2010 FINAL REPORT

Lake Wallenpaupack
Water Quality Monitoring Program

January 12, 2012

Prepared for:

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ACKNOWLEDGEMENTS

Aqua Link would like to extend its appreciation to the Directors of the Lake Wallenpaupack Watershed Management District (LWWMD) and their organizations for their strong commitment and dedication in protecting and improving the water quality of Lake Wallenpaupack and all of its tributaries throughout Pike, Wayne, Lackawanna and Monroe Counties. Special thanks are extended to Mr. Nick Spinelli, LWWMD Executive Director, for all of his assistance throughout the duration of this project.

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EXECUTIVE SUMMARY

Lake Wallenpaupack, a 5,700-acre reservoir, is an extremely valuable multi-recreational and economic resource for Northeastern Pennsylvania. The lake is nestled within the Pocono Mountains in Pike and Wayne Counties. Lake Wallenpaupack is used extensively for a wide variety of water-related activities including swimming, fishing, boating, water skiing, and snowmobiling.

Over the years, the water quality of Lake Wallenpaupack has been routinely monitored since 1980. In 2010, the Lake Wallenpaupack Watershed Management District retained Aqua Link to analyze the 2010 lake water quality data and prepare the 2010 annual report. As part of this report, Aqua Link also compared the 2010 data to the historical data collected from 1980 through 2009 to determine whether lake water quality has improved or degraded over the past 31 years.

Lake Wallenpaupack was classified as a slightly eutrophic reservoir in 2010. The mean Carlson TSI values for total phosphorus, chlorophyll-a, and Secchi disk transparency were 52, 56, and 50, respectively, for 2010. The lake was thermally stratified from May through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified. Phytoplankton data indicate that blue-green algae (Cyanophyta) were dominant during the growing season. The most common genera were *Aphanizomenon* and *Anabaena*.

Based upon trend analysis, the water quality of Lake Wallenpaupack has generally improved since 1980. Total phosphorus concentrations in surface and bottom waters and Secchi transparency (water clarity) have gradually improved. Total nitrogen concentrations in surface and bottom waters marginally increased along with chlorophyll-a concentrations and phytoplankton biomass.

Over the past 31 years, water clarity (Secchi transparency) improved although chlorophyll-a and phytoplankton biomass have slightly increased. This appears to be related to a shift in the phytoplankton community, where blue-green algal dominance is less prevalent. The shift in the phytoplankton community may be attributed to decreases in total phosphorus and increases in total nitrogen in the lake. In general, higher nitrogen to phosphorus concentration ratios in lakes often favor green (Chlorophyta) over blue-green (Cyanophyta) algae resulting in more species diversity and improved water clarity and aesthetics.

1. Introduction

Lake Wallenpaupack, a 5,700-acre reservoir, is an extremely valuable multi-recreational and economic resource for Northeastern Pennsylvania. The lake is nestled within the Pocono Mountains in Pike and Wayne Counties. Lake Wallenpaupack is used extensively for a wide variety of water-related activities including swimming, fishing, boating, water skiing, and snowmobiling. Lake Wallenpaupack is within vacationing distance of millions of inhabitants of the mid Atlantic states. Philadelphia, New York City, Trenton, Scranton and Wilkes-Barre are all located within 100 miles of Lake Wallenpaupack, and the lake receives substantial use by these city residents. The Lake Wallenpaupack watershed is quite extensive and encompasses 219 square miles spread over four counties and 14 townships as shown in Figure 1.1 (LWWMD website at www.wallenpaupack watershed.org).

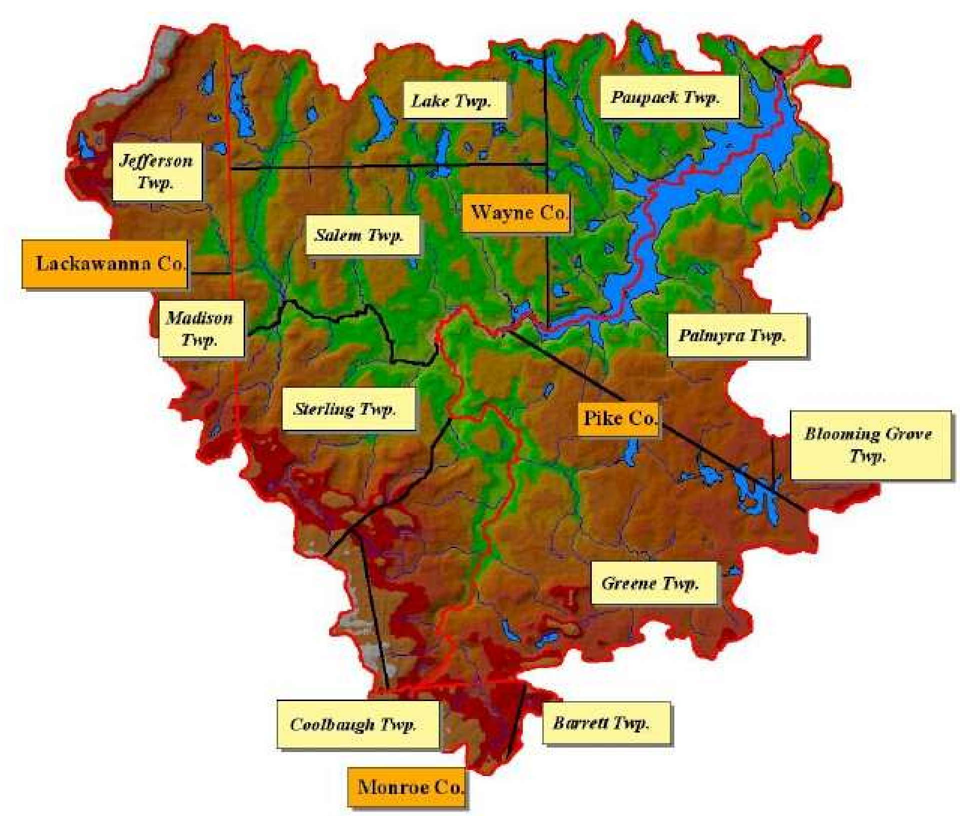

Figure 1.1 Lake Wallenpaupack Watershed

In 1926, the Pennsylvania Power & Light Co. (PP&L) dammed the creek and built the lake to supply water for a hydroelectric power plant. Building the lake was a monumental task, considering that mules and steam engines were the only source of power for construction projects in those days. It took 2,700 people about two years to do the job. Farms, barns and houses in the lake bed were demolished or moved, trees were cut down, utility poles and 17 miles of roadway were moved, and a cemetery was relocated. Wallenpaupack Creek was rerouted while the concrete dam was being built. PP&L also built a dike in Tafton to impound Wallenpaupack Creek. Once the dam and dike were completed, the stream was allowed to resume its course and fill the lake with water (LWWMD website at www.wallenpaupackwatershed.org).

Over the years, the water quality of Lake Wallenpaupack has been routinely monitored since 1980. In 2010, the Lake Wallenpaupack Watershed Management District (hereinafter referred to as the LWWMD) retained Aqua Link to analyze the 2010 lake water quality data and prepare this report, which provides our conclusions and recommendations. As part of this report, Aqua Link also compared the 2010 to the historical data collected from 1980 through 2009 to determine whether lake water quality has improved or degraded over the past 31 years.

In the Winter 2009-10, the District retained Aqua Link to develop the historical water quality data for the period of 1980 through 2009. This historical water quality database served as the foundation for this report and will subsequently be used to analyze all newly acquired lake water quality data from this point forward.

2. Lake Water Quality Monitoring Program

LWWMD monitored the water quality of Lake Wallenpaupack in 2010. The lake was monitored at Stations 3 and 5 in 2010 (Figure 2.1). These monitoring stations were monitored once a month during May through October.

In 2010, *insitu* water temperature and dissolved oxygen data were collected at the designated lake stations on each study date. These *insitu* data (dissolved oxygen and water temperature) were collected at one-meter intervals from the surface to the bottom of the lake at each station using a YSI (Yellow Springs Instruments) Model 85 meter. Secchi disk transparency (water clarity) was measured and recorded using a standard 8-inch (20 cm) freshwater Secchi disk at the lake stations on each study date.

In 2010, water samples were collected at two different depths on each study date at Stations 3 and 5. Surface samples were collected one meter (3.3 feet) below the lake's surface and bottom samples were collected one meter (3.3 feet) above the lake sediments. All water samples were collected using a Kemmerer water sampler unit. Once collected, all water samples were placed in bottles, preserved accordingly in the field, and then shipped to the certified contract laboratory for further analysis. The collected surface water samples were analyzed for alkalinity, total phosphorus, soluble reactive phosphorus (namely orthophosphorus), nitrate, nitrite, total Kjeldahl nitrogen, ammonia, total suspended solids, and chlorophyll-a. The bottom water samples were analyzed for alkalinity, total phosphorus, soluble reactive phosphorus, nitrate, nitrite, total Kjeldahl nitrogen, ammonia, and total suspended solids. In addition, composite samples of the photic zone were collected for phytoplankton and zooplankton analysis (identification and enumeration) at Station 3 on each study date. Discrete water samples were collected using the Kemmerer sampler and placed into a bucket to form composited samples for later phytoplankton identification and enumeration. The composite sample for zooplankton identification and enumeration was obtained by vertically towing the lake water column using a 80 um (micron) mesh plankton net. The photic zone was represented as twice the Secchi disk depth on each study date.

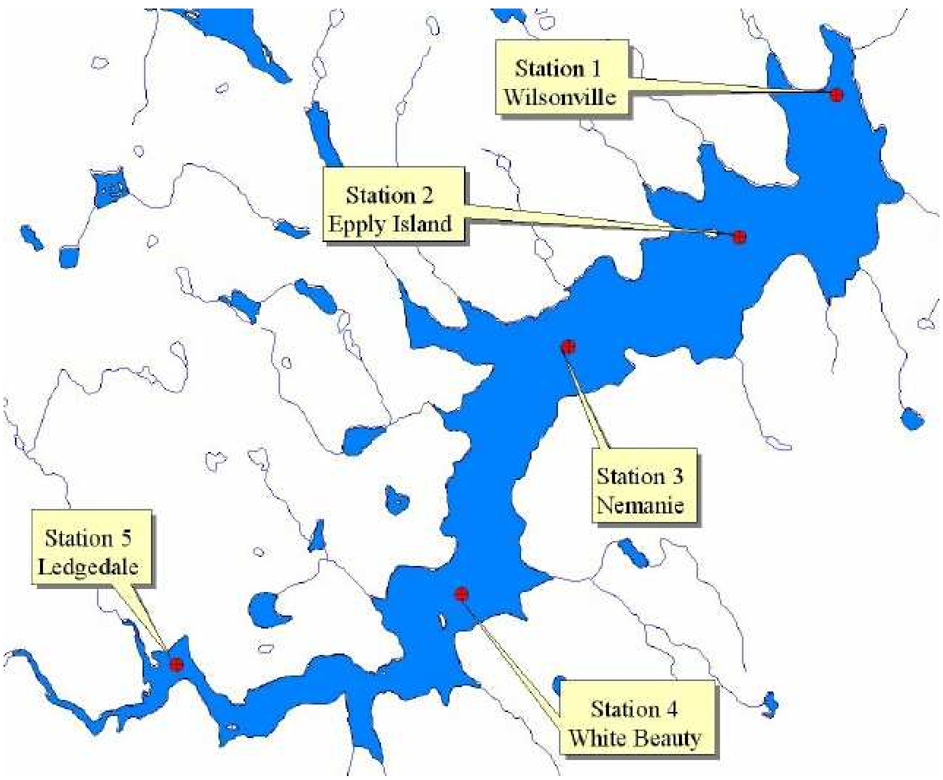

Figure 2.1 Lake Monitoring Stations

All collected water chemistry samples were shipped directly to the contract laboratory, ECM (Environmental Compliance Monitoring, Inc.) in Hillsborough, New Jersey, for analysis. All phytoplankton samples were preserved in the field and subsequently analyzed by Dr. Kenneth Wagner of Wilbraham, Massachusetts.

3. Local Climatological Data

Aqua Link acquired and analyzed local climatological data, which are representative for Northeastern Pennsylvania (Figures 3.1 and 3.2). Overall, 2010 was a warmer and drier year when compared to data presented over the past 31 years.

Figure 3.1 shows the average (mean) air temperatures for the growing season (May through October) from 1980 through 2010. Monthly temperature data were obtained via the Internet at the Pennsylvania State Climatologist website. Information at this website is provided by the College of Earth and Mineral Sciences at Penn State. Data were collected by averaging temperature data (in degrees Fahrenheit) for the months of May through October for each of the study years.

Figure 3.2 shows the total precipitation amounts from 1980 through 2010. Annual precipitation data was obtained via the Internet at the NOAA national weather service website. Precipitation measurements (recorded in inches) were report for Avoca, Pennsylvania from 1980 through 2010.

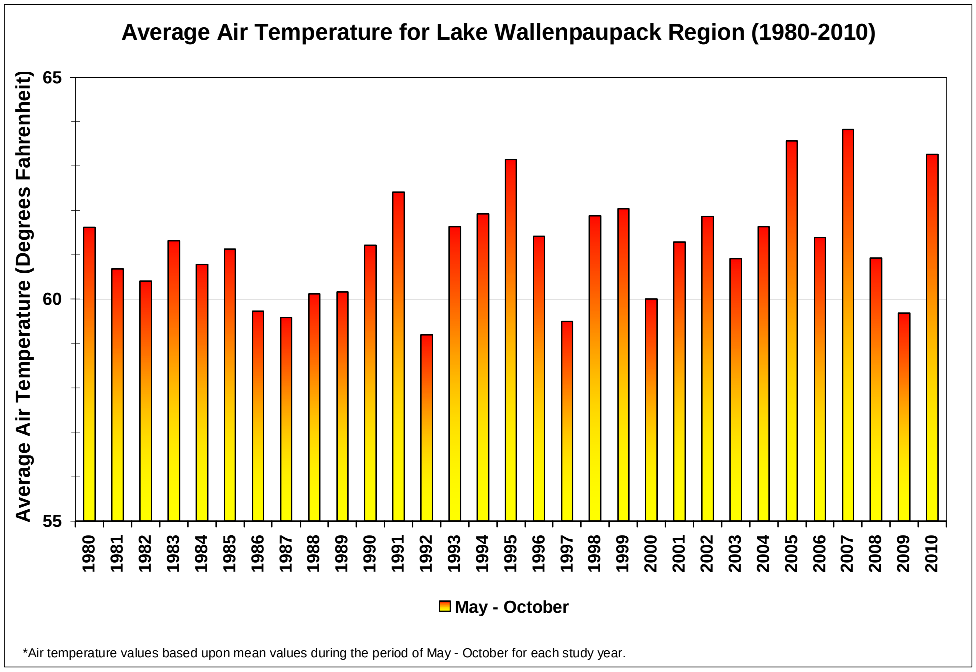

Figure 3.1 Historical Air Temperature Data in the Lake Wallenpaupack Region

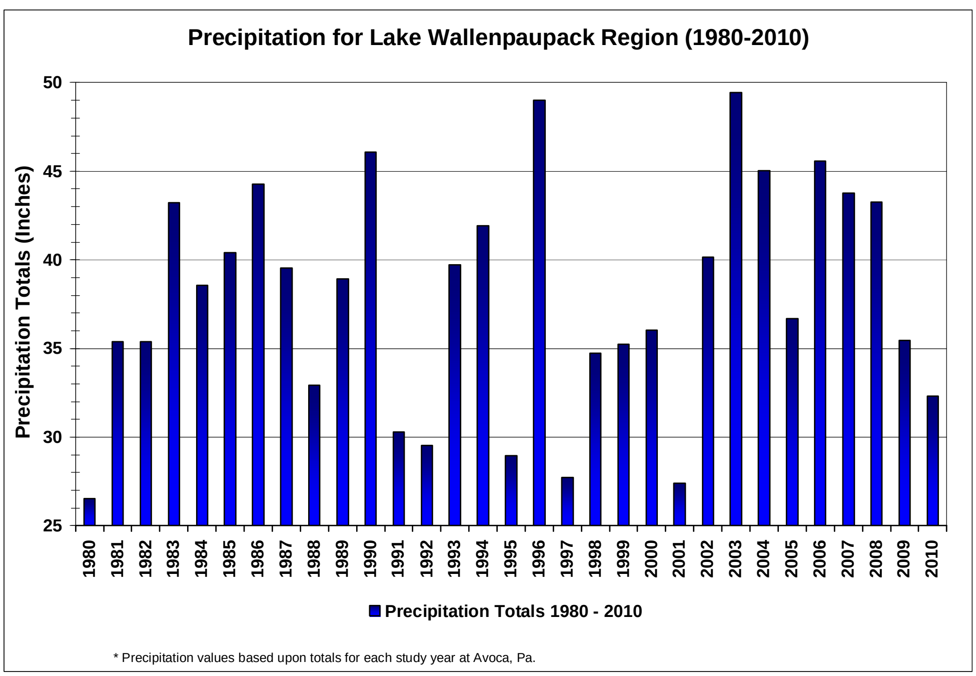

Figure 3.2 Historical Precipitation Data in the Lake Wallenpaupack Region

4. Lake Water Quality Data Results for 2010

The water quality data for Lake Wallenpaupack in 2010 are presented in this section of the report. As discussed in Section 2, the lake was monitored at Stations 3 and 5 in 2010 (Figure 2.1). The majority of this report focuses on the water quality data collected at Station 3, which is centrally located within the lake. This station has historically been used to describe the overall water quality of Lake Wallenpaupack and this appears to be quite logical based upon our review of data since 1980. In contrast, Station 5 is located uplake near the confluence of Wallenpaupack Creek and represents more eutrophic conditions – especially with respect to nutrients. Wallenpaupack Creek is the major tributary to the lake and drains a substantial portion of the massive Lake Wallenpaupack watershed (Figure 1.1).

With the exception of dissolved oxygen and water temperature, the water quality data at Station 3 are presented as average (mean) values for the growing season (May through October). The growing season is a very important time period since this is the time when the lakes are most heavily used (e.g. recreation, aesthetics) and most water quality problems, as related to eutrophication, occur. All of the lake data that were collected and analyzed in 2010 are presented in Appendix C.

4.1. Temperature and Dissolved Oxygen

In late spring or the beginning of summer, many moderately deep to deep temperate lakes develop stratified layers of water. Under stratified conditions, warmer and colder waters are near the lake's surface (epilimnion) and the lake's bottom (hypolimnion), respectively. As the temperature differences become greater between these two water layers, the resistance to mixing increases. During lake stratification, the epilimnion is usually oxygen-rich due to photosynthesis and direct inputs from the atmosphere, while the hypolimnion may become depleted of oxygen due to the respiration of aquatic organisms. As previously discussed, aquatic organisms (e.g., bacteria, fungi, protozoan, zooplankton, macroinvertebrates, fish) consume dissolved oxygen in order to metabolize prey or detritus (U.S. EPA 1980, U.S. EPA 1990 and U.S. EPA 1993).

Conversely, shallow temperate lakes may only become weakly stratified during the summer months or some lakes may never stratify at all. The overall degree and duration of stratification in weakly stratified lakes are largely dependent upon local wind conditions and the morphological characteristics of the lake itself. During windy days, surface wave action may be sufficient to partially or completely destratify (mix) a lake. Conversely, a shallow lake may become partially stratified on windless days.

Overall, water temperatures and dissolved oxygen concentrations are very important with regards to a lake's fishery. In general, the optimal water temperature for salmonid fish (i.e., trout) is 55 to 60 °F (12.8 to 15.6 °C). Trout may withstand water temperatures above 80 °F (26.7 °C) for several hours, but if water temperatures exceed 75 °F (23.9 °C) for extended periods, high trout mortality is expected (Pennsylvania State University). Conversely, non-salmonid fish such as golden shiners, bass, bluegills, can grow well even when water temperatures exceed 80 °F (26.7 °C). In general, safe minimum dissolved oxygen concentrations for adult salmonid and non-salmonid fish are 5.0 and 3.0 mg/L, respectively. When dissolved oxygen concentrations fall below these concentrations, production impairment of the lake's fishery can be expected.

In addition to impacting the lake's fishery, low dissolved oxygen levels in the bottom waters of a lake will often accelerate the release of nutrients such as soluble orthophosphorus (analytically measured as dissolved reactive phosphorus) and ammonia nitrogen, from anoxic (oxygen depleted) in-lake sediments. In particular, the accelerated release rates of nutrients (referred to as internal loading) can represent a substantial portion of all incoming nutrients to a lake. Increased nutrient loadings via in-lake sediments may further degrade lake water quality by increasing the production of both phytoplankton and aquatic macrophytes (vascular plants).

Lake Wallenpaupack

The 2010 water temperature and dissolved oxygen profile data for Lake Wallenpaupack are graphically presented in Figures 4.1 through 4.2. The maximum water depth at Station 3 was 13.5 meters (44.3 feet) in 2010. The lake was strongly, thermally stratified during the months of June, July and August (Figure 4.1). Figure 4.2 shows that dissolved oxygen levels rapidly decreased within deeper lake waters (hypolimnion). The thermocline, which is the point where the temperature change is the greatest, divides the epilimnion (surface waters) and the hypolimnion (bottom waters), was located at a depth of approximately 5 to 7 meters (16 to 23 feet) during the period of June through August.

In 2010, it should be noted that LWWMD only recorded dissolved oxygen values as percent saturation in June through October as opposed to reporting both the concentration (mg/L) and percent saturation. Conversely, LWWMD recorded the dissolved oxygen data only as concentration. As expected, these two parameters are closely related where percent saturation values less than 30 percent typically correspond to dissolved oxygen concentrations less than 1 mg/L in Pennsylvania lakes. In past reports, historical dissolved oxygen data discussions (1980-2009) primarily focused on concentration rather than percent saturation and this is standard for most lake studies and investigations. In the future, dissolved oxygen data should be recorded as concentration (mg/L) and percent saturation throughout the water column at all monitoring stations on all study dates.

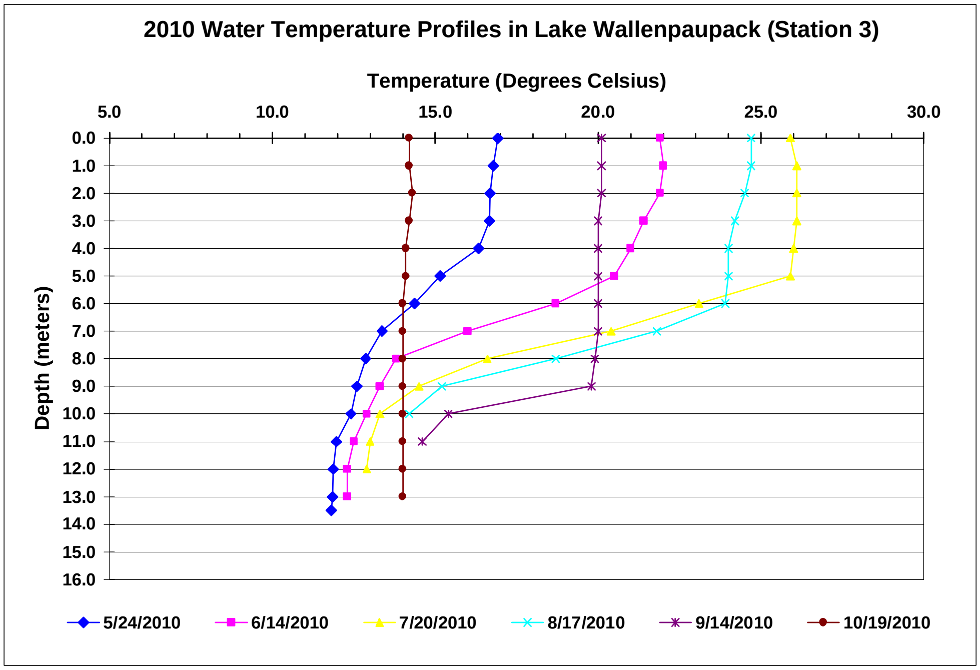

Figure 4.1 Water Temperature Profiles at Station 3 in 2010

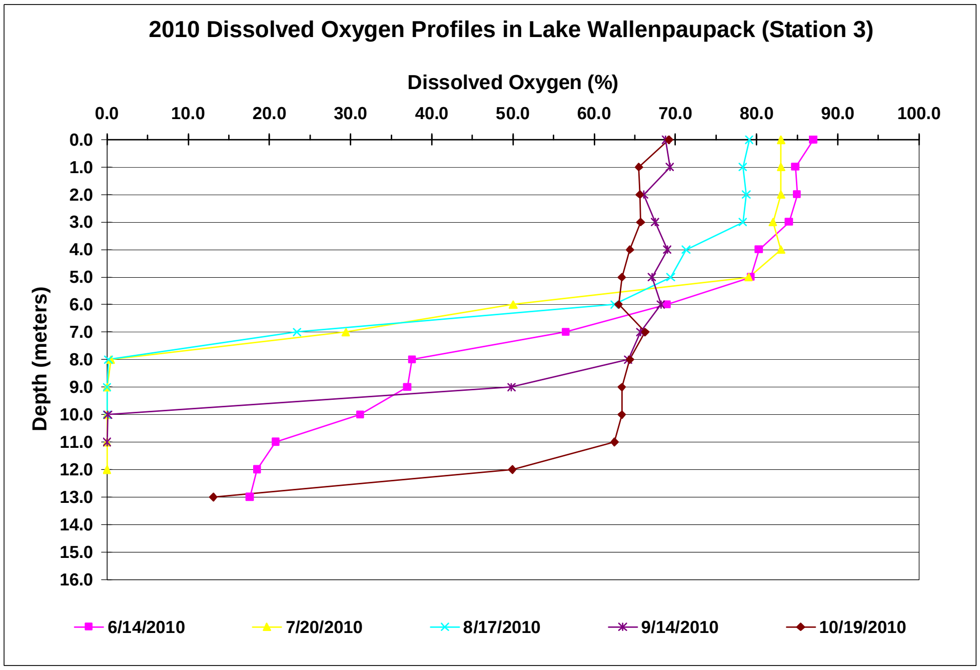

Figure 4.2 Dissolved Oxygen Profiles at Station 3 in 2010

4.2. pH & Alkalinity

The pH and alkalinity of water are directly related to one another. In general, as alkalinity increases, the pH of the water also increases. The acidity or basicity of a solution is most often expressed as pH. The term pH is defined as the logarithm of the reciprocal (or its negative logarithm) of the hydrogen ion concentration. Therefore, a one unit change in pH represents a ten-fold increase or decrease in the hydrogen ion concentration (as pH decreases, the hydrogen ion concentration increases). The pH scale ranges from 0 to 14 standard units where a value of 7 indicates neutral conditions. Water becomes more acidic when pH values fall below 7 and more basic when pH values rise above 7. In general, most natural waters usually have a pH values between 6.5 and 8.5.

Aquatic life in lakes can be adversely impacted when pH levels drop too low in lakes. When pH concentrations fall below 6.0 standard units, there is a greater risk to increase the concentration of heavy metals, in particular aluminum. High concentrations of hydrogen and aluminum ions are known to adversely affect the ion regulation of aquatic organisms, a condition referred to as "osmoregulatory failure". When osmoregulatory failure occurs, high hydrogen and aluminum concentrations induce the leaching of sodium and chloride ions from the body fluids of fish and other aquatic organisms (U.S. EPA, 1990). As summarized by J. Baker, pH values ranging from 5.5 to 6.0 standard units can result in the loss of sensitive minnows and dace, which may be important as forage fish for game fish. In addition, the pH levels below 6.0 are also known to adversely affect the reproductive success rates of game fish, such as walleye (U.S. EPA, 1990).

Alkalinity refers to the capacity of water to neutralize (or buffer against) acid inputs. Alkalinity of natural waters is due primarily to the presence of hydroxides (OH^-), bicarbonates (HCO_3^-), carbonates (CO_3^{2-}) and occasionally borates, silicates and phosphates. Therefore, the carbonate–bicarbonate equilibrium system (CO_2 - HCO_3^- - CO_3^{2-}) is the major buffering mechanism in freshwater lakes (Wetzel 1983).

Alkalinity is typically expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate). Waters having a pH below 4.5 contain no alkalinity. Low alkalinity is the main indicator of susceptibility of aquatic organisms to acidic inputs (e.g., acid rain and acidic dry fallout). Waters with pH values ranging from 6 to 9 are largely comprised of bicarbonate (HCO_3^-). At higher pH values, carbonate ($CO_3^{=}$) plays a more important role in the buffering capacity of the water. Lakes with watersheds that contain sedimentary carbonate rocks are high in dissolved carbonates (hard-water lakes). Conversely, lakes in granite or igneous rocks are low in dissolved carbonates (soft water lakes). In the Northeastern U.S., the alkalinity of natural surface waters typically ranges from 5 to over 200 mg/L as $CaCO_3$.

Lake Wallenpaupack

The mean pH values for surface and bottom waters could not be reported for the 2010 study period (Table 4.1). LWWMD only collected pH data in May (surface to bottom) and June (surface only). In the future, at a minimum, pH data should be measured and recorded in surface and bottom waters at all monitoring stations on all study dates.

The mean alkalinity concentrations for surface and bottom waters in 2010 are presented in Table 4.1. The mean values are considered somewhat low, but typical for lakes within the Pocono Mountain region and the Northeastern U.S. Overall, the mean alkalinity concentrations should be sufficiently high enough to regulate or maintain stable pH levels in the lake. This simply means that the lake is not highly susceptible to acidic inputs such as, acid rain, acidic runoff from snowmelt and acidic dry deposition. Conversely, when acidic inputs are episodically high, the pH levels in the lake may decline, thereby providing additional stress on acid intolerant aquatic organisms.

Table 4.1 Mean pH & Alkalinity Concentrations at Station 3 in 2010

Year	pH (standard units, s.u.)		Alkalinity (mg/l as $CaCO_3$)	
	Surface	Bottom	Surface	Bottom
2010	-----	-----	10.8	14.4

Note: Insufficient data were collected by LWWMD to determine mean pH value for the 2010 study period.

4.3. Phosphorus

Total phosphorus represents the sum of all forms of phosphorus. Total phosphorus includes dissolved and particulate organic phosphates (e.g., algae and other aquatic organisms), inorganic particulate phosphorus as soil particles and other solids, polyphosphates from detergents and dissolved orthophosphates. Soluble (or dissolved) orthophosphate (determined analytically as dissolved reactive phosphorus) is the phosphorus form that is most readily available for algal uptake. Soluble orthophosphate is usually reported as dissolved reactive phosphorus because laboratory analysis takes place under acid conditions and may result in the hydrolysis of some other phosphorus forms. Total phosphorus levels are strongly affected by the daily phosphorus loadings to a lake, while soluble orthophosphate levels are largely affected by algal consumption during the growing season.

Based on criteria established by Nurnberg (2001), a lake is classified as oligotrophic, mesotrophic, eutrophic and hypereutrophic when surface total phosphorus concentrations are less than 0.010 mg/l as P, 0.010 to 0.030 mg/l as P, 0.031 to 0.100 mg/l as P and greater than 0.100 mg/l as P, respectively.

Lake Wallenpaupack

The 2010 mean total phosphorus concentrations for surface and bottom waters were 0.027 and 0.043 mg/L as P, respectively (Table 4.2). The higher concentrations in the bottom waters are likely due to the settling of dead algae and the release of phosphorus from anoxic sediments (sediments containing no dissolved oxygen). Based upon the above criteria, the mean total phosphorus concentrations for surface waters suggest that Lake Wallenpaupack is classified as highly mesotrophic in 2010.

The 2010 mean dissolved reactive phosphorus concentrations for surface and bottom waters were 0.004 and 0.015 mg/L as P, respectively (Table 4.2). Extremely low dissolved reactive phosphorus concentrations (at or below the detection limit) indicate that this form of phosphorus is rapidly used by phytoplankton as soon as it becomes available within the lake.

Table 4.2 Mean Phosphorus Concentrations at Station 3 in 2010

Year	*Total Phosphorus (mg/L as P)*		*Dissolved Reactive Phosphorus (mg/L as P)*	
	Surface	*Bottom*	*Surface*	*Bottom*
2010	0.027	0.043	0.004	0.015

4.4. Nitrogen

Nitrogen compounds are also important for the growth and reproduction of phytoplankton and aquatic macrophytes. The common inorganic forms of nitrogen in water are nitrate (NO_3^-), nitrite (NO_2^-) and ammonia (NH_3). In water, ammonia is present primarily as ammonium (NH_4^+) and undissociated ammonium hydroxide (NH_4OH). Of these two forms, undissociated ammonium hydroxide is toxic and its toxicity increases as pH and water temperature increase. Overall, the most dominant form of inorganic nitrogen present in lakes depends largely on the dissolved oxygen concentrations. Nitrate is the form usually found in surface waters, while ammonia is only stable under anaerobic (low oxygen) conditions. Nitrite is an intermediate form of nitrogen, which is generally considered unstable. Nitrate and nitrite (referred to as total oxidized nitrogen) are often analyzed together and reported as NO_3 + NO_2-N, although nitrite concentrations are usually insignificant as noted previously. Total Kjeldahl nitrogen (TKN) concentrations include ammonia and organic nitrogen (both soluble and particulate forms). Organic nitrogen can be easily estimated by subtracting ammonia nitrogen from total Kjeldahl nitrogen concentrations. Total nitrogen is calculated by summing the nitrate-nitrite, ammonia and organic nitrogen fractions together.

According to Nurnberg (2001), lakes with surface total nitrogen concentrations less than 0.350 mg/l as N are classified as oligotrophic, from 0.350 to 0.650 mg/l as N are classified as mesotrophic, from 0.651 to 1.200 mg/L are classified as eutrophic and greater than 1.200 mg/l as N are classified as hypereutrophic.

Lake Wallenpaupack

The 2010 mean total nitrogen, total Kjeldahl nitrogen (TKN), nitrate plus nitrite nitrogen, and ammonia nitrogen concentrations for surface and bottom waters are presented in Table 4.3. Overall, the 2010 mean total nitrogen concentration for the bottom waters was about twice as high as the mean concentration for the surface waters. This higher value in the bottom waters is most likely attributed to higher levels of ammonia nitrogen and nitrate plus nitrite nitrogen. Higher ammonia concentrations in the bottom waters are due to low dissolved oxygen concentrations plus the accelerated release rates by anoxic sediments (sediments containing no dissolved oxygen).

Table 4.3 Mean Nitrogen Concentrations at Station 3 in 2010

Year	Total Nitrogen (mg/L as N)		Total Kjeldahl Nitrogen (mg/L as N)		Nitrate + Nitrite (mg/L as N)		Ammonia (mg/L as N)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
2010	0.454	1.026	0.355	0.908	0.119	0.118	0.033	0.142

Based upon the Nurnberg criteria (2001), the mean total nitrogen concentrations for surface waters are at a moderate level and thereby suggesting that Lake Wallenpaupack was classified as mesotrophic in 2010.

4.5. Secchi Disk Transparency & Chlorophyll-a

The transparency, or clarity, of a lake is most often reported as the Secchi disk depth. This measurement is taken by lowering a circular black-and-white disk, which is 20 cm (8 inches) in diameter, into the water until it is no longer visible. Observed Secchi disk depths range from a few centimeters in very turbid lakes to over 40 meters in the clearest known lakes (Wetzel, 1983). Although somewhat simplistic and subjective, this field monitoring method probably best represents those lake conditions that are most often perceived by lake users and the general public.

Secchi disk transparency is related to the transmission of light in water, and depends on both the absorption and scattering of light. The absorption of light in dark-colored waters reduces light transmission. Light scattering is usually a more important factor than absorption in determining Secchi depths. Scattering can be caused by water discoloration or by the presence of both particulate organic matter (e.g., algal cells) and inorganic materials (e.g., suspended clay particles).

In general, a lake is classified as oligotrophic, mesotrophic, eutrophic and hypereutrophic when Secchi disk transparency values are greater than 4.0 meters, 4.0 to 2.0 meters, 1.9 to 1.0 meters and less than 1.0 meter, respectively (Nurnberg 2001).

Chlorophyll-a is a pigment that gives all plants their green color. The function of chlorophyll-a is to convert sunlight to chemical energy in the process known as photosynthesis. Because chlorophyll-a constitutes about 1 to 2 percent of the dry weight of planktonic algae, the amount of chlorophyll-a in a water sample is an indicator of phytoplankton biomass. According to Nurnberg (2001), a lake is generally classified oligotrophic, mesotrophic, eutrophic and hypereutrophic when chlorophyll-a concentrations are less than 3.5 ug/l, 3.5 to 9.0 ug/l, 9.1 to 25.0 ug/l and greater than 25.0 ug/l (micrograms per liter), respectively.

<u>Lake Wallenpaupack</u>

The 2010 mean Secchi disk transparency value for Lake Wallenpaupack was 2.0 meters. Based upon Nurnberg (2001), the lake is classified as highly mesotrophic, but bordering on slightly eutrophic. Secchi disk transparency values ranged from 1.5 to 2.5 meters for all study dates. It should be noted that the lowest transparency values occurred when the highest phytoplankton biomass levels were recorded in the lake in July and October 2010 (Figure 4.5).

The 2010 mean chlorophyll-a concentration in Lake Wallenpaupack was 13.6 ug/L. Chlorophyll-a concentrations ranged from 7.3 to 18.3 ug/L during the study period. According to the Nurnberg criteria, the mean chlorophyll-a concentration indicates slightly eutrophic conditions.

Table 4.4 Mean Secchi & Chlorophyll-a Values at Station 3 in 2010

Year	*Secchi Disk Transparency (m)*	*Chlorophyll-a (ug/l)*
2010	2.0	13.6

4.6. Total Suspended Solids

The concentration of total suspended solids in a lake is a measure of the amount of particulate matter in the water column. Suspended solids include both organic matter including phytoplankton and inorganic materials like soil particles.

Lake Wallenpaupack

The 2010 mean total suspended solids concentrations for surface and bottom waters are presented in Table 4.5. The concentrations for surface and bottom waters are considered low to moderately low, respectively. These concentrations are typical for lake systems containing moderate levels of aquatic productivity in the form of phytoplankton and/or sediment loadings from the surrounding watershed.

4.7. Phytoplankton & Zooplankton Biomass

The quantity of phytoplankton (free floating, microscopic aquatic plants commonly referred to as algae) and macrophytes (vascular aquatic plants) are primary biological indicators of lake trophic conditions. Small aquatic animals, namely zooplankton and macroinvertebrates, graze upon algae and fragments of aquatic plants. Larger invertebrates and fish then consume the above grazers and to a lesser extent, some aquatic plants.

Table 4.5 Mean Total Suspended Solids Concentrations at Station 3 in 2010

Year	Total Suspended Solids (mg/l)	
	Surface	Bottom
2010	2.3	4.3

Information about the plankton community composition and succession is extremely useful when attempting to gain a better understanding about various lake problems. For example, eutrophic lakes often support unbalanced phytoplankton communities characterized by very large numbers of relatively few species. The number of larger zooplankton will tend to decrease during periods when blue-green algae are dominant. Conversely, oligotrophic lakes and acidic lakes often have smaller populations of both phytoplankton and zooplankton. Acidic lakes typically will also have lower species diversity.

4.7.1. Phytoplankton

Phytoplankton are free floating, microscopic aquatic plants that have little or no resistance to currents and live suspended in open water. Their forms may be unicellular, colonial or filamentous. As photosynthetic organisms (primary producers), phytoplankton form the base of aquatic food chain and are grazed upon by zooplankton and herbivorous fish.

A healthy lake should support a diverse assemblage of phytoplankton, in which many algal species are represented. Excessive growth of a few species is usually undesirable. Such growth can result in dissolved oxygen depletion during the night, when the algae are respiring rather than photosynthesizing. Dissolved oxygen depletion also can occur shortly after a massive "algal bloom" due to increased levels of respiration by bacteria and other microorganisms that are metabolizing dead algal cells. Excessive growth of some species of algae, particularly members of the blue-green group, may cause taste and odor problems, release toxic substances to the water, or give the water an unattractive green soupy or scummy appearance.

Planktonic productivity is commonly expressed in terms of density and biomass. Phytoplankton densities are most frequently expressed as cells per milliliter (cells/ml). Biomass is commonly expressed on a mass per volume basis as micrograms per liter (µg/l). Of the two, biomass provides a better estimate of the actual standing crop of phytoplankton in lake systems.

<u>Lake Wallenpaupack</u>

The phytoplankton community in 2010 was represented by genera from seven different taxa: Bacillariophyta (diatoms), Chlorophyta (green algae), Chrysophyta (golden-brown algae), Cryptophyta (cryptomonads), Cyanophyta (blue-green algae), Euglenophyta (euglenoids), and Pyrrhophyta (fire algae). The phytoplankton biomasses in Lake Wallenpaupack ranged from 2,570 to 7,739 ug/L (micrograms per liter) for 2010, as shown in Figure 4.3. The highest phytoplankton biomass value was reported in July of 2010. In general, phytoplankton biomass below 2,500 ug/l are considered low, ranging from 2,500 to 7,500 ug/l are moderately low to moderately high, ranging from 7,500 to 10,000 ug/l are high and above 10,000 are considered very high. Biomasses often exceeding 5,000 ug/l are perceived by many as “algal bloom” conditions.

Phytoplankton biomass peaked in July 2010 and was largely dominated by *Aphanizomenon* (Cyanophyte) and *Anabaena* (Cyanophyte) as shown in Figure 4.3. As previously mentioned, biomass values for 2010, ranged from a minimum of 2,570 to a maximum value of 7,739 ug/L (Figure 4.3). Overall, the phytoplankton assemblages, with some exception during the months of July and October of 2010, were considered moderately well distributed among taxa during the 2010 study period.

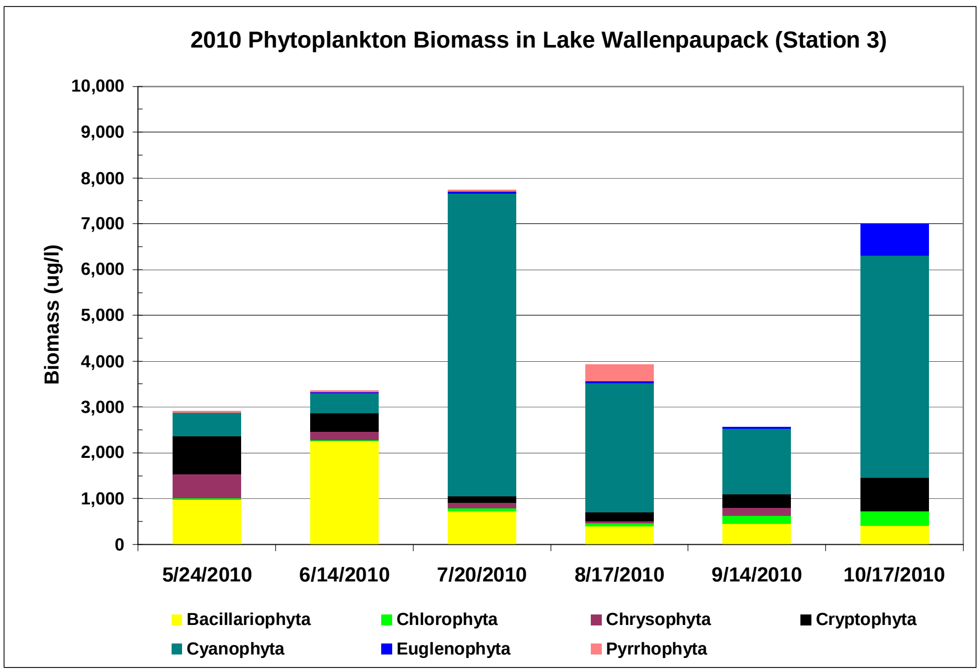

Figure 4.3 Phytoplankton Biomass at Station 3 in 2010

Overall, the 2010 study year contained lower to average amounts of phytoplankton when compared to the historical data. There are several plausible reasons for these differences. First, 2010 was a warmer and drier when compared to the same time period (Section 3). Secondly, different aquatic biologists were retained for phytoplankton analysis (identification, enumeration and analysis).

4.7.2. Zooplankton

Zooplankton are suspended microscopic animals whose movements in a lake are primarily dependent upon water currents. The zooplankton of freshwater ecosystems are dominated primarily by four major groups: the protozoa, the rotifers and two subclasses of crustacea, the cladocerans (i.e., water fleas) and the copepods. Zooplankton are generally smaller than 2 millimeters (one-tenth of an inch) in size and primarily feed on algae, other zooplankton, and plant and animal particles. Zooplankton grazing can have a significant impact on phytoplankton species composition and productivity (i.e. biomass) through selective grazing (e.g., size of zooplankton influences what size phytoplankton are consumed) and nutrient recycling. Zooplankton are then consumed by fish, waterfowl, aquatic insects, and others, thereby playing a vital role in the transfer of energy from phytoplankton to higher trophic levels.

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Zooplankton communities in 2010 were represented by genera from three different taxa: Rotifera (rotifers), Copapoda (crustacean), and Cladoceran (crustacean). Zooplankton biomass values between May through October of 2010 are shown in Figure 4.4. This figure indicates to some degree the direct relationship of phytoplankton and zooplankton populations in the aquatic food chain (Appendix B). Zooplankton biomass will often increase shortly after phytoplankton biomass increases. This complex relationship can be dramatically impacted by a number of factors including types of phytoplankton species present, fish predation, and water quality. It is well documented that many species of blue-green algae are not highly edible by zooplankton. Under such conditions, zooplankton biomass will often decrease although phytoplankton biomass increases.

The data suggests Copepods and Cladocerans dominated the zooplankton community throughout the growing season of 2010. Similarly to the phytoplankton, zooplankton populations were considered fairly well distributed among taxa during the 2010 growing season. One interesting observation was the lack of Protozoans found during the 2010. Although at a low level, Protozoans were represented in the 2009 data set.

Similar to Section 4.7.1, different aquatic biologists were retained for zooplankton analysis (identification, enumeration and analysis. Therefore, laboratory methodology differences (e.g. subsampling and counting methods) may have accounted for some variation when comparing data.

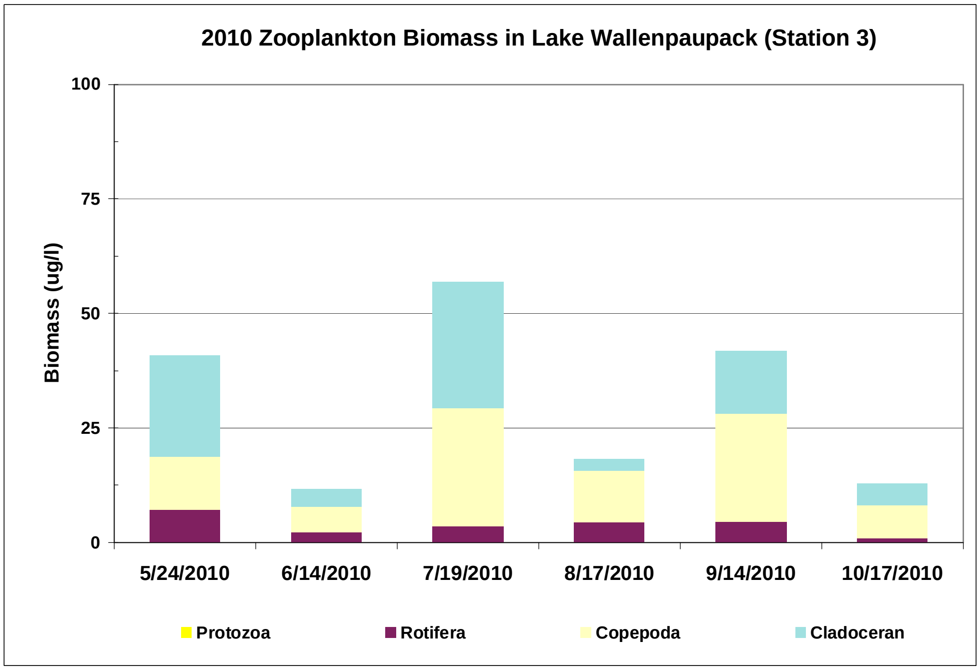

Figure 4.4 Zooplankton Biomass at Station 3 in 2010

4.8. Carlson's Trophic State Index Values

The Trophic State Index (TSI) developed by Carlson (1977) is among the most commonly used indicators of lake trophic state. This index is actually composed of three separate indices based on measurements of total phosphorus concentrations, chlorophyll-a concentrations and Secchi disk depths for many lakes. Total phosphorus was chosen for the index because phosphorus is often the nutrient limiting for phytoplanktonic growth in lakes. Chlorophyll-a is a plant pigment present in all algae and is used to provide an indication of the biomass of phytoplankton and Secchi disk depth is a common measure of lake transparency.

As part of this study, TSI values were determined for total phosphorus, chlorophyll-a, and Secchi depth data for each of the study dates. Total phosphorus concentrations, chlorophyll-a concentrations, and Secchi disk depths were logarithmically converted to a trophic state scale ranging from 1 to 100. Increasing values for the Trophic State Index are indicative of increasing lake trophic states. In general, index values less 35 to 40 are indicative of oligotrophic conditions, while index values greater than 50 to 55 are indicative of eutrophic lake conditions. The Pennsylvania Department of Environmental Protection (PA DEP) classifies lakes according to the following: oligotrophic (less than 40), mesotrophic (40 to 50), eutrophic (50 to 65) and hyper-eutrophic (greater than 65) as noted in its 2002 PA Water Quality Assessment 305(b) Report.

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The calculated 2010 mean Carlson TSI values for Secchi depth, chlorophyll-a, and total phosphorus are presented in Table 4.6. The TSI values for chlorophyll-a and total phosphorus suggest that Lake Wallenpaupack is classified as slightly eutrophic. The Secchi depth transparency suggests either highly mesotrophic or slightly eutrophic.

Overall, the TSI values for Secchi depth transparency and chlorophyll-a were similar to the TSI value for total phosphorus. This often occurs in lakes that are phosphorus limiting. When divergence occurs between the TSI values, more emphasis is placed upon the TSI value for chlorophyll-a during the summer months.

Table 4.6 Mean Carlson's TSI Values at Station 3 in 2010

Year	*Trophic State Index (TSI) Values*		
	Secchi Depth	*Chl-a*	*Total P*
2010	50	56	52

Note: Mean TSI values determined by averaging the individual TSI values for each parameter during the 2010 study period.

4.9. Summary of Lake Assessment Data

Lake Wallenpaupack was classified as a slightly eutrophic reservoir in 2010. The mean Carlson TSI values for total phosphorus, chlorophyll-a, and Secchi disk transparency were 52, 56, and 50, respectively, for 2010.

The lake thermally stratified in 2010 and therefore is considered a moderately deep, dimictic reservoir (lake). Dimictic lakes are those lakes that thermally stratify during most of the growing season (May through October). In this study, Lake Wallenpaupack was thermally stratified from May through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified.

The lake was the most thermally stratified during the months of June, July and August in 2010. As in the past, the dissolved oxygen levels rapidly decreased within deeper lake waters (hypolimnion).

The thermocline, which is the point where the temperature change is the greatest, divides the epilimnion (surface waters) and the hypolimnion (bottom waters), was located at a depth of approximately 5 to 7 meters (16 to 23 feet) in June through August.

Phytoplankton data indicate that blue-green algae (Cyanophyta) were dominant during the growing season. The most common genera were *Aphanizomenon* and *Anabaena*. Further observation concluded that zooplankton biomass generally increased shortly after the phytoplankton biomass increased. Zooplankton biomass often increased following a sharp increase in phytoplankton biomass. This is a typical response where zooplankton numbers increase to graze down the higher amounts of phytoplankton biomass, thereby naturally balancing the aquatic ecosystem.

5. Historical Lake Water Quality Trends

Aqua Link evaluated historical water quality data collected in Lake Wallenpaupack from 1980 through 2010. Key water quality parameters that are discussed in Sections 5.1 through 5.6 are total phosphorus, total nitrogen, Secchi disk transparency, chlorophyll-a, plankton biomass (phytoplankton and zooplankton), and Carlson Trophic State Index (TSI) values. Total phosphorus and total nitrogen data are presented for surface (eplimnion) and bottom (hypolimnion) waters.

The comparison of recently acquired data to past data is commonly referred to as "water quality trend analysis". Professional lake and water resource managers commonly evaluate complex historical water quality data using trend analysis. Overall, water quality trend analysis is a very powerful tool in assessing whether lake water quality has improved, degraded or remained unchanged over time.

Lake water quality trends for the key water quality parameters are presented below graphically for Station 3. Station 3, which is centrally located within the lake, has historically been used to describe the overall water quality of Lake Wallenpaupack (Section 4). The graphs contain annual mean (average) concentrations and values for the key water quality parameters for the growing season (May through October).

As observed in Figures 5.1 through 5.9, lake water quality often varies seasonally and annually and these variations can be affected by numerous factors including local climatological conditions. To assess any water quality trends, "best fit" lines were determined statistically using linear regression and these lines were plotted on Figures 5.1 through 5.9. The slopes of these regression lines were used to assess the overall degree of water quality improvement or degradation in the lake.

5.1. Phosphorus

The mean total phosphorus concentrations from 1980 through 2010 for surface and bottom waters are shown in Figures 5.1 and 5.2, respectively. The total phosphorus levels in both surface and bottom levels have slightly decreased in 2010. These concentration decreases may be attributed to lower phosphorus loadings from the surrounding watershed. As noted in Section 3, the 2010 study year was a relatively hot and dry as shown in Figures 3.1 and 3.2. In terms of trends, Figures 5.1 and 5.2 indicate that total phosphorus concentrations have gradually decreased since 1980.

5.2. Nitrogen

The mean total nitrogen concentrations from 1980 through 2010 for surface and bottom waters are shown in Figures 5.3 and 5.4, respectively. The mean total nitrogen concentration for surface

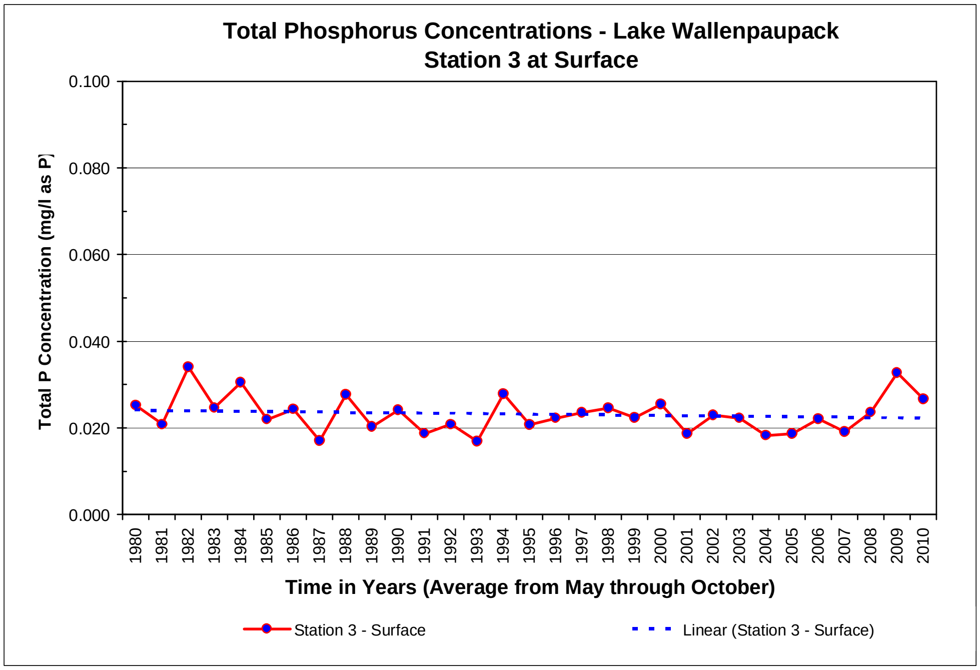

Figure 5.1 Historical Total Phosphorus Concentrations in Surface Waters

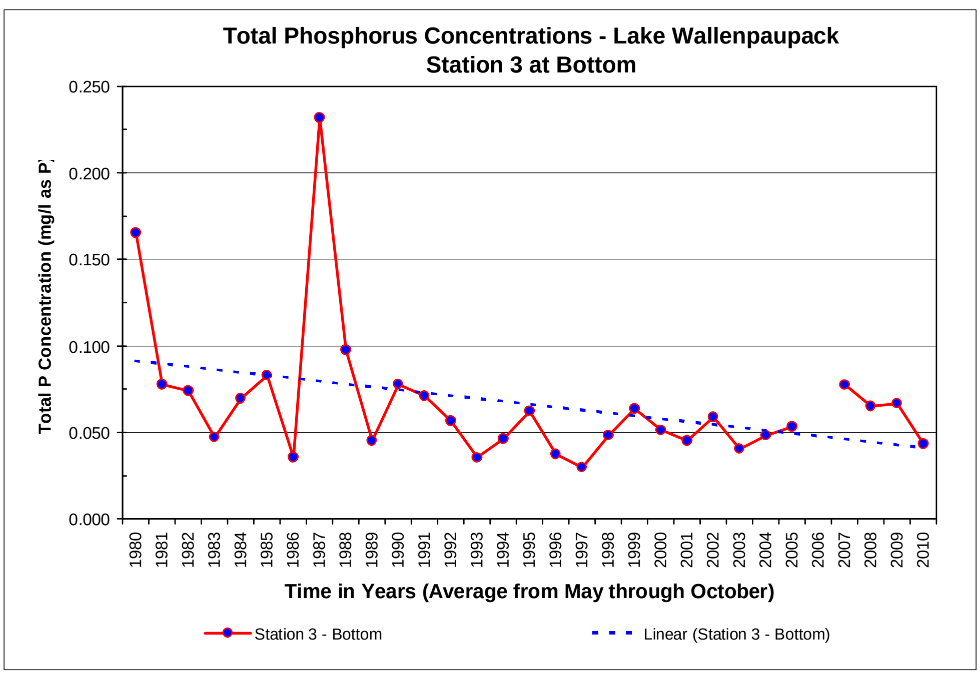

Figure 5.2 Historical Total Phosphorus Concentrations in Bottom Waters

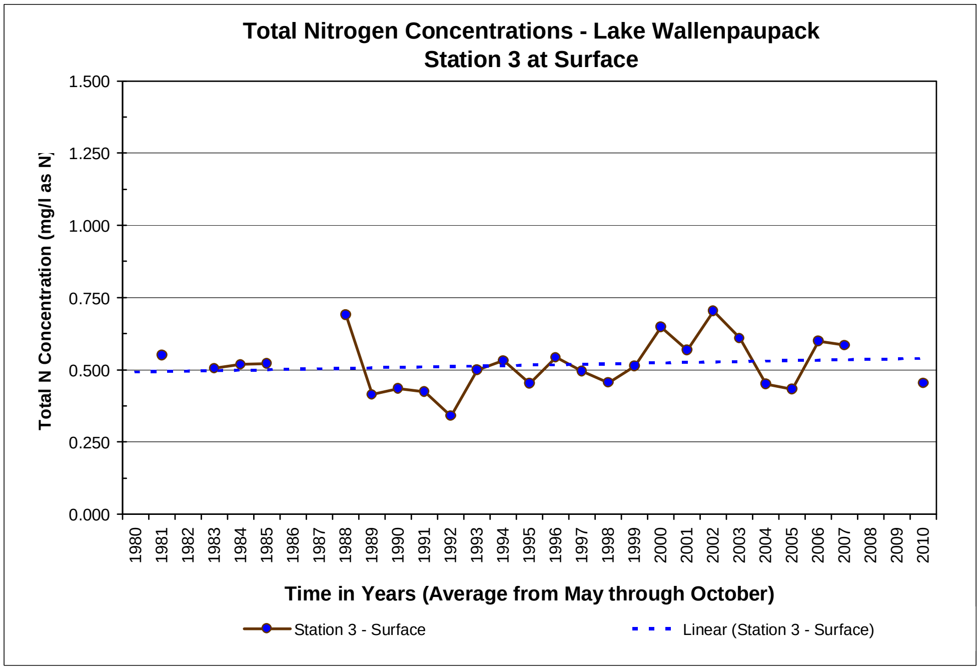

Figure 5.3 Historical Total Nitrogen Concentrations in Surface Waters

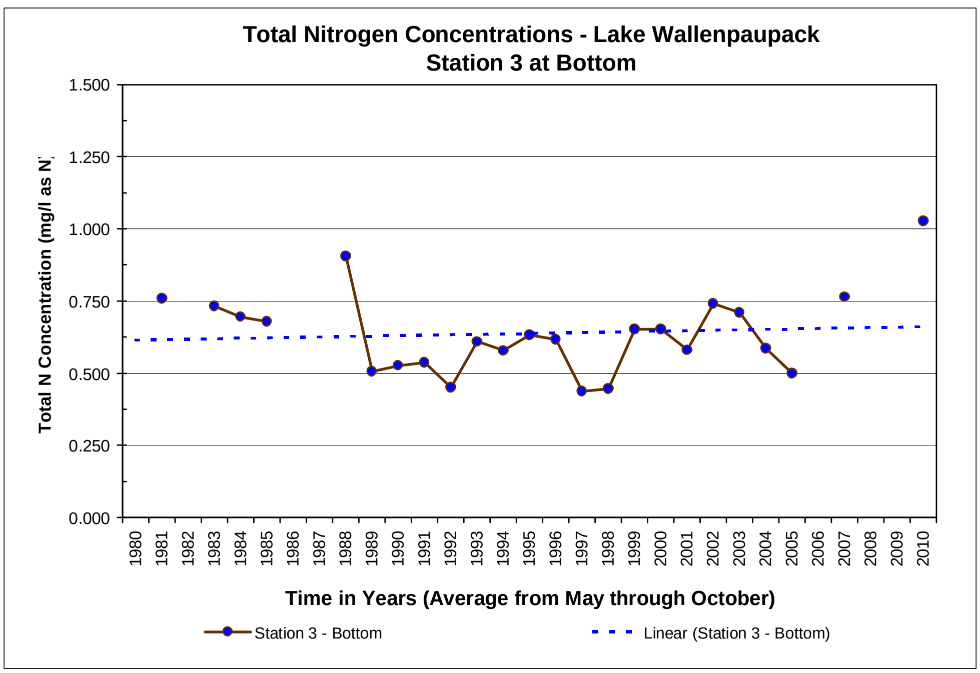

Figure 5.4 Historical Total Nitrogen Concentrations in Bottom Waters

waters once again fell below 0.500 mg/L as N. Conversely, the mean total nitrogen concentration for bottom waters reached its highest level since 1980. In terms of trends, Figures 5.3 and 5.4 indicate that total nitrogen concentrations in the lake have gradually increased since 1980.

5.3. Secchi Transparency

The mean Secchi disk transparency from 1980 through 2010 is shown in Figure 5.5. The mean Secchi depth slightly decreased in 2010. In terms of trends, Figure 5.5 indicates that lake transparency has steadily improved since 1980.

5.4. Chlorophyll-a

The mean chlorophyll-a from 1980 through 2010 is shown in Figure 5.6. The mean chlorophyll-a concentration slightly increased in 2010, but still remained below 15.0 ug/L. In terms of trends, Figure 5.6 shows that chlorophyll-a concentrations have slightly increased since 1980.

5.5. Phytoplankton & Zooplankton Biomass

The mean phytoplankton and zooplankton biomass from 1980 through 2010 is shown in Figures 5.7 and 5.8, respectively. Similar to chlorophyll-a, Figure 5.7 shows that phytoplankton biomass has slightly increased since 1980. Conversely, the zooplankton biomass has widely fluctuated and only a slight decrease in biomass was observed over the past 31 years.

Although the biomass has slightly increased, blue-green dominance (more species diversity) appears to be decreasing as shown in Figure 5.7. As noted in Section 5.3, this change in the phytoplankton community may be related to decreases in total phosphorus (Figures 5.1 and 5.2) and increases in total nitrogen (Figures 5.3 and 5.4). In general, higher nitrogen to phosphorus concentration ratios in lakes often favor green (Chlorophyta) over blue-green algae resulting in more species diversity and improved water clarity and aesthetics.

5.6. Carlson Trophic State Index Values

The mean Carlson Trophic State Index (TSI) values for total phosphorus, chlorophyll-a, and Secchi depth transparency from 1980 through 2010 is shown in Figures 5.9. As expected, the total phosphorus and Secchi transparency have gradually improved, while chlorophyll-a has marginally increased over the past 31 years.

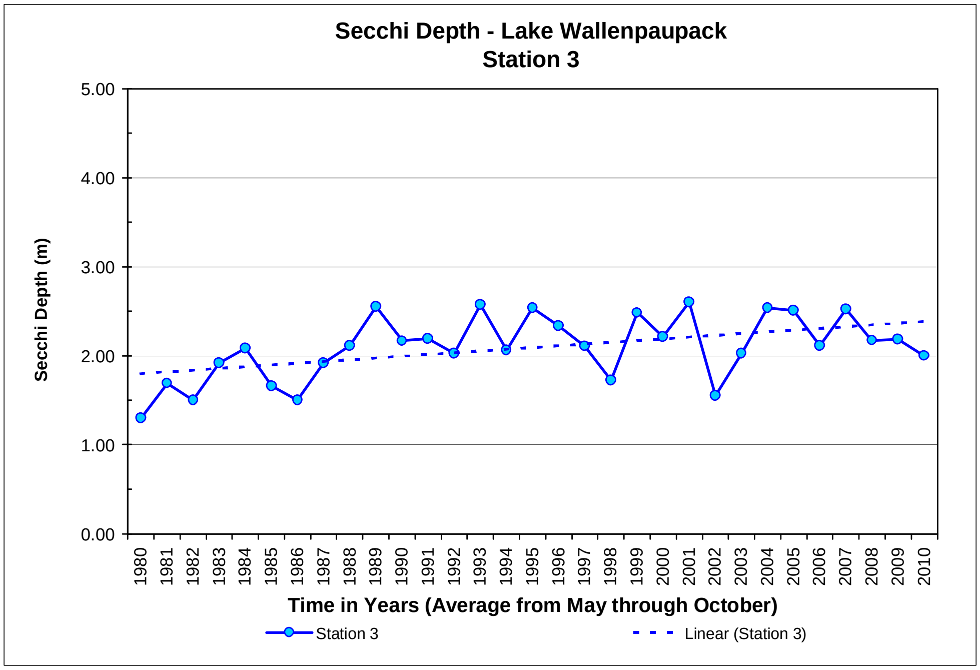

Figure 5.5 Historical Secchi Disk Transparency

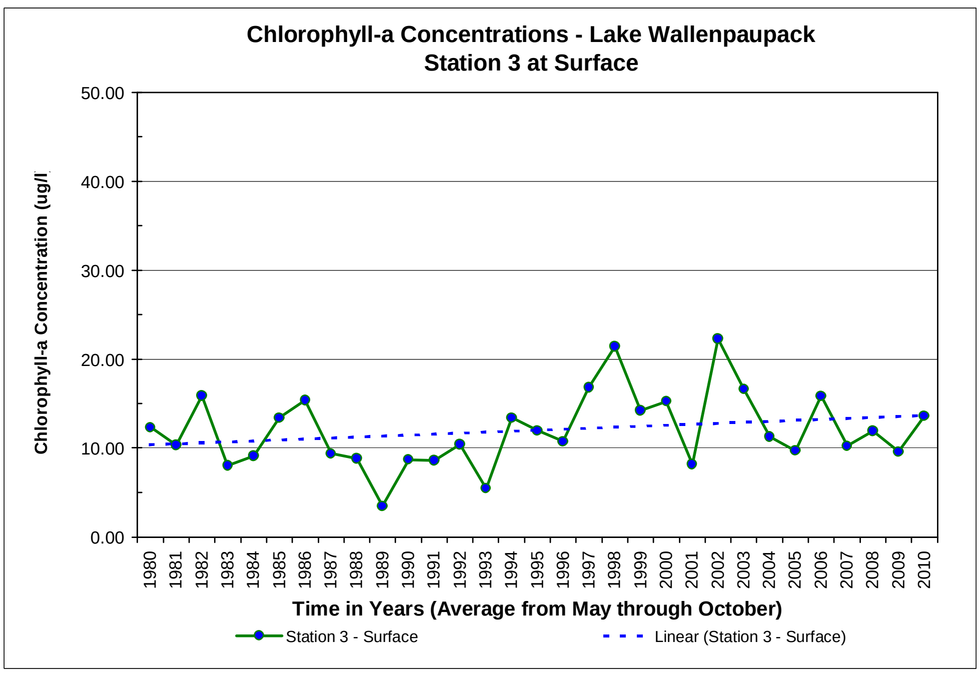

Figure 5.6 Historical Chlorophyll-a Concentrations

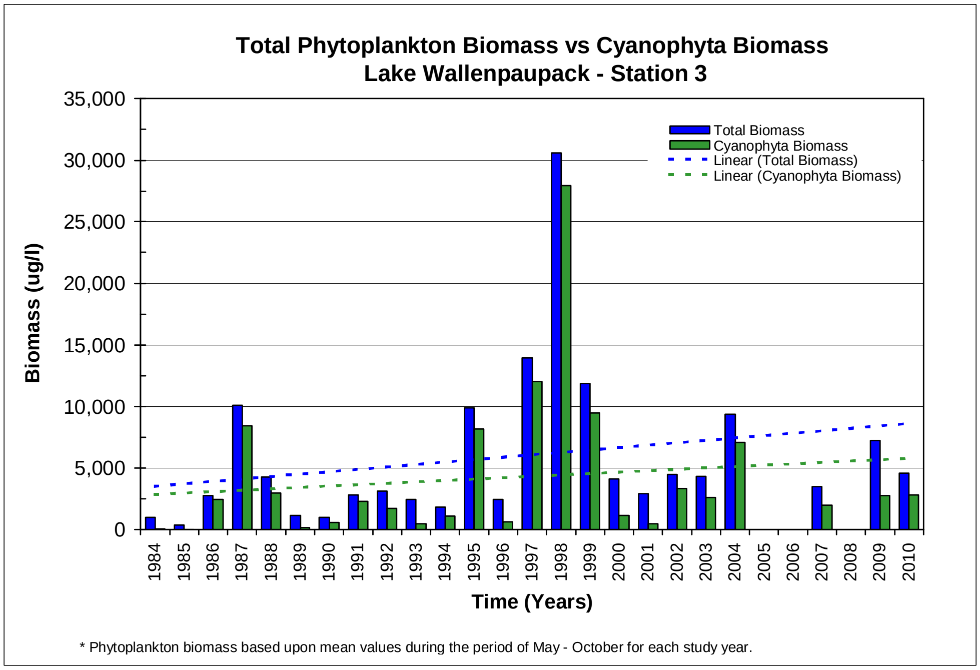

Figure 5.7 Historical Phytoplankton Biomass

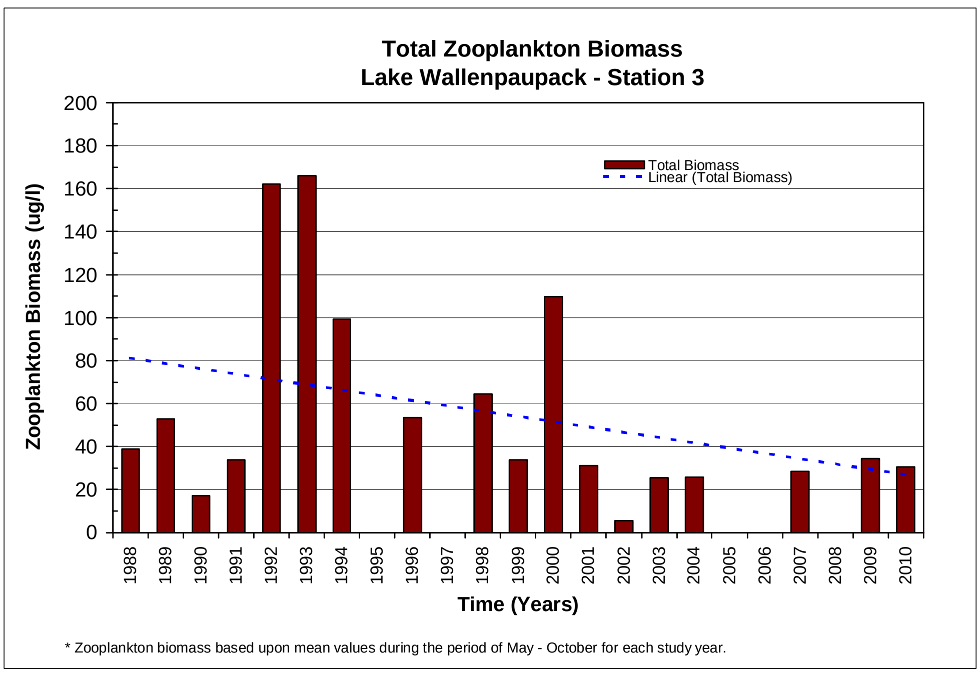

Figure 5.8 Historical Zooplankton Biomass

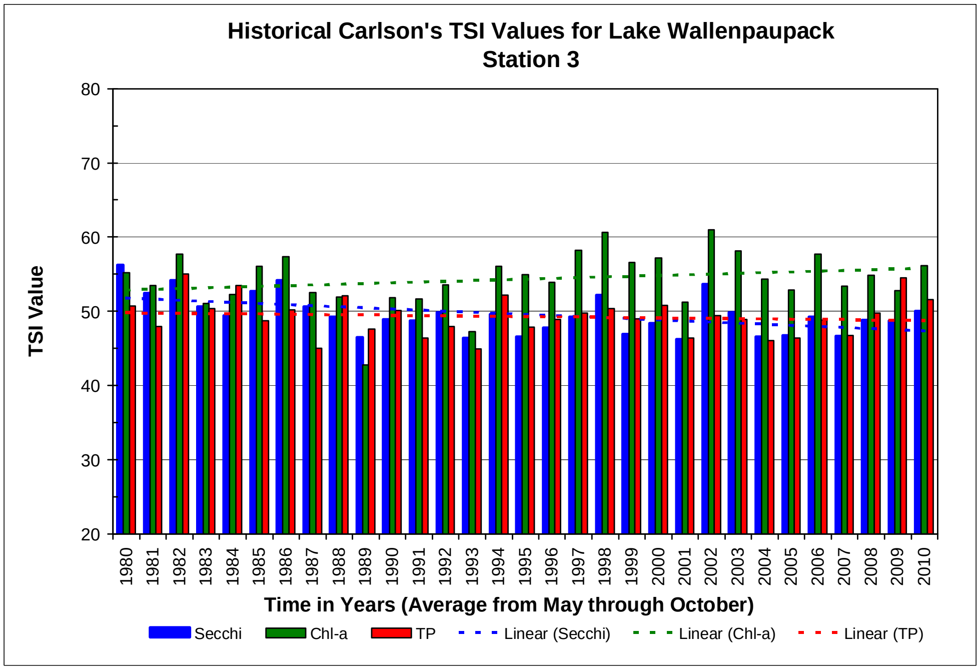

Figure 5.9 Historical Carlson's TSI Values

5.7. Summary of Historical Lake Data

Based upon trend analysis, the water quality of Lake Wallenpaupack has generally improved since 1980. Total phosphorus concentrations in surface and bottom waters and Secchi transparency (water clarity) have gradually improved over the past 31 years. In contrast, total nitrogen concentrations in surface and bottom waters marginally increased along with chlorophyll-a concentrations and phytoplankton biomass. The least amount of change was for zooplankton biomass, where only a slight decrease in biomass was observed over time.

It should be noted that water clarity (Secchi transparency) actually improved even though chlorophyll-a concentrations and phytoplankton biomass increased. Improved water clarity may be related to a shift in the phytoplankton community, where nuisance blue-green algal dominance appears to be decreasing. This shift may be attributed to decreases in total phosphorus and increases in total nitrogen in the lake. In general, higher nitrogen to phosphorus concentration ratios in lakes often favor green (Chlorophyta) over blue-green (Cyanophyta) algae.

6. Conclusions and Recommendations

Lake Wallenpaupack was classified as a slightly eutrophic reservoir in 2010. The mean Carlson TSI values for total phosphorus, chlorophyll-a, and Secchi disk transparency were 52, 56, and 50, respectively, for 2010. The lake was thermally stratified in 2010 from May through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified.

The lake was the most thermally stratified during the months of June, July and August in 2010. As in the past, the dissolved oxygen levels rapidly decreased within deeper lake waters (hypolimnion). The thermocline, which is the point where the temperature change is the greatest, divides the epilimnion (surface waters) and the hypolimnion (bottom waters), was located at a depth of approximately at 5 to 7 meters (16 to 23 feet) in June through August.

Phytoplankton data indicate that blue-green algae (Cyanophyta) are dominant during the months of July through October in 2010. The most common genera were *Aphanizomenon* and *Anabaena*. Further observation concluded that zooplankton biomass, in general, increased shortly after the phytoplankton biomass increased.

Based upon trend analysis, the water quality of Lake Wallenpaupack has generally improved since 1980. Total phosphorus concentrations in surface and bottom waters and Secchi transparency (water clarity) have gradually improved. Total nitrogen concentrations in surface and bottom waters marginally increased along with chlorophyll-a concentrations and phytoplankton biomass.

Over the past 31 years, water clarity (Secchi transparency) increased although chlorophyll-a and phytoplankton biomass have slightly increased. This appears to be related to a shift in the phytoplankton community, where blue-green algal dominance is less prevalent. The shift in the phytoplankton community may be attributed to decreases in total phosphorus and increases in total nitrogen in the lake. In general, higher nitrogen to phosphorus concentration ratios in lakes often favor green (Chlorophyta) over blue-green (Cyanophyta) algae resulting in more species diversity and improved water clarity and aesthetics.

Based upon the above conclusions, Aqua Link offers the following recommendations to the District:

1. Aqua Link should be retained to analyze future lake water quality data and prepare future annual lake reports. All lake water quality data would be entered into the newly created historical lake water quality database, as developed by Aqua Link, and subsequently analyzed by Aqua Link.

2. Aqua Link should be retained by the District to assist in all future lake monitoring activities. Aqua Link would be responsible for collecting all *insitu* water quality data using our instrumentation and data loggers.

3. ECM, Inc. should be retained as the contract laboratory for all water quality analysis. ECM will be responsible for analyzing water samples for the following parameters: alkalinity, total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total suspended solids and chlorophyll-a. The District should request that ECM use all Method Detection Limits (MDL) as established by Aqua Link for the 2010 lake monitoring program.

4. All phytoplankton and zooplankton samples should continue to be analyzed using the same methods used by Dr. Kenneth Wagner. All plankton data should be sent directly to Aqua Link in a Microsoft Excel format, thereby allowing us to easily import any newly acquired data into the water quality database for data analysis.

5. The lake should continue to be monitored at Stations 3 and 5. These stations should be monitored at least monthly from May through October. On each study date at each station, *insitu* water quality data (pH, dissolved oxygen, temperature, conductivity, specific conductance, total dissolved solids, and ORP) should be collected at one-meter intervals throughout the water column. Secchi disk transparency should also be measured and recorded.

6. Lake water samples should be collected at two sampling depths (surface and bottom) at each lake station. Surface water quality samples should be collected and analyzed for the following parameters: alkalinity, total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total suspended solids and chlorophyll-a. Bottom water quality samples will be collected and analyzed for the following parameters: alkalinity, total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrate, nitrite, and total suspended solids. In addition, lake water samples should be collected for phytoplankton and zooplankton analysis. Phytoplankton samples should be collected as composited samples of the photic zone – defined as twice the Secchi depth. Zooplankton samples should be collected as vertical tows of the entire water column with a 80 micron plankton net.

7. Literature Cited

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APPENDIX A

Glossary of Lake & Watershed Management Terms

APPENDIX B

Primer on Lake Ecology & Watershed Concepts

APPENDIX C

2010 Lake Water Quality Data