, streams and wastewater treatment plant effluents). Figure 3.8 shows average annual concentrations as bar graphs for the different categories. Note that the scales of these bar plots are different for C*ryptosporidium* and *Giardia*. Figure 3.8 also depicts the protozoa concentration deleted at wastewater treatment plant effluents. No pathogens were detected at two upgraded wastewater treatment plants: Grahamsville (RGC) and Tannersville (STLE).

Results from 2001 confirm results previously reported: (a) *Giardia* was found at more locations than *Cryptosporidium* (39 and 19, respectively), and (b) *Giardia* was found in greater numbers than *Cryptosporidium* (4.15 100 L^{-1} and 0.176 100 L^{-1}, respectively). The results showed further that wastewater treatment plant effluent samples had the highest levels of both pathogens and that stream locations generally had greater levels than “upstream” reservoir locations.

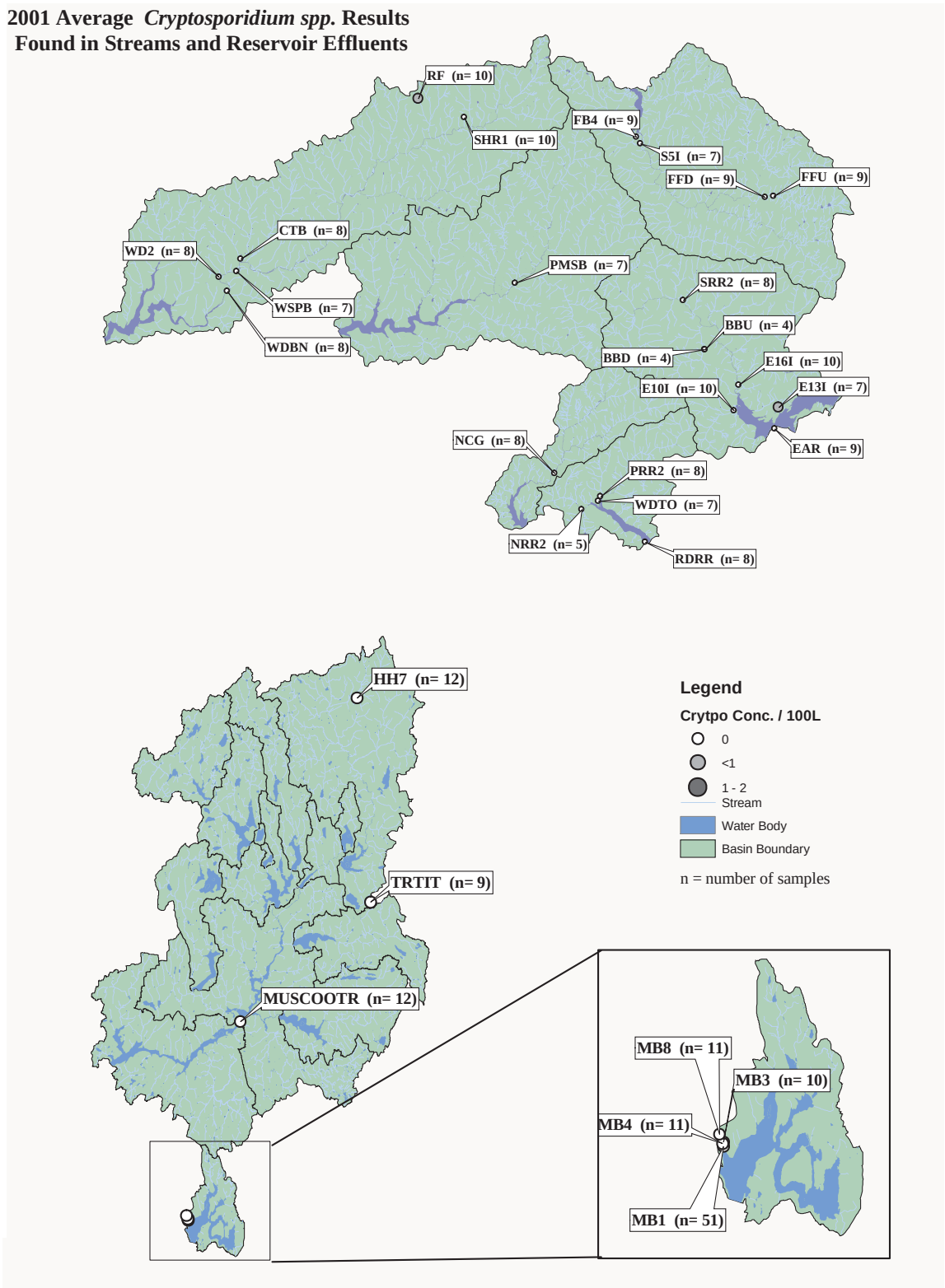


Figure 3.6 Average *Cryptosporidium* concentrations in the NYC watersheds.

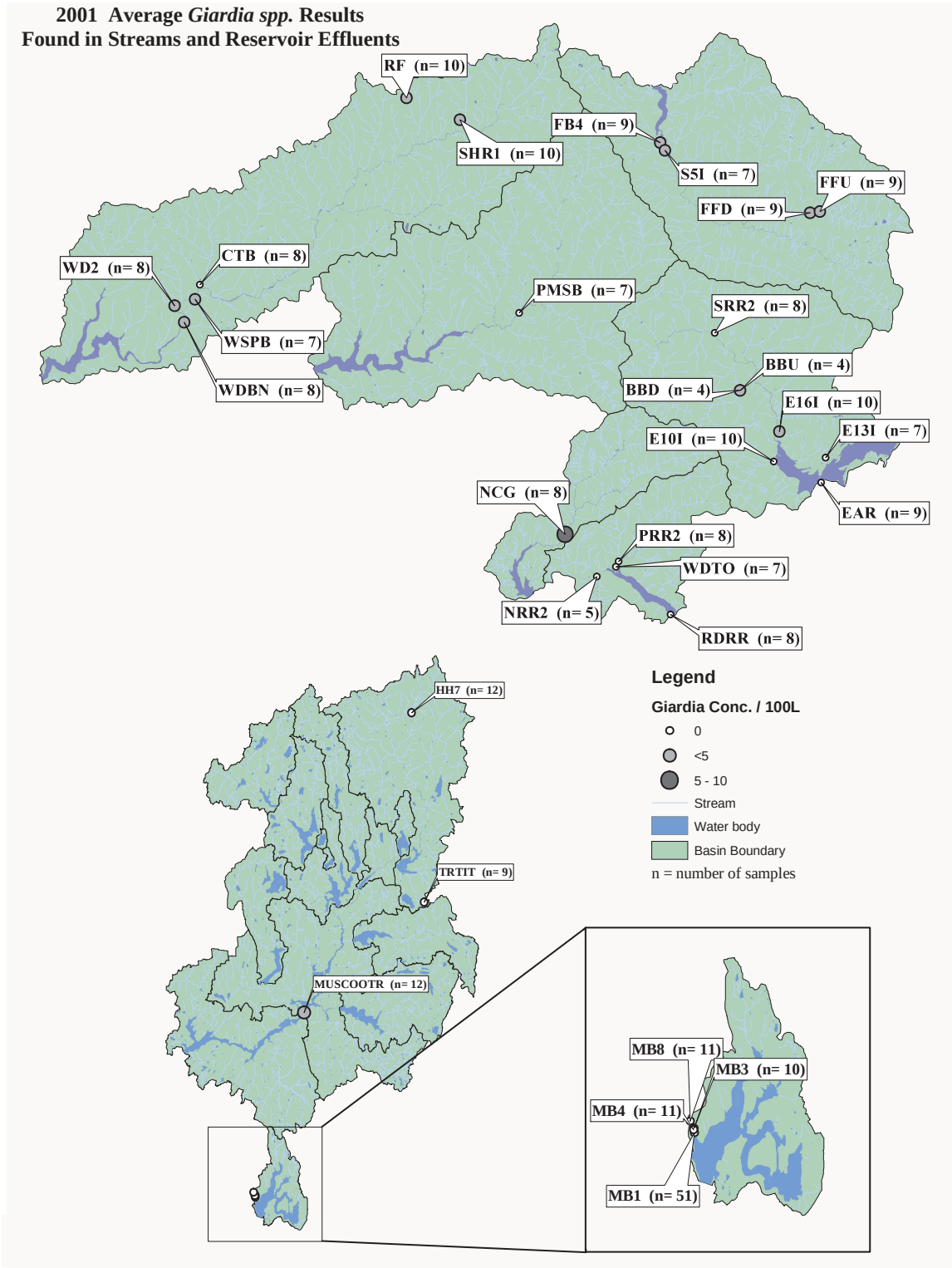


Figure 3.7 Average *Giardia* concentrations in the NYC watersheds.

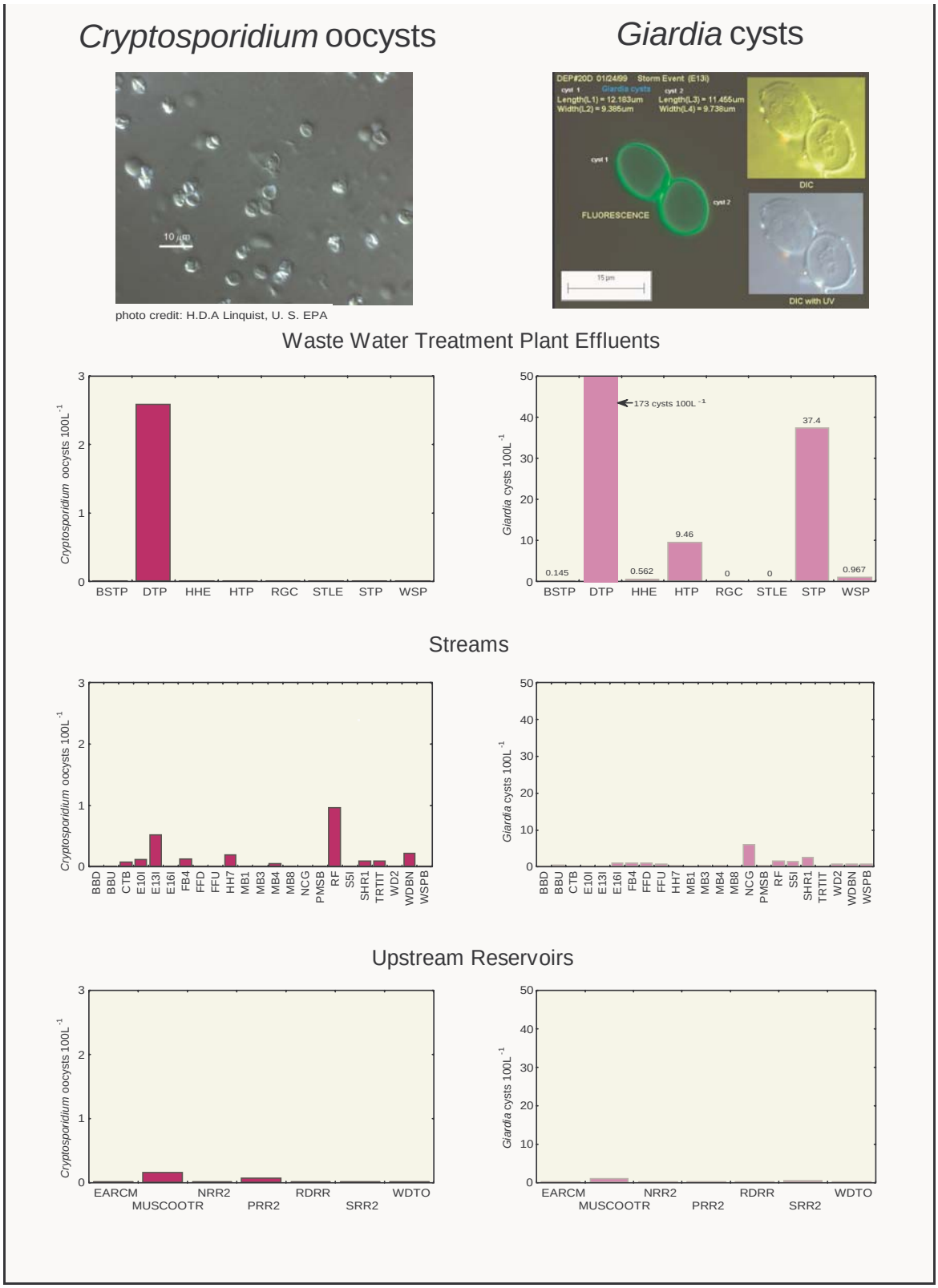


Figure 3.8 2001 Average fixed frequency pathogen sampling results in the NYC watersheds.

The second component of the sampling program is the “storm event ” monitoring. Samples are collected during rain storms because water runoff from storms washes off particulate materials from the landscape. This makes sample collection during these times an important part in understanding water quality. Six stormwater autosamplers for pathogen monitoring designed and built by the Pathogen Monitoring Program staff, were in operations during 2001. These units shown in Figure3.9 are designed to automatically collect samples during a storm event. The battery-powered autosamplers consist of a programmable onboard computer, water level sensing equipment, pumps, electrically controlled valves, flowmeters and filters. During rainfall and other runoff events, the units detect rising stream levels that "trigger" the computer driven sampling sequence to collect up to 8 samples per event. The autosamplers allow automated collection of several storm events at the same time and increase staff productivity by reducing the need to be present at the sampling site during the storm.

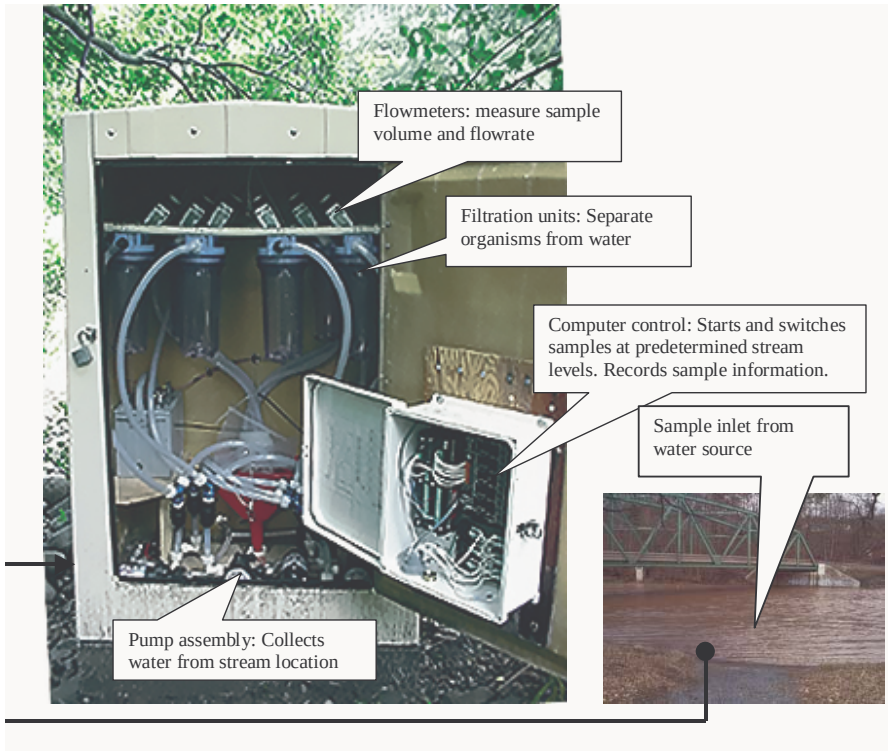


Figure 3.9 Pathogen Stormwater Autosampler.

Results from the eight samples collected by each autosampler can be compared on a chart with the stream flow profile during the storm. These charts called “pollutographs” indicate that the majority of the mass of Giardia occurs before the peak flow of the storm (first flush). Cryptosporidium peak concentrations occurs during the peak flow of the storm. Results also indicate that the concentration of pathogens is higher during storms than the average levels sampled during base flow. This data suggests that storm run off transports Cryptosporidium and Giardia from soil surface into streams.

3.3 Which basins are phosphorus-restricted?

A phosphorus-restricted basin is defined in the New York City's revised “Rules and Regulations for the Protection from Contamination, Degradation and Pollution of the New York City Water Supply and its Sources” (City Administrative Procedure Act 1997) (WRRs) as "the drainage basin of a reservoir or controlled lake in which the total phosphorus (TP) load results in phosphorus concentrations above those provided in the DEC Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993)." 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 basins, 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 basin analysis can be found in “Methodology for Determining Phosphorus Restricted Basins (DEP 1997)”; and in Appendix C. The phosphorus-restricted basins are indicated in Figure 3.10 and Table 3.1. The last two assessments and the geometric mean phosphorus concentration for 2001 are shown in Figure 3.11.

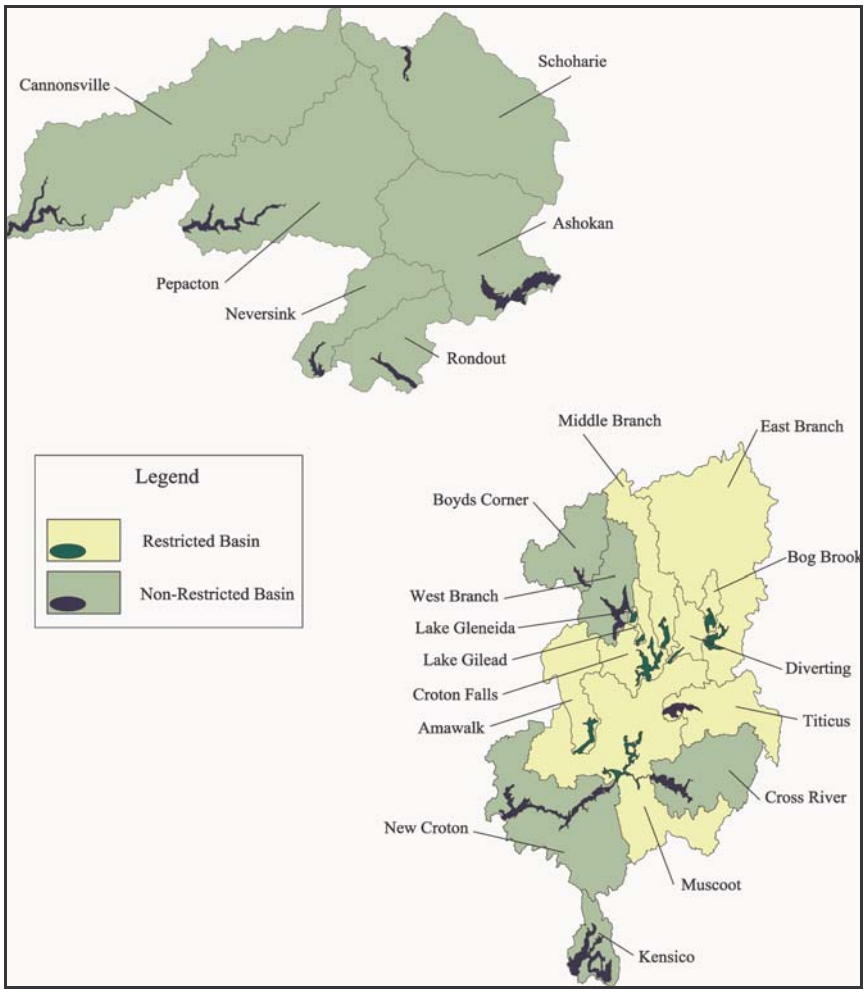


Figure 3.10 Phosphorus restricted basins in 2001.

Table 3.1. Phosphorus restricted basins determination.*

Middle Branch	Bog Brook	East Branch	Titicus
Diverting	Muscoot	Amawalk	
Croton Fall	Lake Gilead	Lake Gleneida	

*Determinations of phosphorus-restricted status are based on two consecutive 5-year assessments and become effective upon release of DEP's Annual Watershed Water Quality Report.

.

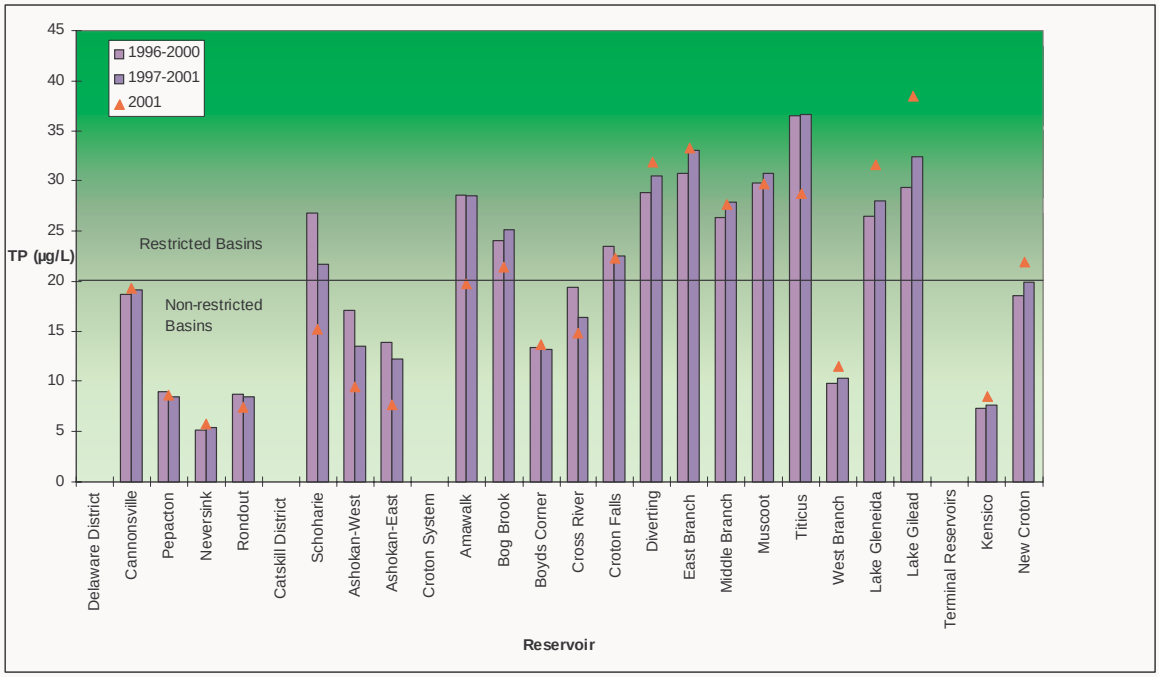


Figure 3.11 Phosphorus restricted basin assessments with the current year 2001 geometric mean phosphorus concentration displayed for comparison.

3.4 Which basins are coliform-restricted?

New York City's revised WRRs prohibit new or expanded wastewater treatment plants with surface discharges from being located within coliform-restricted basins, and calls for analysis of coliform run-off 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.

The standards used for AA waters are that the monthly median value for **total coliforms** (number 100 m L^{-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} based on a minimum of five examinations. 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 requirements for filtration avoidance fecal coliform requirements set forth under the Surface Water Treatment Rule.) The WRRs also specify that where the Department determines that any exceedances of the above standards are due to "*non-perennial, non-anthropogenic sources, 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 have precedent. More recent writings emphasize the fact that fecal (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 basins have been determined to be coliform-restricted:

Table 3.2. Coliform-restricted status of reservoir basins based on 1996-2000 and 1997-2001 assessments

Reservoir Basin	2001 Assessment
Kensico	Not Restricted
New Croton	Not Restricted
Ashokan	Not Restricted
Rondout	Not Restricted
West Branch	Not Determined*

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

3.5 What streams represent the major flow into NYC's reservoirs, and what is their water quality?

The stream sites used in this report are presented in Table 3.3 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 that they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds.

Table 3.3. Sites 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.

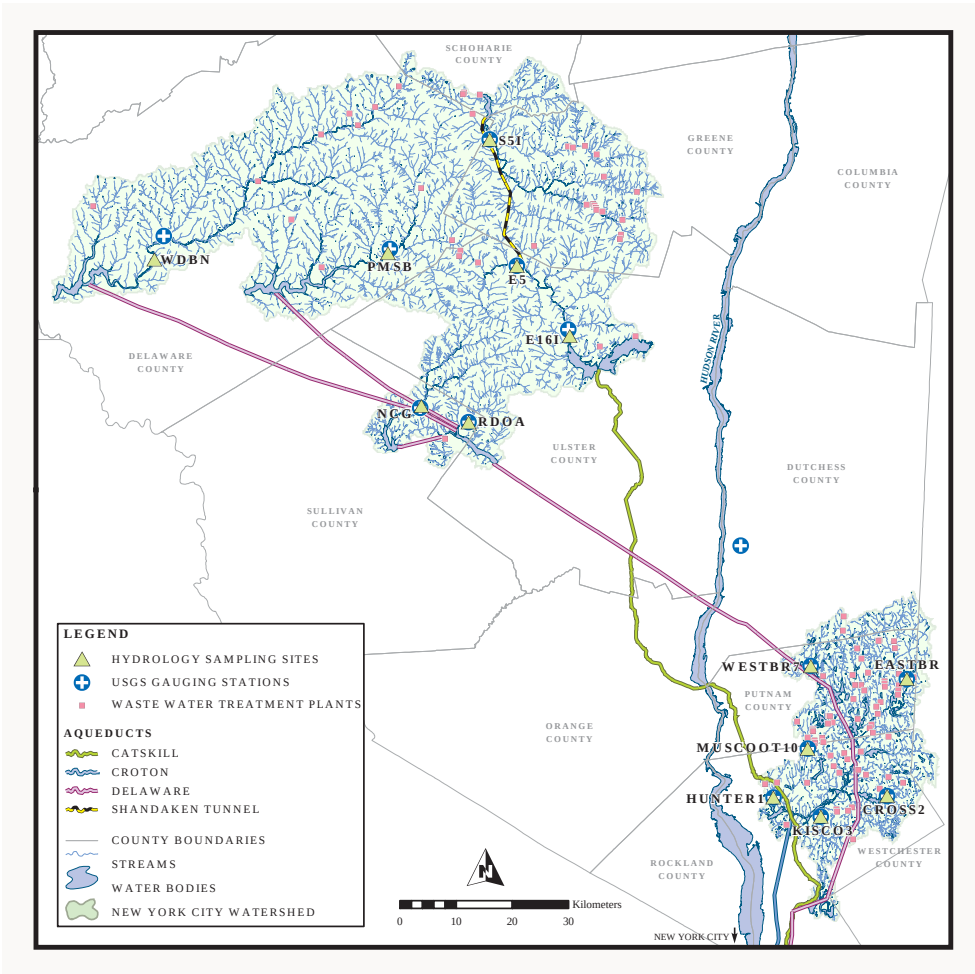


Figure 3.12 Locations of sampling sites and USGS stations.

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

The results presented are based on grab samples generally collected twice a month. Figure 3.13 compares the 2001 median values against historic values for the previous ten years (1991-2000). 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

Other than the inflow to the Ashokan Reservoir, the turbidity levels for 2001 were generally within the range of historic values (Figure 3.13a). In the Ashokan, the turbidity was somewhat elevated. This is likely due to the effects a December 2000 storm had on the Schoharie Reservoir. The turbidity persisted in the reservoir, and subsequently affected turbidity in the Ashokan watershed.

Total Phosphorus in Streams

In the WOH system, total phosphorus levels (Figure 3.13b) were for the most part slightly below the historic values. The lack of runoff in 2001 minimized the delivery of total phosphorus to the streams from nonpoint sources. However, in the EOH system total phosphorus (Figure. 3.13b) values were above the historic values. The minimized flow in the streams reduced the dilution effect on point source discharges which are much more prevalent in the EOH than the WOH System (Figure 3.12). Additionally, there was a methodology change in 2000 resulting in slightly higher concentrations being determined thereafter.

Coliforms (fecal and total) in Streams

Like total phosphorus, the coliform levels (Figure 3.13c and d) in the WOH System were generally slightly below historic values, while in the EOH System coliform values (Figure 3.13 c and d) were slightly above them. Again the explanation is likely due to the lack of runoff providing a transport mechanism for nonpoint source pollution in the WOH, while the lack of runoff reduced the dilution effects of point source pollutants in the EOH System. Some anomalies occurred in the EOH system, but this may be a result of a short period of record (e.g. Kisco3) for some sites.

A fecal coliform benchmark of 200 cfu 100 mL^{-1} is shown as a dashed line on Figure 3.13c. This benchmark relates to the NYS DEC (1998) water standard (expressed as a monthly geometric mean of five samples, the standard being <200 cfu 100 mL^{-1}) for fecal coliforms. The 2001 median values for all streams shown here lie well below this value

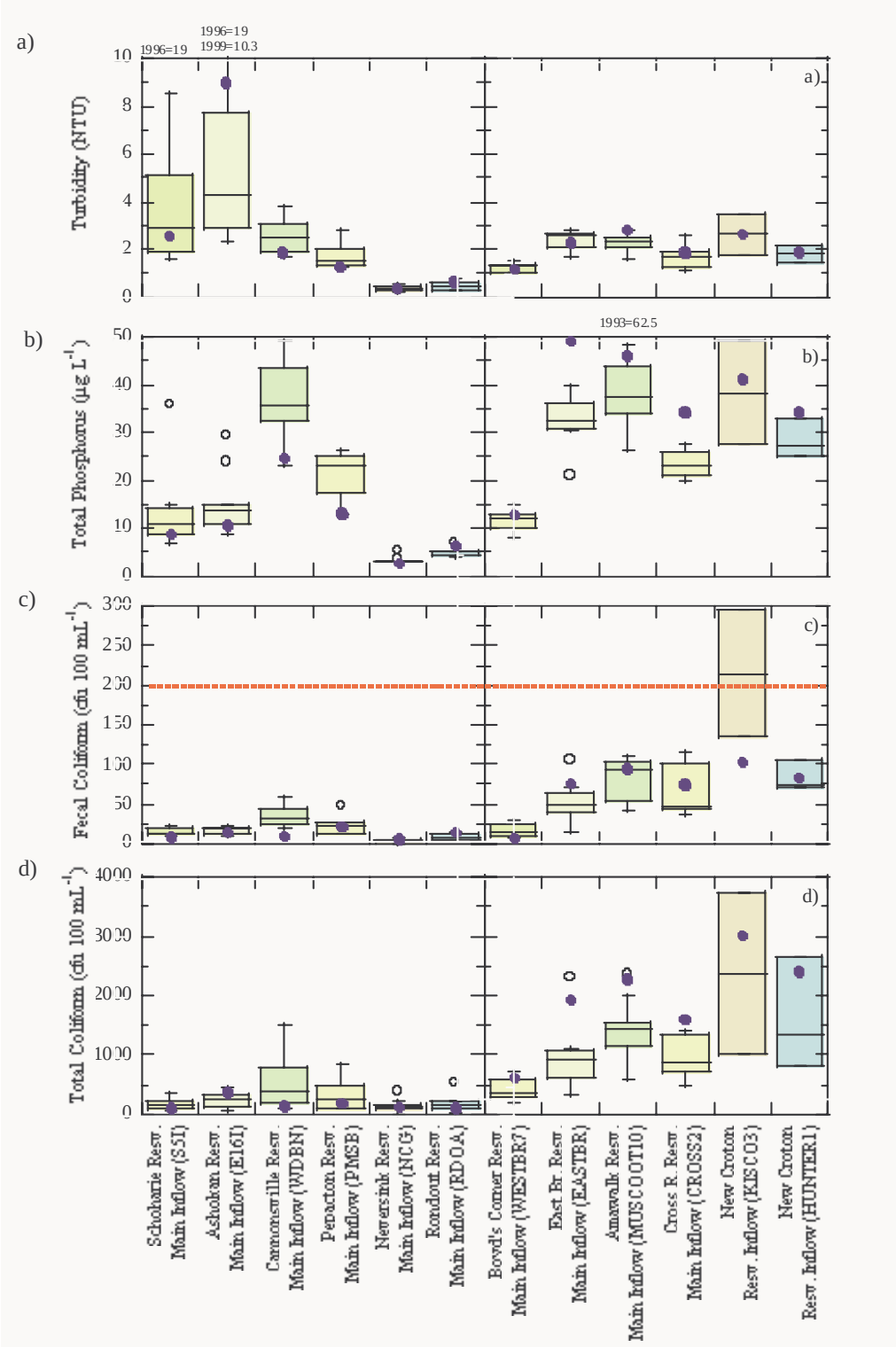


Figure 3.13 Boxplot of annual medians (1991-2000) for a) turbidity b) total phosphorus c) fecal coliforms d) total coliforms for selected streams (reservoir inflow) sites with the value for 2001 displayed as a dot.

3.6 What is the quality of water in NYC's reservoirs?

NYC scientists monitor numerous water quality analytes at various sites and depths in the City's reservoirs. These analytes include nutrients, algae, bacteria, physical parameters, and metals. We will focus, however, on three primary indicators (turbidity, coliform bacteria, and total phosphorus) to assess reservoir water quality in this section of the report.

Turbidity in Reservoirs

Turbidity, an optical measurement broadly reflective of the amount of suspended materials present, was slightly higher than normal conditions (i.e., the long-term conditions) for most reservoirs in 2001 (Figure 3.14). This was most likely due to the dry conditions experienced later in the year. Lower reservoir elevations permitted increased wave and wind erosion of exposed shoreline thus increasing the turbidity-causing particles in the water column. In addition, as reservoirs drop in elevation incoming streams resuspend sediments which were formerly deposited on the reservoir bottom. Overall, turbidity was relatively low (<5 NTU) at most reservoirs. The horizontal dotted line at 5 NTU in Figure 3.14 refers to the SWTR criterion appropriate for source water reservoirs. At the key source water reservoirs (i.e., Rondout, Ashokan - East, Kensico, West Branch and New Croton) turbidity was extremely low (i.e., ≤ 2 NTU), and well below the SWTR citerion. These reservoirs benefit from settling activity taking place in upstream reservoirs. Additional settling happens within the source water reservoirs, and this is reflected at the withdrawal (key point) location prior to entry into distribution. Schoharie Reservoir, an outlying Catskill reservoir, experiences the highest turbidity because its watershed streams run through areas of clay. Stream runoff events mobilize the sediments laid down adjacent to the stream course. The high concentration of clay-sized particles are transported to the reservoir, where they stay in suspension for long periods due to the extremely small size of the particles.

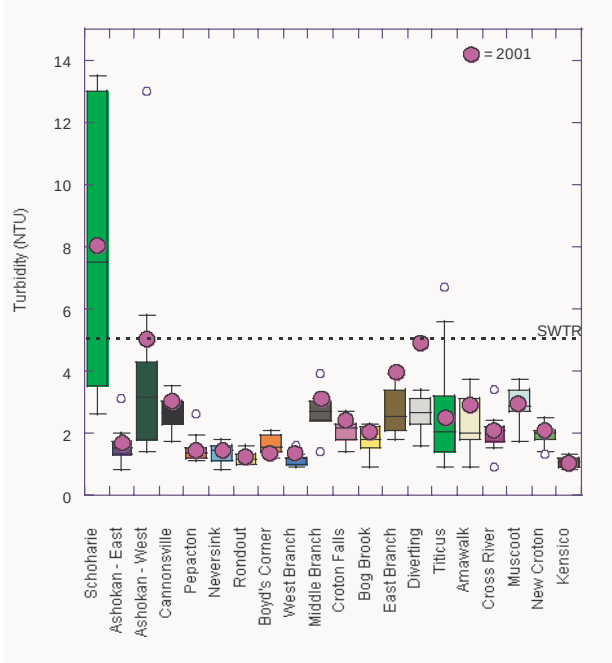


Figure 3.14 Annual median turbidity levels in NYC Reservoirs (2001 vs. 1991-2000). Data was obtained from multiple sites, multiple depths, at routine sampling frequencies from April

Total Phosphorus in Reservoirs

Total phosphorus (TP), an important nutrient for algal growth, was higher for most Croton system reservoirs than for Catskill or Delaware system reservoirs in 2001, as has been observed in the past (Figure 3.15). This is most likely due to the higher human population density surrounding the reservoirs and the 60 WWTPs scattered through out the Croton System. TP may have been higher in some Croton reservoirs in 2001 due to the lack of dilution of WWTP effluents in streams caused by the dry conditions. Cannonsville Reservoir stands out as with its elevated total phosphorus (TP) concentration in the Delaware District. Agriculture, which is predominant land activity in the basin, is known to contribute high concentrations of phosphorus during runoff. There are also seven WWTPs in the Cannonsville basin which also produce elevated concentrations of TP. A reduction in TP levels was observed at Schoharie Reservoir in 2001. TP levels had been greatly elevated for an extended period following two significant flooding events (January thaw 1996 and Tropical Storm Floyd 1999). The horizontal dotted line at 15 µg L^{-1} drawn in Figure 3.15, refers to the TMDL guidance value appropriate for source water reservoirs. Of the source water reservoirs, only New Croton Reservoir exceeded this guidance value in 2001. The horizontal solid line at 20 µg L^{-1}, drawn in Figure 3.15, refers to the DEC ambient water quality guidance value appropriate for reservoirs other than source waters. Most Croton System reservoirs exceeded or equaled this value, as did Cannonsville in the Delaware System, during 2001.

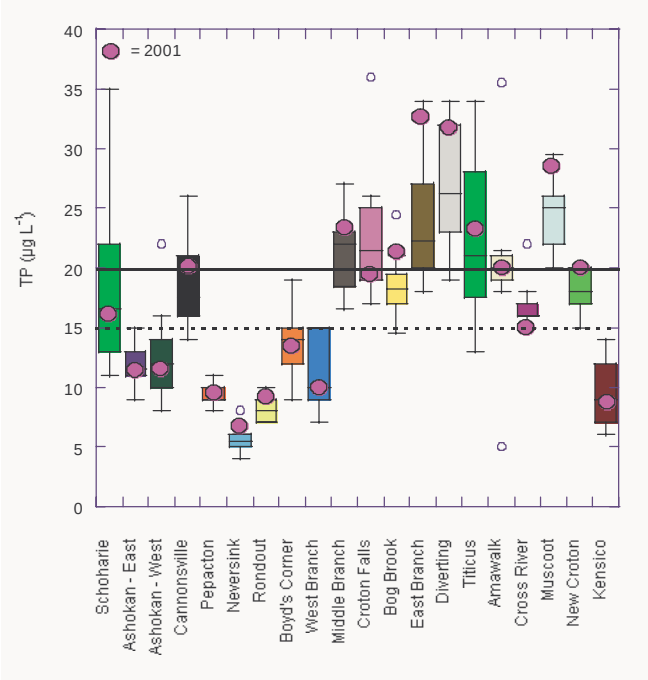


Figure 3.15 Annual median total phosphorus concentration in NYC Reservoirs (2001 vs. 1991-2000). Data was obtained from multiple sites, multiple depths, at routine sampling frequencies from April through December.

Coliforms (fecal and total) in Reservoirs

Coliform bacteria include fecal coliform and total coliform counts, which are regulated in source waters by the Safe Drinking Water Act (SDWA) at levels of 20 cfu 100 mL^{-1} and 100 cfu 100 mL^{-1}, respectively. Both are used as indicators of potential pathogen contamination, however, only the fecal coliform limit is applicable here as this takes precedence when both are measured. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals. The long-term annual medians for fecal coliform levels never exceeded 20 cfu 100 mL-1 for any of the reservoirs (Figure 3.16). Muscoot Reservoir, however, was among the reservoirs having the high-

est levels. In 2001, median fecal coliform levels were at the low end of the long-term range for all reservoirs. There are many possible causes, but one contributing factor may have been the reduced precipitation and run-off in the latter half of the year. The low median values for 2001 in Kensico and New Croton were supported by the key point data for the two reservoirs as reported in section 3.1 The long-term (1993-2000) annual median levels of total coliform have exceeded 100 cfu 100 mL^{-1} at times in Schoharie, Rondout, Diverting and Muscoot reservoirs (Figure 3.16). In 2001, however, only Diverting and Muscoot had a median that exceeded this level. The source of total coliform may have been terrestrial, which is typical of the summer "blooms" observed in Rondout in previous years.

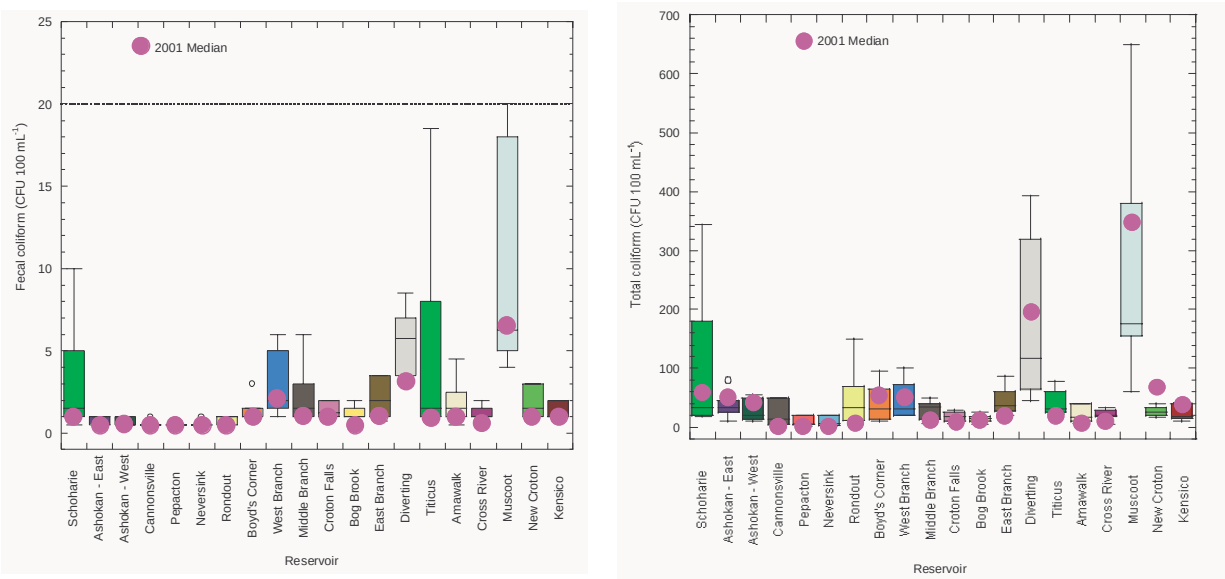


Figure 3.16 Annual median coliform levels in NYC Reservoirs (2001 vs. 1993-2000). Data was obtained from multiple sites, multiple depths, at routine sampling frequencies from April through December.

Specific conductance (conductivity) is a measure of water's ability to conduct an electrical current and is a simple way to measure the relative amount of dissolved inorganic ions it contains. Specific conductance of a water body varies according to the underlying geology of a drainage area, its hydrology, and changes in the natural landscape. Sedimentary and metamorphic rocks dissolve more rapidly than igneous rocks. The hydrology of a basin determines the degree of dilution that takes place. Development may lead to the introduction of additional dissolved substances into waterways, and typical examples include road salt, fertilizers, waste water treatment plant effluent, etc. Other changes in the landscape, such as vegetation or wetland disturbance, may affect conductivity by reducing the ability of such natural areas to remove dissolved substances from water. The net result of these factors together determines the conductivity of a water body.

Conductivity in all Catskill and Delaware System reservoirs (including West Branch and Kensico) were below 100 µS $cm^{-1,}$ indicating relatively low concentrations of dissolved inorganic ions. In contrast, all Croton System reservoirs were above 100 µS cm^{-1} in conductivity, reflecting the differences in geology and higher density of development in the drainage basins east of the Hudson River. The low flow conditions (and lack of dilution) in 2001 also influenced conductivity in the Croton System reservoirs. Conductivity in these reservoirs was affected to a greater extent than the Catskill and Delaware System reservoirs when 2001 is compared to the box plot of historic mean values (Figure3.17) Conductivity in the Croton System Reservoirs was substantially above the historical values.

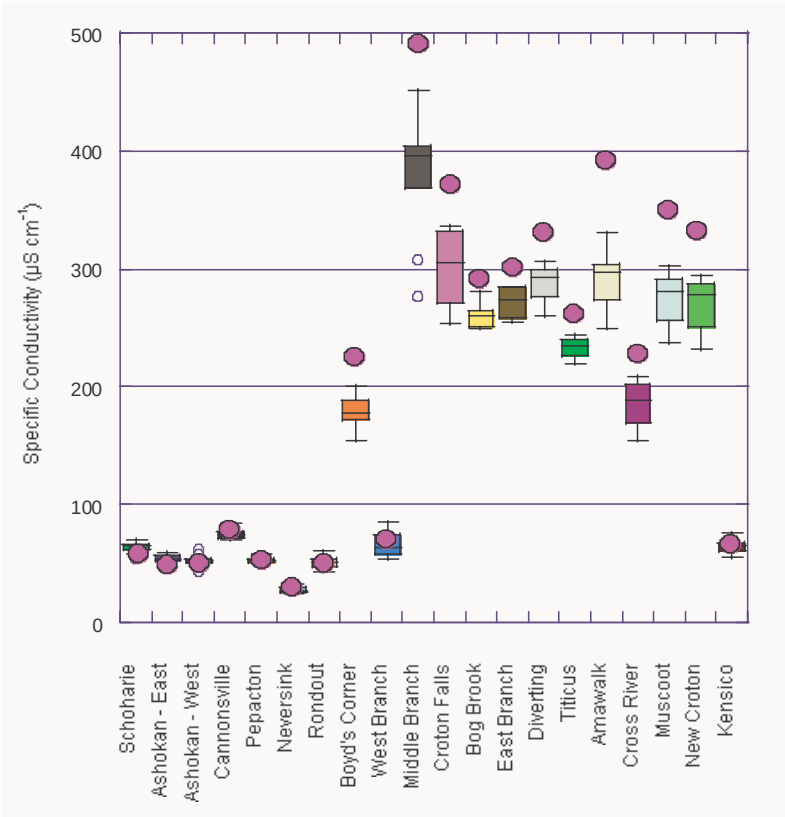


Figure 3.17 A comparison of historic annual conductivity in reservoirs with 2001 values shown as a dot.

Table 3.4 presents reservoir-wide mean 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 C gives additional statistical information for these reservoirs and the keypoints at their outflows. Table 3.4 shows that New Croton has several differences from the other three. It is higher in the concentrations of major ions, i.e., calcium, sodium, and chloride, and this is reflected in higher alkalinity, conductivity, and hardness. New Croton also contains higher nutrient concentrations (total P, total N, nitrate/nitrite–N, and ammoniacal–N) which is manifested in higher algal production (plankton areal counts and chlorophyll *a* concentration). This, in turn leads to higher turbidity and lower transparency (Secchi depth). New Croton is also more discolored and contains higher concen-

trations of iron, manganese, and organic carbon. In most instances Kensico Reservoir is, not surprisingly, very similar to Ashokan and Rondout reservoirs since these provide nearly all of the water flowing into Kensico.

Table 3.4. Reservoir-wide mean values for a variety of physical, biological and chemical analytes for the four source water reservoirs: Kensico, New Croton, Ashokan (east basin), and Rondout.

Analytes	Water Quality Standard	Kensico Reservoir	New Croton Reservoir	East Ashokan Basin	Rondout Reservoir
		Mean	Mean	Mean	Mean
PHYSICAL					
Temperature (C)		10.9	13.4	12.3	11.3
pH (units)	6.5-8.5	6.87	7.64	7.03	6.95
Alkalinity (mg/l)		12.34	58.52	11.21	9.81
Conductivity (µs/cm)		68	333	52	57
Hardness (mg/l)		19.43	82.93	16.68	18.56
Color (units)	(15)	11	25	9	10
Turbidity (NTU)	(5), *	1.5	3.2	2.3	1.5
Secchi Disk Depth (m)		4.81	3.11	4.54	4.82
BIOLOGICAL					
Chlorophyll *a* (µg/l)	7	10.98	26.18	5.96	4.38
Total Phytoplankton (SAU)	2000	659	1288	730	388
CHEMICAL					
Total Organic Carbon (mg/l)		1.4	3.2	1.6	1.7
Total Phosphorus (µg/l)	15, *	9	30	9	9
Total Nitrogen (mg/l)	*	0.38	0.648	0.294	0.425
Nitrate + Nitrite (mg/l)	10	0.204	0.31	0.12	0.27
Total Ammoniacal-N (mg/l)	2	0.023	0.129	0.026	0.008
Iron (mg/l)	0.3	0.08	0.31	0.1	0.04
Manganese (mg/l)	0.3	0.165	0.252	0.083	0.061
Lead (µg/l)	50	1.2	0.6	ND	ND
Copper (µg/l)	200	1.1	1.1	ND	1
Calcium (mg/l)		5.56	21.22	5.23	5.34
Sodium (mg/l)		4.71	26.61	3.12	3.88
Chloride (mg/l)	250	6.2	54	5.7	5.5

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

Trophic state indices (TSI) can be used to summarize the overall productivity of lakes and reservoirs. Three trophic state categories (oligotrophic, mesotrophic, and eutrophic) are used to separate and describe different levels of biological activity and water quality. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters on the other hand are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (i.e., chlorophyll *a*, total phosphorus, and Secchi disk) to delineate the trophic state of a body of water. The Carlson Trophic State Index ranges from approximately 0 to 100 (there really are no upper or lower bounds), and is scaled so that values under 40 indicate oligotrophy, values between 40 and 50 indicate mesotrophy, and values greater than 50 indicate eutrophy. Trophic indices are generally calculated from data collected in the photic zone of the reservoir during the growing season (the DEP definition of this is May through October) when the relationship between the variables is tightest. DEP water supply managers prefer reservoirs of a lower trophic state since these require minimal or no chemical treatments and produce better water quality at the tap.

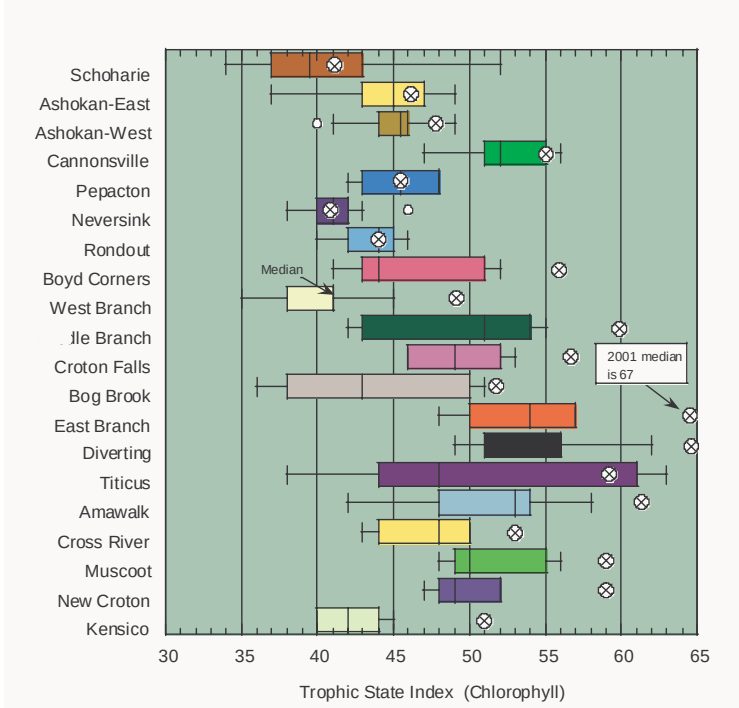


Figure 3.18 Trophic State Index of the New York City reservoirs based on chlorophyll *a* concentration.

In order to help understand the trophic status results, the relationship of this variable with two other explanatory variables (phosphorus and secchi depth transparency) are examined.

The TSI values (based on chlorophyll *a*) shown in Figure 3.18 indicate that reservoirs like Cannonsville, Croton Falls, Diverting, Amawalk, East Branch, and Muscoot are clearly eutrophic, whereas Schoharie, Neversink, and Kensico are oligotrophic. Median TSI (Chl *a*) values in all Catskill and East-of-Hudson reservoirs for 2001 were higher than the long-term (1991-2000) median. This may be an artifact of using a new chlorophyll methodology and the results should be looked at on a relative basis.

The relationship of chlorophyll *a* and phosphorus

In general, reservoirs from the Catskill and Delaware Systems (including Kensico and West Branch) were low in nutrients (as measured by total phosphorus) and algal response (as indicated by chlorophyll *a*). Cannonsville Reservoir was an exception to this generality and followed Croton System reservoirs in elevated total phosphorus and algal biomass. Schoharie Reservoir stands out with a moderate phosphorus concentration, yet extremely low chlorophyll concentration. Muscoot, East Branch, and Diverting Reservoirs have the highest phosphorus concentrations in both the long-term (1991-2000) and 2001 periods, and were among the highest algal producers.

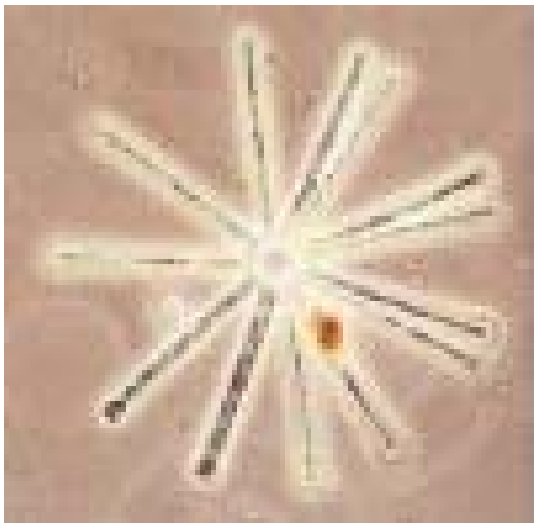


Figure 3.19 *Asterionella formosa*, a phytoplankton species typically found in NYC's reservoirs

The data for the 2001 period exhibited higher chlorophyll *a* concentrations than for the long term-term period (1991-2000). These differences are most likely due to the change in chlorophyll *a* methodology. High Performance Liquid Chromatography (HPLC) seems to be more sensitive than methods used previously in measuring chlorophyll *a*.

Nurnberg's (1996) trophic state analyses of North American lakes closely matched our results for the long-term period (Figure 3.20). Her work focused on studies which relied almost exclusively on results obtained by spectrophotometer and fluorometer. These relationships imply that the phosphorus concentration of a water body is a primary determinant of chlorophyll (algal biomass) concentrations.

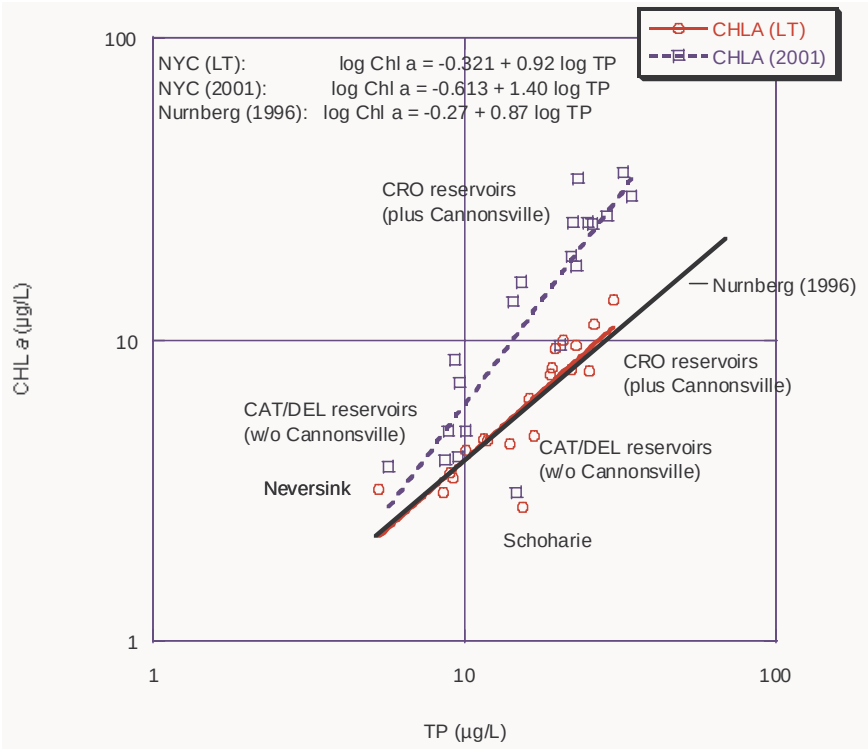


Figure 3.20 Mean chlorophyll *a* vs. total phosphorus concentration in samples collected in the photic zone during the growing season (May-October) in NYC reservoirs over a 10 year period (1991-2000) and for 2001.

Notes: EOH chlorophyll data from 1995-1997 removed from the analysis. Chlorophyll *a* results were obtained through use of spectrophotometer or fluorometer method from 1991-2000, and by HPLC during 2001. TP results were obtained by Valderamma method (1980) from 1991- 1999, and by APHA (1992; 1998) from 2000-2001.

The relationship of water transparency and chlorophyll *a*

Secchi transparency (Z_{SD}) is inversely related to algal biomass, as indicated by chlorophyll *a* concentration (Chl *a*), in NYC reservoirs (Figure 3.21). Catskill (CAT) and Delaware (DEL) reservoirs had deeper transparencies and less chlorophyll *a* content than Croton System (CRO) reservoirs. Schoharie Reservoir again stands out from the others by exhibiting low transparency and chlorophyll *a* concentration. It is likely that the elevated concentration of suspended sediments, a chronic problem at Schoharie, blocks the transmission of light resulting in lower transparency and reduction in primary productivity.

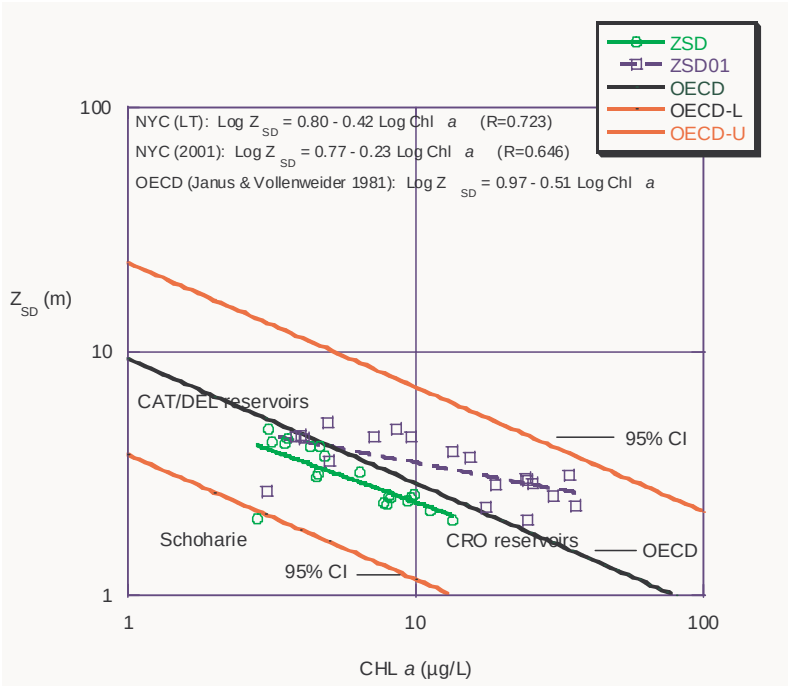


Figure 3.21 Secchi depth transparency (Z_{SD}) vs. mean chlorophyll *a* (Chl *a*) in samples collected in the photic zone during the growing season (May-October) in NYC reservoirs over a 10 year period (1991-2000) and for 2001.

Notes: EOH chlorophyll data from 1995-1997 were removed from the analysis. Chl a results were obtained through use of spectrophotometer or fluorometer method from 1991-2000, and by HPLC during 2001. Z_{SD} 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 (Smith and Hoover, 1999; Smith 2001) during 1999-2001 producing slightly higher values.

A notable difference in the Chl *a* vs. Z_{SD} response was observed between the year 2001 and the long-term (10 year) average, a possible consequence of the methodology changes (Figure 3.21).

NYC reservoirs generally conform to the expectations for northern temperate lakes (Janus and Vollenweider 1981) for the relationship between Chl *a* and Z_{SD} in inland waters. Schoharie, however, is located below the 95% confidence levels (Figure 3.21)—mostly a result of the higher concentration of light-reducing suspensoids in the reservoir.

Figure 3.22 Secchi disc measurement with a *viewer box* on the *sunny side* of the boat.

The three plots (TSI, Chl a vs. TP, and Chl a vs. ZSD) can be used in unison to provide valuable information about the reservoirs. They suggest, for example, that algal growth is driven by TP for most reservoirs and that, in general, algae dominate light attenu-

ation. The high TSI values tell us that reservoirs like Cannonsville, Croton Falls, Diverting, East Branch, and Muscoot are clearly eutrophic and that most likely blue-green algae dominate there. We can also see that non-algal particulates usually dominate light attenuation in Schoharie. Terminal receiving-water reservoirs (closer to distribution) tend to be at a lower trophic state than outlying source waters, thus providing better quality water to consumers.

3.8 What are disinfection by-products (DBPs), where do they come from, and are current levels acceptable?

Disinfection by-products (DBPs) are compounds that are formed when organic matter in raw water reacts with chlorine during the disinfection process. One group of these compounds, which DEP monitors, is the trihalomethanes (THM), of which chloroform is the main constituent. The USEPA has set limits on THM and other DBPs, such as the haloacetic acids (HAAs), because they are potential carcinogens.

Trihalomethane levels are typically higher in the Croton System and, as a result, have been the subject of recent research. The sources of precursors for disinfection by-products in New Croton Reservoir have been assessed via monitoring of trihalomethane formation potential (THMFP) in the reservoir and in its major tributaries from 1992 through 1998. As a result of this initial work, DEP undertook a multi-objective study of THMFP sources in 1999. In 2001, draft reports were completed and the highlights of this study were:

- THMFP in New Croton appears to originate primarily from upstream terrestrial sources,
- Four upstream reservoirs (Amawalk, Croton Falls, Cross River and Diverting) acted as sinks of THMFP precursors. Titicus was undergoing dam rehabilitation during this study. The low reservoir elevation may have caused the reservoir to act like a source of precursors, but the cause is not clear.
- Wetlands and, at times WWTPs, proved to be significant sources of the THMFP concentrations in the streams, and
- THMFP concentrations in New Croton Reservoir were linked to potential THM levels at Jerome Park Reservoir.

Regular monitoring of the distribution system THM compliance monitoring sites provides the status of THM levels compared to EPA limits. Figure 3.23 illustrates the monitoring results for the Catskill/Delaware and Croton systems. All three systems are below the historical 100 $\mu g\ L^{-1}$ MCL as well as the 80 $\mu g\ L^{-1}$ MCL which became effective in 2002. While THM levels are below the historical and new limit, there are other DBPs such as the haloacetic acids (HAAs) which are now regulated, as of 2002 at an MCL of 60 $\mu g\ L^{-1}$, that may be of more concern in the near future.

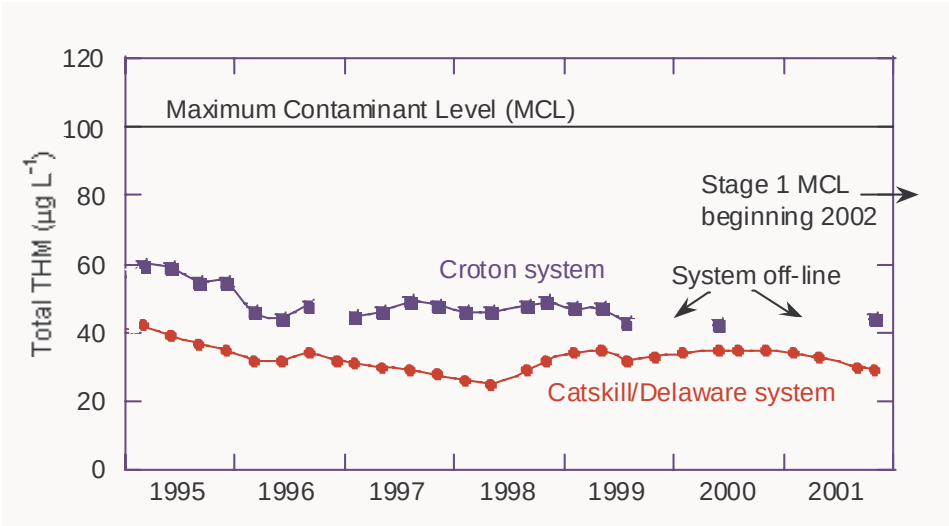


Figure 3.23 Total Trihalomethanes (THM) concentrations found in the Croton and Catskill/Delaware distribution systems 1995 through 2001 plotted as quarterly running averages

3.9 Is water quality changing in the streams, reservoirs, and keypoints?

This question was recently addressed in the document entitled "New York City's 2001 Watershed Protection Program Summary, Assessment and Long-term Plan" that can be found on the web at: (http://www.nyc.gov/dep/html/fadplan.html). This document provided an evaluation of the City's performance in implementing the New York City Watershed Memorandum of Agreement (MOA) and presented the City's long-term plan for watershed protection. Continuation of the filtration waiver issued by the USEPA pursuant to the May 1997 New York City Filtration Avoidance Determination (FAD) has been granted. This decision was based on the information available that demonstrates that the City's water supply meets all federal water quality standards and has an extensive watershed protection and remediation program to prevent degradation well into the future.

Within this document, trends for the City's water resources were analyzed using data for the period 1993 through 1999. Stream waters reported on were representative of the major inflows to the Catskill and Delaware reservoirs and the analytes considered were flow (to assist in data interpretation), total phosphorus, turbidity, and fecal and total coliforms. The reservoirs reported on were the Catskill/Delaware system (including West Branch) plus Kensico with analytes as for streams but with the addition of trophic state index (derived from chlorophyll *a*) and conductivity. The keypoints reported on were the aqueduct sites leaving Rondout, Ashokan, West Branch and Kensico reservoirs, for the analytes fecal and total coliforms, and turbidity. The data were analyzed using non-parametric statistics (Seasonal Kendall slope and trend significance) for streams and keypoints, and by a variety of techniques for reservoirs. Details of the analysis and discussion of the issues dealt with, including the confounding effects of methods changes on the analysis, are discussed in the above document.

The main findings were:

Streams

- *Fecal coliform*: there was a slight uptrend in the Esopus Creek (E16I), and slight downtrend at Rondout Creek (RDOA).
- *Total coliform*: there was a downtrend in the west branch of the Delaware River (WDBN) and at RDOA, and uptrends at both Catskill sites at the Esopus (E16I) and Schoharie (S5I) Creeks.
- *Turbidity*: there were uptrends for all sites except the east branch of the Delaware River (WDBN), as a consequence of storm events.
- *Total phosphorus*: there was an uptrend at both Catskill sites, as a consequence of storm events. There was a downtrend for all four Delaware sites.

Reservoirs

- *Fecal coliform*: there were substantial downtrends at Kensico Reservoir as a consequence of the Bird Management Program.
- *Total coliform*: there was an uptrend in both Ashokan Reservoir basins as a consequence of storm events.
- *Turbidity*: there was an uptrend in Schoharie reservoir. West Branch and Kensico uptrended very slightly. All uptrends are a consequence of storms.
- *Total phosphorus*: there were downtrends in most reservoirs, the exceptions being Schoharie Reservoir and the west basin of Ashokan where there were uptrends as a consequence of storms
- *Trophic State Index*: there were uptrends for both basins of Ashokan Reservoir and Schoharie, and a very slight uptrend in West Branch. There are small downtrends in Pepacton and Rondout Reservoirs.
- *Conductivity*: there are downtrends in most reservoirs as a consequence of the dilution effects of storms. Cannonsville Reservoir experienced an uptrend.

Keypoints

- *Fecal coliform*: there were downtrends for Rondout (RDRR) and both Kensico keypoints (CATLEFF and DEL18).
- *Total coliform*: there were downtrends for both Kensico keypoints (CATLEFF and DEL18), and uptrends for Ashokan (EAR) and West Branch (DEL10) keypoints.
- *Turbidity*: there was a downtrend at the Rondout (RDRR), Kensico (CATLEFF), and West Branch (DEL10) keypoints, and an uptrend at the Ashokan keypoint (EAR).

Further trend analysis is not scheduled for another five years and will be reported on then (2006). The main reason for this is that on the geographic scale of a reservoir's watershed changes in water quality, as a consequence of watershed management practices, are not expected to be discernible observable over a short time frame since natural environmental variation will mask such effects. Sufficient time must pass for small incremental changes, such as water quality improvements due to watershed management programs, to accumulate before such changes will become identifiable as trends.

4. Watershed Management

4.1 How do contaminants get into the water supply?

Figure 4.1 Storm flow is responsible for the transport of non-point source contaminants from the landscape into the water supply .

As water travels over the land or through the ground, it dissolves naturally-occurring minerals and, in some cases, contaminants from either animal or human activities. Typically, only man-made or anthropogenic sources are considered “pollutants” but naturally occurring substances can also be problematic (e.g. arsenic). Contaminant sources are further classified as point or nonpoint sources. A point source originates from a single, discrete location (i.e. a “point”). A good example is wastewater treatment plant effluent which is discharged from a pipe. Nonpoint sources are diffuse and do not have a single point of origin, and are generally carried off the land surface during rain events. Management efforts generally focus on the man-made contaminant sources, and are tailored to the type of source (i.e. point or nonpoint) and the way the contaminants are transported (e.g. stormwater runoff).

4.2 How can watershed management improve water quality?

Watershed management can be defined as the process of organizing and guiding land and natural resources' use on a watershed to provide for the often competing needs and priorities of all stakeholders. In the case of the NYC watershed, the stakeholders include the water supply consumers, the watershed residents, and flora and fauna that comprise the ecological community. With careful planning and communication, water quality can be protected and improved while still serving multiple watershed uses.

Many scientific studies demonstrate the direct connection between the activities within a drainage basin and the quality of its water resources. Such relationships exist when management practices are lacking and contaminants are simply washed off the landscape by rain or melting snow, or released directly into streams, that then flow into the water supply. The essence of watershed management is to remove or prevent contaminants from reaching the natural flow-path of water. Examples of the City's major watershed programs that are based on this concept of un-coupling and reducing contaminants from the water supply are listed in Section 4.3 (below.) A comprehen-

sive summary of the accomplishments of the City's watershed protection programs can be found in the Filtration Avoidance Annual Report, completed in March 2002. The evaluation of what these programs are expected to achieve, in terms of water quality improvement, are presented in the remainder of this chapter, and evaluated collectively in the subsequent chapter on watershed modeling (Chapter 5.) A more detailed exposition of this evaluation can be found in the report entitled "Filtration Avoidance Supplemental Annual Report: Assessing the Effectiveness of the Water Supply Protection Measures Undertaken in the Catskill and Delaware Systems" (NYCDEP, 1999.) This report is available on the DEP website.

4.3 What kind of watershed management programs does DEP have and what are the recent accomplishments?

DEP has many programs in place that are devoted to watershed management for the purpose of improving and protecting the water supply. Some of the major programs are listed in Table 4.1 along with their most significant accomplishments to date.

Table 4.1: DEP watershed programs and achievements.

DEP Programs	Achievements
Watershed Agricultural Program	Working through the Watershed Agricultural Council, the City funds development of farm plans and implementation of structural and non-structural best management practices. To date, more than 90% of watershed farms have signed up to participate in the program. Hundreds of Best Management Practices have been installed on farms targeting reductions in polluted runoff. The City has augmented the program with the addition of a City/federal cost-sharing effort known as the Conservation Reserve Enhancement Program (CREP). CREP pays farmers to take sensitive riparian buffer lands, adjacent to waterbodies, out of active farm use and re-establish a vegetative buffer. Further, the City is implementing new intitiatives to target small farms in the watershed and farms in the Croton system.
Land Acquisition	The City seeks to acquire lands in high priority areas of the watershed from willing sellers. After five years, the City has solicited owners of more than 280,000 acres of watershed land and has secured more than 41,700 acres through either fee acquisition or the purchase of easements.
Watershed Rules & Regulations	On May 1, 1997, enhanced Watershed Rules and Regulations became effective, replacing regulations that had been in place since 1953. Since the new regulations became effective, DEP staff has reviewed thousands of applications for projects that proposed one or more regulated activities, requiring numerous changes to proposed development to better protect water quality.

Table 4.1: DEP watershed programs and achievements.

DEP Programs	Achievements
Environmental and Economic Partnership Programs	New York City spent more than $290 million to support a variety of partnership programs in accordance with the terms of the MOA. The City, in conjunction with its partners, has continued to implement programs that have remediated more than 1,300 failing septic systems, upgraded 30 facilities that store winter road de-icing materials, constructed stormwater BMPs in areas with previously uncontrolled stormwater runoff and has developed solutions to wastewater problems in some of the larger, unsewered hamlets and villages WOH.
Wastewater Treatment Plant (WWTP) Upgrades	DEP has completed the upgrades to tertiary treatment of the six City-owned wastewater treatment facilities that account for 40% of the WWTP flow in the west of Hudson watershed, at a cost of more than $240 million. There are 34 non-City-owned surface-discharging WWTPs in the Catskill/Delaware watershed, Upgrade designs are proceeding quickly and construction has begun at many WOH facilities. Construction has been completed on facilities that account for approximately 83% of non-City-owned Catskill/Delaware WWTP flow.
Protection of Kensico Reservoir	The City has implemented a variety of programs to ensure protection of Kensico Reservoir. Construction of best management practices designed to reduce pollutants conveyed to the reservoir by stormwater run-off is nearly complete. The City completed preventative dredging of sediments from the areas in front of Delaware Aqueduct Shaft 18 and the Catskill Upper Effluent Chamber (CUEC). A turbidity curtain is maintained to protect the CUEC, waterfowl management continues to be exceptionally effective in maintaining low levels of fecal coliform bacteria, and the Kensico Environmental Enhancement Program (KEEP) maintains an educational link with the community focused on pollution prevention. In addition, the City has teamed up with the Town of North Castle and a number of corporations in the Kensico basin to form the Kensico Watershed Improvement Committee (KWIC). Under KWIC, the corporate landowners in the basin will undertake a range of voluntary measures to protect water quality, including minimizing use of pesticides.

4.4 How can DEP reduce point sources of contaminants?

WWTP Phosphorus Reductions

Wastewater treatment plants (WWTPs) represent potential sources of contaminants to the reservoirs and are categorized as point sources. As part of the overall water quality monitoring and protection program, DEP staff inspect all of the WWTPs quarterly and sample the effluents twice-monthly (city-owned plants are monitored weekly). Total phosphorus is one important analyte that is moni-

tored and tracked since this nutrient is a limiting factor for algal biomass in the reservoirs. DEP staff calculates phosphorus loads after an extensive review of the water quality data and the facility data. (At present, the 2001 loads are not yet completed.)

DEP data indicates that phosphorus from WWTPs has been decreasing since the mid 1990's (Figure 4.2). Much of these load reductions can be attributed to intervention and 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 maintenance, and/or increased use of certified operators. WWTP owners may also implement suggestions made by DEP staff in quarterly inspection reports without requiring the pressure of lawsuits 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 performance overall.

WWTP Upgrades

The Watershed Rules and Regulations (WRR) require that surface-discharging WWTPs upgrade their treatment processes to include phosphorus removal and microfiltration for removal of pathogenic protozoans. Although these WWTP upgrades are currently in-progress, the City-owned facilities are complete. The monitoring data before and after a facility upgrade shows a dramatic reduction in phosphorus loads (Figure 4.3). Based on this type of data, DEP expects that WWTPs will be negligible sources of phosphorus after the upgrade program is completed.

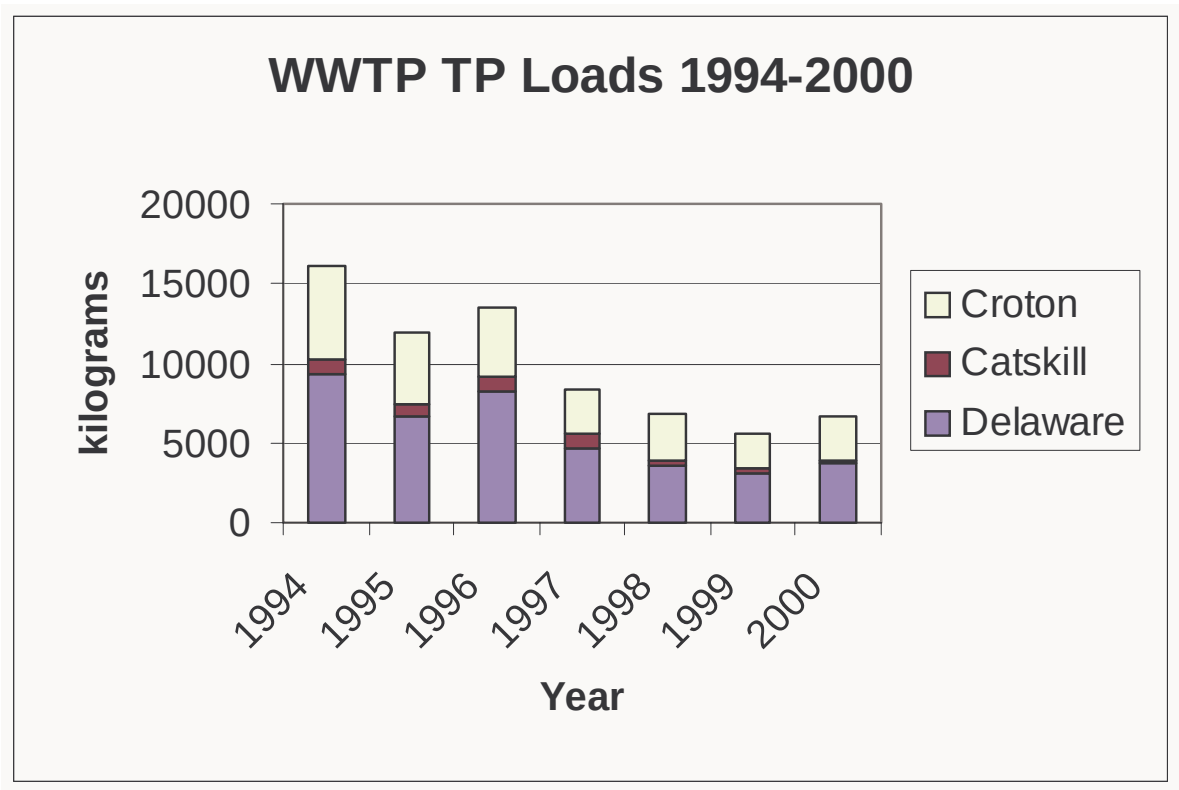


Figure 4.2 Wastewater treatment plant TP loads by district, 1994 - 2000.

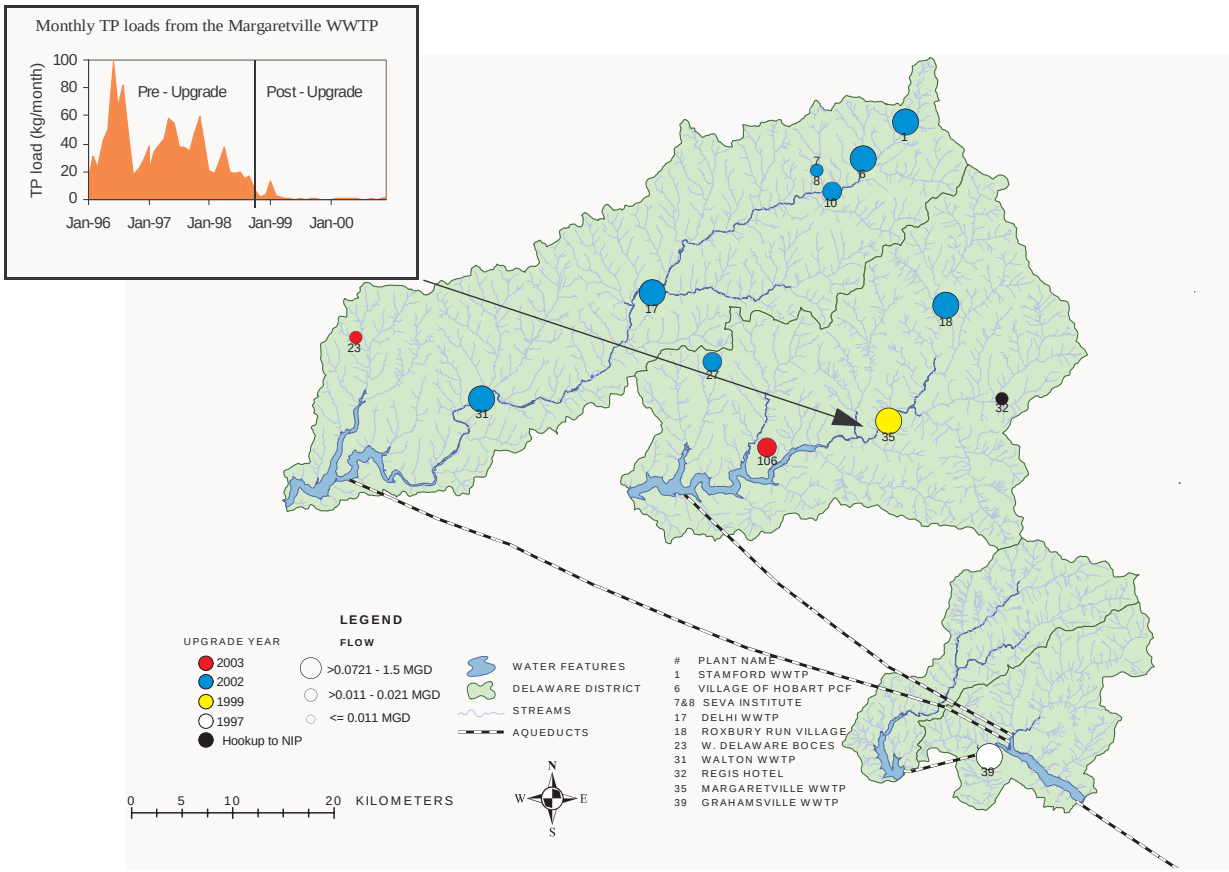


Figure 4.2 Upgrade schedule for Delaware District WWTPs.

WWTPs can also be sources of pathogenic organisms. A total of 91 samples were collected for human enteric virus analysis at eight wastewater treatment plants during 2001. These included 66 treated effluent and 25 raw sewage influent samples collected concurrently. Samples were collected and analyzed in accordance with the methodology specified by USEPA's Information Collection Rule (Fout et al., 1996). Influent samples consisted of a 1L grab while effluent samples consisted of 62L filtered through a special Virosorb™ cartridge. Comparisons between the number of viruses in influent and effluent provide an estimate of a treatment plant's efficiency. A plant that reduces the number of viruses by a factor of ten is rated as having "one log removal". Likewise plants reducing the number of viruses by factors of 100, 1,000, and 10,000 are rated as having "two", "three", and "four log removal", respectively.

Figure 4.4 shows the average results of virus sampling at WWTP influents and effluents. In examining these results note that scales are different by four orders of magnitude (influent scale 1-250,000 vs. effluent scale 1-25). Log removal values calculated for the Delhi, Stamford and Tannersville WWTP's were 4.71, 4.24, 4.14, respectively. These values are equivalent to between

99.99 and 99.999% removal of viruses. Log removal values could not be calculated for the remainder of the plants because no viruses were isolated in either all influent, all effluent or both. While the absence of viruses in samples prevents calculation of the log removal value, it is an indication of clean water leaving the treatment plants.

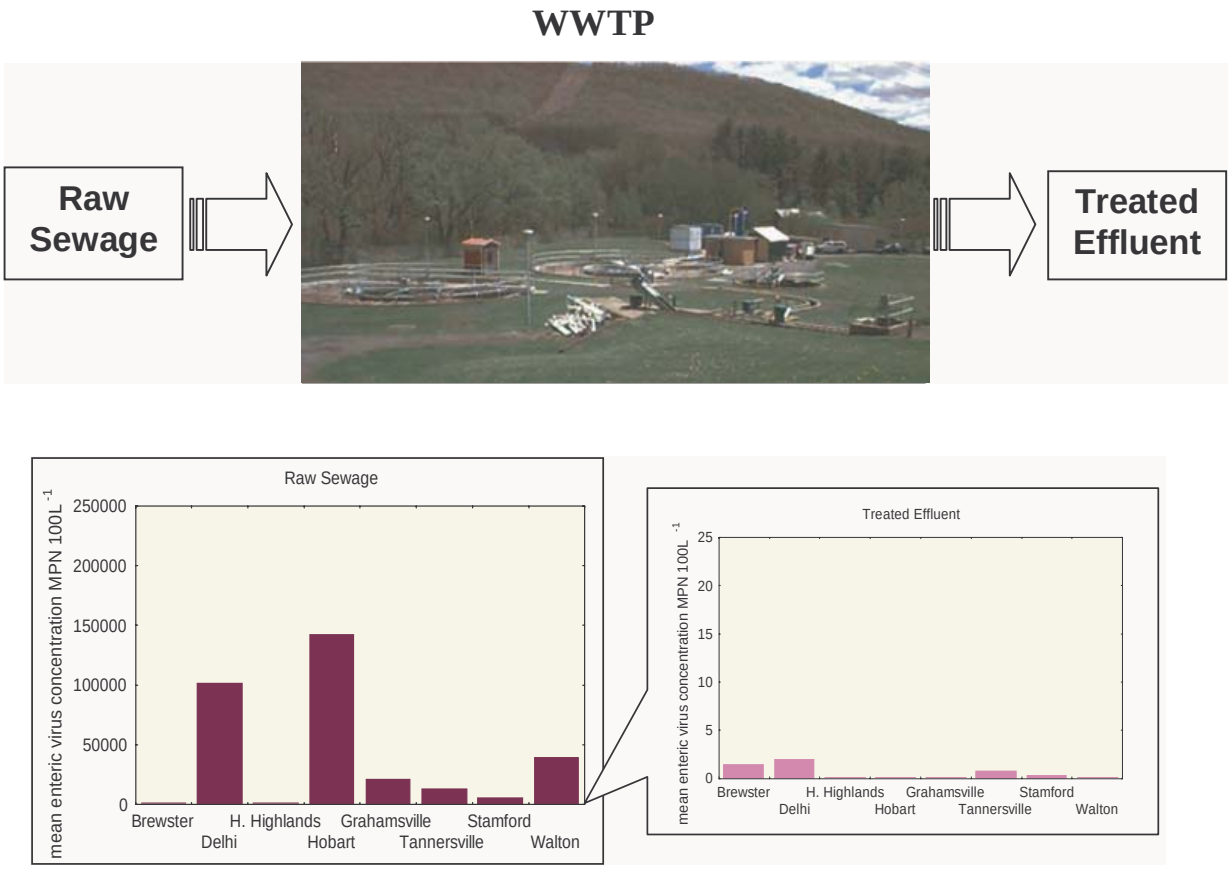


Figure 4.3 Typical waste water treatment plant reductions in average virus concentration.

Water samples for *Cryptosporidium* and *Giardia* analysis were also collected to evaluate the benefits of wastewater treatment plant upgrades on eliminating these protozoan pathogens. The effort began in 1993 and is on-going at two WWTPs. These WWTPs are located in Grahamsville and Tannersville. Both plants were upgraded in 1997. The sampling frequency was typically monthly except for a period in September and October 1993 when weekly samples were collected. All samples were collected and analyzed with the ASTM method P229 (ASTM, 1992) using a sample volume of 190L. Figure 4.5 shows the annual averages of *Cryptosporidium* and *Giardia* at each of the two plants.

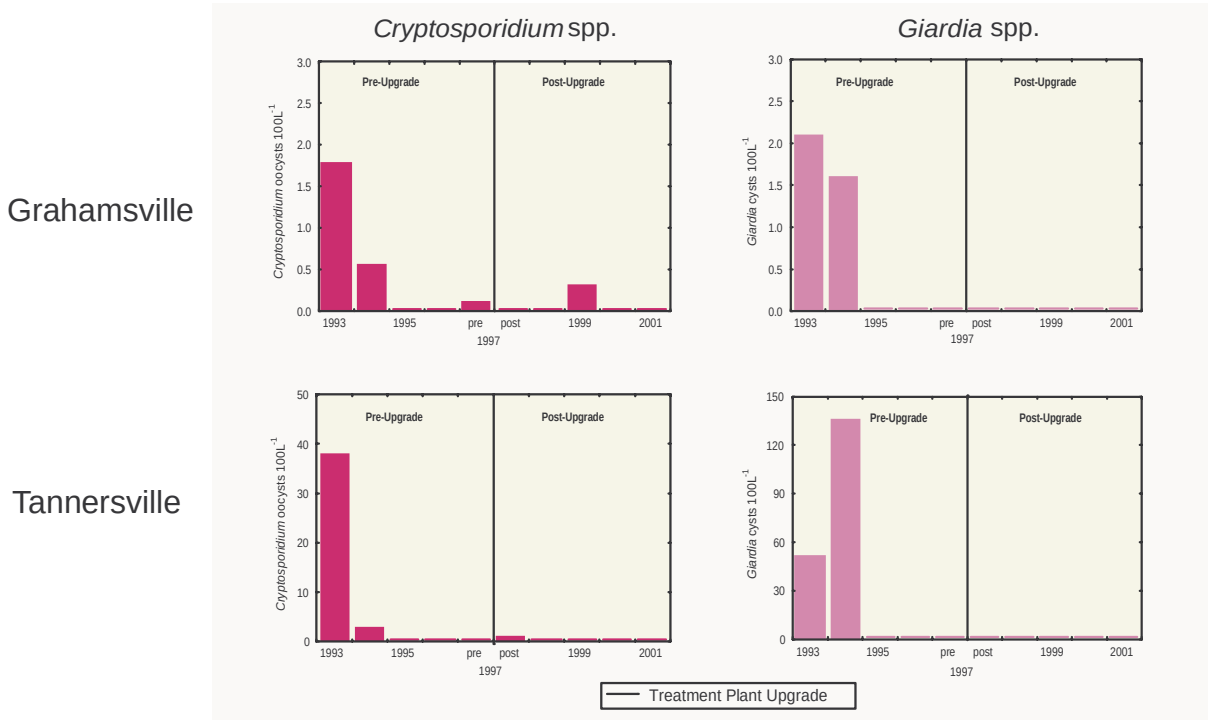


Figure 4.4 Waste water treatment plant upgrades resulted in a reduction of the average *Cryptosporidium* and *Giardia* concentrations of WWTP effluents.

At the Grahamsville plant, DEP collected 46 samples prior to the upgrade, which was completed in October 1997 and 48 samples after. Results from the pre-upgrade samples were low with an average *Cryptosporidium* concentration of 0.638 oocysts $100L^{-1}$ from detections on 6 of the 46 sampling occasions. The average *Giardia* concentration was similarly low at 0.844 cysts $100L^{-1}$ also with detections on 6 of the 46 sampling occasions. Since completion of the upgrade there have been no detections of *Giardia* in 48 occasions, which yields an average of zero cysts $100L^{-1}$ and 1 detection of *Cryptosporidium* yielding an average of 0.0786 oocysts $100L^{-1}$.

At the Tannersville plant, DEP collected 39 samples prior to the upgrade completed in June 1997 and 52 samples after. Results from the pre-upgrade period were generally higher than Grahamsville with an average *Cryptosporidium* concentration of 10.6 oocysts $100L^{-1}$ from detections on 10 of the 39 sampling occasions. The average *Giardia* concentration was 51.4 cysts $100L^{-1}$ from detections on 12 of the 39 sampling occasions. Results from the post-upgrade period averaged 0.0998 oocysts $100L^{-1}$ for *Cryptosporidium* and 0.250 cysts $100L^{-1}$ for *Giardia*. Although the Tannersville plant had some initial pathogen detections during the first year of operation (3 samples positive for *Cryptosporidium*, 4 for *Giardia*), the plant has had no pathogen detections since June 4, 1998.

In summary, it appears that the waste water treatment plant upgrade program has been successful at these two plants. Treated effluent levels of *Cryptosporidium* were reduced about 10 times at the Grahamsville WWTP where concentrations were initially low, while *Giardia* was virtually eliminated from the effluent. In contrast the Tannersville plant had higher initial pathogen concentrations consequently greater reductions in treated effluent levels by about 100 times for *Cryptosporidium* and 200 times for *Giardia* were achieved.

4.5 How can DEP reduce nonpoint sources of contaminants?

Nonpoint sources of contaminants are more difficult to control than point sources due to their diffuse nature. Management efforts must consider both reduction of the contaminant sources as well as transport mechanisms. Since the entire watershed land area can be considered a "nonpoint source" of contaminants, management efforts must also be prioritized to address the most significant sources first.

DEP is involved in several efforts to address nonpoint sources of contaminants. A few examples of nonpoint source efforts that are managed or monitored include:

- The Total Maximum Daily Load (TMDL) program is an example of managing both point and nonpoint sources.
- The Croton Watershed Strategy project is an example of developing a broad management framework and prioritizing management efforts.
- Kensico Stormwater BMP Installation
- Waterfowl Harassment
- Roadway Deicers

TMDLs

The TMDL process is a watershed-based approach to managing point and nonpoint sources of contaminants to achieve water quality standards. In the NYC watershed, the TMDLs were developed for total phosphorus and has been a joint effort between the United States Environmental Protection Agency (EPA), New York State Department of Environmental Conservation (DEC) and the DEP. DEC is responsible for developing and implementing TMDLs under the Clean Water Act. DEP is providing technical assistance to the State TMDL program in the form of data analysis and modeling of the NYC reservoirs to support the efforts of DEC in establishing TMDLs. Phase I TMDLs were approved by EPA in April 1997. DEP released a series of Phase II TMDL technical reports in March 1999; DEC submitted the Phase II TMDL package to EPA in June 2000; and EPA approved the Phase II TMDLs in October 2000.

The MOA requires two reports describing the impacts of existing City and State programs on nonpoint source loads of phosphorus and potential nonpoint source management practices that could be implemented in order to achieve the Phase II TMDLs in the watershed. The first report, coauthored by DEP and DEC, was released on April 30, 2001. This report described the impacts of

existing City and State programs on nonpoint source loads of phosphorus and potential nonpoint source management practices that could be implemented in order to achieve the Phase II TMDLs in the watershed. This report provided some additional watershed analyses to assist stakeholders in allocating phosphorus reductions. The second report, authored by DEC, was released in April 2002.

Implementing the necessary phosphorus reductions to achieve the Phase II TMDLs is a complicated task, involving many stakeholders. These reports represent critical steps in the overall process which is likely to continue for many years. DEP is planning on using the results of the Croton Watershed Strategy project, discussed below, to assist in reducing nonpoint sources of phosphorus.

Croton Watershed Strategy

The Croton Watershed Strategy project is a two-year contract (December 2000 – March 2003) that will provide an integrated framework for management of the Croton System. The concept is to evaluate the point and nonpoint sources of water quality impairment in the watershed for a variety of contaminants (i.e. nutrients, pathogens, total suspended solids, toxics, and pesticides) and use this information to develop a targeted watershed management plan to protect and improve water quality in the streams and reservoirs. This project, including the management tools that will be developed, will assist DEP in focusing limited resources on critical areas and sub-basins to achieve a maximum water quality benefit.

Under this contract, pertinent data has been collected from a variety of federal, state, county, and municipal sources, including DEP's extensive data bases, and organized in a Geographical Information System (GIS) format. The consultants are also developing GIS-based management software for the Department which will allow for more efficient use of available data, better integration of programs and the ability to update the analyses as better data becomes available. The project will identify existing and potential point and nonpoint sources of environmental impairment at the sub-basin scale (~80 sub-basins), as well as suggest management alternatives for addressing these sources and prioritizing areas for implementation efforts. DEP will then review these recommendations and incorporate them in a Nonpoint Source Management Plan.

Stormwater Best Management Practices for Pollutant Removals

DEP has implemented a Kensico Reservoir watershed management and protection plan that targets the control of fecal coliform bacteria and turbidity. As part of this plan, DEP has constructed nine extended detention basins (with a 10th to be constructed soon) on streams that discharge into Kensico Reservoir. With the construction of these BMPs, DEP developed a stormwater monitoring program to evaluate the effectiveness of these structures in reducing loads of fecal coliform, total suspended solids, turbidity (a quasi-load) and total phosphorus. Between 2000 and 2007, DEP intends to monitor at least one year's worth of storm events at each of these extended detention basins to quantify their ability to reduce loads of the above analytes.

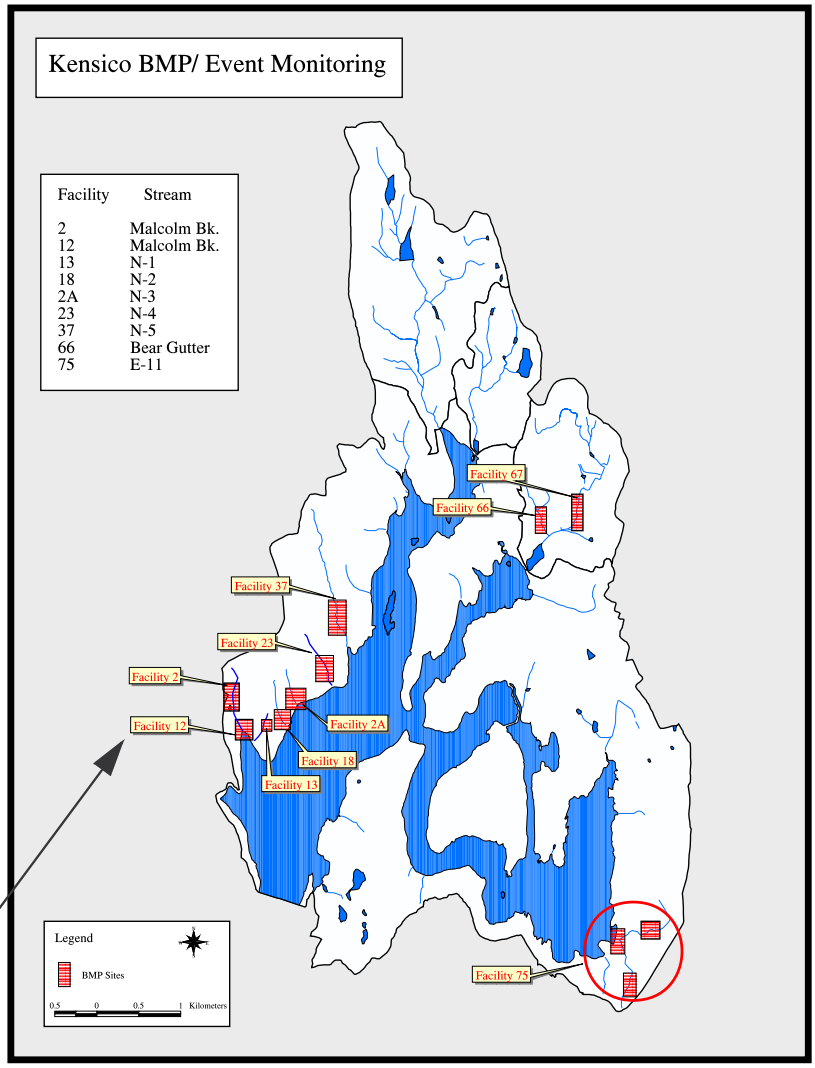


Figure 4.5 Map of Kensico Reservoir watershed with locations of extended detention basin BMPs.

Figure 4.6 BMP Facility 12 following a rain event.

As part of this program, BMP Facility 12 was monitored between March 2000 and September 2001. During this period, sufficient data were collected to calculate storm loads of fecal coliform during 11 events, total suspended solids during 13 events and turbidity and total phosphorus during 14 events. The Regression of Loads technique (Martin and Smoot, 1986) was used to calculate load removal efficiencies (Figure 4.8). This technique calculates the regression between the input loads and output loads, where 1 minus the slope of the regression line (constrained through the origin) is assumed to be the percent reduction of analyte load. Based on this analysis, BMP Facility 12 was found to remove 49% of the fecal coliform loads, 73% of the total suspended solids loads, 51% of the turbidity quasi-loads and 54% of the total phosphorus loads.

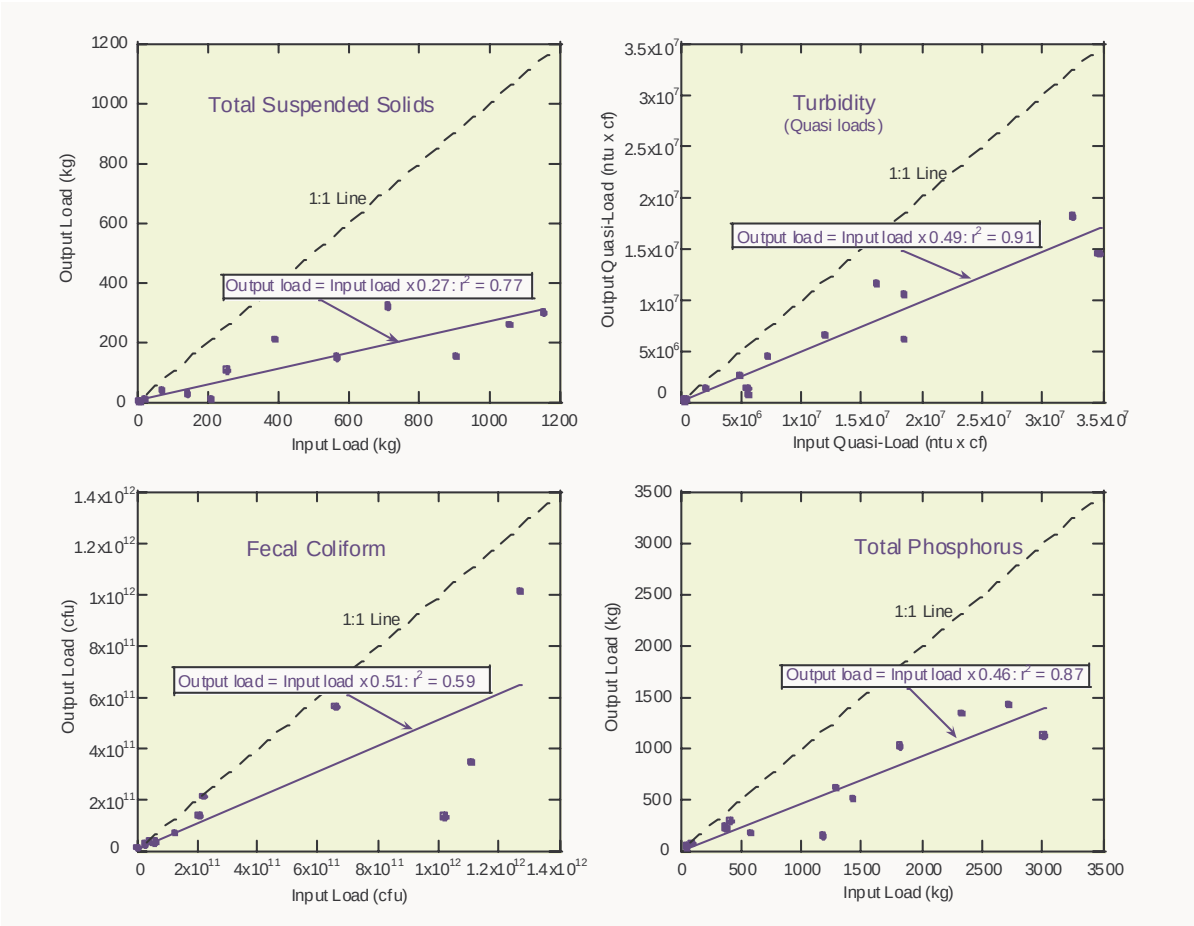


Figure 4.7 Load reduction regressions for Facility 12 (Malcolm Brook) extended detention basins. For turbidity, true mass loads cannot be estimated because the measurement is an arbitrary assessment of light side-scatter.

Waterbird Management

Figure 4.8 Canada geese are sometimes the cause of high bacterial levels in reservoirs.

DEP's Wildlife Studies Group, responsible for the development and implementation of the Waterfowl Management Program (WMP) at Kensico, continued to monitor and reduce populations of waterbirds. Federal and state approved wildlife management techniques were used to maintain significantly lower fecal coliform bacteria levels during the period of April 1, 2001 through March 31, 2002. Bird population surveys were conducted throughout the year (except from 9/12/01 to 1/8/02 due to an evaluation period of the terrorist threat). The data presented in Figure 4.10 represents a count of all overnight roosting waterbirds including Canada Geese (*Branta canadensis*), gulls (*Larus* spp), Mute Swans (*Cygnus olor*), ducks, Loons, Coots, and Cormorants and fecal coliform bacteria from the period August 1992 through December 2001. Additional waterbird populations surveys were initiated at Croton Falls Reservoir (drought-related) and continued at reservoirs source to Kensico (West Branch, Rondout, and Ashokan) and at Hillview and Jerome. Overhead wires to preclude bird activity on the surface of the reservoir were maintained by Operations staff for all of Hillview Reservoir including the north basin at Jerome Reservoir. Waterbird populations remained low enough to forestall active harassment and not impact water quality at these locations. Egg-depredation for Canada geese was conducted at Jerome, West Branch, and Rondout Reservoirs in 2001. Bird harassment activities using motorboats and pyrotechnics were employed by Wildlife Staff, DEP Police and Watershed Inspectors in January 2001 at Rondout Reservoir during a temporary rise in fecal coliform bacteria. 2001 was the ninth consecutive year that DEP's Waterfowl Management Program effectively reduced waterbird populations and averted related seasonal increases in fecal coliform bacteria.

Roadway Deicers

Over the past several years, a number of liquid additives to sand and salt piles for winter road maintenance have entered the market. While the Watershed Rules and Regulations do not regulate these products for use in the NYC watershed, DEP has found that some of these products have very high concentrations of total phosphorus that could compromise efforts to reduce phosphorus in many of the reservoir basins. A working group was formed, composed of staff from the NYS Attorney General's Office, New York State Department of Conservation (NYSDEC), New York State Department of Transportation (NYSDOT), New York State Department of Health (NYSDOH) and DEP, to compile information and develop guidance materials for various town, county, and state DOTs in the watershed. DEP monitoring indicated a wide range of phosphorus concentrations in the liquid deicers as well as in the sand that is also applied. Application rates of deicers also varied widely throughout the watershed, further complicating the development of a watershed-wide standard practice.

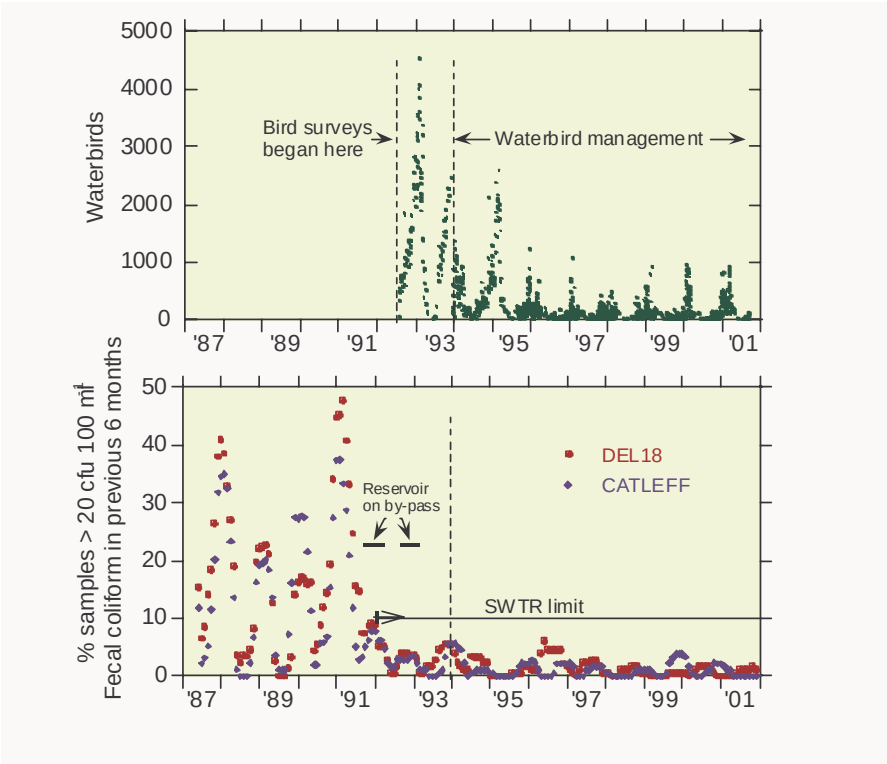


Figure 4.9 The effects of waterbird management on source water fecal coliform concentrations.

Note: The upper plot shows bird numbers on Kensico Reservoir, the lower plot the compliance with the Surface Water Treatment Rule for Fecal coliforms at the CATLEFF and DEL18 effluent chambers.

Despite the various complexities and the competing interests, however, a non-binding guidance document was released which balances the need to protect water quality while not being overly restrictive to the DOTs that use the less-costly liquid deicers. As part of this effort, DEP has agreed to take a leading role in gathering the necessary information for this program. This includes development of a survey form for DOTs to document their usage and chemical analysis of additional winter road maintenance materials as they enter the market. All involved in this process hope that with additional information and outreach, water quality will not suffer any negative impacts due to winter road maintenance activities.

4.6 How can DEP enhance protection of the Water Supply?

One way to enhance protection of the water supply is to clearly identify all areas that should fall under state or federal regulatory protection and to ensure that the regulations are applied appropriately. The Stream Reclassification Program and Wetland Mapping effort are prime examples of DEP's efforts to enhance protection through documentation of the current condition of our existing resources.

Stream Reclassification

NYSDEC assigns surface water bodies a classification based on the best usage of the water body, e.g., contact recreation, water supply. Water quality standards vary according to the classification and are designed to protect the highest use of the water body. Streams that are intended to sustain trout or trout spawning have additional requirements for dissolved oxygen concentration and temperature. These additional requirements strengthen the compliance criteria in the permits of any regulated actions, such as WWTP effluent discharge or stream disturbances.

Figure 4.10 Adult brook trout (*Salvelinus fontinalis*).

DEP has been conducting reclassification surveys since 1996 to demonstrate the presence of trout or areas of trout-spawning. Once a year, reclassification petitions for all the streams that qualify for trout or trout-spawning designation are sent to NYSDEC. To date, streams in the Kensico, West Branch, New Croton, Rondout, Ashokan and Schoharie basins have been inventoried and petitions submitted to NYSDEC for final determination of the classification upgrades (Figure 4.13). NYSDEC recently approved all petitions for the Lower Hudson drainage, and hundreds of streams have been reclassified. The Lower Hudson drainage system included the Croton, Ashokan and Rondout drainage basins of the NYC watershed.

Figure 4.11 Documenting captured fish characteristics during stream reclassification surveys.

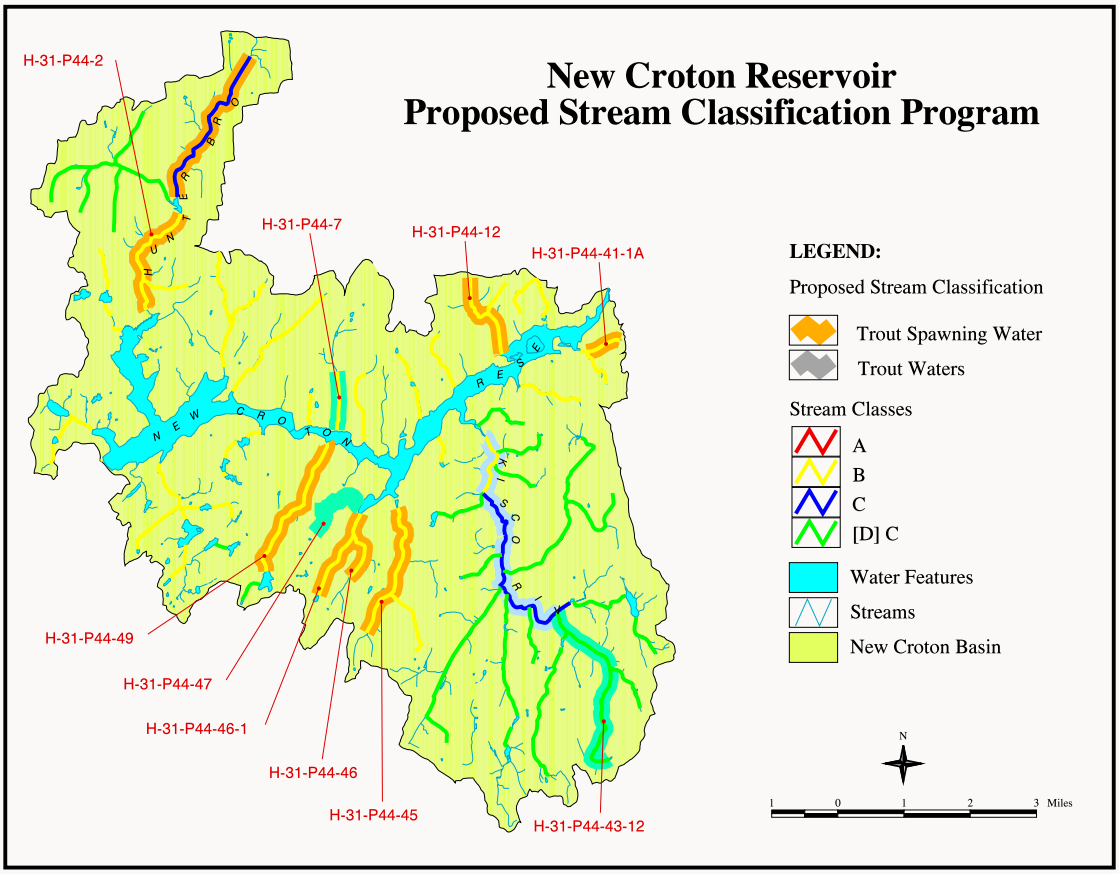


Figure 4.12 New Croton Reservoir proposed Stream Classification Program. A total of 26.6 miles of stream segments were proposed for reclassification in the New Croton basin.

Wetlands Research

Natural wetlands provide a variety of water quality benefits for surface and groundwater. DEP has a comprehensive Wetlands Protection Strategy that includes both regulatory and research components. Wetlands are regulated at several levels of government: federal (i.e. USACOE), state (i.e. NYSDEC) and local (i.e. town ordinances and the the Watershed Rules and Regulations). Typically only larger wetlands are regulated and threshold size varies between regulations. DEP has been actively involved in improving the accuracy of wetland map-

Figure 4.13 A lotic reference wetland located within the West Branch Reservoir Basin of the Croton Watershed.

ping in the watershed. The mapping is initially done through remote sensing techniques followed by field verification. In 2001, Natural Resources staff worked closely with DEC to update of the State wetland maps for the NYC watershed.

Wetland research within DEP has centered on the classification of wetland types based on their landscape position and hydrologic characteristics. This is related to their capacity to act as natural filters of water that flows into the streams and reservoirs. In 2001, USFWS completed the wetland characterization for the Cannonsville and Neversink watersheds and conducted extensive field verification with DEP staff. The classification of wetlands is proceeding for the remainder of the watershed. A monitoring program was conducted from 2000 to 2002 to document the water quality impacts of different types of wetlands in West Branch and Boyd Corners basins, and this pilot program will be extended to the Catskill/Delaware watersheds in 2002. This research will allow a better understanding of how wetlands affect water quality as well as better criteria to set priorities for wetland protection programs.

4.7 Does DEP evaluate biological integrity?

Biological monitoring provides an assessment of water quality which complements chemical (e.g. pH) and physical (e.g. discharge) monitoring. While physical and chemical monitoring capture a "snap-shot" in time, biological monitoring allows us to see the cumulative effects of environmental variation over time. Combining biological, chemical and physical monitoring data can provide valuable insight into aquatic habitat and water quality goals in a region, and help identify possible sources of water quality degradation. DEP initiated the Benthic Macroinvertebrate Biomonitoring program in 1994 and by the end of 2001 had established 117 stream biomonitoring sites. Subsamples of 100 organisms from each site are identified and evaluated for the total number of taxa present, the number of sensitive species, and similarity of the subsample community to an "ideal", stream community. Figure 4.16 shows the Water Quality scores by system for 1994 - 2000. As is seen in most years, the Croton System streams have consistently lower water quality scores overall than the Catskill / Delaware streams. The combined effects of differences in the geology, density of human population, development, and other factors are reflected in the biological differences shown here.

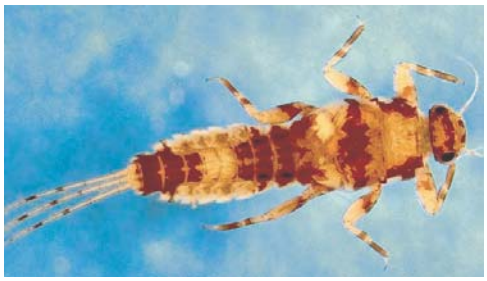


Figure 4.14 *Ephemerella sp* - an example of the benthic organisms used to evaluate environmental quality.

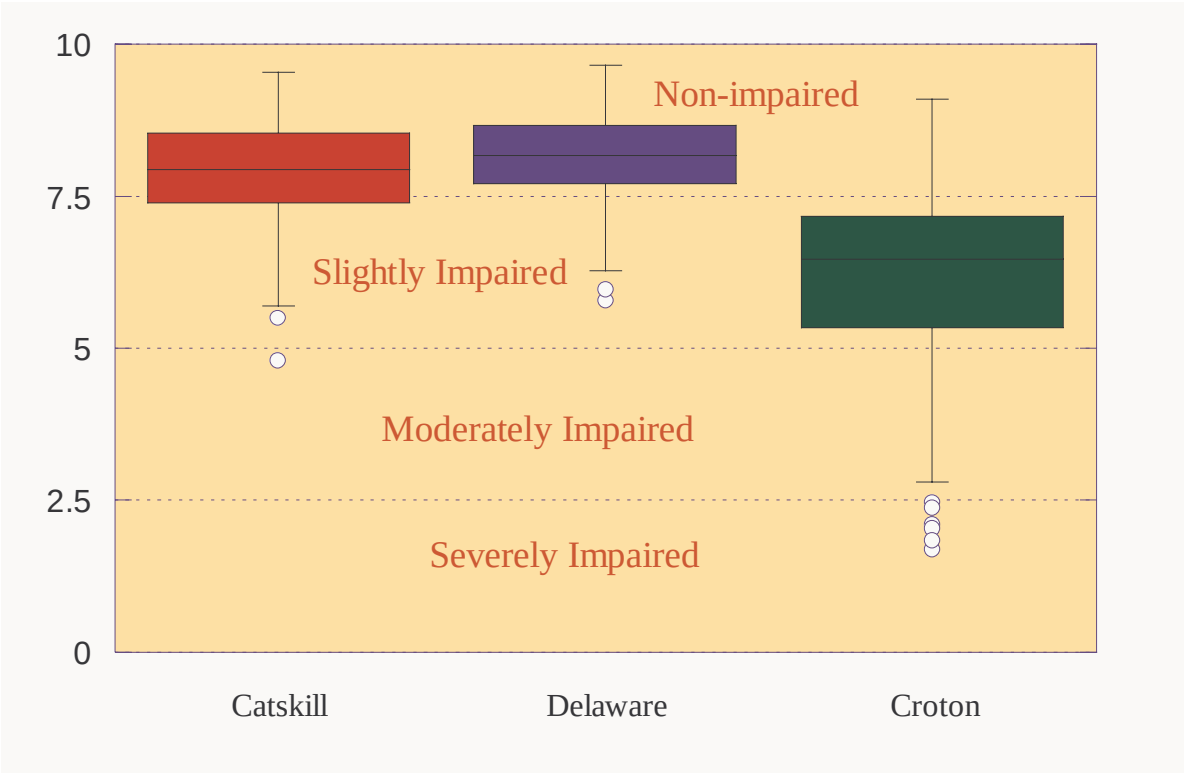


Figure 4.15 Boxplots of stream biomonitoring water quality scores, 1994-2000 data.

5. Model Development and Applications

5.1 Why are models important?

DEP is developing and applying terrestrial and reservoir models to support watershed management and reservoir operations. Terrestrial models simulate water and nutrient loadings from the reservoir watersheds as a function of weather, watershed physiography (soils, topography), land use and watershed management. Reservoir models simulate in-lake hydrodynamics (water levels and flows), thermal structure, and nutrient and chlorophyll levels (indicators of eutrophication) as a function of weather, reservoir bathymetry, and nutrient loadings. The linkage of terrestrial and reservoir models provides a powerful tool for simulating the effects of weather, land use, watershed management, and reservoir operations on water quality in the NYC reservoirs.

The reservoir models are also capable of simulating movement and dispersion of conservative substances within the reservoir. Such applications are useful for predicting the short-term effects of contaminant spills or runoff events, and guides decisions on short-term reservoir routing operations to minimize and contain any contaminants found in the reservoir system.

5.2 How are models being used to guide water supply operations?

A wide range of issues can be addressed with two-dimensional reservoir management models, such as the impacts of contaminant spills and runoff events. These models will predict features of temporal responses such as time-of travel, and support evaluation of modifications in reservoir response that could be achieved through various management alternatives (e.g., depths of withdrawal). Annually, applications of these models will be presented for appropriate issues. Below, an example of such a model application is presented.

In 2001, the two-dimensional reservoir management models were applied to evaluate the response of Cannonsville Reservoir, and the downstream reservoir (Rondout) that receives the water withdrawn from Cannonsville, to a “hypothetical pulse” (e.g., “spill”) of a conservative tracer substance. The model run assumed that the tracer was added to the West Branch of the Delaware River (WBDR, the primary tributary to Cannonsville Reservoir). The hypothetical pulse load was input at the mouth of WBDR on May 31, 1993 to achieve a concentration of 1000 $mg \cdot l^{-1}$ over one hour (Figure 5.1a). Hydrologic and withdrawal/operating conditions that actually prevailed in that year were used for this scenario analysis.

The tracer was predicted to first reach the upper water supply intake (No. 3) in Cannonsville Reservoir several days after the pulse input, followed by generally progressive increases to a peak concentration (~0.2 $mg \cdot l^{-1}$) about 60 days later (Figure 5.1b).

The response at the mid-depth water supply intake (No. 2) was delayed, as increases did not occur until late June; the maximum (~0.2 mg·l^{-1}) was not reached until mid-August at this location. Increases in the tracer concentration at the deepest intake were delayed until August, and the peak (~0.14 mg·l^{-1}) did not occur until early October. The "leading edge" of the tracer was predicted to first arrive at the water supply intakes of Rondout Reservoir in mid-July (Figure 5.1c). The intakes first affected in this downstream reservoir are at mid-depths (No.'s 2 and 3), because water from Cannonsville was withdrawn from stratified (colder and relatively dense) layers and thus enters subsurface depths of Rondout. The shallowest (No. 4) and deepest (No. 1) intakes are predicted to be influenced last, and not until late August. Predicted concentrations for this downstream reservoir are diminished compared to Cannonsville due to dilution from other inputs (e.g., Pepacton Reservoir, Neversink Reservoir, and Rondout River). The model can also be used to evaluate the extent to which tracer concentrations can be minimized through alternative selections of withdrawal depths. In this way appropriate decisions can be made to maximize water quality that flows into distribution.

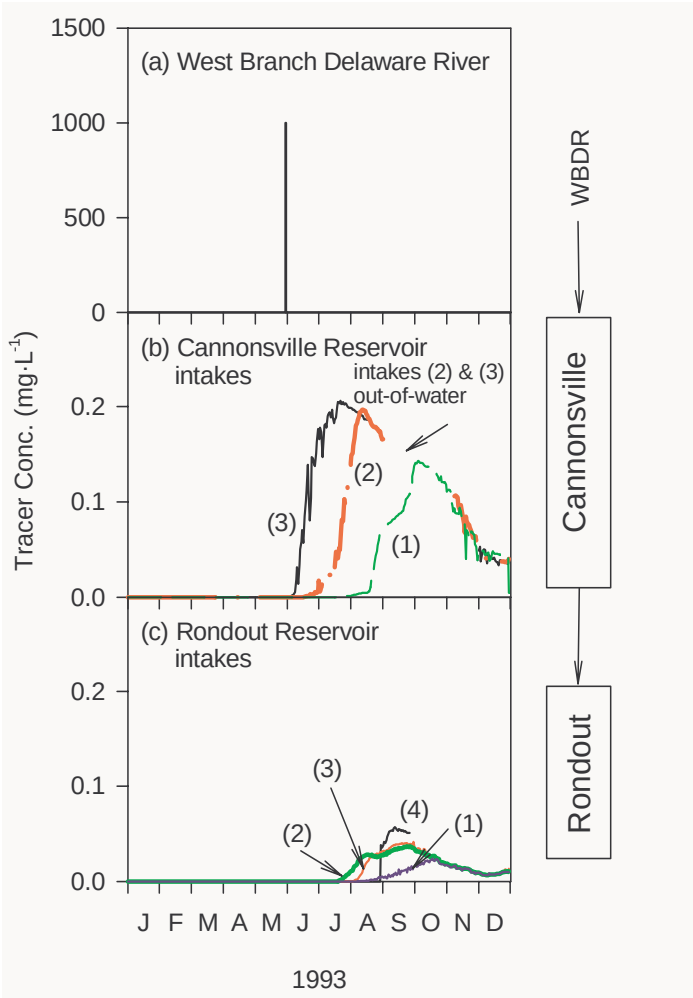


Figure 5.1 Predicted time course of tracer concentrations at three water supply intakes in Cannonsville Reservoir at four water supply intakes in downstream Rondout Reservoir.

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

Modeling provides DEP with the capability to quantify and predict changes in sources of phosphorus and effects of phosphorus loads on reservoir water quality. Reservoir eutrophication is influence by weather, land use, watershed management, and reservoir operational changes. The assessment of potential impacts of land use, watershed and reservoir management guides decisions on priorities of management programs and policy for the long-term preservation of the water supply.

The terrestrial watershed model named the Generalized Watershed Loading Function (GWLF) Model, has been used to estimate average annual dissolved and particulate phosphorus loads to the Catskill/Delaware System Reservoirs, from different watershed sources under baseline conditions (before implementation of watershed management programs). The results given in Figure 5.2 suggest that elevated phosphorus loads to Cannonsville reservoir result from significant contributions from agriculture and Waste Water Treatment Plants (WWTPs). These findings support DEP's decision to emphasize and channel significant resources to upgrading WWTPs, and to controlling agricultural loads through the Watershed Agricultural Program.

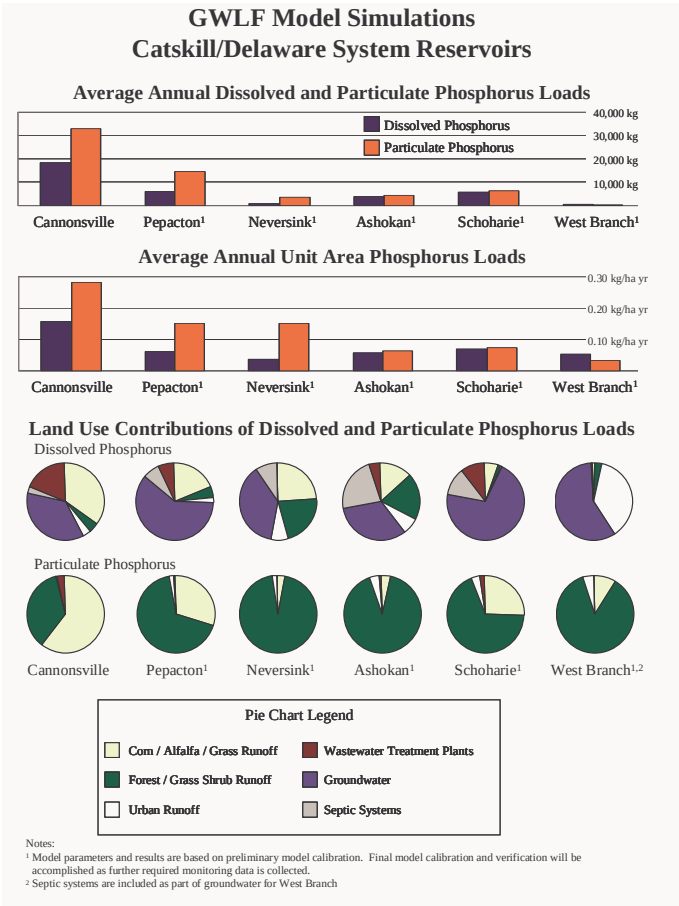


Figure 5.2 Sources of dissolved and particulate loads to Catskill/Delaware System Reservoirs, under baseline conditions (before implementation of watershed management programs).

In Figure 5.2 the top bar chart shows average annual modeled dissolved and particulate phosphorus loads to the reservoirs for the 30 year period (1969-1998). The second bar chart shows phosphorus loading per unit area, which is the average annual loads divided by the watershed area. Pie charts show the relative contributions of sources of phosphorus loads to the reservoir based on the model results. Model input included land use from 1992 satellite imagery, average wastewater treatment plant loads for 1993-1995, and watershed population estimates from the 1990 census. Rondout watershed was omitted due to insufficient storm data for model calibration.

An evaluation of watershed management programs in Cannonsville and Pepacton watersheds, using GWLF and the one-dimensional reservoir model, was undertaken to evaluate anticipated reductions in phosphorus loadings and reservoir eutrophication. Four watershed management programs were evaluated: Watershed Agricultural Program, Stormwater Retrofit Program, Septic system Rehabilitation Program, and Waste Water Treatment Plant Upgrade Program.

DEP has adopted a probabilistic modeling approach to accommodate the influence of variations in environmental conditions and meteorology in particular on water quality. This modeling strategy uses long-term records (the 1966-1999 interval was used here) of meteorological data and coupled changes in streamflow, material loading, and reservoir operations (Figure 5.3) as input for continuous, multiple-year model simulations to reflect the effects of interannual variations in these conditions. The water quality predictions that result are inherently representative as they are based on actual historical conditions. The probabilistic approach integrates the hydrologic (water balance), hydrothermal and water quality models (i.e., hindcasting models) for each of the reservoirs, and a watershed loading model for each reservoir (Figure 5.3). The watershed model, GWLF, provides simulations of stream flow and material loading (e.g., total dissolved phosphorus, particulate phosphorus, total dissolved nitrogen and dissolved organic carbon), for the entire simulation interval based on the long-term historical record.

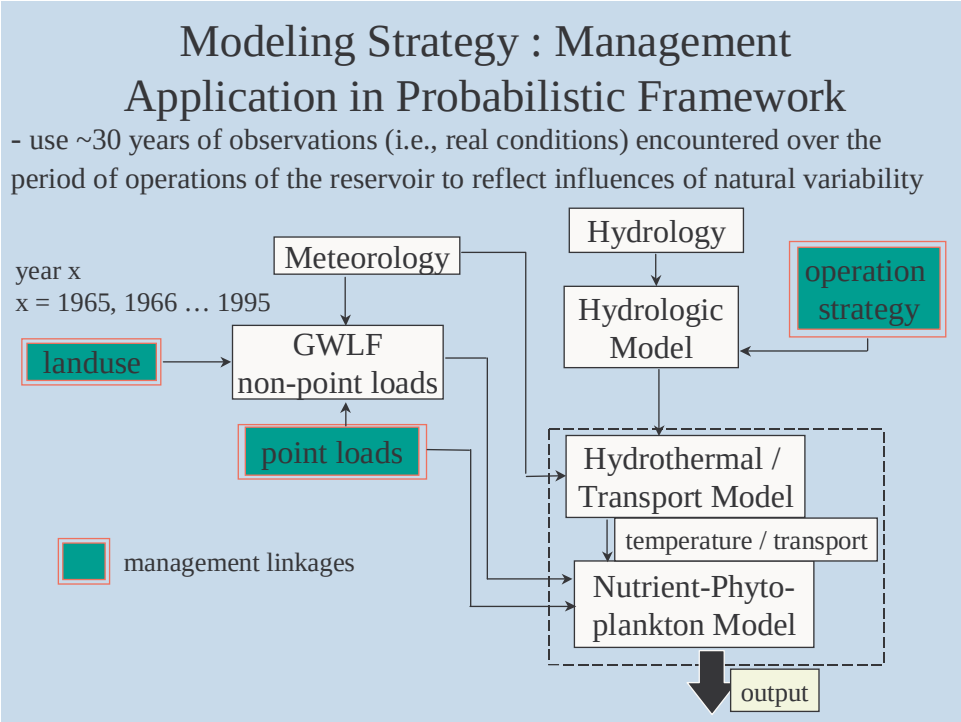


Figure 5.3 Schematic showing the modeling framework that simulates multiple years, using a specified loading condition and historical meteorological, hydrological and operational data to provide water quality predictions in a probabilistic format.

The effects of phosphorus loading reductions due to watershed management on chlorophyll *a* predictions in Cannonsville Reservoir, based on 34-year simulations, are shown in Figure 5.4. *Before* implementation of watershed management BMPs, an average annual dissolved phosphorus load prediction of 18,021 kg/yr from the Cannonsville watershed results in an average growing season chlorophyll *a* prediction of 14.2 µg/ l in the reservoir. *After* BMPs are implemented, a 27.1% predicted reduction of annual dissolved phosphorus load (13143 kg/year) results in a 31.7% reduction in predicted average growing season chlorophyll a (9.7 µg/l) in the reservoir. Most of the dissolved phosphorus loading reduction is due to point source upgrades (16.0%), agricultural runoff BMPs (8.1%) and septic system remediation (2.6%). In contrast, a 28.1% predicted reduction in particulate phosphorus loads to Cannonsville Reservoir, due mostly to agricultural runoff BMPs, resulted in a minor 1.4% predicted reduction in average growing season chlorophyll *a* (14.0 µg/l) in the reservoir.

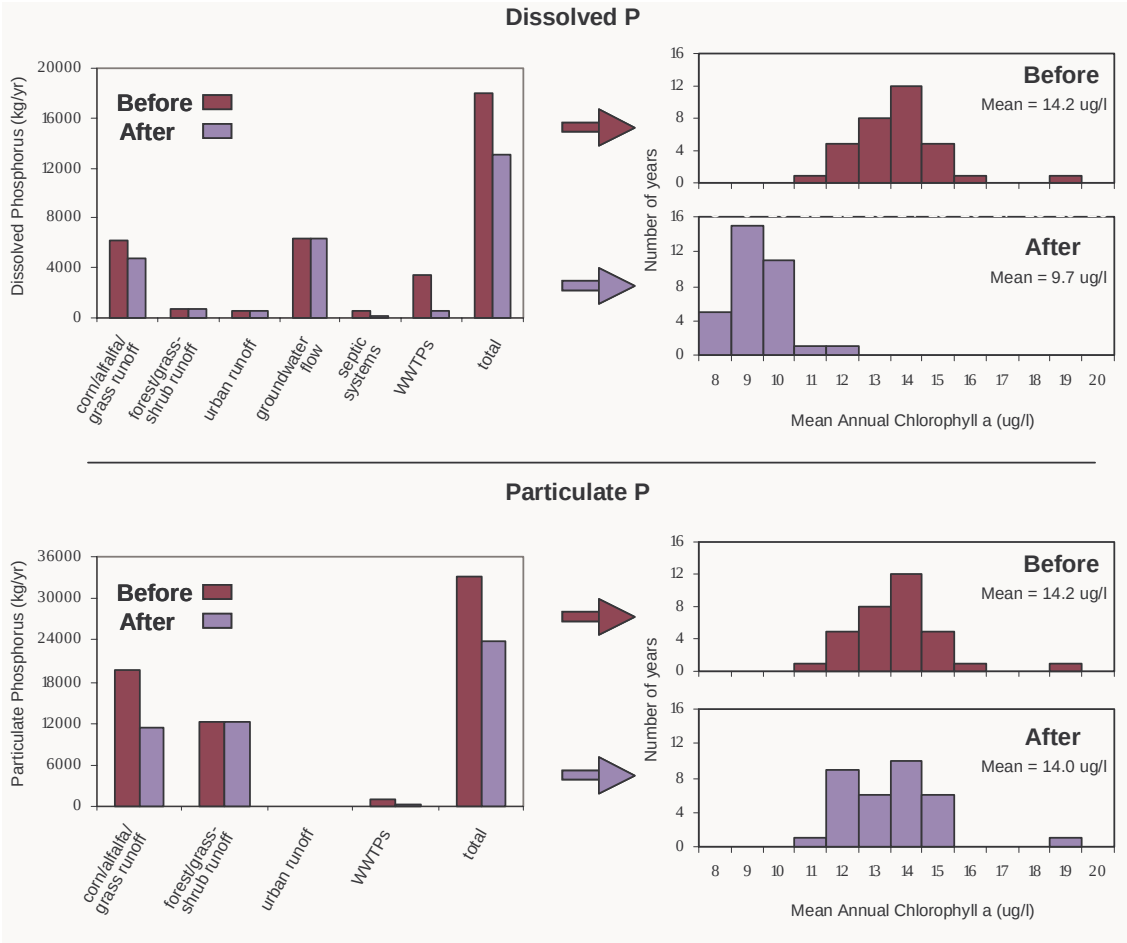


Figure 5.4 Effects of dissolved and particulate phosphorus loading reductions before and after program implementation on chlorophyll *a* predictions in Cannonsville Reservoir.

Results for the same analysis applied to Pepacton Reservoir are given in Figure 5.5. *Before* implementation of watershed management BMPs, an average annual dissolved phosphorus load prediction of 5,658 kg/yr from the Pepacton watershed results in an average growing season chlorophyll *a* prediction of 5.2 µg/l in the reservoir. *After* BMPs are implemented, a 10.7% predicted reduction of annual dissolved phosphorus load (5,055 kg/year) results in a 5.2% reduction in predicted average growing season chlorophyll a (4.9 µg/l) in the reservoir. Most of the dissolved phosphorus loading reduction is due to the combined effects of septic system remediation (5.4%), agricultural runoff BMPs (3.8%), and point source upgrades (1.4%). In contrast, an 11.4% predicted reduction in particulate phosphorus loads to Pepacton reservoir, due mostly to agricultural runoff BMPs, resulted in a 1.2% predicted reduction in average growing season chlorophyll *a* (5.1 µg/l) in the reservoir.

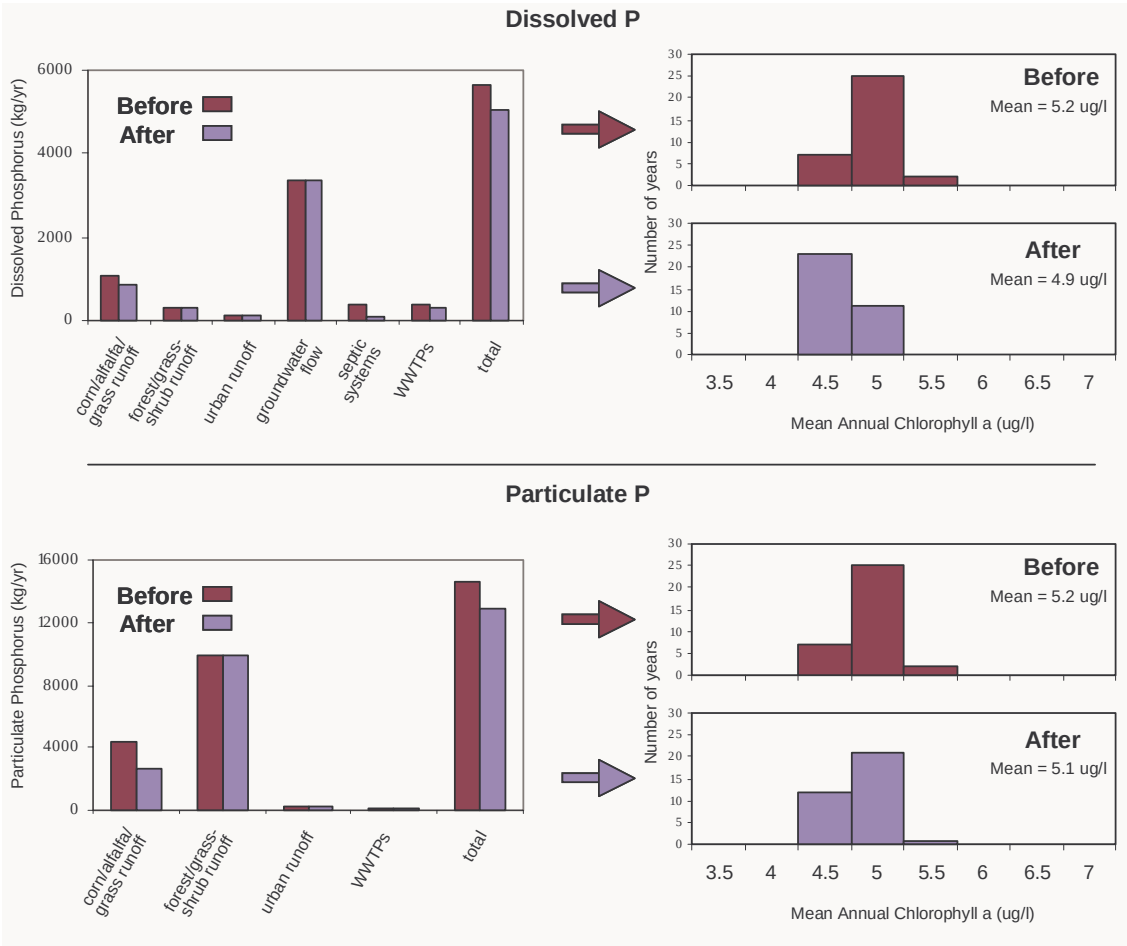


Figure 5.5 Effects of dissolved and particulate phosphorus loading reductions on chlorophyll *a* predictions in Pepacton Reservoir.

The difference in response by the two reservoirs is due mainly to the fact that Cannonsville receives excessive P loading from its watershed while Pepacton's nutrient loading falls within acceptable limits. These model results illustrate the importance of implementing phosphorus reduction strategies targeting the dissolved form of phosphorus.

5.4 What was accomplished in 2001 in the development of modeling capabilities?

At the start of 2001, preliminary reservoir and watershed models for the Catskill and Delaware System Reservoirs had been developed and tested, and linked watershed-reservoir model runs had been performed to test the modeling framework. In 2001 reservoir model and GWLF hydrologic model calibration and verification was completed for all Catskill and Delaware System reservoirs. Work continued on calibrating the GWLF water quality models for the remaining Catskill and Delaware System watersheds.

Testing of the models will continue as new monitoring data are acquired to represent new environmental conditions and reservoir water quality. This will serve to: (1) continue to challenge the validity of the frameworks, (2) demonstrate performance of the models over a broad range, (3) identify potential short-comings in the models, (4) provide insights into the behavior of the reservoirs and their responses to perturbations, (5) promote timely handling and analysis of monitoring data, and (6) serve as one form of QA of monitoring data that are inputs to the models.

A schematic that presents features of this annual testing (shaded components), within the context of the strategy to continue to support management actions with these quantitative tools, is presented as Figure 5.6. Continued acceptable model performance will support continued application of these tools to address management issues (Figure 5.6). If model performance is found to be unacceptable, re-calibration (modest changes in model coefficients that result in acceptable performance) will be evaluated. Repeated improved performance through the same re-calibrated model would lead to an update in the management model. If re-calibration remains unsuccessful, this could lead to other more profound changes in the model frameworks, that would probably require additional special studies. The use of models to hindcast and forecast water quality are further explained in Appendix E.

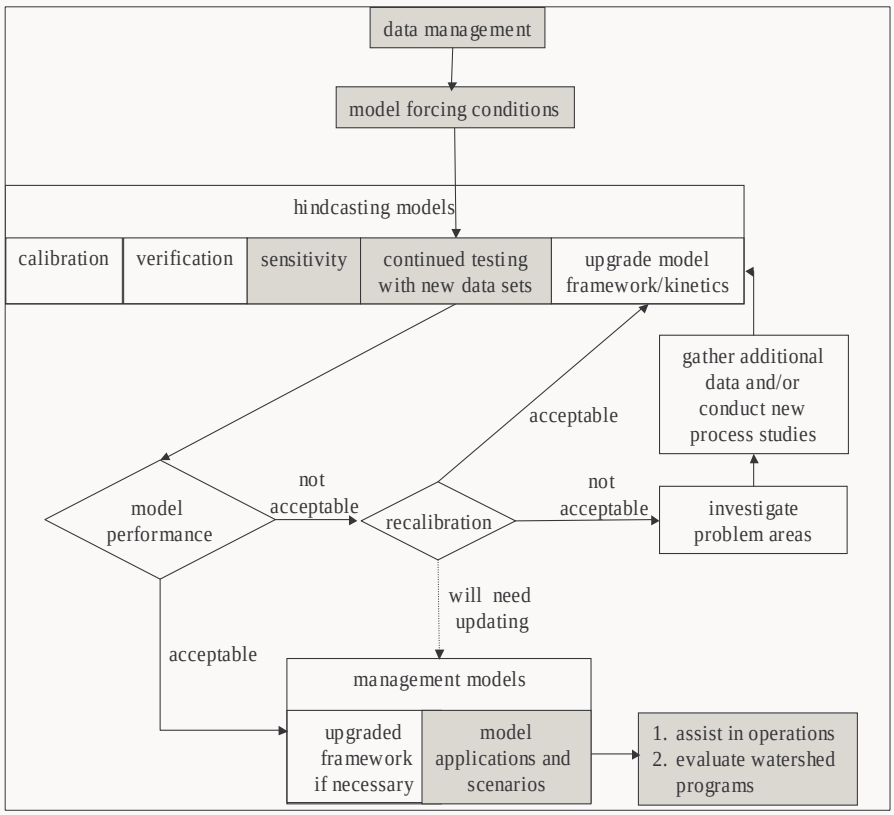


Figure 5.6 Schematic showing how continued testing and application of models relates to use of management models for making informed decisions with respect to water supply protection (shaded areas depict features of annual testing and application).

5.5 Modeling milestones completed in 2001

The milestones for terrestrial modeling include:

- Data acquired including: land use, SCS Runoff Curve Number, and USLE Erosion Potential maps; and updated time series of stream flow, water quality, precipitation, air temperature at NCDC meteorological monitoring sites.
- GWLF hydrology sub-models were calibrated and verified for Schoharie, Ashokan, and West Branch Reservoir watersheds.
- GWLF water quality sub-models were calibrated for Schoharie, Ashokan, and West Branch Reservoir watersheds.
- Water quality monitoring data needs identified.
- Ability to evaluate BMPs was added.
- GWLF was functionally linked to the reservoir model.
- Preliminary evaluation of the effectiveness of MOA programs in Cannonsville and Pepacton watersheds.

The milestones for reservoir modeling include:

- A data network was set up including limnological, meteorological, hydrologic, and stream loading files for all years available beginning in 1995.
- Testing of one- and two-dimensional hydrothermal and water quality models for the Catskill/Delaware reservoirs was competed.
- Model development and testing was supported by extensive site-specific data and kinetic studies.
- Sensitivity analyses were run
- Software development of a linked predictive set of models for the Catskill/Delaware reservoir system began in April 2001.
- A plan has been developed to implement a monitoring program to support modeling testing.

Future directions for the modeling program include: continued data acquisition; continued calibration and verification of Catskill/Delaware GWLF and reservoir eutrophication models using additional monitoring data; refinement of terrestrial and reservoir eutrophication models and model linkages; continued applications and use of models to guide watershed/reservoir management and operational support; and expansion of modeling capabilities to address water quality issues beyond eutrophication/nutrient cycling, including THM precursors and sediment resuspension.

6. Further Research

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

DEP extends its capabilities through grants and contracts. In recent years, the appropriation of approximately $20 million under the Safe Drinking Water Act (SDWA), earmarked for the NYC Watershed, has supported a number of DEP projects devoted to guiding watershed management. These projects have typically allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. In addition, contracts are needed to support the work of the Division.

6.2 What DEP projects are supported through SDWA grants?

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

6.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 6.2. The primary types of contracts are: i) Operation and Maintenance, ii) Monitoring, and iii) Research and Development. The "Operations and Maintenance" contracts are typically renewed each year since they are devoted to supporting the on-going 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 SDWA grants.

Grant Number	Federal Fiscal Year of Grant	Dollar Amount in Millions	Projects Supported
1	1998	0.435	1. Croton Terrestrial Modeling Evaluation 2. NYC Ambient Water Quality Monitoring 3. Hydrological Database
2	1999	0.99	1. 1-D Croton System Model
3	2000	2.7	1. Water Quality Data Analysis and Communication 2. Ambient Surface Water Monitoring 3. Wetland Water Quality Functional Assessment 4. Stream Management: A.Calibrating USGS Gages B.Reference Reach Design C.Monitoring BMP Effectiveness D.Sediment Loading Modeling 5. Pathogen Fate, Transport, and Source Identification 6. Identification of Watershed Sources of E. coli 7. Event-based Pathogen Monitoring Strategies) 8. Stormwater BMP Monitoring Demonstration
4	2001	2.3	Continuing Projects (from previous grant) 1. Ambient Surface Water Quality Monitoring 2. Wetland Functional Assessment 3. Stream Management Program 4. Pathogen Fate and Transport 5. USGS Forest Health and Soil Nutrient Status New Projects: 6. TP Tracking System 7. Croton System Modeling 8. Kensico Model Enhancement 9. Ribotyping: Effects of Septics vs Sewers

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 WHO 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

References

Fout, G. S., F.W. Schaffer III, J.W. Messer, D.R. Dahling, and R.E. Stetler. 1996. ICR Microbial Laboratory Manual, EPA/600/R-95/178. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., 233p

Janus, L. L. and R. A. Vollenweider (1981). The OECD Cooperative Programme on Eutrophication. Burlington, Ontario, National Water Research Institute, Inland Waters Directorate, Canada Centre for Inland Waters.

Nurnberg, G. K. 1996. Trophic state of clear and colored, soft and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton, and fish. Journal of Lake and Reservoir Management 12(4): 432-447.

NYC-DEP. 1998. Drought Management Plan and Rules. Valhalla, NY, New York City Department of Environmental Protection: 21pp.

Smith, D. G. (2001). A protocol for standardizing Secchi disk measurements. Lake and Reservoir Management 17(2): 90-96.

Smith, D. G. and C. M. Hoover 1999. Use of a viewer box in Secchi disk measurements. JAWRA 35(5): 1183-1189.

Supreme Court Decree. 1982. recommendations of the parties to the US Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Resolution 78-20. The “Good Faith Agreement”. November 1982.

Glossary List

Alkalinity - Having the properties of a base with a pH of more than 7. A common alkaline is baking soda.

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 - A measure of the amount of particles suspended in water; determined by using a secchi disk or turbidity test.

Coliforms – Bacteria found in intestinal tract of humans and animals; can cause potentially dangerous bacterial 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. The amount is usually expressed in parts per million (ppm) or milligrams per liter (mg/L).

E. coli – A bacteria associated with fecal contamination. Some *E. coli* can cause serious diseases.

Eutrophic – Water high in nutrients, high in algal growth, and 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 organisms found in the intestinal tracts of people and 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 – Sampling location just prior to disinfection.

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 – Water intermediate between oligoptrophic and eutrophic.

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

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

Oligotrophic – Water low in nutrients, low in algal growth, and tends 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 – An organism typically found in the intestinal tracts of mammals, capable of producing disease.

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

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 layer in a body of water into which daylight penetrates in sufficient amounts to influence living organisms.

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

Protozoa – A single cell organism. 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 clarity of water. The disk is lowered into the water until it cannot be seen and then the depth of the disk is measured.

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

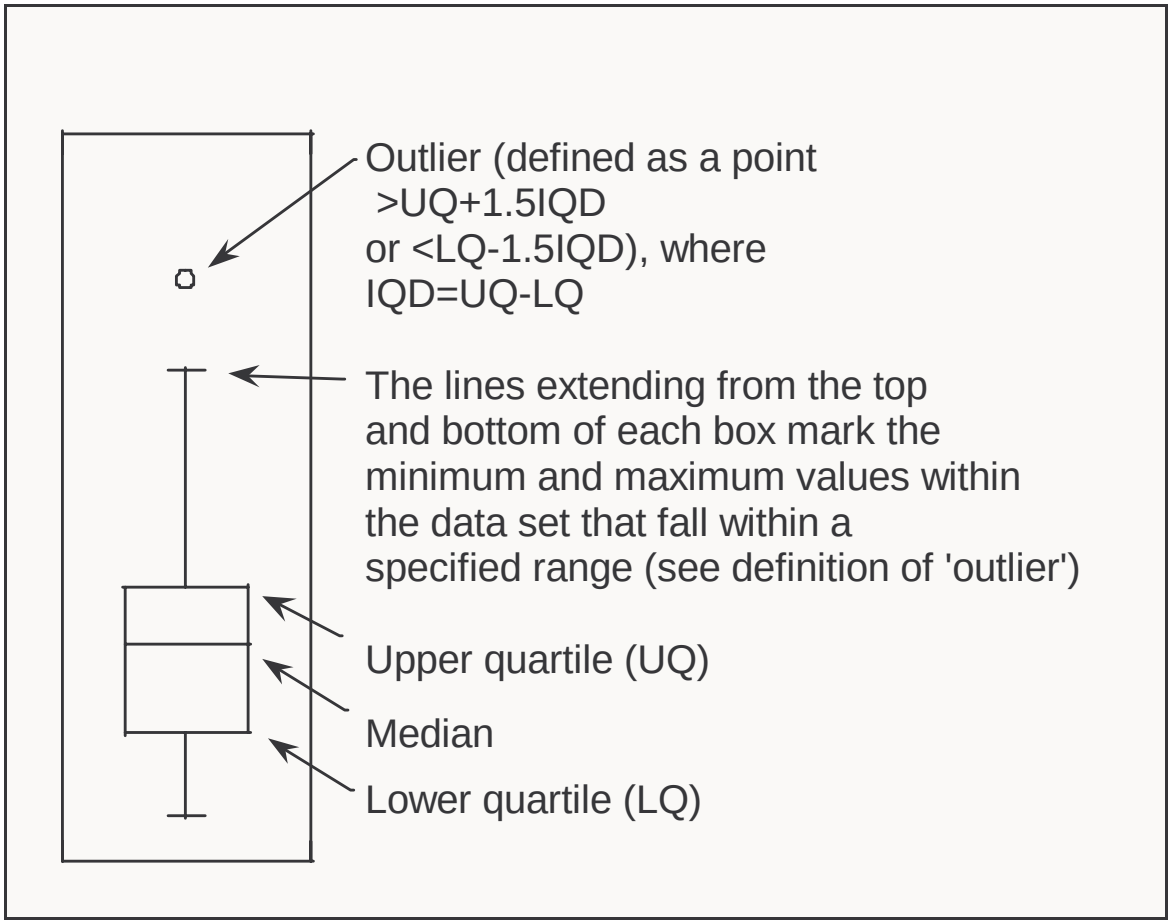
Trophic State – Refers to a level of nutrients in a waterbody (i.e., eutrophic, mesotrophic, oligotrophic).

Turbidity – A measure of the degree of clarity of a solution. For cloudy water, turbidity would be high; for clear water, turbidity would be low.

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

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

Appendix A - Key to Box Plots



Appendix B - Routine Pathogen Program Sampling Location Codes and Descriptions

The following provides information on the pathogen sampling location codes and descriptions.

Table B.1. Pathogen sampling location codes and descriptions.

SITE	DESCRIPTION
CATSKILL SYSTEM	
ASHOKAN WATERSHED	
BBD	BEAVER BROOK DOWNSTREAM, WOODLAND VALLEY
BBU	BEAVER BROOK UPSTREAM, WOODLAND VALLEY
EAR	ASHOKAN RESERVOIR EFFLUENT, ASHOKAN
E13I	ASHOKAN BROOK, RT. 28, SHOKAN
E10I	ASHOKAN RESERVOIR INFLUENT, BUSHKILL, OLIVE
E16I	ASHOKAN RESERVOIR INFLUENT, ESOPUS CREEK, BOICEVILLE
SRR2	SCHOHARIE RESERVOIR EFFLUENT, SHANDAKEN
SCHOHARIE WATERSHED	
FB4	JOHNSON HOLLOW BROOK, PRATTSVILLE
FFD	FARBER FARM DOWNSTREAM, EAST KILL STREAM, JEWETT
FFU	FARBER FARM UPSTREAM, EAST KILL STREAM, JEWETT
HHE	HUNTER HIGHLANDS STP, HUNTER
S5I	SCHOHARIE RESERVOIR INFLUENT, SCHOHARIE CREEK, PRATTSVILLE
STLEG	TANNERSVILLE STP
DELAWARE SYSTEM	
CANNONSVILLE WATERSHED	
CTB	THIRD BROOK, WALTON
DTP	DELHI STP
HTP	HOBART STP
STP	STANFORD STP
WD2	W.B.D.R. DECAY SITE #2, WALTON
WDBN	CANNONSVILLE RESERVOIR INFLUENT, W.B.D.R., BEERSTON
WSP	WALTON STP
WSPB	W.B.D.R., WALTON
RF	ROBERTSON FARM, NORTH END OF CROWE RD.
SHR1	ABANDON AGRICULTURAL SITE, SHAW RD.
NEVERSINK WATERSHED	
NCG	NEVERSINK RESERVOIR INFLUENT, NEVERSINK RIVER, CLARYVILLE
PEPACTON WATERSHED	
PMSB	PEPACTON RESERVOIR INFLUENT, MARGARETVILLE
RONDOUT WATERSHED	
NRR2	NEVERSINK RESERVOIR EFFLUENT, GRAHAMSVILLE
PRR2	PEPACTON RESERVOIR EFFLUENT, E.D.T.O., NEVERSINK
RDRR	RONDOUT RESERVOIR EFFLUENT CHAMBER, NAPANOCK
RGC	GRAHAMSVILLE STP

Table B.1. Pathogen sampling location codes and descriptions.

WDTO	CANNONSVILLE RESERVOIR EFFLUENT, W.D.T.O., GRAHAMSVILLE
KENSICO WATERSHED	
CATALUM	ALUM PLANT LOCATEDON CATSKILL AQUEDUCT,
PLEASANTVILLE	
CATLEFF	CATSKILL AQUEDUCT LOWER EFFLUENT CHAMBER
DEL18	DELAWARE AQUEDUCT –SHAFT 18, EFFLUENT FROM
KENSICO RESERVOIR	
DEL17	DELAWARE AQUEDUCT – SHAFT 17 INFLUENT TO KENSICO RESERVOIR
MB1	MALCOLM BROOK, BELOW WEST SHORE DR. BMP
MB3 & MB4	WEST SHORE DR. BMP
MB8	MALCOLM BROOK, BELOW STEVENS AVE BMP
CROTON SYSTEM	
DIVERTING WATERSHED	
BSTP	BREWSTER SEWAGE TREATMENT PLANT
EAST BRANCH WATERSHED	
HH7	TRIBUTARY TO HAVILAND HOLLOW BROOK, HAVILAND HOLLOW RD AND CO. ROUTE 37.
NEW CROTON WATERSHED	
CROGH	EFFLUENT OF NEW CROTON RESERVOIR, NEW CROTON GATEHOUSE
MUSCOOT WATERSHED	
MUSCOOTR	MUSCOOT RELEASE, GATEHOUSE AT DAM DIVIDING THE MUSCOOT AND NEW CROTON RESERVOIRS.
TITICUS WATERSHED	
TRTIT	TRIBUTARY TO TITICUT RIVER WILLOW FARM, NORTH SALEM

Appendix C - Method to Determine Phosphorus-Restricted Basins

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

The five most recent annual geometric means are averaged arithmetically, and this average constitutes one assessment. The "running average" method weights each year equally thus reducing the effects of unusual hydrology or phosphorus loading for any given year, while maintaining an accurate assessment of the current conditions in the reservoir. If any reservoir has less than three surveys during a growing season, then that annual average may or may not be representative of the reservoir, and the data for the undersampled year is 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 mg L^{-1}. A basin will is as unrestricted if the five year mean plus standard error is below the guidance value of 20 mg $L^{-1,}$ and phosphorus restricted if it is equal to or greater than 20 mg $L^{-1,}$ unless the Department, using its best professional judgment, determines that the phosphorus restricted designation is due to an unusual and unpredictable event unlikely to occur in the future. A reservoir basin designation, as phosphorus restricted or unrestricted, may change through time based on the outcome of this annual assessment. However, a basin must have two consecutive assessments (i.e. two years in a row) that result in the new designation in order to officially change the designation.

Phosphorus Restricted Basin Determination

The phosphorus restricted basin status was derived from two, consecutive assessments (1996 - 2000; 1997 - 2001) using the above methodology. Table B.1 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 (Table B.2). Figure 3.10 graphically depicts the phosphorus restriction status of the NYC Reservoirs and the year 2001 phosphorus concentration.

There are a few changes in Phosphorus Restricted Basin Status.

- In 1996, Schoharie Reservoir was subjected to extreme levels of turbidity due to the 100-year flood that occurred in January of that year. Consequently, the phosphorus concentration in the reservoir more than doubled from previous years. While the turbidity and phosphorus levels

have declined, the one large value for 1996 is enough to result in a phosphorus restricted designation for Schoharie reservoir. Again in September 1999, Schoharie was impacted by flooding, as a result of Tropical Storm Floyd, which brought in large amounts of suspended material. Since these events were unusual and unpredictable and do 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.

- Titicus Reservoir, Cross River Reservoir and Amawalk Reservoir were undergoing dam reconstruction during late 1996 and all of 1997. To accommodate the construction, water levels in these reservoirs were drawn down significantly and routine monitoring of these basins could not be accomplished every month. Because of this, Cross River did not have three complete surveys for the 1996 and 1997 growing seasons. Titicus did not have three complete surveys in 1997. The assessments for 2000 and 2001, therefore, were performed without these years. Amawalk, however, did have the minimum number of complete surveys necessary each year for the assessment.
- Cannonsville Reservoir had two successive assessments in which the five year geometric means were below 20μg L^{-1}, and has, therefore, improved (albeit slightly) to a non-restricted status.

It should be noted that during 2000 and 2001 there were changes to TP analytical methodology which produced slightly higher values in these years. For the purpose of this analysis it is assumed that there are no differences due to methodology.

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

Reservoir Basin	1996	1997	1998	1999	2000	2001
	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$
Delaware District						
Cannonsville Reservoir	16.85	21.02	17.06	17.27	17.20	19.3
Pepacton Reservoir	9.87	8.16	7.85	8.93	8.10	8.6
Neversink Reservoir	5.25	5.06	3.29	5.13	5.26	5.8
Rondout Reservoir	8.35	6.33	7.59	7.65	10.40	7.4
Catskill District						
Schoharie Reservoir	34.49	18.44	18.71	25.92	21.31	15.2
Ashokan-West Reservoir	22.63	14.48	14.23	14.23	9.56	9.4
Ashokan-East Reservoir	16.23	13.73	12.65	11.00	10.60	7.7
Croton District						
Amawalk Reservoir	20.50	21.11	23.52	22.12	38.63	19.8
Bog Brook Reservoir	14.80	14.13	19.83	18.01	34.73	21.4
Boyd Corners Reservoir	14.60	5.06	8.74	12.61	16.00	13.6
Cross River Reservoir	22.84	*	16.83	10.85	17.15	14.8
Croton Falls Reservoir	25.81	19.76	19.59	16.54	26.09	22.3
Diverting Reservoir	23.95	23.11	33.42	22.95	30.02	31.8
East Branch Reservoir	19.85	25.11	31.55	19.47	39.01	33.3
Middle Branch Reservoir	18.67	18.92	25.97	23.18	32.42	27.7
Muscoot Reservoir	24.45	23.31	29.34	26.46	35.00	29.7
Titicus Reservoir	21.25	*	38.13	37.31	33.58	28.7
West Branch Reservoir	9.53	5.55	6.56	7.12	13.29	11.5
Lake Gleneida	26.37	24.00	21.34	22.00	30.36	31.6
Lake Gilead	27.59	21.51	23.21	28.07	34.89	38.4
Source Water						
Kensico Reservoir Reservoir	7.41	5.37	5.34	5.80	9.11	8.5
New Croton Reservoir	16.42	15.00	15.76	15.88	22.68	21.9

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

Table C.2. Phosphorus Restricted Reservoir Basins for 2001. 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.

Reservoir Basin	96 - 00 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	97 - 01 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	Phosphorus Restricted Status
Delaware District			
Cannonsville Reservoir	18.7	19.2	
Pepacton Reservoir	9.0	8.5	
Neversink Reservoir	5.2	5.3	
Rondout Reservoir	8.7	8.55	
Catskill District			
Schoharie Reservoir*	26.8	21.7	
Ashokan-West Reservoir	17.1	13.6	
Ashokan-East Reservoir	13.9	12.2	
Croton District			
Amawalk Reservoir	28.6	28.5	Restricted
Bog Brook Reservoir	24.1	25.1	Restricted
Boyd Corners Reservoir	13.4	13.1	
Cross River Reservoir	19.4	16.4	
Croton Falls Reservoir	23.4	22.5	Restricted
Diverting Reservoir	28.8	30.5	Restricted
East Branch Reservoir	30.7	33.1	Restricted
Middle Branch Reservoir	26.4	27.9	Restricted
Muscoot Reservoir	29.8	30.7	Restricted
Titicus Reservoir	36.5	26.6	Restricted
West Branch Reservoir	9.8	10.3	
Lake Gleneida	26.5	28.0	Restricted
Lake Gilead	29.4	32.5	Restricted
Source Water			
Kensico Reservoir Reservoir	7.3	7.6	
New Croton Reservoir	18.6	19.9	

*The Methodology allows for best professional judgement. In 1996, Schoharie Reservoir was subjected to extreme levels of turbidity due to the 100-year flood that occurred in January of 1996. The phosphorus concentration in the reservoir more than doubled from previous years. While the turbidity and phosphorus levels have declined, the one large value for 1996 is enough to result in a phosphorus restricted designation for Schoharie reservoir. Since this event was "an unusual and unpredictable event" that is not resulting in eutrophication of the reservoir, the Department is utilizing its best professional judgment and is not designating Schoharie basin as phosphorus restricted.

Appendix D - Comparison of Reservoir-wide Mean Values of Selected Analytes

Table D.1 Expanded version of Table 3.4

Analytes	Water Quality Standard	Kensico Reservoir			New Croton Reservoir			East Ashokan Basin			Rondout Reservoir		
		N	Range	Mean	N	Range	Mean	N	Range	Mean	N	Range	Mean
PHYSICAL													
Temperature (C)		272	2.7-21.4	10.9	240	3.8-25.7	13.4	134	3.2-24.4	12.3	255	2.8-19	11.3
pH (units)	6.5-8.5	262	5.9-7.7	6.87	230	6.7-9	7.64	134	6.03-8.35	7.03	137	6.2-7.62	6.95
Alkalinity (mg-$^{1)}$		79	10.5-14.5	12.34	64	48-67.6	58.52	52	0.02-13	11.21	119	4.52-11.8	9.81
Conductivity (µS cm-1)		262	56-85	68	228	291-360	333	134	46-60	52	255	40-66	57
Hardness (mg-1)		20	16.38-22.38	19.43	59	61.75-93.09	82.93	53	15.22-18.37	16.68	108	12.39-21.59	18.56
Color (Pt-co units)	(15)	278	7-15	11	260	10-55	25	133	4-14	9	255	5-13	10
Turbidity (NTU)	(5), *	278	0.6-2.5	1.5	260	0.7-11	3.2	134	0.7-4.8	2.3	255	0.6-2.9	1.5
Secchi Disk Depth (m)		19	3.7-6.4	4.81	18	1.9-4.2	3.11	18	2.5-7	4.54	17	3.8-5.8	4.82
BIOLOGICAL													
Chlorophyll *a* (µg/l)	7	117	1.1-56	10.98	91	2.4-54.1	26.18	59	2.49-13.68	5.96	87	1.2-7.7	4.38
Total Phytoplankton (SAU)	2000	157	20-1800	659	185	10-3800	1288	117	ND-2000	730	255	ND-1100	388
CHEMICAL													
Total Organic Carbon (mg-1)		261	0.8-2	1.4	244	ND-4.2	3.2	30	1.2-2.1	1.6	46	1.38-2.1	1.7
Total Phosphorus (µg-1)	15, *	228	ND-13	9	232	2-75	30	123	ND-16	9	237	3.4-15	9
Total Nitrogen (mg-1)	*	100	0.268-0.478	0.38	105	0.328-0.899	0.648	101	0.14-0.46	0.294	119	0.271-0.571	0.425
Nitrate + Nitrite-N (mg-1)	10	269	0.008-0.324	0.204	239	ND-0.644	0.31	126	ND-0.27	0.12	210	0.12-0.443	0.27
Total Ammoniacal-N (mg-1)	2	265	ND-0.05	0.023	218	ND-0.533	0.129	124	0.01-0.05	0.026	210	ND-0.024	0.008
Iron (mg-1)	0.3	50	ND-0.14	0.08	178	ND-1.67	0.31	53	0.015-0.45	0.1	108	ND-0.1	0.04
Manganese (mg-1)	0.3	49	ND	0.165	177	ND-1.93	0.252	53	ND-0.632	0.083	108	0.006-0.3	0.061
Lead (µg-1)	50	30	ND-4.7	1.2	65	ND-1.6	0.6	17	ND	ND	36	ND-0.2	ND
Copper (µg-1)	200	49	0.6-2.2	1.1	46	0.8-1.5	1.1	53	ND	ND	108	ND-2.3	1
Calcium (mg-1)		20	4.7-6.28	5.56	59	18.1-25.1	21.22	53	4.76-5.82	5.23	108	3.56-6.11	5.34
Sodium (mg-1)		20	3.35-6.7	4.71	57	18.1-31.6	26.61	53	2.79-3.53	3.12	36	2.53-5.27	3.88
Chloride (mg-1)	250	80	4.5-6.8	6.2	55	41.2-62.7	54	91	4.7-6.7	5.7	108	3-7.9	5.5

Table 1: Selected keypoint data

Analytes	Water Quality Standard	Kensico CATLEFF			Kensico DEL18			Delaware Aqueduct at Rondout			Catskill Aqueduct at Ashokan			Croton Aqueduct (Gatehouse)		
		N	Range	Mean	N	Range	Mean	N	Range	Mean	N	Range	Mean	N	Range	Mean
PHYSICAL																
Temperature (C)		365	0.5-19	10.8	365	0.5-19.2	10.7	308	0-15.5	8.2	344	1-20	9.9	364	2.5-15.1	7.6
pH (units)	6.5-8.5	395	6.5-7.3	7.03	396	6.56-7.33	7.05	304	6.53-7.37	6.98	340	6.01-7.09	6.69	394	6.55-7.73	7.4
Alkalinity (mg/l)		110	5.9-12.5	10.96	112	9.4-12.4	11.03	14	8.88-12	10.36	59	10.4-13.2	11.55	81	52.9-66.9	57.48
Conductivity (µs/cm)		395	57-77	67	396	57-79	66	305	46-64	59	340	53-66	59	394	302-356	333
Hardness (mg/l)		8	17.24-29.32	20.24	8	17.26-22.49	18.78	14	15.82-20.77	18.52	12	15.66-19.83	17.36	10	81.69-96.58	88.29
Color (units)	(15)	395	7-13	10	396	7-13	10	305	4-12	9	340	6-13	10	394	11-23	20
Turbidity (NTU)	5	395	0.5-1.8	1	396	0.5-1.8	1	305	0.6-1.9	1	343	1.1-9.8	3.8	394	0.6-1.3	1
CHEMICAL																
Total Organic Carbon (mg/l)		44	0.8-1.8	1.4	44	0.7-1.8	1.5	0		.	47	1.4-1.8	1.6	45	2.1-3.4	2.8
Total Phosphorus (µg/l)	(15)	46	5-13	8	47	5-14	9	59	4.8-12	9	52	ND-27	12	43	7-19	14
Total Nitrogen (mg/l)		0			0			27	0.271-0.564	0.416	0			0		
Nitrate + Nitrite (mg/l)		46	0.115-0.241	0.187	46	0.118-0.273	0.188	58	0.168-0.347	0.256	53	ND-0.23	0.134	42	0.049-0.598	0.411
Total Ammoniacal-N (mg/l)		48	ND-0.038	0.021	48	ND-0.032	0.016	58	ND-0.025	0.011	53	0.01-0.05	0.027	44	ND-0.06	0.032
Iron (mg/l)		8	ND-0.07	ND	8	ND-0.06	0.04	14	ND-0.08	0.03	13	0.015-0.36	0.09	11	0.05-0.16	0.08
Manganese (mg/l)		8	ND	ND	7	ND	0.046	14	0.014-0.034	0.024	13	ND-0.123	0.037	21	ND-0.1	0.068
Lead (µg/l)		117	ND	0.3	117	ND	0.3	5	ND	ND	4	ND	ND	125	ND	0.3

continued...

...continued

Table 1: Selected keypoint data

Analytes	Water Quality Standard	Kensico CATLEFF			Kensico DEL18			Delaware Aqueduct at Rondout			Catskill Aqueduct at Ashokan			Croton Aqueduct (Gatehouse)		
Copper (µg/l)		116	ND-1.9	1.3	117	ND-2.2	1.8	15	ND-3.2	1.3	12	ND	ND	125	ND-2	1.5
Calcium (mg/l)		8	5.01-6.22	5.45	8	5.02-6.29	5.4	14	4.54-5.98	5.34	12	4.9-6.34	5.41	10	20.9-25.3	22.95
Sodium (mg/l)		8	3.22-5.53	4.02	8	3.21-5.56	3.97	14	2.67-3.96	3.47	12	2.84-3.72	3.18	10	23-33.7	27.9
Chloride (mg/l)		77	3.4-7.5	5.6	79	4-8.6	5.6	15	1.9-6	5.2	52	4.1-6.9	5.5	74	41.3-65	56.3
BIOLOGICAL																
Total Coliforms (CFU/100ml)	(200)	394	ND-400	72	395	ND-329	66	281	ND-28	8	310	ND-1800	272	389	ND-153	33
Fecal Coliforms (CFU/100ml)	20	394	ND-7	2	395	ND-9	2	281	ND-5	1	310	ND-8	2	389	ND-5	1
Giardia[1]		41	ND4 (17) - 2.001	0.926	41	ND4 (10) - 4.001	0.926	ns	ns	ns	ns	ns	ns	41	ND4 (29) - 1.993	0.472
Giardia[2]		ns	ns	ns	ns	ns	ns	8	ND	ND	9	ND	ND	ns	ns	ns
Giardia3		12	ND4 (5) - 0.06	0.02	12	ND4 (4) - 0.058	0.026	ns	ns	ns	ns	ns	ns	12	ND4 (10) - 0.02	0.003
Cryptosporidium[1]		41	ND4 (37) - 1.000	0.146	41	ND4 (35) - 1.000	0.146	ns	ns	ns	ns	ns	ns	41	ND4 (37) - 1.000	0.001
Cryptosporidium[2]		ns	ns	ns	ns	ns	ns	8	ND	ND	9	ND	ND	ns	ns	ns
Cryptosporidium3		12	ND4 (9) - 0.02	0.005	12	ND4 (9) - 0.02	0.005	ns	ns	ns	ns	ns	ns	12	ND4 (8) - 0.02	0.007

Water Quality Standards
An asterisk denoted a narrative water quality standard. The numeric water quality standards are from 6NYCRR, Part 703 with the following exceptions: the chlorophyll a, total phosporus and total phytoplankton standards are internal NYCDEP target values. 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.
Notes
The data represents a summary of all samples, taken at all water depths, for 2001 with the followng exceptions chlorophyll a statistics were calculated from photic zone samples only: sechi disk depth statistics were calculated from reservoir sampling site (near the damn) only.
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
Detections Limits : Values less than the tection limit have been converted to half the detection limit for calculations of the means
Analytical detection limits vary bt analyte and by laboratory. The analyses were performed on undigested samples

1 USEPA ICR method analysis performed 1/1 - 10/14; units are concentration per 100 [-1L]

2 ASTM P229 protocol analysis performed; units are concentration per 100 [-1L]

3 USEPA 1623HV analysis performed 10/15 -12/3;1 units are concentration per 1 [-1L]

4 (n) Where n is the number of samples that did not contain *Cryptosporidium spp.* or *Giardia spp.*
ND = Non-Detect

Detection Limits: Values less than the detection limit have been converted to half the detection limit for calculations of the means, except for Giardia spp. and Cryptosporidium spp. ND is taken to be zero.

ns = not sampled

Appendix E - Hindcasting versus Forecasting Models

Both the one- and two-dimensional models are available in two formats: (1) to support hindcasting (model testing) and sensitivity analyses, and (2) for forecasting/projection to support management analyses and actions. The hindcasting models are used to simulate documented reservoir conditions based on measurements of forcing (e.g., meteorology, hydrology, material loads) and reservoir conditions (Figure C.1a). Model performance is evaluated by comparing the simulations of water quality to actual measurements (observations). The credibility of the hindcasting models (i.e., performance) is critical as they serve as the foundation of the forecasting/projection models (Figure C.1b).

The forecasting models utilize the same frameworks as the hindcasting models originally developed and tested for past measurements and forcing data. Examples of DEP's model applications are as follows. Long-term planning for protection of NY City reservoirs from eutrophication-based degradations of water quality is addressed through application of the one-dimensional water quality management models. The one-dimensional hydrothermal management model can be used to forecast the shifts in outflow temperatures that would result from systematic changes in reservoir operation (e.g., depth of withdrawal). The two-dimensional management models have utility to investigate a wide range of scenarios for short-term events, such as the effects of chemical spills, WWTP upsets, and runoff events. Simulations of time-of-travel from inflows to water supply intakes can be conducted with these forecasting tools. Multi-basin (e.g., reservoirs in series) scenario analyses are also supported with both the one- and two-dimensional forecasting models.

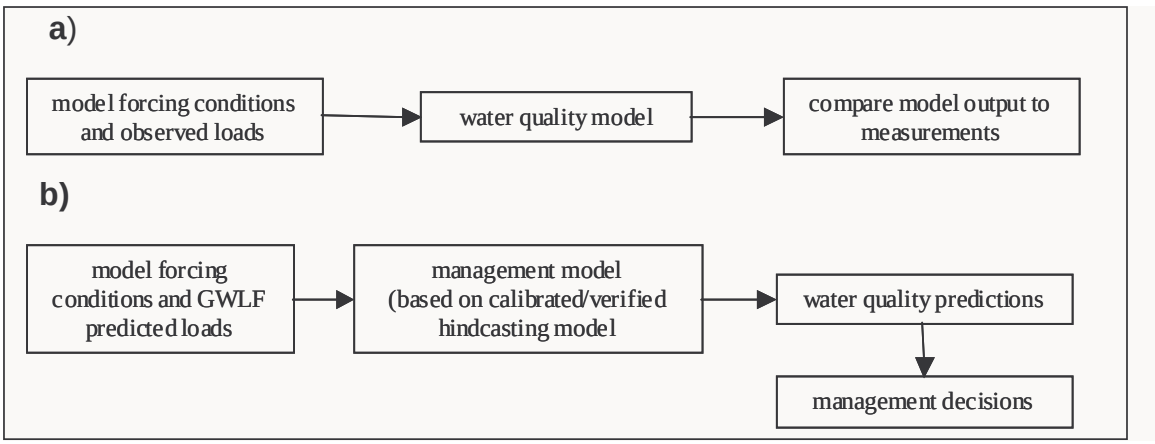
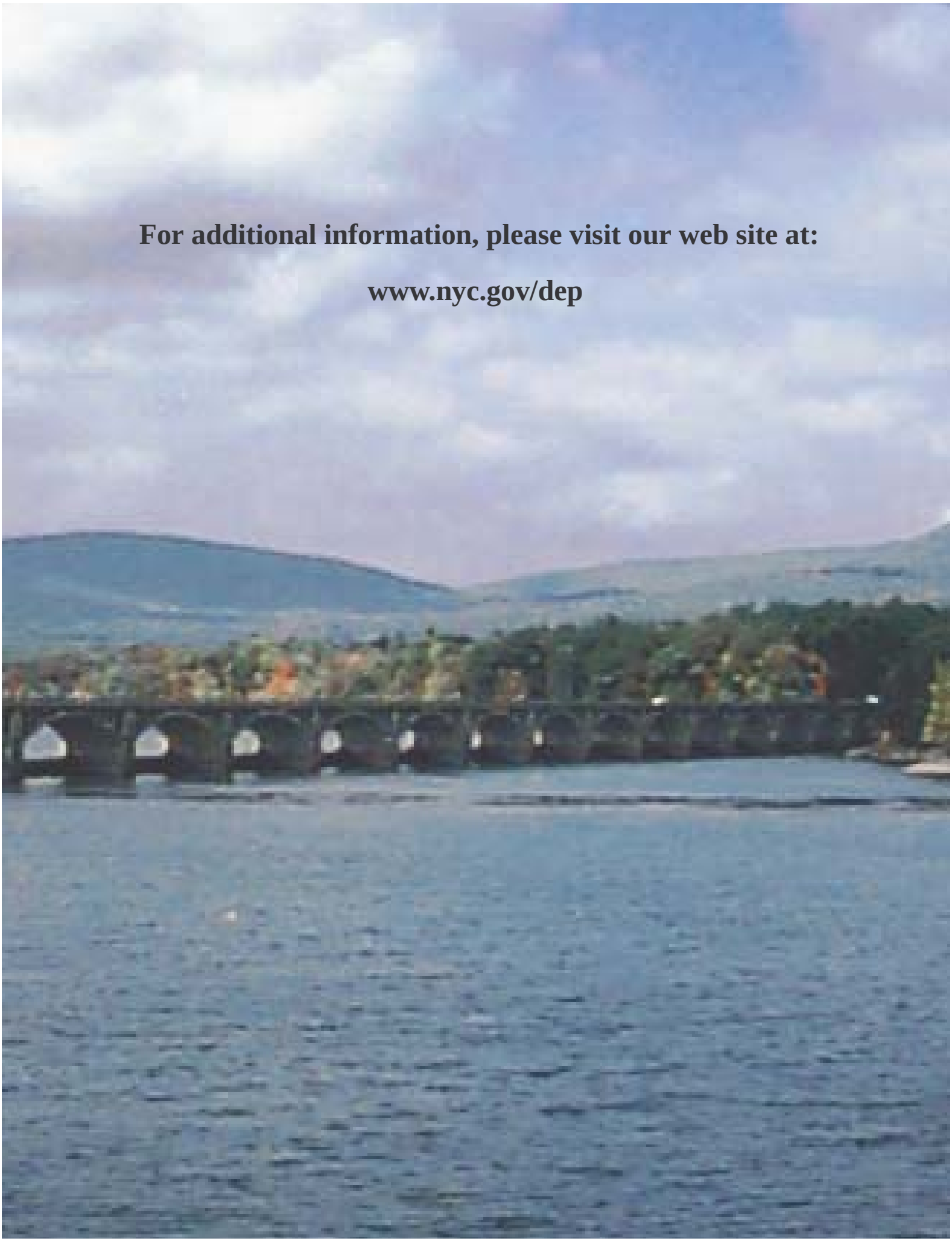


Figure E.1 Schematic showing the differences between (a) the hindcasting model and (b) the forecasting model.



For additional information, please visit our web site at:

www.nyc.gov/dep