Pompton Lake and Ramapo River TMDL Support Study

(NE-PASSAIC-1):

For Work Supporting the Department of Environmental Protection in the Development of Total Maximum Daily Loads (TMDLs) or Other Management Responses to Restore Impaired Waterbodies in the Non-Tidal Passaic River Basin

FINAL

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EXECUTIVE SUMMARY

This study was undertaken to support New Jersey Department of Environmental Protection's (NJDEP) total maximum daily load (TMDL) and watershed restoration efforts within the Passaic River Basin. Its goal was to assess the water quality of the Pompton Lake-Ramapo River system to support decisions regarding lake restoration. There were four main objectives:

1. Evaluate existing data to characterize water quality impairments, if any, to Pompton Lake.
2. Apply existing information to quantify phosphorus loads to Pompton Lake.
3. Determine whether an empirical relationship can be established for in-lake phosphorus concentration and influent phosphorus loads.
4. Identify data and research gaps that need to be addressed in order to develop a lake restoration plan.

Water quality impairments.

Pompton Lake is designated as an FW2-NT water body in New Jersey's Surface Water Quality Standards. Although it is not listed as impaired based on phosphorus or dissolved oxygen in New Jersey's Integrated List, in-lake total phosphorus (TP) concentrations measured near the dam exceed the water quality standard 70 percent or more of the time during the period of record. In addition, chlorophyll-a (chla) concentrations measured by North Jersey District Water Supply Commission (NJDWSC) exceed the seasonal average threshold of 24 µg/L 22 percent of the time.

This evaluation of impairment is incomplete, however. NJDWSC's data were collected from surface water samples taken at the dam and it is not clear to what degree these data are representative of water quality throughout the lake. Moreover, the NJDWSC TP data exhibited unusual patterns in the late 1990s. In addition, it is not known whether bottom waters become hypoxic during summer. The older USGS TP data collected by vertically integrating the water column may be more representative of lake waters, but this monitor program was terminated in 1996.

Phosphorus loads

TP loads to the lake were estimated by summing three components: loads at the US Geological Survey (USGS)/Mahwah gage, estimated using in-stream TP and flow data; non-point source loads downstream of the gage estimated using the export coefficient approach; and point source loads downstream of the gage estimated from treatment plant records. The total phosphorus load entering Pompton Lake averaged 20,500 kg/yr for the period 1993-2001.

- Approximately 70 percent of the TP load entering Pompton Lake originates in the New York State portion of the watershed.
- Permitted point source discharges are responsible for more than 50 percent of the TP load to the lake.
- More than 99 percent of the permitted point source discharges for TP occur in New York State.
- Residential land use in New Jersey's portion of the watershed accounts for 17 percent of the total TP load to the lake, while other developed uses (urban, commercial, industrial) account for another 8 percent of total TP load.

The availability of in-stream data at the USGS/Mahwah gage permitted an evaluation of the export coefficient approach used to estimate non-point source loads downstream of the gage. The annual TP load from the New York portion of the watershed calculated using point source data, land use areas, and export coefficients is about two times the load estimated from the data at the gage. This suggests that the export coefficients overestimate non-point source loadings in this watershed to a significant degree, which may be due in part to retention of phosphorus within the watershed. TP from point sources may also be retained within the river.

Beyond the potential overestimation of the non-point source component, three other issues impact the accuracy of the TP load estimate. First, the estimate does not take account of any loss of TP between the USGS/Mahwah station and the lake. However, the smaller size of the New Jersey sub-basins relative to the sub-basin north of the gage at Mahwah suggests that TP losses due to retention within the watershed may be less important than in New York. Second, the estimate does not include sources of TP internal to the lake. Third, the calculated load at the USGS/Mahwah station relies on a regression between TP concentration and flow at the USGS/Mahwah gage. An evaluation of the uncertainty associated with the load estimate requires the collection of additional field data described in this report.

Relationship of in-lake phosphorus concentration to influent phosphorus loads.

NJDEP recently established TMDLs for several lakes following a procedure based upon Reckhow's (1979) model (NJDEP 2003b, 2003c, 2003d). The applicability of the Reckhow analysis to Pompton Lake is uncertain: mean phosphorus concentrations and average areal phosphorus load lie within the range of Reckhow's data set, although Pompton Lake's average areal water load of 375 m/yr is larger than the maximum of 190 m/yr in Reckhow's data set.

The estimate of the average in-lake TP concentration using the Reckhow model is 0.063 mg/L. For the period 1987-1996, the average TP concentration measured by USGS is 0.08 mg/L, within 30% of the average concentration computed by the Reckhow model. In other lake TMDLs, NJDEP based the required load reduction on the estimated average in-lake concentration and a target concentration of 0.02 mg/L, incorporating a margin of safety (MOS). Based on the measured USGS average concentration, attainment of this target concentration would require a somewhat greater load reduction (75%) than that indicated by the Reckhow model (68%).

The lake data provided the opportunity to explore an alternative method of computing the load reduction required to meet the water quality standard. According to the water quality standard, in-lake phosphorus concentrations may not exceed 0.05 mg/L; this is generally interpreted to mean that concentrations may not exceed the standard more than 10 percent of the time. The 90th percentile of the TP data from the USGS Pompton Lake Dam site is 0.13 mg/L. In order to reach the standard of 0.05 mg/L 90 percent of the time (i.e., to achieve compliance with the standard 90 percent of the time), a 62 percent reduction in this value would be required.

The Reckhow model provides an estimated load reduction that is similar to load reduction estimates based upon the in-lake data. These analyses are provided for illustrative purposes only; this document is not a TMDL report.

Data and research gaps

A clear statement of goals for the lake is necessary for developing an effective management/restoration plan. These may include a satisfactory fishery, good aesthetics (smell and appearance), a sustainable ecological community, and water quality adequate for use of the lake waters as a water supply. Furthermore, a set of quantitative targets that are derived from these goals is required. Water quality standards provide a partial set of targets, but do not address ecological concerns. Site-specific or seasonal TP standards, for example, offer a more flexible approach to achieving lake goals and should be considered.

Additional information concerning the status of the lake is needed, for example the extent of nuisance blooms and macrophyte growth, the quality of the lake's fishery, and the structure of the biological community. Additional water quality data are would help to characterize water quality throughout the lake and to define the phosphorus mass balance for the lake.

An important next step in the development of a management/restoration plan for Pompton Lake is the development of a more complete conceptual model for the lake. In addition, it is necessary to assess the key linkages between potential management/restoration activities and lake targets. For example, the role of internal sources of phosphorus (i.e., from lake sediments) is not well-understood in Pompton Lake. Additional data are needed to develop a mass balance for phosphorus in the lake in order to quantify the response of lake TP levels to reductions in loads.

SECTION 1
INTRODUCTION

1.1 OBJECTIVES

The NJDEP has undertaken several projects in the non-tidal Passaic River Basin to support NJDEP's development of total maximum daily loads (TMDLs) and other management strategies to restore impaired water bodies within the basin. In order to facilitate management decisions regarding restoration within the basin, NJDEP, in conjunction with the Passaic River TMDL Work Group, identified several studies that would provide the necessary information and decision-support tools (NJDEP 2002). Pompton Lake and the Ramapo River from the New York state line to the lake was one area identified as needing further study. While the river itself has impaired water quality, described further below, little is known about the status of Pompton Lake. Pursuant to a subcontract with the Rutgers, State University of New Jersey EcoComplex (NJEC)[1], this study was undertaken to provide NJDEP with an assessment of the Pompton Lake-Ramapo River system to support decisions regarding lake restoration.

This study has four main objectives:

1. Evaluate existing data to characterize water quality impairments, if any, to Pompton Lake.

2. Apply existing information to quantify phosphorus loads to Pompton Lake.

3. Determine whether an empirical relationship can be established for in-lake phosphorus concentration and influent phosphorus loads.

4. Identify data and research gaps that need to be addressed in order to develop a lake restoration plan.

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[1] Through a contract with NJDEP, NJEC provides programmatic and technical support for New Jersey's TMDL program, including the administration of this study.

The rest of this section describes the regulatory and programmatic background relevant to Ramapo River, Pompton Lake and the non-tidal Passaic River Basin. Section 2 addresses objective 1, providing a description of Pompton Lake and its watershed. Water quality data are evaluated in that section to define the extent of water quality impairments within the lake. Phosphorus, specifically TP, is the primary nutrient of concern with respect to water quality and loadings to the lake, primarily because of known upstream and downstream violations of New Jersey's Surface Water Quality Standards (SWQS) for this nutrient. Our evaluation also includes chla and dissolved oxygen (DO), as these are fundamental to an assessment of eutrophication.

Section 3 addresses objective 2. Phosphorus loads, from both point sources and non-point sources, are quantified. Section 4 addresses objective 3. A preliminary set of TMDL-like calculations of the percent reduction in phosphorus loads required to meet water quality standards is presented. These include an analysis based upon phosphorus loads to the lake (Reckhow 1979), as well as two analyses based upon the in-lake data. Section 5 addresses objective 4. Data needed to develop an effective restoration plan are discussed. In addition, an appendix is included that provides a set of charts presenting the water quality data collected by NJDEP in November 2003.

Finally, it should be noted that while this study addresses phosphorus loads and their potential impact on phosphorus concentrations, this Pompton Lake report is not a TMDL report.

1.2 REGULATORY ENVIRONMENT

The SWQS for a particular element or compound for a specific water body consists of three components: a designated use or uses, a numerical and/or narrative standard, and an anti-degradation policy. The status of a given water body with respect to attainment of its designated uses is indicated in the state's biennial Integrated Water Quality Monitoring and Assessment Report (Integrated List), as required under sections 305(b) and 303(d) of the Federal Clean Water Act. The applicable SWQS and status of the Ramapo River and Pompton Lake are reviewed below.

The Ramapo River from the New York/New Jersey state line to the Pompton River, including Pompton Lake, is classified as FW2-NT (freshwater, non-trout). Designated uses in FW2 waters are:

- maintenance, migration, and propagation of the natural and established biota;
- primary and secondary contact recreation;
- industrial and agricultural water supply;
- public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation, and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection; and
- any other reasonable uses[2].

New Jersey establishes water quality standards in its New Jersey Administrative Code 7:9B-1.14(c) Surface Water Quality Standards for FW2, SE and SC Waters. The following standards are established for FW2-NT designated waters:

- 24-hour average DO concentrations not less than 5.0 [mg/L], but not less than 4.0 [mg/L] at any time.
- Phosphorus as total P shall not exceed 0.05 [mg/L] in any lake, pond or reservoir, or in a tributary at the point where it enters such bodies of water, except where watershed or site-specific criteria are developed pursuant to N.J.A.C. 7:9B-1.5(g)3.
- Except as necessary to satisfy the more stringent criteria in the paragraph above or where watershed or site-specific criteria are developed pursuant to N.J.A.C 7:9B-1.5(g)3, phosphorus as total P shall not exceed 0.1 [mg/l] in any stream, unless it can be demonstrated that total P is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses.

Water bodies are placed in one of five categories as defined by U.S. Environmental Protection Agency's (USEPA) Guidance for Developing Integrated Reports. Listed water bodies in the Ramapo River watershed are identified in Table 1-1. Sublist 1 describes a water body that is attaining all water quality standards and in which no designated use is threatened. Sublist 2 describes a water body that is attaining one or more designated uses, and in which no designated use is threatened, or no data are available to determine if the remaining designated uses are threatened. New Jersey's 2002 Integrated Water Quality Monitoring and Assessment Report ("Integrated List")[3] uses a modified version of USEPA's Guidance for Developing Integrated Reports, in which Sublist 1 and 2 are combined into one classification: a water body that is attaining a water quality standard and in which other uses are not assessed due to lack of data. Sublist 3 describes a water body whose designated use could not be determined because of insufficient data. Sublist 4 refers to a water body that is impaired or threatened for one or more designated uses. Sublist 4 water bodies do not require a TMDL to be developed, either because a TMDL has been completed, enforceable pollution control measures are expected to result in full attainment of the water quality standard, or the impairment is not caused by a pollutant. A water body placed in Sublist 5 does not attain the water quality standard and is impaired or threatened for one or more designated uses by a pollutant. A Sublist 5 water body requires the development of a TMDL.

[2] New Jersey Administrative Code (NJAC) 7:9B
[3] http://www.state.nj.us/dep/wmm/sgwqt/wat/integratedlist/integratedlist.htm

Table 1-1. Abridged 2002 Integrated List of water bodies in the Ramapo River watershed.

Sublist	Station Name/Water body	Site ID	Parameters	Data Source
1,2	Ramapo River at Lenape Ln in Oakland	AN0267	Aquatic Life	NJDEP AMNET
1,2	Ramapo River at Pompton Lakes	01388000	Phosphorus, pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, Unionized Ammonia	NJDEP/ USGS Data
1,2	Ramapo River at W Ramapo Ave in Mahwah Twp	AN0266	Aquatic Life	NDEP AMNET
1,2	Ramapo River near Mahwah	01387500, 3-SITE-9; 3-RAM-1	pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Sodium, Chromium, Copper, Lead, Nickel, Selenium, Zinc	NJDEP/ USGS Data
3	Ramapo River at Dawes Highway	01388100	Fecal Coliform, pH, Nitrate, TSS	NJDEP/USGS Data
3	Ramapo River near Mahwah	01387500	Arsenic, Cadmium, Mercury	NJDEP/USGS Data, Metal Recon
5	Pompton Lake-03	Pompton Lake	Fish-Mercury	NJDEP Fish Tissue Monitoring
5	Ramapo River near Mahwah	01387500, 3-SITE-9, 3-RAM-1	Phosphorus, Fecal Coliform	NJDEP/USGS Data, Metal Recon

Although Ramapo River near Mahwah was placed on Sublist 1 for attaining the water quality standards for the listed water quality parameters, it was placed on Sublist 5 for phosphorus and fecal coliform and therefore requires a TMDL[4]. Pompton Lake is listed on Sublist 5 for mercury contamination in fish. Pompton Lake is not listed for phosphorus. One goal of this project is to evaluate the water quality of the lake to provide NJDEP with the information needed to determine whether it should be listed for TMDL development and what restoration efforts might be needed.

[4] NJDEP adopted a fecal coliform TMDL for the Ramapo River in March 2003.

SECTION 2
POMPTON LAKE AND WATERSHED

2.1 SITE DESCRIPTION AND BACKGROUND

Pompton Lake is a 71-hectare impoundment on the Ramapo River, formed by the Pompton Lake Dam (Figure 2-1). The lake is located in Passaic County, New Jersey between Wayne Township and the Borough of Pompton Lakes. The dam is owned by the NJDWSC, and lake waters serve as a supplemental drinking water source. The 150 million gallon per day (MGD) Ramapo Pump Station supplies water as needed to the Wanaque Reservoir.

The lake is fed primarily by the Ramapo River, but also receives ungaged inflow from Acid Brook and smaller tributaries. The Ramapo River continues downstream of Pompton Lake Dam, flowing into the Pompton River, which is a tributary to the Passaic River.

The area of the Pompton Lake watershed is 176 mi^2 (45,600 ha). Twenty-five percent of the watershed falls within New Jersey's Watershed Management Area (WMA) 3, and 75 percent (132 mi^2; 34,300 ha) of the drainage area lies within New York State.

WMA 3 is one of 20 Watershed Management Areas within New Jersey. WMA 3 spans four counties (Bergen, Morris, Passaic, and Sussex) and 21 municipalities, covering 238 mi^2. Major rivers within WMA 3 are the Pequannock, Wanaque, Ramapo, and Pompton Rivers. The USGS Hackensack-Passaic Hydrologic Cataloging Unit (HUC 02030103), covering northeastern New Jersey and parts of New York, includes both the Passaic River Basin (WMAs 3, 4, and 5) and the Hackensack River Basin (WMA 5).

The municipalities in the drainage area are experiencing population growth and land development, including those along the banks of the Ramapo River upstream of the lake. New development upstream of Pompton Lake is evidenced by a combined 15.7 percent increase in population in the communities of Mahwah, Oakland, Pompton Lakes, and Wayne between 1990 and 2000, according to U.S. census data. At the same time, Mahwah, Oakland, Bergen County, the State of New Jersey and private organizations have been working to preserve a green corridor along the Ramapo River. Ramapo Valley County Reservation (3000 acres), Campgaw Mountain County Reservation, Ramapo Mountain State Forest, Camp Glen Gray (750 acres) and Sun Valley Farms (218 acres) in Mahwah, and the 181-acre Camp Tamarack in Oakland comprise a large piece of this corridor. The total amount of contiguous protected land in the Ramapo Mountains is now 13,400 acres, running between Passaic County and the New Jersey/New York border.

2.2 WATER QUALITY

Data from four stations provided the primary basis for characterizing water quality in Pompton Lake and the Ramapo River (Figure 2-1):

- USGS/Mahwah. Gage 01387500 is located on the Ramapo River at Mahwah, New Jersey, 8 miles upstream of Pompton Lake.
- PVWC/Oakland. The Passaic Valley Water Commission (PVWC) sampled the Ramapo River at Pleasureland, Oakland, which is located just upstream of the lake. Collection of water quality data at this station ceased in 2001.
- USGS/Pompton Lake. USGS gage 01388000 is located in Pompton Lake, less than 10 meters upstream of the dam. Vertically-integrated composite samples were collected. Collection of water quality data at this station ceased in 1996.
- NJDWSC/Pompton Lake. NJDWSC samples on the lakeside of the diversion channel for the Ramapo River 700 Pump Station, less than 10 meters upstream of the dam. Surface samples are collected.

In addition, NJDEP conducted a one-day sampling program to provide a snapshot assessment of in-lake water quality and to describe the bathymetry of the lake. This survey was conducted on November 18, 2003 and is discussed in this report.

Finally, NJDEP is conducting a study following the methodology described in the Technical Manual for Phosphorus Evaluations for NJPDES Discharge to Surface Water Permits ("Phosphorus Protocol"; NJDEP 2003a) to evaluate water quality in the Passaic River Basin. One study site is located just upstream of the lake. It is anticipated that the data from this study will be available in the near future.

The results from the November 18, 2003 NJDEP survey are described in the next section. The historical water quality data collected at the four above-mentioned stations are presented next. Finally, these data are evaluated for evidence of impairment in Pompton Lake and the Ramapo River.

2.2.1 November 18, 2003 Sampling Event

On November 18, 2003, NJDEP personnel collected water samples and measured in-lake parameters. Water depth was determined by a sounding line at 13 locations within the lake (Figure 2-2). Temperature, conductivity, and DO were recorded in one-foot depth intervals at three locations along the central axis of the lake. At these three sites, pH and turbidity were measured at mid-depth, and transparency, as measured by Secchi disk, was determined. Mid-depth grab samples taken at each of the three central axis stations (including a duplicate sample at Station B-3) were analyzed for the following water quality parameters; chla, TP, dissolved ortho-phosphate (D-OPO_4), nitrate and nitrite (NO_3, NO_2), ammonia (NH_3), and total Kjeldahl nitrogen (TKN; Figure 2-2).

The results of the November 2003 sampling effort are summarized in Table 2-1. A complete set of plots showing all of the data is presented in Appendix A. The duplicate samples were averaged. TP concentration exceeded the lake standard of 0.05 mg/L at one station with a concentration of 0.07 mg/L (Figure A-2). Chla concentrations were well below the threshold concentration of 24 μg/L used by NJDEP as an indicator of eutrophication. DO concentrations were greater than the 24-hour average standard of 5 mg/L and the instantaneous minimum of 4 mg/L. DO concentrations near the surface reached 90 percent saturation; the minimum observed DO concentration was 9.2 mg/L (75 percent saturation) at the deepest depth sampled in the lake (15 feet) in the lower portion of the lake (Figure A-1). Temperature was relatively constant across all depths, varying by less than 0.5°C at any of the three stations sampled. A lack of vertical gradients in temperature, conductivity and DO indicated that the lake was well mixed at the time of this sampling program, with the possible exception of the bottom one-third of the water column at Station C-2 in the lower portion of the lake, where DO concentrations were 0.5 mg/L lower than in the upper two-thirds of the water column.

Table 2-1. Water quality conditions in Pompton Lake, November 2003.

Parameter	Standard/ Threshold	Mean	Range	
			Min	Max
Total Phosphorus (mg P/L)	0.05	0.06	0.05	0.07
o-Phosphate (mg P/L)	-	0.03	0.03	0.03
Chlorophyll-a (µg/L)	24	2.12	1.3	2.7
Dissolved Oxygen [1]	5.0/4.0	10.14	9.2	11.1
Dissolved Oxygen Saturation (%)	-	82.77	74.6	90.4
pH	6.5-8.5	7.41	7.4	7.6
Ammonia (total; mg N/L)		ND (0.05)	ND (0.05)	ND (0.05)
Ammonia (unionized; mg N/L)	0.05	-	-	-
Total Kjeldahl Nitrogen (mg N/L)	-	0.27	0.14	0.41
Nitrate (mg N/L)	10	1.05	1.01	1.09
Nitrite (mg N/L)	-	ND (0.03)	ND (0.03)	ND (0.03)
Secchi disk depth (m)	-	7.59	6.0	8.0
Turbidity (ntu)	-	1.64	1.5	2.2
Conductivity (mhos)	-	356	344	369

[1]Dissolved oxygen: 24-hour average standard/ instantaneous minimum standard.

2.2.2 Historical Water Quality Data

2.2.2.1 Flow

The USGS measures stream flow at the USGS/Mahwah Station and the USGS/Pompton Lake Station. Daily average flow rates at the two stations from 1983 to 2002 are shown on Figure 2-3. The mean and 7Q10 flow rates at USGS/Mahwah are 223 and 23 cfs, respectively. The mean and 7Q10 flow rates at USGS/Pompton Lake are 281 and 29 cfs, respectively.

In addition to flow out of the lake at the dam, the Ramapo Pump Station diverts water as needed to Wanaque Reservoir. Diversion of as much as 280 cfs (150 MGD) is permitted, but no pumping is permitted at stream flows below 40 MGD (74 cfs) or during the months of July and August. During the period 1993 through 2002, the median, mean, and 90th percentile values of the daily diversions, when they occurred, were 132, 136, and 244 cfs, respectively[5]. Diversions occurred on less than 15 percent of the days during this period. No diversions occurred during the years 1997, 1998, 2000, 2001, and 2003.

2.2.2.2 Total Phosphorus

TP concentrations were measured at all four stations. Figure 2-4 shows the temporal trend of TP at the two upstream stations, USGS/Mahwah and PVWC/Oakland. Closed circles represent measurements taken during the growing season (May through September), and open circles represent measurements taken during the rest of the year.

Prior to 1993, USGS/Mahwah exhibited an annual cycle of TP concentrations; TP concentrations were generally higher during the growing season than during the rest of the year. After 1993, variability in the data increased, and the annual cycle was less consistent. Tukey plots of these data illustrate this increase in variability; the annual interquartile ranges (25th to 75th percentiles, represented by the boxes) are generally larger after 1993 (Figure 2-5). The

[5] Daily diversion data for 1993 through 2002 courtesy of North Jersey District Water Supply Commission, personal communication.

mean TP concentration at USGS/Mahwah is 0.19 mg/L for the years from 1983 through 2002, which is greater than the stream water standard for phosphorus of 0.1 mg/L.

The record is much more limited at PVWC/Oakland (Figure 2-4). TP concentrations at PVWC/Oakland were similar to concentrations measured at USGS/Mahwah in 1995, but were considerably lower than concentrations at USGS/Mahwah in the period 1999 through 2002. The mean concentration over the entire record is 0.11 mg/L. The reason for the difference between these two stations in the later years is not clear. Possible contributing factors include: analytical differences between the laboratories; dilution of river water with groundwater between these two stations; and deposition of particulate phosphorus in the river between the two locations.

Temporal trends in phosphorus concentrations at NJDWSC/Pompton Lake and USGS/Pompton Lake are displayed on Figure 2-6. Prior to 1993, TP levels at the two stations were similar, and there was evidence of an annual cycle. In 1993 and 1994, TP concentrations at NJDWSC/Pompton Lake declined to levels generally below the 0.05 mg/L standard. This decline was not observed at USGS/Pompton Lake. In 1994, some higher TP concentrations, more characteristic of the historical record, were observed at NJDWSC/Pompton Lake. Levels at both stations were higher and more variable in 1995 than in previous years. The USGS/Pompton Lake station has not been sampled since 1996.

From 1996 until 1999, TP concentrations at NJDWSC/Pompton Lake increased consistently; the rise was evident during all seasons. In 2000, levels declined. In 2001, the most recent year for which data were available for this project, some elevated levels were observed. The causes of these patterns are not known.

The mean TP concentrations at NJDWSC/Pompton Lake (0.11 mg/L) and USGS/Pompton Lake (0.08 mg/L) are greater than the in-lake standard for TP of 0.05 mg/L. With few exceptions, the medians from each year have been above the lake standard of 0.05 mg/L (Figure 2-7).

The frequency distributions of TP concentrations measured at the two stations are compared on Figure 2-8. The period from 1988 through 1996, when data from both monitoring stations were available, was included in this analysis. Seventy and 60 percent of the samples collected in the lake by USGS and NJDWSC, respectively, exceeded the 0.05 mg/L standard. The two stations exhibited similar medians and 90th percentile concentrations. The concentrations at the tails of the distributions differed, however. Differences at the lower concentrations may be attributable to different detection limits. Above the 90th percentile, TP concentrations measured at NJDWSC/Pompton Lake are higher than at USGS/Pompton Lake. This may be due to differences in sampling procedures: USGS collected vertically-integrated composite samples, while NJDWSC collected surface grabs. In addition, differences in analytical procedures, sampling location, or days on which samples were collected might contribute to this difference in the distribution of measured values.

2.2.2.3 Chlorophyll-a

Chla concentrations were measured at two stations: USGS/Mahwah and NJDWSC/Pompton Lake. A total of six samples were analyzed for chla by USGS at the Mahwah station between the years 2000 and 2002 (Figure 2-9). The mean concentration is 14.3 µg/L. One sample exceeded the threshold value of 24 µg/L. NJDWSC sampled for chla in Pompton Lake in the years 1988 through 1991 and 1997 through 2002 (Figure 2-10). An annual growth cycle is evident. The mean chla concentration is 18.66 µg/L, and 22 percent of the samples exceeded 24 µg/L.

2.2.2.4 Dissolved Oxygen

DO concentrations were measured at all four stations (Figures 2-11 and 2-12). As for TP, filled circles on these figures represent data collected during the growing season and open circles represent data collected during the non-growing season. The line represents DO saturation (Chapra 1997):

$$C_{sat} = \exp\left(-139.34 + \left(\frac{1.58X10^5}{T_a}\right) - \left(\frac{6.64X10^7}{T_a^{\ 2}}\right) + \left(\frac{1.24X10^{10}}{T_a^{\ 3}}\right) - \left(\frac{8.62X10^{11}}{T_a^{\ 4}}\right)\right) \qquad (2\text{-}1)$$

where C_{sat} is defined as the DO concentration at saturation and T_a is the water temperature in degrees Kelvin. The equation assumes zero salinity and pressure at 1 atm.

DO concentrations measured in the Ramapo River at Mahwah did not violate the 5 mg/L standard (Figure 2-11) during the entire period of record (1980 through 2002). Levels during the growing season have generally been lower than saturation.

DO concentrations measured at PVWC/Oakland, during the period of record (1994 through 2001), were less than 4 mg/L 6.4 percent of the time (Figure 2-11). Levels during the growing season have generally been lower than saturation.

DO concentrations measured in the lake have often been greater than saturation during the growing season, suggesting excessive algal growth and eutrophic conditions (Figure 2-12). Concentrations measured at NJDWSC/Pompton Lake fell below the 24-hour average of 5 mg/L once during the period of record (1988 through 2001). Concentrations measured at USGS/Pompton Lake fell below the 24-hour average of 5 mg/L three times during the period of record (1988 through 2001); these values were also lower than the instantaneous standard of 4 mg/L.

2.2.3 Evidence for Water Quality Impairment

Table 2-2 summarizes the frequency with which the data from the four stations violate the TP and DO standards and the chla threshold.

TP concentrations at the stream stations are compared with the stream standard of 0.1 mg/L, and TP concentrations in the lake are compared with the lake standard of 0.05 mg/L. TP concentrations at the USGS/Mahwah station and at the two lake stations exceeded the stream and lake standards, respectively, between 66 and 71 percent of the time. TP levels at PVWC/Oakland exceeded the standard much less frequently (17 percent of the time).

The chla threshold is based on a seasonal average of 24 µg/L. The overall frequency of exceedance for the period of record was determined for chla, along with exceedances determined by season (Table 2-2). The threshold was exceeded 17 percent of the time overall and 33 percent of the time in the summer at USGS/Mahwah. The threshold was exceeded 22 percent of the time at NJDWSC/Pompton Lake; exceedances were observed in spring, summer, and autumn.

DO measurements were compared with the 24-hour average standard of 5 mg/L and the instantaneous standard of 4 mg/L. At all four stations, DO concentrations violated standards less than 10 percent of the time. The maximum frequency of violation was 6.4 percent at PVWC/Oakland.

Thus, Pompton Lake exhibits evidence of eutrophication and water quality impairment: TP, as measured just above the dam, frequently exceeded the lake standard of 0.05 mg/L. Phytoplankton biomass, as measured by chla, frequently exceeded the seasonal threshold value of 24 µg/L used by NJDEP as an indicator of algal bloom conditions. Oxygen levels in the lake were often supersaturated during the growing season, suggesting excessive in-lake primary production.

The observation of frequent exceedances of the stream TP standard at the USGS/Mahwah gage station is important, because, as will be shown in Section 3, this represents the major source of phosphorus to the lake.

While these data provide evidence for impairment, they do not provide a picture that is sufficient for development of an effective restoration plan. Both lake stations are located at the southern end of the lake near the dam. The USGS samples are vertically-integrated composites, while the NJDWSC are surface water grab samples. The degree to which they are representative of conditions throughout the lake is not known. No observations of bottom water DO were available, other than measurements performed in the November 2003 sampling program; these are needed to assess bottom water hypoxia. The extent of macrophyte growth within the lake is not known. While TP is often the limiting factor in lake ecosystems, the extent to which TP limits primary production in Pompton Lake is not known, and, thus, the potential benefits of reductions in TP loads cannot be quantified. Finally, the TP data collected in the lake have historically exhibited patterns that raise questions concerning both the mechanisms controlling TP dynamics as well as the representativeness of these data. The subject patterns include: the temporary decline in TP at the NJDWSC/Pompton Lake station in 1993 and 1994 that was not observed at USGS/Pompton Lake; and the rise in TP concentrations from 1996 through 1999 and the subsequent decline observed at NJDWSC/Pompton Lake.

Table 2-2. Frequency of violations of selected water quality standards from long-term monitoring stations.

Measurement	Standard/Threshold*	Percent Violations			
		USGS 01387500 Mahwah	PVWC Oakland	NJDWSC Pompton Lake	USGS 01388000 Pompton Lake
Total phosphorus (stream)	< 0.1 mg/L	66	17		
Total phosphorus (lake)	< 0.05 mg/L			71	70
Chlorophyll-a	seasonal mean < 24µg/L	17	-	22	-
	summer	33	-	40	-
	autumn	-	-	20	-
	spring	0	-	33	-
	winter	-	-	0	-
Dissolved oxygen	> 5 mg/L (24-hour average)	1.6	6.4	1.3	2.2
Dissolved oxygen	> 4 mg/L (instantaneous)	1.1	6.4	0.7	2.2

* Based on FW2-NT water body standards and NJDEP's Technical Manual for Phosphorus Evaluations (NJDEP 2003a)..

SECTION 3
QUANTIFICATION OF PHOSPHORUS LOADS

3.1 APPROACH

Point source loads were derived from Discharge Monitoring Report (DMR) data for the permitted wastewater treatment facilities in the watershed. In-stream loads at the USGS/Mahwah station were developed from an empirical relationship between measured flow and phosphorus concentration. Non-point source loads were calculated using the Export Coefficient Method. This is the same method as available in the model PLOAD, which is contained in USEPA's Better Assessment Science Integrating Point and Non-Point Sources (BASINS) program. Export coefficients are also known as unit area loading coefficients. The export coefficient method uses the product of land use area and export coefficients to determine the annual TP load in each sub-basin, as defined by the following equation:

$$L_p = \sum_i \left(EC_i \cdot A_i \right) \qquad (3\text{-}1)$$

where:

L_P = pollutant load (kg/year)

EC_i = export coefficient for land use type i (kg/hectare-year)

A_i = area of land use type i (hectares)

The TP load at the USGS/Mahwah gage on the Ramapo River, calculated using the in-stream data, was added to point and non-point source loads from the watershed downstream of the gage to estimate the TP load entering Pompton Lake.

The in-stream data at the USGS/Mahwah gage provided an opportunity to evaluate the non-point source loading methodology. Non-point source loads for the watershed upstream of the gage were calculated using the export coefficient approach. These loads, combined with the point source loads from upstream of the gage, were then compared with the loads estimated using the TP and flow data collected at the gage.

The methods and data sources used to calculate point and non-point source loads are described next, followed by the calculation of loads at the Mahwah gage. Finally, loads to Pompton Lake are presented.

3.2 NON-POINT AND POINT SOURCE METHODS

3.2.1 Non-Point Source Loads

The watershed-based approach involves delineating the watershed, determining the areas for each land use category, and applying an export coefficient for each land use category to derive a total non-point source load.

3.2.1.1 Delineation of Pompton Lake Watershed

The Pompton Lake watershed was delineated into five sub-basins: East of Pompton Lake, West of Pompton Lake, Northeast of Pompton Lake, Northwest of Pompton Lake, and North of USGS/Mahwah (Table 3-1 and Figure 3-1). The area north of the USGS/Mahwah gage, nearly all of which is located in New York, comprises 75 percent of the Pompton Lake watershed. The land areas within New Jersey, upstream of the lake, comprise 21 percent of the watershed. The land areas east and west of Pompton Lake, draining directly into the lake, comprise 4 percent of the watershed.

Table 3-1. Subdivisions of Pompton Lake watershed for TP loading analysis.

Sub-basin	Area (hectares)
West of Pompton Lake	603
East of Pompton Lake	1,353
Northwest of Pompton Lake	3,838
Northeast of Pompton Lake	5,517
North of USGS/Mahwah	34,278

3.2.1.2 Land Use

Land use distributions for the portion of the Pompton Lake watershed located in New Jersey were assessed using NJDEP's 1995/97 "*Land use/Land cover Update, Pompton, Wanaque and Ramapo Watershed Management Area, WMA-3*". This updated data set uses a combination of the 1995/97 color infrared (CIR) imagery and the 1986 land use/land cover (LU/LC) layer from NJDEP's geographical information system (GIS) data base, which was generated using the LU/LC from the Integrated Terrain Unit Mapping (ITUM) project and the Freshwater Wetlands (FWW) data from the New Jersey Freshwater Wetlands Mapping Project. A modified version of the Anderson Classification system was used to describe land use areas in this file.

Land use distributions for the portion of the watershed located in New York were assessed using National Land Cover Data (NLCD) for New York, last updated in July 2000. The NLCD is based on a 30-meter Landsat thematic mapper data obtained by the Multi-Resolution Land Characterization (MRLC) Consortium. The data were produced under the direction of the USGS as part of the MRLC Regional Land Cover Characterization Project. This data set used the NLCD Land Cover Classification System to categorize land use.

To assess the Pompton Lake watershed as a whole, the NJDEP and NLCD data sets were merged. As different classification systems were used in each data set, land use assignments in the merged data set were made based on the land use descriptions provided in the original data sets (Table 3-2).

The entire watershed covers an area of 45,600 hectares. Forested areas comprise 70 percent of the total Pompton Lake watershed (Figure 3-2; Table 3-2). Residential areas comprise 17 percent of the total watershed area.

Table 3-2. Pompton Lake watershed land use area.

Land use	Area (hectares)
Agriculture	440
Barren/Transitional	110
Forest	31,755
Water	1,813
Wetlands	1,368
Recreational	290
Residential-High, Medium	2,058
Residential-Low, Rural	5,694
Urban	412
Commercial	1,280
Industrial	371

3.2.1.3 Export Coefficients

Most of the export coefficients used in this study were provided by NJDEP. These were determined by NJDEP using NJDEP's Loading Coefficient Analysis and Selection Tool (LCAST) data base of export coefficients (Al-Ebus 2003; NJDEP 2001). The one exception was the export coefficient for recreational areas, which was not provided by NJDEP. For this coefficient, the average of the values presented in LCAST was used. The unit area phosphorus loading from atmospheric deposition, applied as a direct load to the 71 hectares of Pompton Lake, was based on a statewide value from the New Jersey Atmospheric Deposition Network (Eisenreich and Reinfelder 2001). The export coefficients used in determining non-point source TP loads to the Pompton Lake watershed are listed in Table 3-3.

Table 3-3. Export coefficients for total phosphorus used in the TP loading analysis.

Land use	Export Coefficient (kg TP/ha/yr)
Agriculture	1.50
Barren/Transitional	0.60
Forest/Water/Wetlands	0.10
Recreational	0.03
Residential-High, Medium	1.60
Residential-Low, Rural	0.70
Urban	1.10
Commercial	2.40
Industrial	1.70
Atm Deposition (Direct)	0.07

3.2.2 Point Source Loads

Average point source loads from facilities in the watershed were calculated based on the DMRs provided by NJDEP, which covered the periods between 1997 and 2002 for New York facilities and between 1997 and 2000 for New Jersey facilities. Averages were calculated using all available years for each facility. The point sources, listed in Table 3-4, are located in the sub-basin North of USGS/Mahwah and the sub-basin Northeast of Pompton Lake (Figure 3-3). The loads presented here are the same as the loads reported in the WMA 3 Characterization and Assessment Report (Killam-Najarian 2002), with one exception: the load from Nepera, Inc. was not included in the WMA 3 report.

Table 3-4. Major point source discharges into the Pompton Lake watershed.

Facility	Sub-basin	TP Load (kg/yr)
Chapel Hill Estates STP	Northeast of Pompton Lake	0.22
Skyview-High BR STP	Northeast of Pompton Lake	1.0
Oakwood Knolls WWTP	Northeast of Pompton Lake	1.1
Indian Hills High School WTP	Northeast of Pompton Lake	3.2
Oakland Care Center	Northeast of Pompton Lake	4.3
Ramapo River Club WTP	Northeast of Pompton Lake	6.4
Sloatsburg (V) WWTP	North of USGS/Mahwah	58
Hamlet WWTP	North of USGS/Mahwah	164
Nepera, Inc	North of USGS/Mahwah	441
Tuxedo Park (V) WWTP	North of USGS/Mahwah	490
Suffern (V) STP	North of USGS/Mahwah	4,000
OCSD #1 Harriman STP	North of USGS/Mahwah	11,600

3.3 PHOSPHORUS LOADS IN THE RAMAPO RIVER AT THE USGS/MAHWAH GAGE

The relationship between flow rate and TP concentration at the USGS/Mahwah gage was used to estimate TP loads (Figure 3-4). The relationship between flow and phosphorus is logarithmic, indicating that TP levels in the river are dominated by point sources. During low flow, phosphorus concentrations are high because the majority of the flow is from point sources, which are high in phosphorus, whereas during high flow, the phosphorus concentrations are low due to dilution. Generally, within WMA 3, wastewater treatment plant upgrades occurred before 1993 (Killam-Najarian 2002); therefore, regressions between log(flow) and log (TP concentration) were calculated for two time periods—prior to 1993 and 1993 to 2002. The relationship for data prior to 1993 is given by Equation 3-2 (r^2 =0.65), and for 1993 to 2002, the relationship is given by Equation 3-3 (r^2 =0.80).

$$TP = 2.44Q^{-0.581} \tag{3-2}$$

$$TP = 2.36Q^{-0.612} \tag{3-3}$$

where:

TP = total phosphorus concentration (mg/L)

Q = flow (cfs)

The upper panel on Figure 3-5 presents the regressions, which are very similar. The lower panel shows both the observed TP concentrations and the TP concentrations derived from the 1993 to 2002 regression. The average annual load at Mahwah, based upon the flow and TP data, is 14,400 kg/yr for the years 1993-2001, and 13,800 for the years 1997 to 2002 (Figure 3-6). These two time periods were chosen for consistency with subsequent analyses.

The non-point source TP loads to the area north of USGS/Mahwah gage, estimated based upon the export coefficient approach, are summarized in Table 3-5, along with the point source loads calculated for the entire period of record (1997-2002). According to the export coefficient analysis and point source data, 64 percent of the load is generated from point sources. Aside from point sources, the significant contributors of phosphorus to the watershed are forest/wetlands/water (which comprises 77 percent of the area of this sub-basin), low density/rural residential land, and commercial land. The estimated total TP load to the river is 26,315 kg/yr.

Table 3-5. Annual total phosphorus loads by land use for the watershed area north of the USGS/Mahwah gage.

Land use	Area (hectares)	TP Load (kg/yr)
Agriculture	392	588
Barren/Transitional	11	7
Forest/Water/Wetlands	28,349	2,835
Recreational	7	0
Residential-High, Medium	698	1,118
Residential-Low, Rural	3,760	2,632
Urban	80	88
Commercial	946	2,271
Industrial	35	60
Point Sources (NYS Total; 1997-2002)		16,717
Total TP Load		**26,315**

The annual TP load for the period 1997-2002, based upon the USGS/Mahwah gage data (13,800 kg/yr), is about half of the annual load derived using the watershed approach (26,315 kg/yr) and is even lower than the estimated annual average of upstream total point source loads (16,717 kg/yr). This suggests that the export coefficients overestimate non-point source loadings in this watershed to a significant degree, which may be due in part to retention of phosphorus within the watershed. It also suggests that there may be significant retention of point source TP within the river upstream of the gage. The largest point source contributor, OCSD #1 Harriman STP, provides 70 percent of the total TP point source load to the river. It is located near the northern boundary of the watershed, approximately 17 miles upstream of the USGS/Mahwah gage, and, thus, the TP released from its outfall might be expected to exhibit greater retention in the system than TP released from the other point sources located closer to the USGS/Mahwah gage.

The loads estimated directly from the water quality data are likely to be more accurate because of the large amount of TP data available for the USGS/Mahwah gage, the quality of the regression of TP versus flow [r^2 values of 0.65 (pre-1993) and 0.80 (1993 to 2002)], and the uncertainties associated with the export coefficient approach. The loads derived from the USGS/Mahwah gage are therefore used as the TP load for the sub-basin North of Mahwah gage in the calculation of total TP loads to Pompton Lake.

3.4 PHOSPHORUS LOADS TO POMPTON LAKE

For the sub-basins downstream of the Mahwah gage, non-point TP loads were calculated based on the export coefficient approach and point source loads were based on discharge monitoring records. Loads for the period 1993-2001 are summarized by land use in Table 3-6[6].

The TP load entering Pompton Lake on an annual basis is estimated to be 20,500 kg/yr. In contrast to the sub-basin north of USGS/Mahwah gage, New Jersey point sources contribute less than 0.1 percent of TP load to the lake. Residential land use contributes 3,530 kg/day, or 17 percent of the TP load to Pompton Lake. The phosphorus load entering at Mahwah accounts for 70 percent of the total load entering Pompton Lake.

Table 3-6. Annual total phosphorus loads to Pompton Lake.

Land use	Area (hectares)	TP Load (kg/yr)
Agriculture	48	73
Barren/Transitional	99	59
Forest/Water/Wetlands	6,587	659
Recreational	283	8
Residential-High, Medium	1,359	2,175
Residential-Low, Rural	1,934	1,354
Urban	332	365
Commercial	334	801
Industrial	336	571
Atmospheric Deposition (Direct)	83	6
Internal Sources		(no data)
Load at USGS Gage at Mahwah (1993-2001)		14,396
Point Sources (NJ Total)		16
Total TP Load		**20,482**

This study does not include quantification of Pompton Lake's internal sources of phosphorus load. Internal sources include remineralization and release of sediment phosphorus and groundwater inputs. Unfortunately, lacking information on the contribution of groundwater to the lake or on lake sediments and bottom water oxygen[7], no reasonable estimate can be made for the internal loads to Pompton Lake. Internal sources for Cranberry Lake, Lake Hopatcong, and Lake Musconetcong were estimated to be 10 to 16 percent of total TP loads (NJDEP 2003c). Ghost Lake had an internal load estimate of 57 percent, but this small lake is fed only through surface runoff and groundwater flow.

There are four sources of uncertainty associated with the load estimate. First, non-point source loadings may be overestimated, as suggested by the USGS/Mahwah gage data described

[6] The period 1993-2001 was chosen for consistency with the availability of in-lake TP data from NJDWSC. See Section 5.

[7] Under oxic sediment conditions, phosphate is bound to particulate iron in the sediments. Under anoxic condition, brought about by the bacterially-mediated decay of organic matter in sediments and bottom waters, phosphate is released and diffuses into the water column.

above. Second, TP that is present at the USGS/Mahwah station may be retained within the New Jersey section of the Ramapo River. However, the smaller size of each of these sub-basins relative to the sub-basin north of the gage at Mahwah suggests that TP losses due to retention within the watershed may be less important than in New York. Third, internal TP sources within the lake are not included. Fourth, there is uncertainty regarding the regression of TP and flow rate at the USGS/Mahwah gage.

Total TP loads to Pompton Lake were estimated on an annual basis by adding the annual loads calculated at the USGS/Mahwah gage to the estimated long-term average load from sources downstream of the gage (Figure 3-7).

In addition to assessing the loads on a land use basis, the loads were broken out by sub-basin (Figure 3-8). On this figure, the colors of the pie chart coordinate with the watershed map. As mentioned above, the sub-basin north of the USGS gage at Mahwah represents 70 percent of the total load. Northwest of Pompton Lake accounts for 20 percent of the load, East of Pompton Lake account for 4 percent of the load and West of Pompton Lake and Northwest of Pompton Lake account for 3 percent each.

The assessment of phosphorus loads was refined even further. Loads from each sub-basin were calculated on a land use basis (Figures 4-9 through 4-12). In each of these figures, the large pie chart on the right displays the distribution of loads from the various land uses and from point sources within the sub-basin. The small pie chart to the upper left of the TP loads pie chart shows the proportion of total load to Pompton Lake contributed by the sub-basin. The large pie chart on the left represents the distribution of land use in the sub-basin. The small pie chart to the upper left of the large one shows the proportion of the total land area within New Jersey contributed by the sub-basin[8].

[8] Note the difference in the interpretation of the two small pie charts. The loading chart provides an indication of the potential benefits of reducing loads from each sub-basin on total loads to the lake. The landuse chart shows the proportion of area within the New Jersey portion of the watershed that would be affected by non-point source restoration efforts.

The sub-basin Northeast of Pompton Lake contributes 3,990 kg TP/yr to the watershed (Figure 3-9), which is about 20 percent of the total load to the lake. The loads from residential land uses account for more than half of this load. Thus, for example, elimination of all TP loads from residential areas in this sub-basin would potentially reduce loads to Pompton Lake by as much as 10 percent.

The TP load to the watershed from Northwest of Pompton Lake is 673 kg TP/yr (Figure 3-10). Deciduous forests comprise 83 percent of the land area and contribute approximately half of the TP load from the sub-basin Northwest of Pompton Lake. The total TP load from the Northwest of Pompton Lake sub-basin, however, represents only 3 percent of the TP load to Pompton Lake.

The TP load from East of Pompton Lake is 771 kg/yr (Figure 3-11). This accounts for 4 percent of the total load to the watershed. High-density and low-density residential land contributes to 18 and 19 percent of the land area and 49 and 22 percent of the TP load from East of Pompton Lake, respectively. Commercial land is the third largest contributor of phosphorus loads (11 percent).

The TP load from West of Pompton Lake is 607 kg/yr (Figure 3-12). This accounts for 3 percent of the total load to the watershed. High density residential land accounts for less than half the land use, but 62 percent of the load. The other large contributors to load from West of Pompton Lake include commercial land (19 percent) and industrial land (9 percent).

SECTION 4
RELATIONSHIP BETWEEN PHOSPHORUS CONCENTRATIONS AND LOADS

One objective of this study was to determine whether an empirical relationship can be established between in-lake phosphorus concentrations and influent phosphorus loads. Such a relationship would provide a basis for assessing the load reductions necessary to achieve target concentrations. Simple generic relationships have been established based on data from multiple systems (Chapra 1997). These models assume a linear relationship between load and concentration. NJDEP has summarized a number of these models in its recent lakes TMDLS (NJDEP, 2003a, 2003b, 2003c). In those TMDLs, NJDEP used the Reckhow (1979) model to estimate TP concentration from load, because the data upon which the model was based were collected in lakes exhibiting a broad range of hydrologic, morphological, and loading characteristics, and because Reckhow performed an explicit analysis of uncertainty which allows for the development of a Margin of Safety calculation for TMDLs in which it is used. The utility of this model is that it offers a means of prediction when lake concentration data are lacking. Its uncertainty comes primarily from the fact that its parameters are not site-specific. In addition, its temporal and spatial resolution is limited, and feedbacks with algal biomass are not included (Thomann 1977).

The availability of both upstream and in-lake TP data for Pompton Lake provides an opportunity to estimate in-lake phosphorus concentration for comparison with the concentration predicted using the estimated TP load and the Reckhow model. In this way, the applicability of the Reckhow model to Pompton Lake can be assessed.

4.1 THE RECKHOW MODEL

Reckhow (1979) developed a simple mass balance model, based on phosphorus load and water load, to estimate in-lake phosphorus concentration. Reckhow derived the model using data collected from 47 northern temperate lakes. NJDEP has used this model to estimate TP concentrations in its recently established lake TMDLs (NJDEP 2003b, 2003c, 2003d). The model is described below and applied to Pompton Lake.

The Reckhow model provides a relationship between phosphorus load, water load and in-lake phosphorus concentration:

$$P = \frac{P_a}{11.6 + 1.2Q_a} \qquad (4\text{-}1)$$

where:

P = in-lake phosphorus concentration (mg/L)

P_a = areal phosphorus load (g/m^2-yr)

Q_a = areal water load (m/yr)

Furthermore:

$$Q_a = \frac{Q}{A} \qquad (4\text{-}2)$$

where:

Q = volumetric water load (m^3/yr)

A = lake area (m^2)

The average areal water load to Pompton Lake (Q_a) is 375 m/yr, based on the average flow measured at the USGS/Pompton Lake station between 1993 and 2001 (287 cfs or $2.6X10^8$ m^3/yr), the average diversion flow (11.4 cfs or $1.0X10^7$ m^3/yr), and a lake area of 71 ha.[9] The areal phosphorus load was calculated using the average load at Mahwah from the years 1993 through 2001 summed with non-point and point sources in the four sub-basins in New Jersey (20,482 kg/yr). The areal phosphorus load during this time period is 28.8 g/m^2-yr.

Pompton Lake has some, but not all, of the characteristics of the lakes upon which Reckhow based his analyses (Table 4-1). Mean phosphorus concentrations at the two stations just upstream of Pompton Lake Dam are 0.08 mg/L (USGS; 1987-1996) and 0.11 mg/L (NJDWSC; 1988-2001), within the range of 0.004 and 0.14 in Reckhow's data set. The average areal phosphorus load is 28.8 g/m^2-yr, again within the range of Reckhow's data set. Pompton Lake's average areal water load of 375 m/yr, however, is larger than maximum of 190 m/yr in Reckhow's data set. Thus, the applicability of the Reckhow analysis to Pompton Lake is uncertain.

Table 4-1. Lake characteristics suitable for the Reckhow model.

Characteristic	Minimum	Maximum
Phosphorus concentration (mg/L)	0.004	0.14
Average influent phosphorus concentration (mg/L)	-	0.30
Areal phosphorus load (g/m^2-yr)	0.07	31
Areal water load (m/yr)	1.2	190

Using the Reckhow model, the estimated TP load is predicted to result in an average in-lake TP concentration of 0.063 mg/L.

Table 4-2. Current conditions, target concentration, and potential load reduction for total phosphorus in Pompton Lake – illustrative calculation.

Areal Water Load (m/yr)	Current Areal TP Load (g/m^2-yr)	Calculated TP_{lake} (mg/L)	Target TP (mg/L)	TP Load Reduction (%)
375	28.8	0.063	0.02	68
In-lake TP concentration estimated based upon the Reckhow model.				

[9] Lake area, considering wet surface area only and excluding an island, was derived from the high-resolution coverage of the USGS National Hydrography Dataset (http://nhd.usgs.gov).

4.2 MEASURED IN-LAKE TP CONCENTRATIONS

Average TP concentrations measured near the Pompton Lake Dam were compared with the results of the Reckhow model. The USGS data were used for this comparison, because the samples were collected as vertically integrated composites and thus provide values that are consistent with the assumptions of the Reckhow model; the NJDWSC data include only surface water samples. Furthermore, the NJDWSC data exhibit apparently anomalous behavior in more recent years (Figure 2-6), which may not be representative of overall long-term lake conditions. Nonetheless, it should be noted that the two data sets produce similar medians and 90th percentile values for the same time period (1988-1996; Figure 3-8).

For the period 1987-1996 (the available record), the average TP concentration measured by USGS is 0.08 mg/L, within 30% of the average concentration computed using the Reckhow model (0.063 mg/L; data collected at USGS/Mahwah within the past 12 years, 1993-2001). These two time periods are used, because they represent reasonable choices for each data set for use in characterizing lake water quality for the purpose of TMDL development, because they balance reasonable length of record with recent dates of collection. For comparison, the average TP concentration measured by NJDWSC for the period 1993-2001 was 0.12 mg/L, and for the entire period of record (1988-2001), 0.11 mg/L.

The percent reduction in TP loads that might be required in a phosphorus TMDL can be illustrated using both the Reckhow model results and the in-lake data. NJDEP (2003a, 2003b, 2003c) established a TP target for the average TP concentration of 0.02 mg/L based on a margin of safety (MOS) that would guarantee that TP concentrations remain below the standard of 0.05 mg/L more than 90 percent of the time. This target may or may not be appropriate for Pompton Lake; it is used here for illustrative purposes only. In order to meet the target of 0.02 mg/L, a load reduction of 68 percent would be required based upon the results of the Reckhow model (Table 4-2; 1993-2001). Based on the USGS/Pompton Lake mean TP concentration of 0.08 mg/L (available record, 1987-1996), a 75 percent reduction would be required. For comparison, based upon the NJDWSC/Pompton Lake measured mean concentration (available record, 1988-2001), a somewhat greater load reduction would be required (82 percent).

The lake data also provide an alternative means of computing the percent reduction required to meet the water quality standard. According to the water quality standard, in-lake phosphorus concentrations may not exceed 0.05 mg/L; this is generally interpreted to mean that concentrations may not exceed the standard more than 10 percent of the time. The 90th percentile of the vertically-integrated TP data from the USGS/Pompton Lake station is 0.13 mg/L (1987-1996; Figure 4-1). In order to reach the standard of 0.05 mg/L 90 percent of the time, a 62 percent reduction in this value would be required.

The above analyses provide illustrative potential load reductions designed to bring the lake into compliance with the 0.05 mg/L TP standard; if it is determined that a TMDL is required, NJDEP will develop the actual TMDL. The Reckhow model provides an estimated load reduction (68%) that is similar to the load reductions estimated based upon the in-lake data; the Reckhow value lies between the load reductions estimated based upon the average of the USGS data (75%) and the 90th percentile of the USGS data (62%).

As indicated in this section and in Section 3, there are uncertainties associated with both influent TP loads, which are used in the Reckhow calculation (primarily retention within the Ramapo River and internal loads within the lake) and with in-lake TP concentrations (primarily the degree to which the data are representative of current conditions throughout the lake). These uncertainties could be reduced by the collection of additional in-lake data, as described in the next section. Such data would permit the development of a mass balance for TP, which would quantitatively link the external loads, internal loads and in-lake concentrations.

SECTION 5
LAKE RESTORATION

5.1 COMPONENTS OF AN EFFECTIVE RESTORATION PLAN

A TMDL represents one tool of many that can be used to manage or restore Pompton Lake. In this section, we place the TMDL in the broader context of a restoration plan for the lake. The development of an effective management or restoration plan must be based upon a clear statement of goals, quantitative targets that are derived from these goals, knowledge of the status of the lake relative to the targets, and an understanding of the natural processes controlling the target variables. This last item includes an understanding of the tools that are available for lake management (e.g., nutrient reduction, biomanipulation) and the relationships between these tools and the target variables.

The designated uses for Pompton Lake provide a starting point for establishment of goals:

- maintenance, migration and propagation of the natural and established biota;
- primary and secondary contact recreation;
- industrial and agricultural water supply;
- public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation, and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection; and
- any other reasonable uses[10].

Pompton Lake is a shallow lake in an urbanized environment. The lake is actively used for secondary contact recreational activities such as fishing and boating. Thus, goals for the lake

[10] New Jersey Administrative Code (NJAC) 7:9B

may include a satisfactory fishery, good aesthetics (smell and appearance), a sustainable ecological community, and water quality adequate for use of the lake waters as a water supply.

The water quality standards discussed in this report provide quantitative targets. These standards, however, do not directly address issues such as the quality of the fishery, the frequency of nuisance algal blooms, and macrophyte growth. In addition, site-specific refinements of some standards may be appropriate to develop the most effective management/restoration plan. For example, the water quality standard for TP is based upon a generic relationship between average TP concentration and the degree of eutrophication; depending on the particular conditions of Pompton Lake and goals for the lake, a site-specific version of this standard may be appropriate.

As indicated above, the available information is insufficient to fully characterize the status of the lake, specifically, its water quality and ecological community. With respect to water quality, the lake, based on data collected upstream and at the dam, may be eutrophic. With respect to fishing, the lake presently has a fish consumption advisory due to mercury. Other information concerning the status of the lake is not available, for example the extent of nuisance blooms and macrophyte growth, the quality of the lake's fishery, and the structure of the biological community.

There are a variety of actions that can be undertaken to restore a lake, including: reductions in point source nutrient loadings, reductions in non-point source loadings, removal of plant material from the lake, and manipulation of the fish community. To develop a management/restoration plan, the potential effectiveness of each activity should be evaluated. This requires an understanding of the physical, chemical and biological processes that control those characteristics of the lake that are of importance, that is, the goals and targets. This understanding forms the basis for a conceptual model of the lake that can guide the decision-making process. The final step in developing a lake management/restoration plan is quantifying those components of the conceptual model as required to effectively guide management/restoration activities.

The next section provides a discussion of the conceptual model needed for the lake. Thereafter, recommendations are provided for the next steps needed to guide NJDEP in its development of a management strategy for the lake.

5.2 LAKE CONCEPTUAL MODEL

Figure 5-1 provides a simple conceptual model for TP in Pompton Lake. This conceptual model reflects tasks undertaken as part of this study, namely the estimation of TP loads and in-lake concentration. Thus, its focus is relatively narrow. This model is built around a water quality view of phosphorus dynamics. Water quality frameworks focus on those processes that control aquatic systems from the bottom up: a limiting nutrient such as phosphorus controls water quality by controlling phytoplankton biomass, with consequent feedbacks involving light penetration (water clarity), DO concentration (hypoxia driven by the decay of plant matter), and macrophyte growth.

This model is incomplete, however. The addition of an ecological component to the conceptual model of the lake, including invertebrate and fish communities, would permit the model to address lake goals, such as a healthy fishery. Furthermore, it would permit the model to address a range of potential management activities that operate in a top-down fashion, for example control of algal biomass and turbidity through the promotion of macrophyte growth, reduction of benthivorous fish, and manipulation of planktivorous and piscivorous fish populations so that zooplankton are allowed to reach sufficient biomass to exert control on phytoplankton biomass (Jeppesen and Sammalkorpi 2002). Thus, an important next step in the development of a management/restoration plan for Pompton Lake is the development of a more complete conceptual model for the lake.

Quantifying the key linkages between potential management/restoration activities and lake targets is the final step in developing an effective plan. Although there is a strong relationship between flow and phosphorus concentration at USGS/Mahwah (Figure 3-4), the relationship between flow and TP concentration at USGS/Pompton Lake is weak (Figure 5-2; r^2

= 0.16). Similarly, there is no clear relationship between monthly average TP concentrations at USGS/Mahwah and in the lake (Figure 5-3; left panel: USGS/Pompton Lake station; right panel: NJDWSC/Pompton Lake station). This suggests that the TP concentrations observed in Pompton Lake are not directly coupled to influent loads, at least on these relatively short time scales, and, therefore, that phosphorus concentrations within the lake may not respond on short time scales to upstream load reductions. Additional dilution or additional phosphorus loadings downstream of the USGS/Mahwah station, storage of phosphorus in plant tissue, deposition of phosphorus within the river and lake, and release of phosphorus from sediments may contribute to the control of in-lake TP concentrations and may delay the response of lake TP levels to upstream nutrient reductions. Thus, it is important to better understand the processes controlling TP dynamics in the lake to develop an effective management/restoration plan.

5.3 NEXT STEPS

Additional efforts are suggested to refine the TMDL calculation and to develop an effective management/restoration plan:

- Finalize a set of goals and quantitative targets for the lake.
- Complete the development of a conceptual model for the lake.
- Collect data to evaluate the status of the lake, that is, the nature and extent of impairments.
- Collect data needed to quantify linkages between management/restoration activities and goals and targets, in particular the link between TP loads and in-lake concentrations.

Goals, targets and the conceptual model were discussed in the previous section. In the rest of this section, we discuss data needed to evaluate lake status and quantify linkages.

For some indicators of impairment, there are no data. These indicators include macrophyte biomass and the condition of the fishery. One or two surveys should be conducted for these components of the ecosystem during the growing season. The survey of the fish community should include measurement of abundance and body size distribution for each species.

For the water quality indicators, while there are data collected near the dam, there are no data available throughout the rest of Pompton Lake during the summer; it is necessary to establish whether surface water samples taken at the dam are representative of conditions throughout the lake. A monitoring program conducted during the growing season that includes nutrients, suspended solids, DO, clarity and chlorophyll-a, measured at several locations throughout the lake, would satisfy this need. Sampling should be frequent enough to observe nuisance blooms. Surface and bottom samples should be collected to evaluate whether bottom waters become hypoxic during the summer.

To reduce the uncertainty associated with the TMDL, it is necessary to better define the relationship between TP loads and concentrations, that is, to assess the contribution of internal loads to lake concentrations. This will require the collection of additional in-lake data to complete the phosphorus mass balance for the lake. Efforts may include the following:

- Incorporate the data from the Phosphorus Protocol study of the Passaic River Basin when they become available.
- Incorporate the most recent data from the NJDWSC/Pompton Lake station.
- Estimate phosphorus loads from direct stormwater drainage from the towns Pompton Lakes and Wayne.
- Monitor water quality and flow in the Ramapo River, just upstream of the lake. There is evidence in the historical data set for differences between TP levels measured at the PVWC/Oakland and USGS/Mahwah stations. Monitoring data along the Ramapo River will aid the evaluation of the sources and fates of TP within the Ramapo River and Pompton Lake. This program could be integrated with in-lake monitoring discussed above.

The development of a management/restoration plan for Pompton Lake can be approached in an adaptive manner to meet the goals for the lake in the most cost-effective way: data collection programs, the conceptual model, and management/restoration plans can be reconsidered and, if necessary, modified as new information becomes available. The suggestions presented here provide a starting point for developing a management/restoration plan for Pompton Lake.

SECTION 6
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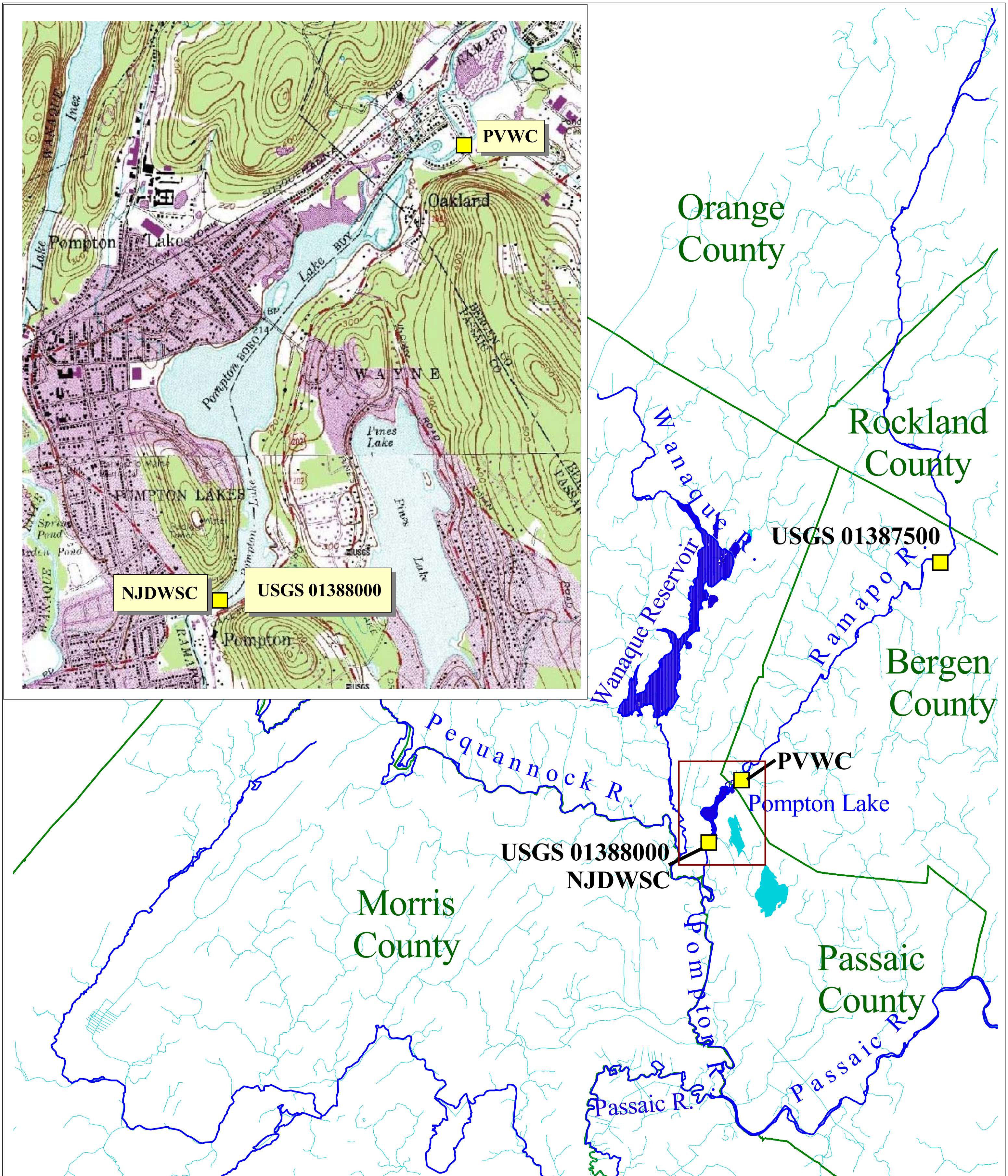

Figure 2-1. Ramapo River drainage to the confluence of the Pompton and Passaic Rivers.

LEGEND

- Select Water Quality Stations
- County Lines
- Main Rivers
- Rivers

Data Sources: Counties are from ESRI. Waterbodies are from USGS (NHD) Other data are from BASINS.

GRAPHIC SCALE

1 0 1 Miles

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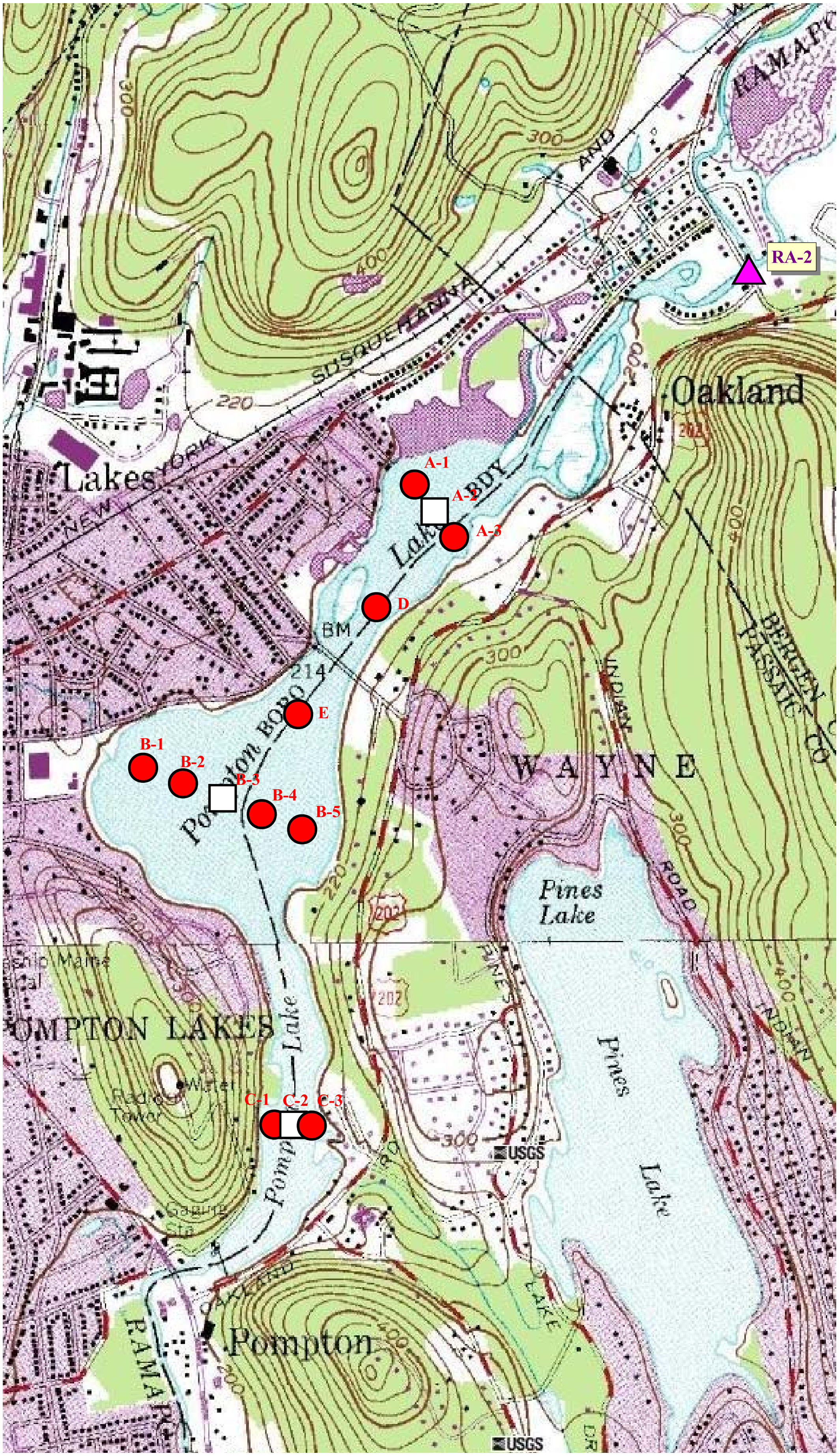
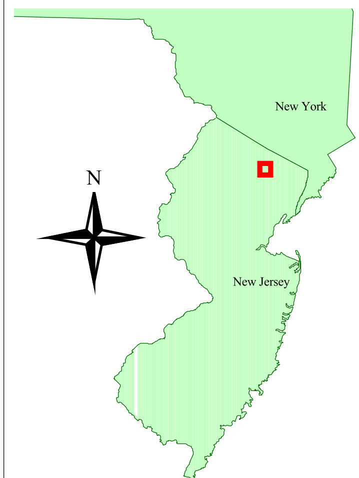


Locator map



Graphic scale

400 0 400 800 Feet

Legend

Sampling locations

- Depth
- Depth/T/C/DO/pH/ transparency/ chla/nutrients
- Omni Station Location

Figure 2-2. Location of Pompton Lake sampling stations from the November 18, 2003 survey.

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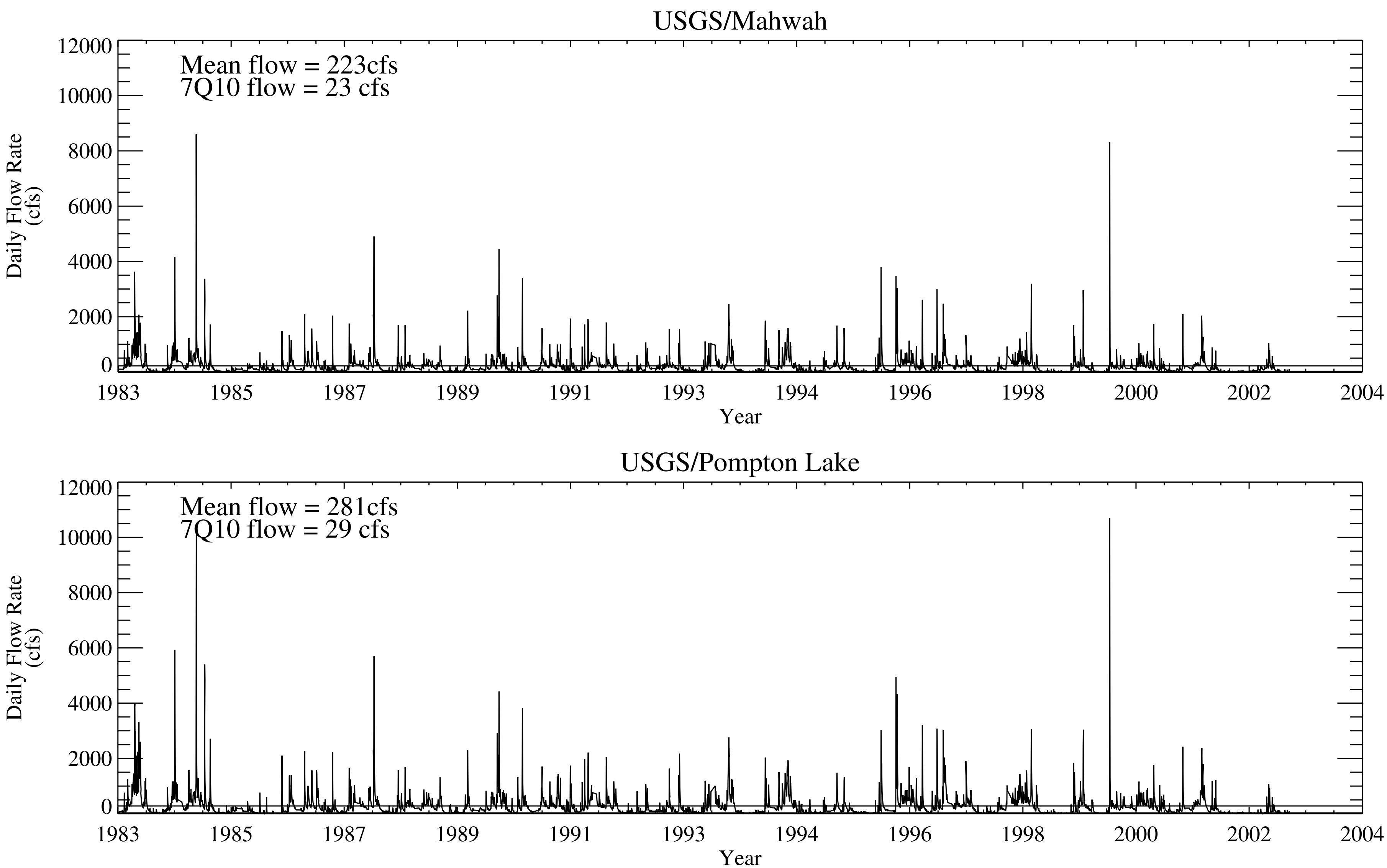

Figure 2-3. Daily average flow for the Ramapo River at gages located upstream of Pompton Lake and at the lake's outlet (1983-2002).

Data Source: USGS

Horizontal line represents mean flow for time period shown.

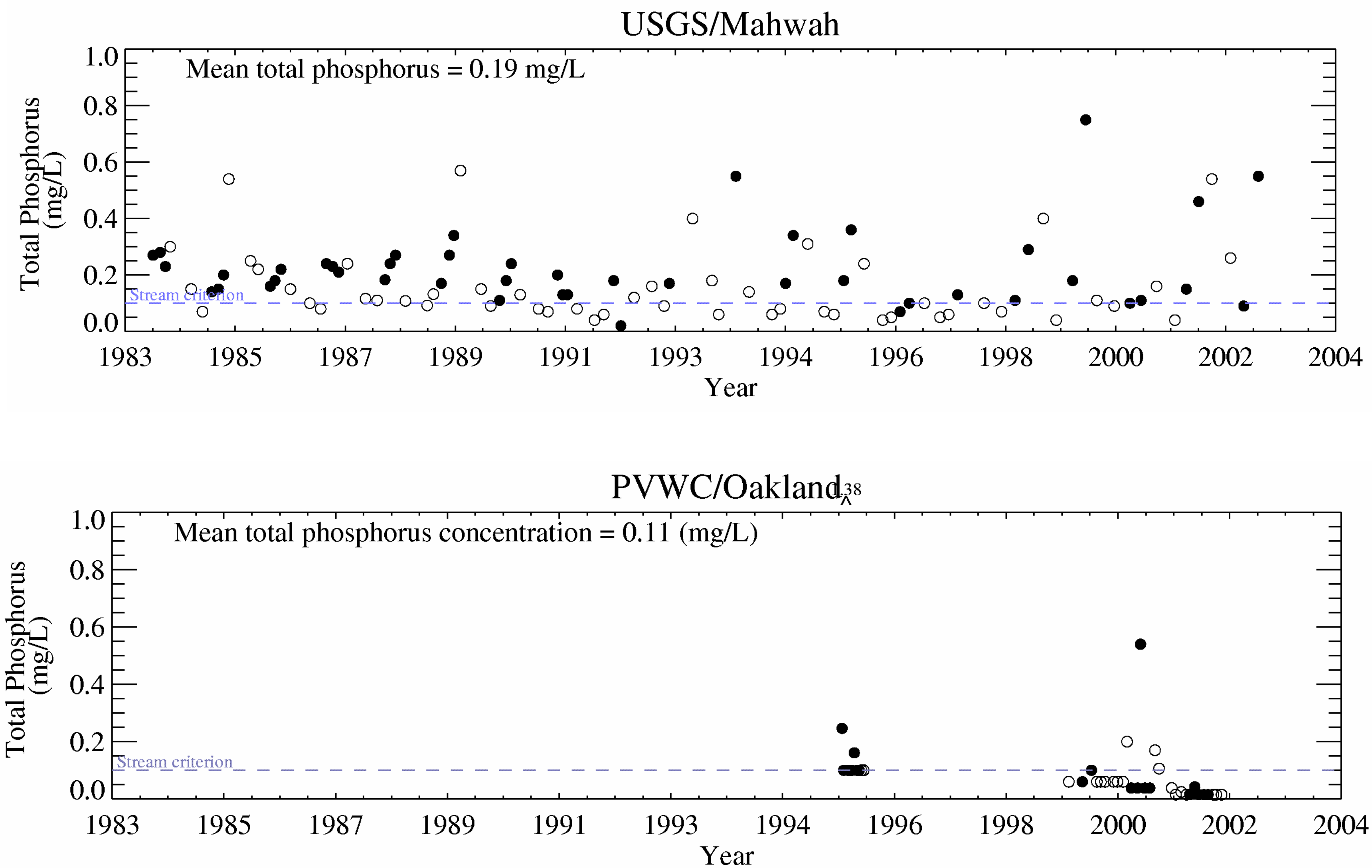

Figure 2-4. Total phosphorus concentration time series at two Ramapo River locations upstream of Pompton Lake. *Filled symbols represent samples taken during the growing season (May through September).*

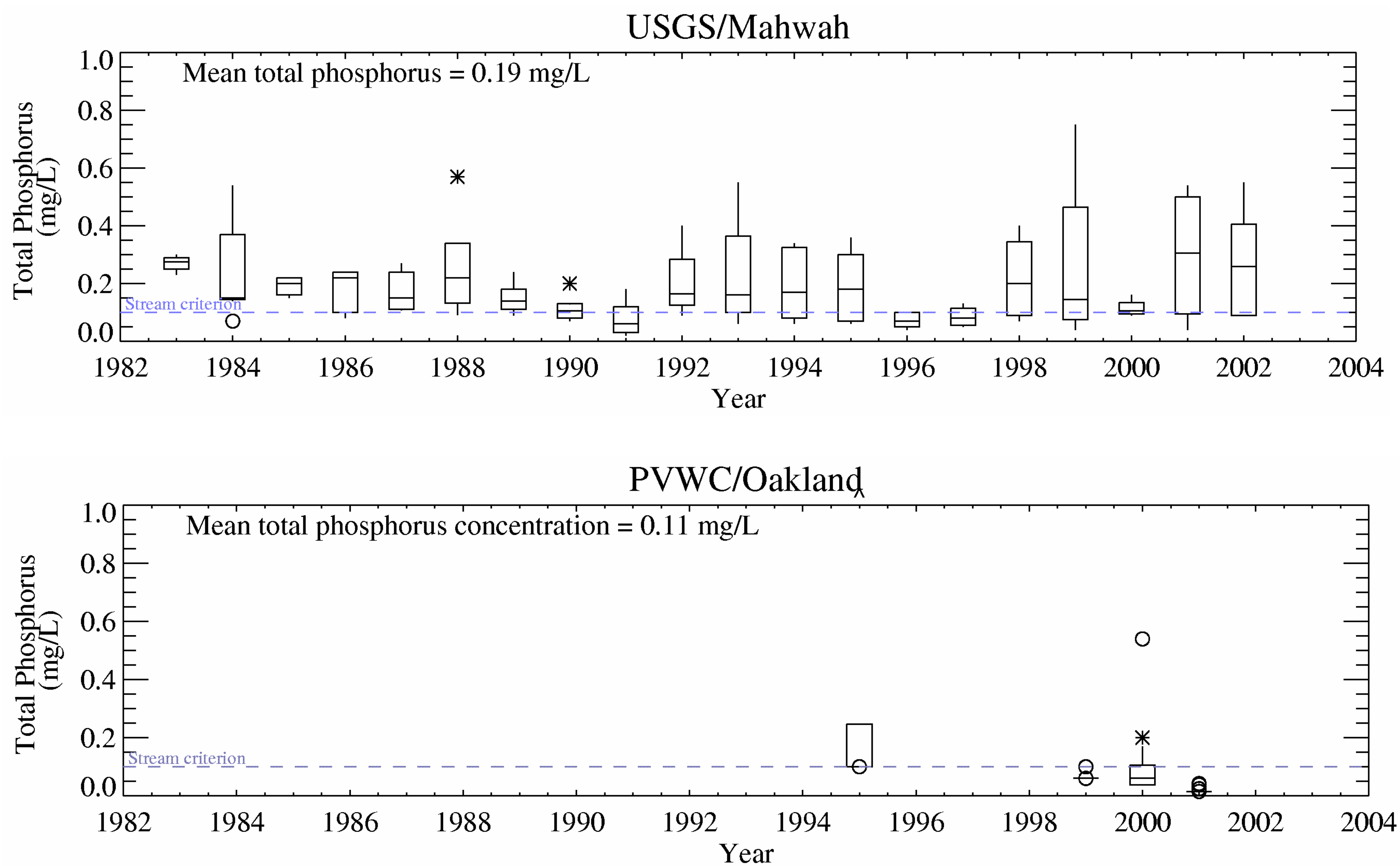

Figure 2-5. Annual characteristics of total phosphorus concentration at two Ramapo River locations upstream of Pompton Lake.

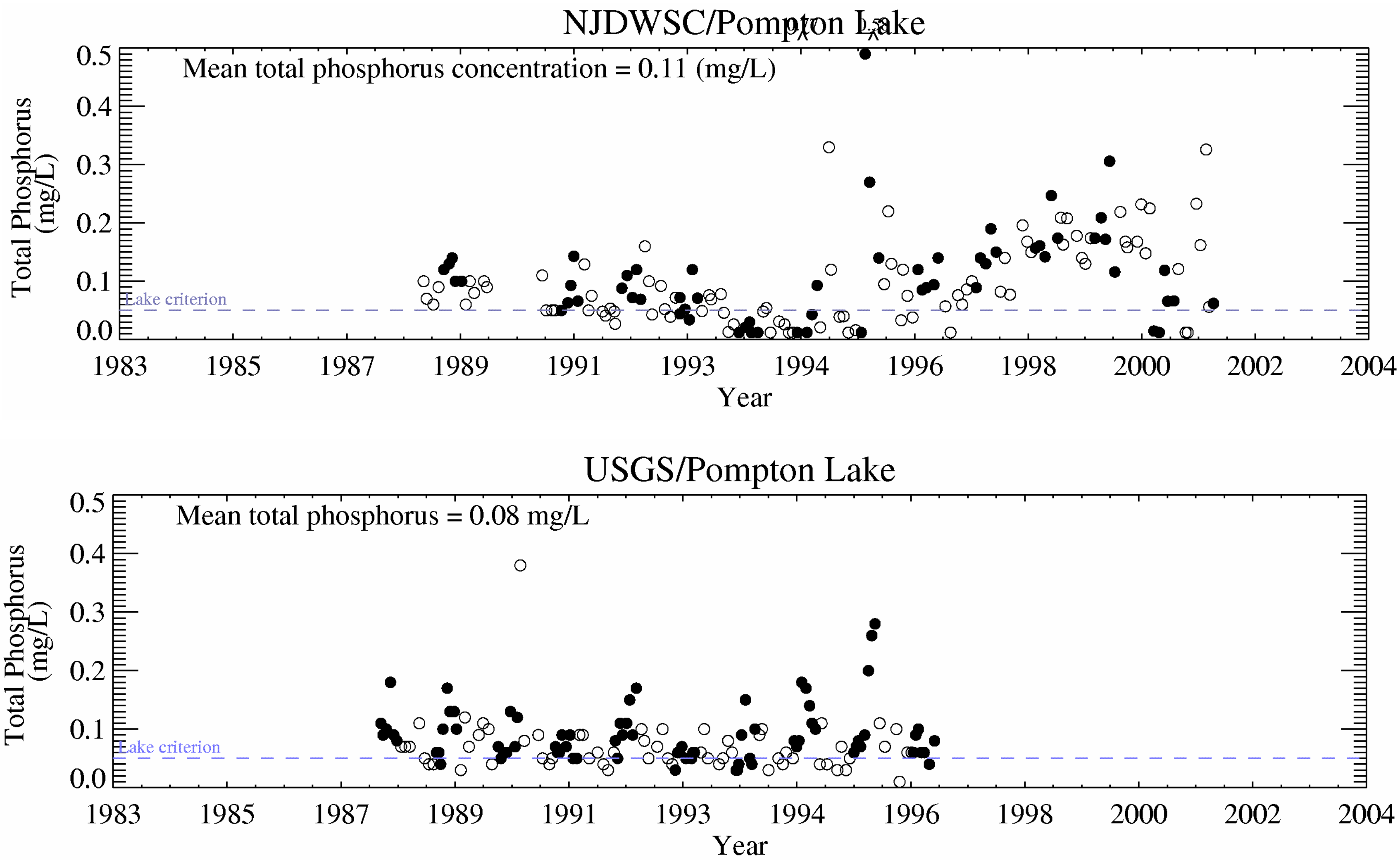

Figure 2-6. Total phosphorus concentration for data collected at Pompton Lake Dam.
Filled symbols represent samples taken during the growing season (May through September).

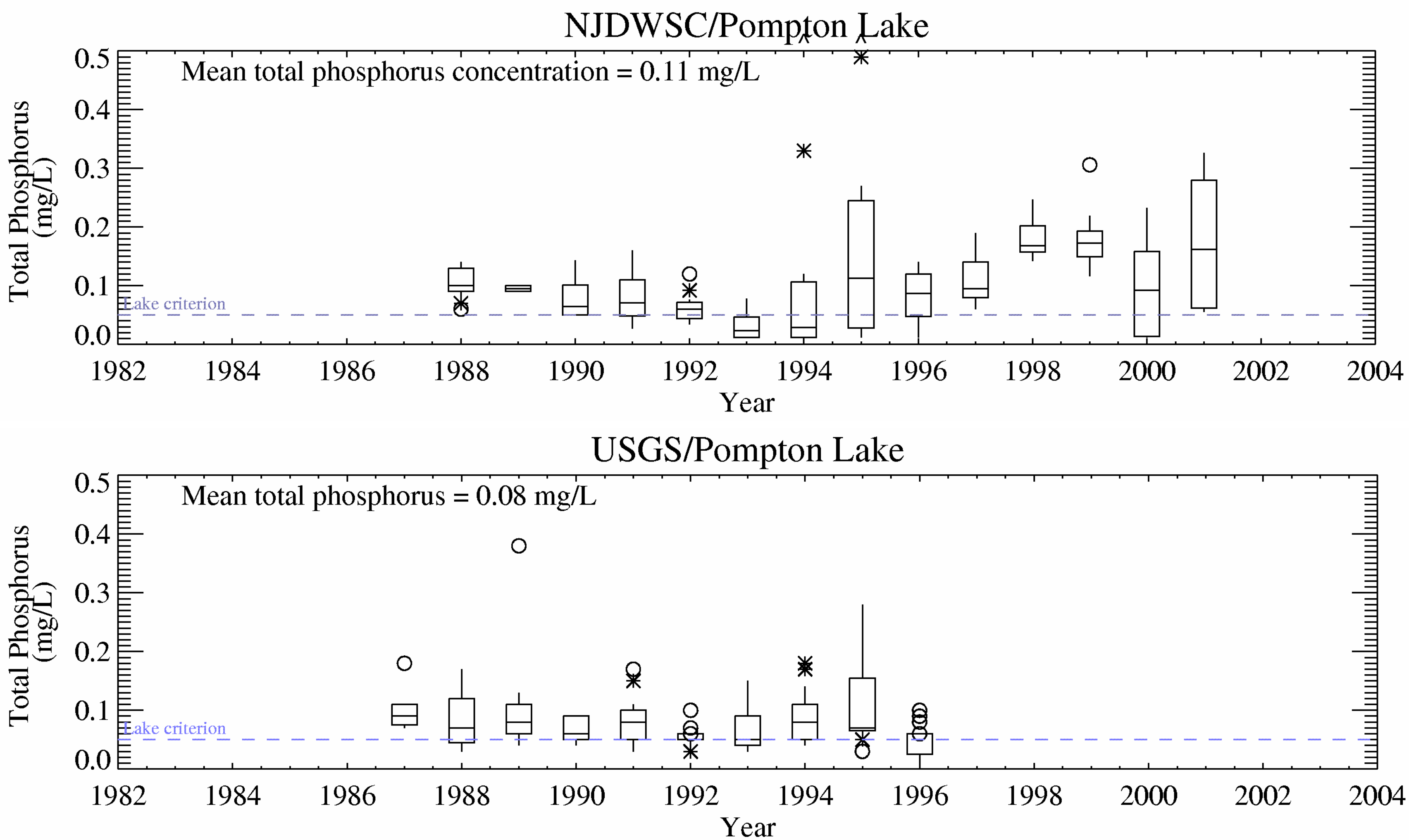

Figure 2-7. Annual characteristics of total phosphorus concentration at Pompton Lake Dam.

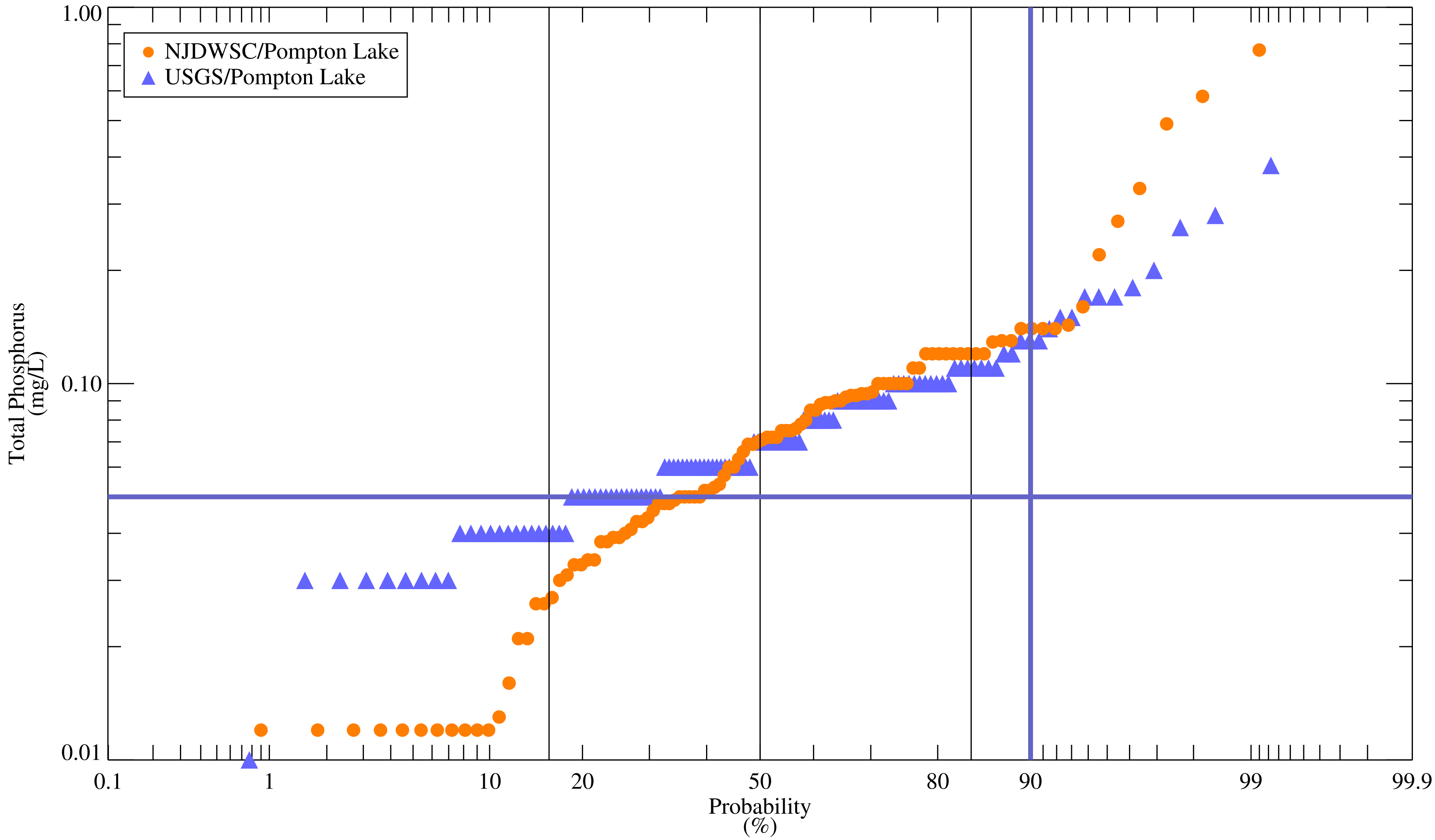

Figure 2-8. Comparison of USGS and NJDWSC total phosphorus concentrations at Pompton Lake Dam (1988-1996)

Data Source: USGS and NJDWSC; 1988 - 1996

Horizontal blue line represents total phosphorus lake criterion of 0.05 mg/l. Vertical blue line represents the 90th percentile.

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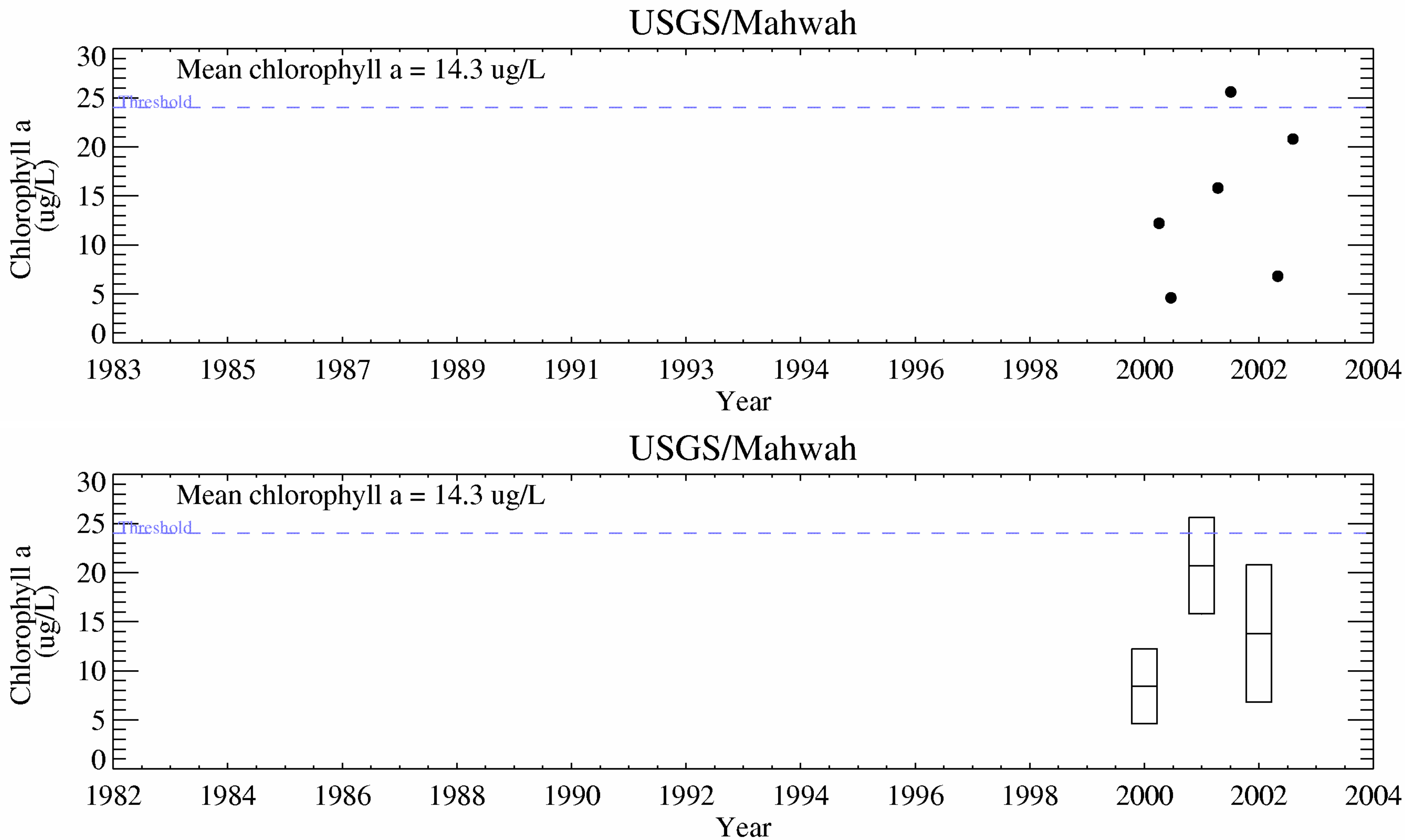

Figure 2-9. Chlorophyll-a concentration at Ramapo River at Mahwah (USGS).
Filled symbols represent samples taken during the growing season (May through September).

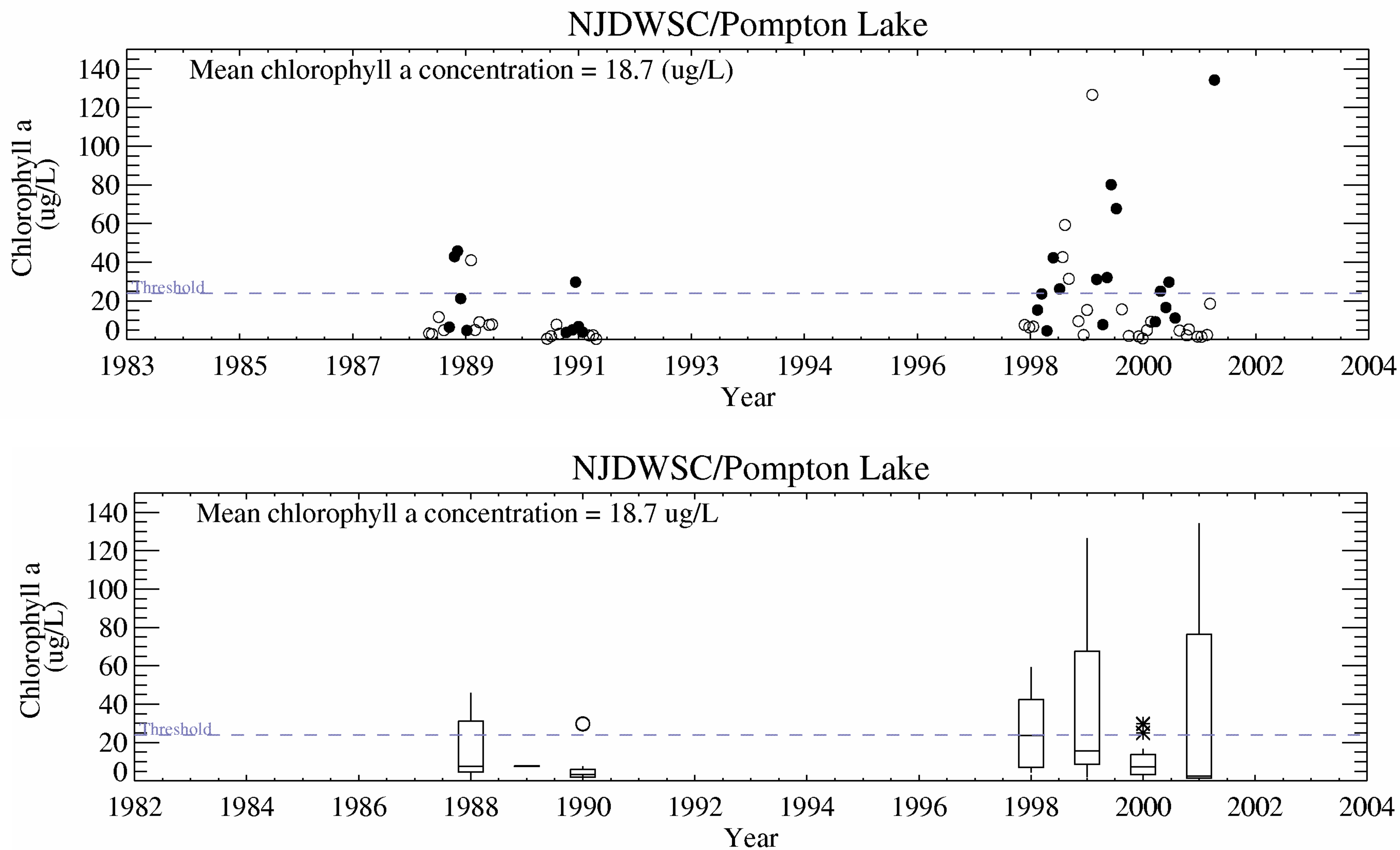

Figure 2-10. Chlorophyll-a concentration at Pompton Lake Dam (NJDWSC).
Filled symbols represent samples taken during the growing season (May through September).

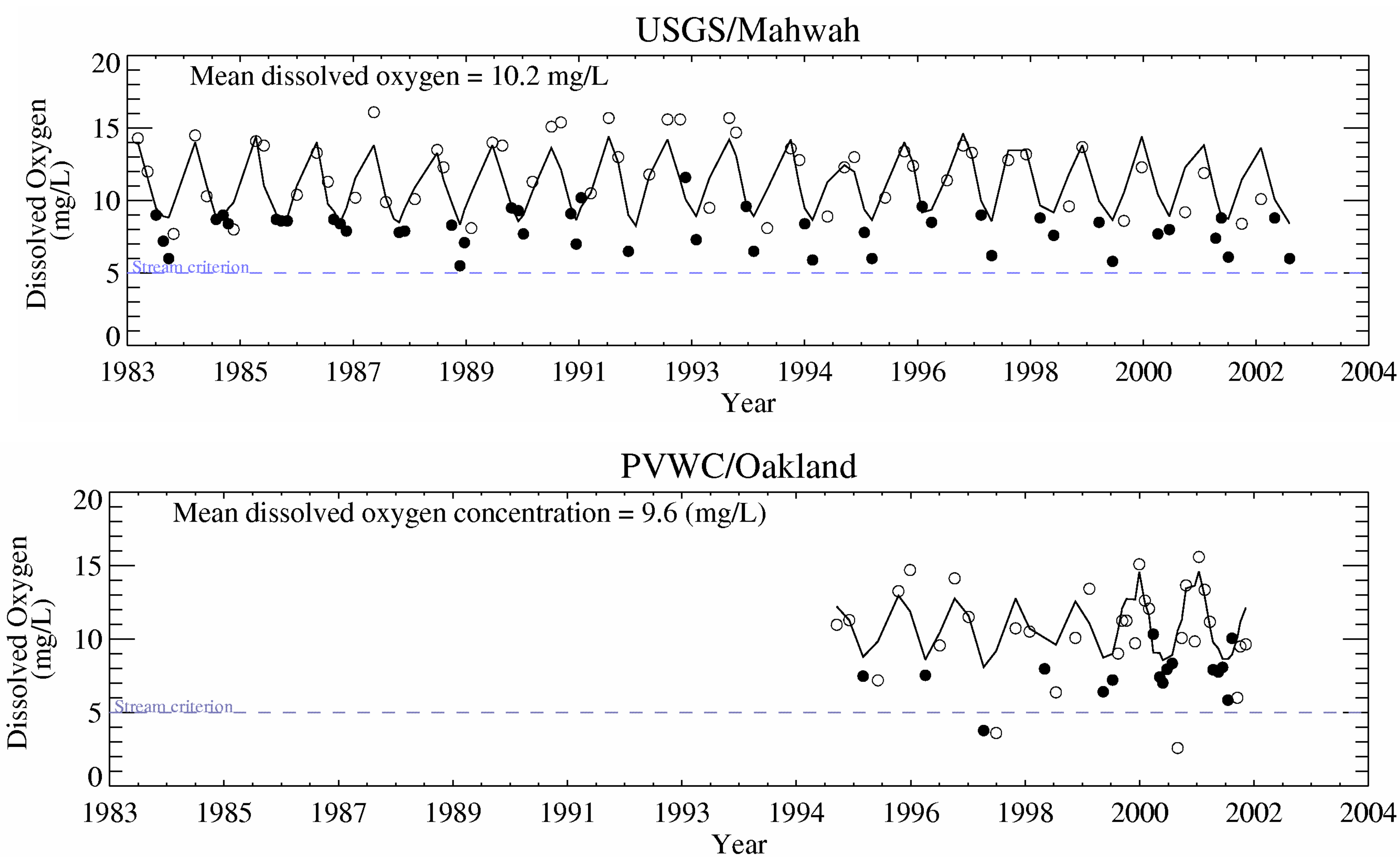

Figure 2-11. Dissolved oxygen concentration time series at two Ramapo River locations above Pompton Lake.
Filled symbols represent samples taken during the growing season (May through September).
Solid line represents calculated D.O. saturation

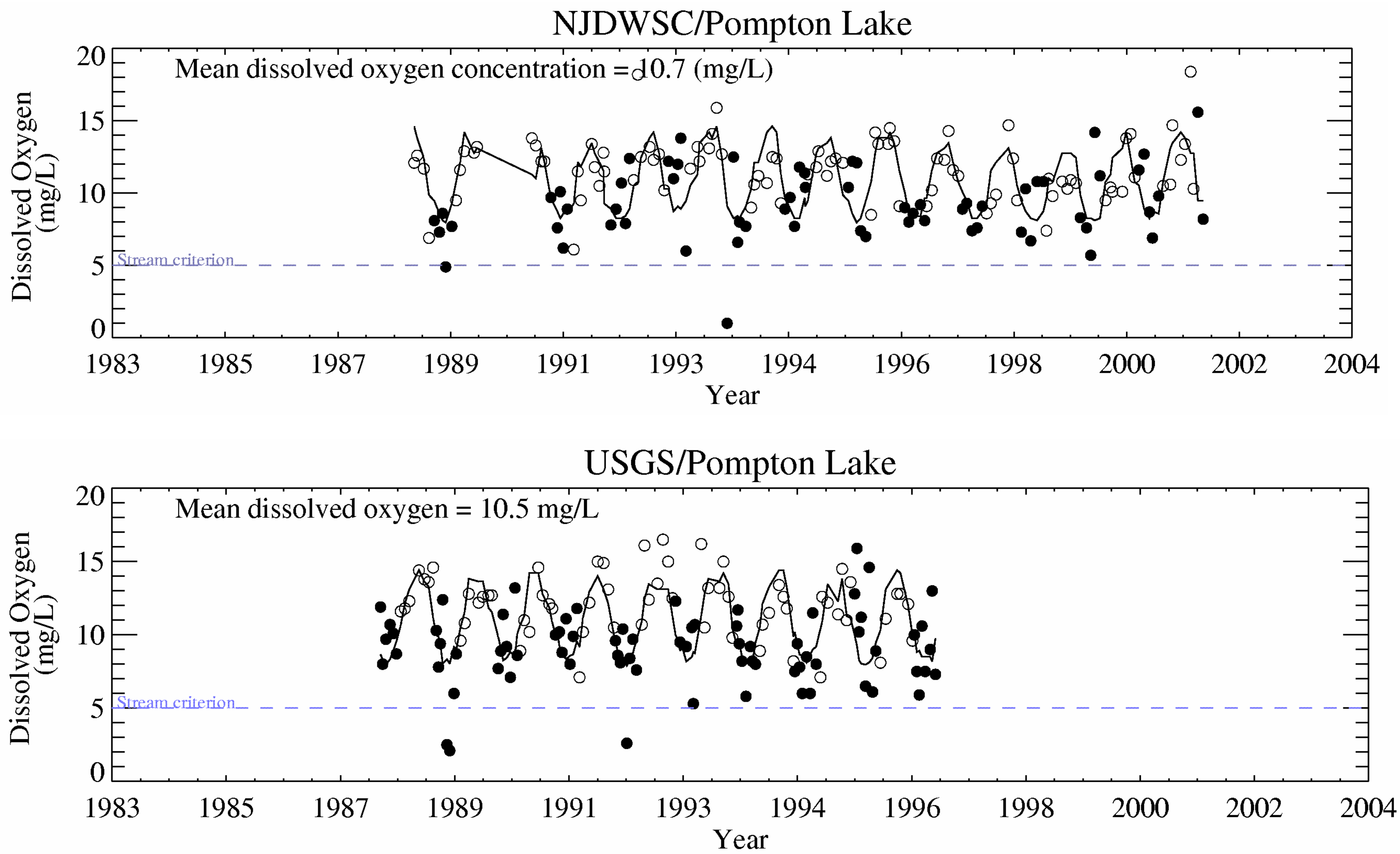

Figure 2-12. Dissolved oxygen concentration time series at Pompton Lake Dam from NJDWSC and USGS.
Filled symbols represent samples taken during the growing season (May through September).
Solid line represents calculated D.O. saturation

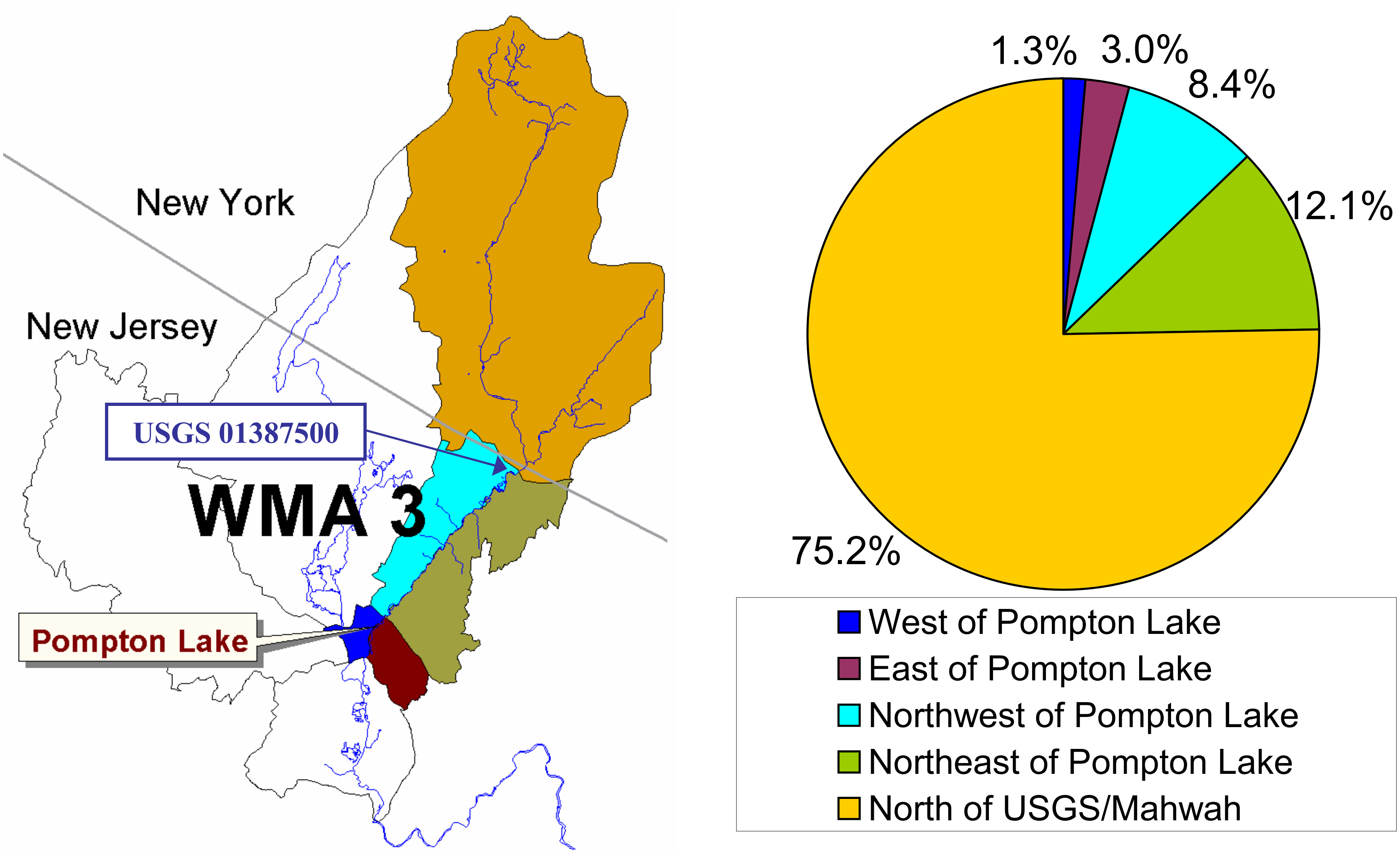

Figure 3-1. Subdivision of Pompton Lake watershed for total phosphorus load analysis.
Percentages of total area are presented on the pie chart

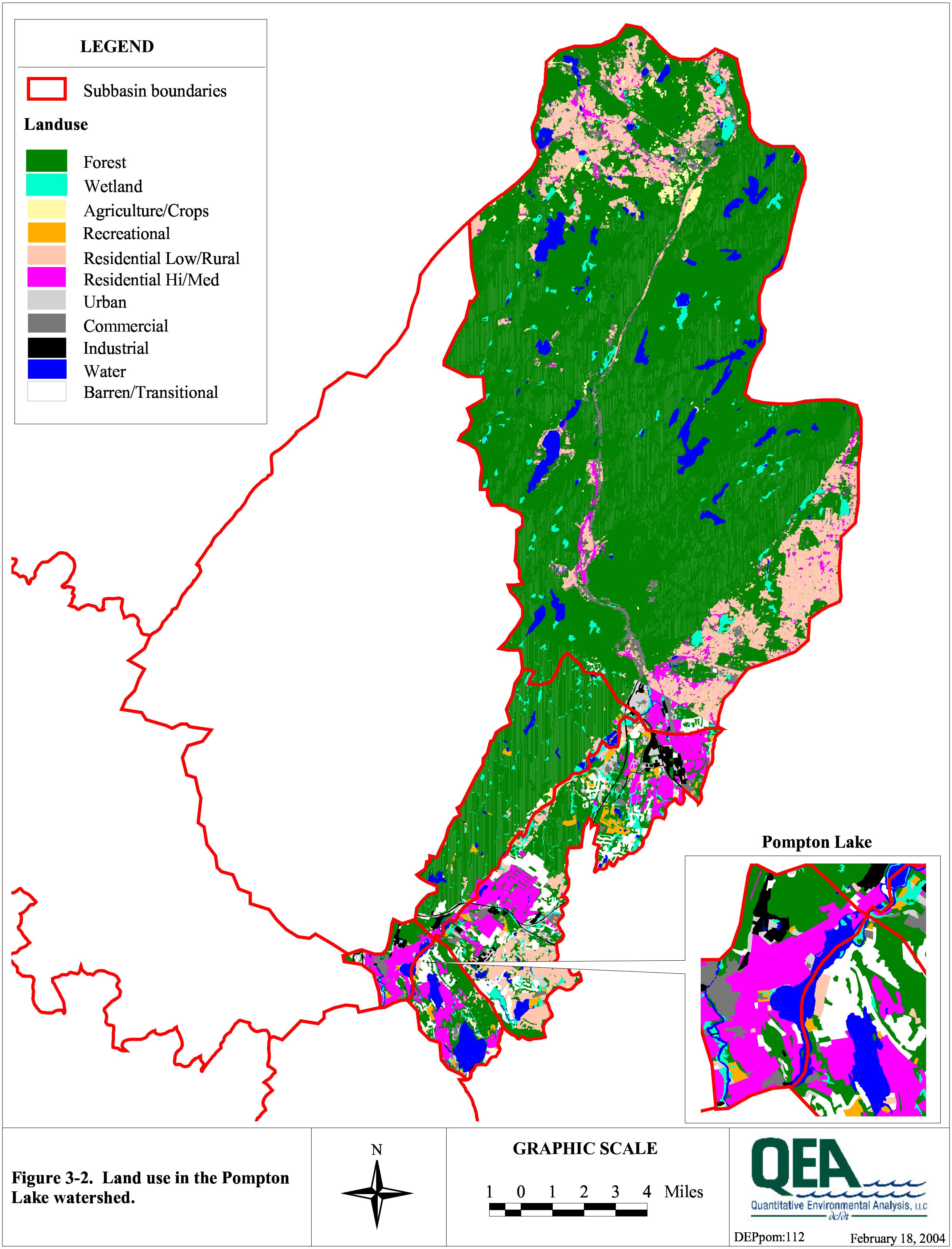

Figure 3-2. Land use in the Pompton Lake watershed.

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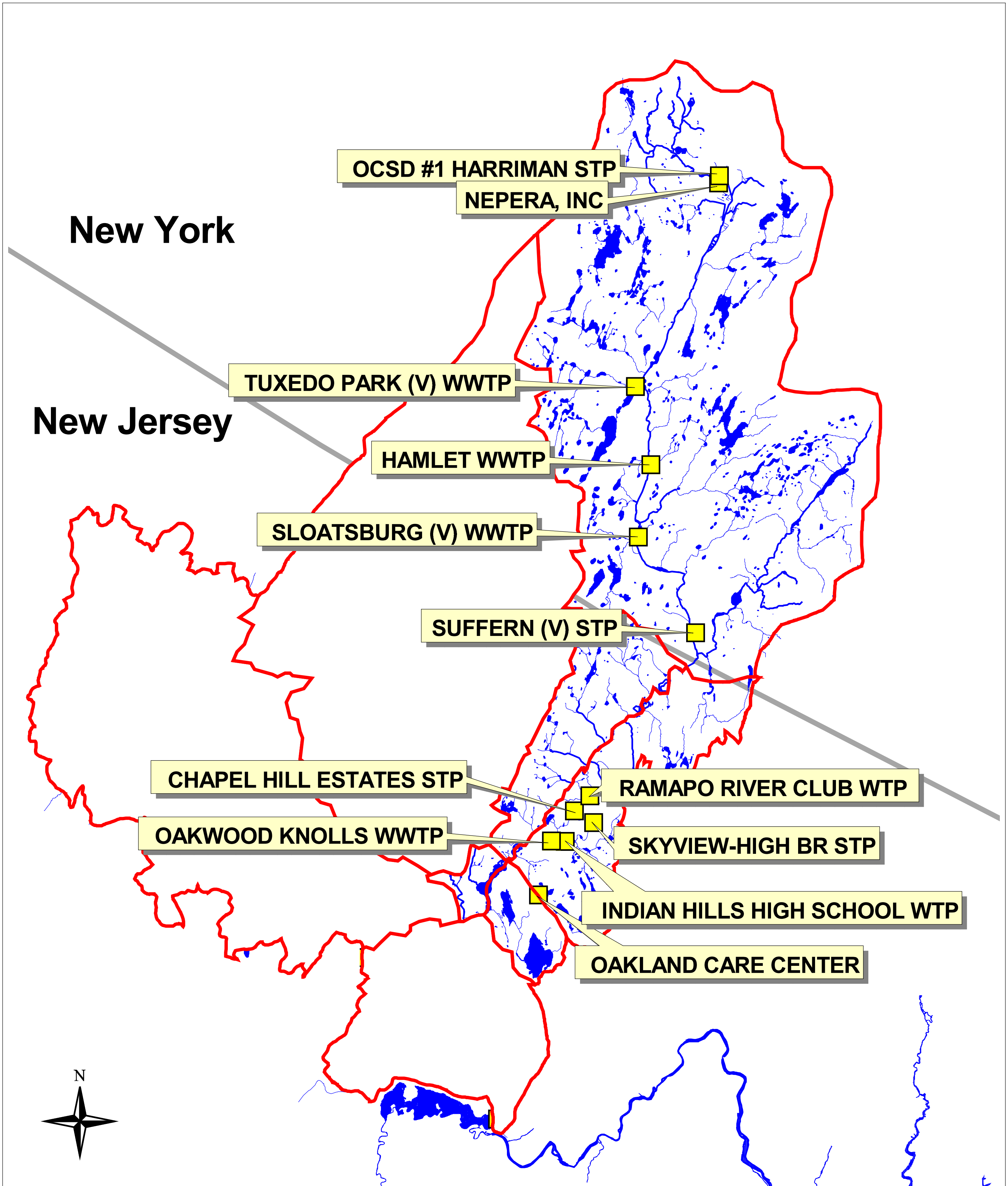

Figure 3-3. Location of major point source discharges in the Pompton Lake watershed.

LEGEND
Point sources
Subdivisions of watershed
Water body
State line

GRAPHIC SCALE
1 0 1 Miles

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Quantitative Environmental Analysis, LLC

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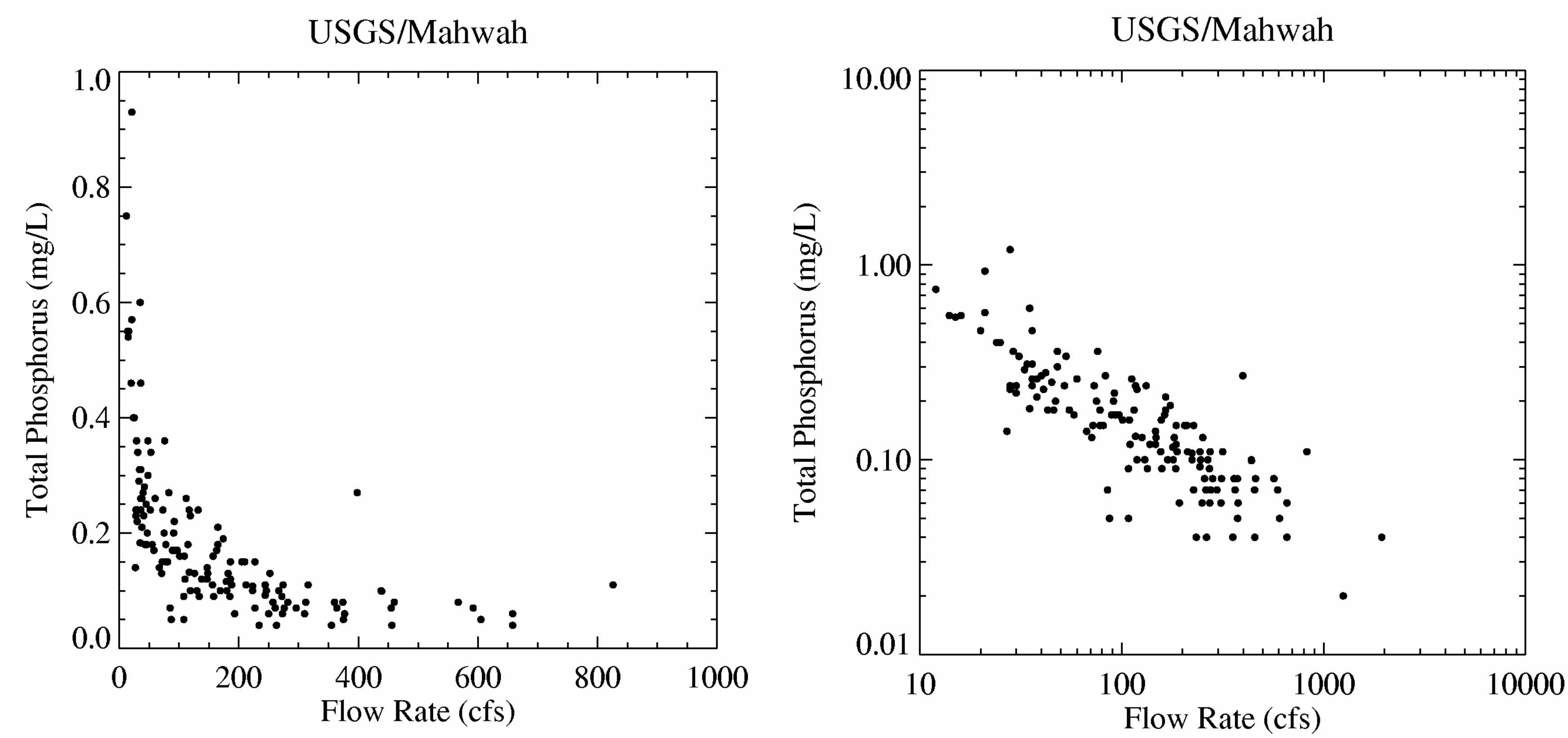

Figure 3-4. Relationship between total phosphorus concentration and flow at Ramapo River at Mahwah.

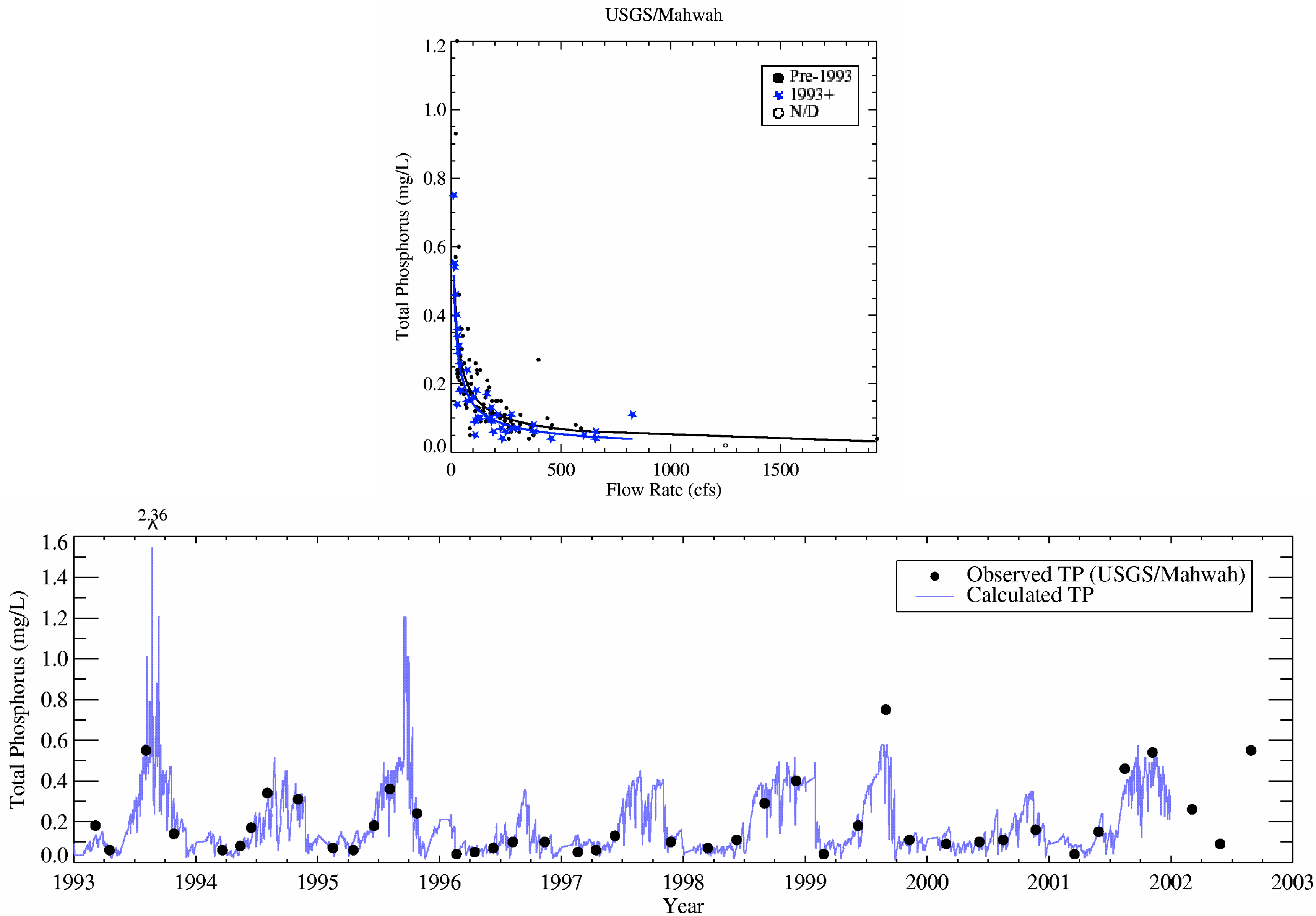

Figure 3-5. Development of loads from total phosphorus concentration and flow data at Ramapo River at Mahwah.

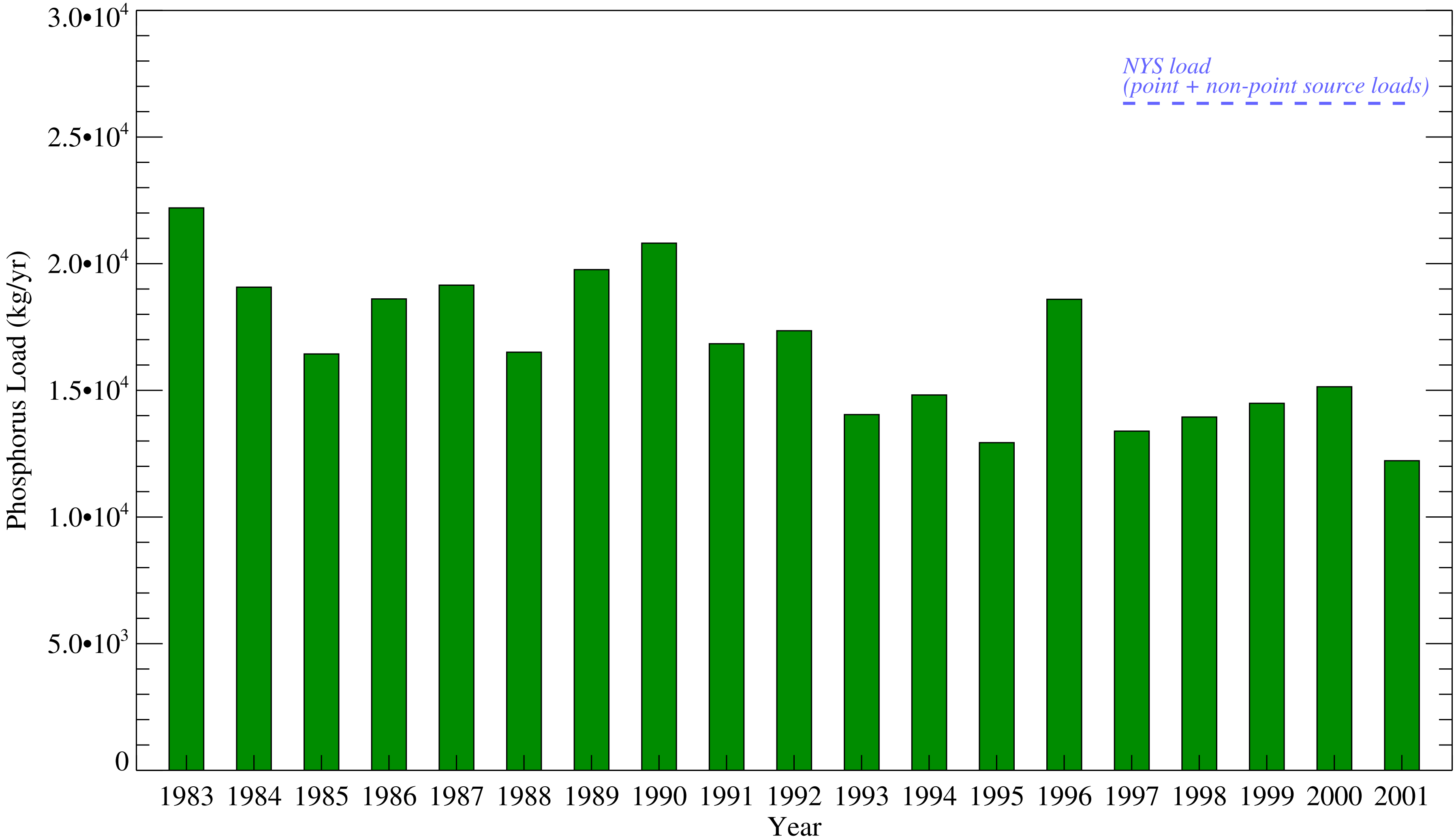

Figure 3-6. Observed annual total phosphorus loads at Ramapo River at Mahwah.

Dashed line represents point sources (1997 - 2002 average) and non-point source loads calculated using the export coefficient method for watershed North of USGS/Mahwah.

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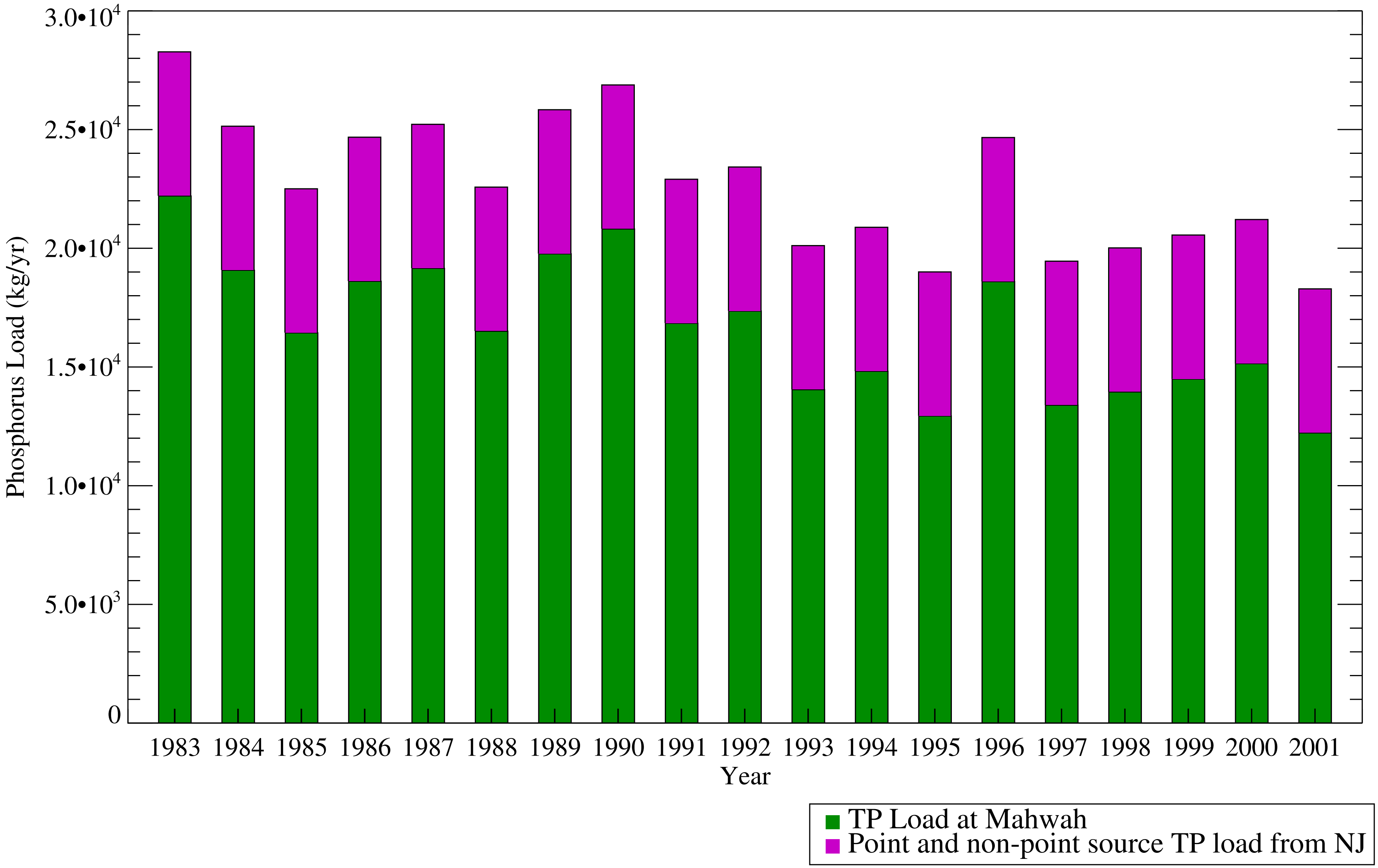

Figure 3-7. Calculated annual total phosphorus loads to Pompton Lake.

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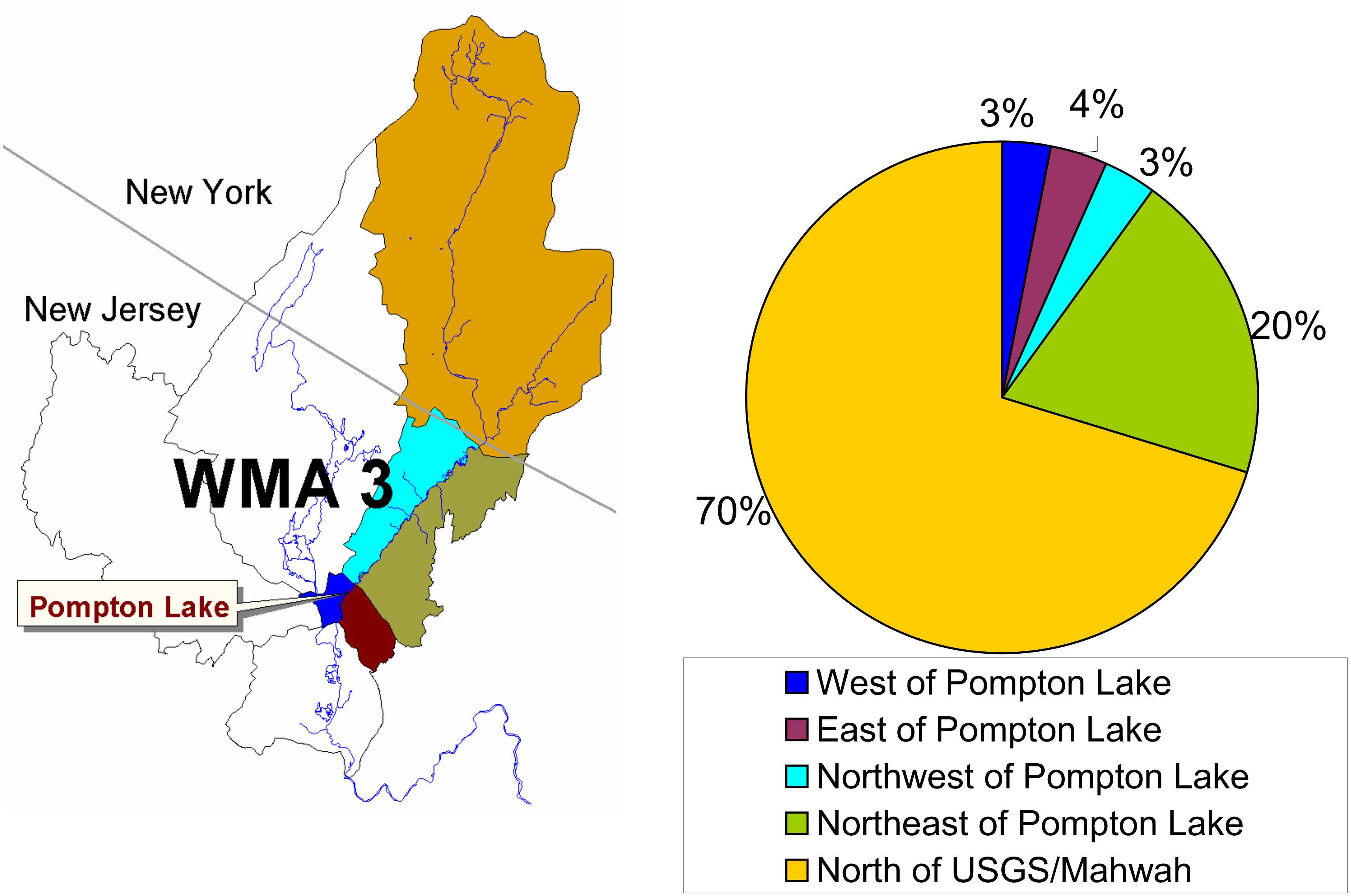

Figure 3-8. Total phosphorus loads by sub-watershed.
Percentages of total load are presented on the pie chart

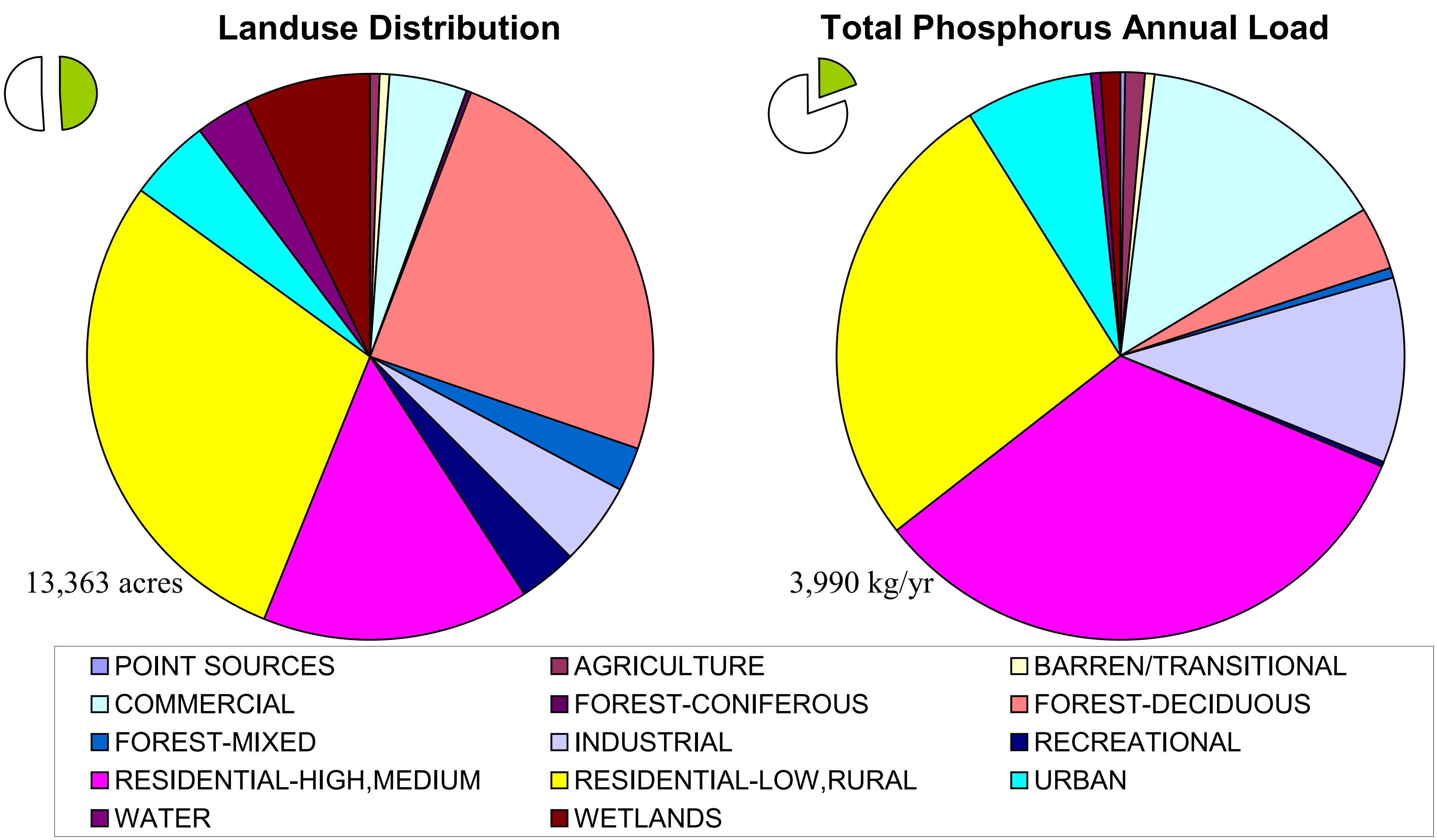

Figure 3-9. Annual total phosphorus loads by land use—Northeast of Pompton Lake.
Legend order, from left to right and top to bottom, corresponds with pie slices clockwise from the top; point sources are indicated in 'Total Phosphorus Annual Load' only when present. Landuse distribution inset pie chart represents proportion of total land area within New Jersey contributed by the sub-basin. The TP load inset pie chart represents proportion of total load to Pompton Lake contributed by the sub-basin. The inset pie-charts are color coordinated with the map on Figure 4-8.

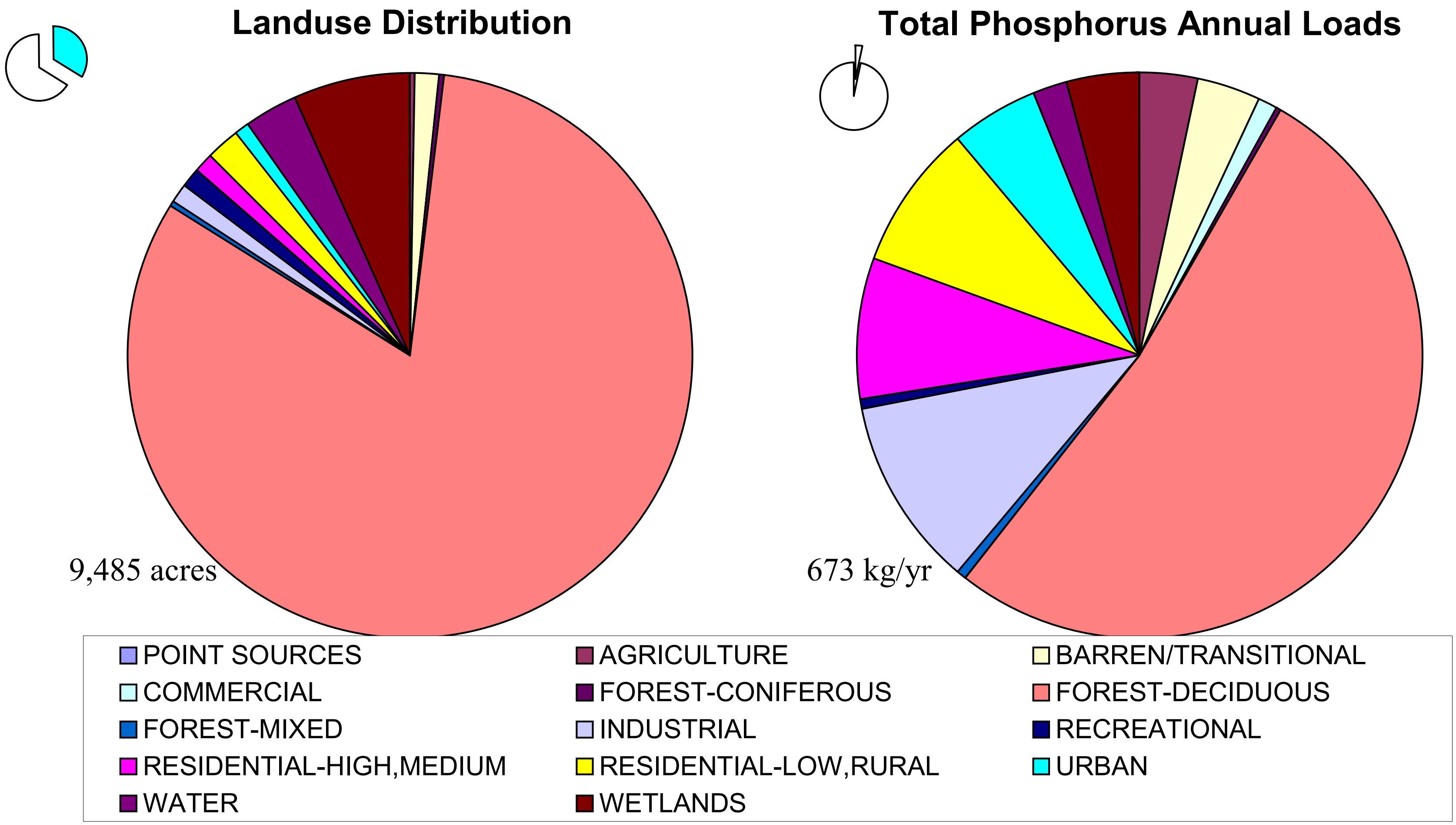

Figure 3-10. Annual total phosphorus loads by land use—Northwest of Pompton Lake.
Legend order, from left to right and top to bottom, corresponds with pie slices clockwise from the top; point sources are indicated in 'Total Phosphorus Annual Load' only when present. Landuse distribution inset pie chart represents proportion of total land area within New Jersey contributed by the sub-basin. The TP load inset pie chart represents proportion of total load to Pompton Lake contributed by the sub-basin. The inset pie-charts are color coordinated with the map on Figure 4-8.

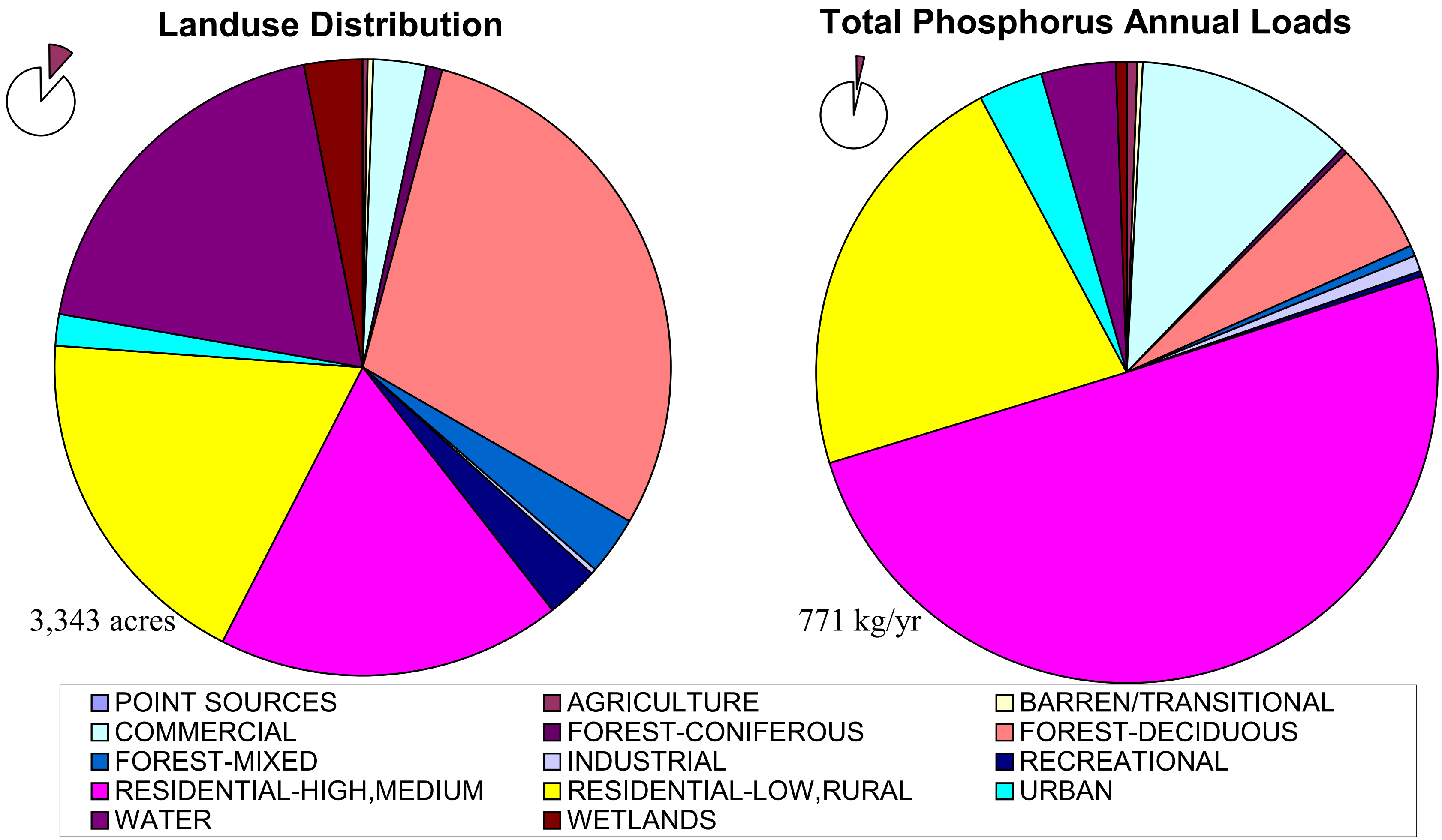

Figure 3-11. Annual total phosphorus loads by land use—East of Pompton Lake.
Legend order, from left to right and top to bottom, corresponds with pie slices clockwise from the top; point sources are indicated in 'Total Phosphorus Annual Load' only when present. Landuse distribution inset pie chart represents proportion of total land area within New Jersey contributed by the sub-basin. The TP load inset pie chart represents proportion of total load to Pompton Lake contributed by the sub-basin. The inset pie-charts are color coordinated with the map on Figure 4-8.

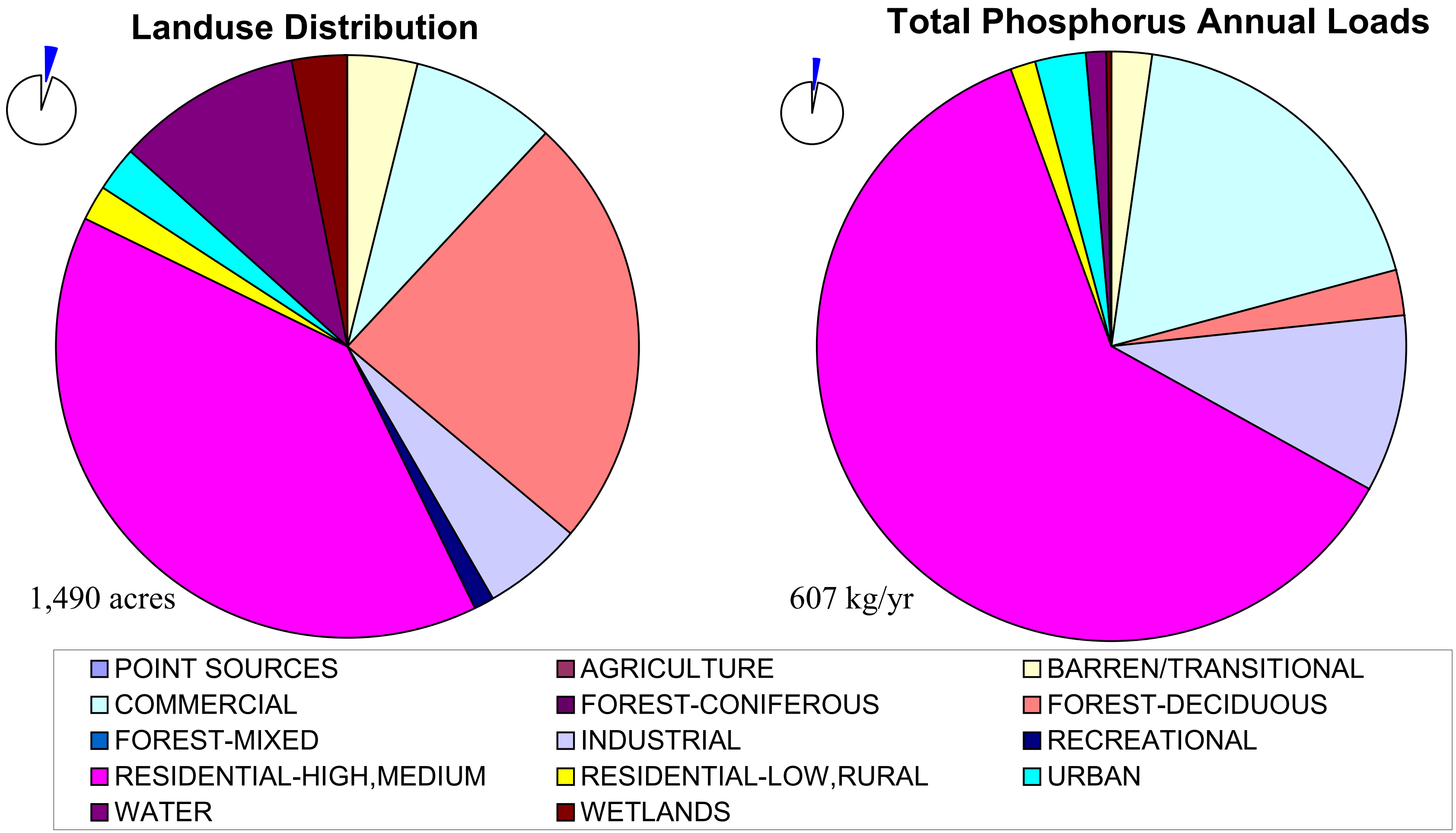

Figure 3-12. Annual total phosphorus loads by land use—West of Pompton Lake.
Legend order, from left to right and top to bottom, corresponds with pie slices clockwise from the top; point sources are indicated in 'Total Phosphorus Annual Load' only when present. Landuse distribution inset pie chart represents proportion of total land area within New Jersey contributed by the sub-basin. The TP load inset pie chart represents proportion of total load to Pompton Lake contributed by the sub-basin. The inset pie-charts are color coordinated with the map on Figure 4-8.

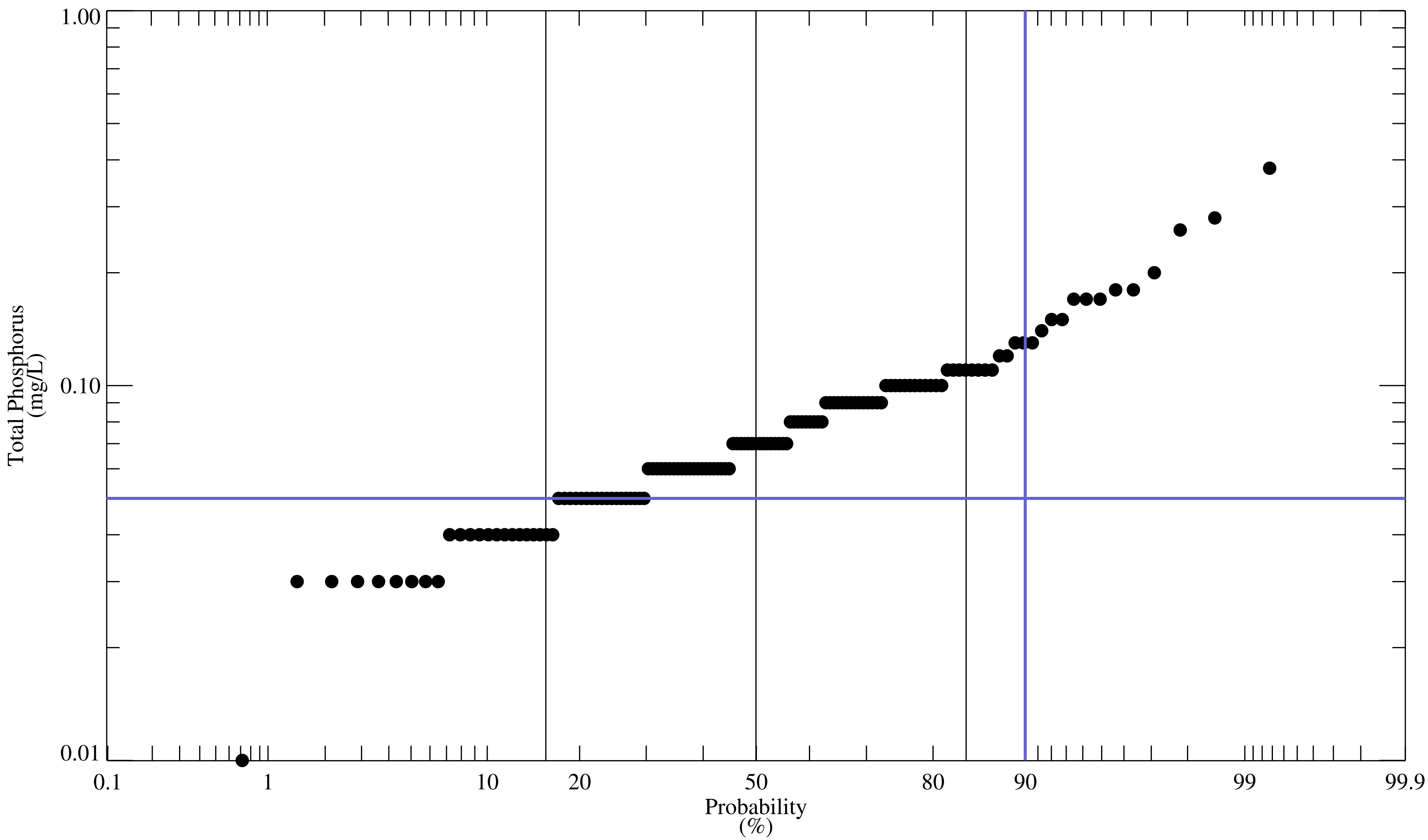

Figure 4-1. Evaluation of lake total phosphorus concentrations for estimating required load reduction.

Data Source: USGS (1987-1996)

Horizontal blue line represents total phosphorus lake standard of 0.05 mg/l. Vertical blue line represents the 90th percentile.

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Fri Jul 01 16:07:19 2005

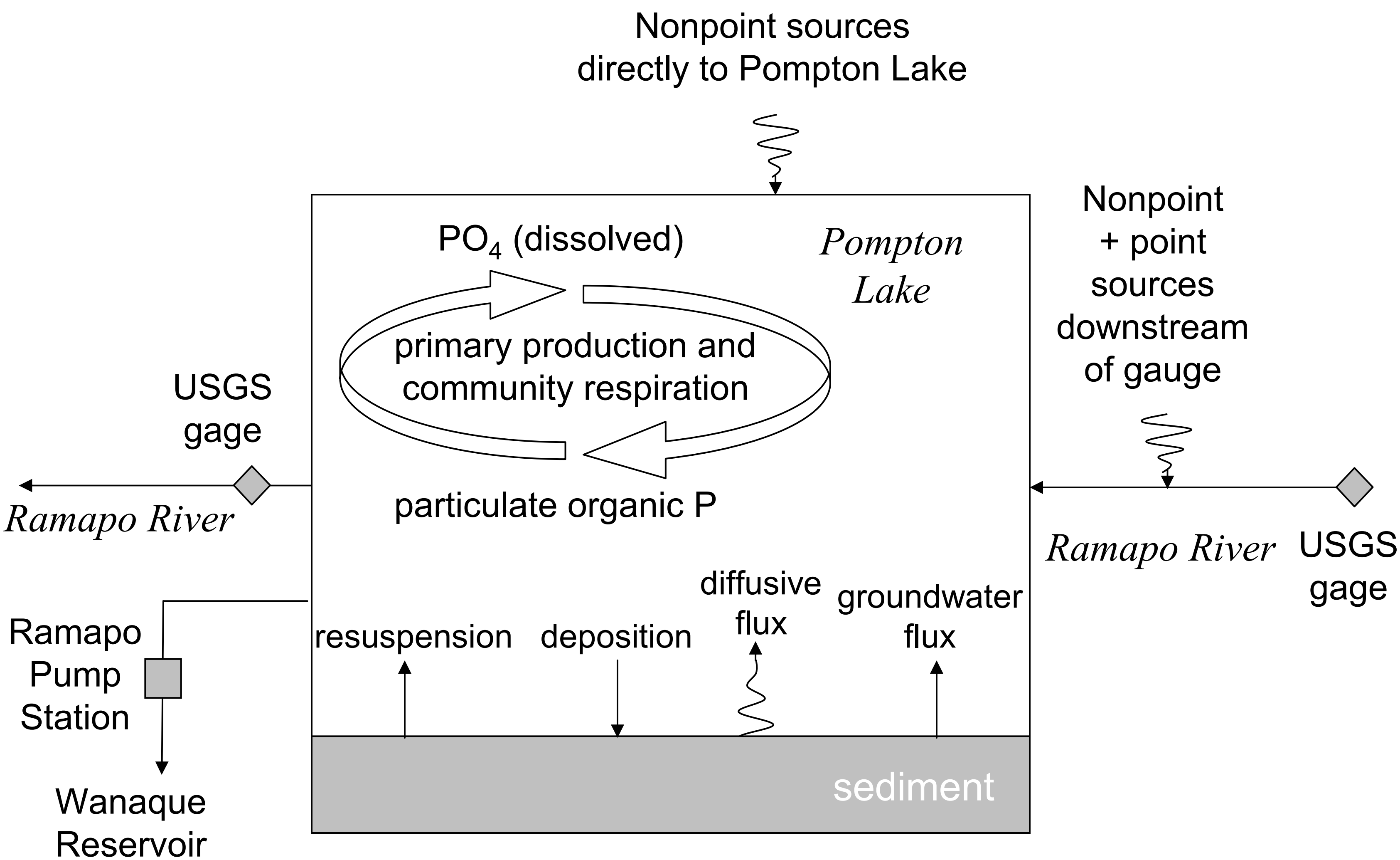


Figure 5-1. Conceptual model of lake phosphorus fate and transport.

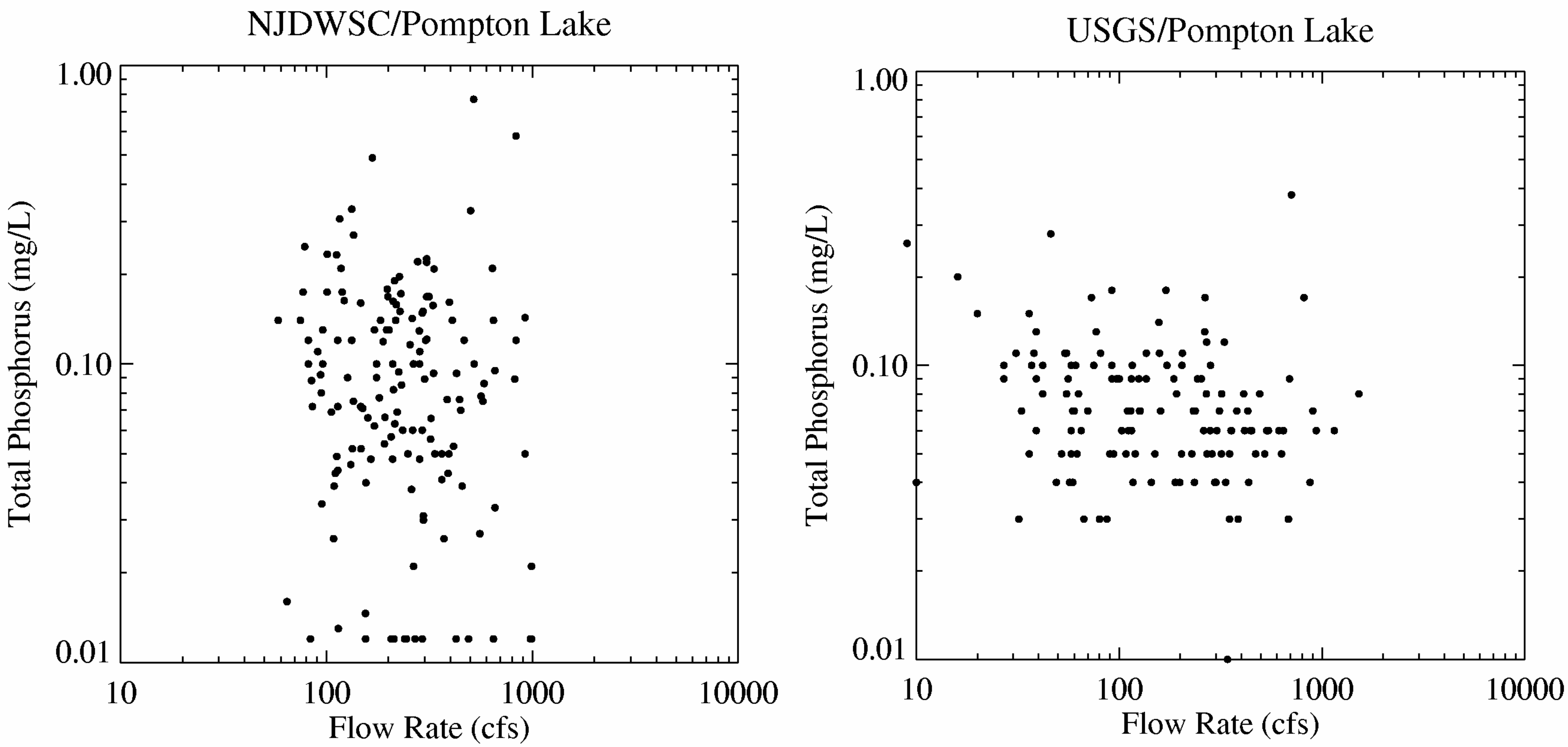


Figure 5-2. Relationship between total phosphorus concentration and flow at Pompton Lake Dam.

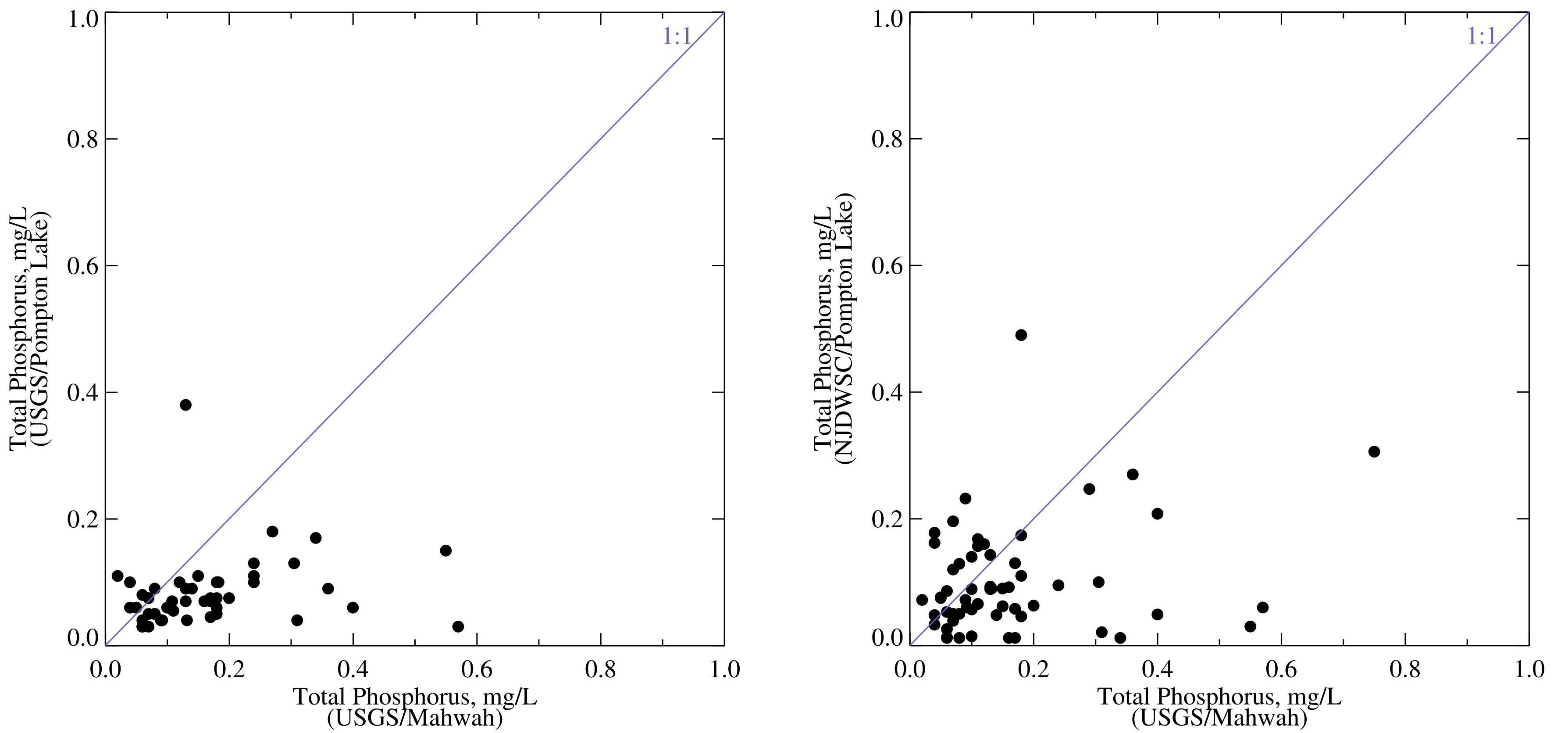


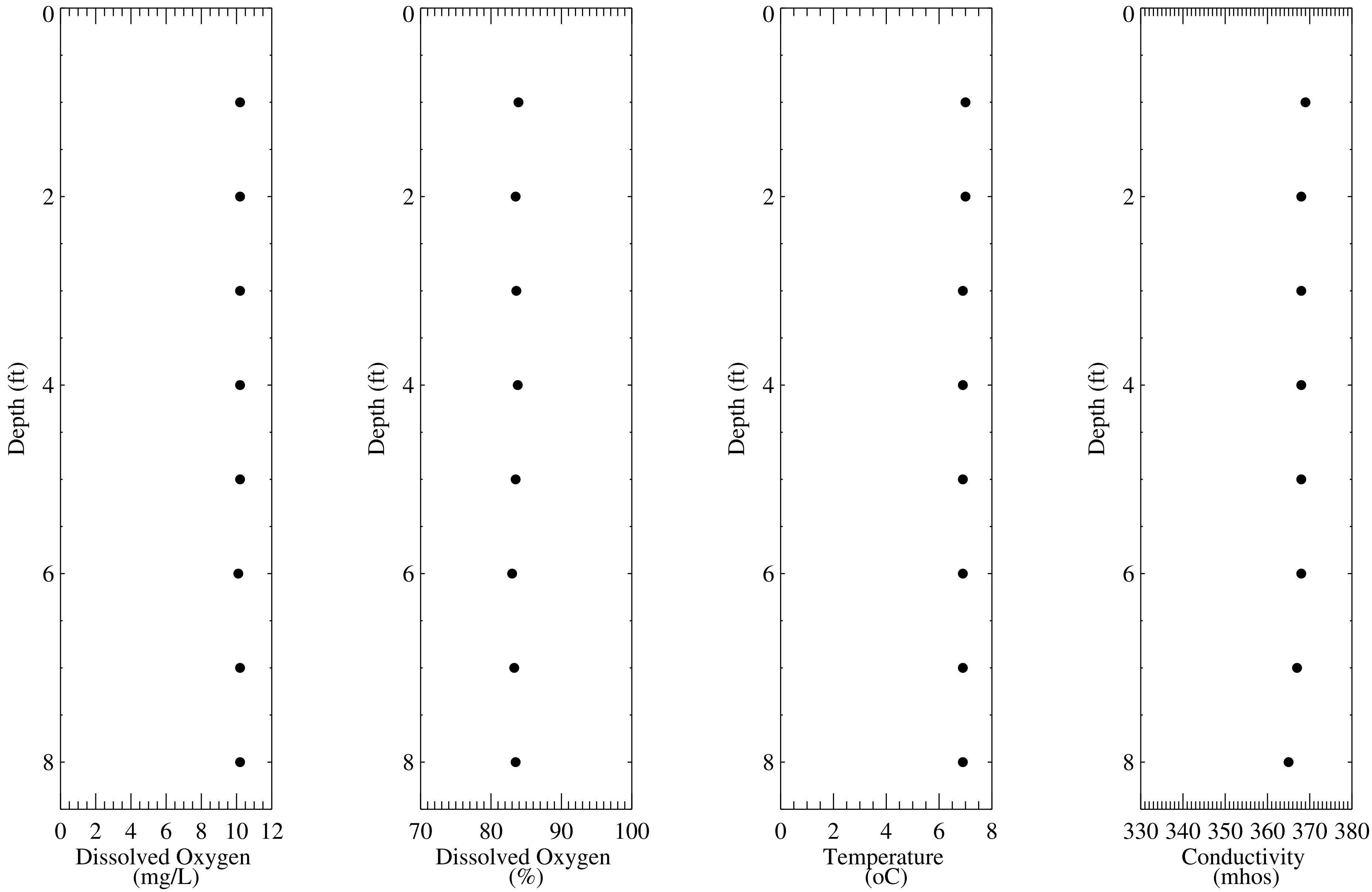
Figure 5-3. Comparison of total phosphorus concentrations from two downstream stations with total phosphorus concentrations from USGS gage at Mahwah.

Data Sources: NJDWSC and USGS

Monthly averages of total phosphorus were used to match concentrations from each station.

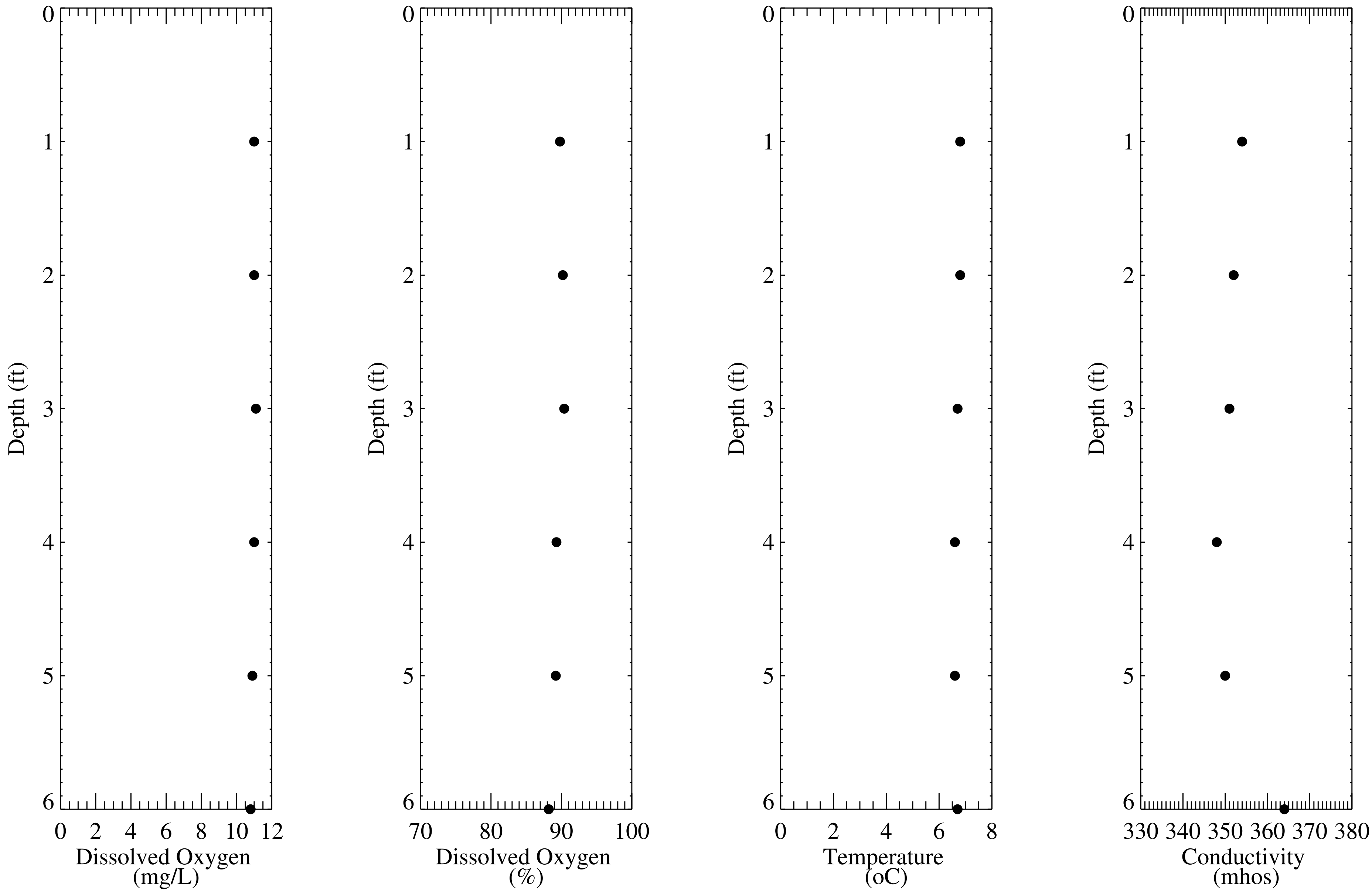
DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Cross-Plots\PVSC_NJDWSC_USGS_CrossPlots_20040102.pro
Thu Feb 19 14:35:04 2004

APPENDIX A-1. VERTICAL PROFILES OF DO CONCENTRATION AND PERCENT SATURATION, AND OF TEMPERATURE AND CONDUCTIVITY AT THREE LOCATIONS IN POMPTON LAKE, NOVEMBER 18, 2003.



Water column profiles for A2 sampling station in Pompton Lake.

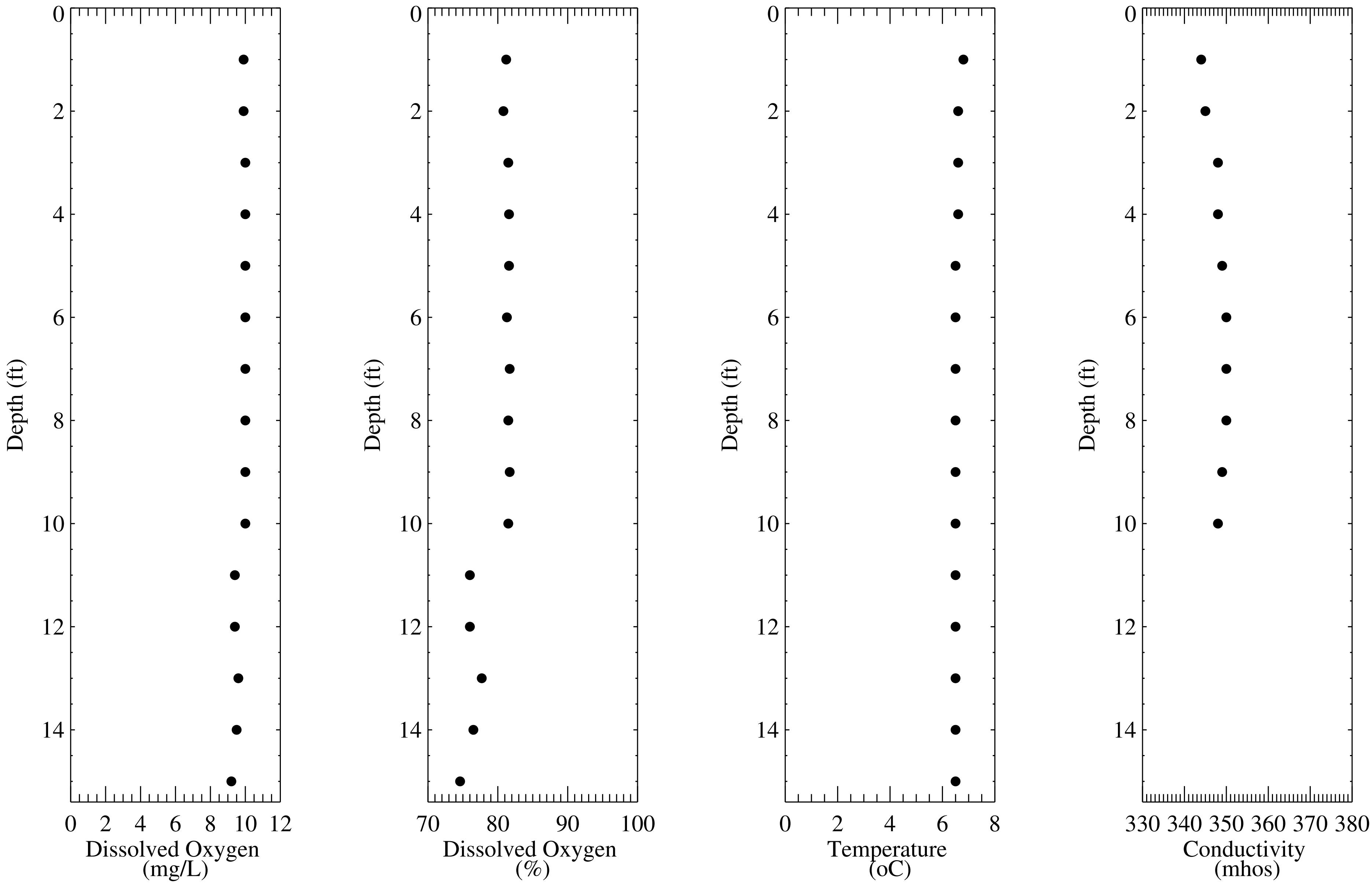
Data Sources: QEA/NJDEP (November 18, 2003 Sampling Effort)



Water column profiles for B3 sampling station in Pompton Lake.

Data Sources: QEA/NJDEP (November 18, 2003 Sampling Effort)

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:25 2004

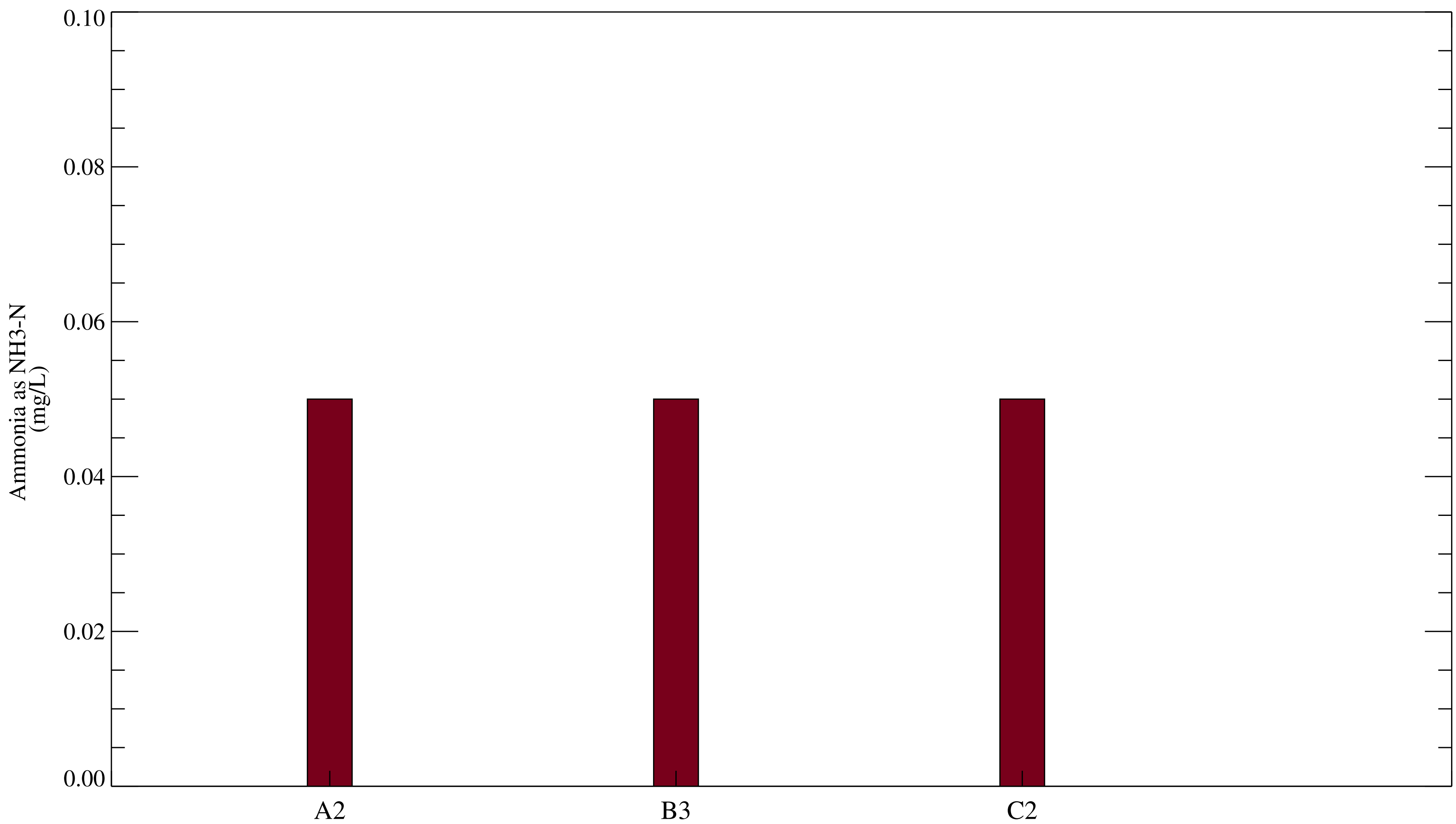


Water column profiles for C2 sampling station in Pompton Lake.

Data Sources: QEA/NJDEP (November 18, 2003 Sampling Effort)

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:25 2004

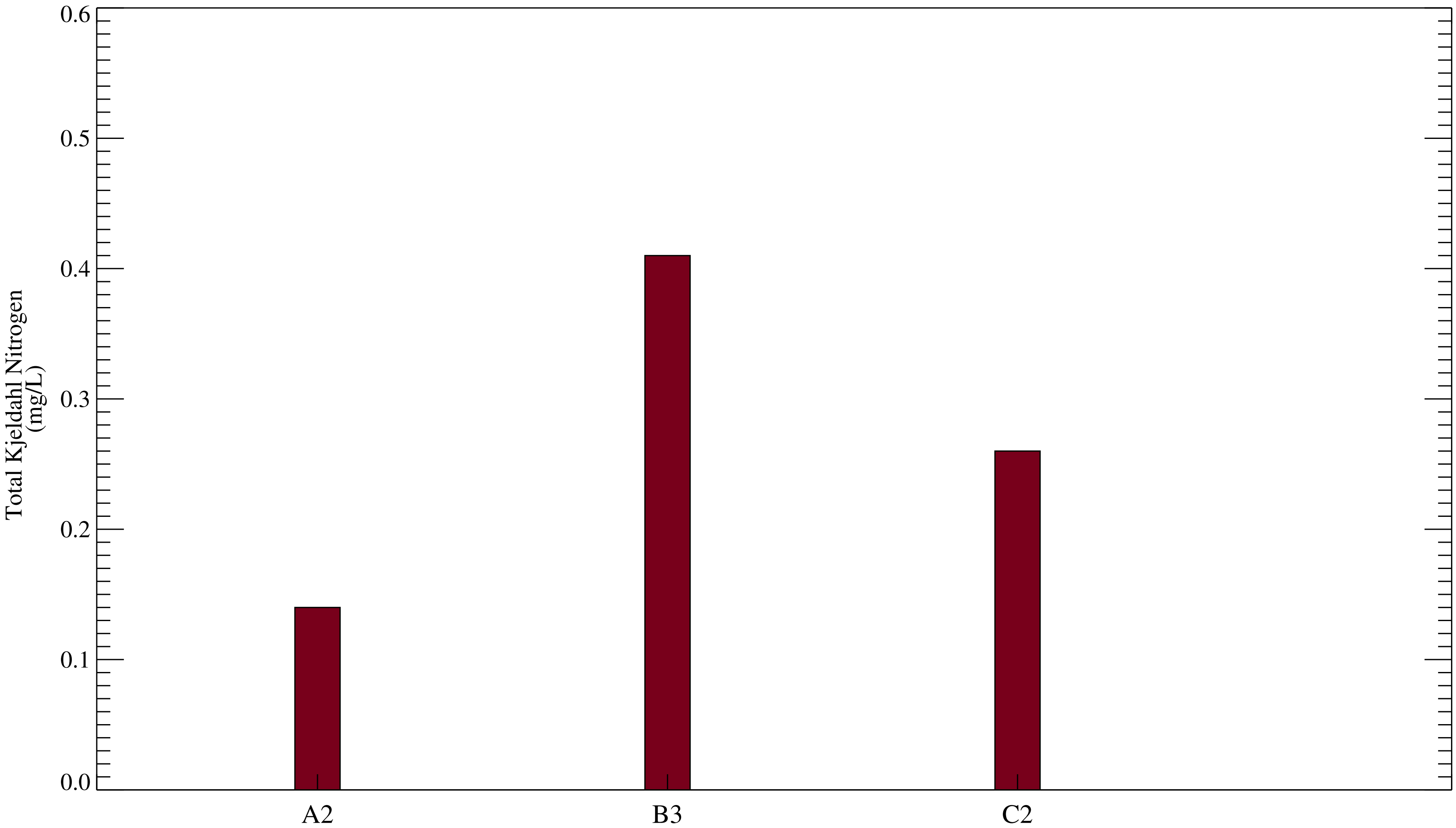
APPENDIX A-2. CHLOROPHYLL-A AND NUTRIENT CONCENTRATIONS AT THREE LOCATIONS IN POMPTON LAKE, NOVEMBER 18, 2003



Ammonia concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP
Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

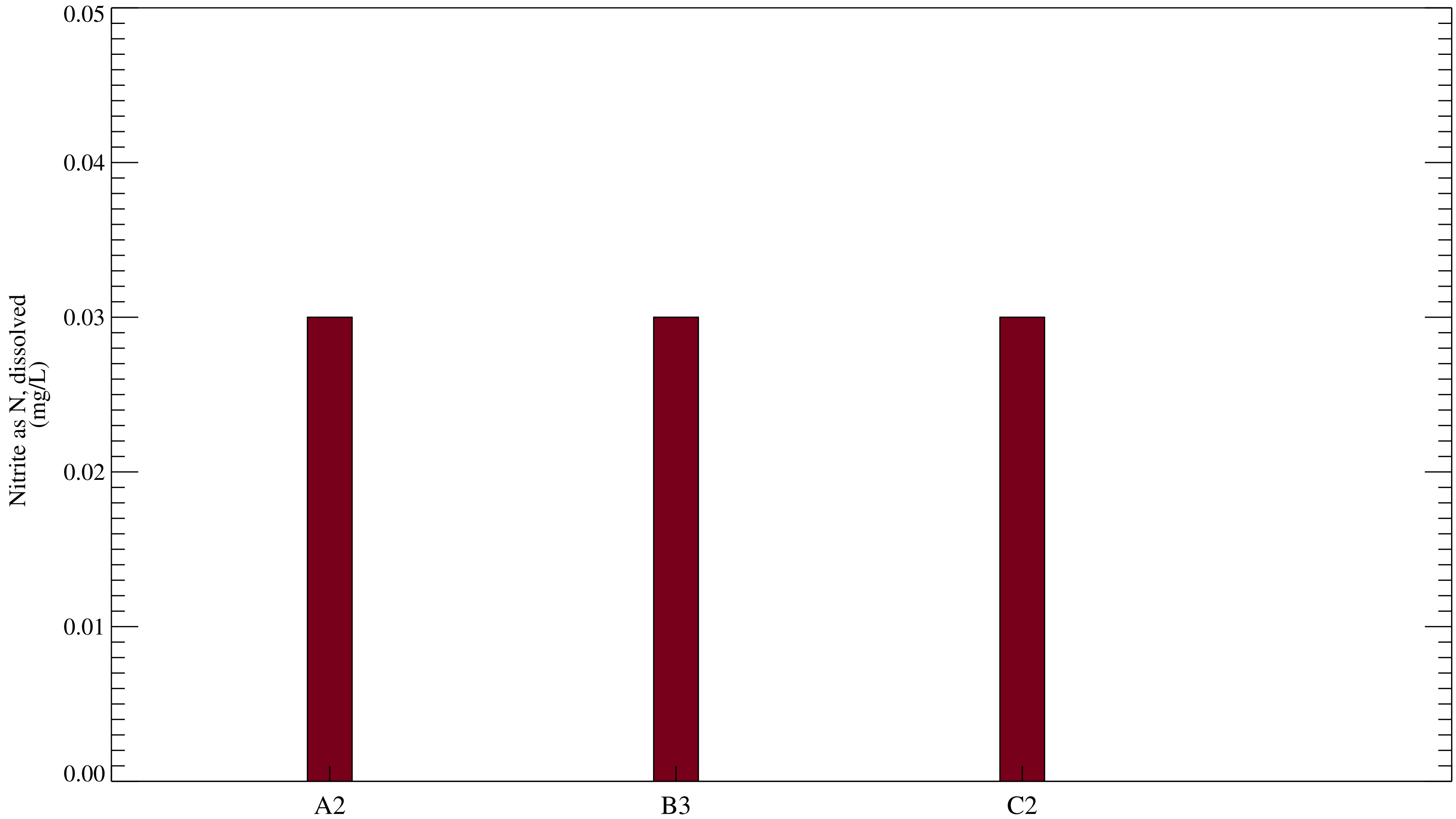
DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:21 2004



Total kjeldahl nitrogen concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP
Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:21 2004

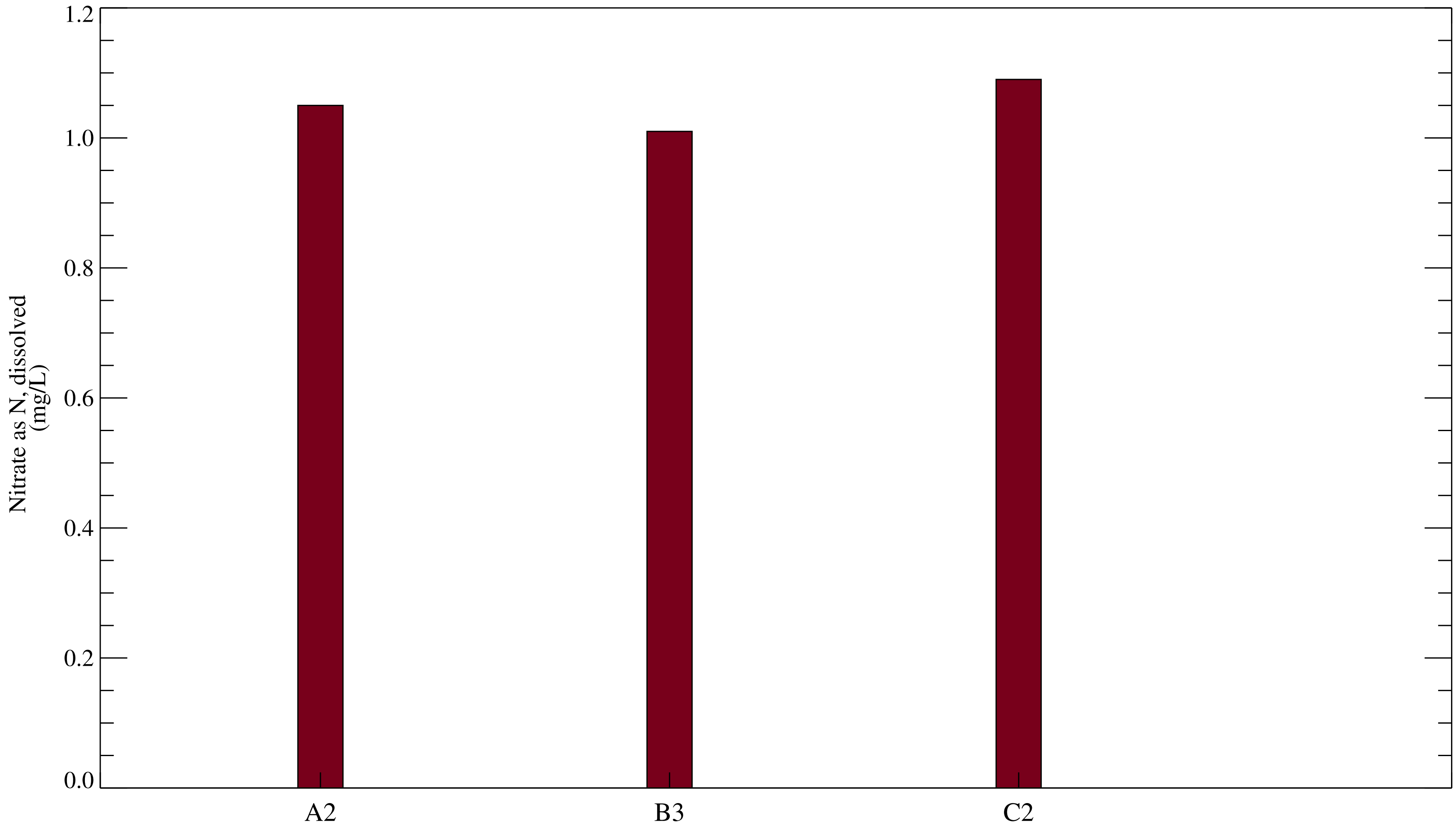


Dissolved nitrite concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP

Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:21 2004

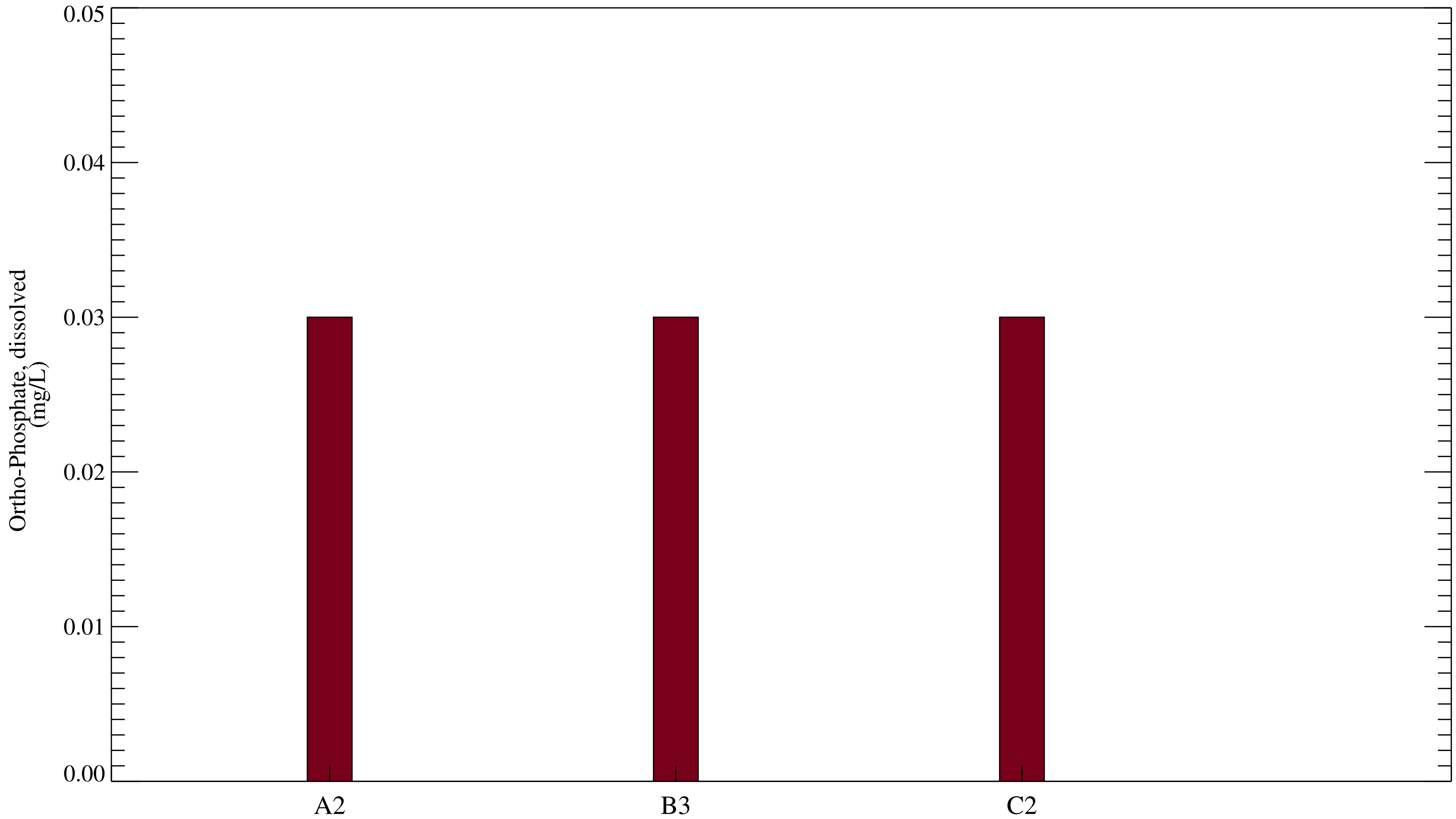


Dissolved nitrate concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP

Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

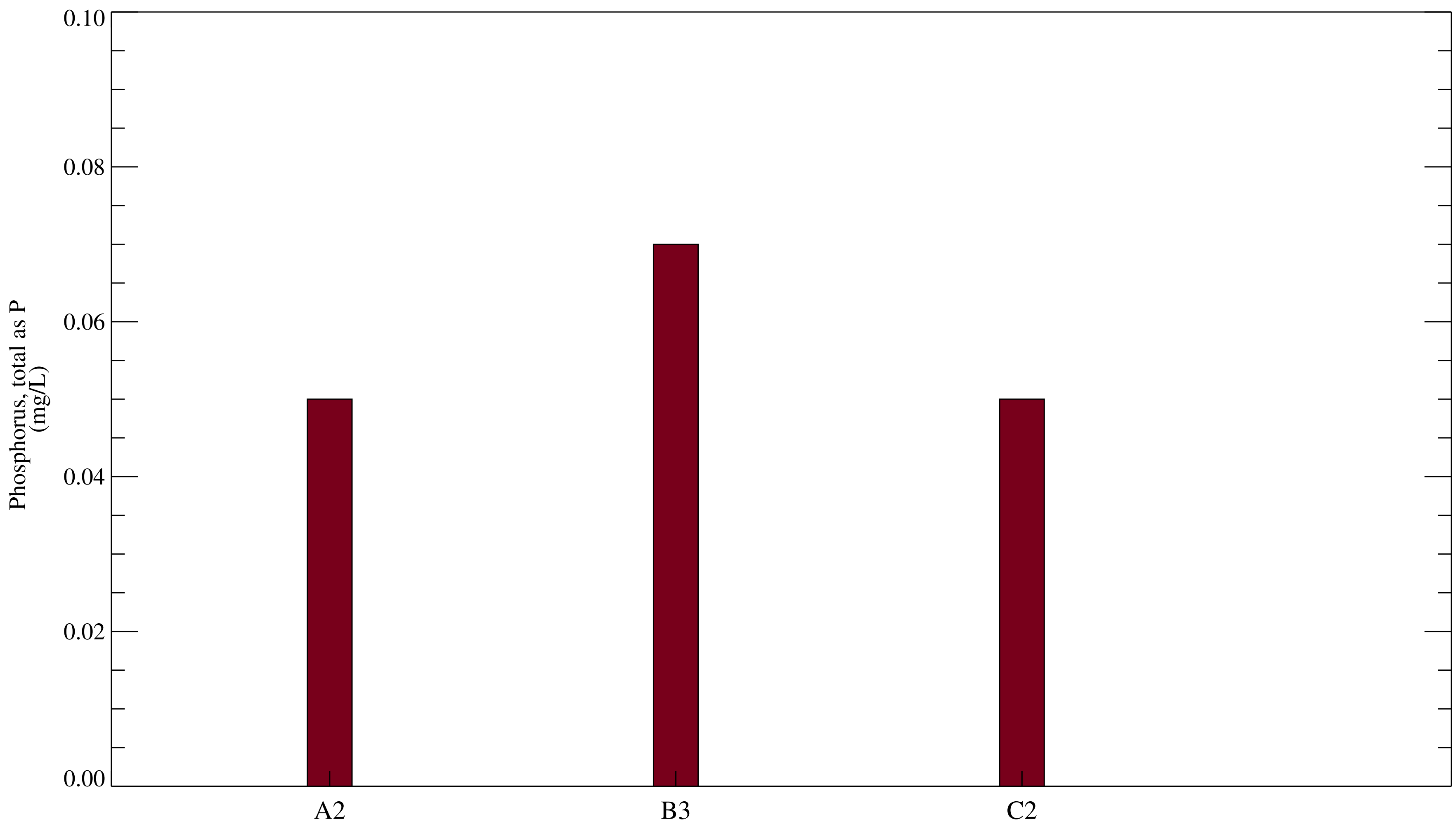
DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:22 2004



Ortho-Phosphate concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP
Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:22 2004

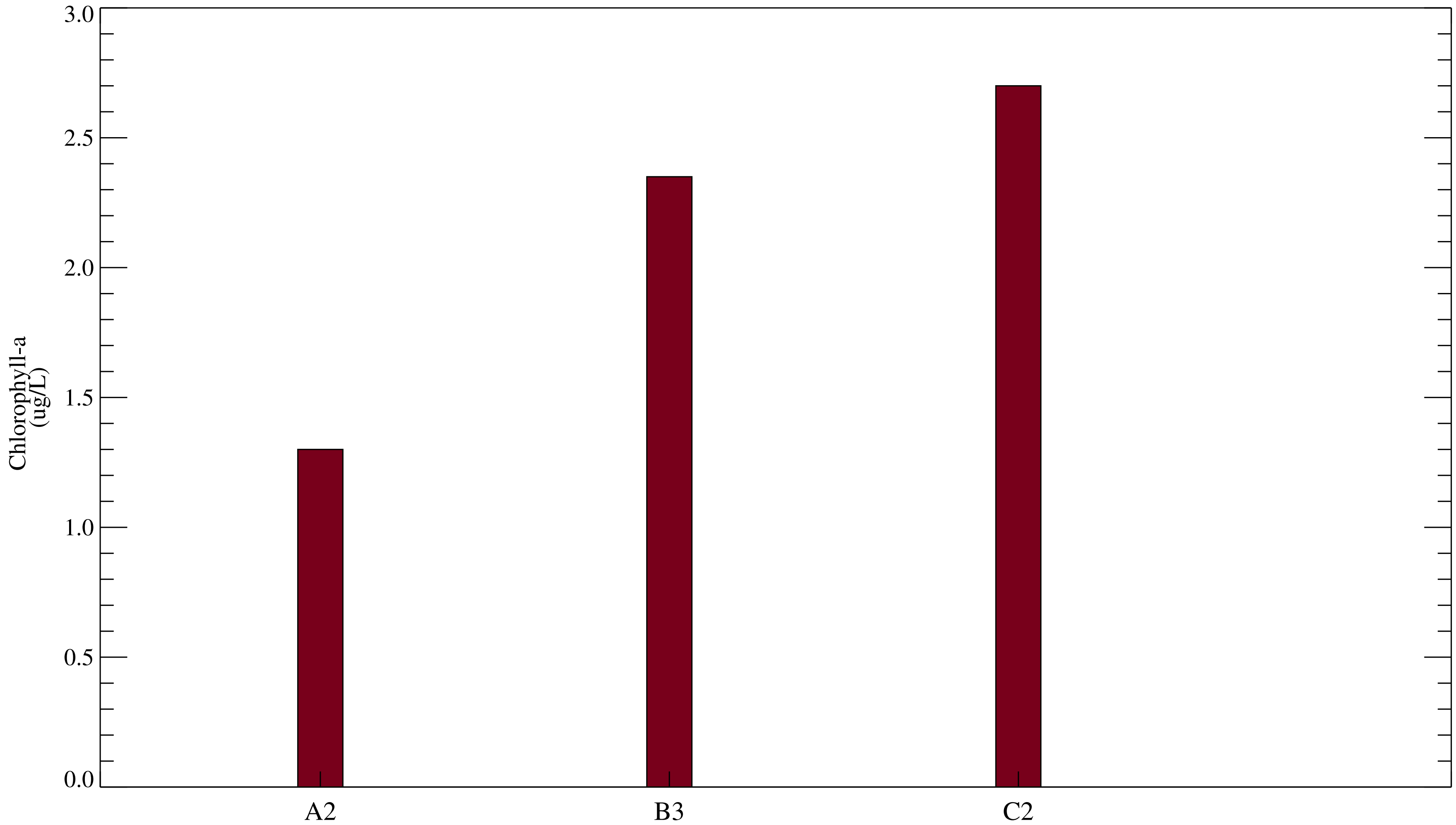


Total phosphorus concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP

Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.

DR - \\Mark\d_drive\Jobs\DEPpom\Analysis\Data_Analysis\Pompton_Sampling\Pompton_Lake_2003_Sampling_Effort_20031224.pro
Thu Feb 19 15:37:22 2004



Chlorophyll-a concentrations in Pompton Lake (November 18, 2003 Sampling Effort).

Data Sources: QEA/NJDEP
Measurements below detection limit were set to detection limit.
Values from duplicate samples were averaged with the sample value.