New York City
Department of Environmental Protection

Integrated Monitoring Report

Prepared by the Division of Drinking Water Quality Control

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

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Executive Summary

This report provides a description of an integrated, objective-based framework for three water quality monitoring programs conducted by New York City Department of Environmental Protection (DEP). It provides the justification and rationale for updated monitoring efforts of the Hydrology, Limnology, and Pathogen Programs and is designed to provide scientifically defensible information for the understanding, protection, and management of the New York City water supply. To achieve these goals, DEP has formulated a monitoring program based upon separate, clearly defined objectives. The list of objectives was derived from DEP's operational needs, regulatory requirements, legally binding mandates, and research questions that must be answered in order to formulate effective watershed protection policy.

By an integrated program, DEP means that the monitoring requirements from two or more programs have been coordinated to address the same objectives, where applicable. Conversely, DEP has worked closely with program staff, to identify the objectives requiring information from more than one monitoring program, and to ensure that the resulting data collection efforts are adequate to achieve these objectives. For example, hydrological flow information is the basis of both quantitative and qualitative information and is used by several programs for many mass transport or modeling studies. However, for the purposes of developing an integrated program, it is necessary to ensure that flow information is obtained at a frequency and at locations necessary to meet priorities and data needs of these other DEP groups as well as the Hydrology Program (*e.g.*, terrestrial modeling). This new framework also represents a thorough review of long-standing monitoring programs to ensure that sampling objectives meet current needs and that samples are collected efficiently while avoiding redundancy (*e.g.,* avoiding having multiple programs collect the same information). Efficiency is a necessity due to the increasing demands for information and increasing costs for analyses.

DEP's monitoring program design has proceeded from definition of objectives to specifications of sampling design. Several elements must be considered in design including site selection, choice of analytes, methodology to be used, and sampling frequency. One of the pervasive themes in this report is the importance of retaining the same method for trend detection. When trends are sought, methodology should remain constant and sampling frequency must be chosen according to data variability and the statistical confidence and power required. It must be recognized that short-term intensive sampling is redundant and possibly insufficient because the effects of seasonality, extreme events and non-uniform variance must be accounted for (Lettenmaier, 1976, 1978; Loftis and Ward, 1980). The practical consequence is (Lettenmaier *et al.*, 1982, pp 62-63) that it is difficult to detect a trend on the order of the water quality variable's standard deviation for n smaller than 50-100. Thus for a trend to be detected with reasonable confidence and power, *the network must stay fixed for at least five years to provide a sufficient sample size ($n \geq 60$)*; this is the approximate time period that will be required to achieve several of the trend detection objectives described in this document.

The Hydrology Program is designed to meet eight major objectives as follows:

- •Trend Detection
- •Landscape Scale Water Quality Monitoring
- •Terrestrial Modeling Support
- •Reservoir Modeling Support
- •Biological Monitoring Support
- •Assessment of Waste Water Treatment Plant Effects on Streams
- •Best Management Practices (BMPs)
- •Policy and Management Based Surveillance Monitoring

The total number of samples required to meet the Hydrology Programs objectives is approximately 3,200 taken at approximately180 sites throughout the watershed that will result in about 52,000 analyses per annum.

The Limnology Program is designed to meet five major objectives.

- •Reservoir Operations Monitoring
- •Reservoir Water Quality Status
- •Trend Detection
- •Reservoir Modeling Support
- •Policy and Management Based Surveillance Monitoring

The network design proposed in this section provides a comprehensive and integrated reservoir monitoring network to address short-term and long-term water quality concerns. Care has been taken to ensure that it is integrated with other DEP programs (*e.g.*, the Hydrology Program and Keypoints' sampling as performed by Laboratory staff) as appropriate. The total number of samples required to meet the Limnology Program's objectives is approximately 4,800 taken at approximately 100 sites throughout the 19 reservoirs and 3 controlled lakes that will result in about 44,000 analyses per annum.

The Pathogen Program monitors *Cryptosporidium* oocysts, *Giardia* cysts and human enteric viruses throughout the watershed. The overall goal of the Program is to develop an understanding of the sources, fate and transport of pathogens in the watershed. The information is needed to support risk assessment and risk management activities, and to ensure the continued safety of the New York City Water Supply. Since 1992, DEP has utilized three separate methods to analyze its 'source waters' for (oo)cysts, and is now using EPA Method 1623 (50 L) for monitoring source water keypoints. The preponderance of data demonstrate that New York City's 'source waters' contains low levels of oocysts in comparison with the treatment standards set in the proposed Long Term 2 Enhanced Surface Treatment Rule (LT2SWTR) regulations. Overall, average concentrations of *Cryptosporidium* spp. oocysts with any of the three methods used since

1992 fall below the 0.01 (oo)cyst L^{-1} level proposed in the LT2ESWTR. In addition, the average *Cryptosporidium* spp. concentrations of the source water were low relative to the model average of 0.034 oocysts L^{-1} found for unfiltered water supplies during the ICR (U.S.E.P.A., 2001).

Past data also shows that fixed frequency monitoring at a limited number of stream sites has not revealed much insight into (oo)cyst presence and distribution. When *Cryptosporidium* spp. oocysts have been detected, they have been found generally at levels of 3 oocysts/ 100L or less. Even at WWTP effluent sites, there was a relatively low frequency of detection (8.5% of samples) and the concentration ranged from 1 to 185 oocysts/100L, with most detections found in the 1-5 oocysts/100L range.

Past data also shows that pathogen concentrations show little relationship to land cover. Twenty-three sites were monitored by fixed-frequency sampling for several years and pathogen concentrations were plotted against percentages of generalized land cover. However, from the plots, it is evident that four sites in particular, RF, SHR1, CTB, and TRTIT, appear to be consistently higher in pathogen concentrations than the remaining 19 sites.

Based on the general findings of low concentrations at most sites, the general approach that will be taken by the Pathogen Program will be to progress from integrator sites to indicator sites, thereby working from low to high spatial resolution to identify sources. The program presented here is also different from the previous program in its focus on collecting water samples that are more likely to detect (oo)cysts, including samples taken close to potential sources and during storms. Research will be undertaken to improve and expand event-based monitoring. Additionally, DEP will utilize Method 1623 (50L) for watershed samples to improve the comparability of data from the watershed with data collected at the 'source water' keypoints. A fixed-frequency network within the watershed is also proposed to support trend detection activities.

The objectives of the program are categorized as follows:

- Compliance Monitoring
- Surveillance Monitoring
- Watershed Research
- Methodological Studies.

The first two areas address long-term, on-going monitoring for compliance and surveillance while the last two areas address short-term concise research and development studies. The watershed research studies are designed to answer specific questions that will provide the foundation for future investigations. Monitoring the environment for pathogens remains a new science with new analytical methods. DEP will stay at the leading edge of this science by implementing the latest methods and by conducting appropriate research. In order to address the objectives of

the program, the total number of samples required is approximately 1,500 taken at approximately 100 fixed and 150 source-defined sites throughout the watershed that will result in about 6,000 analyses.

1. Introduction

1.1 Scope of this Document

This document presents a synopsis of three of DEP's upstate water quality monitoring programs: Hydrology, Limnology, and Pathogens. These summaries have been designed to meet the expanding scope of DEP's data uses including requirements for watershed and reservoir models, mandates, and regulations, as well as fulfilling data needs to ensure that management requirements are adequately addressed. The Programs are designed to meet the current and future data requirements of DEP including the long-term evaluation of MOA programs. The programs are subject to change but any changes will not take place without the prior approval of DEP management and outside agencies, as appropriate.

Each program is objective based. The list of objectives for each Program was derived by compiling the information needs of DWQC, and the review of legally binding mandates, agreements, and/or documents which pertain to New York City's Watershed Water Quality Monitoring Program. These documents include: the 1997 New York City Watershed Memorandum of Agreement; New York City's Proposed Enhanced Watershed Protection Monitoring Program (DEP 1996); Comprehensive Watershed Monitoring: A Framework for the New York City Reservoirs (ILSI 1998); New York City Watershed Filtration Avoidance Determination Mid-Course Review (EPA 2000); Watershed Management for Potable Water Supply: Assessing New York City Strategy (NRC 2000); and the New York State, Water Quality Regulations, Title 6, Chapter X, Parts 700-705.

1.2 Background on Water Quality Monitoring Network Design

Historically, water quality monitoring networks have been designed almost exclusively by determining "what" and "how" to monitor and rarely examining the question of "why" (Sanders *et al*., 1983). Typically, such designs produce large amounts of data which are difficult to analyze and often more difficult to interpret. This phenomenon is described by Ward *et al.* (1986) as "data rich and information poor" and is prevalent in many, if not most, routine water quality monitoring programs. The problem is associated with not defining the informational goals of the program prior to the design of the monitoring network. The result is an accumulation of data that contributes little or no information to the understanding of the system. The data collection process becomes an end in itself. In addition, individual studies and investigations traditionally have not been conducted in concert with existing "fixed", long-term monitoring programs. This often results in disjointed, inconsistent information and at times, a duplication of effort resulting in limited applicability. In order to avoid these difficulties, the starting point is the definition of objectives.

Considerable effort has been made over the years to define the logic and science to be used in designing water quality monitoring networks. Ward (1996) describes a detailed summary of these efforts and further argues that water quality monitoring programs must be thought of, and designed as, water quality information systems. This philosophy, as discussed by Ward *et al.* (1990), emphasizes the need to;

1) define the information goals,
2) define what information can be furnished by the monitoring effort,
3) design the monitoring network,
4) document data collection procedures, and
5) document the information and reporting procedures.

Similarly, Smith *et al.* (1990) describe a similar approach used in designing the national water quality network for New Zealand. Careful consideration was given to a comprehensive list of tasks before the network was implemented. These included,

1) define goals and objectives,
2) confirm statistical design criteria,
3) produce a list of analytes,
4) recommend data analysis procedures, and
5) recommend reporting procedures.

The information goals of management often require the network design to address water quality issues, which demand distinct, spatial and temporal monitoring efforts. These efforts may, for example, require a combination of surveys, fixed frequency-long term and intensive-short term strategies. The design of a water quality monitoring network *must recognize the significance of coordination and integration in monitoring strategies*. The integration of distinct water quality monitoring efforts is essential in providing consistent and applicable water quality information (Ward *et al*., 1990; Payne and Ford, 1988).

The information needs and goals of management and other stake-holders must define the monitoring network design. Once the information needs are clearly defined, consideration must be given to determining what information the monitoring effort is capable of providing and whether or not this meets expectations. By addressing these issues initially, a statistically-based, goal-oriented monitoring network can be designed to provide the necessary information for managers to adequately manage the resource. This effort, in conjunction with integrating supplemental investigations and programs with “fixed” monitoring networks, will result in a monitoring program that produces both consistent and useful water quality information.

This concept has been applied to the NYCDEP's Hydrology, Limnology, and Pathogens monitoring programs. The document below describes the protocol and rationale used in the design of the network. The proposed design is intended to establish an integrated monitoring framework, which addresses both short-term and long-term water quality concerns.

1.3 Framework for an Integrated Monitoring Network

To ensure the most efficient gathering of data, the monitoring programs are integrated with each other through common data requirements. Several data collection programs, *e.g.*, Hydrology and Limnology, may contribute to a single objective, *e.g.*, Reservoir Modeling, so it is essential that data from each collection program be coordinated with others.

The purpose of this document is to produce a formalized framework for the Hydrology, Limnology, and Pathogens water quality monitoring Programs conducted by the NYCDEP. It provides the rationale and justification for a comprehensive, integrated monitoring network which fulfills the present information requirements of the department through clearly defined objectives.

The goal of the framework is to establish a water quality monitoring network, which provides scientifically defensible information regarding the understanding, protection, and management of the New York City water supply. The information needs required to achieve this goal are compiled as objectives, each of which is clearly defined (in statistical terms if possible). Each objective specifies and justifies where possible: sampling frequency; statistical design criteria; analytes; and data analysis protocol. These attributes are synthesized for each objective within each program (Figure 1.1). Note that Quality Assurance Project Plans (QAPPs) are required for each individual objective.

The conceptual framework used to produce the integrated monitoring network is depicted in Figure 1.2. Prior to the design of each of the three water quality monitoring programs described here (Hydrology, Limnology, and Pathogens), the objectives were defined. This was achieved as a consequence of the requirements of the information end users, *i.e.*, DEP management, regulators, and other external agencies. The objectives lead to the temporal, spatial, and analytical requirements for data collection. Statistical features of the historic database were used to guide the sampling design where possible. Following field sample collection, field measurement, and laboratory analysis of samples, data will be entered into the DEP database. Finally, information will be created from the data to address the needs of the end users. These needs will be reviewed periodically to ensure that the information produced is appropriate. This may result in a change to the objectives and hence to the sampling program.

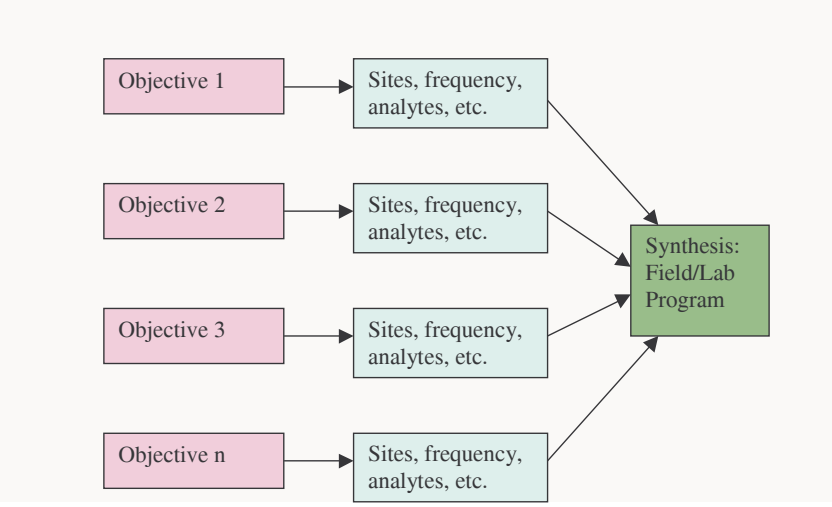

Figure 1.1 The conceptual model used to derive the monitoring and analytical requirements for each Program.

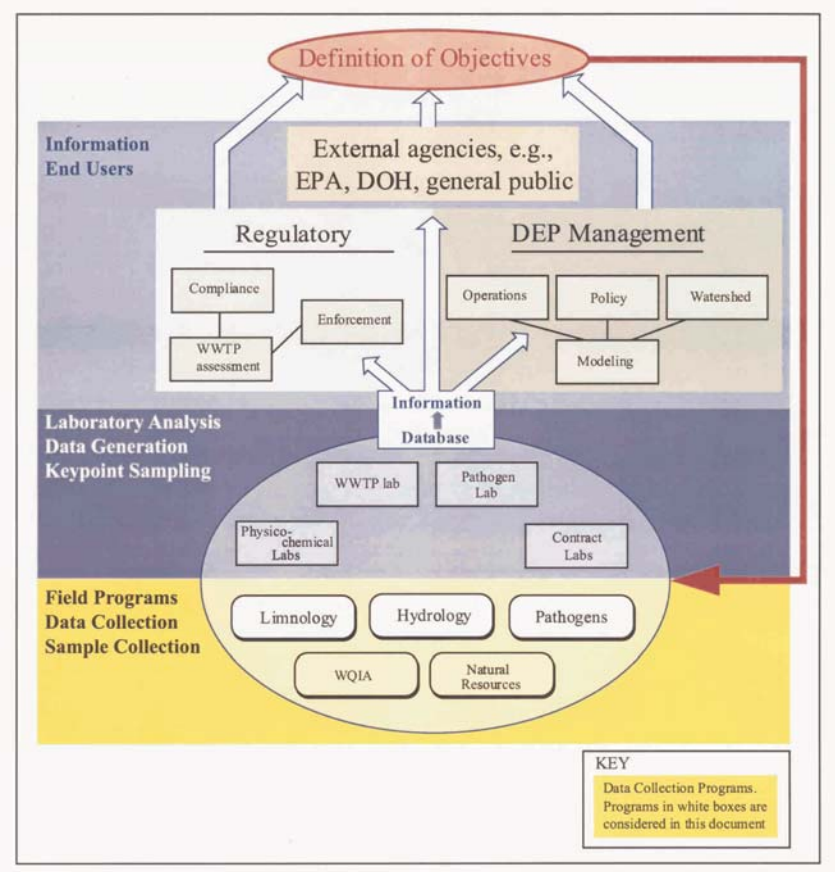

Figure 1.2 A conceptual framework of the data collection programs and their links with data users.

Inherent in the design of any long-term program is data continuity. It is essential that any observed changes in data reflect changes in the environment and not be a consequence of methodological changes (*e.g.*, Shapiro and Swain, 1983; Smith *et al.*,1996; Smith, 2000). This is important not only for trend analysis where step-trends, *i.e.*, sudden increases or decreases in mean values (whether visually apparent or not) can cause data trends, but also for other data where year-by-year comparisons are made, *e.g.*, in P-restricted basin studies and modeling. Analytical methods must remain constant wherever possible because it has been shown that even very small changes in methods (even filters) can cause differences in results (Newell and Morrison, 1993). Because analytical changes are sometime unavoidable, DEP will endeavor to account for such method changes by running paired method comparisons wherever possible to allow appropriate data comparison (*e.g.*, Newell *et al.*, 1993).

Another aspect of laboratory data which can create problems for trend detection, in particular, is that of non-reporting data that falls below the "analytical detection limit"; this is called "data censoring" and its effects, including trend masking and trend induction, have been reported in the literature (*e.g.*, Gilliom *et al.*, 1984; Bell, 1990; Porter *et al.*, 1988; Ellis and Gilbert, 1980). DEP intends to take account of less than detection limit data in its trend analysis.

To assist in the definition of each objective, direct quotes from the mandates or regulations are provided as appropriate. Other objectives required a description of the rationale and justification for their inclusion in this proposed sampling program. The final result of the compilation of sampling needs to meet DEP's objectives is summarized in Table 1.1.

Table 1.1. Summary table of sites, samples, and analyses for three of DEP's Field Programs.

	Hydrology	Limnology	Pathogens
# of Sites	173	97	120 fixed 200 source defined
# of Samples	≈ 3,200	≈ 4,800	≈ 2000
# of Analyses	≈ 52,200	≈ 44,300	≈ 6000

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2. Hydrology Monitoring Program

2.1 Introduction

This section provides a formalized framework for the stream water quality monitoring program as conducted by NYCDEP's Hydrology Program. It provides the justification and rationale for each monitoring effort as conducted by the Hydrology Program. The overall goal of the Program is to establish a stream water quality monitoring network which provides scientifically defensible information regarding the understanding, protection, and management of the New York City water supply. The information needs required to achieve this goal are compiled as separate objectives, each of which is clearly defined. The list of objectives was derived from DEP programs, and the review of legally binding mandates, agreements, and documents which pertain to New York City's Watershed Water Quality Monitoring Program.

There are eight major objectives. Within each objective, site selection, sampling frequency, statistical design criteria, analytes, and data analysis protocol are specified and justified. Although objectives are independent, careful consideration and effort was made to compose a monitoring network that integrates and coordinates the sampling effort of different programs. This integrative approach results in a monitoring network that efficiently produces the appropriate water quality information for water supply management.

The first Objective (2.1), *Trend Detection,* is a fixed frequency monitoring design, intended to detect a monotonic trend in the mean value of approximately the standard deviation of the detrended data over a five year period with reasonable confidence and power. The data from this objective will also be used to assess the status of stream water quality.

The second Objective (2.2), *Landscape Scale Water Quality Monitoring,* is a variable frequency monitoring design to evaluate spatial and temporal changes in stream flow chemistry that occur through various land-use types. The hydrologic and water quality requirements for these objectives have been developed and justified by Hydrology Program staff.

Reservoir and Terrestrial Modeling Support constitute the third and fourth Objectives (2.3 and 2.4), respectively. The data collected are used to calibrate, validate and optimize reservoir and terrestrial models to enable them to be of optimal management value. Both reservoir and terrestrial modeling programs require adequate daily and monthly loads for selected analytes. This is accomplished by combining fixed frequency and storm event monitoring at selected gauged reservoir tributaries. The TMDL needs are also addressed through the Modeling Program. The hydrologic and water quality requirements for this objective have been developed and justified by staff of the Modeling Program.

The stream chemistry data collected for the fifth objective (2.5), *Biological Monitoring Support*, is used to develop an understanding of watershed-specific relationships between water quality and the macrobenthic community. Macroinvertebrates are collected annually at two types of sites, fixed routine and synoptic supplemental. The program requires selected water quality analytes to be collected at base flow conditions during the month of macroinvertebrate collection. The hydrologic and water quality requirements for this objective have been developed and justified by staff of the Water Quality Impact and Assessment Program (WQIA).

In accordance with Addendum E of the DEC/DEP Memorandum of Understanding, *Assessment of Waste Water Treatment Plant effects on streams* is assessed in the sixth objective (2.6). Water quality samples are collected above and below twelve selected treatment plants once each month. Selected analytes, as specified in Addendum E, are analyzed and used to track treatment plant performance. Water quality downstream of the discharge is examined for violations of State Ambient Water Quality Standards. The hydrologic and water quality requirements for this objective have been developed and justified by staff of the Water Quality Impact and Assessment Program.

The seventh objective (2.7) is a compilation of the investigation of *Best Management Practice (BMP) Assessments*. Studies described within this objective are intended to be of relatively short duration. Currently, these investigations include: 1) *Assessment of BMPs on Turbidity Reduction in the Batavia Kill Sub-basin*; 2) *Assessment of BMP Effectiveness in two New Croton Reservoir Sub-basins*; and 3) *Assessment of BMP Effectiveness Kensico Reservoir Tributaries*.

Policy and Management Based Surveillance Monitoring constitutes the objective (2.8) The monitoring efforts embodied within this broad objective are designed to fulfill the Department's water quality policy/management based goals, which are not addressed with other existing water quality monitoring efforts. The specific surveillance monitoring designs (*i.e.,* site selection, sampling frequency, etc.) associated with each monitoring effort, are determined based upon the Department's policy as directed by management. Surveillance monitoring, as defined in this objective, is intended to be of long duration. In accordance with this definition, *Trace and Other Metal Occurrence Monitoring* has been included in this objective (2.8.1). For Catskill and Delaware Districts, sampling sites are located on the major tributary for each reservoir at the terminal USGS site and upstream in the centroid of the watershed, where ever possible. Because of the cascading reservoir design of the East of Hudson District, metal monitoring sites have been located at reservoir releases and main inflow tributaries. Samples are collected quarterly and results compared to the standards stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and EPA National Primary and Secondary Water Quality Regulations. There are two other sub-objectives within Objective 2.8—*Source Water Tributary Monitoring (2.8.2)*is designed to provide additional surveillance of tributary streams to Kensico, and West Branch Reservoirs, and *Croton Watershed*

Consent Decree Monitoring (2.8.3) which addresses the stream monitoring requirements of the Croton Consent Decree. The hydrologic and water quality requirements for this objective have been developed and justified by the NYC, DEP managerial staff.

Additionally, the Hydrology Monitoring Program is responsible for two data collection programs that supplement the objectives described above. The first program is the United States Geological Survey (USGS) stream gauge network and the second is the DEP meteorological network.

Stream flow data is an essential component in the calculation of pollutant loads and in the interpretation of water quality data. The information is used to calibrate/verify models, evaluate the effectiveness of management practices, and assists in operation of the water supply system. Currently, a total of 86 USGS gauge stations are located in the watershed. Site selection criteria for the stream gauges included: paired upper-lower sites in the same watershed, land use, a multivariate cluster analysis, and specific data needs. The data are collected and managed by the USGS.

The meteorological network, which is operated and maintained by the Hydrology Program, consists of 24 meteorological stations located throughout the EOH and WOH systems. The data collected from this network provides the input data to water quality models, allows for a more comprehensive interpretation of water quality observations, and is used in the operation and management of the water supply system. Site selection criteria for the meteorological network included: watershed-wide coverage of each reservoir basin, precipitation patterns, elevational gradients, model requirements (*e.g.*, a station at each West-of-Hudson reservoir), accessibility, and landowner cooperation. Each station measures: air temperature, relative humidity, rainfall, snow depth, solar radiation, photosynthetically active radiation (selected sites only), wind speed, and wind direction. The instruments are interrogated at minute intervals and values are summarized hourly (summed or averaged).

The network design proposed in this section provides a comprehensive and integrated stream water quality monitoring network as performed by the Hydrology Program to address New York City's short-term and long-term water quality concerns. Care has been taken to ensure that it is integrated with other Programs, *e.g.*, the Limnology Program, as appropriate.

2.2 Hydrology Program Objectives

Objective 2.1: Trend Detection for Stream Water Quality

To collect appropriate data so that long-term trends in the most important water quality analytes for the New York City potable water supplies can be determined.

The intention is to be able to detect a monotonic trend in mean value of approximately the standard deviation of the detrended data (*i.e.*, the record after removal of any trend and seasonality) over a five year period with reasonable confidence and power.

To ensure that trend analysis reflects *environmental* changes, and not artificially-induced program changes, ideally, there should be *no changes* in any aspect of the monitoring program which may induce a step-trend. Such changes include alterations to field sampling techniques, sample site locations, and time of sampling. Any laboratory changes, such as equipment, filters, and analytical methods must be discussed with the Program Supervisor well in advance because of the possible ramifications for data analysis. If a change is necessary, preferably there should be a method overlap for one year at the main stem sites as a minimum given their importance.

Sites

Sites are selected on the basis of providing data so that at least an indication of the cause of any trends detected can be established. They are selected on the basis of a wide distribution of current and predicted land-use changes. Site locations have been chosen for a variety of reasons. They have been selected on main river inputs as close to the reservoirs as possible to provide an indication of the trends in water which feed immediately into the reservoir. Sites have also been selected in appropriate contributing catchments to attempt to better establish causes of trends. Some sites high in the catchment are selected because they are presently little disturbed by humans and there is a high likelihood of minimal change in the future. These sites are affected mainly by meteorological events and other natural phenomena. Because flow measurement or assessment is required for all sites, a pre-requisite for site location is an adjacent or nearby flow/stage recorder. Samples will be collected at or near a USGS gauging station. Flow at sample sites and sub-basins that do not have a USGS gauge station will be estimated via indexing to nearby sub-basins that do have a gauge station.

Selection of sub-basins for the location of West of Hudson (WOH) monitoring sites was made using a synthesis of data derived from Geographic Information System (GIS) coverages for small and medium scale sub-basins. Multivariate analysis was performed to aid in classifying sub-basins according to their similarity in landscape traits. The traits selected represent the salient features commonly used to characterize stream ecosystems and factors that influence stream flow and water quality. Agglomerative cluster analysis (van Tongeren, 1987) was used to identify similarities in 74 sub-basins in the NYC watersheds west of the Hudson River, representing a total land area of approximately 4,100 km^2. Land area and land use, hydrologic, climatic, geomorphic, and edaphic characteristics were among the kinds of variables included in the analysis. Several key water quality variables, as well as historical water quality data, were also included in the descriptive statistical analysis that provides a basis for site selection and for extrapolating from areas that have continuous stream flow gauges to ungauged sites. Because of the physiographic

features and cascading engineered design of reservoirs in the Croton River Watershed, sites were selected below each reservoir's release and at, or near, the terminal end of each reservoir's main tributary. Outlined below are the selected sites and the rationale for inclusion (Tables 2.1-2.17)

Catskill District

Table 2.1. Catskill District, Ashokan Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
AEHG	Headwater of Esopus Creek	Small scale homogeneous forested catchment in the south-western boundary of the Esopus basin.
ABCG	Birch Creek @ Big Indian	Located at the terminal end of the Birch Creek sub-basin. This sub-basin differs from other sub-basins within the Esopus drainage with regard to land use. It contains the town center of Pine Hill and the Pine Hill Sewage Treatment Plant.
BNV	Bushnellville Creek	Medium scale basin primarily forested. This sub-basin is broadly similar and representative of several other sub-basins within the Esopus basin with regard to physiographic and demographic features.
AEBP*	Esopus Creek below Schoharie Reservoir Diversion	Represents the mixed waters of the Esopus Creek and the Schoharie Reservoir Diversion
E5	Esopus Creek @ Allaben	Located on the Esopus Creek at Allaben, this site divides the Upper Esopus Creek drainage from the lower Esopus Creek drainage. It represents an integrated site of moderate size and multiple land uses.
SRR2	Schoharie Reservoir Diversion	At times provides majority of water to Esopus Creek
WDL	Woodland Valley Creek	Medium scale basin primarily forested. This sub-basin is broadly similar and representative of several other sub-basins within the Esopus basin with regard to physio-graphic and demographic features.
BRD	Broad Street Hollow	Medium scale basin primarily forested. This sub-basin is broadly similar and representative of several other sub-basins within the Esopus basin with regard to physiographic and demographic features.
ASCHG	Hollow Tree Brook near Lanes-ville (Headwaters of Stony Clove)	Small scale homogeneous forested catchment in the northeast ern boundary of the Esopus basin.
SCL	Stony Clove near Phoenicia	This sub-basin is broadly similar and representative of several other sub-basins within the Esopus basin with regard to physio graphic and demographic features.
ABKHG	Mink Hollow (Headwaters of Beaver Kill)	Small scale homogeneous forested catchment in the south-eastern boundary of the Esopus basin. The data from this site will be; 1) compared and compiled with other small scale for-ested monitoring stations within the Esopus basin and region-ally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/diverse land-use monitoring station data.

Table 2.1. Catskill District, Ashokan Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
BK	Beaver Kill	Medium scale basin of multiple land uses. This sub-basin is broadly similar and representative of several other sub-basins within the Esopus basin with regard to physio-graphic and demographic features.
LBK	Little Beaver Kill near Mt. Tremper	Terminal monitoring point of the Little Beaver Kill sub-basin. This basin differs from other sub-basins within the Esopus drainage with regard to physiographic and demographic attributes. The basin possesses the greatest potential for urban development within this drainage
E10I	Bush Kill	Medium scale sub-basin that is tributary to Ashokan Reservoir
E16I	Esopus Creek @ Cold Brook	Terminal monitoring station for Esopus Creek drainage basin above Ashokan Reservoir.

* Only turbidity, TSS and clarity measurements will be made at this site.

Table 2.2. Catskill District, Schoharie Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
SSHG	Headwaters of Schoharie Creek	Small scale homogeneous forested catchment in the south-eastern boundary of the Schoharie basin. The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the Schoharie basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/diverse land-use monitoring station data
S4	Schoharie Creek at Lexington	Located on the Schoharie Creek below the confluence with the East Kill, on Schoharie Creek. This site is intended to divide the Lower Schoharie Creek drainage from the Upper Schoha-rie Creek drainage. It represents a basin of medium size and diverse land uses.
SEK	East Kill near Jewett Center	Located near the terminal end of the East Kill sub-basin. This sub-basin contains a mixture of urban dwellings, agricultural land uses, and 1 town center.
SWKHG	West Kill below Hunter Brook, near Spruceton	Small scale homogeneous forested catchment in the southern boundary of the Schoharie basin. The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the Schoharie basin and regionally across other basins to characterize water quality in undis-turbed forested catchments, 2) used to compare regional for-ested monitoring station data to down stream/diverse land- use monitoring station data
SWK	Westkill near West Kill	Located on the West Kill near the confluence of Schoharie Creek. This sub-basin is currently under increasing develop mental pressure.

Table 2.2. Catskill District, Schoharie Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
SBKHG	Batavia Kill near Maple Crest	Small scale homogeneous forested catchment in the eastern boundary of the Schoharie basin. The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the Schoharie basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/diverse land- use monitoring station data
S10	Batavia Kill	Located near the terminal end of the Batavia Kill sub-basin. This is the largest sub-basin within the Schoharie Creek drainage. It contains 4 town centers and 1 ski resort.
S5I	Schoharie Creek @ Prattsville	Terminal monitoring point for Schoharie Creek drainage basin above Schoharie Reservoir.
STHHG	Headwaters of Bear Kill	Small scale homogeneous forested catchment in the northwestern boundary of the Schoharie basin. The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the Schoharie basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/diverse land-use monitoring station data
S6I	Bear Kill near Prattsville	Located near the terminal end of the Bear Kill sub-basin. It contains the town center of Grand Gorge, the Grand Gorge STP and its drainage is confluent to the Schoharie Reservoir.
S7I	Manor Kill near Conesville	Located near the terminal end of the Manor Kill sub-basin. This sub-basin has a proportionately larger agricultural land use than other gauged sub-basins within Schoharie basin.

Delaware District

Table 2.3. Delaware District, Cannonsville Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
WDHOA	West Branch Delaware River above Hobart	Near the headwaters of Delaware River. Medium scale catchment comprised of a mosaic of landuses
CTNBG	Town Brook	Terminal site near the confluence with West Branch of Delaware River. Medium scale catchment, primarily agricultural

Table 2.3. Delaware District, Cannonsville Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
CTNHG	Headwaters of Town Brook	Small scale homogeneous forested catchment The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/ diverse land-use monitoring station data
CDG	West Branch Delaware River near Delhi	Located on the West Branch Delaware River. This site is intended to divide the Lower West Branch Delaware River drainage from the Upper West Branch Delaware River drainage. It represents a basin of medium to large size and diverse land uses.
CLDG	Little Delaware River	Located near the terminal end of the sub-basin basin. This sub-basin is larger than other agricultural land use sub-basins within this system.
CCBHG	Headwaters of Little Delaware	Small scale homogeneous forested catchment The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/ diverse land-use monitoring station data
CEBG	East Brook	Located near the terminal end of east Brook near the confluence with West Branch Delaware River. Medium scale sub-basin, primarily agricultural. This sub-basin is broadly similar and representative of several other sub-basins within the West Branch Delaware River basin with regard to physiographic and demographic features
CEBHG	Headwater of East Brook	Small scale homogeneous forested catchment The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/ diverse land-use monitoring station data
WDBN	West Branch Delaware River @ Beerston Bridge	Terminal monitoring point for West Branch Delaware River drainage basin above Cannonsville Reservoir.

Table 2.3. Delaware District, Cannonsville Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
C-7	Trout Creek	Located near the terminal end of Trout Creek near the confluence with Cannonsville Reservoir. Medium scale sub-basin, primarily agricultural. This sub-basin is broadly similar and representative of several other sub- basins within the West Branch Delaware River basin with regard to physiographic and demographic features
C-8	Loomis Creek	Medium Scale catchment with similar physiographic and demographic features to Trout Creek. Tributary to Cannonsville Reservoir.
CSBG	Sherruck Brook	Small scale homogeneous forested catchment The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/ diverse land-use monitoring station data

Table 2.4. Delaware District, Pepacton Reservoir basin hydrology sampling sites for trend detection

Site Code	Site Description	Reason for Inclusion
PROXG	East Branch Delaware River near Roxbury	Located on the East Branch Delaware River. This site is intended to divide the Lower East Branch Delaware River drainage from the Upper East Branch Delaware River drainage. It represents a basin of medium to large size and diverse land uses.
P-50	Batavia Kill	Medium Scale catchment with similar physiographic and demographic features to Platte Kill.
PBKG	Bush Kill	Medium scale basin of multiple land uses. This sub-basin is broadly similar and representative of several other sub-basins within the Pepacton basin with regard to physiographic and demographic features.
PDRY	Dry Brook	Medium scale basin of multiple land uses. This sub-basin is broadly similar and representative of several other sub-basins within the Pepacton basin with regard to physiographic and demographic features.
PMSB	East Branch Delaware River @ Margaretville	Terminal monitoring point for West Branch Delaware River drain age basin above Pepacton Reservoir.

Table 2.4. Delaware District, Pepacton Reservoir basin hydrology sampling sites for trend detection

Site Code	Site Description	Reason for Inclusion
P-21	Platte Kill	Medium scale sub-basin primarily of agricultural land use. Representative of other sub-basins within the Pepacton watershed. Tributary to Pepacton Reservoir
P-60	Mill Brook	Medium scale sub-basin primarily forested.
P-13	Tremper Kill	Medium scale sub-basin primarily of agricultural land use. Representative of other sub-basins within the Pepacton watershed. Tributary to Pepacton Reservoir
P-8	Fall Clove	Medium scale sub-basin primarily of agricultural land use. Representative of other sub-basins within the Pepacton watershed. Tributary to Pepacton Reservoir
P-7	Terry Clove	Medium scale sub-basin primarily of agricultural land use. Representative of other sub-basins within the Pepacton watershed. Tributary to Pepacton Reservoir

Table 2.5. Delaware District, Rondout Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
RRHG	Headwaters of Rondout Creek	Small scale homogeneous forested catchment The data from this site will be; 1) compared and compiled with other small scale forested monitoring stations within the basin and regionally across other basins to characterize water quality in undisturbed forested catchments, 2) used to compare regional forested monitoring station data to down stream/diverse land-use monitoring station data
RDOA	Rondout Creek	Terminal monitoring site of Rondout Creek above Rondout Reservoir
RD1	Sugarloaf Brook	Terminal monitoring site of Sugar Loaf Brook above Rondout Reservoir
RGB	Chestnut Creek	Terminal monitoring site of Chestnut Creek above Rondout Reservoir
RD4	Trout Creek	Terminal monitoring site of Trout Creek above Rondout Reservoir

Table 2.6. Delaware District, Neversink Reservoir basin hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
NWBR	West Branch Neversink River	Terminal monitoring site of West Branch Neversink River
NEBG	East Branch Neversink River	Terminal monitoring site of East Branch Neversink River
NCG	Neversink @ Claryville	Terminal monitoring site of Neversink River above Neversink Reservoir
NK6	Kramer Brook	Terminal monitoring site of Kramer Brook above Neversink Reservoir

East of Hudson District

Table 2.7. East of Hudson District hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
BB5	Brady Brook	Primarily Agricultural sub-basin
MUDTRIB1	Tributary of Muddy Brook	Sub-basin of multiple land use
EBCR3	East Branch Croton River below Haviland Hollow Brook	Separates most of the Great Swamp from the rest of the drainage Basin.
HH7	Haviland Hollow Brook	Terminal monitoring site of Haviland Hollow Brook before confluence with Great Swamp
EASTBR	East Branch Croton River above East Branch Reservoir	Terminal monitoring site of East Branch Croton River above East Branch Reservoir
LEETOWN3	Leetown Brook	Terminal monitoring site of Leetown Brook above Boyds Reservoir
WESTBR7	West Branch Croton River above West Branch Reservoir	Terminal monitoring site of West Branch Croton River above West Branch Reservoir
HORSEPD1	Horse Pound Brook	Terminal monitoring site of Horse Pound Brook above West Branch Reservoir
GYPSYTRL1	Gypsy Trail Brook	Terminal monitoring site above West Branch Reservoir
MIDBR3	Middle Branch Croton River above Middle Branch Reservoir	Terminal monitoring site of Middle Branch Croton River above Middle Branch Reservoir
MIKE2	Michael Brook above Croton Falls Reservoir	Terminal monitoring site of Michael Brook above Croton Falls Reservoir

Table 2.7. East of Hudson District hydrology sampling sites for trend detection.

Site Code	Site Description	Reason for Inclusion
MUSCOOT10	Muscoot River above Amawalk Reservoir	Terminal monitoring site of Muscoot River above Amawalk
PLUM2	Plum Brook	Terminal monitoring site of Plum Brook above Muscoot Reservoir
TITICUS1	Titicus River above Titicus Reservoir	Terminal monitoring site of Titicus River above Titicus Reservoir
CROSS2	Cross River above Cross Reservoir	Terminal monitoring site of Cross River above Cross Reservoir
STONE5	Stone Hill Brook above Muscoot Reservoir	Terminal monitoring site of Stone Hill Brook above Muscoot Reservoir
KISCO3	Kisco River above New Croton Reservoir	Terminal monitoring site of Kisco River above New Croton Reservoir
HUNTER1	Hunter Brook above New Croton Reservoir	Terminal monitoring site of Hunter Brook above New Croton Reservoir
MUSCOOT5	Muscoot River above Muscoot Reservoir	Terminal monitoring site of Muscoot River above Muscoot Reservoir
BOYDR	Boyds Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
WESTBRR	West Branch Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
BOGEAST-BRR	Combined Releases of East Branch and Bog Brook Reservoirs	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
DIVERTR	Diverting Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
CROFALLSR	Croton Falls Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
TITICUSR	Titicus Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
CROSSRVR	Cross River Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir
AMAWALKR	Amawalk Reservoir Release	Because of the cascading design of the EOH District, each release constitutes the greatest contributor of water to the next down stream reservoir

Sampling Frequency

When trends in data are sought, it must be recognized that there is no point in carrying out short-term intensive sampling because the effects of seasonality, extreme events and non-uniform variance must be accounted for (Lettenmaier, 1976, 1978; Loftis and Ward, 1980). The practical consequence is (Lettenmaier *et al.*, 1982, pp 62-63) that it is difficult to detect a trend on the order of the water quality variable's standard deviation for *n* smaller than 50-100. This is supported by the work of Hirsch and Slack (1984) of the USGS who examined a robust non-parametric trend test and stated that reasonable power for trend detection for rivers may only be attainable after five years of sampling. More recently, Smith and McBride (1990) have confirmed these findings. After five years of monthly sampling (n = 60) the confidence and power to detect a trend of approximately 1.15 standard deviations is 85% ($\alpha = \beta = 15\%$) or 1.65 standard deviations if $\alpha = \beta = 5\%$. In other words, the higher the confidence and power required, the greater the trend must be before it can be detected. Thus for a trend to be detected with reasonable confidence and power, *the network must stay fixed for at least five years to provide a sufficient sample size ($n \geq 60$).* For main tributary monitoring sites immediately upstream of West of Hudson reservoirs, greater confidence and power is suggested for Turbidity, Total Phosphorus (TP), and Total/Fecal Coliform (TC/FC) with trend detectability of the order of the standard deviation. Twice-monthly sampling at these sites allows for a trend detectability of approximately 1.1 standard deviations with confidence and power equal to 95% over a five year period (n = 120). Auto correlation is ignored and justified, because the data analysis for trend detection will be confined solely to the period of record (Loftis *et al*, 1991). The time of sample collection must also be given careful consideration. Samples should be collected $\pm$ 2 days of the scheduled collection day and each site should be collected within $\pm$ 60 minutes of a "routinely scheduled" sample time to avoid the effects of diurnal variation.

Analytes

These have been selected on the basis of what is most likely to be of practical consequence to the City in up to 10 years time (Table 2.8). It is impossible to foresee every contingency, therefore best judgment has been applied. Clarity measurements will only be made at one location on each reservoir's main tributary West of Hudson with the exception of the Esopus Creek where there are several sites.

Table 2.8. List of analytes for trend detection.

Analyte	Reason for inclusion
Flow	Required for flow adjustment technique in trend detection
pH	Specific range required to support aquatic life and regulating chemical composition of water, NYS-DEC Water Quality Regulation/Part703 water quality standard
Temperature	Important in the regulation of biotic community structure and function, and critical in regulating the chemical composition of water
Alkalinity	A measurement of acid neutralizing capacity, buffering capacity
Conductivity	Measured surrogate for total inorganic ions
Visual Clarity y_{BD}[1]	Related to recreational water use, directly linked to beam attenuation coefficient
Total / Fecal [2] Coliform	Indicator of potential pathogen contamination, NYS-DEC Water Quality Regulation/Part703 water quality standard
Turbidity [2, 3]	Related to a sites suspended solids concentration and water clarity, NYS-DEC Water Quality Regulation/Part703 narrative standard
TSS[3]	Interferes with disinfecting processes, mechanism of pathogen transport
Dissolved Oxygen	Essential aquatic life requirement, used as an indicator of chemical and biochemical activities in water, NYS-DEC Water Quality Regulation/ Part703 water quality standard
Dissolved Chloride	Major component of road salt, indicator of septic system failures
Dissolved Silica	Essential requirement for diatoms, concentration/Q relationships may be used as a surrogate for indirect estimates of flow
Dissolved SO_4	End product of acid deposition
Dissolved K	Na/K ratio used to determine and characterize hydrologic flow path
Dissolved Mg	Ca/Mg ratio used to determine and characterize hydrologic flow path
Dissolved Na	Major component of road salt
Dissolved Ca	Essential mineral for zebra mussels, observed Ca depletions observed in forested catchments
TOC/ DOC	Major source of energy to heterotrophic food webs
Nitrogen	The determination of the various forms of nitrogen assists in the understanding of the relationship between the readily bio-available nitrogen fractions and the pool from which they were derived. Sources of nitrogen include atmospheric input, runoff from anthropogenic activities, WWTP effluents, and agricultural fertilizers. Nitrogen is a fundamental building block required for growth by algae and other plants.
NH_3-N	Utilized preferentially over NO_x-N by autotrophs and bacteria, essential aquatic life requirement
NO_x-N	Essential aquatic life requirement

Table 2.8. List of analytes for trend detection.

Analyte	Reason for inclusion
Total Dissolved N	Pool of organic and inorganic dissolved N species
Total N	Total pool of dissolved and particulate N
Phosphorus	Productivity in lakes and reservoirs is most often limited by the supply of inorganic phosphorus. The determination of the various forms of phosphorus assists in the understanding of the relationship between readily bio-available forms and the pool from which they were derived. This understanding can assist watershed managers and planners in decisions concerning phosphorus control.
Total Dissolved P	Measurement of dissolved reactive phosphorus and dissolved organic complex phosphorus, used to determine dissolved organic P (DOP = TDP - SRP).
TP [2]	Pool of dissolved and particulate P
SRP	Soluble reactive P, most readily biologically available

[1] To be conducted at the following West of Hudson sites: E16I, E5, AEBP, S5I, PMSB, WDBN, RDOA, NCG
[2] Only these analytes to be analyzed twice each month at E16I, S5I, SRR2, PMSB, WDBN, NCG, RDOA
[3] Also collected at the time of clarity measurements

Data Analysis Protocol

The protocol for rivers will use nonparametric statistics because in ordinary linear regression over time, the assumption of normally distributed data is often violated (*e.g.*, Smith and Maasdam, 1994). The statistical power to detect trends is also greatly diminished when using a linear regression with data that fail to account for data seasonality. The techniques used will be the seasonal Kendall Sen slope estimator to estimate trend magnitude accompanied by the seasonal Kendall trend test to indicate statistical significance. These tests are included in the WQstat Plus package (Intelligent Decisions Technologies, Ltd, Longmont, CO.). Because most water quality data are flow dependent, it is essential that any trend detection protocol includes an analysis which removes that predictable portion of variability which is caused by flow. This will be accomplished using LOcally WEighted regression Scatterplot Smoothing (LOWESS) (Cleveland, 1979). LOWESS is a robust technique (Lettenmaier et al. 1991) and has been used successfully by the USGS in their examination of national water quality trends (Lanfear and Alexander, 1990: Helsel, 1993) and by Smith et al. (1996) in New Zealand.

Time of Study

On-going

Objective 2.2: Landscape Scale Water Quality Monitoring

To identify the relationships of selected water quality analytes under varying hydrologic conditions and various spatial scales and land use settings in the Catskill and Delaware Districts.

Sites

Five sub-basins with upper and lower paired sites, plus three additional upper forested sites were selected throughout the watersheds of the Catskill and Delaware Reservoir systems. Site selection was based on an assessment of watershed characteristics and land use. Where possible, natural forested sites were selected for the upper sites while lower sites encompass land uses characterized as active or fallow farms, suburban, or a mosaic of land use settings.

The sites for this objective are:

Catskill District

Table 2.9. Catskill District hydrology sampling sites for Landscape Scale Water Quality Monitoring.

Reservoir Basin	Site	Site Location
Schoharie	SBKHG	Batavia Kill near Maple Crest, NY, upper site
	S10	Batavia Kill @ Red Falls, nr. Prattsville, NY, lower site
Ashokan	ASCHG	Hollow Tree Brook at Lanesville, NY, upper site
	SCL	Stony Clove near Phoenicia, NY, lower site
	ABKHG	Beaver Kill Tributary above Lake Hill, NY, upper site

Delaware District

Table 2.10. Delaware District hydrology sampling sites for Landscape Scale Water Quality Monitoring.

Reservoir Basin	Site	Site Location
Cannonsville	CTNHG	Town Brook Tributary southeast of Hobart, NY, upper site
	CTNBG	Town Brook, southeast of Hobart, NY, lower site
	CEBHG	Wolf Creek at Mundale, NY, upper site
	CEBG	East Brook east of Walton, NY, lower site
Neversink	0143400680	E Branch Neversink R NE of Denning, NY ("Tisons"); upper site
	01434021	W Branch Neversink R nr Winisook nr Frost Valley; upper site
	01434025	Biscuit Brook at Frost Valley, NY; upper site
	NCG	Neversink River near Claryville, NY; lower site

Sampling Frequency

Monthly baseflow samples will be collected during the approximately 8 months of non-freezing conditions. During the remaining 4 months baseflow samples will be collected every two weeks. Baseflow samples will be collected manually. Six storms will be sampled annually to capture range in runoff conditions at each site. Storm samples will be collected with automatic stream sampling equipment. For each storm event, five to eight samples will be analyzed. The samples will be distributed throughout the rising and falling limbs of the hydrograph.

Analytes

Stream water samples are analyzed for the following analytes (see Objective 2.1 for justification):

A. Major Cations
- Calcium
- Magnesium
- Potassium
- Sodium

B. Major Anions
- Chloride
- Fluoride
- Sulfate

C. Nitrogen
- Ammonium
- Nitrate
- Total Nitrogen
- Dissolved Organic Nitrogen

D. Phosphorus
- Orthophosphate
- Dissolved Phosphorus
- Total Recoverable Phosphorus

E. Silicon

F. Aluminum (included because of possible mobilization in acidified conditions)
- Aluminum
- Total Monomeric Aluminum
- Organic Monomeric Aluminum

G. Acid Neutralizing Capacity

H. Conductivity

I. pH

J. DOC

K. Temperature
L. TSS

Data Analysis Protocol

Data from baseflow and storm samples will be used to compute loadings coefficients for those analytes listed above and relate them to the different land These data will help aid managers and scientists assess the impact of farming best management practices and changes in land use patterns that occur impact water quality. Water quality monitoring data from the upper and lower used to identify the most effective management strategies.

Time of Study

On-going. Will be reviewed in five years.

Objective 2.3: Reservoir Modeling Support

To provide long-term tributary water quality load data for the Reservoir Modeling Program so that "hindcasting" reservoir water quality (eutrophication) models can be calibrated under a variety of environmental conditions.

Sites

Sampling will be conducted at all gauged tributary sites for each reservoir so that the best estimate of nutrient loads can be obtained. To obtain the necessary data, sites closest to the mouth of gauged inflows are required. Release and spill sites are also required (for budget purposes). Stream monitoring sites are as follows:

Table 2.11. Hydrology sampling sites for reservoir modeling support.

Reservoir	Inflow Site(s) (parentheses = no storm sampling conducted)
Cannonsville	WDBN; (C7)
Pepacton	(PMSB); (P13); P60; P21; PMG
Neversink	NCG
Rondout	(RDOA; RGB)
Schoharie	S5I; S7I; S6I
Ashokan	E16I; (E10I)
West Branch	(HORSEPD)

Releases: CNB, PDB, NB, RB, WESTBRR, SRR2, BOYDSR
Spills: SS, ASP

Sampling Frequency

Inflows

There are two facets to the assessment of loads, viz., fixed frequency and stormflow. The monitoring strategy for each is different. To obtain the required data for reservoir water quality monitoring, storm event and twice-monthly fixed frequency sampling is required (Walker 1987; Effler, S.W., Upstate Freshwater Institute (UFI), pers. comm.).

Fixed Frequency: All gauged inflow sites are to be sampled twice-monthly *except* for the West Branch and Rondout Reservoir tributaries for which monthly sampling is adequate. All releases and spills will be sampled monthly.

Storm events At this time, event monitoring will be conducted at the major inflow sites for Neversink, Pepacton, Ashokan and Schoharie Reservoirs. For the Cannonsville Reservoir inflow (West Branch Delaware River) monitoring will not be required beyond 2002. Because of the immense volume of water provided by the aqueducts and tunnels to Rondout and West Branch Reservoirs, storm event monitoring will not be necessary for streams tributary to these reservoirs for reservoir modeling purposes. Monitoring will alternate on an annual basis between Neversink and Pepacton reservoir inflows in the Delaware District and Ashokan and Schoharie reservoir inflows in the Catskill District. A schedule is outline below. Sampling and data reporting will be conducted on a calendar year basis.

Reservoirs	Calendar Years
Ashokan & Pepacton	2002, 2004
Schoharie & Neversink	2003, 2005
Cannonsville	2002

Requirements for storm monitoring are somewhat subjective and less easy to precisely define. Storm monitoring efforts should obtain samples from six or more events per year. As much as possible, event sampling should be distributed throughout the year which includes spring snow melt and major summer storms. This is required for a minimum of 2 years for each reservoir. Loads are required to be as accurate as possible. In addition spring snowmelt events and summer storms are required.

Analytes

All analytes specified below are variables for the reservoir water quality models and are thus required for this objective.

Table 2.12. List of analytes for reservoir modeling support.

phosphorus:	TP, TDP, SRP
nitrogen:	NO_x-N, TDN (TDN is analyzed on fixed frequency samples and only at the following sites during storm event monitoring: PMG, NCG, E16I, S5I), NH_3 (only analyzed on fixed frequency samples)
carbon:	DOC
other:	Flow, turbidity, conductivity, temperature, (conductivity and temperature on fixed frequency samples only)

Meteorological Requirements: The meteorological requirements for the reservoir model include temperature, photosynthetically active radiation (PAR), solar radiation, wind speed, wind direction and relative humidity.

Data Analysis Protocol

Daily loads will be calculated by multiplying concentration by mean daily flow. Linear interpolation will be used to estimate analyte concentration between sampling days. The product of mean daily flow and estimated concentration from linear interpolation will be the estimated daily load. Storm loads will be partitioned between days such that daily loads will reflect the contribution from base load and storm load for that day. Daily loads will be calculated by Hydrology Program staff using USGS provisional data and forwarded to Reservoir Modeling in a format that includes raw data and computations used. Once final USGS data become available, any corrections will be made by Hydrology Program staff and forwarded to Reservoir Modeling. Meteorological data will be reported to Reservoir Modeling as requested.

Time for Study

An evaluation of the model needs will be conducted by the Reservoir Modeling staff after 2 years of data collection for each reservoir.

Objective 2.4: Terrestrial Modeling Support

To provide stream water quality load data for the Terrestrial Modeling Program to calibrate and validate current terrestrial water quality models and to assist in the further development and improvement of these models.

Long-term stream water quality data is used for optimization, verification and continued improvement of the Generalized Watershed Loading Function (GWLF) model, DEP's watershed scale terrestrial water quality model. Monitoring of nutrients and solids to the reservoirs are required to calibrate and verify DEP's watershed scale model for reservoir loads. Obtaining this data requires the monitoring of the major tributaries to the reservoirs. Additionally, effective model development requires meteorological data.

Water quality data is necessary for estimating the loads to the Cat/Del system reservoirs. These reservoir loads are important to a number of DEP efforts including:

- Daily and monthly reservoir loads for input into reservoir water quality models being validated by DEP.
- Estimation of effects of land management scenarios on reservoir loadings.
- Support in evaluating the TMDL through annual and monthly reservoir loading estimates.

Water quality monitoring at this scale should be focused on providing daily and monthly reservoir loads for verification of DEP's watershed scale model (GWLF) under a wide variety of hydrologic conditions. This requires monitoring of major reservoir tributaries during both storm events and interstorm periods.

Sites

Loads are required for each of the major streams entering the reservoirs. Sites which do not include a flow gauge are of considerably less value for terrestrial modeling efforts, therefore only sites with USGS gauges are listed below.

Table 2.13. Hydrology sampling sites for terrestrial modeling support.

Reservoir	Inflow Site(s) (parentheses = no storm sampling conducted)
Cannonsville:	WDBN (conducted by DEC under contract)
	(C7)
Pepacton:	(PMSB)
	PMG [1]
	P21
	P60
	(P13)
Neversink:	NCG
Rondout:	RDOA
	RGB
Schoharie:	S5I
	S7I
	S6I
Ashokan:	(SRR2)
	E16I
	(E10I)
West Branch	WESTBR7
	(HORSEPD)

[1] storm event monitoring only

Sampling Frequency

To date, the GWLF model has been developed as both a daily and a monthly loading model. As such, both daily and monthly loads to the reservoirs are required for verification of modeling results. To obtain the required data storm events and twice monthly fixed frequency sampling are required. Storm monitoring efforts should obtain sampling from six or more events per year. As much as possible, event sampling should be distributed throughout the year which includes spring snow melt and major summer storms.

Analytes

Flow, TDP, TP, SRP, TSS, DOC NO_x–N, TDN (TDN is analyzed on fixed frequency samples and only at the following sites during storm event monitoring: RDOA, WESTBR7, PMG, NCG, E16I, S5I), NH_3 (only analyzed on fixed frequency samples).

Meteorological Requirements:

The meteorological requirements for the watershed scale model (GWLF) include daily precipitation and daily minimum and maximum temperature. These data are currently collected as part of Hydrology's meteorological monitoring network.

Data Analysis Protocol

Both daily and monthly loads will be calculated by multiplying concentration with mean daily flow. Linear interpolation will be used to estimate analyte concentration between sampling days. The product of mean daily flow and estimated concentration from linear interpolation will be the estimated daily load. Storm loads will be partitioned between days such that daily loads will reflect the contribution from base load and storm load for that day. Daily loads will be calculated by Hydrology Program staff (except for WDBN where DEC will provide load data) using USGS provisional data and forwarded to Terrestrial Modeling in a format that includes raw data and computations used. Once final USGS data become available, any corrections will be made by Hydrology Program staff and forwarded to Terrestrial Modeling. Meteorological data will be reported to Terrestrial Modeling as requested.

Time of Study

An evaluation of the model needs will be conducted after 2 years of data collection.

Reservoirs	Calendar Years
West Branch, Ashokan, Pepacton,	2002, 2004
West Branch, Rondout, Neversink, Schoharie	2003, 2005
Cannonsville	2003, 2004, and possibly 2005

Objective 2.5: Biological Monitoring Support

To provide water quality data for the Water Quality Impact Assessment Program to assess the health of stream benthic communities through the sampling and identification of benthic macroinvertebrates.

Data on stream chemistry is needed in order to develop an understanding of watershed-specific relationships between water quality and the macrobenthic community.

Sites

Site selection justifications: The criteria below are considered when selecting sampling sites for the biomonitoring program.

1. *Are there suspected water quality impacts from an existing pollution source?.*
2. *Are land use changes or BMPs proposed or underway in the vicinity of the site which could change the character of the stream to a degree detectable by qualitative sampling of the benthos?*
3. *Is routine DWQC Hydrology Program sampling conducted near the site which would allow the Water Quality Impact and Assessment Program (WQIA) to examine correlations between chemical or bacterial parameters and the benthic community?*
4. *Is the stream a major tributary of the receiving reservoir?*
5. *Is the site believed to represent relatively unimpaired and/or pristine (reference) conditions for the District?*
6. *May the site contain or has it been shown in the past to contain rare taxa?*

The routine sites are listed below together with the justifications for selection. Additional sites may be added at the discretion of the Program Supervisor. When additional monitoring sites are required, the District Hydrologist will be notified to collect water quality samples at the selected site in accordance with the sampling frequency outlined below.

Catskill District

Table 2.14. Catskill District hydrology sampling sites for bio-monitoring support.

Site #	Reservoir Basin	Location	Justification*
215	Ashokan	Esopus Creek, upstream of Fox Hollow Rd. Crossing in Shandaken, Hydrology site E5	3,5
227	Ashokan	Esopus Creek, upstream of confluence with Woodland Valley Creek	1
202	Schoharie	Schoharie Creek, downstream of Town of Hunter, Hydrology site S3	1,3,4
206	Schoharie	Batavia Kill, upstream of Rt. 23A bridge, Hydrology site S10	3,4

Table 2.14. Catskill District hydrology sampling sites for bio-monitoring support.

Site #	Reservoir Basin	Location	Justification*
204	Schoharie	Schoharie Creek, upstream of Prattsville Bridge and Hydrology site S5I	3

Delaware District

Table 2.15. Delaware District hydrology sampling sites for bio-monitoring support.

Site #	Reservoir Basin	Location	Justification*
301	Cannonsville	West Branch Delaware River upstream of Hydrology site WDHOA in Hobart	3
304	Cannonsville	West Branch Delaware River, downstream from Walton WWTP outfall, Hydrology site WSPB	1,3,4
320	Cannonsville	West Branch Delaware River at Hydrology site WDBN	3,4
307	Neversink	Aden Brook, downstream of Aden Road crossing, monitoring site NK4	2,
316	Pepacton	East Branch Delaware River. Hydrology site PMSB	1,3,4
330	Pepacton	Bush Kill, off Old Rt. 28, Hydrology site PBKG	2,3
321	Pepacton	East Branch Delaware River, above Old River Road crossing in Roxbury, Hydrology site EDRB	1,3,4

East of Hudson

Table 2.16. East of Hudson District hydrology sampling sites for bio-monitoring support.

Site #	Reservoir Basin	Location	Justification*
101	East Branch	Brady Brook, Hydrology site BB5	2
109	East Branch	East Branch of Croton River, Hydrology site EASTBR	2,3,4
134	New Croton	Hunter Brook, Hydrology site HUNTER1	3
107	New Croton	Kisco River, approximately 10 meters upstream of Rt.133 bridge, site KISCO5	3,4
112	Amawalk	Muscoot River, Hydro site MUSCOOT10	3,4
103	West Branch	Horse Pound Brook, approximately 1 km north of West Branch Reservoir	3,4

* See list of justifications above

Sampling Frequency

Two base flow water quality samples are to be collected during the month of the benthic sampling (August for East of Hudson and September for West of Hudson).

Analytes

A parametric correlation analysis on 1996 and 1997 data separately was conducted between the routine hydrology data set and the metric values calculated from the macrobenthic samples. The following analytes yielded a significant ($p < 0.05$) relationship with at least one of the metrics: pH, Conductivity, Temperature, Dissolved Oxygen, Chloride, NO_x–N, TP, TDP, Fecal Coliform, TOC, Turbidity, and TSS. These are the required analytes for this objective.

Data Analysis Protocol

There are three ways in which relationships between stream chemistry and the macrobenthos are planned to be explored: (1) simple linear correlation between analytes and metrics used to describe the biological data, (2) after clustering the sites based on their taxa lists, examining whether or not significant differences exists in stream chemistry between sites within a given cluster, and (3) after clustering the sites based on their taxa lists, examining whether or not significant differences exist in stream chemistry data between clusters. Ultimately, DEP would like to describe one or more reference macrobenthic communities, and the chemical concentrations associated with the reference community(ies) will help connect biological and water quality goals.

Time of Study

On-going

Objective 2.6: Assessment of Waste Water Treatment Plant Effects on Streams

To provide appropriate water quality data for the WQIA Program to determine if wastewater treatment plant discharges are degrading water quality downstream from selected plants, as defined in Addendum E of the DEC/DEP MOU.

Sites

Monitoring locations are located above and below selected WWTP effluents.

Catskill District

Table 2.17. Catskill District hydrology sampling sites for the assessment of waste water treatment plant effects on streams.

WWTP	Sites
Tannersville	S1, S2
Grand Gorge	S8, S9
Pine Hill	E3, E15

Delaware District

Table 2.18. Delaware District hydrology sampling sites for the assessment of waste water treatment plant effects on streams.

WWTP	Sites
Stamford	WDSTM, WDSTB
Hobart	WDHOM, WDHOB
South Kortright,	SKTPA, SKTPB
Delhi	DTPA, DTPB
Walton	WSPA, WSPB
Roxbury Run	EDRA, EDRB
Margaretville	PMSA, PMSB
Grahamsville	RGA, RGB

Industrial Discharge	Sites
Dairyvest	CPB, CDVA, CDVB
Moutainside Farm	PSR, DCDA, DCDB

East of Hudson District

Table 2.19. East of Hudson District hydrology sampling sites for the assessment of waste water treatment plant effects on streams.

WWTP	Sites
Yorktown Heights	HMILL4, HMILL7

Sampling Frequency

According to Addendum E of the DEC/DEP MOU which describes a one-tailed paired-difference t-test for determining whether or not a WWTP is discharging unacceptable amounts of a given analyte, 12 data points over a 12 month period are required for analysis, hence monthly sampling. Samples need to be collected above and below target discharges.

Analytes

The list of analytes specified in Addendum E or specifically requested by the Program Supervisor are: pH, Conductivity, Temperature, DO, Total/Fecal Coliform, TP, SRP, NH_x-N, NO_x-N.

These analytes are generally sufficient to track plant performance, but other analytes may be needed on a case-by-case basis.

Data Analysis Protocol

Water quality data downstream of the discharge is examined for violations of State Aquatic Water Quality Standards (AWQS). If the difference is not significantly less than the allowable difference, the WWTP is assumed to be the source of the AWQS violation. All enforcement actions are coordinated between DEC & DEP.

Time of Study

On-going. The necessity to continue monitoring each site will be addressed on a regular basis.

Objective 2.7: BMP Assessments

To assess the effects of stream remediation measures (Best Management Practices (BMPs)) on stream water quality.

Objective 2.7.1: Assessment of BMPs on Turbidity Reduction in the Batavia Kill Sub-Basin

The Stream Management Program of DEP is implementing best management practices (BMPs) to reduce the sediment and turbidity originating in the Red Falls area of the Batavia Kill sub-basin of the Schoharie Watershed. This study will quantify any change in turbidity and sediment load, which might occur due to the installation of these BMPs. This will be done by monitoring water quality above and below the sediment source area, both before and after BMP installation.

Sites

Sites were chosen above and below selected stream reaches where BMPs will be installed based upon the Stream Management Programs data requirements.

Table 2.20. Hydrology sampling sites for the assessment of BMPs on turbidity reduction in the Batavia Kill sub-basin.

Site Code	Location
S10.	Batavia Kill downstream of both BMP zones. Samples collected just upstream from the Rt. 23A bridge, near the confluence of the Batavia Kill and Schoharie Creek.
S10-RF.	Batavia Kill immediately upstream from Red Falls, between the Red Falls and Conine BMP zones.
S10-1.	Batavia Kill upstream of both BMP zones. Samples collected adjacent to the lands of Robert and Diana Corson, Rt. 23, just upstream of Red Falls.
SBB.	Brandau Brook, a small tributary that enters the Batavia Kill immediately below Red Falls, between S10-RF and S10.

Sampling Frequency

Storm events only: Samples from approximately 10 events per year will be submitted for TSS and turbidity analyses.

Analytes

Total suspended solids (TSS), Turbidity, Flow

Data Analysis Protocol

Data will be analyzed to determine if the BMP had a measurable impact on TSS and turbidity in the stream. Analysis will be on-going during the project so that staff remain aware of conditions at the sites.

Calculations and Equations (example)

Ratio method. If there was no difference in total suspended sediment load between sites S10 and S10-1, the ratio of the sites would equal one ($TSS_{(S10)}$: $TSS_{(S10-1)}$ = 1). If the sediment load was higher at the downstream site (S10), then the ratio would be greater than one ($TSS_{(S10)}$: $TSS_{(S10-1)}$ > 1); previous sampling has shown this to be the case. If the BMPs are effective, this ratio will decrease. The more effective the BMPs, the closer to one the ratio will become. This should be true for turbidity also. These ratios will be calculated for each storm, before and after BMP installation, and presented as bar graphs. Visual inspection will permit assessment of the effectiveness of the BMPs.

Sediment load calculation. Sediment load will be calculated for each high runoff event (rain storm, snowmelt, etc.) for which samples have been analyzed. The "instantaneous" load is calculated for each sample analyzed, then summed over all samples to obtain total storm load.

Time of Study

Start date: Spring, 1998.

End date: Sampling ends 12/31/05. Final report expected to be issued by 10/1/06.

Objective 2.7.2: Assessment of BMP Effectiveness in Two New Croton Reservoir Sub-Basins

This sub-objective will identify water quality effects from land use changes and the construction of best management practices by initiating and providing high runoff event monitoring in a manner that is sufficient to identify the effects of land use changes, including the construction of best management practices, on high runoff water quality. Specifically, loads and event mean

concentrations of total phosphorus, total dissolved phosphorus, NO_x-N, total suspended solids and dissolved organic carbon, calculated during high runoff events, will be compared between impact monitoring locations and control monitoring locations.

Sites

1) French5: located downstream of a proposed golf course in the Town of Yorktown, on an unnamed tributary to the New Croton Reservoir watershed;
2) Cathy7: located downstream of a proposed high density housing development, in the Town of Yorktown, on a tributary of Hunter Brook, within the New Croton Reservoir watershed;
3) White5: located as a reference site, downstream from Westchester County Parkland in the Town of Yorktown, on an unnamed tributary to the New Croton Reservoir.

Sampling Frequency

Fixed frequency samples are collected twice monthly. High runoff event monitoring samples are collected during storm events; we expect to monitor 8 storm events each year, with 10 samples collected from each site during each event. Storm event samples will be submitted to a contract lab for analysis.

Analytes

Total Phosphorus, Total Dissolved Phosphorus, NO_x-N, Total Suspended Solids, Dissolved Organic Carbon.

Data Analysis Protocol

Nutrient loads will be calculated by the integrated loading method described in Longobucco and Rafferty (1998). The mean nutrient concentration between two sampling points will be multiplied by the total volume of flow recorded between these two sampling points. The loads calculated for each interval will be summed to determine the total load for the storm. Loads and Event Mean Concentrations will be compared as described in the EPA "Paired Watershed Study Design" fact sheet (841-F-93-009).

Time of Study

The study will proceed as funding permits. We anticipate monitoring the sub-basins for a period of up to two years before construction activities begin at the development sites. We expect construction to continue for another two years. Following construction, we anticipate monitoring an additional five years to evaluate post-construction stream responses. These time frames may change as the land owners await permit approvals and construction contracts.

Objective 2.7.3: Assessment of BMP Effectiveness on Kensico Reservoir Tributaries

A) To quantify the fecal coliform and total suspended solids load reductions that can be attributed to extended detention basins constructed on Kensico watershed streams.

B) To quantify the total phosphorus load reduction that can be attributed to extended detention basins constructed on Kensico watershed streams.

Sites

The table below provides each monitoring locations BMP Facility Number, sub-basins designation, and sampling location site code.

Table 2.21. Hydrology sampling sites for the assessment of BMP effectiveness on Kensico Reservoir tributaries.

Facility Number	Sub-basin	Sampling Location Site Codes
2	MB	MB-8, MB-9
12	MB	MB-1, MB-3, MB-4
13	N1	N1-1,N1-2
18	N2	N2-1, N2-2
2A	N3	N3-1, N3-2
23	N4	N4-1, N4-2
37	N5	N5-1, N5-2, N5-3
66	BGC8	BGC8-1, BGC8-2, BGC8-3
67	BGC5	BG-1, BG-2, BG-3
75	E11	E11-1, E11-2, E11-3

Sampling Frequency

In order to evaluate the effectiveness of all BMPs, we will monitor one or two BMPs each year, then rotate equipment to the rest of the BMPs until all of the BMPs have been monitored. We expect to monitor between 6 and 10 storm events during the course of a monitoring year, with approximately 10 samples collected from each site during each storm event.

Analytes

Fecal Coliform, Turbidity, Total Suspended Solids, Total Phosphorus

Data Analysis Protocol

Results of monitoring will be reported to EPA annually in the Kensico Watershed Management Report. Results to be reported will include:

i) Sites monitored during the period;

ii) Number of storm events monitored and samples collected during the period;

iii) For each extended detention basins monitored, a comparison of input and output loads of fecal coliform, total suspended solids, and total phosphorus on a storm by storm and median annual load basis; and comparison of input and output turbidity levels and duration of elevated turbidity;

iv) Problems that occurred during the period;

v) Recommendations for future work.

Fecal coliform data that is returned with < detection limit will be considered as zero cfu/100ml. Data with codes of ≥ will use the value given.

Extended detention basin input and output loads for fecal coliform bacteria, total suspended solids (TSS), total phosphorus will be calculated by the integrated loading method (Longobucco and Rafferty, 1998). Peak turbidity levels entering and exiting the BMPs will be compared, as well as the duration of elevated turbidity levels. The output load will be subtracted from the input load for each storm. The remainder will be divided by the input load, and multiplied by 100, providing a percent removal rate for each storm. The median percent removal rate of the ten storms monitored at each extended detention basin will be considered as the annual high runoff pollutant removal efficiency for each extended detention basin. The design values for each extended detention basin are given in the table below.

Table 2.22. Design values for extended detention basins.

Basin Number	Sub-basin	Design Storm (inches of rainfall)	Design TSS Removal Efficiency	Design Fecal Coliform Bacteria Removal Efficiency
12	Malcolm Brook	1.0	86%	65%
13	N1	1.5	91%	60%
18	N2	0.5	81%	41%
2A	N3	0.9	60%	38%
23	N4	1.4	72%	52%
37	N5	1.2	78%	54%
66	BGC8	1.5	95%	64%
67	BGC5	0.8	77%	59%
75	E11	1.0	96%	70%

Time of Study

Start date: 2002.

End date: 2010

Objective 2.8: Policy and Management Based Surveillance Monitoring

To monitor selected water quality analytes at selected sites that focus on DEP's water quality policy /management goals and policy formulation, which are not addressed by other existing water quality monitoring efforts.

Sites, Sample Frequency, and Analytes

Sites, sample frequency and analytes will be determined based upon fulfilling DEP's specific short and long term policy and management goals and objectives as requested by management.

Objective 2.8.1: Trace and Other Metal Occurrence Monitoring

To compare ambient stream water metals concentrations to the Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the EPA National Primary and Secondary Drinking Water Standards.

Sites

Water quality monitoring sites for metals occurrence monitoring are located at two locations on the major tributary to Schoharie and Pepacton Reservoirs. These sites are at or near the USGS gauging stations situated at the terminal end of each reservoirs major tributary and an upstream site located centroid in the watershed, on the main stem of that tributary. For Neversink and Rondout Reservoirs, only the terminal site of major tributaries of been selected. For Ashokan and Cannonsville Reservoir watersheds three sites have been selected. Because of the cascading design of the reservoir system East of Hudson, sites have been selected on each reservoirs main tributary and release. Sampling dates for this objective will coincide with the sampling dates for monthly fixed frequency monitoring (Objective 2.1).

Catskill District

Table 2.23. Catskill District hydrology sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site
Ashokan Watershed	E16I, E5, SRR2
Schoharie Watershed	S5I, S4

Delaware District

Table 2.24. Delaware District hydrology sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site
Cannonsville	WDBN, CDG, WDHOA
Pepacton	PMSB, PROXG
Neversink	NCG
Rondout	RDOA, RGB

East of Hudson District

Table 2.25. East of Hudson District hydrology sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site
Croton River	WESTBR7, BOYDR, HORSEPD1,GYPSYTRL1, MIDBR3, WESTBRR, EASTBR, MIKE2, BOGEASTBRR, DIVERTR, CROFALLSR, MUSCOOT10, TITICUSR, TITICUS1, PLUM2, AMAWALKR, CROSSRVR, CROSS2, MUSCOOT5, HUNTER1, STONE5, KISCO3

Sample Frequency

Samples are to be collected during the months of February, May, August and November. Metals sampling should coincide with the monthly fixed frequency monitoring (Objective 2.1).

Analytes

The Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the EPA National Primary and Secondary Drinking Water Standards will be applied to the selected toxic and other metals listed below. Flow, TSS and turbidity are also required to assist in data interpretation.

Total: Ag, Al, As, Ba, Be, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sb, Se, Tl, Zn

Data Analysis Protocol

Metal concentrations will be reviewed on a quarterly basis and compared to Part 703.5 and EPA National Primary and Secondary Drinking Water Standards. Additional samples may be collected within the basin as necessary.

Time of Study

On-going

Table 2.26. Water Quality Surface Water Standards from Part 700.

Analyte (class waters)	Type	Standard (µg/l)
Total Ag (A,AA)	H(WS)	50
Total As (A,AA)	H(WS)	50
Total Ba (A,AA,)	H(WS)	1,000
Total Cd (A,AA)	H(WS)	5
Total Cr (A,AA)	H(WS)	50
Total Cu (A,AA)	H(WS)	200
Total Hg (A,AA)	H(WS)	0.7
Total Mg (A,AA)	H(WS)	35,000
Total Mn (A,AA)	H(WS)	300
Total Ni (A, AA)	H(WS)	100
Total Pb (A,AA,)	H(WS)	50
Total Sb (A,AA)	H(WS)	3
Total Se (A,AA,B,C)	H(WS)	10

Table 2.27. EPA National Primary and Secondary Drinking Water Quality Standards.

Analyte	Primary Standard (µg/l)	Secondary Standard (µg/l)
Ag		100
Al		50-200
As	10	
Ba	2,000	
Be	4	
Cd	5	
Cr	100	
Cu	1,300	
Cu		1,000
Fe		300
Hg	2	
Mn		50
Pb	0	
Sb	6	
Se	50	
Tl	0.5	
Zn		5,000

Objective 2.8.2: Kensico and West Branch Reservoirs Tributary Monitoring

To monitor streams tributary to Kensico Reservoir and West Branch Reservoir, where additional surveillance is desired.

Sites

Table 2.28. Hydrology sampling sites for source water tributary monitoring.

Reservoir Basin	Site
West Branch	WESTBR7, LEETOWN3, HORSEPD1, GYPSYTRL1, LONGPD1
Kensico	WHIP, N12, N5-1, MB1, BG-1, E9, E10, E11

Sampling Frequency

Monthly

Analytes

For all sites *except E9 and E10:* Fecal Coliform, Total Coliform, pH, Specific Conductivity, Dissolved Oxygen and Temperature, Turbidity, Alkalinity, Chloride, NH_3-N, NO_x-N, TN, DOC, TP, TSS, VSS.

For sites *E9 and E10*: Fecal Coliform, Total Coliform, pH, Field Specific Conductivity, Dissolved Oxygen and Temperature, Turbidity

Data Analysis Protocol

Data will be reviewed monthly and reported as requested, or if major perturbations are noted in the data.

Time of Study

On-going

Objective 2.8.3 Croton Watershed Consent Decree Monitoring

In accordance with the Croton Watershed Consent Decree, "During the term of this Consent Decree, the City shall conduct the following sampling for coliforms… for at least 40 sites in streams throughout the Croton watershed".

Sites

COLABAUGH1, CORNELL1, ILLINGTON1, KITCHAWAN1, NCBAILEY, PURDY1, SAWMILL1, CATHY7, WHITE5, FRENCH5, HORSEPD1, GYPSYTRL1, LONGPD1, BOYDR, WESTBRR, WESTBR7, LEETOWN3, CROSSRVR, CROSS2, TITICUSR, TITICUS1, MUSCOOT10, AMAWALKR, MIKE2, CROFALLSR, STONE5, HMILL7, HMILL4, PLUM2, MUSCOOT5, DIVERTR, BOGEASTBRR, EASTBR, EBCR3, HH7, MUDTRIB1, BB5, MIDBR3, KISCO3, HUNTER1,

Sampling Frequency

Twice monthly

Analytes

Fecal Coliform, Total Coliform

Data Analysis Protocol

Data will be reviewed monthly and included in the Croton Water System Consent Decree Monitoring Reports.

Time of Study

Until the terms of the Croton Consent Decree are satisfied

2.3 Summary of Hydrology Monitoring Program

The monitoring network described above was constructed from a compilation of Objectives derived from DEP's information needs and was assisted by a review of legally binding mandates, agreements, and reports pertaining to New York City's watershed water quality monitoring program. Because of the complexity of the Program, it is summarized below as a series of tables. The tables contain: the number of sites included in each Objective for the three watersheds separately; a list of analytes measured for each objective; and a list of sites (codes) included in each Objective for each of the three watersheds. The tables are followed by maps depicting the sites visited for each objective.

Table 2.29. Number of sites by objective in each system.

System	Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6
Catskill	25	5	8	6	5	6
Delaware	31	8	14	10	6	22
East-of-Hudson	27	0	3	2	6	2
Grand Total	83	13	25	18	17	30
System	Obj. 2.7.1	Obj. 2.7.2	Obj. 2.7.3	Obj. 2.8.1	Obj. 2.8.2	Obj. 2.8.3
Catskill	4			5		
Delaware				8		
East-of-Hudson		3	10	20	13	40
Grand Total	4	3	10	33	13	40

Table 2.30. List of analytes by objective.

Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.1	Obj. 2.7.2	Obj. 2.7.3	Obj. 2.8.1	Obj. 2.8.2	Obj. 2.8.3
TEMP	TEMP	TEMP	FLOW	TEMP	TEMP	FLOW	TP	TURB	FLOW	TEMP	FCOLI
FLOW	FLOW	FLOW	TP	DO	DO	TURB	TDP	FCOLI	TURB	DO	TCOLI
DO	PH	COND	TDP	PH	PH	TSS	NO_x--N	TP	TSS	PH	
PH	TURB	TURB	SRP	COND	COND		DOC	TSS	Ag (Total)	COND	
COND	TSS	TP	TDN	TURB	FCOLI		TSS		Al (Total)	TURB	
TURB	ALK	TDP	NO_x-N	FCOLI	TCOLI				As (Total)	FCOLI	
y_{BD}	TP	SRP	NH_x-N	TP	TP				Ba (Total)	TCOLI	
FCOLI	TDP	TDN	DOC	TDP	SRP				Be (Total)	ALK	
TCOLI	SRP	NO_x-N	TSS	NO_x-N	NO_x-N				Cd (Total)	TP	
ALK	TN	NH_x-N		CL	NH_x-N				Cr (Total)	TN	
TP	NO_x-N	DOC		TOC					Cu (Total)	NO_x-N	
TDP	NO_x-N			TSS					Cu (Total)	NO_x-N	
SRP	DON								Fe (Total)	CL	
TN	CL								Hg (Total)	DOC	
TDN	FL								Mg (Total)	TSS	
NO_x-N	SO4								Mn (Total)	VSS	

Table 2.30. List of analytes by objective.

Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.1	Obj. 2.7.2	Obj. 2.7.3	Obj. 2.8.1	Obj. 2.8.2	Obj. 2.8.3
NO_x-N	SI								Ni (Total)		
SiO_2	Ca (Dissolved)								Pb (Total)		
SO_4	K (Dissolved)								Sb (Total)		
CL	Mg (Dissolved)								Se (Total)		
DOC	Na (Dissolved)								Tl (Total)		
TOC	Al (Total and organic monomeric)								Zn (Total)		
TSS											
Ca (Dissolved)											
K (Dissolved)											
Mg (Dissolved)											
Na (Dissolved)											

Table 2.31. List of sites by objective.

System	Site Code	Obj 2.1	Obj 2.2	Obj 2.3	Obj 2.4	Obj 2.5	Obj. 2.6	Obj 2.7.1	Obj 2.7.2	Obj 2.7.3	Obj 2.8.1	Obj 2.8.2	Obj 2.8.3
Catskill													
	ABCG	X											
	ABKHG	X	X										
	AEAWDL					X							
	AEBP	X											
	AEHG	X											
	ASCHG	X	X										
	ASP (spill)			X									
	BK	X											
	BNV	X											
	BRD	X											
	E10I	X		X	X								
	E15						X						
	E16I	X		X	X						X		
	E3						X						
	E5	X				X					X		
	LBK	X											
	S1						X						
	S10	X	X			X		X					
	S10-1							X					
	S10-RF							X					

Table 2.31. List of sites by objective.

System	Site Code	Obj 2.1	Obj 2.2	Obj 2.3	Obj 2.4	Obj 2.5	Obj. 2.6	Obj 2.7.1	Obj 2.7.2	Obj 2.7.3	Obj 2.8.1	Obj 2.8.2	Obj 2.8.3
	S2						X						
	S3					X							
	S4	X									X		
	S5I	X		X	X	X					X		
	S6I	X		X	X								
	S7I	X		X	X								
	S8						X						
	S9						X						
	SBB							X					
	SBKHG	X	X										
	SCL	X	X										
	SEK	X											
	SRR2 (release)	X		X	X						X		
	SS (spill)			X									
	SSHG	X											
	STHHG	X											
	SWK	X											
	SWKHG	X											
	WDL	X											
Total		25	5	8	6	5	6	4			5		
Delaware													
	C-7	X		X	X								
	C-8	X											
	CCBHG	X											
	CDG	X									X		
	CDVA						X						
	CDVB						X						
	CEBG	X	X										
	CEBHG	X	X										
	CLDG	X											
	CNB			X									
	CPB						X						
	CSBG	X											
	CTNBG	X	X										
	CTNHG	X	X										
	DCDA						X						
	DCDB						X						
	DTPA						X						
	DTPB						X						
	EDRA						X						
	EDRB					X	X						
	NB			X									
	NCG	X	X	X	X						X		

Table 2.31. List of sites by objective.

System	Site Code	Obj 2.1	Obj 2.2	Obj 2.3	Obj 2.4	Obj 2.5	Obj. 2.6	Obj 2.7.1	Obj 2.7.2	Obj 2.7.3	Obj 2.8.1	Obj 2.8.2	Obj 2.8.3
	NEBG	X											
	NK4					X							
	NK6	X											
	NWBR	X											
	P-13	X		X	X								
	P-21	X		X	X								
	P-50	X											
	P-60	X		X	X								
	P-7	X											
	P-8	X											
	PBKG	X				X							
	PDB			X									
	PDRY	X											
	PMG			X	X								
	PMSA						X						
	PMSB	X		X	X	X	X				X		
	PROXG	X									X		
	PSR						X						
	RB			X									
	RD1	X											
	RD4	X											
	RDOA	X		X	X						X		
	RGA						X						
	RGB	X		X	X		X				X		
	RRHG	X											
	SKTPA						X						
	SKTPB						X						
	WDBN	X		X	X	X					X		
	WDHOA	X				X					X		
	WDHOB						X						
	WDHOM						X						
	WDSTB						X						
	WDSTM						X						
	WSPA						X						
	WSPB					X	X						
	0143400680		X										
	01434021		X										
	01434025		X										
Total		31	8	14	10	6	22				8		
East-of-Hudson													
	AMAWALKR	X									X		X
	BB5	X				X							X
	BG-1/BG-2/BG-3									X			
	BG9											X	

Table 2.31. List of sites by objective.

System	Site Code	Obj 2.1	Obj 2.2	Obj 2.3	Obj 2.4	Obj 2.5	Obj. 2.6	Obj 2.7.1	Obj 2.7.2	Obj 2.7.3	Obj 2.8.1	Obj 2.8.2	Obj 2.8.3
	BGC8-1/BGC8-2/ BGC8-3									X			
	BOGEASTBRR	X									X		X
	BOYDR	X		X							X		X
	CATHY7								X				X
	COLABAUGH1												X
	CORNELL1												X
	CROFALLSR	X									X		X
	CROSS2	X									X		X
	CROSSRVR	X									X		X
	DIVERTR	X									X		X
	ILLINGTON1												X
	E10											X	
	E11											X	
	E11-1/E11-2/E11-3									X			
	E9											X	
	EASTBR	X				X					X		X
	EBCR3	X											X
	FRENCH5								X				X
	GYPSYTRL1	X									X	X	X
	HH7	X											X
	HMILL4						X						X
	HMILL7						X						X
	HORSEPD1	X		X	X	X					X	X	X
	HUNTER1	X				X					X		X
	KISCO3	X									X		X
	KISCO5					X							
	KITCHAWAN1												X
	LEETOWN3	X										X	X
	LONGPD1											X	X
	MB-1											X	
	MB-1/MB-3/MB-4									X			
	MB-8/MB-9									X			
	MIDBR3	X									X		X
	MIKE2	X									X		X
	MUDTRIB1	X											X
	MUSCOOT10	X				X					X		X
	MUSCOOT5	X									X		X
	N1-1/N1-2									X			
	N12											X	
	N2-1/N2-2									X			
	N3-1/N3-2									X			
	N4-1/N4-2									X			

Table 2.31. List of sites by objective.

System	Site Code	Obj 2.1	Obj 2.2	Obj 2.3	Obj 2.4	Obj 2.5	Obj. 2.6	Obj 2.7.1	Obj 2.7.2	Obj 2.7.3	Obj 2.8.1	Obj 2.8.2	Obj 2.8.3
	N5-1											X	
	N5-1/N5-2/N5-3									X			
	NCBAILEY1												X
	PLUM2	X									X		X
	PURDY1												X
	SAWMILL1												X
	STONE5	X									X		X
	TITICUS1	X									X		X
	TITICUSR	X									X		X
	WESTBR7	X			X						X	X	X
	WESTBRR	X		X							X		X
	WHIP											X	
	WHITE5								X				X
Total		27	0	3	2	6	2		3	10	20	13	40
Grand Total		83	13	25	18	17	30	4	3	10	33	13	40

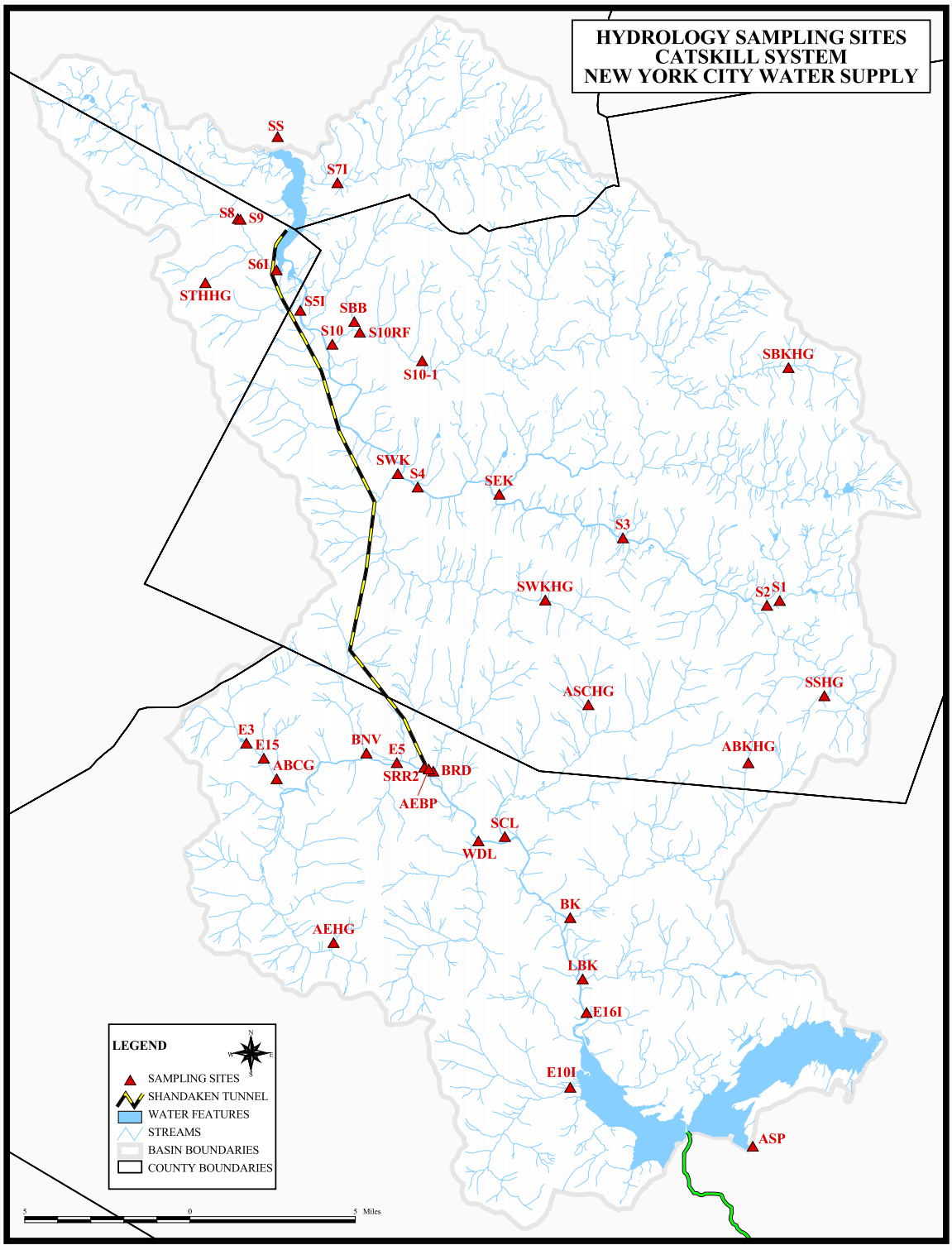

Figure 2.1. Catskill District hydrology sampling sites.

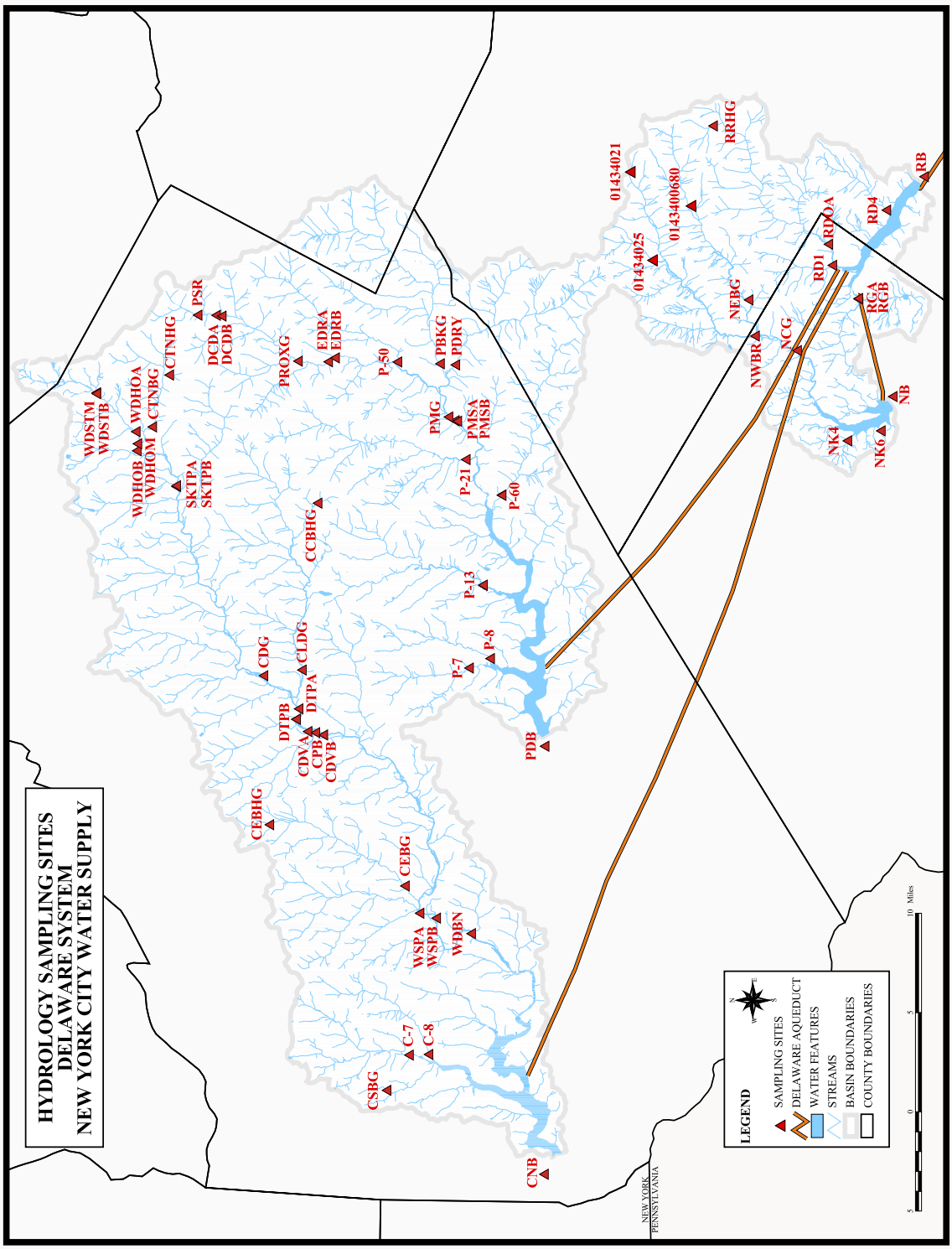

Figure 2.2. Delaware District hydrology sampling sites.

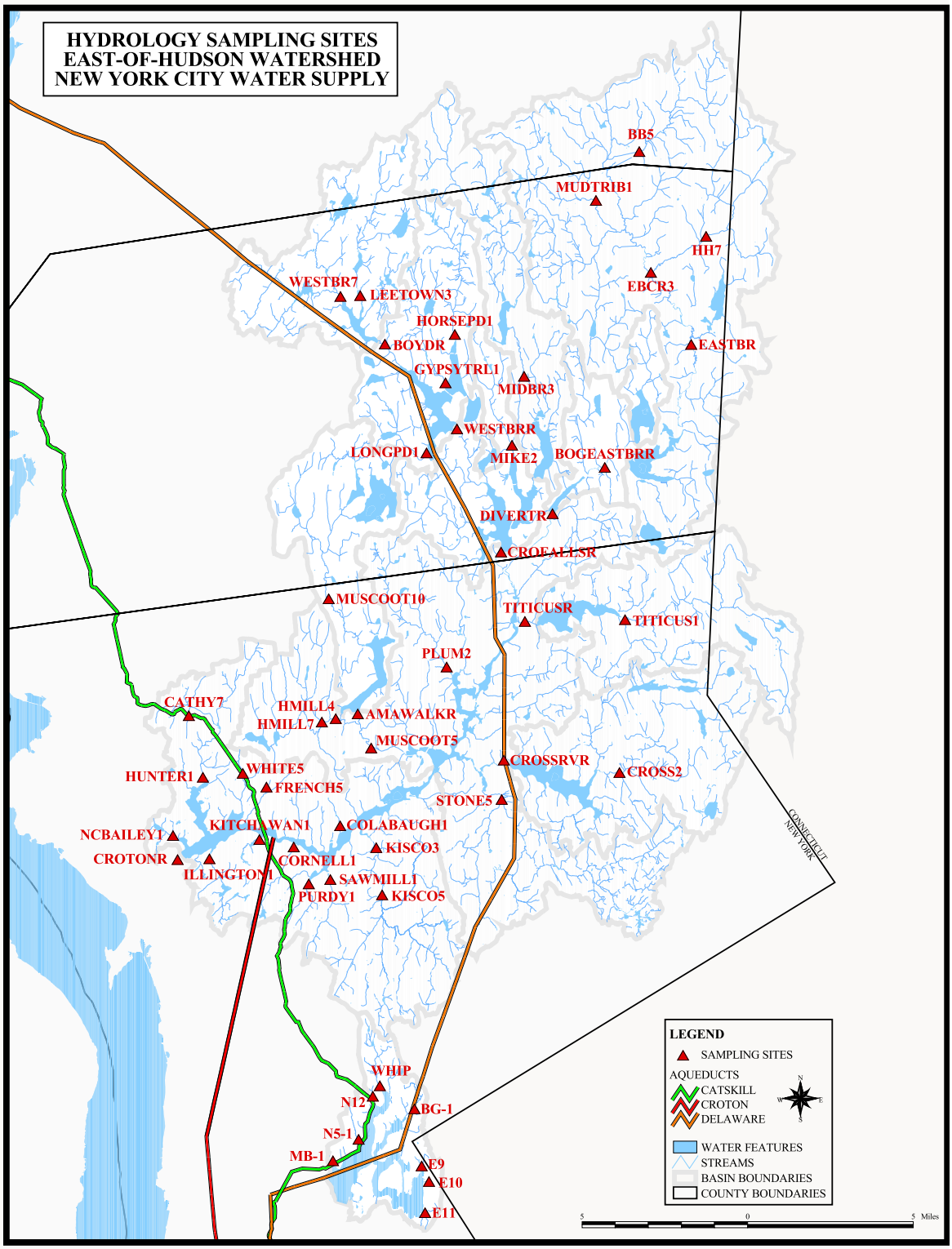

Figure 2.3. East of Hudson District hydrology sampling sites.

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3. Limnology Monitoring Program

3.1 Introduction

This section describes a formalized framework for the water quality monitoring program as conducted by the NYCDEP Limnology Program. It provides the justification and rationale for each monitoring effort as conducted by the Limnology Program. The overall goal of the Program is to establish a reservoir water quality monitoring network which provides scientifically defensible information regarding the understanding, protection, and management of the New York City water supply. The information needs required to achieve this goal are compiled as separate objectives, each of which is clearly defined. The list of objectives was derived from existing and prospective DEP programs, and the review of legally binding mandates, agreements, and documents which pertain to New York City's Watershed Water Quality Monitoring Program.

The Limnology Program consists of five major objectives. Within each objective, site selection, sampling frequency, statistical design criteria, analytes, and data analysis protocol are specified and justified wherever possible. Although objectives are independent, careful consideration and effort was made to compose a monitoring network which integrates and coordinates sampling effort. This integrative approach results in a monitoring framework that is efficient and produces the appropriate water quality information for water supply management.

Reservoir Operations Support, the first objective, will provide management with the data necessary to operate the water supply system's myriad of aqueducts, releases, and diversions in order to supply the best quality water to NYC consumers. It also provides the information necessary to identify the type and severity of any water quality problems as they arise and allows DEP to prepare for any *in situ* treatments, as necessary. The requirements for this objective have been developed and justified by Management.

Reservoir Trend Detection, the second objective, is intended to detect a monotonic trend in the mean value of approximately the standard deviation of the detrended data over a seven year period with reasonable confidence and power. The requirements for this objective have been developed and justified by the Limnology Program staff.

Reservoir Status, the third objective, is based on a fixed frequency monitoring design and is intended to provide an indication of conditions of selected analytes over a short period of time (most recent three years). The requirements for this objective have been developed and justified by the Limnology Program staff.

Reservoir Modeling Support, the fourth objective, is intended to provide limnological data to calibrate, validate and optimize reservoir water quality models to enable them to be of optimal management value. The data will support evaluation of model performance and will expand the environmental conditions under which the models are tested. The requirements for this objective have been developed and justified by the Reservoir Modeling Program staff.

Policy and Management Based Surveillance Monitoring, the fifth objective, is designed to fulfill the Department's water quality policy/management based goals, which are not addressed with other existing water quality monitoring efforts. The specific surveillance monitoring designs (*i.e.,* site selection, sampling frequency, etc.) associated with each monitoring effort, are determined based upon the Department's policy as directed by management. Surveillance monitoring, as defined in this objective, is intended to be of long duration. *Metal Occurrence Monitoring*, the first component of this objective, calls for the collection of samples and comparison to the standards stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and EPA National Primary and Secondary Drinking Water Quality Regulations. *Croton Consent Decree Monitoring*, the second component, addresses the limnological monitoring requirements set forth by the Croton Consent Decree. *Phosphorus Restricted Basin Monitoring* and *Coliform Restricted Basin Monitoring*, the third and fourth components respectively, identify the sampling required for satisfying the data requirements needed to perform the annual assessment of reservoir phosphorus and coliform restriction status as specified in NYCDEP's "Rules and Regulations for the Protection from Contamination, Degradation and Pollution of the New York City Water Supply". The requirements for this objective have been developed and justified by Management.

The network design proposed in this section provides a comprehensive and integrated reservoir water quality monitoring network as performed by the Limnology Program to address New York City's short-term and long-term water quality concerns. Care has been taken to ensure that it is integrated with other Programs (*e.g.*, the Hydrology Program and Keypoints' sampling as performed by Laboratory staff) as appropriate.

3.2 Limnology Program Objectives

Objective 3.1: Reservoir Operations Support

To provide management with the necessary reservoir water quality data for the operation of reservoir aqueducts, releases and diversions.

Sites

Catskill District

Table 3.1. Catskill District limnology sampling sites for management and operations support.

Reservoir	Sites						
Ashokan	1EA	1.4EA	2EA	3EA	3.2EA	4EA	5EA
Schoharie	2SS	3SS					

Delaware District

Table 3.2. Delaware District limnology sampling sites for management and operations support.

Reservoir	Sites			
Rondout	1RR	2RR	3RR	
Neversink	1NN	2NN	3NN	
Pepacton	3EDP	4EDP	5EDP	
Cannonsville	2WDC	3WDC	4WDC	5WDC

East of Hudson District

Table 3.3. East of Hudson District limnology sampling sites for management and operations support.

Reservoir	Sites						
Kensico	1BRK	2BRK	3BRK	4BRK	5BRK		
New Croton	1CNC	1.1CNC	1.2CNC	2CNC	3CNC	4CNC	6CNC
West Branch	1CWB	2CWB	3CWB				

The protocol for determining sampling depths is described in the appendix.

Sample Frequency

Bi-weekly. Additional sampling may be required by management as dictated by conditions. Samples are to be collected from March through December if conditions permit.

Analytes

Turbidity, Conductivity, Color, Temperature, pH, Dissolved Oxygen, Odor, Total Coliform, Fecal Coliform, Phytoplankton[1] (Total and Dominant genus name and count), Sample Depth, Total Fe[2], Mn[2]

1. Plankton analyses will be conducted only on the 3 meter sample at all sites and at all sampling depths at the intake sites.

2. Total Fe and Mn data collected for the operation of the Croton Aqueduct. Samples collected at all depths at sites 1 and 4 as described in Section 2 of the Appendix and at the elevation intakes at sites 1.1 and 1.2 on New Croton Reservoir under stratified conditions.

Reporting Protocol

Results are reported to management in the Reservoir Weekly Water Quality Report.

Objective 3.2: Reservoir Trend Detection

To collect appropriate data so that long-term trends in the most important water quality analytes for the New York City potable water supplies can be determined.

The intention is to be able to detect a monotonic trend in mean value of approximately the standard deviation of the detrended data (*i.e.*, the record after removal of any trend and seasonality) over a seven-year period with reasonable confidence and power.

To ensure that trend analysis reflects *environmental* changes, and not artificially-induced program changes, ideally, there should be *no changes* in any aspect of the monitoring program which may induce a step-trend. Such changes include alterations to field sampling techniques, sample site locations, and time of sampling. Any laboratory changes, such as equipment, filters, and analytical methods must be discussed with the Program supervisor well in advance to discuss the possible ramifications for data analysis. If a change is necessary, preferably there should be a method overlap for one year at the intake sites as a minimum given their importance.

Sites

Samples are to be collected at each of the following sites listed in Tables 3.4 through 3.7 below. The protocol for determining sampling depth is described in the appendix for each analyte unless otherwise affirmed. Aqueduct as well as limnology sites are included due to public interest in water being transferred towards distribution.

Catskill District

Table 3.4. Catskill District limnology sites for trend detection.

Reservoir	Sites				
Ashokan	1EA	2EA	3EA	4EA	5EA
Schoharie	1SS	2SS	3SS		

Delaware District

Table 3.5. Delaware District limnology sites for trend detection.

Reservoir	Site				
Cannonsville	1WDC	2WDC	3WDC	4WDC	5WDC
Pepacton	1EDP	2EDP	3EDP	4EDP	5EDP
Neversink	1NN	2NN	3NN	4NN	
Rondout	1RR	2RR	3RR		

East of Hudson District

Table 3.6. East of Hudson District limnology sites for trend detection.

Reservoir	Site							
Kensico	1BRK	2BRK	3BRK	4BRK	5BRK	6BRK	7BRK	8BRK
New Croton	1CNC	2CNC	3CNC	4CNC	5CNC	6CNC	7CNC	8CNC
Muscoot	1CM	2CM	4CM	6CM				
Amawalk	1CA	3CA						
Cross River	1CCR	3CCR						
Titicus	1CT	3CT						
Croton Falls	1CCF	2CCF	3CCF	4CCF	5CCF			
Diverting	1CD	2CD						
Middle Branch	1CMB	3CMB						
West Branch	1CWB	2CWB	3CWB	4CWB				
East Branch	1CEB	3CEB						
Bog Brook	1CBB	3CBB						
Boyds Corners	1CBC	2CBC	3CBC					

Aqueducts

Table 3.7. Catskill and Delaware District aqueduct sampling sites for trend detection.

Reservoir	Site
Ashokan	EAR
Schoharie	SRR2
Rondout	RDRR
Neversink	NRR2
Pepacton	PRR2
Cannonsville	WDTO
Kensico	DEL17, DEL18, CATALUM, CATLEFF
West Branch	DEL9, DEL10

Sampling Frequency

Samples will be collected monthly from April through November for each analyte listed below. Additionally, samples will be collected on each Catskill and Delaware District reservoir twice monthly at all sites listed above for Total Phosphorus, Total Coliform, Fecal Coliform, and Turbidity. Aqueduct sites will be collected throughout the entire year. The interval between monthly surveys shall not exceed five weeks. After seven years of monthly sampling (n = 63) the confidence and power to detect a trend of approximately 1.15 standard deviations is 85% ($a = \beta = 15\%$) or 1.65 standard deviations if $a = \beta = 5\%$. In other words, the higher the confidence and power required, the greater the trend must be before it can be detected. Thus for a trend to be detected with reasonable confidence and power, *the network must stay fixed for at least seven years to provide a sufficient sample size (n = 63).* As described above for reservoirs in the

Catskill and Delaware Districts, greater confidence and power is suggested for Turbidity, Total Phosphorus, and Total Coliform and Fecal Coliform trend detectability of the order of the standard deviation.

Twice-monthly sampling for these analytes allows for a trend detectability of approximately 1.1 standard deviations with confidence and power equal to 95% over a seven year period (n = 126). Auto correlation is ignored and justified, because the data analysis for trend detection will be confined solely to the period of record (Loftis et. al. 1991) (see Chapter 2).

Analytes

These have been selected on the basis of what is most likely to be of practical consequence to the City in up to 10 years time. It is impossible to foresee every contingency, therefore best judgment has been applied.

Table 3.8. List of analytes for trend detection.

Analyte	Reason for Inclusion
Color	Early alert to potential contravention of NYS health standard (SDWA)
Odor	Early alert to potential taste and odor problems
Secchi depth Z_{VB}	Indicator of water clarity, used to assess trophic state
Photic Depth I_z	Identifies zone of active primary production
pH	Specific range required to support aquatic life and regulating chemical composition of water, NYS-DEC Water Quality Regulation/Part703 water quality standard
Temperature	Important in the regulation of biotic community structure and function, critical in regulating the chemical composition of water, regulates reservoir processes and distribution of constituents
Conductivity	Measured surrogate for total inorganic ions
Turbidity	Related to a site's suspended solids concentration and water clarity, NYS-DEC Water Quality Regulation/Part703 narrative standard and to manage for compliance with SDWA standards
TSS[1]	Interferes with disinfecting processes, mechanism of pathogen transport, cause of decrease in clarity
Dissolved Oxygen	Essential aquatic life requirement, used as an indicator of chemical and biochemical activities in water, NYS-DEC Water Quality Regulation/Part703 water quality standard
DOC	Major source of energy to heterotrophic food webs, provides insight into THM formation potential, potential source of color in humic waters
Total / Fecal Coliform	Indicator of potential pathogen contamination, NYS-DEC Water Quality Regulation/Part703 water quality standard, and to manage for compliance with SDWA standards
Chl *a*	Useful in assessing primary productivity and trophic state

Table 3.8. List of analytes for trend detection.

Analyte	Reason for Inclusion
Phytoplankton	Indicators of nutrient enrichment, useful in predicting taste and odor problems, and to manage for compliance with DWQC standards
Nitrogen	The determination of the various forms of nitrogen assists in the understanding of the relationship between the readily bio-available nitrogen fractions and the pool from which they were derived. Sources of nitrogen include atmospheric input, runoff from anthropogenic activities, WWTP effluents, and agricultural fertilizers. Nitrogen is a fundamental building block required for growth by algae and other plants.
NH_X–N	Utilized preferentially over NOx–N by autotrophs and bacteria, essential aquatic life requirement, indicative of anoxic conditions during which the toxic form – free ammonia is produced.
NO_x–N	Essential aquatic life requirement
Total Dissolved Nitrogen (TDN)	Pool of organic and inorganic dissolved N species
Total Nitrogen	Total pool of dissolved and particulate N
Phosphorus	Productivity in lakes and reservoirs is most often limited by the supply of inorganic phosphorus. The determination of the various forms of phosphorus assists in the understanding of the relationship between readily bio-available forms and the pool from which they were derived. This understanding can assist watershed managers and planners in decisions concerning phosphorus control.
Total Dissolved Phosphorus (TDP)	Measurement of dissolved reactive phosphorus and dissolved organic and dissolved complex phosphorus, used to determine dissolved organic P (DOP = TDP - SRP). This provides organic + complex inorganic P, also considered to be the total pool of biologically available P.
Total Phosphorus (TP)	Pool of dissolved and particulate P
Soluble Reactive Phosphorus (SRP)	SRP, most readily biologically available (almost exclusively inorganic P)
Resv. Elev.	Explanatory variable used to assist in interpretation of water quality variables
Tot. Storage	Explanatory variable used to assist in interpretation of water quality variables
Release Flow	Explanatory variable used to assist in interpretation of water quality variables
Spill Flow	Explanatory variable used to assist in interpretation of water quality variables
Diversion Flow	Explanatory variable used to assist in interpretation of water quality variables

[1] TSS collected only at dam and intake sites for Delaware District reservoirs, West Branch, New Croton and Kensico Reservoirs. TSS to be collected quarterly at only dam sites for EOH reservoirs and controlled lakes TSS to be collected at all sites and depths for Catskill District reservoirs.

Data Analysis Protocol

The protocol for reservoirs will use nonparametric statistics. The techniques used will be the seasonal Kendall Sen slope estimator to estimate monotonic trend magnitude accompanied by the seasonal Kendall trend test to indicate statistical significance. These tests are included in the WQstat Plus package (Intelligent Decisions Technologies, Ltd, Longmont, CO.). A visual trend assessment will be accomplished using LOcally WEighted regression Scatterplot Smoothing (LOWESS) (Cleveland, 1979). Parametric statistics may also be used as an additional tool (Lakewatch, Seveno, NZ) (see Chapter 2).

Time of Study

On-going. The program will be evaluated continuously to ensure the necessary data is collected to fulfill this objective.

Objective 3.3: Reservoir Status

To assess current reservoir water quality status. This objective will provide an indication of conditions over a recent, relatively short period of time. Reservoir water quality status is defined here as the average conditions for those selected analytes to be of most importance over a three year period. This period is relatively short so that any trends are likely to be minimal, but long enough so that short-term fluctuations caused by, for instance, meteorological perturbations are minimized.

Sites

Samples are to be collected at each of the following sites listed in the table below. The protocol for determining sampling depth is described in the Appendix for each analyte unless otherwise affirmed.

Catskill District

Table 3.9. Catskill District limnology sampling sites for the assessment of reservoir status.

Reservoir	Sites				
Ashokan	1EA	2EA	3EA	4EA	5EA
Schoharie	1SS	2SS	3SS	4SS*	

*TP and chlorophyll only

Delaware District

Table 3.10. Delaware District limnology sampling sites for the assessment of reservoir status.

Reservoir	Sites					
Cannonsville	1WDC	2WDC	3WDC	4WDC	5WDC	6WDC*
Pepacton	1EDP	2EDP	3EDP	4EDP	5EDP	6EDP*
Neversink	1NN	2NN	3NN	4NN		
Rondout	1RR	2RR	3RR			

*TP and chlorophyll only

East of Hudson District

Table 3.11. East of Hudson District limnology sampling sites for the assessment of reservoir status.

Reservoir	Sites							
Kensico	1BRK	2BRK	3BRK	4BRK	5BRK	6BRK	7BRK	8BRK
New Croton	1CNC	2CNC	3CNC	4CNC	5CNC	6CNC	7CNC	8CNC
Muscoot	1CM	2CM	4CM	6CM				
Amawalk	1CA	3CA						
Cross River	1CCR	3CCR						
Titicus	1CT	3CT						
Croton Falls	1CCF	2CCF	3CCF	4CCF	5CCF			
Diverting	1CD	2CD						
Middle Branch	1CMB	3CMB						
West Branch	1CWB	2CWB	3CWB	4CWB				
East Branch	1CEB	3CEB						
Bog Brook	1CBB	3CBB						
Boyds Corners	1CBC	2CBC	3CBC					
Kirk Lake	1CKL							
Lake Gleneida	1CGL							
Lake Gilead	1CGD							

Aqueducts

Table 3.12. Catskill and Delaware District aqueduct sampling sites for the assessment of reservoir status. (Note: These sites are monitored by Laboratory staff)

Reservoir	Site
Ashokan	EAR
Schoharie	SRR2
Rondout	RDRR
Neversink	NRR2
Pepacton	PRR2
Cannonsville	WDTO
Kensico	DEL17, DEL18, CATALUM, CATLEFF
West Branch	DEL9, DEL10

Sampling Frequency

Sampling will be conducted monthly for each reservoir and aqueduct from April through November. The interval between monthly surveys shall not exceed five weeks. The 3 controlled lakes will only be sampled during May, August and October.

Analytes

These have been selected on the basis of what is most likely to be of practical consequence to the City in up to 10 years time. It is impossible to foresee every contingency, therefore best judgment has been applied.

Table 3.13. List of analytes for the assessment of reservoir status.

Analyte	Reason for Inclusion
Color	Early alert to potential contravention of NYS health standard (SDWA)
Odor	Early alert to potential taste and odor problems
Secchi depth Z_{VB}	Indicator of water clarity, used to assess trophic state
Photic depth I_z	Identifies zone of active primary production
pH	Specific range required to support aquatic life and regulating chemical composition of water, NYS-DEC Water Quality Regulation/Part703 water quality standard
Temperature	Important in the regulation of biotic community structure and function, critical in regulating the chemical composition of water, regulates reservoir processes and distribution of constituents
Conductivity	Measured surrogate for total inorganic ions
Turbidity	Related to a site's suspended solids concentration and water clarity, NYS-DEC Water Quality Regulation/Part703 narrative standard and to manage for compliance with SDWA standards
TSS[1]	Interferes with disinfecting processes, mechanism of pathogen transport, cause of decrease in clarity
Dissolved Oxygen	Essential aquatic life requirement, used as an indicator of chemical and biochemical activities in water, NYS-DEC Water Quality Regulation/Part703 water quality standard
Dissolved Silica[2]	Essential requirement for diatoms
Dissolved Chloride[3]	Major component of road salt, indicator of septic system failures and other anthropogenic sources
Dissolved SO_4 [3]	End product of acid deposition, source of S^{-2} during anoxia
Dissolved K [3]	Na/K ratio used to determine and characterize hydrologic flow path
Dissolved Mg [3]	Ca/Mg ratio used to determine and characterize hydrologic flow path
Dissolved Na [3]	Major component of road salt
Dissolved Ca [3]	Essential mineral for zebra mussels, observed Ca depletions observed in forested catchments, Ca/Na ratio used to determine anthropogenic impacts
Alkalinity [3]	A measurement of acid neutralizing capacity, buffering capacity, needed for chemical treatment activities
DOC	Major source of energy to heterotrophic food webs, provides insight into THM formation potential, potential source of color in humic waters

Table 3.13. List of analytes for the assessment of reservoir status.

Analyte	Reason for Inclusion
Total / Fecal Coliform	Indicator of potential pathogen contamination, NYS-DEC Water Quality Regulation/Part703 water quality standard, and to manage for compliance with SDWA standards
Chla[4]	Useful in assessing primary productivity and trophic state
Phytoplankton[4]	Indicators of nutrient enrichment, useful in predicting taste and odor problems, and to manage for compliance with DWQC standards
Nitrogen	The determination of the various forms of nitrogen assists in the understanding of the relationship between the readily bio-available nitrogen fractions and the pool from which they were derived. Sources of nitrogen include atmospheric input, run-off from anthropogenic activities, WWTP effluents, and agricultural fertilizers. Nitrogen is a fundamental building block required for growth by algae and other plants.
NH_X–N	Utilized preferentially over NOx–N by autotrophs and bacteria, essential aquatic life requirement, indicative of anoxic conditions during which the toxic form – free ammonia is produced.
NOx–N	Essential aquatic life requirement
Total Dissolved Nitrogen (TDN)	Pool of organic and inorganic dissolved N species
Total Nitrogen (TN)	Total pool of dissolved and particulate N
Phosphorus	Productivity in lakes and reservoirs is most often limited by the supply of inorganic phosphorus. The determination of the various forms of phosphorus assists in the understanding of the relationship between readily bio-available forms and the pool from which they were derived. This understanding can assist watershed managers and planners in decisions concerning phosphorus control.
Total Dissolved Phosphorus (TDP)	Measurement of dissolved reactive phosphorus and dissolved organic and dissolved complex phosphorus, used to determine dissolved organic P (DOP = TDP - SRP).This provides organic + complex inorganic P, also considered to be the total pool of biologically available P.
Total Phosphorus (TP)	Pool of dissolved and particulate P
Soluble Reactive Phosphorus (SRP)	Dissolved reactive P, most readily biologically available (almost exclusively inorganic P)
Reservoir Elevation	Explanatory variable used to assist in interpretation of water quality variables
Tot. Storage	Explanatory variable used to assist in interpretation of water quality variables
Release Flow	Explanatory variable used to assist in interpretation of water quality variables

Table 3.13. List of analytes for the assessment of reservoir status.

Analyte	Reason for Inclusion
Spill Flow	Explanatory variable used to assist in interpretation of water quality variables
Diversion Flow	Explanatory variable used to assist in interpretation of water quality variables

[1] TSS analyzed monthly at dam and intake sites for Delaware District Reservoirs, New Croton and Kensico Reservoirs. TSS to be analyzed quarterly at dam sites for EOH reservoirs and controlled lakes. TSS to be analyzed at all sites and depths for Catskill District Reservoirs

[2] Si to be analyzed monthly at dam sites

[3] Filtered: Ca, Na, K, Mg, Cl, SO_4, and Alkalinity: Samples collected in May, August, and November. See Table 3.14.

[4] Chlorophyll *a* and phytoplankton collected at depth of 3 meters

Table 3.14. Quarterly dissolved major cations, alkalinity, chloride, and sulfate.

District	Reservoir	Sites
West of Hudson	Cannonsville	3, 5
	Pepacton	1, 5
	Neversink	3
	Rondout	2
	Ashokan	1, 5
	Schoharie	2
East of Hudson	Kensico	1, 4
	New Croton	1, 3, 6
	West Branch	1, 4
	Croton Falls	1, 3
	All other Reservoirs & 3 Lakes	1

Data Analysis Protocol

Box plots will be used to compare water quality analytes between each reservoir and against applicable water quality standards and guidelines.

Time of Study

On-going, The program will be evaluated continuously to ensure the necessary data is collected to fulfill this objective.

Objective 3.4: Reservoir Modeling Support

To provide long-term reservoir water quality data for the Reservoir Modeling Program to support eutrophication models.

Reservoir modeling requires in-reservoir limnological data of selected model variables such that model performance can be evaluated. Conducting model runs on data collected in years after initial model calibration, expands the data base of environmental conditions the models are tested under. This exercise provides increased confidence in model performance under a wider range of conditions.

Sites, Sampling Frequency and Analytes

The monitoring plan for reservoir sampling includes a primary site and generally two secondary sites in order to capture water quality variability along each reservoir's longitudinal gradient. The tables below outline the required sampling sites, sampling frequencies and analytes for each reservoir. Sampling will be conducted from April through November. Sampling depths are described in the Appendix.

For the Catskill and Delaware District Reservoirs, the number "1" in the selected cells denotes a required sampling frequency of once per month each year. The letter "a" signifies a sampling frequency of twice per month for those selected sites and analytes on alternating years. The years in which the increased sampling frequency (2x/month) is required for each reservoir are;

Reservoirs	Calendar Years
Ashokan/Pepacton/Cannonsville	2002, 2004
Schoharie/Neversink/Rondout	2003, 2005

Catskill District

Table 3.15. Catskill District limnology sampling sites and analytes for reservoir modeling support.

Site	Reservoir	Phy	TSS	TPLK	Gen1/2	Chla	SRP	TDP	TP	NH_X	NOx	TDN	DOC
1SS	Schoharie	1	1	1	1	1	1	1	1	1	1	1	1
3SS*	Schoharie	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
1EA	Ashokan	1	1	1	1	1	1	1	1	1	1	1	1
3EA*	Ashokan	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
4EA*	Ashokan	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
5EA	Ashokan	1	1	1	1	1	1	1	1	1	1	1	1

Primary sites denoted by (*)
Physicals (Phy) measurements include; Turbidity, Dissolved Oxygen, Conductivity, Temperature, Depth, Photic Depth (I_z) (at primary site only), Secchi Depth (Z_{VB})

Delaware District

Table 3.16. Delaware District limnology sampling sites and analytes for reservoir modeling support.

Site	Reservoir	Phy	TSS	TPLK	Gen1/2	Chla	SRP	TDP	TP	NH_X	NOx	TDN	DOC
1WDC	Cannonsville	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
4WDC*	Cannonsville	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
5WDC	Cannonsville	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
1EDP	Pepacton	1	1	1	1	1	1	1	1	1	1	1	1
3EDP*	Pepacton	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
5EDP	Pepacton	1	1										
1NN*	Neversink	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
3NN	Neversink	1	1	1	1	1	1	1	1	1	1	1	1
4NN	Neversink	1	1										
1RR*	Rondout	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a	1a
2RR	Rondout	1	1	1	1	1	1	1	1	1	1	1	1
3RR	Rondout	1	1	1	1	1	1	1	1	1	1	1	1

Primary sites denoted by (*)
Physicals (Phy) measurements include; Turbidity, Dissolved Oxygen, Conductivity, Temperature, Depth, Photic Depth (I_z)(at primary site only), Secchi Depth (Z_{VB})

As described above, the number "1" in the selected cells in the Croton River System denotes a required sampling frequency of once per month each year. Because of the considerable number of reservoirs which constitute the Croton River Reservoir System, the letter "b" signifies a sampling frequency of twice per month for those selected sites and analytes every 4 years.

Croton River Reservoir System

Table 3.17. East of Hudson District limnology sampling sites and analytes for reservoir modeling support.

Site	Reservoir	Phy	TSS	TPLK	Gen1/2	Chla	SRP	TDP	TP	NH_x-N	NO_x-N	TDN	DOC
1CA*	Amawalk	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CA	Amawalk	1	1										
1CBB*	Bog Bk	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CBB	Bog Bk	1	1										
1CCF*	Croton Falls	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
2CCF	Croton Falls	1	1										
4CCF	Croton Falls	1	1										
1CCR*	Cross River	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CCR	Cross River	1	1										
1CD*	Diverting	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
2CD	Diverting	1	1										
1CM*	Muscoot	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
2CM	Muscoot	1	1	1	1	1	1	1	1	1	1	1	1
4CM	Muscoot	1	1	1	1	1	1	1	1	1	1	1	1
1CEB*	East Branch	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b

Table 3.17. East of Hudson District limnology sampling sites and analytes for reservoir modeling support.

Site	Reservoir	Phy	TSS	TPLK	Gen1/2	Chla	SRP	TDP	TP	NH_x-N	NO_x-N	TDN	DOC
3CEB	East Branch	1	1										
1CMB*	Middle Br	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CMB	Middle Br	1	1										
1CNC*	New Croton	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
4CNC	New Croton	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
8CNC	New Croton	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
1CT*	Titicus	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CT	Titicus	1	1										
1CBC*	Boyds	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CBC	Boyds	1	1										
1CWB	West Branch	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
2CWB*	West Branch	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b	1b
3CWB	West Branch	1	1										
4CWB	West Branch	1	1										

Primary sites denoted by (*)
Physicals (Phy) measurements include; Turbidity, Dissolved Oxygen, Conductivity, Temperature, Depth, Photic Depth (I_z) (at primary site only), Secchi Depth (Z_{VB})

The years in which the increased sampling frequency (2x/month) is required for each reservoir are:

Reservoirs	Calendar Years
New Croton	2002, 2006
West Branch/Boyds/Muscoot/Middle Branch	2003, 2007
Amawalk/Titicus/Cross River/East Branch/Bog Bk./Diverting	2004, 2008
Croton Falls	2005, 2009

Time of Study

On-going, evaluated in 2005 and 2009.

Objective 3.5: Policy and Management Based Surveillance Monitoring

To monitor selected water quality analytes at selected sites that focus on the department's water quality policy /management goals and objectives, which are not addressed with other existing water quality monitoring efforts.

Short-term objectives include such operations as blending or treatment that must be monitored intensively. Long-term goals may include research that answers questions for policy development for watershed protection.

Sites, Sample Frequency, and Analytes

Sites, sample frequency and analytes will be established based upon fulfilling the departments' specific short and long term policy/management goals and objectives as requested by management.

Objective 3.5.1: Trace and Other Metals Occurrence Monitoring

To collect metal samples in each reservoir and compare those concentrations to the Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the EPA National Primary and Secondary Drinking Water Standards will be applied.

Sites

Samples are collected at three meters from the surface and two meters from the bottom at each site listed for all West of Hudson reservoirs, Kensico, New Croton and West Branch Reservoirs. Samples are collected at three meters from the surface at site 1 for all other East of Hudson reservoirs and controlled lakes in May and November, and three meters from the surface and two meters from the bottom at site 1 in August.

Table 3.18. Limnology sampling sites for trace and other metals occurrence monitoring.

District	Reservoir	Sites
West of Hudson	Cannonsville	3, 4
	Pepacton	1, 3
	Neversink	1, 3
	Rondout	1, 3
	Ashokan	1, 3, 4, 5
	Schoharie	3
East of Hudson	Kensico	1, 4
	New Croton	1, 3, 6
	All other Reservoirs & 3 Lakes	1

Sample Frequency

Samples collected in May, August, and November. Sampling dates for this objective must coincide with the sampling dates for Reservoir Status Monitoring (Objective. 3.3).

Analytes

The Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the EPA National Primary and Secondary Drinking Water Standards will be applied to the selected toxic and other metals listed below. TSS and turbidity are also required to assist in data interpretation.

Total: Ag, Al, As, Ba, Be, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Sb, Se, Tl, Zn, TSS, Turbidity

Table 3.19. WQ Surface Water Standards from Part 700.

Analyte (class waters)	Type	Standard (µg/l)
Total Ag (A,AA)	H(WS)	50
Total As (A,AA)	H(WS)	50
Total Ba (A,AA,)	H(WS)	1,000
Total Cd (A,AA)	H(WS)	5
Total Cr (A,AA)	H(WS)	50
Total Cu (A,AA)	H(WS)	200
Total Hg (A,AA)	H(WS)	0.7
Total Mg (A,AA)	H(WS)	35,000
Total Mn (A,AA)	H(WS)	300
Total Ni (A, AA)	H(WS)	100
Total Pb (A,AA,)	H(WS)	50
Total Sb (A,AA)	H(WS)	3
Total Se (A,AA,B,C)	H(WS)	10

Table 3.20. EPA National Primary and Secondary Drinking Water Quality Standards.

Analyte	Primary Standard (µg/l)	Secondary Standard (µg/l)
Ag		100
Al		50-200
As	10	
Ba	2,000	
Be	4	
Cd	5	
Cr	100	
Cu	1,300	1000
Fe		300
Hg	2	
Mn		50
Pb	0	
Sb	6	
Se	50	
Tl	0.5	
Zn		5,000

Data Analysis Protocol/Reporting

Metals concentrations will be reviewed on a quarterly basis and compared to Part 703.5 and EPA National Primary and Secondary Drinking Water Standards. Additional sample collection may be required as deemed necessary by management.

Time of Study

On-going.

Objective 3.5.2: Croton Watershed Consent Decree Monitoring

To support the Croton Watershed Consent Decree, total and fecal coliform samples will be collected in each reservoir and controlled lake of the Croton River Reservoir system.

Sites

Samples to be collected at the sampling sites described in Objective 3.3 during the first sampling of the month and at sites described in Objective 3.1 during the second sampling of the month for New Croton Reservoir.

Sampling Frequency

Once each month for all reservoirs except New Croton, in which twice-monthly sampling will be conducted. Samples collected April through November (except for New Croton in which samples are collected all year, as ice conditions permit).

Analytes

Total and Fecal coliform.

Data Analysis Protocol

Data will be reviewed and reported monthly.

Time of Study

Until the terms of the Croton Consent Decree are satisfied.

Objective 3.5.3: Phosphorus-Restricted Basin Monitoring

To provide data to support DEP's P-restricted basin evaluation strategy.

The NYCDEP's revised "Rules and Regulations for the Protection from Contamination, Degradation and Pollution of the New York City Water Supply and its Sources: (Regulations) became effective May 1, 1997. In Section 18-36, the Regulations prohibit new or expanded wastewater treatment plants with surface discharges from being located within phosphorus restricted basins. A phosphorus restricted basin is defined as "the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental

Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D."

The Regulations also specify that the NYCDEP, on an annual basis, conduct a review of the City's reservoirs to determine which reservoirs are phosphorus restricted. The monitoring support described below provides the necessary data to evaluate basin status with regard to phosphorus restriction.

Sites

Samples are collected at all sites as described in Objective 3.3.

Sampling Frequency

Samples are collected monthly on reservoirs and controlled lakes from May through October.

Analytes

Total Phosphorus

Data Analysis Protocol

The geometric mean phosphorus concentration in each reservoir for each year's growing season (the annual geometric mean phosphorus concentration) will be calculated, and then averaged over a five year period. The five year mean plus the standard error of the mean is considered on "assessment". A basin will be listed as unrestricted if two consecutive assessments are below the guidance value of 20 $\mu g\ L^{-1}$, and phosphorus restricted if it is equal to or greater than 20 $\mu g\ L^{-1}$.

Time of Study

On-going

Objective 3.5.4 Coliform Restricted Basin Monitoring

Objective

To provide total and fecal coliform data from a minimum of five monthly samples collected on each reservoir and controlled lake.

The coliform bacteria samples are collected to assist in the development of a technique for appropriately assessing the restriction status of a reservoir basin. The calculation methodology is currently under review.

Sites

All sampling sites and depths as described in Objective 3.3. Additional depths must be included on any reservoir having two or less sampling locations such that five samples are collected for each reservoir.

Sampling Frequency

Monthly

Determinands

Total and fecal coliform

Data Analysis Protocol

These data are currently being used to assist in defining the protocol for coliform restricted basin determination

3.3 Summary

The monitoring network described above was constructed from a compilation of Objectives derived from DEP's information needs and was assisted by a review of legally binding mandates, agreements, and reports pertaining to New York City's watershed water quality monitoring program. Because of the complexity of the Program, it is summarized below as a series of tables. The tables contain: the number of sites included in each objective for the three watersheds separately; a list of analytes measured for each objective; and a list of reservoir sites (codes) included in each objective for each of the three watersheds. The tables are followed by maps depicting the sites visited for each objective.

Table 3.21. Number of sites by objective in each system.

System	Obj. 3.1	Obj. 3.2	Obj. 3.3	Ob.3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3
Catskill	9	8	9	6	5	0	9
Delaware	13	17	19	12	8	0	19
East-of-Hudson	15	49	49	3	19	37	49
Grand Total	37	74	77	21	32	37	77

Table 3.22. List of analytes by objective.

Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
Color	Color	Color	NO_X-N	Total-Ag	TC	TP	
Odor	Odor	Odor	NH_X-N	Total-Al	FC		
Turbidity	Turbidity	Turbidity	TDN	Total-As			
TC	NO_X-N	Alkalinity	TN	Total-Ba			
FC	NH_X-N	Chloride	TP	Total-Be			

Table 3.22. List of analytes by objective.

Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
Total Plankton (SAU)	TDN	Dissolved Silica	TDP	Total-Cd			
Dom. Genus	TN	Dissolved Sulfate	SRP	Total-Cr			
Secondary Genus	TP	NO_x-N	DOC	Total-Cu			
pH	TDP	NH_x-N	TSS	Total-Fe			
Conductivity	SRP	TDN	Chla	Total-Hg			
DO	DOC	TN	Total Plankton (SAU)	Total-Mg			
Temp	TSS	TP	Dom. Genus	Total-Mn			
Fe	Chla	TDP	Secondary Genus	Total-Ni			
Mn	TC	SRP	pH	Total-Pb			
	FC	DOC	Specific Cond.	Total-Sb			
	Total Plankton	TSS	DO	Total-Se			
	Dom. Genus	Dissolved Ca	Temp	Total-Tl			
	Secondary Genus	Dissolved Na	Secchi depth Z_{VB}	TSS			
	pH	Dissolved K	Photic depth I_z	Turbidity			
	Conductivity	Dissolved Mg	Turbidity	Total-Zn			
	DO	Chla					
	Temp	TC					
	Secchi depth Z_{VB}	FC					
	Photic depth I_z	Total Plankton (SAU)					
	Resv Elev.	Dom. Genus					
	Total Storage	Secondary Genus					
	Mean Daily Aqueduct flow	pH					
	Mean Daily Release flow	Conductivity					
	Mean Daily Spill	DO					
	Mean Daily Diversion flow	Temp					
		Secchi depth Z_{VB}					
		Resv Elev.					
		Total Storage					
		Mean Daily Aqueduct flow					
		Mean Daily Release flow					
		Mean Daily Spill					
		Mean Daily Diversion flow					

Table 3.22. List of analytes by objective.

Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
Photic depth I_z							

SAU - Standard Aerial Units
Z_{VB} - Secchi depth determined with viewer box
I_z - Photic Depth

Table 3.23. List of sites by objective.

System	Site Code	Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
Catskill									
	Ashokan								
	1EA	X	X	X	X	X		X	X
	1.4EA	X							
	2EA	X	X	X				X	X
	3EA	X	X	X	X	X		X	X
	3.2EA	X							
	4EA	X	X	X	X	X		X	X
	5EA	X	X	X	X	X		X	X
	Schoharie								
	1SS		X	X	X			X	X
	2SS	X	X	X				X	X
	3SS	X	X	X	X	X		X	X
	4SS			X1				X	
Delaware									
	Rondout								
	1RR	X	X	X	X	X		X	X
	2RR	X	X	X	X			X	X
	3RR	X	X	X	X	X		X	X
	Neversink								
	1NN	X	X	X	X	X		X	X
	2NN	X	X	X				X	X
	3NN	X	X	X	X	X		X	X
	4NN		X	X	X			X	X
	Cannonsville								
	1WDC		X	X	X			X	X
	2WDC	X	X	X				X	X
	3WDC	X	X	X		X		X	X
	4WDC	X	X	X	X	X		X	X
	5WDC	X	X	X	X			X	X
	6WDC			X 1				X	
	Pepacton								

Table 3.23. List of sites by objective.

System	Site Code	Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
	1EDP		X	X	X	X		X	X
	2EDP2		X	X				X	X
	3EDP	X	X	X	X	X		X	X
	4EDP	X	X	X				X	X
	5EDP	X	X	X	X			X	X
	6EDP			X1				X	
East of Hudson									
	Kensico								
	1BRK	X	X	X		X		X	X
	2BRK	X	X	X				X	X
	3BRK	X	X	X				X	X
	4BRK	X	X	X		X		X	X
	5BRK	X	X	X				X	X
	6BRK		X	X				X	X
	7BRK		X	X				X	X
	8BRK		X	X				X	X
	New Croton								
	1CNC	X	X	X	X	X	X	X	X
	2CNC	X	X	X			X	X	X
	3CNC	X	X	X		X	X	X	X
	4CNC	X	X	X	X		X	X	X
	5CNC		X	X			X	X	X
	6CNC	X	X	X		X	X	X	X
	7CNC		X	X			X	X	X
	8CNC		X	X	X		X	X	X
	1.1CNC	X							
	1.2CNC	X							
	West Branch								
	1CWB	X	X	X		X		X	X
	2CWB	X	X	X				X	X
	3CWB	X	X	X				X	X
	4CWB		X	X				X	X
	Boyd Corners								
	1CBC		X	X		X	X	X	X
	2CBC		X	X			X	X	X
	3CBC2		X	X			X	X	X
	Amawalk								
	1CA		X	X		X	X	X	X
	3CA2		X	X			X	X	X
	Titicus								

Table 3.23. List of sites by objective.

System	Site Code	Obj. 3.1	Obj. 3.2	Obj. 3.3	Obj. 3.4	Obj. 3.5.1	Obj. 3.5.2	Obj. 3.5.3	Obj. 3.5.4
	1CT		X	X		X	X	X	X
	3CT2		X	X			X	X	X
	Cross River								
	1CCR		X	X		X	X	X	X
	3CCR2		X	X			X	X	X
	East Branch								
	1CEB		X	X		X	X	X	X
	3CEB2		X	X			X	X	X
	Bog Brook								
	1CBB		X	X		X	X	X	X
	3CBB2		X	X			X	X	X
	Diverting								
	1CD		X	X		X	X	X	X
	2CD		X	X			X	X	X
	Croton Falls								
	1CCF		X	X		X	X	X	X
	2CCF2		X	X			X	X	X
	3CCF		X	X			X	X	X
	4CCF2		X	X			X	X	X
	5CCF		X	X			X	X	X
	Muscoot								
	1CM		X	X		X	X	X	X
	2CM		X	X			X	X	X
	4CM		X	X			X	X	X
	6CM		X	X			X	X	X
	Middle Branch								
	1CMB		X	X		X	X	X	X
	3CMB2		X	X			X	X	X
	Lake Gleneida								
	1CGL		X	X		X	X	X	X
	Lake Gilead								
	1CGD		X	X		X	X	X	X
	Kirk Lake								
	1CKL		X	X		X	X	X	X

1 TP and Chla only

2 Total phytoplankton not collected at these sites

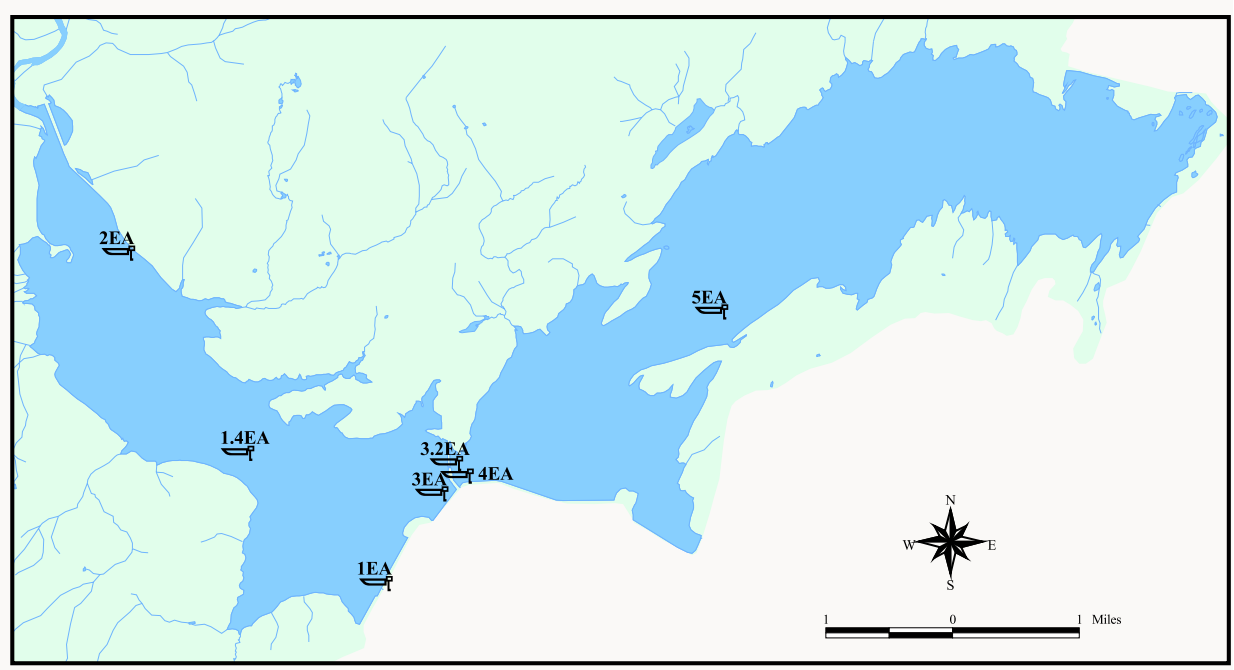

Figure 3.1. Ashokan Reservoir limnology sampling sites.

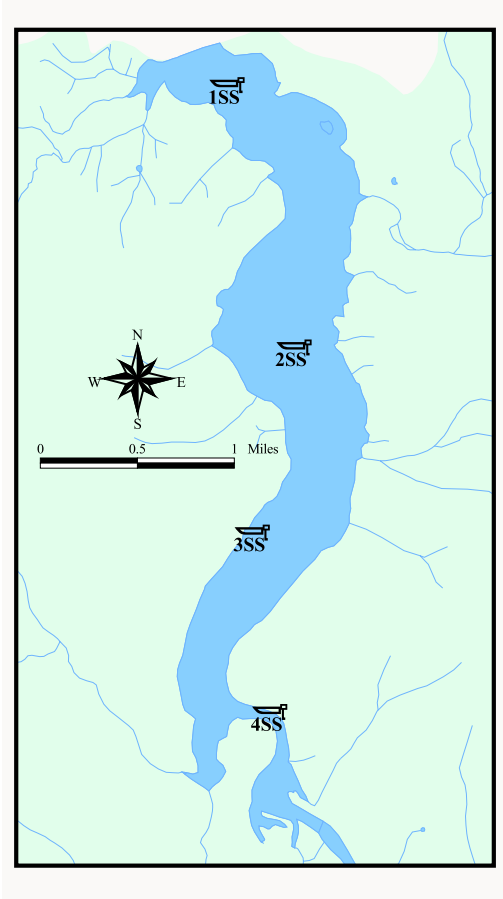

Figure 3.2. Schoharie Reservoir limnology sampling sites.

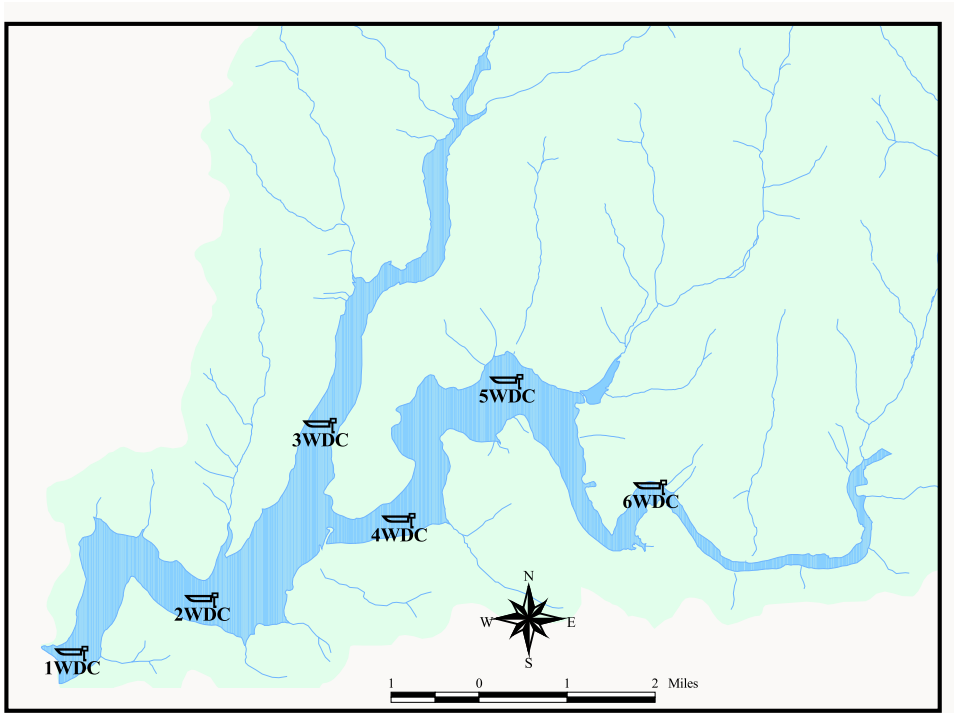

Figure 3.3. Cannonsville Reservoir limnology sampling sites.

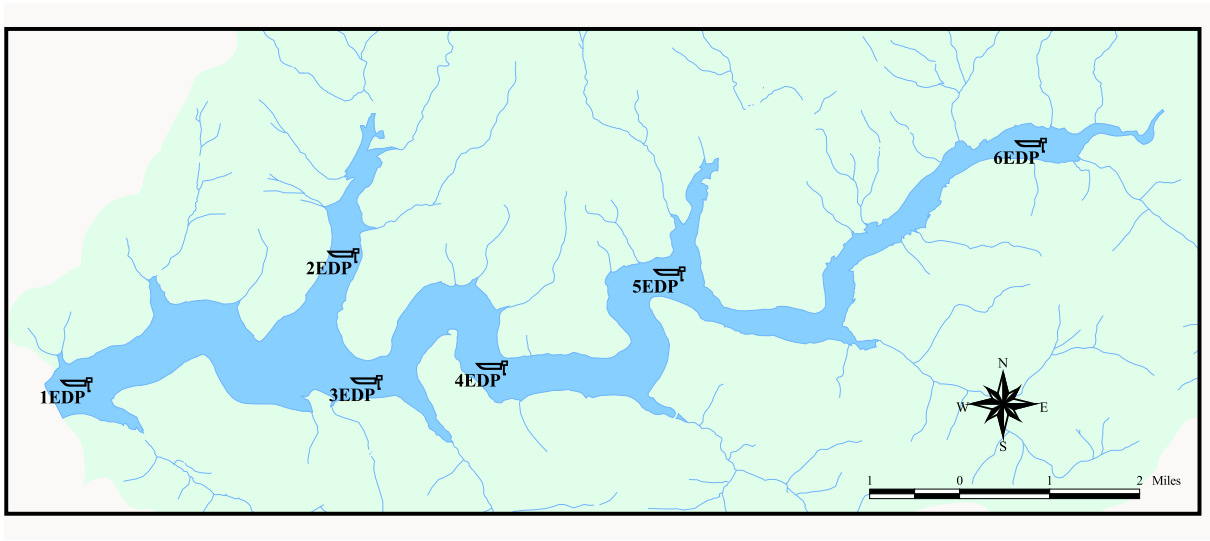

Figure 3.4. Pepacton Reservoir limnology sampling sites.

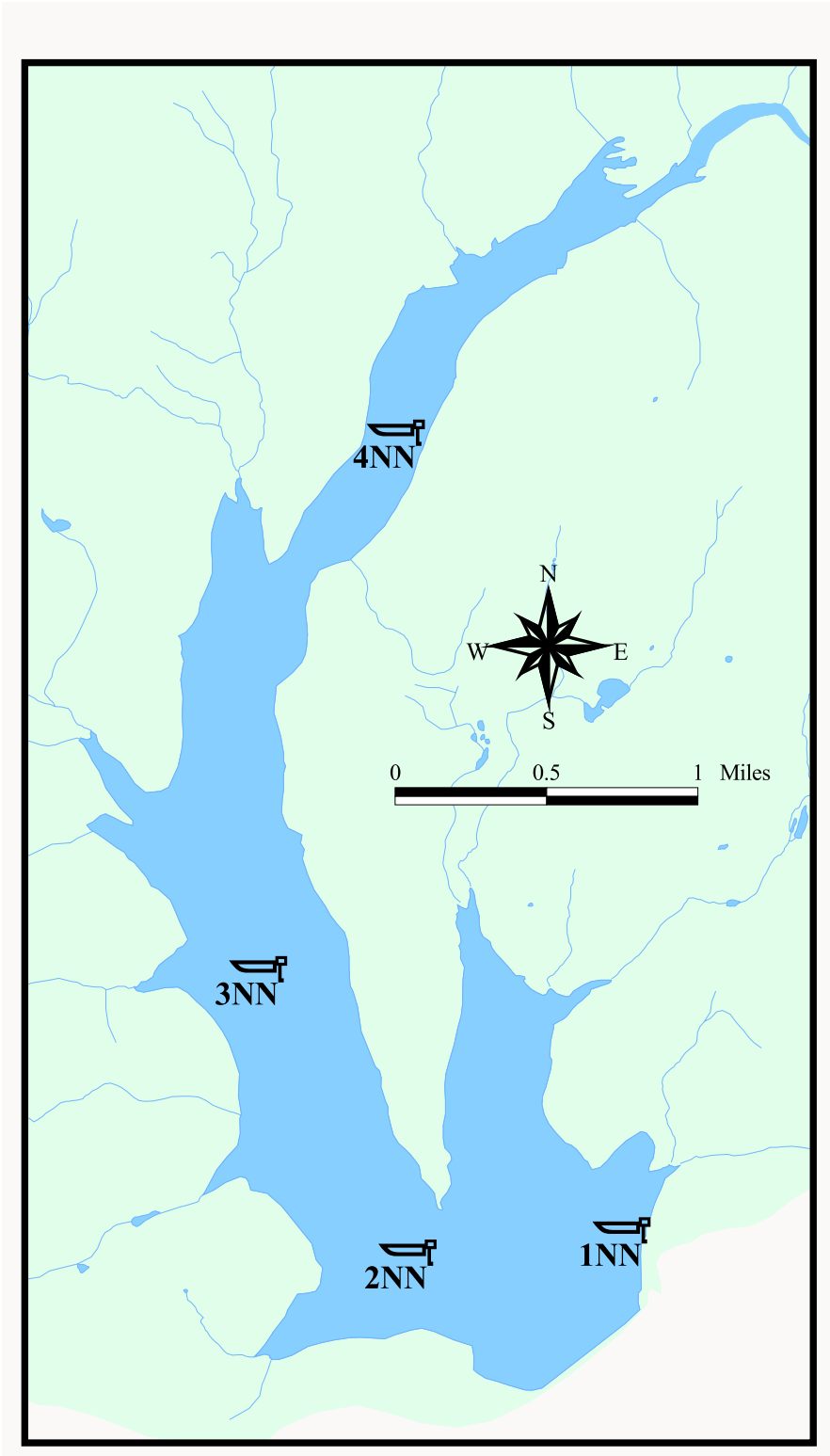

Figure 3.5. Neversink Reservoir limnology sampling sites.

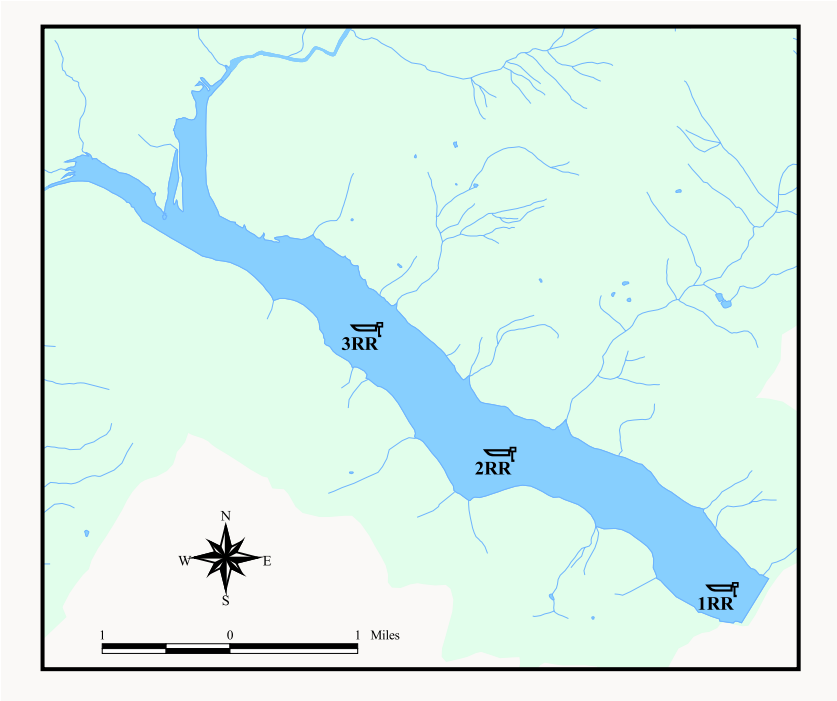

Figure 3.6. Rondout Reservoir limnology sampling sites.

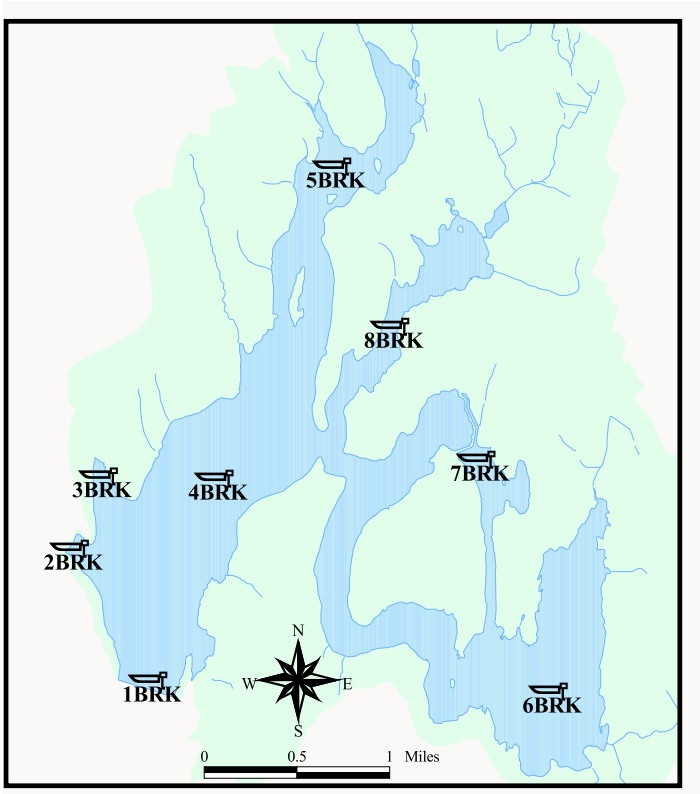

Figure 3.7. Kensico Reservoir limnology sampling sites.

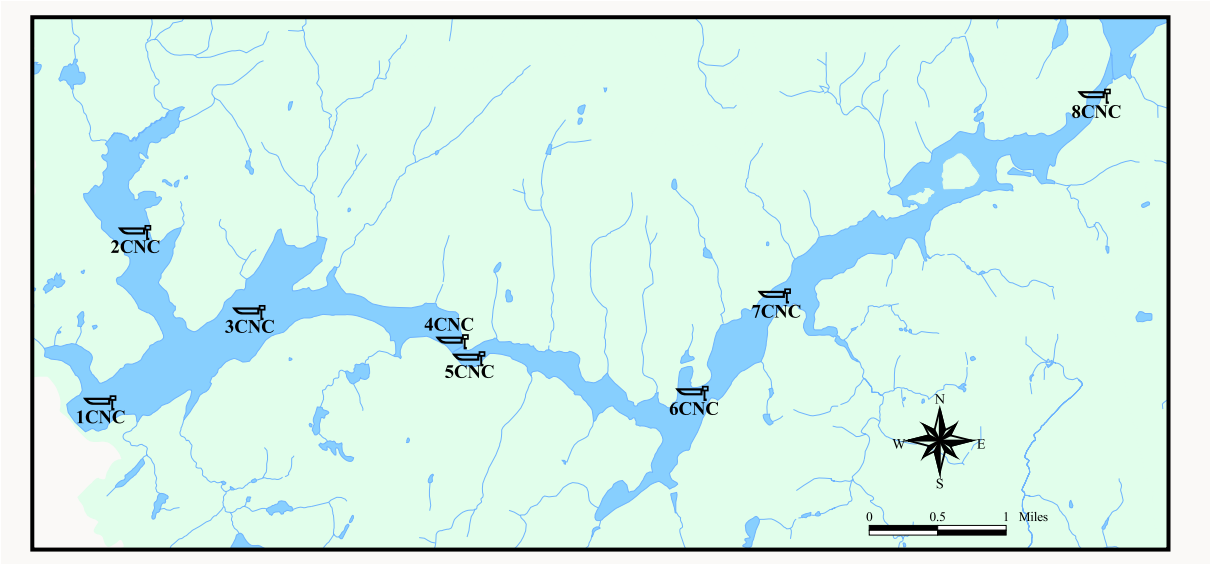

Figure 3.8. New Croton Reservoir limnology sampling sites.

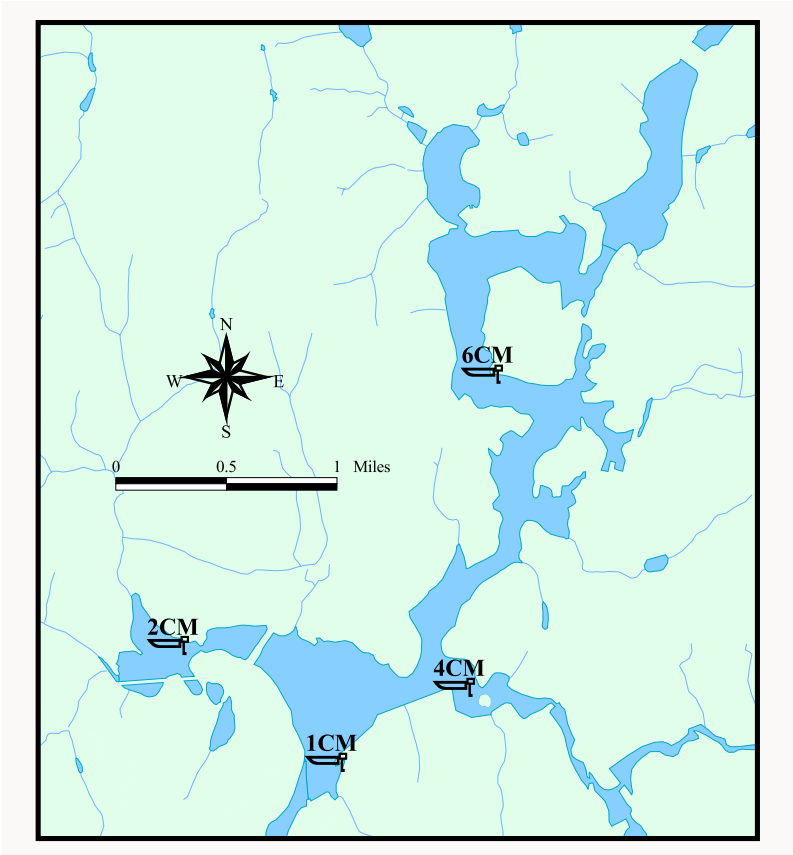

Figure 3.9. Muscoot Reservoir limnology sampling sites.

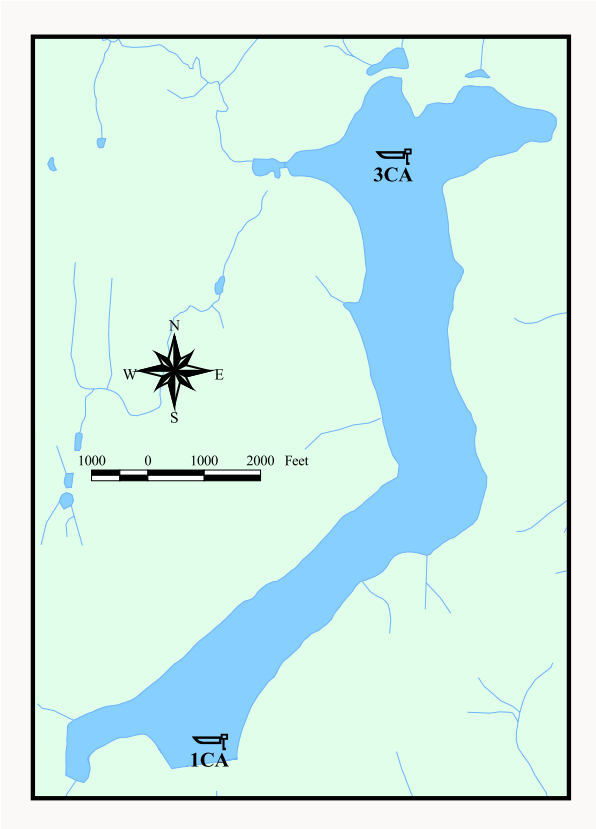

Figure 3.10. Amawalk Reservoir limnology sampling sites.

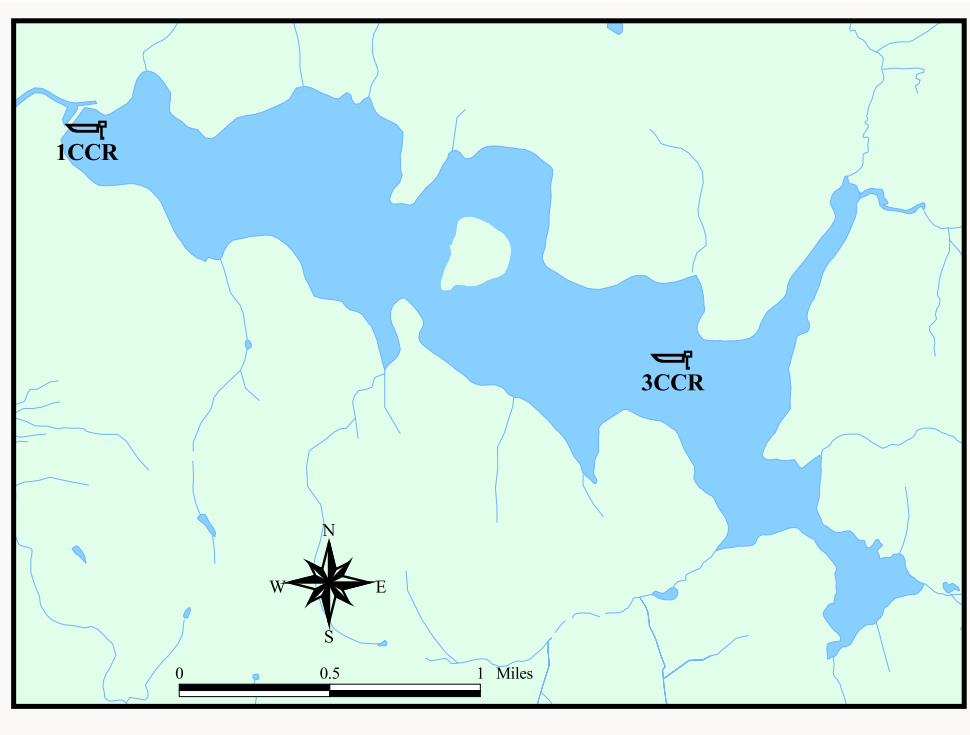

Figure 3.11. Cross River Reservoir limnology sampling sites.

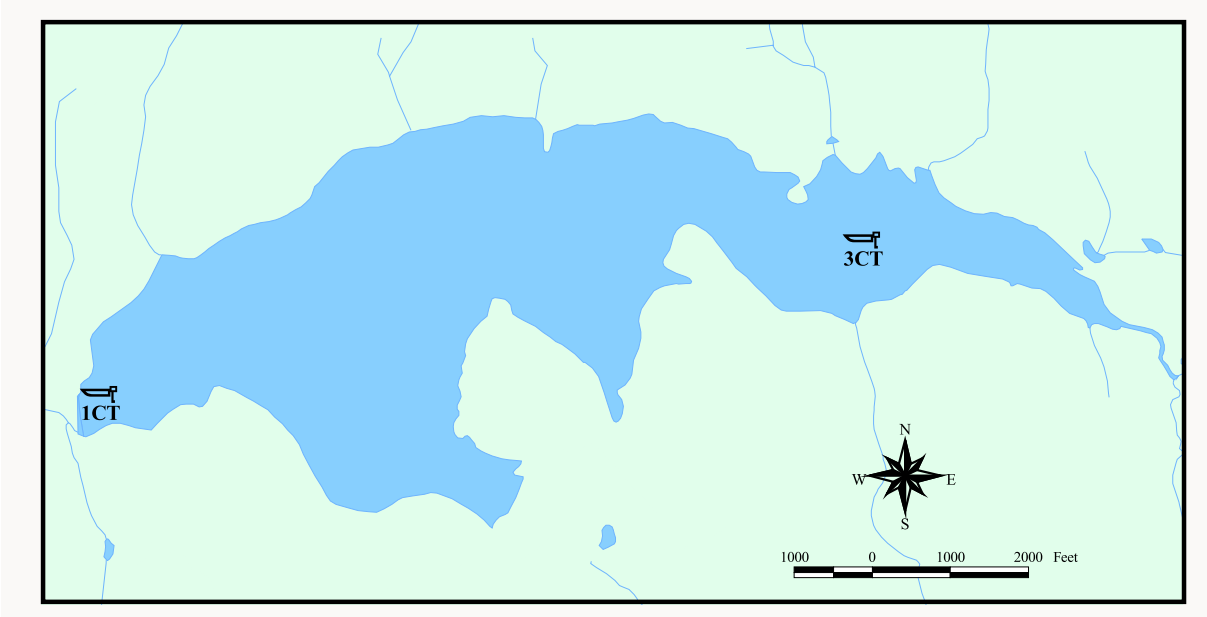

Figure 3.12. Titicus Reservoir limnology sampling sites.

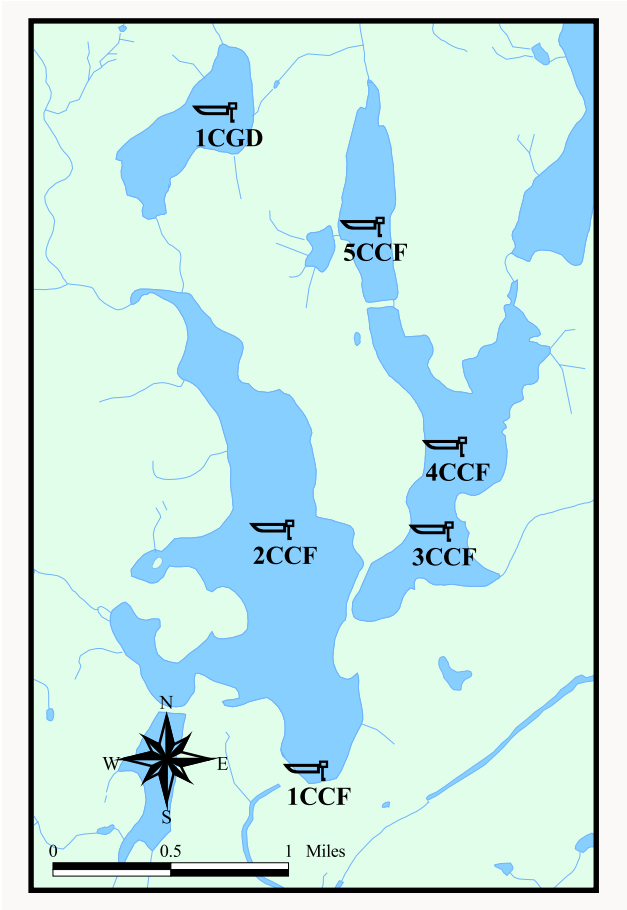

Figure 3.13. Croton Falls Reservoir limnology sampling sites.

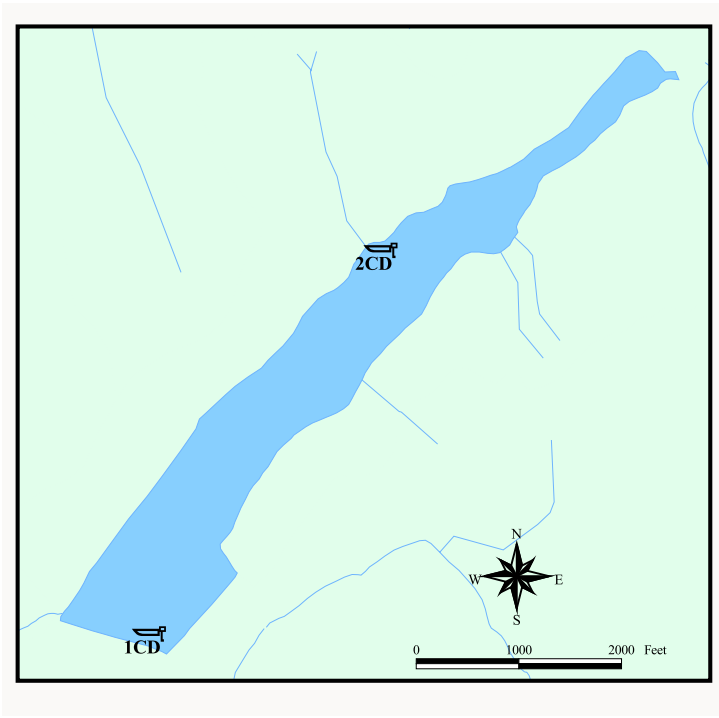

Figure 3.14. Diverting Reservoir limnology sampling sites.

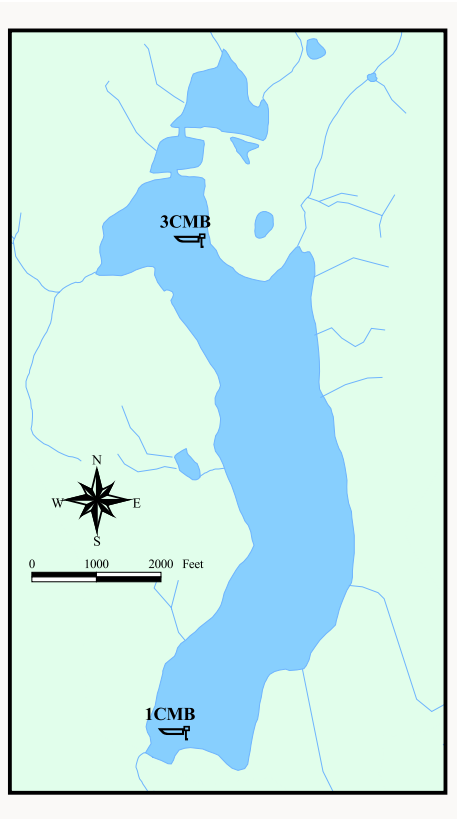

Figure 3.15. Middle Branch Reservoir limnology sampling sites.

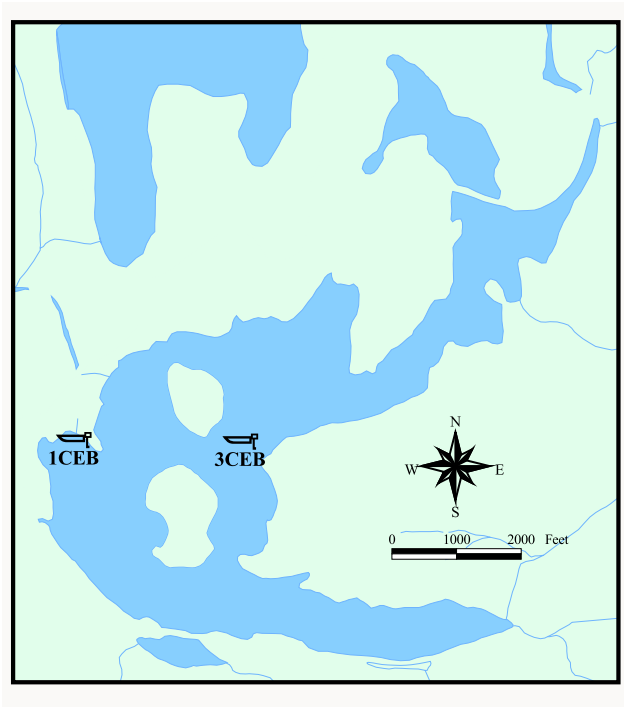

Figure 3.16. East Branch Reservoir limnology sampling sites.

Figure 3.17. Bog Brook Reservoir limnology sampling sites.

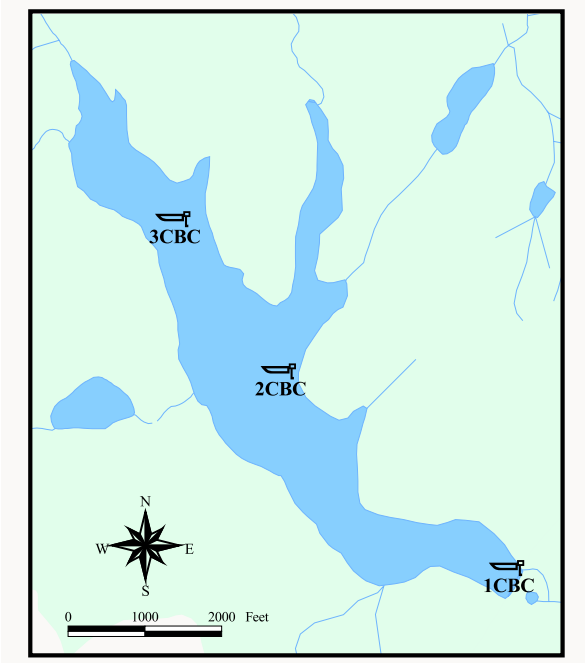

Figure 3.18. Boyd Corners Reservoir limnology sampling sites.

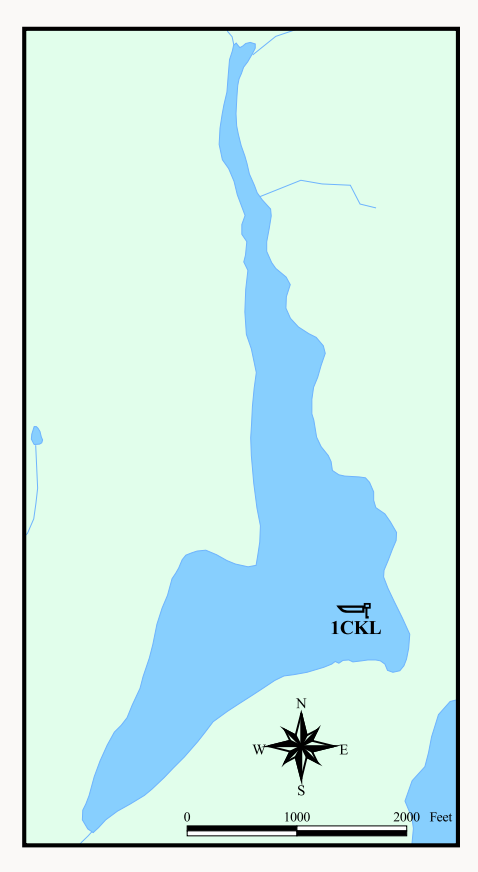

Figure 3.19. Kirk Lake limnology sampling sites.

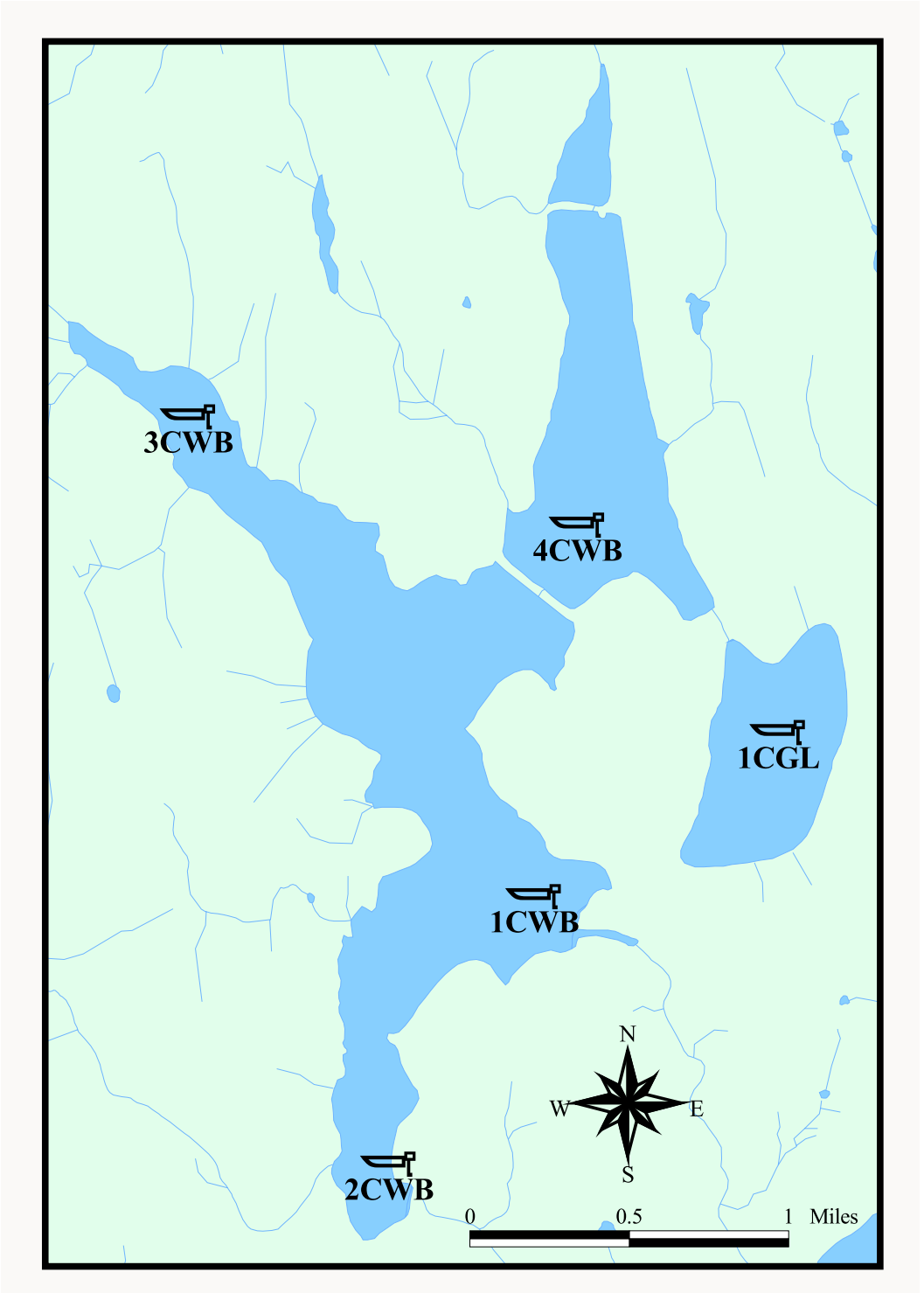

Figure 3.20. West Branch Reservoir/Lake Gleneida limnology sampling sites.

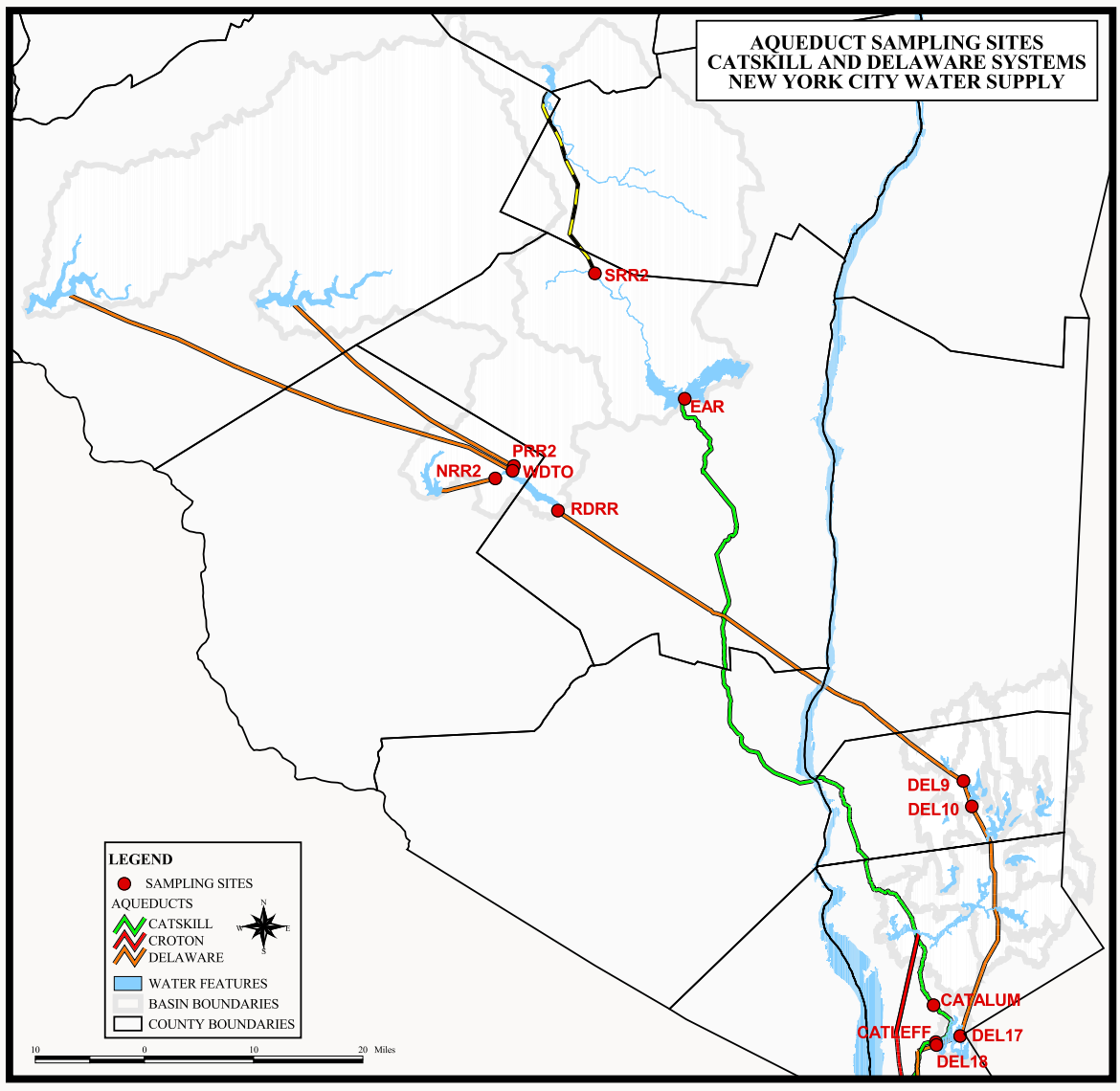

Figure 3.21. Aqueduct sampling sites, Catskill and Delaware Systems.

4. Pathogen Program

This section provides DEP's framework for monitoring the protozoans *Cryptosporidium* and *Giardia*, and human enteric viruses (HEV). The Pathogen Program is responsible for this monitoring. The overall goal of the program is to provide DEP management, the public, and oversight agencies with scientifically defensible data concerning current stream, reservoir and aqueduct concentrations of protozoan pathogens and human enteric viruses within the New York City watershed, as well as information concerning the potential sources and transport characteristics of these potential pathogens. The information is needed to support risk assessment and watershed management activities, and to ensure the continued safety of the New York City Water Supply. The revised framework is comprised of separate, clearly defined objectives, derived from both regulatory obligations and research needs for watershed management.

The Pathogen Program planned four major program categories for the next five years: *Compliance Monitoring, Surveillance Monitoring, Watershed Research,* and *Methodological Studies*. The following are discussed for each objective: site selection, sampling frequencies, analytes, and data analysis procedures. Although statistical analysis requires that sites and initial sampling frequencies be predetermined, DEP realizes that sampling frequency must be flexible and adjust to changes in reservoir operations. Careful consideration was made to compose a monitoring program that integrates and coordinates sampling efforts. This integrative approach will result in a monitoring framework that is efficient and produces the appropriate pathogen information for water supply management. A table showing the integration of sites used to meet Hydrology and Pathogen programs objectives is presented as Appendix Table 7. Results from earlier phases of work provided through this program will be used to develop additional targeted and focused studies for later implementation. Sampling and analysis for protozoans will be completed using EPA Method 1623HV. Sampling and analysis for viruses will be completed using EPA's ICR Method for viruses.

Compliance Monitoring, the first program, addresses sampling obligations under the FAD and the Croton Consent Decree. This monitoring objective is intended to produce timely information on the status of source waters and additional locations listed in the FAD and consent decree. It is a flexible program in that it provides initial sampling frequencies based on typical conditions; however, sampling frequencies may be increased in response to acute events and/or atypical results as, for example, in DEP's *Cryptosporidium* Action Plan.

Surveillance Monitoring, the second program, intends to augment compliance monitoring and the information gained by monitoring the next tier of locations in the watershed. These locations include the up-stream reservoir keypoints, "integrator" stream sites (upstream of the source water reservoirs), as well as perennial streams flowing into Kensico Reservoir. While some of the locations have long-term records available as a reference (using older analytical methods), others are new loca-

tions with little or no historical data. DEP believes that expansion of pathogen monitoring into unexplored locations will provide a more complete picture of pathogen sources and occurrence in the watershed.

Watershed Research, the third program, focuses on the processes that affect the sources and transport of protozoans in the watershed. As opposed to the previous objectives, which have a long-term focus, projects under this objective typically have a shorter duration but more intensive effort. These projects will also tend to narrow their scope to individual watersheds or management practices.

Methodological Studies, the fourth program, seeks to improve methods used to quantify protozoan levels in the watershed. These include field and laboratory methods. Lessons learned from these studies can then be applied to the watershed-wide programs with the goal of improving the overall quality of information.

The objectives described herein provide a framework for the program. The full details of each project, including quality assurance methods, sampling schedules, and specific statistical analyses used to summarize results may be found in individual Quality Assurance Project Plans (QAPPs).

A schedule for the reporting is provided in Table 4.1.

Table 4.1. Pathogen Program reporting schedule.

Objective	Reporting Interval
4.1 Compliance	
4.1.1 Source water keypoints	Weekly/ Monthly/ Semi-annual
4.1.2 Croton Consent Decree	Monthly/ Semi-annual
4.2 Surveillance	
4.2.1 WWTP's	Semi-annual
4.2.2 Upstate Keypoints	Semi-annual
4.2.3 Watershed wide comparison of sub-basins	Semi-annual
4.2.4 Kensico Streams	Semi-annual
4.3 Watershed Research	
4.3.1 Protozoan Source Identification	
Phase 1	Quarterly/ Annual
Phase 2	Quarterly/ Final Report
4.3.2 Stream Indicator Sites	
Phase 1	Quarterly/ Annual
Phase 2	Quarterly/ Final Report
4.3.3 Event-based monitoring for reservoirs	Quarterly/Final Report
4.3.4 Kensico mass balance	Final Report
4.4 Method Development	

Table 4.1. Pathogen Program reporting schedule.

Objective	Reporting Interval
4.4.1 Parameters affecting recoveries	Final report
4.4.2 Duration, flow, and volume	Semi annual/ Final Report
4.4.3 Genotyping	Semi annual/ Final Report

DEP began implementing the projects presented in this report in July 2002 following a program review that began in October 2001. A summary of the program review is presented in Appendix 3 (Pathogen Data Review). Additionally, the review's outcome embraced a number of changes to the Pathogen Program presented in this report. Some of theses changes include the use of a common sampling and analytical method (Method 1623) for all sampling sites, adjustments to the sampling frequencies of certain sites, and addition of new sites. Pathogen sampling frequencies by site and objective are presented in Table 4.2.

Table 4.2. Protozoan pathogens sampling frequencies by site and objective.

	Compliance		**Surveillance**				**Research**			**Methods**		
	Keypoints	Croton Consent Decree	WWTPs	Upstream Keypoints	Sub-basin Comparisons	Kensico Streams	Sources / Sites	Indicator Streams	Mass-Balance	Parameters affecting recoveries	Duration, flow and volume	Genotyping
Objective #	4.1.1	4.1.2	4.2.1	4.2.2	4.2.3	4.2.4	4.3.1	4.3.2	4.3.4	4.4.1	4.4.2	4.4.3
CATLEFF	Wk								X			
CROGH	Wk	Wk										
DEL18	Wk								X			
CATALUM	Wk			Mo					X			
DEL17	Wk			Mo					X	X		
BSTP		Mo										
CROFALLSR		Mo#			Mo							
CROSSRVR		Mo#			Mo							
HH7		Mo										
MUSCOOTR		Mo										
WF		Mo										

Table 4.2. Protozoan pathogens sampling frequencies by site and objective.

	Compliance		Surveillance				Research			Methods		
	Keypoints	Croton Consent Decree	WWTPs	Upstream Keypoints	Sub-basin Comparisons	Kensico Streams	Sources / Sites	Indicator Streams	Mass-Balance	Parameters affecting recoveries	Duration, flow and volume	Genotyping
DCD			Q									
DTP			Q									
EPE			Q									
HHE			Q									
MSC			Q									
RGC			Q									
SGE			Q									
STE			Q									
STP			Q									
WSP			Q									
NRR2				Mo##								
PRR2				Mo##o								
RDRR				Mo##								
SRR2				Mo##								
WDTO				Mo##								
BOYDR					Mo							
CDG					Mo							
E16I					Mo							
E5					Mo							
EBCR3					Mo							
NCG					Mo							
PMSB					Mo							
PROXG					Mo							
RDOA					Mo							
S4					Mo							
S5I					Mo							
TITICUSR					Mo							

Table 4.2. Protozoan pathogens sampling frequencies by site and objective.

	Compliance		Surveillance				Research			Methods		
	Keypoints	Croton Consent Decree	WWTPs	Upstream Keypoints	Sub-basin Comparisons	Kensico Streams	Sources / Sites	Indicator Streams	Mass-Balance	Parameters affecting recoveries	Duration, flow and volume	Genotyping
WBDN					Mo							
BG-9						BMSE			X			
E10						BMSE			X			
E11						BMSE			X			
E9						BMSE			X			
MB1						BMSE			X	X		SE
N12						BMSE			X			
N5-1						BMSE			X			
WHIP						BMSE			X			
Roving sites							X					SE
34 gauges								Q SE				
Kensico Res.									X			
EOH Res.											X	
WOH Res.												

Wk = weekly
Mo = monthly
Mo# = monthly when hydraulic pump is activated
Q = quarterly
Mo## = It is intended that this frequency be increased at appropriate sites if the routine monitoring at source water influents to Kensico Reservoir indicates elevated levels of pathogens.
BM = Bi-monthly (every other month)
BMSE = Bi-monthly (every other month) and storm events
SE = Storm events

With the implementation of the integrated monitoring in July 2002, DEP has used a nationally approved variation of Method 1623 known as “1623HV” for all protozoan samples collected and analyzed. The "HV" indicates "High Volume" since the variation uses a 50-L sample volume instead of the method specified minimum10-L volume. The variation also uses an "Envi-

rochek HV" filter which has an "absolute" pore size rating instead of a "nominal" pore size rating. This variation has been validated by EPA following guidelines of the "performance based measurements system" (USEPA, 1996).

4.1 Compliance Monitoring

Compliance monitoring is comprised of two objectives that address sampling obligations made under the November 2002 Filtration Avoidance Determination (FAD) (Objective 4.1.1) and Croton Consent Decree (Objective 4.1.2). The same sampling and analytical protocol will be used (EPA Method 1623 HV, 50 L sample) for both objectives so that, if required, results can be compared.

DEP's current keypoint monitoring also meets the requirements proposed in the draft "Long-term 2 Enhanced Surface Water Treatment Rule". Although this rule may not be finalized until approximately 2004, DEP has been proactive in collecting background information and in passing the EPA audit for "approval pending" status in 2002, with final laboratory approval status expected upon promulgation of the LT2 rule. DEP began weekly monitoring of the 3 source water keypoints for *Cryptosporidium* with Method 1623HV in October of 2001. By October of 2003, DEP will have completed two years of monitoring and will continue this sampling weekly. This will provide a more extensive database than the monthly monitoring anticipated to be the requirement in the final rule.

Objective 4.1.1: Keypoint Monitoring at Source Water Reservoirs

This monitoring provides information on occurrence of *Cryptosporidium*, *Giardia* and human enteric viruses at source water reservoir and influent keypoints, uses that information to implement the *Cryptosporidium* Action Plan, and continues the monitoring required under Filtration Avoidance Determination.

Sites

Kensico Reservoir and New Croton Reservoir effluents have highest priority for monitoring (Table 4.3 and Figure 4.2). (All figures are presented at the end of each chapter.) These sites are most representative of the water that is delivered to the consumers and are designated “source waters” under routine reservoir operations. The Kensico influent sites are included because they constitute the largest portion of flow at the effluents. Changes in reservoir operations may affect source water designation. As a result of operational changes, Ashokan, Cross River, Croton Falls, Rondout or West Branch Reservoirs may become source waters. DEP will conducts weekly monitoring at all sites meeting the source water definition.

Table 4.3. Source water locations[1] during routine operations.

Site Code	Site Description
CATLEFF	Catskill Aqueduct- lower effluent chamber, effluent from Kensico Reservoir
CROGH	New Croton Aqueduct- Croton lake gatehouse, effluent from New Croton Reservoir
DEL18	Delaware Aqueduct- shaft 18, effluent outflow from Kensico Reservoir
CATALUM	Catskill Aqueduct- alum plant, influent to Kensico Reservoir
DEL17	Delaware Aqueduct- shaft 17, influent to Kensico Reservoir

[1.] Source water designation is determined by reservoir operations. All source water reservoirs are sampled weekly. Kensico Reservoir influents are included since they constitute the largest portion of effluent flow.

Sampling Frequency and Duration

Weekly sampling is ongoing and will continue throughout the duration of the 2002 FAD.

Analytes

See Table 4.4 below. *Cryptosporidium* and *Giardia* are sampled by Method 1623HV using a 50L sample volume. HEV are sampled using the ICR method.

Table 4.4. List of analytes for keypoint monitoring at source water reservoirs.

Analyte	Reason for Inclusion
Giardia cysts	Compliance requirement
Cryptosporidium oocysts	Compliance requirement
Human enteric virus	Compliance requirement
Sample volume	Required for calculating concentration
pH	Important for virus laboratory analysis
Turbidity	Measured for pellet size estimation/interference
Water temperature	Measured to ensure QA/QC
Pressure Differential on sample filter	Estimation of pellet size
Flow at sampling location	Required for flow adjustment

Data Reporting

Results from weekly sampling are used to confirm the high quality of water leaving the reservoirs. These results also provide an indication of pathogen concentrations, prior to chlorination, that would be used to trigger the *Cryptosporidium Action Plan*. Source water results are posted weekly on the DEP web site for public access. The results are also included in the monthly, semi-annual, and annual reports submitted to EPA and NYSDOH. Method1623HV has been used for these keypoints samples since October 2001.

Objective 4.1.2: Croton Consent Decree Monitoring

To comply with the requirements set forth in the Croton Consent Decree. The Croton Consent Decree states "During the term of this Consent Decree, the City shall conduct the following sampling for *Giardia*, *Cryptosporidium* and viruses in the following locations in the Croton Water Supply System and/or Croton Watershed." The locations, site descriptions, and sampling frequency required follow this statement in the Decree document.

Sites

Sites are selected as required by the Croton Consent Decree (Table 4.5) with site locations identified in Table 4.6 and Figure 4.3.

Table 4.5. Croton Consent Decree monitoring requirements.

Location	Site Description	Frequency
Croton Gatehouse	Source Water	Weekly (see Obj. 4.1.1)
Muscoot Reservoir	Croton Reservoir Inflow	Monthly / except annually for viruses
Croton Falls	Croton Falls Reservoir	Monthly when release hydraulic pumping is utilized / except annually for viruses
Cross River	Cross River Reservoir	Monthly when release hydraulic pumping is utilized / except annually for viruses
Tributary to Haviland Hollow Brook	Undisturbed Watershed	Monthly / except annually for viruses
Tributary to Titicus River	Agricultural Watershed	Monthly / except annually for viruses
Downstream from Brewster Sewage Treatment Plant	Wastewater Treatment Plant	Monthly / except bi-monthly for viruses

Table 4.6. Croton Consent Decree sampling sites*.

Site Code	Site Description
CROGH	New Croton Aqueduct- Croton Lake Gatehouse, effluent from New Croton Reservoir (see Obj. 4.1.1)
MUSCOOTR	Muscoot Release, Gatehouse at dam dividing the Muscoot and New Croton Reservoirs
HH7	Haviland Hollow Brook at Brimstone Road
WF (previously identified as TRTIT)	Unnamed drainage downstream of Willow Farm, North Salem, NY
CROFALLSR	Croton Falls Reservoir Release
CROSSRVR	Cross River Reservoir Release
BSTP	Discharge of Brewster Sewage Treatment Plant

*Letter dated June 26, 2002 notified Croton Consent Decree parties that DEP was switching the analytical method to 1623HV and the site code change from TRTIT to WF.

Sampling Frequency and Duration

The sampling frequency is based on the monthly regulatory requirements set forth in the Croton Consent Decree. However, it should be noted that the New Croton Reservoir effluent is sampled weekly (Objective 4.1.1). Sampling will continue until termination of the Croton Consent Decree.

Analytes

The analytes are based on the requirements set forth in the Croton Consent Decree along with measurements that are important to complete and interpret the laboratory analysis (Table 4.7). *Cryptosporidium* and *Giardia* are sampled by Method 1623HV using a 50L sample volume (letter dated June 26, 2002 notified Croton Consent Decree parties that DEP was switching the analytical method to 1623HV). Human enteric virus are sampled using the ICR method.

Table 4.7. List of analytes based on the requirements set forth in the Croton Consent Decree.

Analyte	Reason for Inclusion
Giardia cysts	Croton Consent Decree requirement
Cryptosporidium oocysts	Croton Consent Decree requirement
Human enteric virus	Croton Consent Decree requirement
Sample volume	Required for calculating concentration
pH	Important for virus laboratory analysis
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure Differential on sample filter	Estimation of pellet size
Flow at sampling location	Required for flow adjustment

Data Reporting

The results of the analyses will be reported monthly to the Parties of the Croton Consent Decree, as required in the consent decree.

4.2 Surveillance Monitoring

Surveillance monitoring is comprised of four objectives. The purpose of the first surveillance monitoring objective, 4.2.1, is to conduct long-term (oo)cyst and virus monitoring at waste water treatment plants (WWTPs), and to study effectiveness of West-of-Hudson upgraded WWTPs in accordance with the 2002 FAD. The second objective, 4.2.2, provides surveillance of DEP's upstream reservoirs by conducting fixed-frequency monitoring of the aqueduct keypoints that do not represent source waters under normal system operations. The third objective, 4.2.3, provides a comparison of sub-basin integrator sites, and other sites deemed to be of importance by DEP by means of fixed-frequency sampling over an extended time period. The fourth objective, 4.2.4, provides surveillance of perennial streams flowing into Kensico Reservoir. The same sampling and analytical protocols are used so that results from all four objectives can be compared.

Objective 4.2.1: Long-term (Oo)cyst and Virus Monitoring at Waste Water Treatment Plants (WWTPs)

To monitor WWTPs in accordance with the 2002 FAD which states: “Report on the long-term monitoring of wastewater treatment plants for *Giardia* cysts and *Cryptosporidium* oocysts.” This monitoring program also includes collecting operational information for facilities that use micro-filtration and facilities that use approved equivalent methods for protozoan pathogen reductions. In addition, as part of DEP's surveillance of WWTPs, viruses are also monitored under this objective.

Sites

FAD requirements for pathogen monitoring are explicitly stated only for the Catskill/Delaware supply system. Therefore, only WWTPs within this supply system will be monitored under this objective. The FAD requirement suggests that the plants to be monitored are those that use micro-filtration (or its equivalent). Accordingly, only the effluents from plants that have been upgraded will be included. Monitoring of upgraded WWTPs began in July 2002. By the end of 2002, ten plants were in operation and available for effluent sample collection. Table 4.8 and Figure 4.4 presents the pathogen sampling schedule for WWTPs.

Table 4.8. Wastewater treatment plant sampling implementation schedule.

WWTP	Treatment Type	Permitted Flow (mgd)
Grahamsville	Microfiltration	0.18
Tannersville	Microfiltration	0.8
Grand Gorge	Microfiltration	0.5
Pine Hill	Microfiltration	0.5
Margaretville	Microfiltration	0.4
Hunter Highlands	Dual sand	0.08
Delhi	Dual sand	0.52
Hobart	Microfiltration	0.2
Stamford	Dual sand	0.5
Walton	Dual sand	1.02

Sampling Frequency and Duration

Quarterly, for a period of five years at which time this program will be reassessed.

Analytes

The analytes are based on the requirements set forth in the FAD along with measurements that are important to complete and interpret the laboratory analysis (Table 4.9).

Table 4.9. Analytes for WWTP monitoring.

Analyte	Reason for Inclusion
Giardia cysts	FAD requirement
Cryptosporidium oocysts	FAD requirement
Human enteric virus	DEP surveillance requirement
Sample volume	Required for calculating concentration
pH	Important for virus laboratory analysis
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment

Data Reporting

Reporting will be done on a semi-annual basis in accordance with the 2002 FAD.

Objective 4.2.2: Keypoint Monitoring Upstream of Source Waters

This monitoring provides surveillance of upstream reservoirs by conducting fixed-frequency monitoring of aqueduct keypoints. A joint letter from EPA and NYSDOH states: "It is also critical to move from a research mode to the routine monitoring mode for all the keypoints" (Covey and Gratz, 2001). These sites include the aqueduct keypoints upstream of source waters, under normal system operations.

Sites

The locations chosen for this objective represent aqueduct keypoint sampling sites. These are listed in Table 4.10 and Figure 4.5. Note that the keypoint representative of water drawn from the Ashokan Reservoir (EARCM) is not included here because (a) there are no new inputs between EARCM and CATALUM; therefore they represent the same water mass, and (b) CATALUM is sampled weekly (Objective 4.1.1).

Table 4.10. Keypoint monitoring locations upstream of source waters.

Site Code	Site Description
CATALUM	Catskill Aqueduct- Alum plant, influent to Kensico Reservoir
DEL17	Delaware Aqueduct- Shaft 17, influent to Kensico Reservoir
SRR2	Schoharie Reservoir Effluent at Shandaken tunnel outlet, Shandaken, NY
RDRR	Rondout Reservoir Effluent at Rondout effluent chamber, Napanoch, NY
NRR2	Neversink Reservoir Effluent, Grahamsville, NY
PRR2	Pepacton Reservoir Effluent at East Delaware Tunnel Outlet, Grahamsville, NY
WDTO	Cannonsville Reservoir Effluent at West Delaware Tunnel Outlet, Grahamsville, NY

Sampling Frequency and Duration

These sites are sampled monthly (with the exception of CATALUM and DEL17 which are sampled weekly under Objective 4.1.1). It is intended that this monthly frequency might be increased at appropriate sites if the routine monitoring at source water influents to Kensico Reservoir indicated elevated levels of pathogens. Monitoring began in July 2002 and will continue for five years, when sampling will be re-evaluated in view of the data analysis.

Analytes

The analytes are listed in Table 4.11.

Table 4.11. Analytes for upstream keypoints.

Analyte	Reason for Inclusion
Giardia cysts	DEP surveillance requirement
Cryptosporidium oocysts	DEP surveillance requirement
Sample volume	Required for calculating concentration
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment

Data Reporting

Data are reported semi-annually in the DEP report on Pathogen Studies.

Objective 4.2.3: Watershed-wide Comparison of Sub-basins

This objective compares sub-basin integrator sites, in terms of (oo)cyst concentration and occurrence, by means of fixed-frequency sampling over an extended time period.

Sites

The sites to be studied (Table 4.12 and Figure 4.6) include the lower main stem sites to each of the six West-of-Hudson reservoirs and, for four of these reservoirs, additional integrator sites approximately half-way up the main stem. Five integrator sites have been selected East-of-Hudson to examine much of the input to Muscoot Reservoir.

Table 4.12. Sites for watershed-wide sub-basin comparisons.

Site (code)	Reason for inclusion
Ashokan (E16I and E5)	Full and partial watershed integrator sites
Schoharie (S5I and S4)	Full and partial watershed integrator sites
Rondout (RDOA)	Full watershed integrator site
Neversink (NCG)	Full watershed integrator site
Pepacton (PMSB and PROXG)	Full and partial watershed integrator sites
Cannonsville (WDBN and CDG)	Full and partial watershed integrator sites
East Branch Croton River (EBCR3)	NE integrator site (approx. 20% of the watershed)
Boyd Corners Reservoir Release (BOYDR)	NW integrator site (approx. 10% of the watershed)
Croton Falls Reservoir Release (CROFALLSR)	Integrator site for northern 50% of watershed
Titicus Reservoir Release (TITICUSR)	Eastern integrator site (approx. 10% of the watershed)
Cross River Reservoir Release (CROSSRVR)	SE integrator site (approx. 10% of the watershed)

Sampling Frequency and Duration

Monthly. This sampling is expected to continue unchanged (including the sampling and analytical methodologies) for a minimum of five years. In which case, DEP believes that it may likely have sufficient data to detect any trends over this period with reasonable statistical confidence and power.

Analytes

See Table 4.13 below. The method used for pathogen enumeration will be the 1623HV method using a 50 L sample. HEV are sampled using the ICR method.

Table 4.13. Analytes used for watershed-wide comparison of sub-basins.

Analyte	Reason for Inclusion
Giardia cysts	DEP surveillance requirement
Cryptosporidium oocysts	DEP surveillance requirement
Human enteric virus	DEP surveillance requirement

Table 4.13. Analytes used for watershed-wide comparison of sub-basins.

Analyte	Reason for Inclusion
Sample volume	Required for calculating concentration
pH	Important for virus laboratory analysis
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure Differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment

Data Reporting

Results will be reported in the semi-annual report on Pathogen Studies. Data will be examined for variations with time, between locations and with reservoir keypoint results. Trends may be evaluated once an appropriate sample size is achieved.

Objective 4.2.4: Evaluation Of Kensico Reservoir Stream Inputs

To assess the contribution of pathogens to Kensico Reservoir from perennial streams. Information from the eight perennial streams is expected to indicate either that certain locations warrant further investigation, or confirm that sources within the sub-basins are negligible. This information will also provide a database of observations that can be used for mass balance analysis (Objective 4.3.4).

Sites

Table 4.14 and Figure 4.7 present the sampling locations for the evaluation of Kensico influent streams.

Table 4.14. Kensico Reservoir sampling locations perennial stream inflows.

Site Code	Site Description	Reason for Inclusion
BG-9	Discharge of Bear Gutter Creek	Perennial stream, Kensico input
E10	Discharge of stream E10	Perennial stream, Kensico input
E11	Discharge of stream E11	Perennial stream, Kensico input
E9	Discharge of stream E9	Perennial stream, Kensico input
MB1	Malcolm Brook, below West Shore Dr. BMP	Perennial stream, Kensico input
N12	Discharge of stream N-12	Perennial stream, Kensico input
N5-1	Discharge of stream N-5	Perennial stream, Kensico input
WHIP	Discharge of stream Whippoorwill	Perennial stream, Kensico input

Sampling Frequency and Duration

To provide a baseline of data, every other month fixed frequency monitoring is planned for the eight perennial streams in the Kensico Reservoir watershed. Additionally, storm event monitoring is planned simultaneously for the eight streams utilizing automated storm samplers. For each storm, one sample from each stream site will be submitted to the laboratory for analysis

using Method 1623HV. The sample will be a composite sample made up by flow weighted pooling of up to 20 Liters, in a manner to be determined through completion of Objective 4.4.2 [1]. For each stream and each event, a total pathogen storm load will be calculated. The target throughout the study will be six storm events per year. The duration for this objective is five years. The storm autosamplers required for this study are funded by a Water Resources Development Act grant and the project will begin when the funds for this grant become available in 2004.

Analytes

Table 4.15. Analytes used for evaluation of Kensico stream inputs.

Analyte	Reason for Inclusion
Giardia cysts	DEP surveillance requirement
Cryptosporidium oocysts	DEP surveillance requirement
Sample volume	Required for calculating concentration
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment

Data Analysis Protocol

A report to cover the two-year data collection period will be written once the analytical results are available. The report will include:

- Concentration and flow data resulting from monitoring during the period;
- The loading calculations for storm events monitored during the period;
- A comparison of the occurrence, concentration and loads of (oo)cysts found in the inputs and effluents of Kensico Reservoir;
- Problems that occurred during the reporting period;
- Recommendations for future work.

Flows and concentration data will be compiled as monthly loads that will be organized as a mass balance spreadsheet of inflows and outflows.

4.3 Watershed Research on Sources and Transport of (Oo)cysts

The study of watershed sources and transport of (oo)cysts includes four objectives. These objectives will generally monitor locations for short duration but with high intensity. Some of the research objectives are funded by grants and can only be accomplished when the funds for these grants are available. The purpose of the first watershed research objective is to identify and estimate the magnitude of potential protozoan sources. Objectives 4.3.2 and 4.3.3 will use base and

1. While development of the appropriate storm strategy will require some time, DEP will maintain its storm event surveillance program at Malcolm Brook. This program will capture at least six events per year or as conditions warrant.

event flow sampling to identify the range of (oo)cysts concentrations at integrator sites and in reservoirs. An alternative sample volume (10 Liter instead of 50 Liter) and grab sampling protocol will be used for Objectives 4.3.1, 4.3.2 and 4.2.3. Using the alternative protocol will enable coverage over a greater portion of the watershed. Objective 4.3.4 approaches the development of a pathogen mass balance on Kensico Reservoir using pathogen results, particle counts, and laboratory-derived settling rates.

Several methodological issues will need to be investigated and resolved prior to initiating sampling for the objectives. These issues include:

- Pressure
- Volume
- In-reservoir sampling.

Objective 4.3.1: Protozoan Sources from Specific Site Types

This sampling provides an evaluation of spatial variations in (oo)cyst concentrations in the watershed through enhanced and targeted sampling of a range of diverse potential site types and localized catchments. Potential site types that might be assessed include, but not are not limited to the following:

- Wetlands
- Stormwater outfalls
- BMP detention ponds
- Areas of failing septic systems
- Drainages from housing developments
- Drainages from industrial/corporate parks
- Small creeks and feeder streams
- Agricultural drainages
- Drainages from town centers
- Drainages from golf courses
- Septic spill events

This program also seeks to enable a rapid response to spill events or other conditions that might result in transient increases in (oo)cyst concentrations. This objective is funded by a Safe Drinking Water Act grant and most sampling will occur in 2004 and 2005.

For this objective, primarily 10 Liter samples will be collected and analyzed using EPA Method 1623. During the first year a total of up to 300 samples will be collected as a series of samples. Precipitations and meteorological conditions will be recorded throughout the study. Efforts will be made to sample more wet weather flows (> 0.5” rain within preceding 48 hours) than base flow. To the extent practicable, paired upstream/ downstream sampling will be performed at each site type, and grab samples will also be collected from suspected point sources. The first year study will be a range finding study to classify site types as being positive or negative for protozoan detection and to locate sites with a range of concentrations. During the second year, additional or repeat sampling may be performed at some sites and/ or the objective will include a more quantitative comparison of a smaller set of site types during both base and stormflow conditions.

Sites

Examples of sampling site types for the first year study are listed above, and will be provided in a QAPP. The list of sites may be modified as the project develops and as the data from routine sampling sites warrant follow-up to identify sources. A QAPP for Phase I of this project has been completed. DEP proposes to provide a revised set of sampling locations for this objective every 6 months, through QAPP updates.

Sampling Frequency and Duration

Paired upstream/downstream sampling will be performed each time, where site conditions permit. During the first year, DEP will resample 10% of the sites to provide a qualitative indication of variability in sampling results. SDWA funds have been allocated for a second year.

Analytes

Giardia and *Cryptosporidium* will be analyzed using Method 1623HV and a 10 Liter sample volume.

Table 4.16. Analytes using a 10 Liter sample volume for Source Identification Study.

Analyte	Reason for Inclusion
Giardia cysts	DEP surveillance requirement
Cryptosporidium oocysts	DEP surveillance requirement
Sample volume	Required for calculating concentration
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment
Total Precipitation	Explanatory variable

Data Analysis Protocol

The occurrence of (oo)cysts will be recorded for each location and site type, along with QC and other information associated with weather and hydrology. The results of the first year will be assessed, and a second year targeted investigation protocol will be developed for repeated storm and baseflow surveys (if a potential site type is identified in year 1). Results will be prepared as required under SDWA grant requirements.

Objective 4.3.2: Protozoan Sources from Stream Indicator Sites

To conduct a two-year range-finding study of potential differences in oocyst concentrations within sub-watersheds. This objective will be accomplished by both periodic sampling of gauged stream locations and storm-flow sampling of a subset of locations. This objective builds upon Objective 4.2.3 which provides for monthly fixed frequency monitoring of integrator stream sites that are major influents to WOH reservoirs, as well as several additional sites of interest EOH. It also builds upon Objective 4.3.4 which provides for event based monitoring strategies for paired reservoir and integrator site locations. The results of this research project will be used

to formulate further assessments of sub-watersheds for subsequent years. Thereafter, a subset of locations will be evaluated in subsequent years with a more focused and targeted monitoring program. In addition to the above, DEP proposes to target for further study, two of the four sites identified as having unusual results (compared with other fixed frequency sites). The sites Robertson's Farm (RF) and Shaw Road (SHR1) will be sampled under wet weather flows and compared with other indicator sites, to determine if the unusual results holds up with further investigation using Method 1623.

Sites

There are a total of 67 (49 West-of-Hudson, 18 East-of-Hudson) gauged stream sampling sites within the watershed that are sampled on a fixed frequency basis for long-term trend detection purposes under Objective 2.1 for the hydrology monitoring program. Within this network, 15 integrator sites will be sampled for protozoan pathogens on a monthly fixed frequency basis under Objective 4.2.3. Of the remaining 52 sites, 34 will be sampled on a periodic fixed frequency basis. Because this is a range finding study, 50-liter samples will be collected from each site once per quarter and analyzed using EPA Method 1623. Wet weather flow sampling (> 0.5" /preceding 48 hour period) will be conducted, to the extent practicable at 10% of the sites. Storm water monitoring will be performed following the recommendations from Objective 4.2. In addition to the above, wet weather flow sampling will be targeted towards two sites (RF and SHR1) as having an unusual results of data (compared with other fixed frequency sites). To the extent practicable, event-based sampling will be performed at these two sites each quarter following recommendations from Objective 4.2.

Sampling Frequency and Duration

Each indicator site will be sampled on a quarterly fixed frequency basis over a 2-year period. To the extent practicable, event-based sampling will be conducted at 5 of the sites each quarter (plus two additional sites described above). Event-based sampling sites will be preselected and identified in the QAPP. DEP will attempt to work in one reservoir watershed at a time.

Analytes

Giardia and *Cryptosporidium* will be analyzed using Method 1623HV and a 50 Liter sample volume.

Table 4.17. Analytes using a 50 Liter sample volume for Source Identification Study.

Analyte	Reason for Inclusion
Giardia cysts	DEP surveillance requirement
Cryptosporidium oocysts	DEP surveillance requirement
Sample volume	Required for calculating concentration
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC

Table 4.17. Analytes using a 50 Liter sample volume for Source Identification Study.

Analyte	Reason for Inclusion
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment
Total Precipitation	Explanatory variable

Data Analysis Protocol

The occurrence of (oo)cysts will be recorded for each location and sampling type, along with QC and other information concerning weather and hydrology. The results of the first two years will be assessed to identify potential differences in sub-watershed oocyst concentrations. This information, coupled with the results from the event-based monitoring will be used to define a targeted and quantitative comparison among indicator sites with different land-uses, in subsequent years.

Objective 4.3.3: Development of Event-based Pathogen Monitoring Strategies for Reservoirs

This monitoring provides data on protozoan concentrations in selected reservoirs following storm events, and to qualitatively identify the contributing streams that may be the predominant source(s) of these pathogens. The objective is to develop a sampling strategy that will allow rapid assessment of the impacts of storms on pathogen concentrations within a reservoir.

A comparison of the percentage detection of protozoans in reservoir effluent and influent samples suggests that the reservoirs may act as sinks for protozoans. However, these comparisons were made using an old analytical method (ASTM), and in many cases, these comparisons have been hampered by the many non-detects at both the influent and effluent. Although data collected by DEP indicates that protozoan pathogens, like bacterial pathogens are mobilized by storm events, the fate of a storm driven protozoan pathogen “pulse” (if one exists) has been measured only once at New Croton Reservoir following Hurricane Floyd. Very few (oo)cysts were detected in the water column at the locations sampled in the reservoir. Coincident with the reservoir sampling, samples will be collected from each of the major influents to the reservoirs to estimate relative loads, and from each of the major releases and aqueducts. A maximum of 400 samples will be collected for this program. Sampling of inflows, outflows and the reservoir will be coordinated to determine if a pathogen “signal” (*i.e.*, measurable protozoan concentrations) can be detected in a storm event, and ultimately to identify the potential contributing streams that may be the predominant source(s).

This will help DEP to make comparisons about the relative contributions and risk of each reservoir in terms of potential sources of protozoans and will provide increased surveillance monitoring. Additionally, this information will determine which reservoirs and which reservoir inflows to target for further study.

Sites

DEP will focus its efforts at developing event-based monitoring on three reservoirs. The reservoir surveys will provide for baseline surveys (<0.2 inches of rain in preceding 48 hours) in each of two years (1 spring, 1 summer), and four event-based surveys to capture the distribution of pathogens following major (>1" /24 hour) storm events. All samples will be collected as 10 liter grab samples and analyzed using Method 1623. To the extent practicable, the first round of samples from reservoirs will be collected within 24 hours of a storm. Field instrumentation (*e.g.*, a Hydrolab) will be used to measure water quality on the influent streams, and within the reservoir and this information will be used to select sampling locations within each reservoir that are within a zone of influence of the stream. For example, DEP will measure temperature, and attempt to collect a sample from a zone that is representative of the stream influent temperature. The work effort will begin at one of the reservoirs to help refine the methodology. Based on the results from the first year, the program may be modified to target additional or a specific reservoir(s) for more sampling events.

Sampling Frequency and Duration

As indicated above, DEP will attempt to study four events at each of three reservoirs in the first year. Samples will be collected within one day after peak flow has been recorded at the nearest integrator site stream gauge. In the initial stages of the study, if a "signal" can be detected, follow-up sampling may be performed. Sampling times following a storm event will be refined based on the results from initial surveys. This program is planned for two years.

Analytes

Giardia and *Cryptosporidium* will be analyzed using Method 1623 and a 10L sample volume. The analytes for this objective are the same as those listed in Table 4.17

Data Analysis Protocol

Influent data from storm events will be evaluated to compare differences in loads and to determine if a measurable pulse of protozoan (oo)cysts was detected during the storm event studied. Additionally, the reservoir data and diversion (aqueduct) data will be examined to determine if a measurable number of (oo)cysts was detectable in the reservoir. Comparisons will be made between reservoirs to determine how concentrations following a storm event differed. The data will also be examined to determine, qualitatively, which of the influent streams studied (through samples collected on the reservoir), might be a source of pathogens within the watershed and to target those streams for more intensified monitoring under Objective 4.3.1 or Objective 4.3.2. The data for the first year will be used to make modifications to the program for the second year.

Objective 4.3.4: Kensico Reservoir Mass Balance Analysis

The development of pathogen mass balance will be approached as three separate, but related components. The three components are particle counts, mass balance analysis, and settling rates. The rationale for each of the components is as follows:

- Particle counts are an essential element in turbidity modeling at the current time. They are also potential surrogates for pathogen cysts, and since cyst concentrations are frequently below detection in Kensico Reservoir, particle counts are one approach to the advancement of models that may also be applicable for pathogens. Particle counts will be coordinated with continuous turbidity measurements at 4 sites (*i.e.*, the 2 aqueduct inflows and 2 aqueduct outflows of Kensico Reservoir) to provide model calibration/verification data. This data will be of particular interest when turbidity events occur since it will provide 'time of travel' for (oo)cyst- sized particles from inflows to outflows to improve DEP's current prediction capability of the time of peak values at the effluent locations.
- A rudimentary mass balance will be compiled from concentration and flow measurements of all the major inflows and outflows for Kensico Reservoir. This component will identify the relative importance of the 2 aqueduct inputs, 2 aqueduct outputs, and 8 perennial streams for mass balance calculations. The mass balance will provide a diagnostic evaluation of the magnitude of net loss or gain that is not measured directly and, if significant, will point to the need for other process measurements to advance our understanding of (oo)cysts transport in the environment. The mass balance data will also provide a basis for model input, calibration, and verification.
- Settling rates of *Cryptosporidium* oocysts determined in the laboratory will be used. Experimental settling rates will be used to provide a rate for comparison or use in model runs. (It may also provide insight into whether a brief pre-filtration settling step could be used to improve oocyst recovery in samples with a lot of suspended particulate matter, however, this would have to be developed through separate experiments.)

Background

Kensico Reservoir is a key location with regard to both quality and quantity of the City water supply as the source water for the Catskill and Delaware Systems. Therefore, although pathogen concentrations have been consistently low and are frequently below detection, it remains a focal point for model development and testing. Since the pathogen "signal" is insufficient to provide a basis for model development, this effort is intimately tied to particle modeling as a surrogate. As models improve in their predictive capability and reliability, they will provide a basis for informed decision-making when water quality and /or quantity optimization must be achieved.

Currently, DEP has the capability to employ models to manage turbidity events (*i.e.*, to minimize, to evaluate the need for, and to predict the effects of alum treatments) at Kensico. A two-dimensional (2-D) model, CE-QUAL-W2, developed by Cole and Buchak (1994) was used to simulate turbidity levels at the Kensico Reservoir outlets. The preliminary calibration and verification runs suggest that the current model was able to predict peak reservoir outlet turbidities relatively well (Figure 4.1). Nevertheless, model calibration is still in progress and all results should be considered preliminary. The relationship between turbidity and particle counts must be known to ultimately estimate turbidity at the effluents. Therefore improvement of the database needed to define that relationship is one of the components of the work described here. Other

shortcomings are that predictions of the timing of peak turbidities appears to be too rapid, and dissipation rates after the peak turbidities appears to be too slow. This suggests that additional calibration or perhaps particle size "load" partitioning (portions with different settling rates) could improve predictions. Enhancement of the database with particle counts for a range of particle sizes that can be used for additional calibration runs may improve these shortcomings.

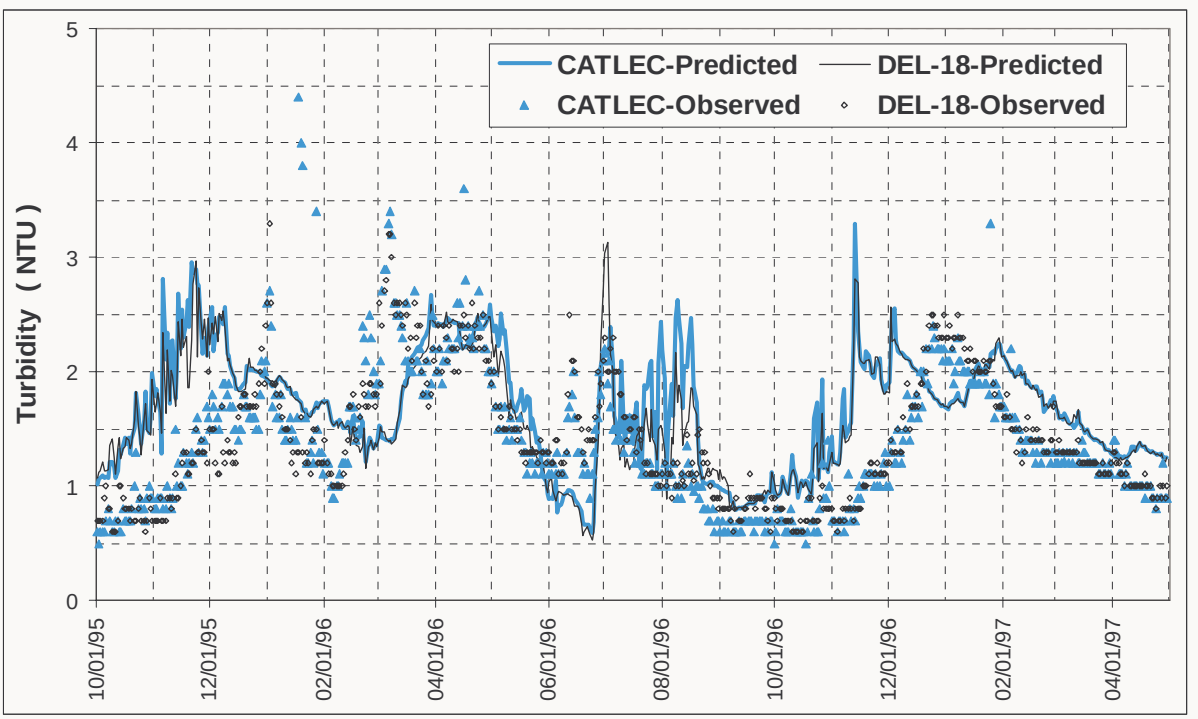

Figure 4.1. Comparison of Kensico 2-D model predictions with aqueduct outlet observations, 1995-1997. (Alum treatments occurred from 1/96 to 6/96 and 12/96 to 1/97.)

Note: CATLEC is also known as CATLEFF.

Given this capability as a starting point, DEP has chosen to improve model development with respect to the three components mentioned above; namely, particle counts at the major inflows and outflows, mass balance evaluation of pathogen cysts, and determination of (oo)cysts settling rates. The following is a description of the sampling needed to improve DEP's knowledge in these areas for the purpose of model development.

Particle Counts for Pathogen Model Development

Particles in six size ranges (channels) will be monitored to provide data for particle, turbidity, and oocyst modeling. Particle sizes to be counted will bracket the size range for *Cryptosporidium* oocysts (*i.e.*, 4-6 microns) and *Giardia* cysts (5-18 microns). The counting will be set up to record on a continuous basis, however, the data of primary interest will be recorded when turbidity events occur. Turbidity, specific conductivity, pH, and temperature are available from existing process control instrumentation. Continuous measurement will allow DEP to cap-

ture the data for such events and will allow additional calibration runs of the 2-D model. This may improve model predictions with respect to the timing of peak values at the outflows. The relationship of turbidity to particle counts will also be developed (as was done for the Cannonsville model.)

Sites

The four sites selected for continuous particle monitoring represent the two aqueduct inflows and two aqueduct outflows of Kensico Reservoir that also account for the major flow of water through the reservoir. (Turbidity is recorded at these locations on a continuous basis.)

Table 4.18. Sampling locations for monitoring particles for pathogen model development

Site Code	Site Description	Reason for Inclusion
DEL17	Delaware Aqueduct: Shaft 17	Major inflow
DEL18	Delaware Aqueduct: Shaft 18	Major outflow
CATALUM	Catskill Aqueduct, Pleasantville Alum Plant	Major inflow
CATLEFF	Catskill Lower Effluent Chamber	Major outflow

Sampling Frequency

Continuous recordings of particles in six size ranges (channels) will be done at all 4 locations (in parallel to turbidity recordings.)

Analytes

Table 4.19. Analytes used for particle counting.

Channels	Reason for Inclusion
1-4 micron	background comparison
5-15 micron	*Cryptosporidium* oocysts size range
8-18 micron	*Giardia* cysts length size range
18-20 micron	background comparison
20-30 micron	background comparison
30-40 micron	background comparison

Data Analysis Protocol

A report that examines the potential for calibration improvement, turbidity estimation improvement and the relationship of particles to pathogen cysts will be written after each of three significant turbidity events. Results to be reported include:

- particle counts in six channels during turbidity events for the monitoring period, as appropriate;
- examine particle count data for turbidity events and analyze timing and peak values between inflows and outflows; use for model calibration as appropriate;
- continue to examine the relationships, if any, between (oo)cysts, particle counts, and turbidity

using particle counts;
- problems that occurred during the reporting period; and
- recommendations for future work will be made based on the information derived from the three turbidity events.

Kensico Mass Balance

This component will use data from Objectives 4.1.1 and 4.2.4. The inflow to the Reservoir is represented in this mass balance by the Catskill and Delaware Aqueducts (more than 99% of flow into the reservoir) and eight perennial streams that represent the remaining flow input (less than 1%). Four of the perennial streams have been gauged by DEP and flow values are readily available from DEP's Hydrology group. The other four will be indexed to calculate flows. The two main outflows from the reservoir are the aqueducts. Other losses and gains (such as deposition, predation, resuspension, waterfowl sources, etc.) are not measured in this initial mass balance, however, the relative importance of these factors will be revealed by this analysis and it will indicate the importance of additional measurements to improve pathogen modeling.

Sampling Frequency and Duration

Depending on the sample location, the sampling frequency will be either weekly or bi-monthly. Event based sampling is also planned. See Objectives 4.2.1 and 4.2.4 for more detail.

Analytes

Analytes are the same as those listed for Objectives 4.2.1 and 4.2.4.

Settling Rate Estimation

This component is a laboratory experiment designed to determine the approximate sedimentation rate of *Cryptosporidium* oocysts. It will be conducted using a concentrated solution of spike material introduced at the top of a sedimentation column. The number of oocysts found in the bottom of the chamber over a range of elapsed time (*e.g.,* 15 min., 1 h, 3 h, 6 h, and 12 h) will be determined and used to estimate sedimentation rates in meters per hour (m h^{-1}). This direct observation can then be compared with sedimentation rates used in modeling runs. If major differences in the rates are seen, other process measurements will be needed to advance model predictions.

Analytes

The number of oocysts in the original spike solution and found in the bottom of sedimentation chambers after specified settling times will be counted by microscopic examination. Automated counting equipment will be employed if possible.

Data Analysis

A plot of the number of oocysts found in the bottom of the settling chamber vs. elapsed time will be constructed. This will show the length of time needed to approach complete settling of the initial spike. Initially, 6 samples will be counted and the experiment will be repeated with an adjustment of the settling times if necessary. The length of the settling column will then be used to calcu-

late a sedimentation rate as a distance per unit time (m h^{-1}.) This will be compared with settling rates found in the literature and those resulting from model calibration. Approximately 30 samples will be counted to estimate a settling rate for *Cryptosporidium* oocysts.

4.4 Methodological Studies

Methodological studies are divided into three objectives. These objectives are focused on improvements to pathogen detection methods both from the sampling and laboratory perspective. Results from methodological studies may then be used for program enhancements. Additional methodological studies may be initiated as problems are identified during the Pathogen Program's implementation. In Objective 4.4.1 experiments will be designed to identify water matrix **composition** affecting recoveries and investigate additional laboratory procedures to improve these recoveries. The impact on (oo)cysts recoveries from variations in volume, flow and sampling time will be studied in objective 4.4.2. Objective 4.4.3 uses genotyping to characterize *Cryptosporidium* beyond the genus classification. This method should enable a more accurate assessment of health risks.

Objective 4.4.1: Parameters Affecting Recovery

To conduct short-term studies targeted to identify parameters affecting recoveries of oocysts. These studies will include field and laboratory components.

Examples of methodological studies include the effect of pressure filter on (oo)cyst recoveries, impact of pellet volume, physical/chemical composition of the pellet on (oo)cyst recovery interferences, and additional laboratory procedures targeted to reduce these interferences and improve (oo)cyst recoveries.

Sites

Sites are targeted for specific matrix physical/chemical properties (*i.e.*, clay or organic content) and detectables (oo)cyst concentrations.

Sampling Frequency and Duration

Sampling frequency and duration will be described in quality assurance program plans prepared for each study.

Analytes

Analytes will include all analytes listed in Table 4.4 and additional analytes targeted to specific studies. Complete list of analytes will be provided in quality assurance program plans prepared for each study.

Data Reporting

Study summaries will be included in the semi-annual reports. Additionally, results may be submitted for publication in peered-reviewed professional publications or conferences.

Objective 4.4.2: A Comparison of Grab vs. Continuous Sampling Methods

The purpose of these field experiments is to compare (a) the results from sampling 10 Liter volumes at low-flow rates (0.4 Liter/minute) with results from sampling larger volumes (50 Liter with the prescribed 2 Liter/minute flow rate); and (b) the results of grab sampling with continuous samples taken over the course of several hours (*e.g.*, 24 hr.) that represent the same site and day. Both average concentrations and standard errors associated with replicate samples will be evaluated. If continuous samples show lower variability, the implication is that this method may be more sensitive for trend detection.

Sites

Two sites (MB1 and DEL17) were selected based on their representation of different pathogen occurrence and concentration levels (Figure 4.8).

Sampling Frequency and Duration

Sampling will be done at two sites with five different days devoted to each site for a total of ten sampling trips. For each sampling trip, six samples will be collected consisting of three replicate samples using each of the two methods (*i.e.*, grab and continuous.) The database will consist of 60 samples.

Analytes

Table 4.20. Analytes used for comparing continuous and grab sampling methods.

Analyte	Reason for Inclusion
Giardia cysts	Organism of interest
Cryptosporidium oocysts	Organism of interest
SampleVolume	Parameter to be optimized. Also required for calculating concentration
Turbidity	Measured for pellet size estimation and degree of potential debris in sample
Water temperature	Measured for QA/QC
Pressure Differential on sample filter	Estimation of pellet size

Data Analysis Protocol

Results to be reported include:

- Data resulting from monitoring during period
- A comparison of the average and standard error of occurrence, and concentration of (oo)cysts found by the two different sampling methods
- Recommendations for future work.

The average concentrations found by using different sampling methods are of interest and the magnitude of the errors is also of interest. This will guide future sampling and method development.

Objective 4.4.3: Cryptosporidium Characterization with Genotyping

To identify the genotype of *Cryptosporidium* oocysts, and, knowing the genotype, assess the risk of these genotypes to cause disease in humans.

The routine methodology used for identifying and enumerating protozoa in water has improved from the well-slide method, to the ICR Method, and now to Method 1623; however, all have fallen short of providing necessary information needed to accurately qualify any health risk to consumers (*i.e.*, infectivity).

The DEP Research Microbiology Unit has participated in a project with the Center for Disease Control and Prevention (CDC) under an AWWARF grant to develop a technique for the detection and differentiation of *118 Cryptosporidium* oocysts in environmental samples. Although the main objective has been method development, by participating, the DEP has been able to identify additional characteristics of *Cryptosporidium* oocysts found in some of New York City's streams (Xiao, *et al*., 2000).

The genotypes of *Cryptosporidium parvum* responsible for causing outbreaks in humans have been identified through molecular typing; however, there has not been direct linkage in the laboratory between those in outbreak cases with those found in water. To help identify the species and genotypes in water, DEP has collected numerous event based storm samples from two streams in the watershed. Samples have been collected and pre-processed by DEP, and then analyzed at CDC using a small-subunit rRNA-based PCR-restriction fragment length polymorphism technique to identify species and sources of the captured oocysts. Data have indicated that all oocysts analyzed thus far have been from non-human sources, and more specifically, they have been from wildlife.

This preliminary data has provided DEP with valuable insight with respect to the sources of *Cryptosporidium* during storms on the studied streams, as well as insight into the high level of detailed information we are now able to obtain with current advancements in environmental molecular microbiology. DEP sought to continue this work through SDWA funding and initial approval has been granted to support the genotyping project. This project is a high priority for DEP. Production of a workplan and QAPP is currently in development. DEP is also contacting government, independent and academic laboratories that can provide this level of genotyping and sequence analysis on *Cryptosporidium* oocysts, to obtain cost, method and QC information.

Sites

Samples are collected during storm events at sites which are currently routinely monitored for protozoan loads. At the present time, two streams influent to Kensico Reservoir are being monitored. Additional sites may be added as funds from a Safe Drinking Water Act grant become available.

Table 4.21. Sample locations for continuous versus grab sample comparison.

Site Code	Site Description	Reason for Inclusion
DEL17	Delaware Aqueduct –shaft 17, influent to Kensico Reservoir	Site represents low (oo)cyst level equivalent to source water.
MB1	Malcolm Brook, below BMP	Site represents known (oo)cysts occurrence from a residential watershed.

Sampling Frequency and Duration

Sampling frequency relies on storm events.

Analytes

Table 4.22. Analytes used for event-based monitoring strategies.

Analyte	Reason for Inclusion
Giardia cysts	Organism of interest
Cryptosporidium oocysts	Organism of interest
Sample volume	Required for calculating concentration
Turbidity	Measured for pellet size estimation
Water temperature	Measured to ensure QA/QC
Pressure differential on sample filter	Estimation of pellet size/interference
Flow at sampling location	Required for flow adjustment

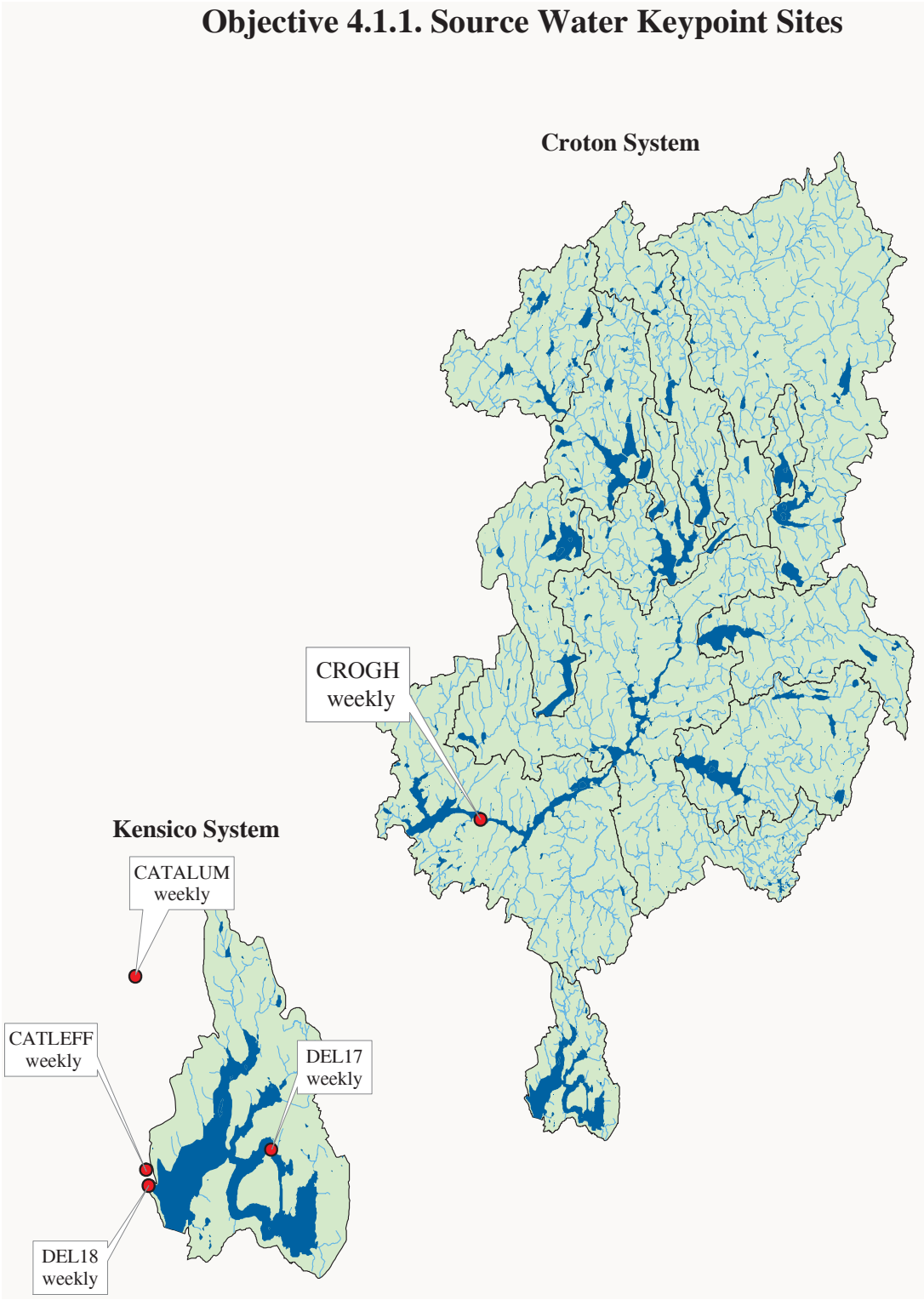

Figure 4.2. Sampling locations for source water keypoint sites.

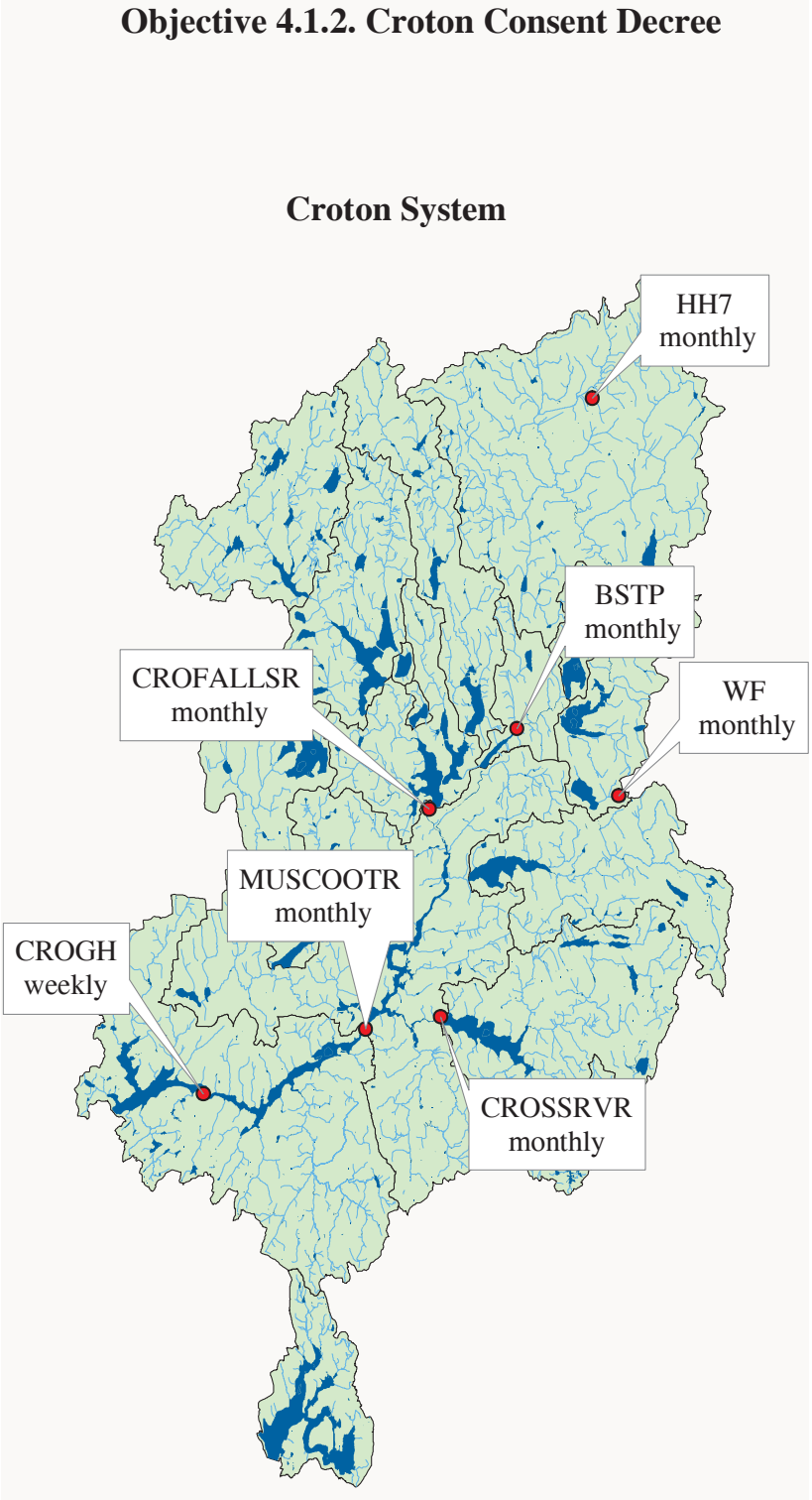

Figure 4.3 Sampling locations for Croton Consent Decree.

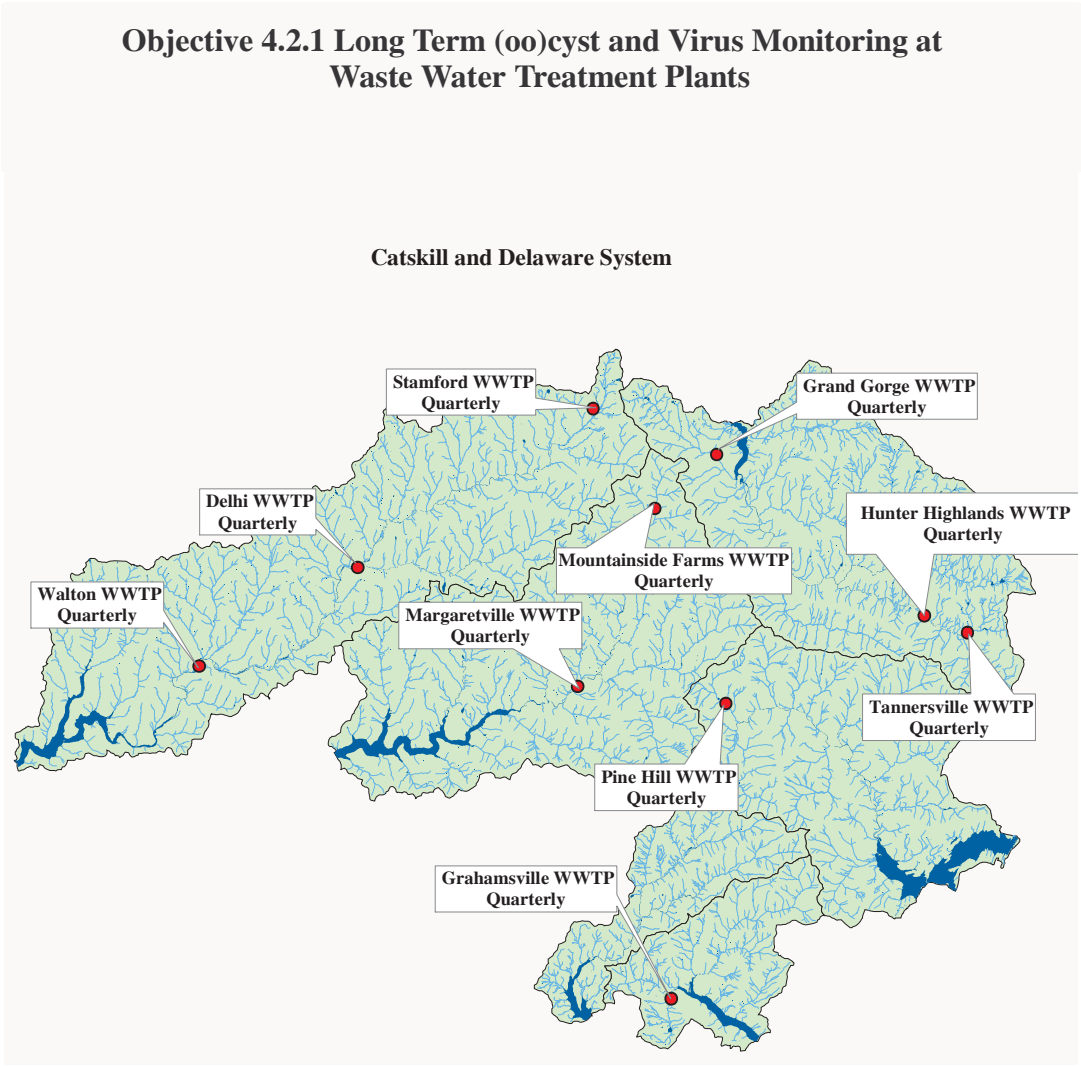

Figure 4.4. Sampling locations for long term (oo)cyst and virus monitoring at waste water treatment plants.

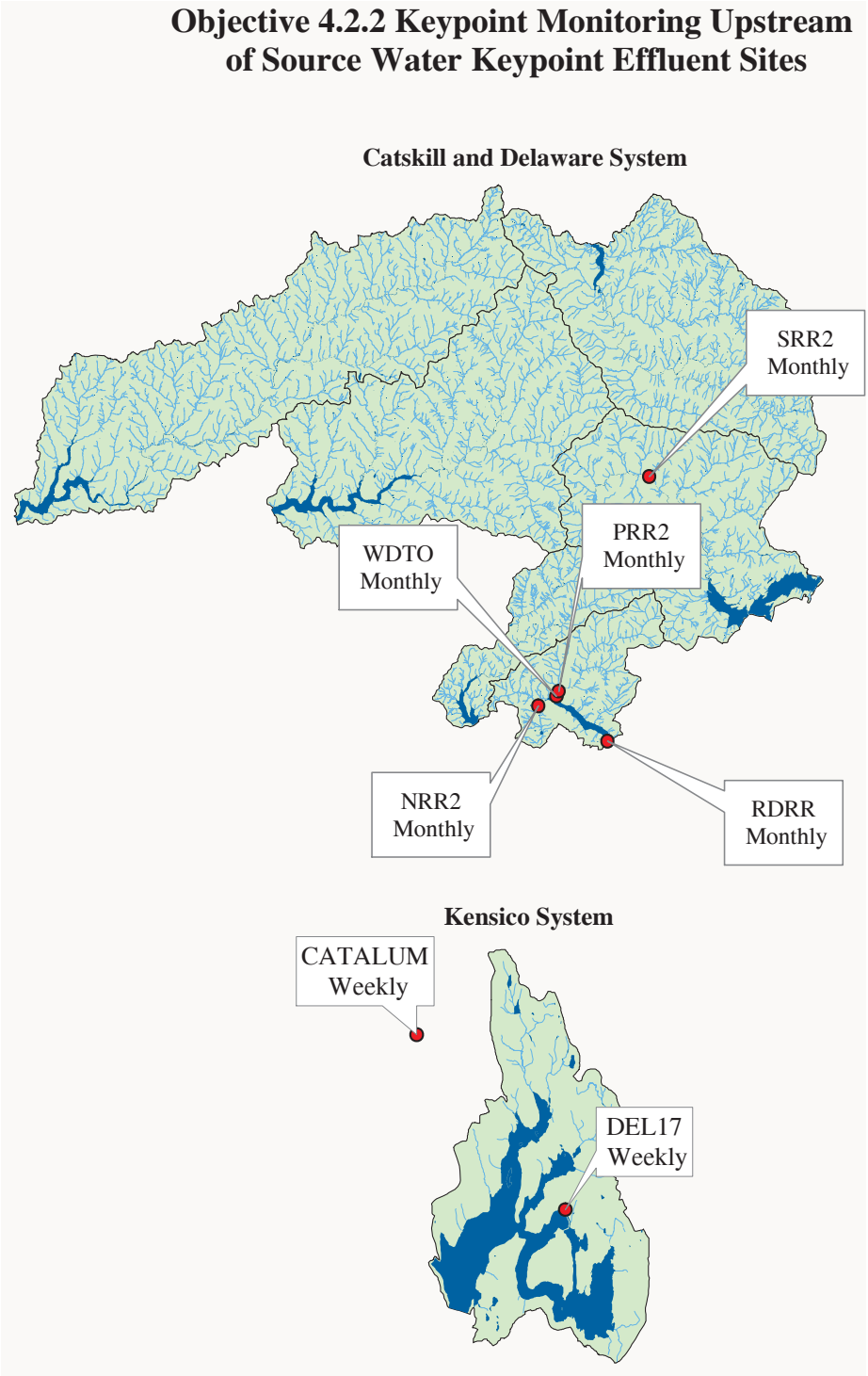

Figure 4.5. Keypoint monitoring upstream of source water keypoint effluent site

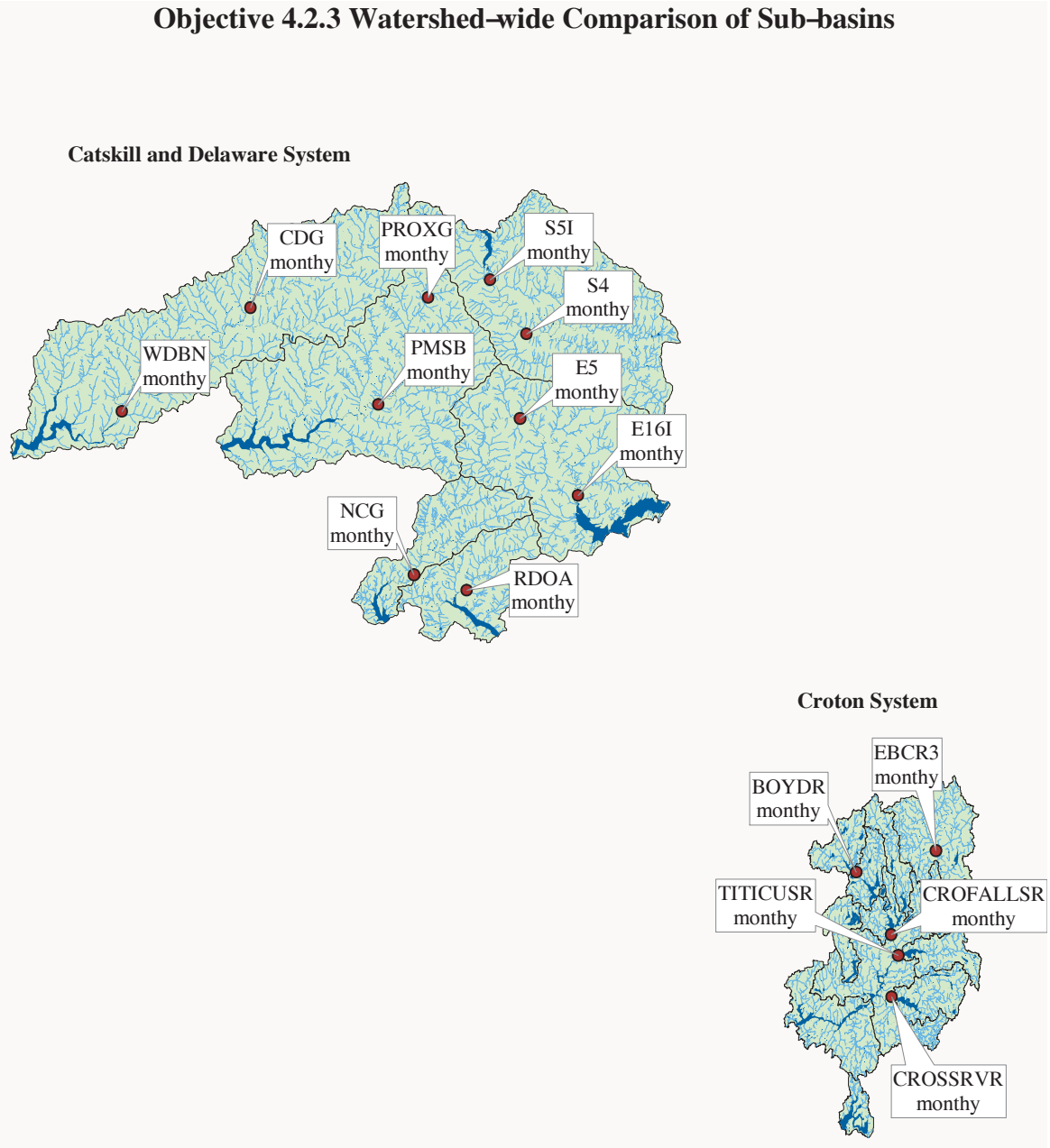

Figure 4.6. Sampling locations for watershed-wide comparison of sub-basins.

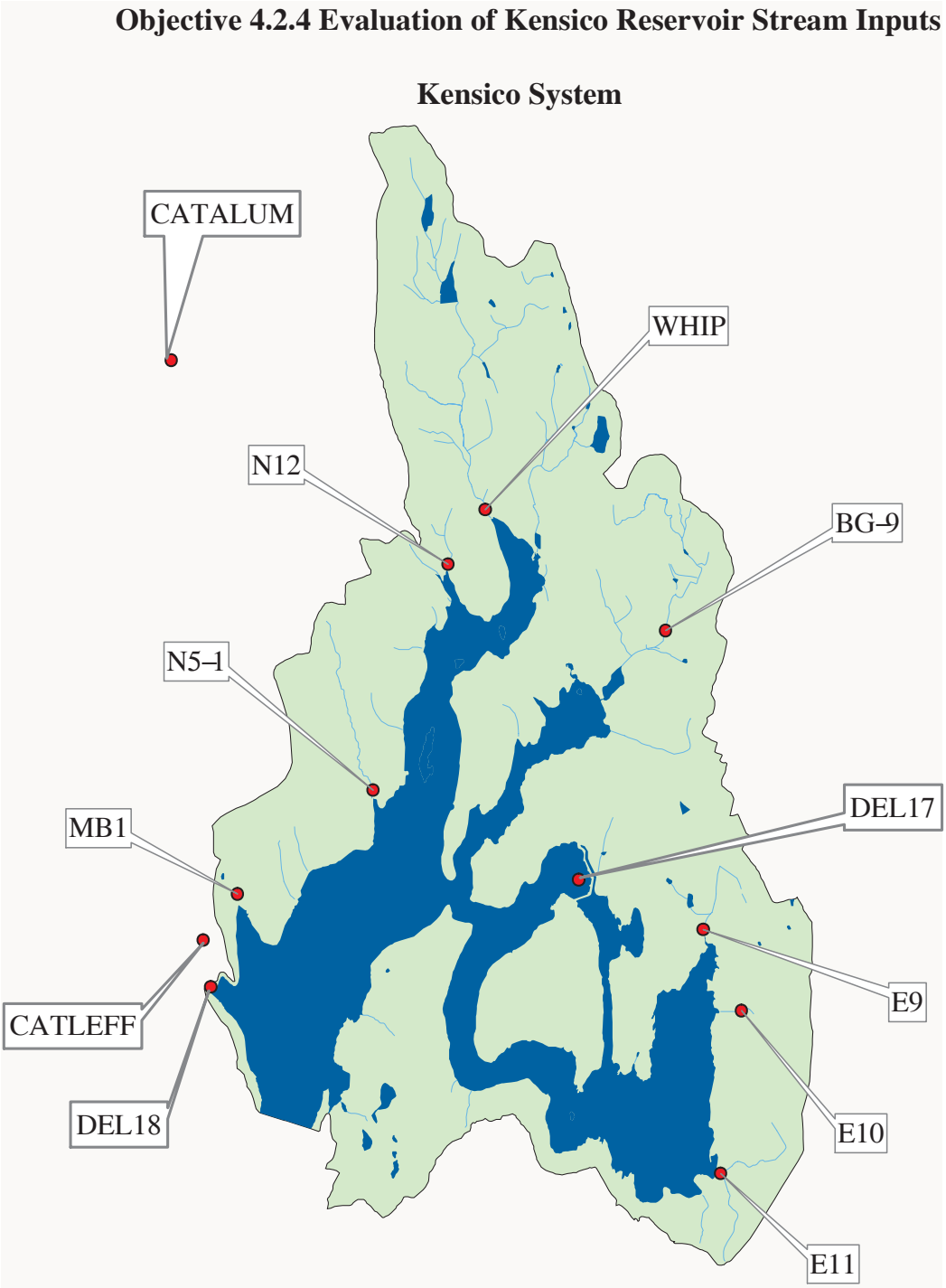

Figure 4.7. Sampling locations for evaluation of Kensico Reservoir streams. Stream sites are sampled every other month, and keypoints are sampled weekly.

Objective 4.4.2 Comparison of Continuous versus Grab Sampling Methods

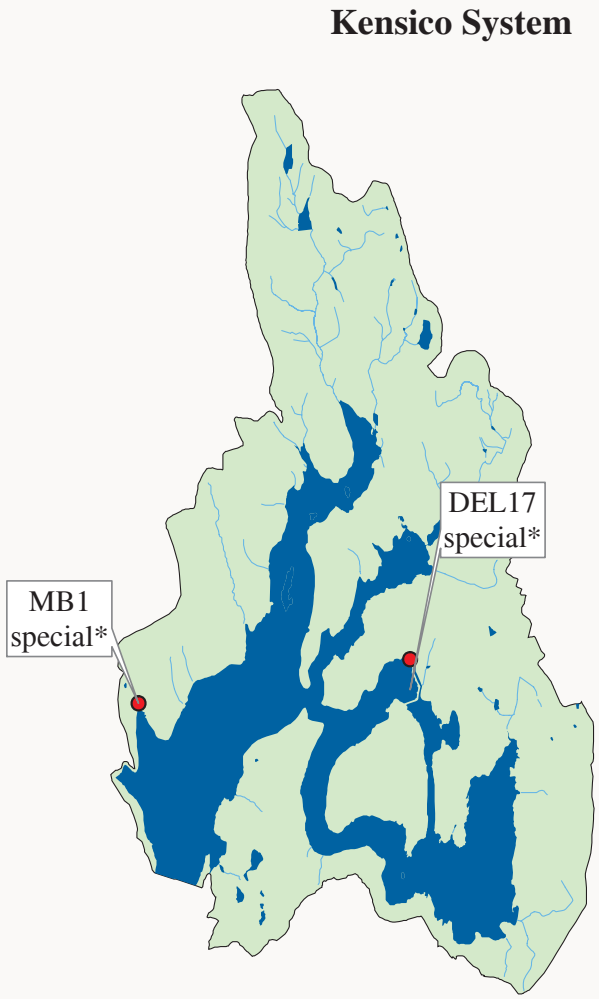

Figure 4.8. Sampling locations for comparison versus grab sampling methods.

References

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USEPA. 1996. EPA Guide to Method Flexibility and Approval of EPA Water Methods. EPA 821-D-96-004. Office of Water, Engineering and Analysis Division. Washington DC 20460.

Xiao, L., K. Alderisio, J. Limor, M. Royer, and A.A. Lal. 2000. Identification of Species and Sources of *Cryptosporidium* Oocysts in Storm Waters with Small-Subunit rRNA-Based Diagnostic and Genotyping Tool. Applied and Environmental Microbiology. 66:5492-5498

5. Program Evaluation Reporting

In Chapter 1, DEP provided the conceptual framework used in the production of this document (Figure 1.2). This framework depicted the complex, interactive nature of the data collection programs and their links with data/information users and other monitoring requirements. The starting point was the definition of Objectives obtained from a variety of sources but the process is dynamic and therefore subject to change. It is necessary to periodically evaluate the overall program to ensure that data/information produced adequately addresses the requirements of end users. The program is meant to be flexible and responsive to the needs of management and others to ensure that sources of potential risk are appropriately evaluated.

On an annual basis, if possible, we intend to evaluate, and report on, at least parts of the program to ensure that the objectives are being met. In this, we intend to examine the appropriateness of the objectives themselves, sampling frequencies, sites, and analytes by means of qualitative and quantitative evaluations. Programs will be modified/enhanced if considered appropriate. The intent here is to report on such modifications/enhancements on an annual basis if possible. This will be in addition to the reporting as noted for each objective.

Appendices

Appendix 1: Trend Analysis Methodology

The initial steps involve an examination of the dataset to identify "outliers", *i.e.*, data points which appear to be in error. One way to accomplish this is by a visual inspection of the raw data plotted against time. Potential outliers may be quite legitimate because the samples were taken during high flow, for instance. Such points are quite acceptable and therefore not removed from the dataset prior to analysis. Other outliers may be removed. This is largely a judgment call based on experience but it is expected that there will be very few such data points in the DEP dataset.

The next procedure, also visual, is to mark the times when analytical procedural changes took place onto a data temporal plot, and a subjective assessment made as to whether these changes might have resulted in a step-trend in the data. A step-trend here is defined as a jump in the data values which may, or may not, be visually apparent. Almost any change in procedure can cause such a step-trend and this must be investigated prior to trend analysis. Ideally there would be no such changes in a dataset but this is sometimes not possible. Data changes may be very subtle and may be masked by the natural variability that occurs in environmental data of this kind. Obvious step-trends as a consequence of analytical changes may require partitioning of the dataset into *before* and *after* datasets that must be analyzed separately. The consequence of data partitioning is that the number of data points per data sub-set is reduced and this creates a reduction in confidence in a detected trend, or possibly worse, a reduction in trend detectability power. In some instances there may not be a visual step-trend in the data but trend analysis on partitioned data could still be performed to better explain the data. Many authors (*e.g.*, Smith *et al*. 1996) have recommended a minimum of five years for trend analysis for a variety of reasons although this is not always possible because of, for example, data partitioning to accommodate analytical changes.

Once the final raw datasets are confirmed, then the trend analysis proper can be commenced. Trend analysis for reservoirs is more complex than for streams or keypoints because of the multiplicity of sampling points and the fact that reservoirs stratify in summer. The use of LOWESS smoothing (LOcally WEighted Scatterplot Smoothing) curves will be used initially to aid the eye in assessing the temporal “flow” of the data although the procedure is somewhat subjective. LOWESS curves will likely be generated using Kaleidagraph (Synergy Software, Reading, PA). Following this, monotonic trend analysis will be undertaken using the following software: WQStat Plus™ (IDT, Longmont, CO), a commercially-available non-parametric approach initially designed for rivers, and LakeWatch (Seveno©, Auckland, New Zealand—www.seveno.com), very recent software specifically designed for lakes which uses parametric statistics. For stream sites, analysis will be conducted on the raw and flow-adjusted data. The

non-parametric approach will use the Seasonal Kendall Test and Seasonal Kendall Sen Slope Estimator procedures (Hirsch *et al*. 1982). The parametric test built into LakeWatch uses simple linear regression, after deseasonalizing, to investigate trends.

The Seasonal Kendall and the parametric test pose the null hypothesis that there is no trend; the alternative hypothesis being that there is in fact an upward or downward trend (a two-sided test). A strong advantage of the non-parametric test is that there are no assumptions made, apart from monotonicity, about the functional form of any trend that may be present; the test merely addresses whether the within-season/between-year differences tend to be monotonic. Outliers also have a lesser effect on the non-parametric tests because they consider the ranks of the data rather than actual values. The effects of serial correlation are always ignored; this is justified because the scale of interest is confined to the period of record (Loftis *et al*., 1991).

The final step will involve tabulation and graphing of the results, as appropriate. Because the graphics from WQStatPlus are unattractive and not exportable, most graphs will be produced in the dedicated graphing package, Kaleidagraph. LOWESS curves will likely be generated using Kaleidagraph. The trend lines produced using WQStat Plus, for each temporal period analyzed and for both the raw and flow-adjusted data, will be graphed by pivoting an appropriately sloping line around the median value. The *p*-values for each trend test will be symbolized as follows:

p-value	Symbol
$p \geq 0.20$	NS (Not Significant)
$p < 0.20$	*
$p < 0.10$	**
$p < 0.05$	***

The lower the *p*-value, the more likely the observed trend is not attributable to chance. Note that the term "NS" does not mean that there is *no* trend. It means that the null hypothesis of "no trend" cannot be rejected (at the $p = 0.2$ level of significance—80% confidence level), and any observed trend could be attributed to chance. It should also be pointed out that it is possible to obtain a 'statistically significant' trend with the Seasonal Kendall Test yet obtain a zero Seasonal Kendall Sen Slope Estimator. This is an odd feature of the procedures and occurs when there are many tied values in the dataset, *e.g.*, many "non-detects". There is a dislocation between the trend test and the slope estimate, that is, the two procedures are carried out independently of each other. The trend slope is computed from the median slope of all possible slopes and, in this instance, is zero.

References

Hirsch, R.M., J.R. Slack and R. A. Smith 1982. Techniques of Trend Analysis for Monthly Water Quality Data. Water Resources Research 18: 107-121

Loftis, J.C.; G.B. McBride; J.C. Ellis 1991. Considerations of scale in water quality monitoring and data analysis. Water Resources Bulletin 27: 255-264.

Smith, D.G., McBride, G.B., Wisse, J., Mink, D. 1996. Trends in New Zealand's National River Water Quality Network. New Zealand Journal of Marine and Freshwater Research 30: 485-500.

Appendix 2: Limnology Program - Sampling Depth Strategy 2003

Goal

The primary goal of DEP's Limnological sample collection strategy is to collect water samples representative of the entire water column. DEP samples the water column, based upon temperature, as thermal stratification affects the water quality characteristics of various depths. When the water column is stratified it is important to sample water from each of the 3 distinct thermal zones (*i.e.*, epilimnion, metalimnion, and hypolimnion).

Definitions

The Limnology Program's definitions of these layers are:

epilimnion: a layer of water in a thermally stratified lake which is warmer, less dense and floats on a cooler, denser water layer (the hypolimnion) and is separated by the metalimnion. The temperature of epilimnetic water changes less than 1°C per meter of depth.

metalimnion: a zone of rapidly changing temperature and density that separates the epilimnion and the hypolimnion in a thermally stratified lake. It is identified in the Limnology Program's by a temperature change of ≥ 1.0°C per meter of depth at its upper boundary and extends to a depth where the temperature change is still greater than 0.2 °C per meter. The metalimnion is the zone in which a discrete thermocline depth (defined below) is established.

hypolimnion: the thermal layer of water below a thermocline that changes very little in temperature (The hypolimnion is identified by the Limnology Program as the zone that changes ≤ 0.2 C meter^{-1}).

thermocline: a layer in the water column having the steepest thermal gradient and changes ≥ 1^0C within 1 meter. The term "thermocline" will not be applied to describe a thermal gradient occurring at, or above, one meter of depth.

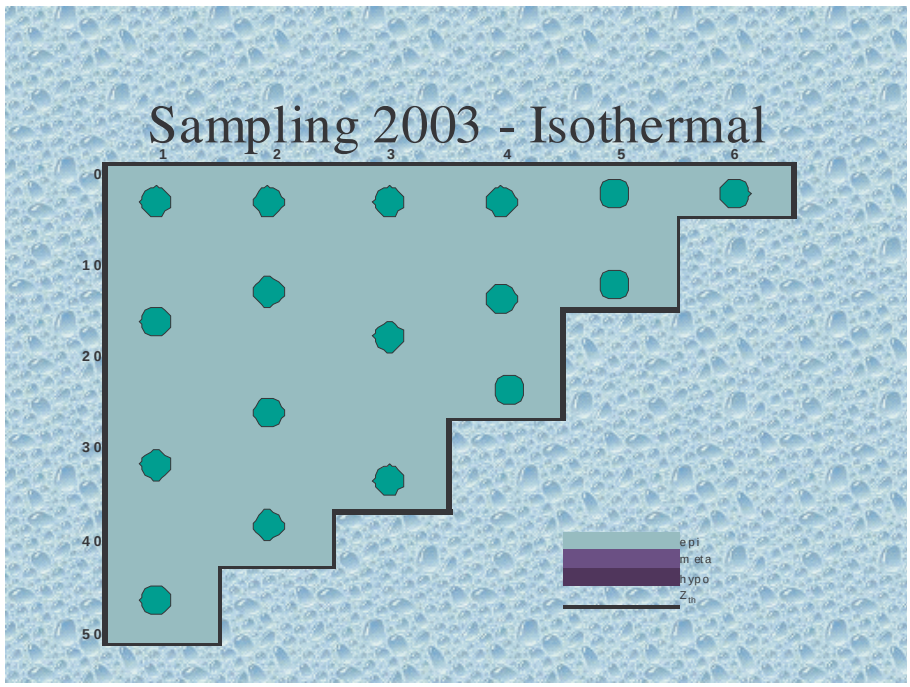
Sampling Strategy

During non-stratified periods, the water column is fairly well mixed, and DEP's Limnology Program collects samples based upon the maximum depth of the water column (Z_{max}) at the monitoring station on the day of the survey. Sampling during this period should be performed as indicated in Appendix Table 1.

Appendix Table 1. Sampling depths during non-stratified conditions.

Maximum depth	No. of Discrete Samples	Samples depth to be collected
0m to 3m	1	Z_{max} -1m
4m to 5m	1	3m
6m to 19m	2	3m, Z_{max}-2m
20m to 39m	3	3m, Z_{max}/2m, Z_{max} -2m
= 40m	4	3m, 1/3 Z_{max}, 2/3 Z_{max}, Z_{max} -2m

An example of sampling during non-stratified, isothermal conditions is provided in Appendix Figure 1.



Appendix Figure 1. Sampling depths during non-stratified conditions.

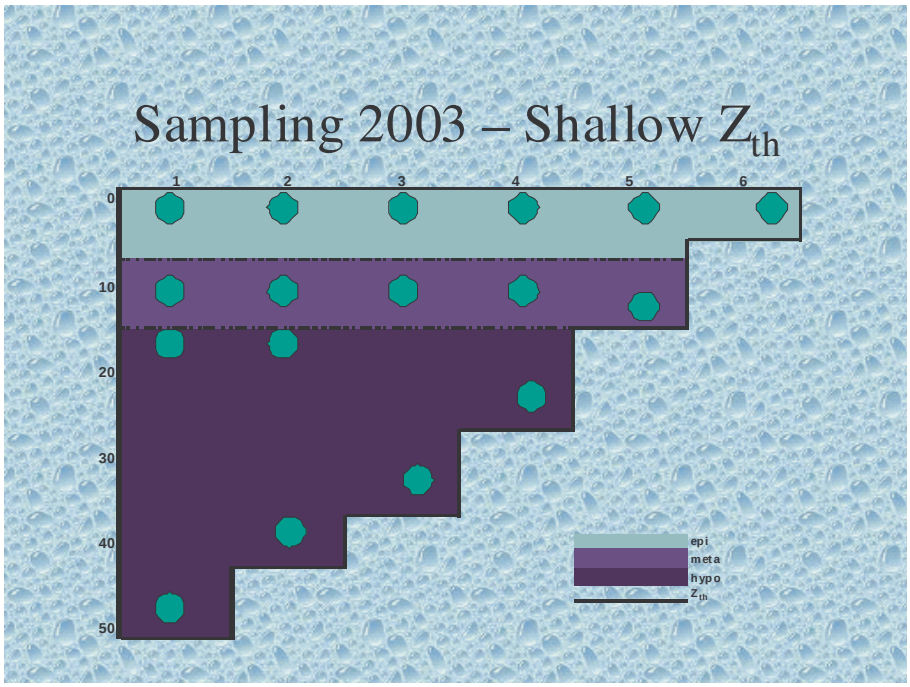
During stratified periods, the goal, in general, is to obtain a sample from each of the three thermal zones (epilimnetic, metalimnetic, and hypolimnetic) in order to appropriately characterize the water column. At very deep sites (>40m), however, an additional sample is taken. The purpose of this sample is to improve our resolution of thick thermal zones. The sample is collected of the lower regions of the epilimnion when the thermocline is deep or the upper area of the hypolimnion when the thermocline is shallow.

During stratified periods, when the thermocline is shallower than ½ of the maximum depth of the water column ($Z_{max}/2$) at the monitoring station on the day of the survey, sampling should be performed as indicated below in Appendix Table 2:

Appendix Table 2. Sampling depths during stratified conditions (with shallow thermoclines) .

Maximum depth	No. of Discrete Samples	Samples depth to be collected
0m to 3m	1	Z_{max} -1m
4m to 5m	1	3m
6m to 19m	2 or 3	3m, Z_{max} -2m, and Z_{th}+1m (if hypo present)
20m to 39m	3	3m, Z_{th}+1m, Z_{max} -2m
= 40m	4	3m, Z_{th} +1m, $Z_{hypoTop}$+1m, Z_{max} -2m

An example of sampling during stratified conditions (with shallow thermoclines) is shown in Appendix Figure 2.



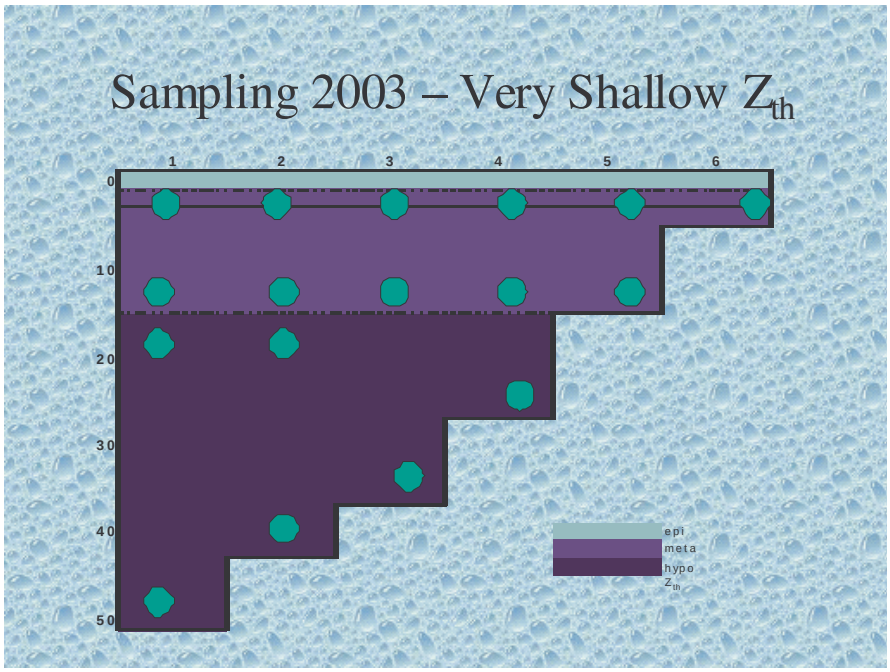
Appendix Figure 2. Sampling depths during stratified conditions (shallow Z_{th}).

During stratified periods, when the thermocline is equal to or shallower than 3m at the monitoring station on the day of the survey, sampling should be performed as indicated below in Appendix Table 3:

Appendix Table 3. Sampling depths during stratified conditions (with very shallow thermocline (< 3 m)).

Maximum depth	No. of Discrete Samples	Samples depth to be collected
0m to 3m	1	Z_{max} - 1m
4m to 5m	1	3m
6m to 19m	2 or 3	3m, Z_{max} -2m, and Z_{th}+1m (if hypo present)
20m to 39m	3	3m, $Z_{metaBOT}$ - 1m, Z_{max} - 2m
= 40m	4	3m, $Z_{metaBOT}$ - 1m, $Z_{hypoTop}$+1m, Z_{max} -2m

An example of sampling during stratified conditions (with very shallow thermoclines) is shown in Appendix Figure 3.



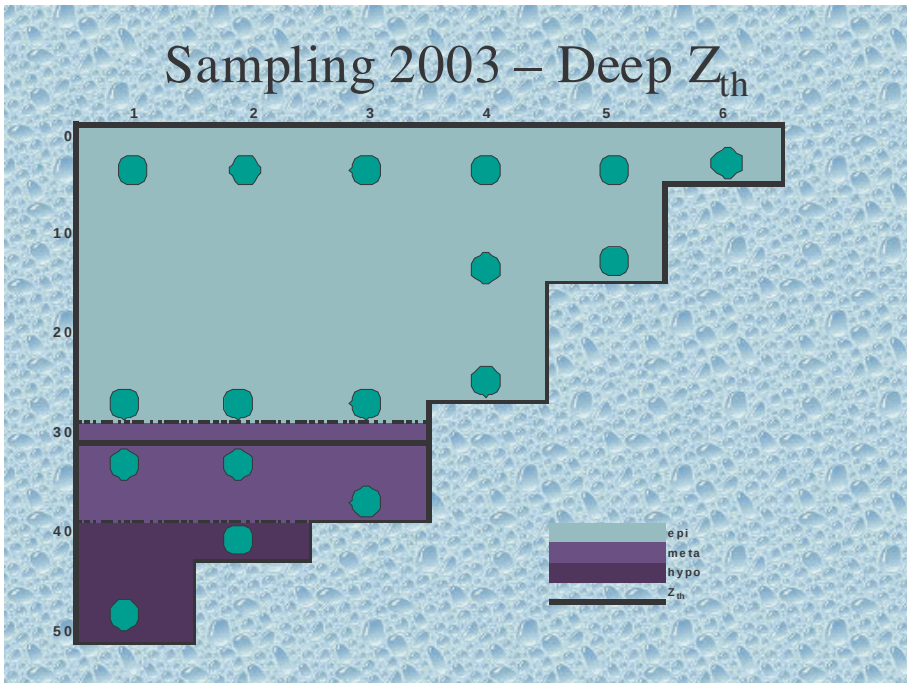
Appendix Figure 3. Sampling depths during stratified conditions (very shallow Z_{th}).

During stratified periods, when the thermocline is deeper than ½ of the maximum depth of the water column ($Z_{max}/2$) at the monitoring station on the day of the survey, sampling should be performed as indicated below in Appendix Table 4:

Appendix Table 4. Sampling depths during stratified conditions (with deep thermoclines).

Maximum depth	No. of Discrete Samples	Samples depth to be collected
0m to 3m	1	Z_{max} - 1m
4m to 5m	1	3m
6m to 19m	2 or 3	3m, Z_{max} -2m, and Z_{th}+1m (if hypo present)
20m to 39m	3	3m, Z_{th} +1m, Z_{max} -2m
= 40m	4	3m, Z_{epiBot} -1m, Z_{th} +1m, Z_{max} -2m

An example of sampling during stratified conditions (with deep thermoclines) is shown in Appendix Figure 4.



Appendix Figure 4. Sampling depths during stratified conditions (deep Z_{th}).

During stratified periods in which an epilimnetic and metalimnetic sample is obtained but no hypolimnetic waters can be obtained at the monitoring station on the day of the survey, then following sampling regime should be enacted Appendix Table 5.

Appendix Table 5. Sampling depths during stratified conditions (with no hypolimnion).

Maximum depth	No. of Discrete Samples	Samples depth to be collected
0m to 3m	1	Z_{max} - 1m
4m to 5m	1	3m
6m to 19m	2	3m, Z_{max} -2m
20m to 39m	3	3m, Z_{epiBot} -1m, Z_{max} -2m
= 40m	4	3m, ½ Z_{epi}, Z_{epiBot} -1m, Z_{max} -2m

An example of sampling during stratified conditions (with no hypolimnion) is shown in Appendix Figure 4 under site 3.

Protocols for selecting appropriate limnological sampling depths during non-stratified and stratified conditions are delineated in flow charts (Appendix Figure 5 and Appendix Figure 6, respectively) below.

Rationale for Depth Selection

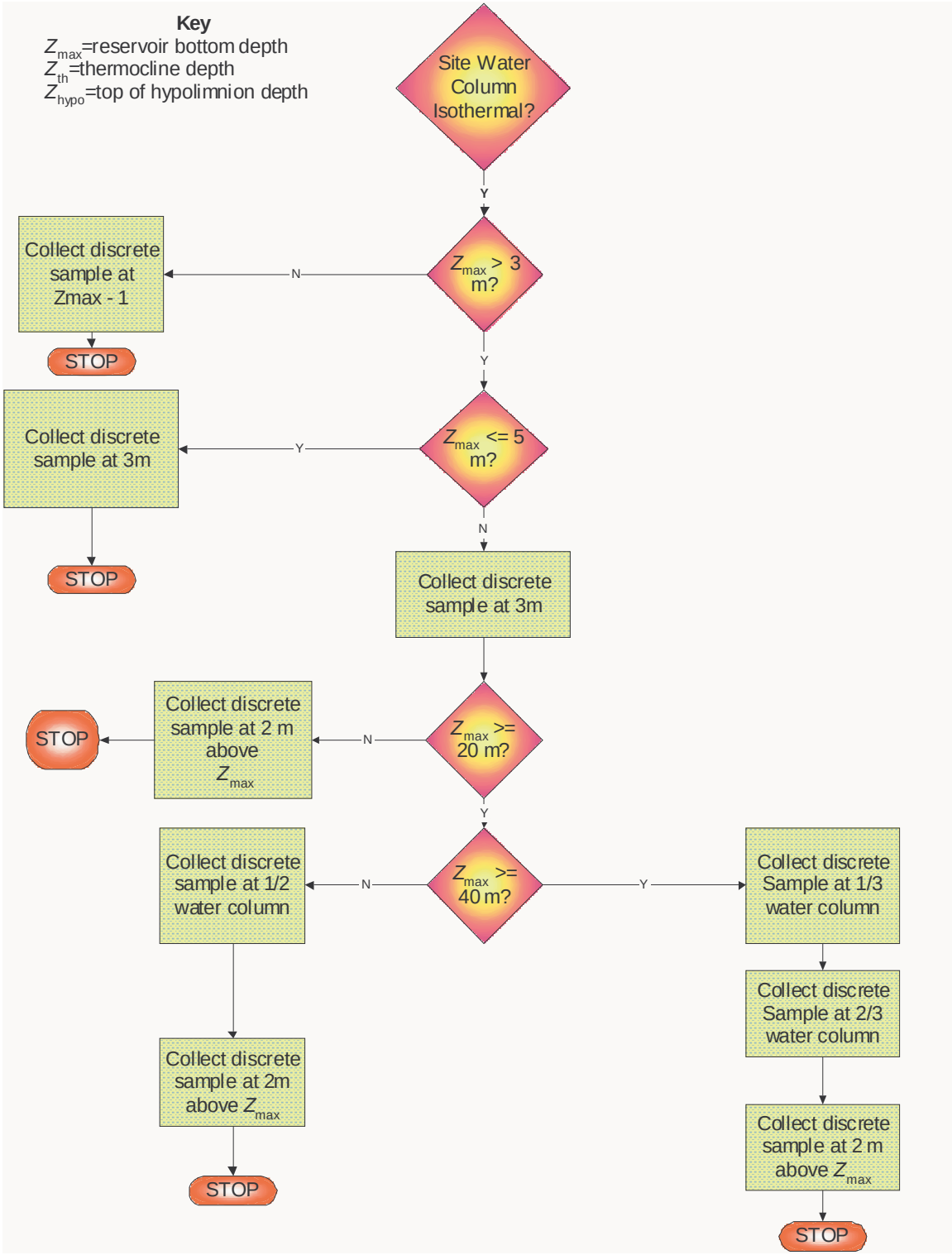
The basis for the selection of each sampling depth is summarized in Appendix Table 6.

Appendix Table 6. Rationale for sample depth selection.

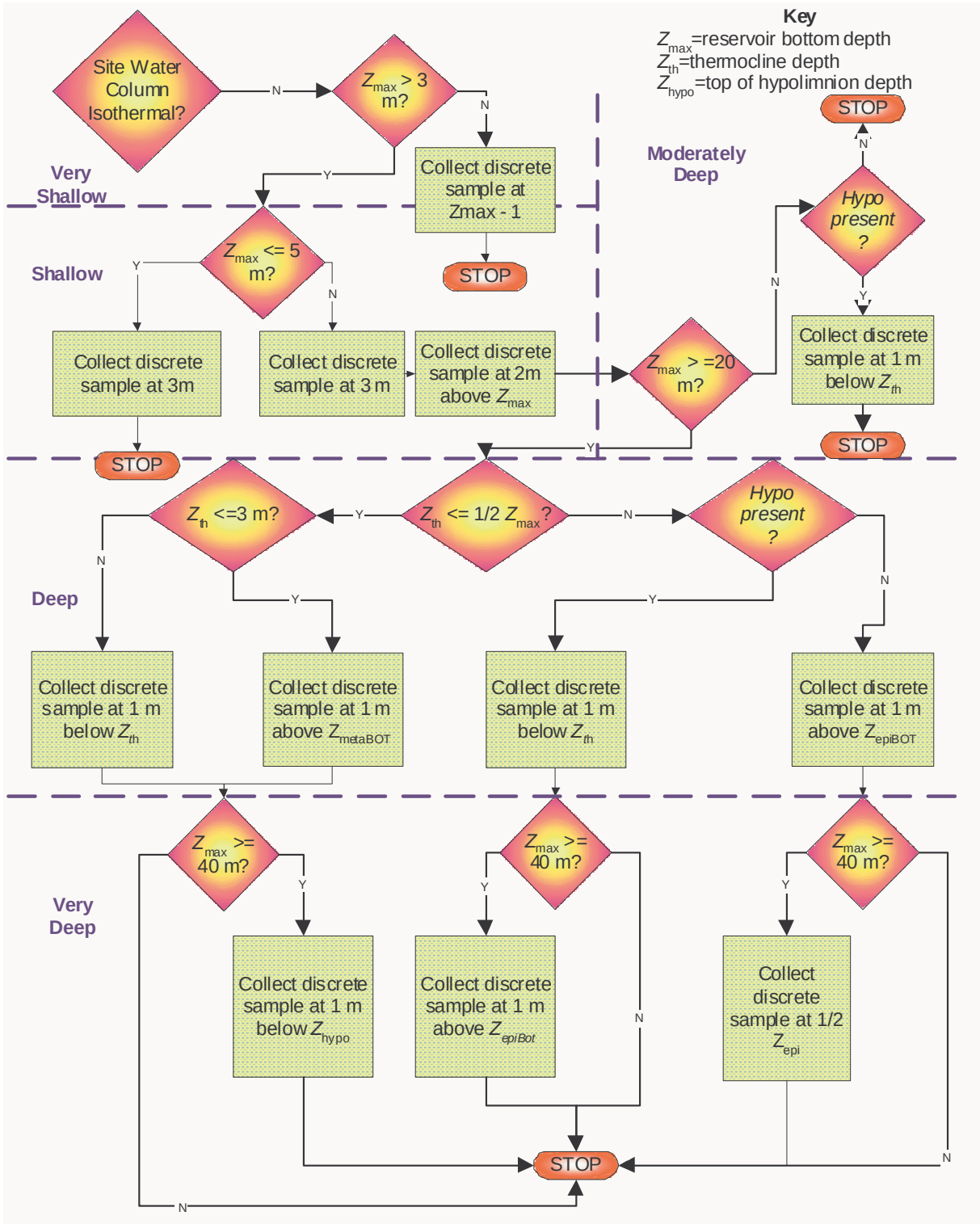
Sample Depth	Rationale for Depth Selection
Z_{max} - 1m	represents the euphotic zone, epilimnetic zone, very shallow conditions, well mixed water column, can't get a 3 m sample due to inadequate depth
3 m	represents euphotic zone, epilimnetic zone, avoids bias of surface water for blue-greens
Z_{th} + 1m	represents the metalimnion, avoids the bias of settling at the thermocline
$Z_{hypoTop}$ + 1m	represents the upper hypolimnion in deep waters with shallow thermoclines
$Z_{metaBOT}$ - 1m	represents the lower metalimnion in deep waters with shallow thermoclines
Z_{epiBot} - 1m	represents the lower epilimnion in deep waters with deep thermoclines
½ Z_{epi}	represents mid epilimnion in deep waters with deep thermoclines and no hypolimnion present
$Z_{max}/2$	represents the mid-water column in moderately deep waters during isothermal conditions
1/3 Z_{max}, 2/3 Z_{max}	represents the mid-water column in deep waters during isothermal conditions
Z_{max} -2m	represents the hypolimnion (in stratified conditions), near bottom conditions (both isothermal and stratified conditions)

Summary

In summary, the sampling schemes above are dependent on the thermal conditions and the maximum depth of each sampling station on any particular day. The intention is to provide representative samples (and adequate coverage) of the water column at monitoring stations with limited resources. The vertical sampling design, described above (which incorporates thermal stratification), complements DEP's site selection (which accommodates differences in longitudinal strata), and should account for the majority of spatial variability in the reservoir water column.



Appendix Figure 5a. Flow chart for collection of supplemental discrete photic samples (Limnology Program 2002).



Appendix Figure 5.b. Sampling protocols during stratified conditions.

Appendix Table 7. Comparison of hydrology and pathogen objectives by site.

System	Site Code	Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.	Obj. 2.8	Obj. 4.1	Obj. 4.2	Obj. 4.3	Obj. 4.4
Catskill												X	
	ABCG	X										X	
	ABKHG	X	X										
	AEAWDL					X							
	AEBP	X											
	AEHG	X										X	
	ASCHG	X	X									X	
	ASP (spill)			X									
	BK	X											
	BNV	X											
	BRD	X											
	E10I	X		X	X							X	
	E15						X						
	E16I	X		X	X				X		X	X	
	E3						X						
	E5	X				X			X		X	X	
	LBK	X										X	
	S1						X						
	S10	X	X			X		X				X	
	S10-1							X					
	S10-RF							X					
	S2						X						
	S3					X							
	S4	X							X		X	X	
	S5I	X		X	X	X			X		X	X	
	S6I	X		X	X							X	
	S7I	X		X	X							X	
	S8						X						
	S9						X						
	SBB							X					
	SBKHG	X	X									X	
	SCL	X	X									X	
	SEK	X										X	
	SRR2 (release)	X		X	X				X		X	X	
	SS (spill)			X									
	SSHG	X										X	
	STHHG	X										X	
	SWK	X										X	
	SWKHG	X										X	
	WDL	X											
Delaware													

Appendix Table 7. Comparison of hydrology and pathogen objectives by site.

System	Site Code	Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.	Obj. 2.8	Obj. 4.1	Obj. 4.2	Obj. 4.3	Obj. 4.4
	C-7	X		X	X							X	
	C-8	X											
	CCBHG	X										X	
	CDG	X							X			X	
	CDVA						X						
	CDVB						X						
	CEBG	X	X									X	
	CEBHG	X	X									X	
	CLDG	X										X	
	CNB			X									
	CPB						X						
	CSBG	X										X	
	CTNBG	X	X									X	
	CTNHG	X	X									X	
	DCDA						X						
	DCDB						X						
	DTPA						X						
	DTPB						X						
	EDRA						X						
	EDRB					X	X						
	NB			X									
	NCG	X	X	X	X				X		X	X	
	NEBG	X										X	
	NK4					X							
	NK6	X											
	NWBR	X										X	
	P-13	X		X	X							X	
	P-21	X		X	X							X	
	P-50	X										X	
	P-60	X		X	X							X	
	P-7	X											
	P-8	X											
	PBKG	X				X						X	
	PDB			X									
	PDRY	X										X	
	PMG			X	X								
	PMSA						X						
	PMSB	X		X	X	X	X		X		X	X	
	PROXG	X							X		X	X	
	PSR						X						
	RB			X									
	RD1	X											
	RD4	X											

Appendix Table 7. Comparison of hydrology and pathogen objectives by site.

System	Site Code	Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.	Obj. 2.8	Obj. 4.1	Obj. 4.2	Obj. 4.3	Obj. 4.4
	RDOA	X		X	X				X		X	X	
	RGA						X						
	RGB	X		X	X		X		X			X	
	RRHG	X										X	
	SKTPA						X						
	SKTPB						X						
	WDBN	X		X	X	X			X		X	X	
	WDHOA	X				X			X			X	
	WDHOB						X						
	WDHOM						X						
	WDSTB						X						
	WDSTM						X						
	WSPA						X						
	WSPB					X	X						
	0143400680		X										
	01434021		X										
	01434025		X										
East-of-Hudson													
	AMAWALKR	X							X			X	
	BB5	X				X			X				
	BG-1/BG-2/BG-3							X				X	
	BG9								X				
	BGC8-1/BGC8-2/ BGC8-3							X					
	BOGEASTBRR	X							X			X	
	BOYDR	X		X					X		X	X	
	CATHY7							X	X				
	COLABAUGH1								X				
	CORNELL1								X				
	CROFALLSR	X							X	X	X	X	
	CROSS2	X							X			X	
	CROSSRVR	X							X	X	X	X	
	DIVERTR	X							X			X	
	ILLINGTON1								X				
	E10								X			X	
	E11											X	
	E11-1/E11-2/E11-3							X					
	E9								X			X	
	EASTBR	X				X			X			X	
	EBCR3	X							X				
	FRENCH5							X	X				
	GYPSYTRL1	X							X				
	HH7	X							X	X		X	

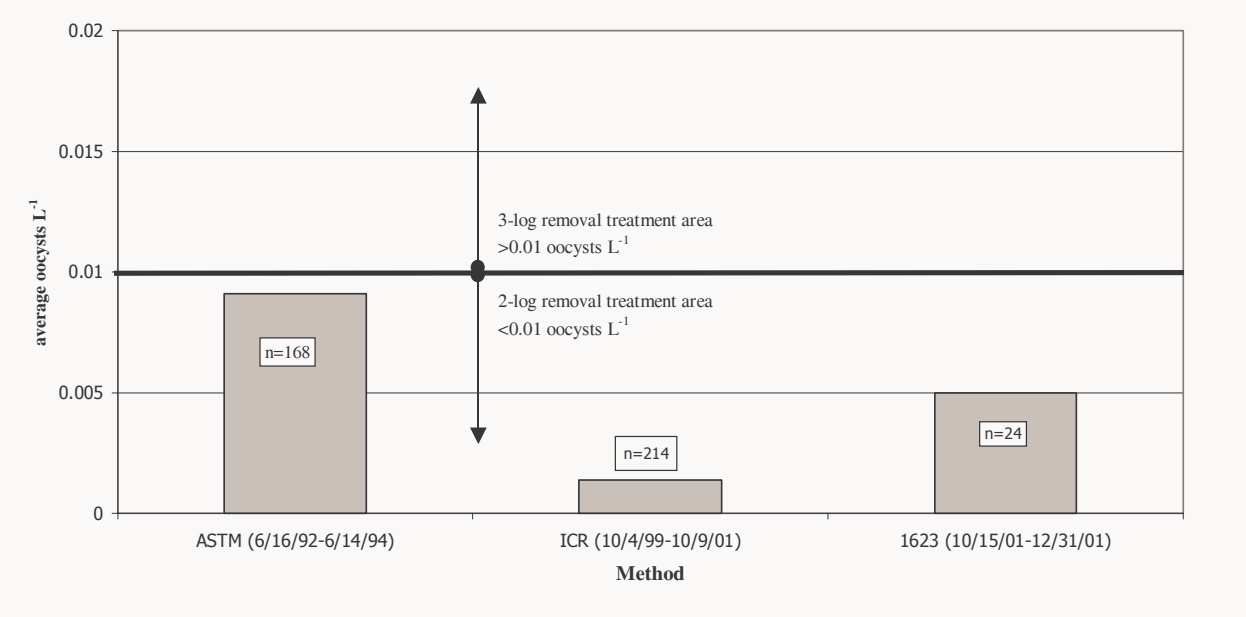
Appendix Table 7. Comparison of hydrology and pathogen objectives by site.

System	Site Code	Obj. 2.1	Obj. 2.2	Obj. 2.3	Obj. 2.4	Obj. 2.5	Obj. 2.6	Obj. 2.7.	Obj. 2.8	Obj. 4.1	Obj. 4.2	Obj. 4.3	Obj. 4.4
	HMILL4						X		X				
	HMILL7						X		X				
	HORSEPD1	X		X	X	X			X			X	
	HUNTER1	X				X			X			X	
	KISCO3	X							X			X	
	KISCO5					X							
	KITCHAWAN1								X				
	LEETOWN3	X							X				
	LONGPD1								X				
	MB-1/MB-3/MB-4							X	X			X	X
	MB-8/MB-9							X					
	MIDBR3	X							X				
	MIKE2	X							X			X	
	MUDTRIB1	X							X				
	MUSCOOT10	X				X			X			X	
	MUSCOOT5	X							X			X	
	N1-1/N1-2							X					
	N12								X			X	
	N2-1/N2-2							X					
	N3-1/N3-2							X					
	N4-1/N4-2							X					
	N5-1/N5-2/N5-3							X	X			X	
	NCBAILEY1								X				
	PLUM2	X							X			X	
	PURDY1								X				
	SAWMILL1								X				
	STONE5	X							X			X	
	TITICUS1	X							X			X	
	TITICUSR	X							X			X	
	WESTBR7	X			X				X			X	
	WESTBRR	X		X					X			X	
	WHIP								X			X	
	WHITE5							X	X				

Appendix 3: Pathogen Data Review

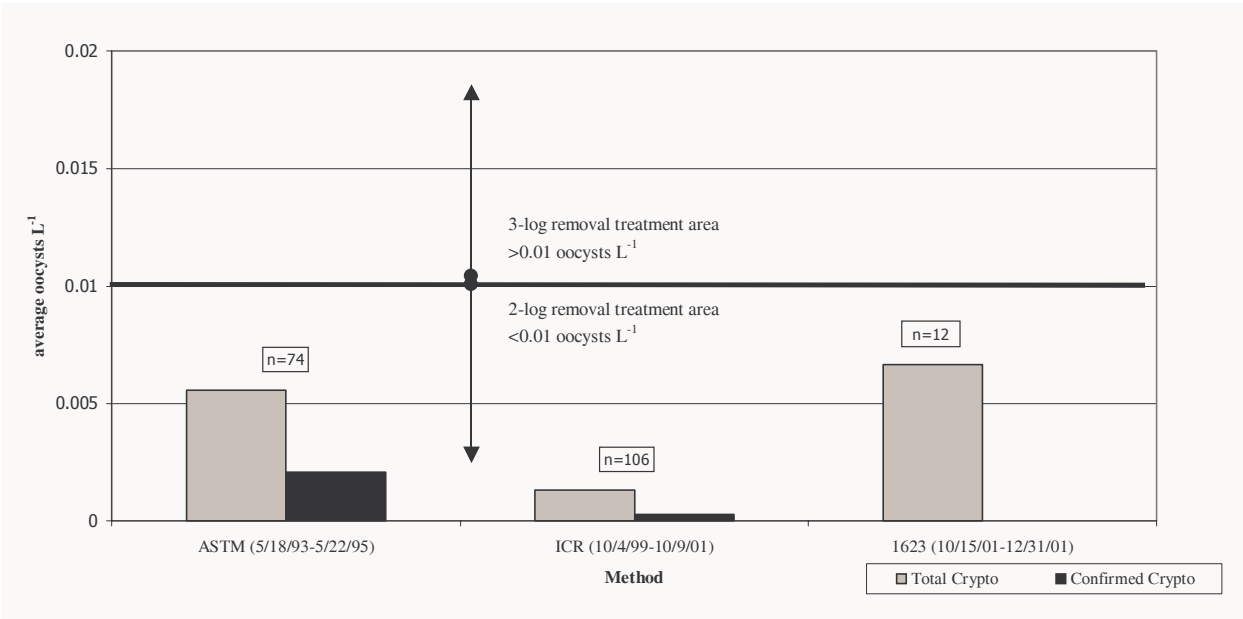
DEP has been monitoring its source waters and the watershed for the presence of protozoan pathogens since 1992, and DEP has reported on its findings in a series of semi-annual reports submitted to EPA under the FAD. It should be noted that the methods for conducting research into sources, fate and concentrations of protozoan pathogens in large watersheds are still evolving, as are the analytical methods used to measure pathogen concentrations in different environmental media. In fact, since 1992, DEP has utilized three separate methods to analyze its source waters for protozoan pathogens including the ASTM Well Slide Method, the method published by EPA as part of the Information Collection Rule (ICR Method), and more recently EPA Method 1623. The application of several different methods has made it difficult to strictly compare all of the data collected since 1992. However, overall, the preponderance of data indicate that the levels of these pathogens in our watershed are low, at least in relation to national norms. For example, New York City's source water contains low levels of oocysts in comparison with the treatment standards in the proposed Long Term 2 Enhanced Surface Treatment Rule (LT2SWTR) regulations.

The proposed LT2SWTR will require large unfiltered utilities to conduct monthly sampling for *Cryptosporidium* spp. oocysts to calculate a two-year average concentration for the purposes of determining the level of treatment required for compliance with the LT2SWTR. Utilities with a monthly average less than 0.01 oocysts L^{-1} will be required to install treatment to achieve a two-log inactivation (99%), those greater than 0.01 oocysts L^{-1} will be required to achieve three-log inactivation (99.9%) with treatment. Appendix Figure 2 presents the average *Cryptosporidium* concentrations detected at the Kensico Reservoir effluent keypoints-DEL 18 and CATLEFF, for each of the three methods (ASTM, ICR Method, Method 1623) that DEP has used (over varying periods of time—as indicated) for monitoring protozoan pathogens in source waters. Appendix Figure 3 provides similar data for the New Croton Reservoir effluent keypoint (CROGH). Overall, the average concentrations of *Cryptosporidium* spp. oocysts in New York City's source waters, with any of the three methods used since 1992, fall below the 0.01 oocyst L^{-1} treatment threshold proposed in the LT2ESWTR. In addition, the average *Cryptosporidium* spp. concentrations of the source water were low relative to the modeled average of 0.034 oocysts L^{-1} found for unfiltered water supplies during the ICR (U.S.E.P.A., 2001).



Appendix Figure 6. Average *Cryptosporidium* oocyst concentrations at Kensico Reservoir effluents and proposed treatment requirements* under the proposed LT2ESWTR.

*Treatment requirements will be determined by a 2-year arithmetic mean of samples analyzed using EPA Method 1623.



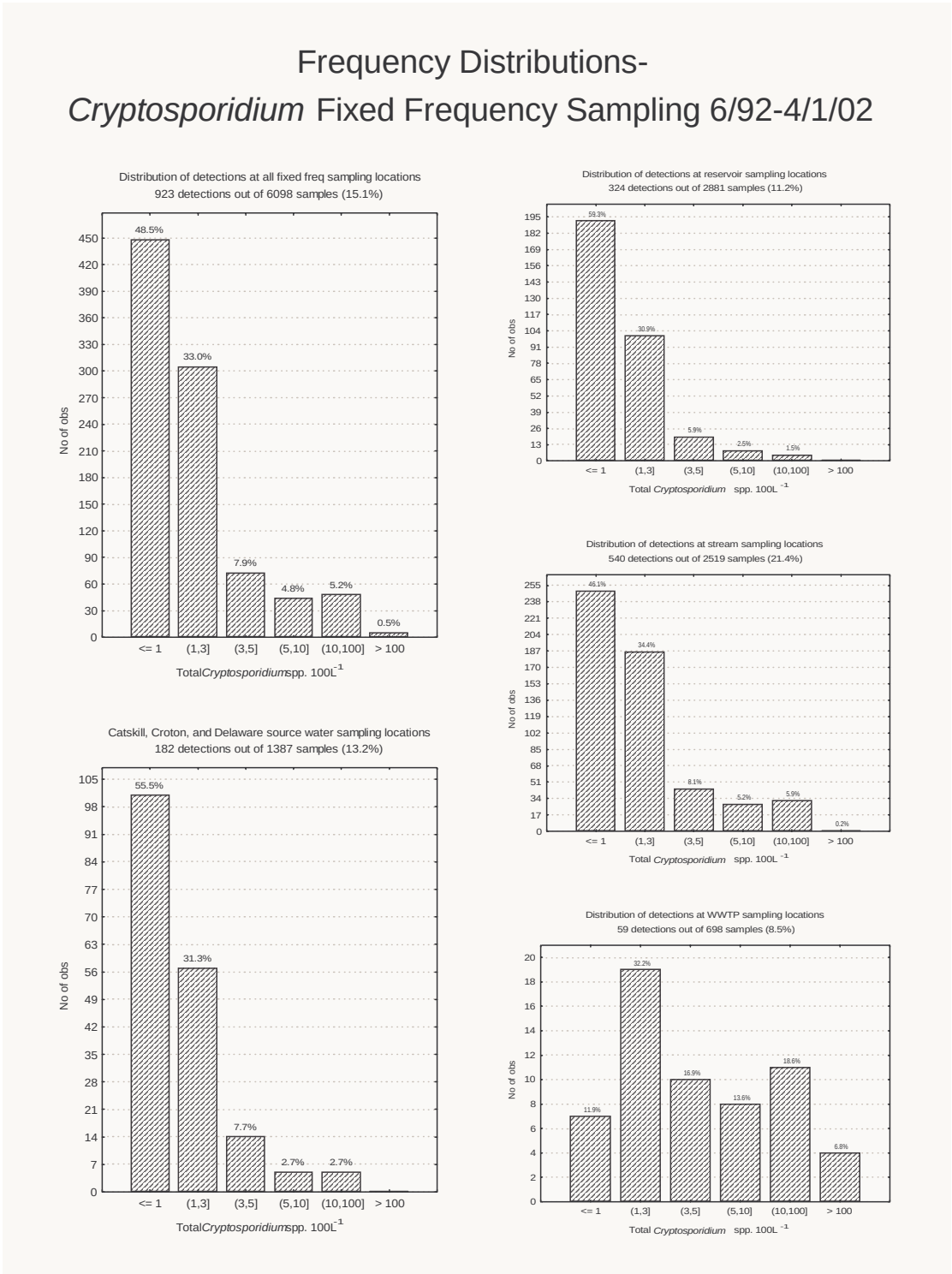
Appendix Figure 7. Average *Cryptosporidium* oocyst concentrations at New Croton Reservoir effluent and proposed treatment requirements* under the proposed LT2ESWTR.

*Treatment requirements will be determined by a 2-year arithmetic mean of samples analyzed using EPA Method 1623.

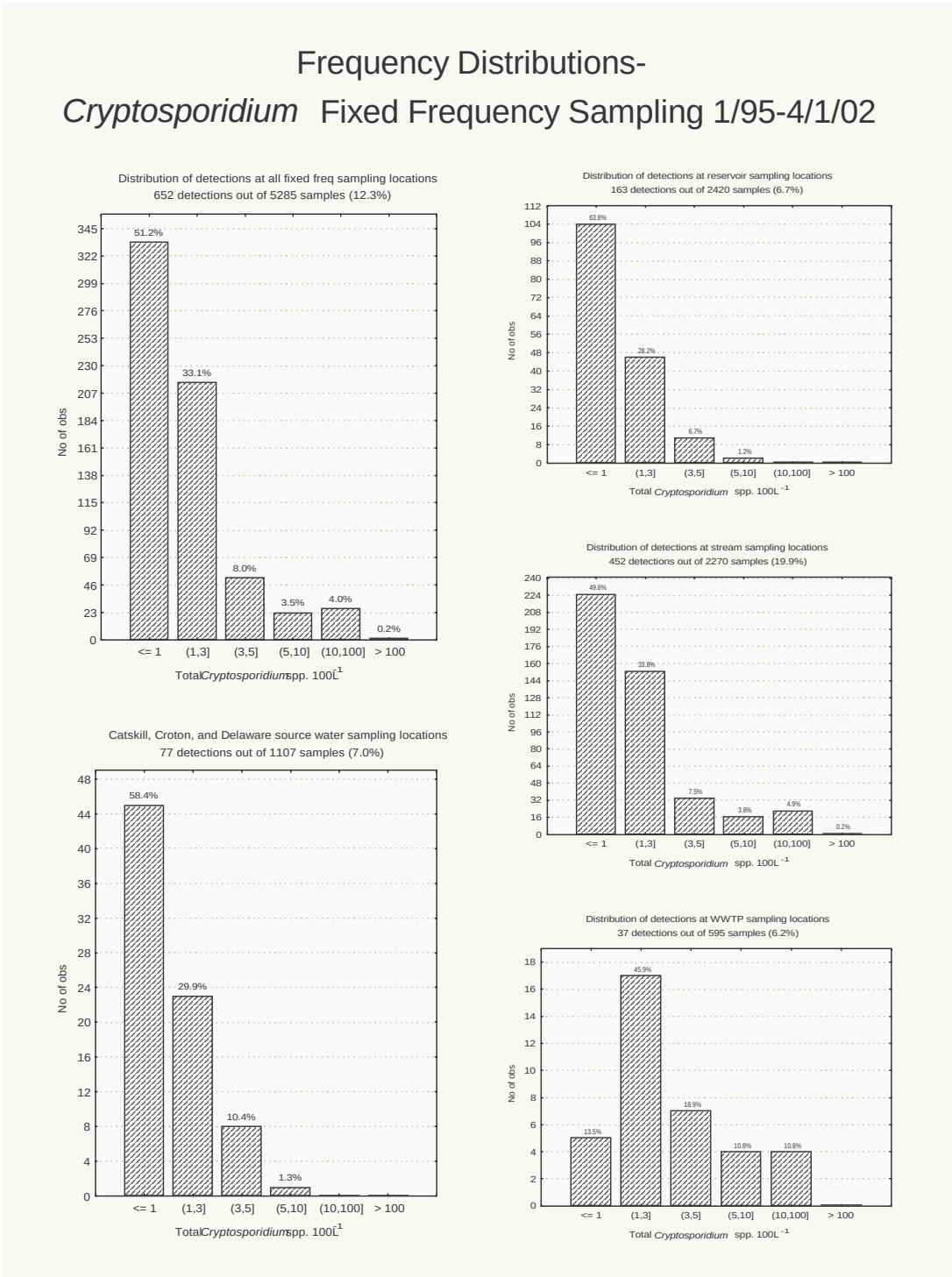
Over the same period of time, DEP has also collected water samples from throughout the watershed, for protozoan pathogen analysis, primarily through a fixed frequency monitoring network with analyses performed using the ASTM Well Slide Method. The results are summarized in Appendix Figures 4 and 5. Appendix Figure 4 provides the frequency distribution of *Cryptosporidium* concentrations (excluding the many data points with no detectable oocysts) for keypoint, reservoir, stream and wastewater effluent samples (and all data combined) collected from the period 6/92-4/02. Appendix Figure 5 provides similar data but only for the period from 1995 to the present. The earlier data was excluded from this figure because of concerns about the consistency of the analyses during the early phase of the monitoring program. When *Cryptosporidium* spp. oocysts have been detected, generally they have been found at levels of 3 oocysts/100L or less. These concentrations, if representative of water quality in the watershed are generally below concentrations likely to trigger further enhanced actions under the *Cryptosporidium* Action Plan (CAP)[1]. The only exception is the levels found at WWTP effluent sites where the relatively few *Cryptosporidium* spp. oocysts detected (8.5% of samples) were distributed between 1 and 185 oocysts/100L, with most observations found in the 1- 5 oocysts/100L range[2].

Since program inception, DEP has expended substantial resources in fixed frequency monitoring at a limited number of integrator stream sites to identify differences between representative sub-basins and to evaluate potential relationships between land cover and protozoan concentrations. However, to a large extent, these efforts have not provided much insight into the occurrence and distribution of (oo)cysts. The FAD deliverable 308e-1 of January 31, 2002 contained tables of land cover data (Table 3) and average Total *Cryptosporidium* concentrations (Table 4). The number of samples analyzed for these sites varied between 28 (E10I) and 438 (MB1) for 23 watershed sites that have been monitored by fixed-frequency sampling for several years using the ASTM Well Slide Method. Average *Cryptosporidium* spp. concentrations are plotted against percentages of generalized land cover (Appendix Figure 6). It is evident that four sites in particular, RF, SHR1, CTB, and TRTIT, appear to be clustered separately from the remaining 19 sites. Further, these sites seem to drive the linear regression relationships, for instance, the concentration vs. %forest (negative slope), and the concentration vs. % grass and crops (positive slope). Therefore, these four sites need to be further investigated.

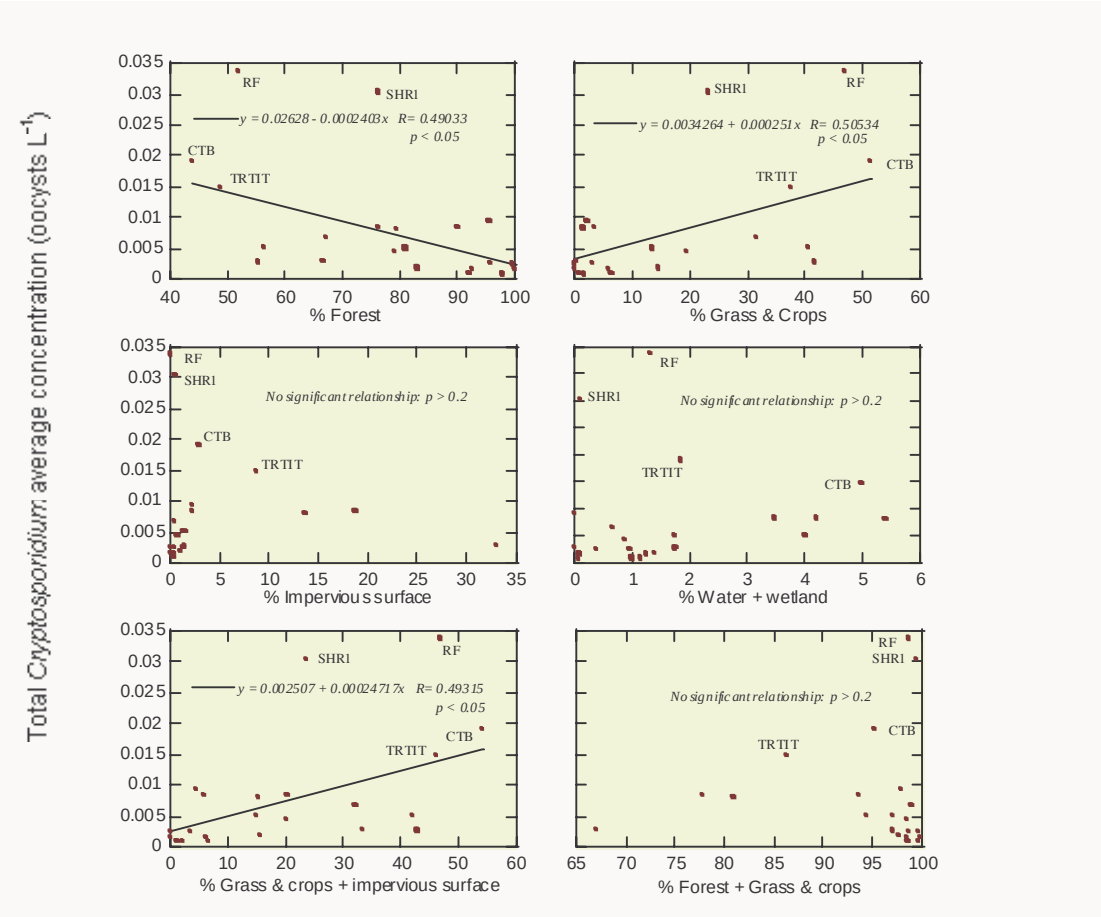
1. The *Cryptosporidium* Action Plan is a required submittal under the FAD, and its implementation will be required under the new FAD. The document, prepared jointly by NYCDEP and the NYCDOH identifies the range of actions to be taken by the two agencies, along with NYSDOH, at various threshold *Cryptosporidium* concentrations detected through weekly monitoring of source waters using Method 1623 HV (50 L).
2. Of note, these data are representative of WWTP's prior to upgrades under the MOA. The assessment of upgraded facilities is discussed as Objective 4.2.1.



Appendix Figure 8. Frequency distributions for different categories of sites - *Cryptosporidium* fixed frequency sampling, 6/92 – 4/1/02 (*i.e.*, inclusive of all data.)



Appendix Figure 9. Frequency distributions for different categories of sites - *Cryptosporidium* fixed frequency sampling, 1/1/95 – 4/1/02 (*i.e.*, period of improved consistency of data.)



Appendix Figure 10. Total *Cryptosporidium* spp. concentrations versus general land use for 23 fixed-frequency sites (see Tables 3 and 4, FAD deliverable of January 31, 2002 308e-1).

Although the data indicate that oocyst concentrations in the watershed, when detectable, are generally below concentrations likely to be of substantive concern in relation to potential action levels identified in the CAP, there are limitations to the sampling program that should be addressed over the next several years. First, it is important to obtain additional data on surface water concentrations of (oo)cysts using Method 1623. This method is being used at our key-points, and appears to provide better and more consistent recovery of oocysts as determined by matrix spikes. The application of Method 1623 throughout the watershed will allow for more direct comparisons between watershed and keypoint sources, particularly if similar volumes of water are sampled, and will provide additional information on locations where the (oo)cyst concentrations could potentially exceed the various trigger levels identified in the CAP. The monitoring should be completed by systematically moving up the watershed from reservoirs, to integrator sites, and to indicator sites and localized catchments. To the extent practicable, the monitoring locations should coincide with the fixed frequency locations utilized by the hydrology

program, since most of these locations have stream gauges (essential for calculating loads), and have been selected to be representative of current and predicted land-use changes. The four sites noted above should be investigated further and compared with control locations.

Second, due to sampling and resource constraints, DEP has been unable to systematically monitor and assess the many different small-scale projects or localized catchments that might be above average sources of protozoan pathogens (or virus). While these small-scale projects are unlikely to impact water quality for the watershed as a whole (due to small catchment size and resulting low relative flow), it is nonetheless important to identify areas with elevated protozoan pathogen concentrations since such locations might be amenable to watershed management (*e.g.,* BMPs) and pollution prevention activities. This type of monitoring should be done, at least initially, through paired upstream/downstream monitoring in and near a variety of potential source types such as areas of failing septic systems or directly from potential point sources (*e.g.,* overflowing sewers).

Third, data collected by DEP indicate that pathogens, like microbial organisms and phosphorus are mobilized by storm events, but the fate of a storm driven pathogen "pulse" (if one exits) following a storm event has been measured only once at New Croton Reservoir following Hurricane Floyd. Very few oocysts were detected in the water column of the reservoir, after the Hurricane. However, it requires a lot of resources and it is difficult to monitor storm events within individual streams; whereas, the reservoirs following a storm event may act as an integrated sample of the many contributing streams. DEP has obtained SDWA funding to examine whether a protozoan pathogen storm "signal" can be detected in a reservoir, following a storm event, as a range finding study. If such signals can be detected, then the relative risk of individual watersheds (as to whether the particular watershed might exceed trigger levels identified under the CAP) might be monitored as effectively by directly sampling the reservoir. Note that monitoring diversions rather than the reservoirs (through limnological sampling) might be acceptable too, if oocysts can be routinely detected in the various watershed diversions. Additional data is also needed on the fate and transport characteristics of oocysts during storm events.

Finally, developing appropriate sampling methods and strategies for monitoring watersheds for protozoan pathogens is still evolving as a science. Additional research needs to be undertaken to improve upon our current approaches and strategies towards sampling. DEP believes that it should continue to focus research on Kensico Reservoir since both influent and effluent keypoints are monitored for pathogens weekly (at a minimum), Malcolm Brook has been a focus of much of DEP's monitoring efforts, and a 3D reservoir model is available. These data coupled with additional storm water data from other influent streams tributary to Kensico may allow for developing additional quantitative information on the fate and transport characteristics of pathogens in reservoirs.

Appendix Table 8. Analytes cross reference table.

	Hydrology								Limnology					Pathogen Program				Keypoint Monitoring	Process Control/ Remote Monitoring
Objectives:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.1, 4.2	3.1, 4.1, 4.2
Parameters: Alkalinity	x	x						x		x								x	
Chla/pigments										x	x	x						x	
Chloride		x			x			x		x								x	
Chlorine residual																	x	x	
Color									x	x	x							x	
Conductivity	x		x		x	x		x	x	x	x	x						x	x
Cryptosporidium (1623HV—10 l)															x				
Cryptosporidium (1623HV—50 l)												x	x						
Dissolved Ca										x								x	
Dissolved K										x								x	
Dissolved Mg										x								x	
Dissolved Na										x								x	
Dissolved Organic Carbon		x	x			x	x		x	x	x						x		
Dissolved Oxy-gen	x				x	x		x	x	x	x	x						x_	
Dissolved Silica									x								x		
Dissolved Sulfate									x								x		
Diversion Flow																			
Dominant Genus								x	x	x	x						x		
DON		x																	
Fecal coliform	x				x	x	x	x	x	x	x		x					x	
Fluoride		x																	x
Flow, Stream/ Aqueduct	x	x	x	x			x	x						x	x	x			
Giardia (1623HV—10L)																x			
Giardia (1623HV—50L)														x	x				
HPC																		x	
Human enteric virus													x	x					

Appendix Table 8. Analytes cross reference table.

	Hydrology								**Limnology**					**Pathogen Program**				**Keypoint Monitoring**	**Process Control/ Remote Monitoring**
Objectives:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.1, 4.2	3.1, 4.1, 4.2
Parameters: Mean Daily Aqueduct Flow									x	x									
Mean Daily Diversion Flow									x	x									
Mean Daily Release Flow									x	x									
Mean Daily Spill									x	x									
NH_x–N		x	x	x		x		x		x	x	x						x	
Nitrogen																			
NO_x-N		x	x	x	x	x	x	x		x	x	x						x	
Odor									x	x	x							x	
ORP																			x
pH	x	x			x	x		x	x	x	x	x		x	x			x	x
Phosphorus																			
Photic depth Iz									x	x	x	x							
Pressure deferential													x	x		x			
Reservoir Elevation									x	x									
Sample Volume													x	x	x	x			
Secchi depth ZVB									x	x	x								
Secondary Genus								x	x	x	x								
Soluble Reactive Phosphorus (SRP)	x	x	x	x		x				x	x	x						x	
TOC/ DOC					x														
Total Ag								x					x					x	
Total Al								x					x					x	
Total As								x					x					x	
Total Ba								x					x					x	
Total Be								x					x					x	
Total Cd								x					x					x	
Total coli	x					x		x	x	x	x		x					x	
Total Cr								x					x					x	
Total Cu								x										x	

Appendix Table 8. Analytes cross reference table.

	Hydrology								Limnology					Pathogen Program				Keypoint Monitoring	Process Control/ Remote Monitoring
Objectives:	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.1, 4.2	3.1, 4.1, 4.2
Parameters: Total Dissolved Nitrogen (TDN)	x		x	x						x	x	x						x	
Total Dissolved Phosphorus (TDP)	x	x	x	x	x		x			x	x	x						x	
Total Fe								x	x				x					x	
Total Hg								x					x					x	
Total Mg								x										x	
Total Mn									x				x					x	
Total Ni													x					x	
Total Nitrogen (TN)	x	x						x		x	x	x						x	
Total Pb													x					x	
Total Phosphorus (TP)	x	x	x	x	x	x	x	x		x	x	x	x					x	
Total Plankton (SAU)								x	x	x	x						x		
Total Precipitation																x			
Total Sb													x					x	
Total Se													x					x	
Total Storage										x	x								
Total Ti													x					x	
Total Zn													x						
TSS		x		x	x		x	x		x	x	x	x					x	
Turbidity	x	x	x		x		x	x	x	x	x	x	x	x	x	x		x	x
Water temperature	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x	x
y_{BD}	x																		