2017 FINAL REPORT

Lake Wallenpaupack Water Quality Monitoring Program

Prepared for:

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TABLE OF CONTENTS

Section No. **Page**

Appendices

Cover Page

Picture of Lake Wallenpaupack taken by Aqua Link.

List of Tables

Table No. **Page**

List of Figures

Figure No. **Page**

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.

2017 LWWMD Board of Directors

LWWMD Executive Director

Nick Spinelli

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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 2017, the Lake Wallenpaupack Watershed Management District (LWWMD) once again retained Aqua Link to serve as the District's lake consultant. Aqua Link and the District monitored the water quality of the lake from May through October. Thereafter, Aqua Link analyzed all of the newly acquired lake data and prepared the annual lake water quality report for the District. As part of this report, Aqua Link also compared the 2017 data to the historical data collected from 1980 through 2016 to determine whether lake water quality has improved or degraded over the past 38 years. The District first hired Aqua Link back in 2010 to rebuild the historical lake water quality database and to redesign the lake water quality monitoring program (Aqua Link 2012).

The water quality of Lake Wallenpaupack in 2017 declined slightly when compared to 2016 with respect to trophic state and its overall appearance. Climatologic factors such as higher than average temperature and average precipitation likely caused much of the decline in water quality. Water clarity was fair to good from May through August and began to decline in September due to increased biomass of phytoplankton (microscopic, free-floating algae). In terms of trophic state, Lake Wallenpaupack was classified as a slightly eutrophic reservoir in 2017. The mean Carlson TSI (Trophic State Index) values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 49, 58, and 50, respectively, for 2017. The lake was thermally stratified in 2017 from May through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified.

Phytoplankton biomass was dominated by genera from taxon Bacillariophyta, Cyanophyta, and Chrysophyta from May through June of 2017. In terms of biomass, From July through October of 2017, two genera from phyla Cyanophyta (Cyanobacteria or blue-green algae), *Aphanizomenon* and *Dolichospermum,* formerly known as *Anabaena* were most dominant. Biomass values for 2017, ranged from a minimum of 2,710 ug/L to a maximum of 6,824 ug/L Overall, the phytoplankton assemblages, with some exception of Cyanophyta dominance from July through October, were considered somewhat well distributed among taxa during the 2017 study period.

Overall, zooplankton biomass values between May through October of 2017 somewhat lower than past years. The reason for this mild decrease in zooplankton biomass is largely unknown and may be attributed to one or more factors. Several plausible explanations for a slight decline in zooplankton biomass are the occurrence of less favorable environmental conditions, lower availability of palatable phytoplankton (more blue-green algae), and more grazing by plankton eating fish (planktivores like shiners, minnows and juvenile gamefish) and aquatic insects in 2017. Furthermore, zooplankton biomass values were considered fairly well distributed among the taxa during the 2017 growing season.

Based upon trend analysis, the water quality of Lake Wallenpaupack has generally improved since 1980 even though there appears to be a significant annual warming trend in Northeastern Pennsylvania. Total phosphorus concentrations in surface and bottom waters and Secchi transparency (water clarity) have gradually improved. Total nitrogen concentrations in surface waters have been relatively steady since sampling began. Total nitrogen concentrations in bottom waters, chlorophyll-a concentrations, and phytoplankton biomass have marginally increased over time.

Lake water clarity (Secchi transparency) has improved even though chlorophyll-a concentrations 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 a decrease in total phosphorus and a slight increase 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).

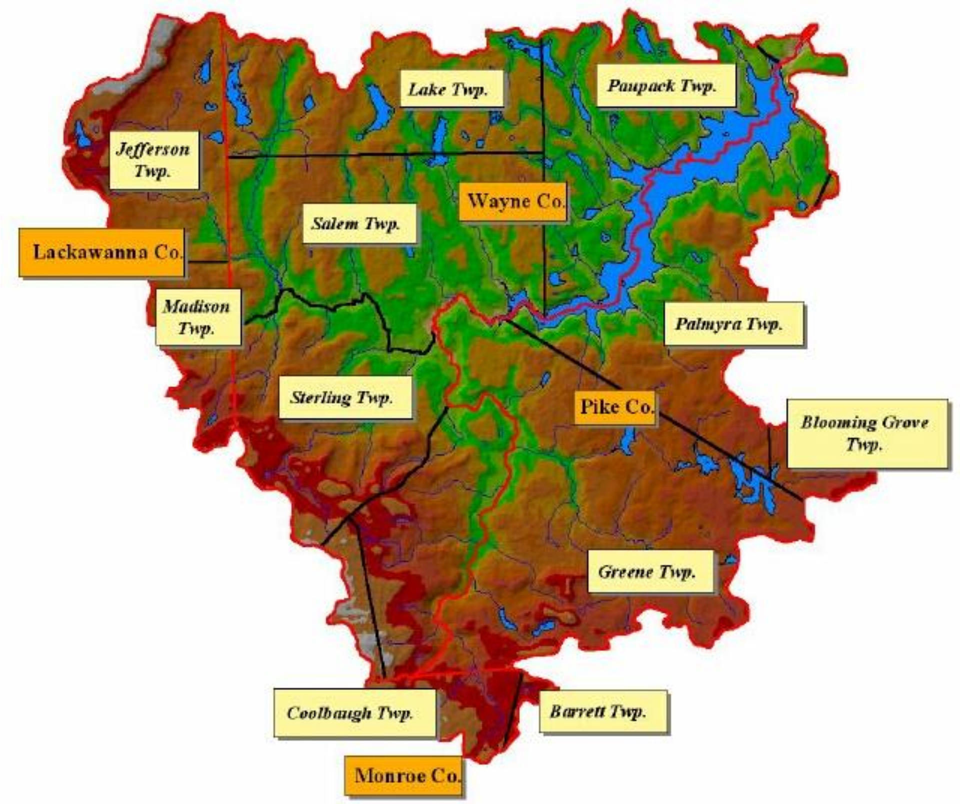


Figure 1.1 Lake Wallenpaupack Watershed

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).

On June 1, 2015, PPL reorganized itself to eventually become Talen Energy. Talen Energy then subsequently sold the lake and its associated dam to Brookfield Renewable Energy Partners, LP on April 1, 2016. Presently, Brookfield Renewable is the current owner of Lake Wallenpaupack.

Over the years, the water quality of Lake Wallenpaupack has been routinely monitored since 1980. In 2017, the Lake Wallenpaupack Watershed Management District (LWWMD) once again retained Aqua Link to assess the water quality of the lake in terms of trophic state and eutrophication. Aqua Link is a nationally recognized environmental consulting firm that specializes in stream, lake and watershed management and restoration. Aqua Link and the District monitored the water quality of the lake from May through October. Thereafter, Aqua Link analyzed all of the newly acquired lake data and prepared this annual lake water quality report for the District.

As part of this final report, Aqua Link thoroughly discusses all of the lake water quality data collected in 2017. Aqua Link also compared the 2017 data to the historical data collected from 1980 through 2016 to determine whether lake water quality has improved or degraded over the past 38 years. Lastly, this final report provides our conclusions and recommendations to further protect and improve lake water quality.

The District first hired Aqua Link back in the winter of 2009-10 to build a historical lake water quality database and to redesign the lake water quality monitoring program (Aqua Link 2012). The historical database initially was comprised of lake water quality data reported at five different lake stations that were typically monitored either bimonthly or monthly throughout the year from 1980 through 2009. This historical water quality database served as the foundation for this report.

Aqua Link redesigned the lake monitoring program to be more cost-effective and more sustainable for the District and its lake partners. Beginning in 2012, the lake monitoring program was reduced to two lake monitoring stations that were monitored monthly from May through October. The monitoring program continued to collect high quality data for those key water quality parameters relating to trophic state and the process of eutrophication. This pared down monitoring program still captures high quality water quality data during both the spring and fall turnover periods plus during the peak of the summer recreational season and early fall when lake problems are most prevalent.

2. Lake Monitoring Program & Field Observations

2.1. Lake Monitoring Program

Aqua Link and LWWMD monitored the water quality of Lake Wallenpaupack in 2017. The lake was monitored at Stations 3 and 5 in 2017 (Figure 2.1). These monitoring stations were monitored once a month during May through October.

In 2017, *insitu* data were collected at the designated lake stations on each study date. These *in-situ* water quality data were measured and recorded. *In-situ* water quality data (pH, dissolved oxygen, temperature, conductivity, specific conductivity, and oxidation reduction potential) were measured and recorded simultaneously using a YSI Model 600XL Sonde and a YSI 600D data logger. These data were collected at one-meter intervals from the surface to the bottom of the lake at each station. In addition, 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 2017, 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 Van Dorn 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, surface samples were collected for phytoplankton and composite samples were collected zooplankton analysis (identification and enumeration) at Station 3 on each study date. Surface water samples were collected using the Van Dorn sampler for later phytoplankton analysis. The composite samples for zooplankton identification and enumeration were obtained by vertically towing the entire lake water column using a 80 um (micron), 6 inch diameter, mesh plankton net.

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 and zooplankton samples were preserved in the field and subsequently analyzed by Dr. Kenneth Wagner of Wilbraham, Massachusetts.

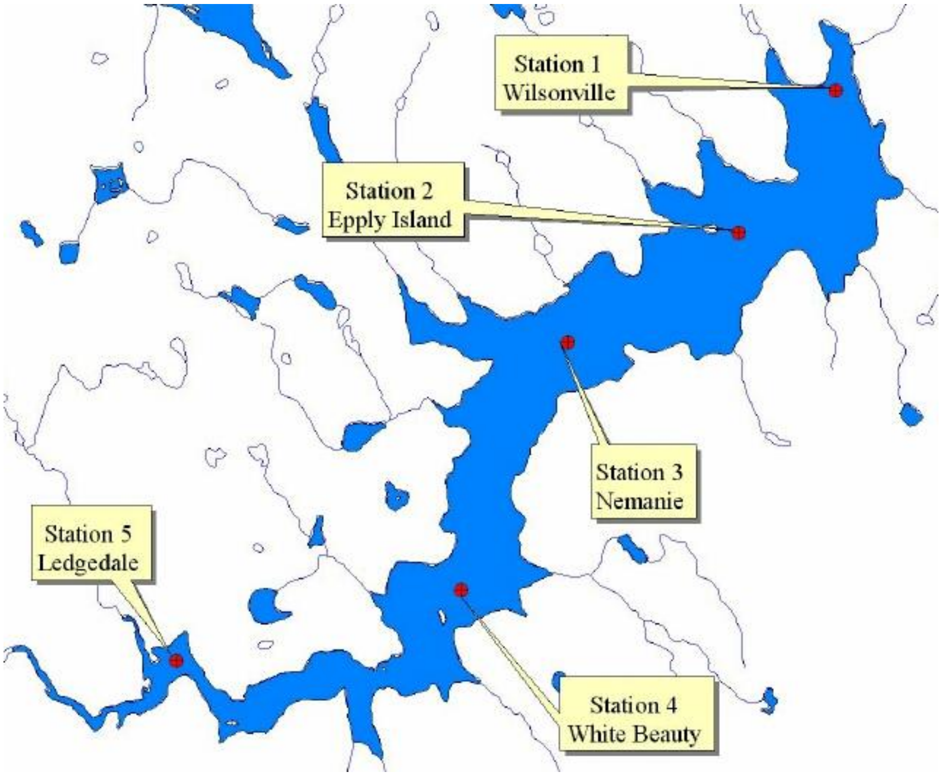


Figure 2.1 Lake Monitoring Stations

2.2. Field Observations

The overall water clarity at Station 3 at Lake Wallenpaupack was relatively consistent from May through August in 2017. During this period, the water was fairly clear, but slightly turbid with a light brownish tint from May through July to a slightly greenish tint in August. At Station 3, the overall water clarity was best from June through August of 2017. However, August was the first month where the water color changed from fairly clear with a light brownish tint to a cloudier appearance with a greenish tint. During August, the overall phytoplankton biomass was not excessive, and therefore, better clarity was observed in August when compared to September, when phytoplankton biomass increased substantially. In September, Aqua Link observed an overall decline in water clarity throughout most of the lake. Reduced water clarity was attributed to blue-green algal blooms. A somewhat significant drop in water clarity (Secchi disk depth of 1.5 meters or 4.9 feet) was observed at Station 3 in September. In addition, mostly in September and October, Aqua Link observed a surface buildup of windblown planktonic algae in some sections of the lake. This is a commonly observed in lakes where planktonic algae are allowed to accumulate in the windward sections of lakes.

As noted previously, lake water clarity first began to deteriorate in August. This deterioration was more pronounced especially in September and slightly less evident in October. In September and October, Aqua Link observed moderate amounts of blue-green algae near the lake surface (within the first meter or less).

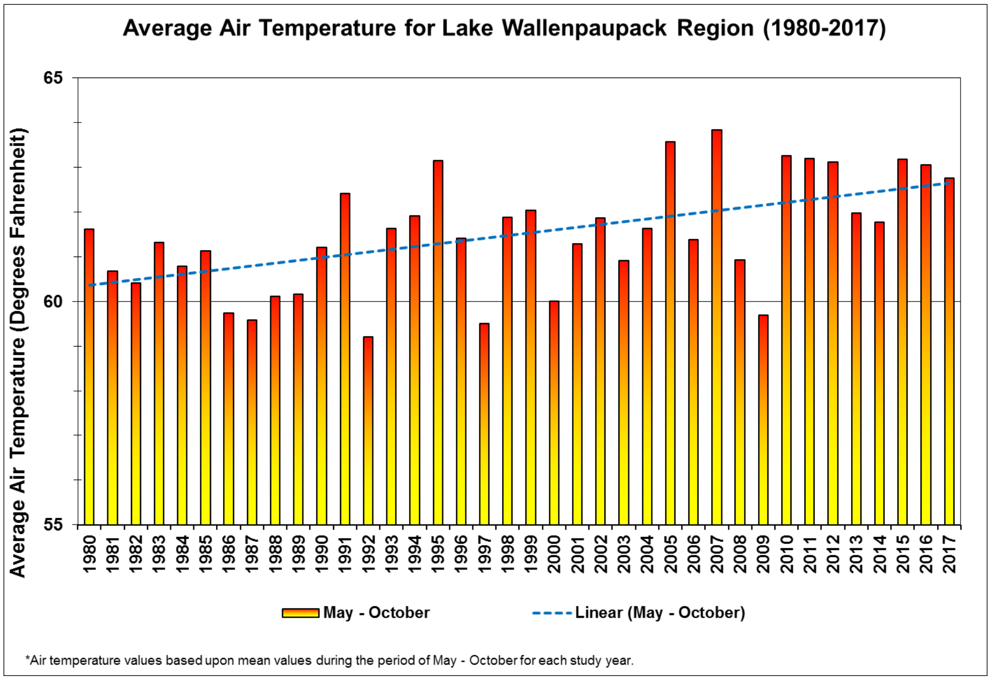
From May through October, no invasive submerged macrophytes were observed in transit to and from the lake monitoring stations (Stations 3 and 5). However, in 2016, Aqua Link was asked to investigate a small patch of submerged plants that was located on the western shore of the lake. Based upon our preliminary field identification, this small patch of aquatic vegetation appeared to be the invasive plant, Eurasian watermilfoil (*Myriophyllum spicatum*). Another possibility is that these plants are a hybrid of Eurasian watermilfoil and native northern watermilfoil (*Myriophyllum sibiricum*). The only way to accurately identify this plant is by collecting and submitting a plant sample to a laboratory for genetic testing.

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, temperatures in 2017 were considered to be above average with average precipitation when compared to data presented over the previous 37 years.

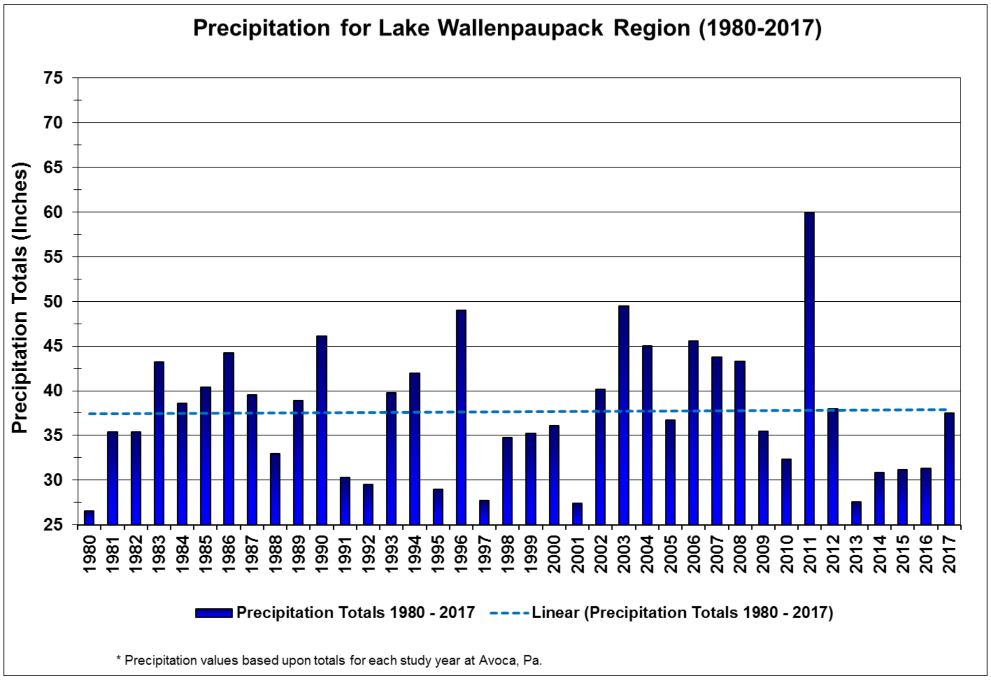
Figure 3.1 shows the average (mean) air temperatures for the growing season (May through October) from 1980 through 2017. Monthly temperature data were obtained via the Internet at the Pennsylvania State Climatologist website. Information at this website is provided by the College of Earth and Mineral 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. The trend line suggests a rise in mean temperatures in the region from the period of May through October since 1980, with some significant yearly fluctuations observed. Over the past 38 years, only ten times has the annual mean air temperature exceeded 62 degrees and six of these years occurred recently from 2010-17 (eight year period). This annual warming trend in the NE PA may be adversely impacting lake water quality due by providing more favorable conditions for algae growth and reproduction – primarily unfavorable blue-green alga species.

Figure 3.2 shows the total precipitation amounts from 1980 through 2017. Annual precipitation data was obtained via the Internet at the NOAA national weather service website. Precipitation measurements (recorded in inches) were reported at Avoca, Pennsylvania from 1980 through 2017. This data was released on a provisional basis and may be subject to change. The trend line suggests relatively consistent annual precipitation in the region since 1980. However, similarly to the average air temperature graph, significant fluctuations through the years are quite evident. Overall, annual precipitation amounts have been consistently low for the past four years prior to 2017, in NE PA. This will inevitably impact the flushing rate and hydraulic residence time of the lake, which in turn will impact lake water quality to some extent. At this point, it is unclear whether lake water quality and clarity are impacted positively or negatively in response to lower hydraulic loadings (lower volumes of incoming water to the lake via streams and shallow groundwater) to the lake.



*Air temperature values based upon mean values during the period of May - October for each study year.

Figure 3.1 Historical Air Temperature Data in the Lake Wallenpaupack Region



* Precipitation values based upon totals for each study year at Avoca, Pa.

Figure 3.2 Historical Precipitation Data in the Lake Wallenpaupack Region

4. Lake Water Quality Data Results for 2017

The water quality data for Lake Wallenpaupack in 2017 are presented in this section of the report. As discussed in Section 2, the lake was monitored at Stations 3 and 5 in 2017 (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 2017 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, and 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 ^{o}F (12.8 to 15.6 ^{o}C). Trout may withstand water temperatures above 80 ^{o}F (26.7 ^{o}C) for several hours, but if water temperatures exceed 75 ^{o}F (23.9 ^{o}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 ^{o}F (26.7 ^{o}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 2017 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 13.2 meters (43.3 feet) in 2017. The lake was strongly, thermally stratified during the months of May through September (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 10 meters (16.4 to 32.8 feet) during the period of May through September.

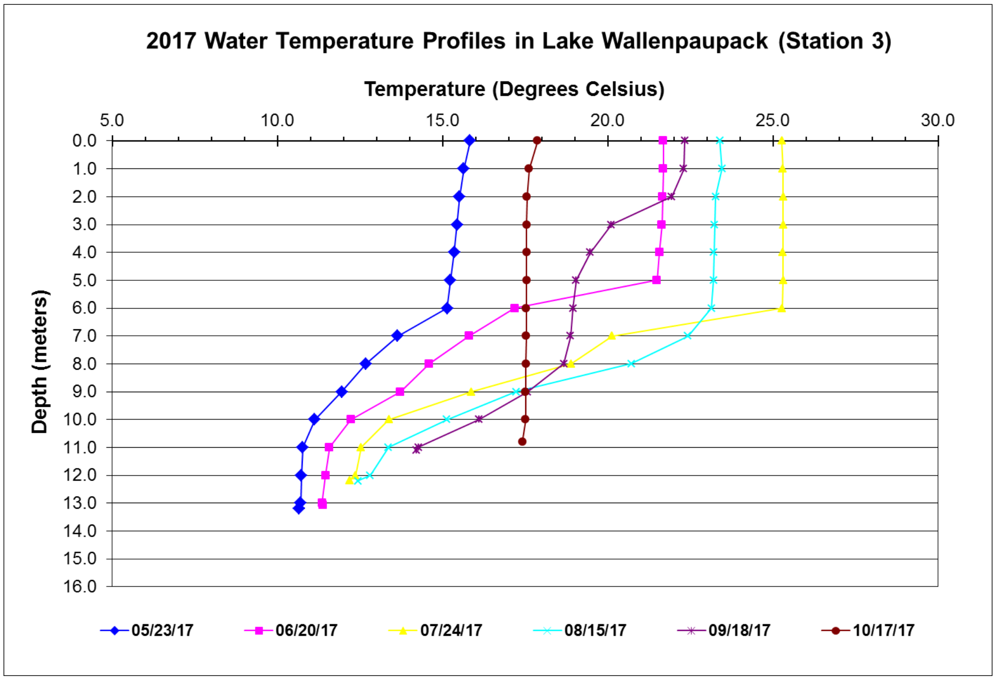


Figure 4.1 Water Temperature Profiles at Station 3 in 2017

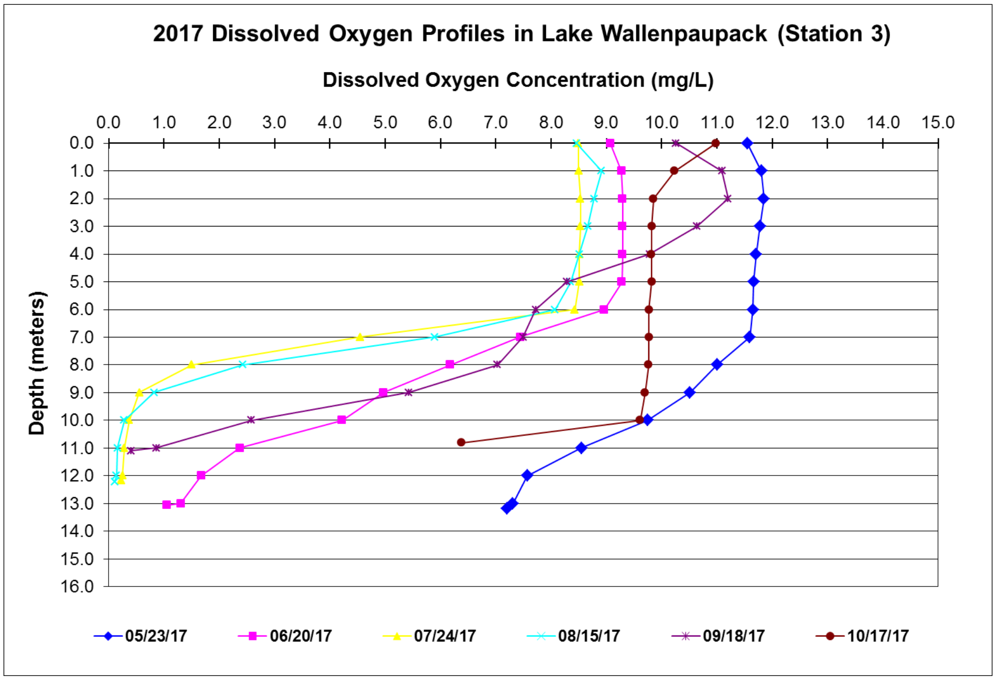


Figure 4.2 Dissolved Oxygen Profiles at Station 3 in 2017

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^{2-}) 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 2017 mean pH values for surface and bottom waters are presented in Table 4.1. Overall, both the surface and bottom waters are considered to be slightly acidic. The slightly higher mean values for the surface waters were due to increased levels of photosynthesis by phytoplankton in the epilimnion (surface waters).

The mean alkalinity concentrations for surface and bottom waters in 2017 are also 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 2017

Year	*pH (standard units, s.u.)*		*Alkalinity (mg/l as $CaCO_3$)*	
	Surface	*Bottom*	*Surface*	*Bottom*
2017	6.27	6.18	27.2	29.8

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 2017 mean total phosphorus concentrations for surface and bottom waters were 0.023 mg/L and 0.057 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 moderately mesotrophic in 2017.

The 2017 mean dissolved reactive phosphorus concentrations for surface and bottom waters were 0.003 mg/L and 0.025 mg/L as P, respectively (Table 4.2). Low dissolved reactive phosphorus concentrations in the surface waters 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 2017

Year	*Total Phosphorus (mg/L as P)*		*Dissolved Reactive Phosphorus (mg/L as P)*	
	Surface	*Bottom*	*Surface*	*Bottom*
2017	0.023	0.057	0.003	0.025

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 2017 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 2017 mean total nitrogen concentration for the bottom waters was moderately higher than 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 2017

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
2017	0.414	0.587	0.372	0.463	0.043	0.124	0.022	0.145

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 2017.

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.

Lake Wallenpaupack

The 2017 mean Secchi disk transparency value for Lake Wallenpaupack was 2.13 meters (7.0 feet). Secchi disk transparency values ranged from 1.5 to 2.8 meters (4.9 to 9.2 feet) for all study dates. Based upon Nurnberg (2001), the lake is classified as highly mesotrophic.

The 2017 mean chlorophyll-a concentration in Lake Wallenpaupack was 15.6 ug/L. Chlorophyll-a concentrations ranged from 8.7 ug/L to 30.0 ug/L during the study period. According to the Nurnberg criteria, the mean chlorophyll-a concentration indicates moderately eutrophic conditions.

It should be noted that the lowest Secchi disk transparencies for the lake occurred when phytoplankton levels were at their highest (highest chlorophyll-a concentrations and phytoplankton biomass) in September followed by October.

Table 4.4 Mean Secchi & Chlorophyll-a Values at Station 3 in 2017

Year	*Secchi Disk Transparency (m)*	*Chlorophyll-a (ug/l)*
2017	2.13	15.6

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 2017 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 moderately low. 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.

Table 4.5 Mean Total Suspended Solids Concentrations at Station 3 in 2017

Year	*Total Suspended Solids (mg/l)*	
	Surface	*Bottom*
2017	3.7	5.5

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.

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.

It should be noted that the nomenclature of phytoplankton taxonomy (i.e. scientific classification) has experienced some minor revisions. This is a regular occurrence in the scientific community; consequently our scientists strive to stay up to date with this ever-changing system. The most notable change regards the genus *Anabaena* in the phylum Cyanophyta. *Anabaena* (Cyanophyta) has been the accepted name of this taxa for countless years. However a change has occurred and now the genus *Anabaena* (Cyanophyta) is known as *Dolichospermum* (Cyanophyta).

Lake Wallenpaupack

The phytoplankton community in 2017 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 2,710 ug/L (micrograms per liter) to 6,824 ug/L for 2017, as shown in Figure 4.3. The highest phytoplankton biomass value was reported in September of 2017. 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 was largely dominated by *Synedra* (Bacillariophyta) followed closely by *Aphanizomenon* (Cyanophyta) and *Cyclotella* (Bacillariophyta) in May of 2017, as shown in Figure 4.3. A shift was observed in June when *Dinobryon* (Chrysophyta) became solely dominant. During July, *Aphanizomenon* was largely dominant followed distantly by *Dinobryon*. From August through September, *Dolichospermum* (Cyanophyta) became the most dominant. In October, the biomass of *Aphanizomenon* increased once again and became slightly more dominant than *Dolichospermum.* As previously mentioned, biomass values for 2017, ranged from a minimum of 2,710 ug/L to a maximum of 6,824 ug/L (Figure 4.3). Overall, the phytoplankton assemblages, with some exception of Cyanophyta dominance from July through October, were considered somewhat well distributed among taxa during the 2017 study period.

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.

Lake Wallenpaupack

Zooplankton communities in 2017 were represented by genera from four different taxa: Protozoa (protozoans), Rotifera (rotifers), Copepoda (crustacean), and Cladoceran (crustacean).

Overall, zooplankton biomass values between May through October of 2017 somewhat lower than past years. The reason for this mild decrease in zooplankton biomass is largely unknown and may be attributed to one or more factors. Several plausible explanations for a slight decline in zooplankton biomass are the occurrence of less favorable environmental conditions, lower availability of palatable phytoplankton (more blue-green algae), and more grazing by plankton eating fish (planktivores like shiners, minnows and juvenile gamefish) and aquatic insects in 2017.

Furthermore, zooplankton biomass values were considered fairly well distributed among the taxa during the 2017 growing season as shown in Figure 4.4. Copepods were most dominant taxa from May through September while Cladocerans were most dominant in October of 2017.

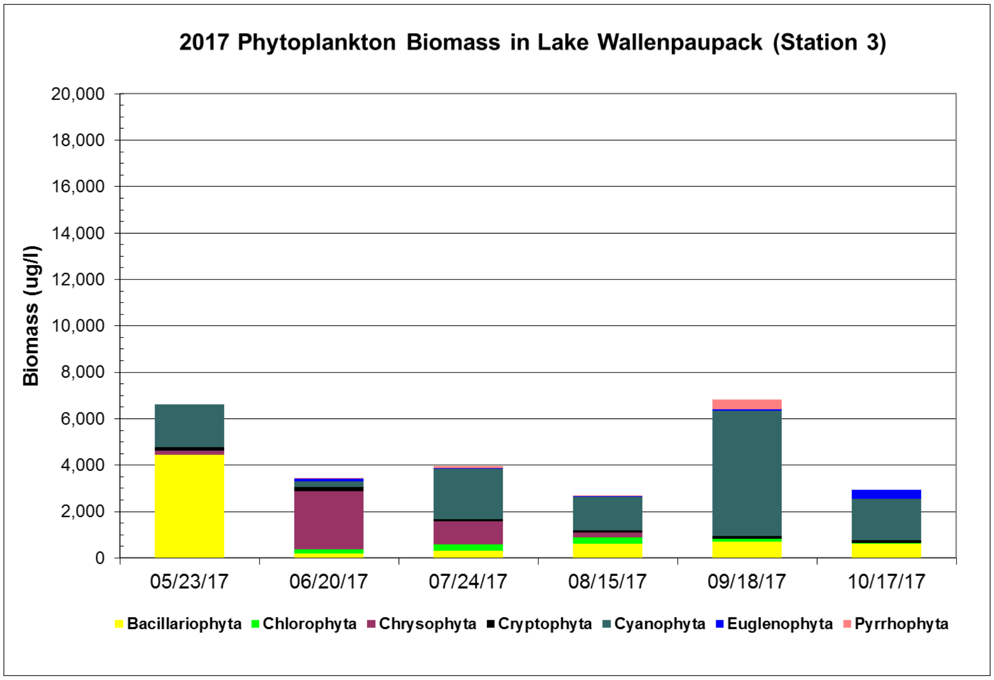


Figure 4.3 Phytoplankton Biomass at Station 3 in 2017

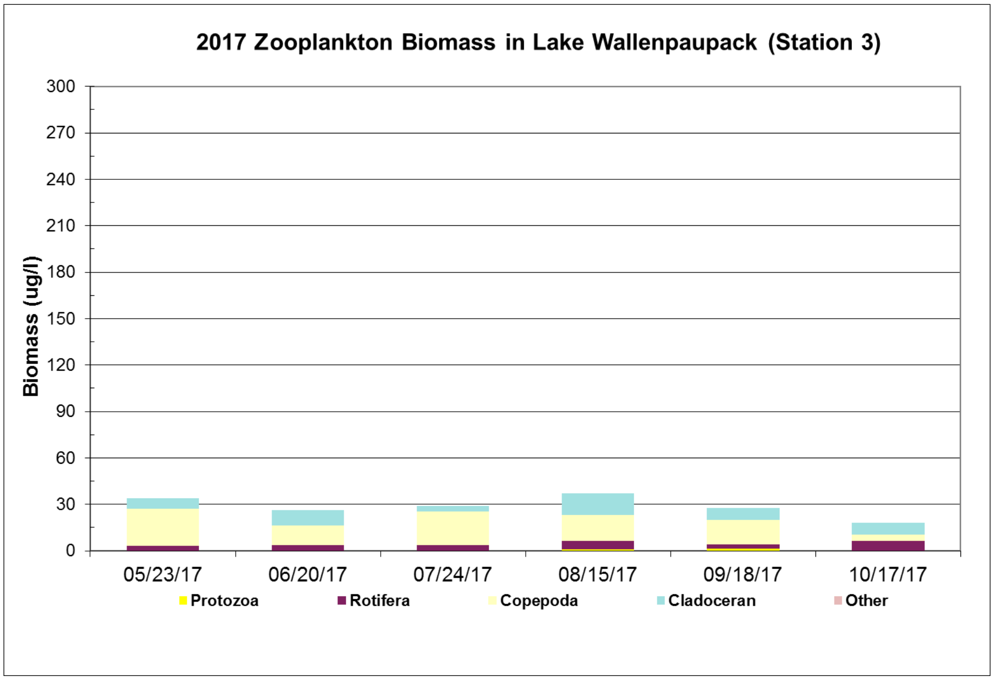


Figure 4.4 Zooplankton Biomass at Station 3 in 2017

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 Secchi disk depths, chlorophyll-a concentrations, and total phosphorus concentrations for many lakes. Secchi disk depth is a common measure of lake transparency. Chlorophyll-a is a plant pigment present in all algae and is used to provide an indication of the biomass of phytoplankton. Total phosphorus was chosen for the index because phosphorus is often the nutrient limiting for phytoplanktonic growth in lakes.

As part of this study, TSI values were determined for Secchi disk depth, chlorophyll-a data, and total phosphorus data for each of the study dates. Secchi disk depths, chlorophyll-a concentrations, and total phosphorus concentrations 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, trophic state 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.

Lake Wallenpaupack

The calculated 2017 mean Carlson TSI values for Secchi depth, chlorophyll-a, and total phosphorus are presented in Table 4.6. The Secchi depth transparency TSI value suggests highly mesotrophic conditions, the chlorophyll-a TSI value suggests eutrophic conditions, while the TSI value for total phosphorus suggests borderline highly mesotrophic - slightly eutrophic conditions. Based upon the above, Lake Wallenpaupack is best classified as a slightly eutrophic reservoir in 2017.

Table 4.6 Mean Carlson's TSI Values at Station 3 in 2017

Year	*Trophic State Index (TSI) Values*		
	Secchi Depth	*Chl-a*	*Total P*
2017	49	58	50

Note: Mean TSI values determined by averaging the individual TSI values for each parameter during the 2017 study period.

4.9. Summary of Lake Assessment Data

Lake Wallenpaupack was classified as a slightly eutrophic reservoir in 2017. The mean Carlson TSI values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 49, 58, and 50, respectively, for 2017. The Secchi depth transparency TSI value suggests highly mesotrophic conditions, the chlorophyll-a TSI value suggests eutrophic conditions, while the TSI value for total phosphorus suggests borderline highly mesotrophic - slightly eutrophic conditions

The lake thermally stratified in 2017 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 thermally stratified during the months of May through September in 2017. 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 10 meters (16.4 to 32.8 feet) during the period of May through September.

Phytoplankton data indicate that blue-green algae (Cyanophyta) were dominant during most of the growing season. The most common genera were *Aphanizomenon* and *Dolichospermum*, formerly known as *Anabaena*, with the exception of May and June of 2017, when a more diverse assemblage was observed.

5. Historical Lake Water Quality Trends

Aqua Link evaluated historical water quality data collected in Lake Wallenpaupack from 1980 through 2017. 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 (epilimnion) 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 is centrally located within the lake and 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 2017 for surface and bottom waters are shown in Figures 5.1 and 5.2, respectively. The total phosphorus levels in both surface and bottom waters increased slightly in 2017 over the 2016 mean values. In terms of trends, Figures 5.1 and 5.2 indicate that total phosphorus concentrations have slightly decreased in the surface waters and significantly decreased in the bottom waters since 1980.

5.2. Nitrogen

The mean total nitrogen concentrations from 1980 through 2017 for surface and bottom waters are shown in Figures 5.3 and 5.4, respectively. The total nitrogen levels in surface decreased slightly and total nitrogen levels in bottom waters increased slightly in 2017 over the 2016 mean values.

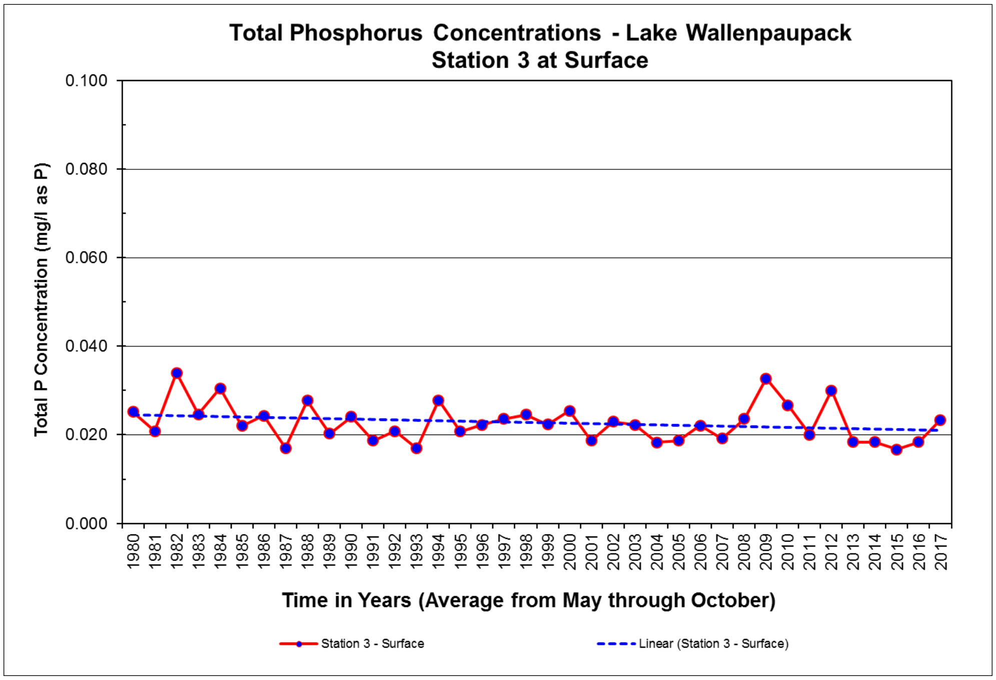


Figure 5.1 Historical Total Phosphorus Concentrations in Surface Waters

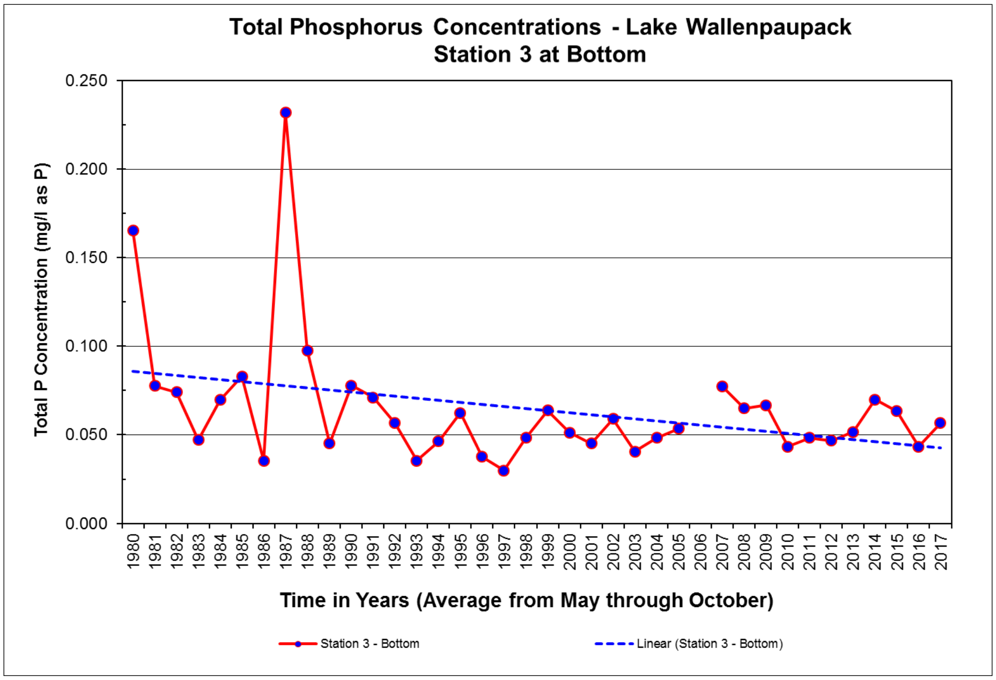


Figure 5.2 Historical Total Phosphorus Concentrations in Bottom Waters

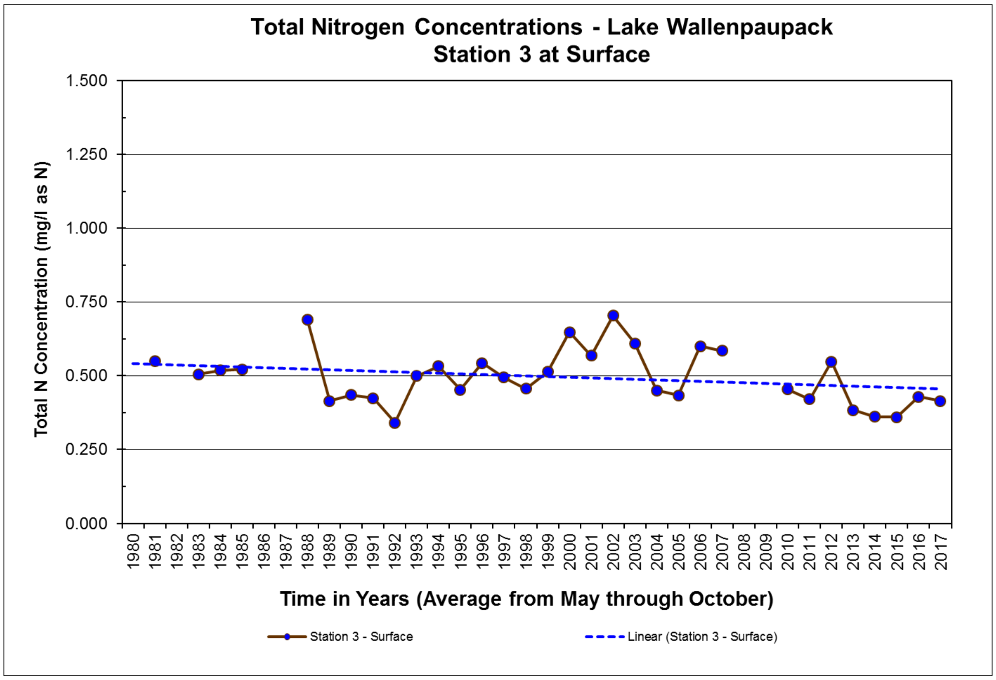


Figure 5.3 Historical Total Nitrogen Concentrations in Surface Waters

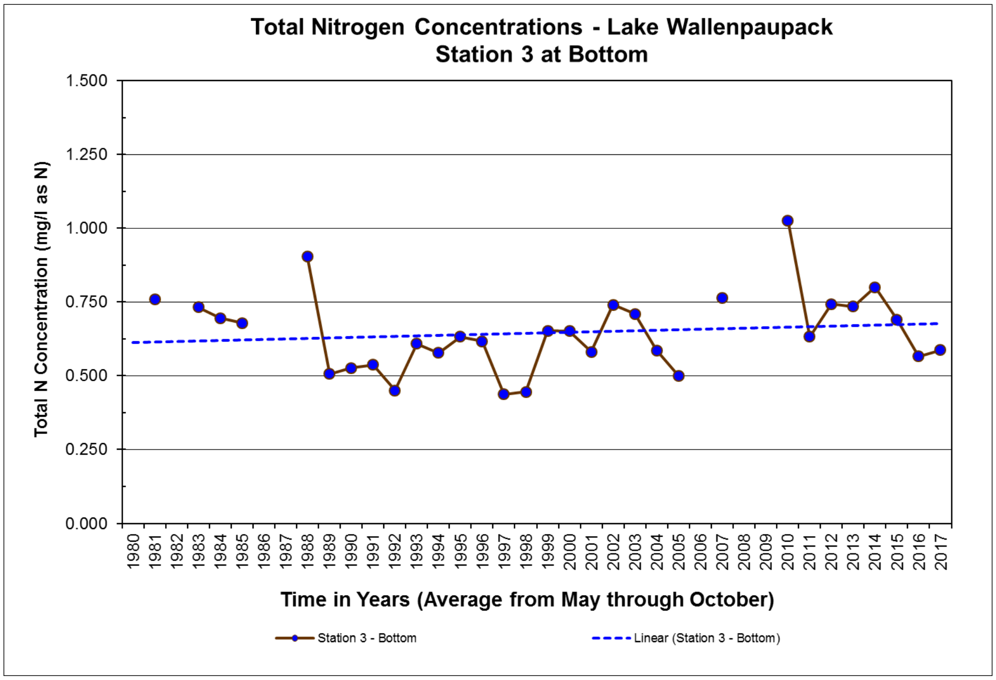


Figure 5.4 Historical Total Nitrogen Concentrations in Bottom Waters

These slight fluctuations are typical from year to year. In terms of trends, Figures 5.3 and 5.4 indicate that total nitrogen concentrations near the lake surface have decreased very slightly while total nitrogen concentrations near the bottom waters have increased very slightly since 1980.

5.3. Secchi Transparency

The mean Secchi disk transparency from 1980 through 2017 is shown in Figure 5.5. The mean Secchi depth decreased slightly from 2016 to 2017. In terms of trends, Figure 5.5 indicates that lake transparency has steadily improved since 1980.

5.4. Chlorophyll-a

The mean chlorophyll-a concentration from 1980 through 2017 are shown in Figure 5.6. The mean chlorophyll-a concentration in 2017 increased slightly from the concentration observed in 2016. Although this increase was observed, the increase was only slight and is a typical season to season fluctuation. In terms of trends, Figure 5.6 shows that chlorophyll-a concentration has slightly increased since 1980.

5.5. Phytoplankton & Zooplankton Biomass

The mean phytoplankton and zooplankton biomass values are historically illustrated in Figures 5.7 and 5.8, respectively. Phytoplankton biomass decreased slightly and zooplankton biomass values decreased considerably in 2017. Overall, Figures 5.7 and 5.8 show that phytoplankton and zooplankton biomass values have fluctuated widely throughout the timeframe indicated. In terms of trends, the plotted regression lines suggest that phytoplankton and zooplankton biomass have slightly increased and decreased, respectively.

Since 2010, total phytoplankton biomass has generally remained below 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 from the unusually high 2016 level. The 2017 biomass more closely corresponds to a typical biomass historically.

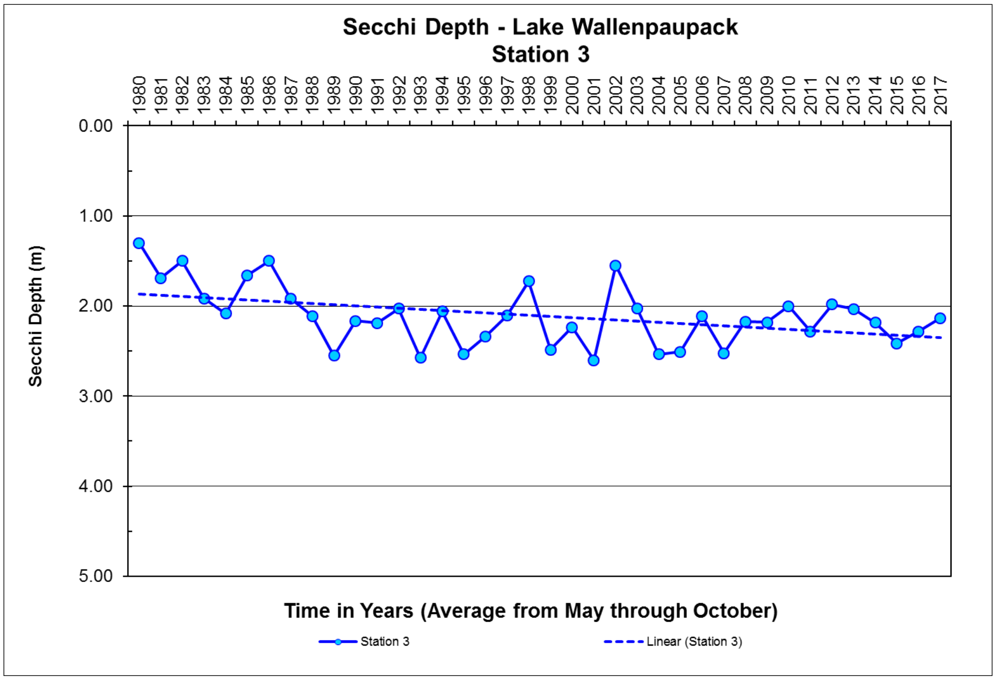


Figure 5.5 Historical Secchi Disk Transparency

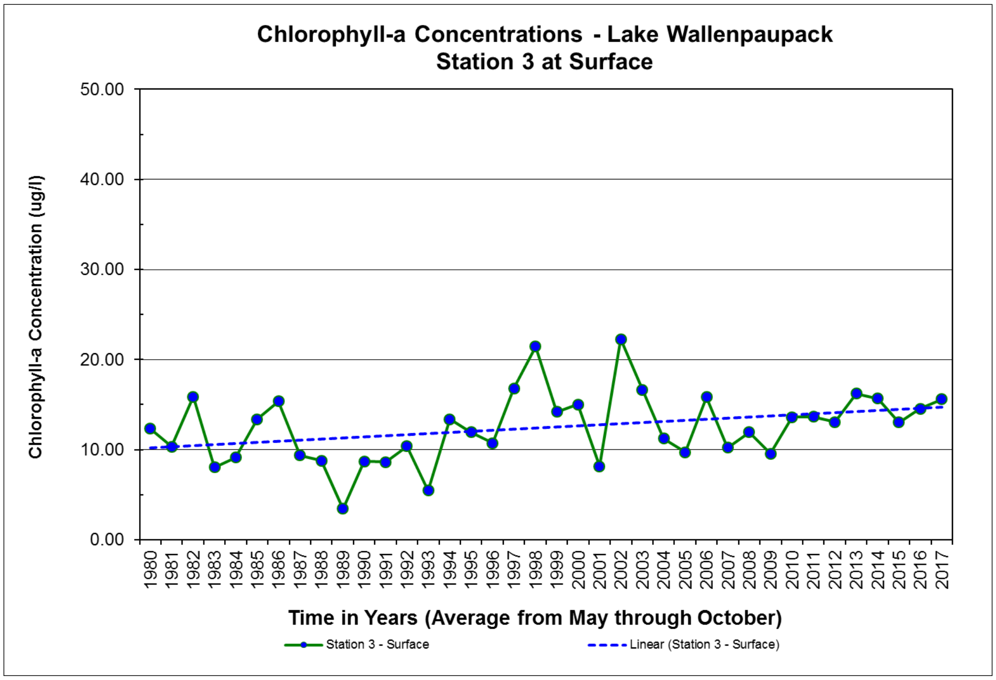


Figure 5.6 Historical Chlorophyll-a Concentrations

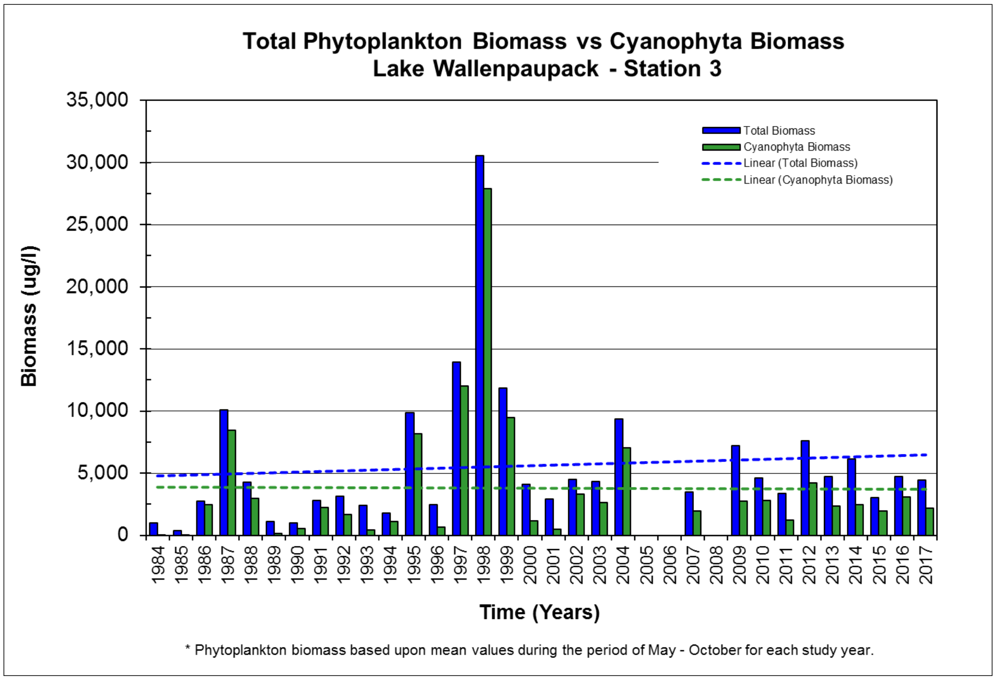


Figure 5.7 Historical Phytoplankton Biomass

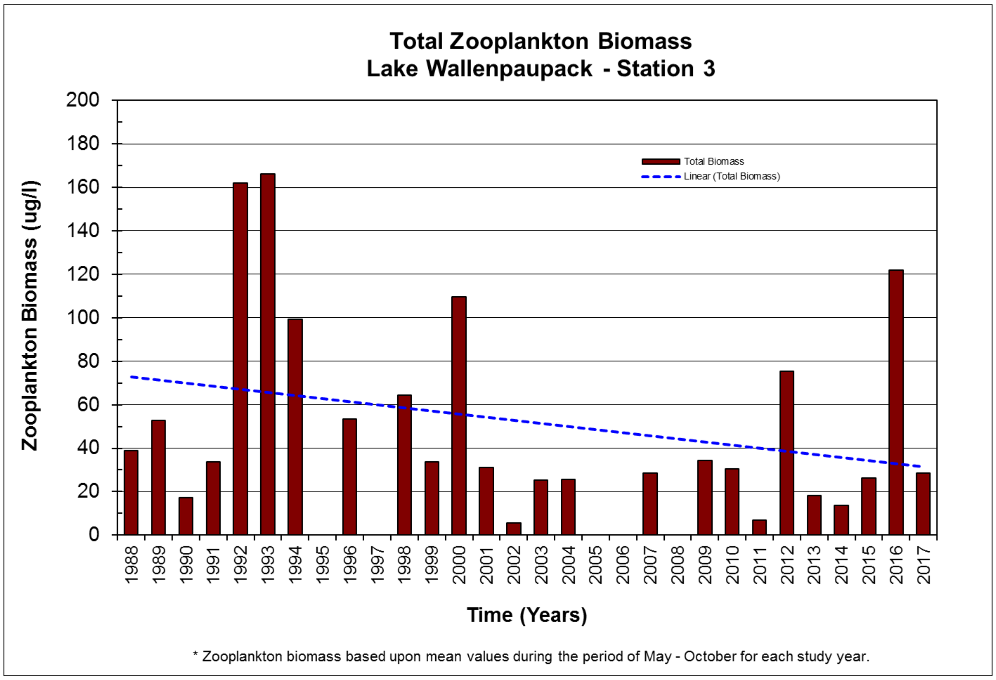


Figure 5.8 Historical Zooplankton Biomass

It is interesting to note that blue-green algal biomass (Cyanophyta) has remained very consistent historically when compared to an increasing total phytoplankton biomass (Figure 5.7). Lower blue-green dominance may be related to decreases in total phosphorus concentrations (Figures 5.1 and 5.2) and relatively consistent total nitrogen concentrations (Figures 5.3 and 5.4). In general, higher nitrogen to phosphorus concentration ratios in lakes often favor green (Chlorophyta) over blue-green algae (Cyanophyta) 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 Secchi disk transparency, chlorophyll-a concentrations, and total phosphorus concentrations from 1980 through 2017 are 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 38 years.

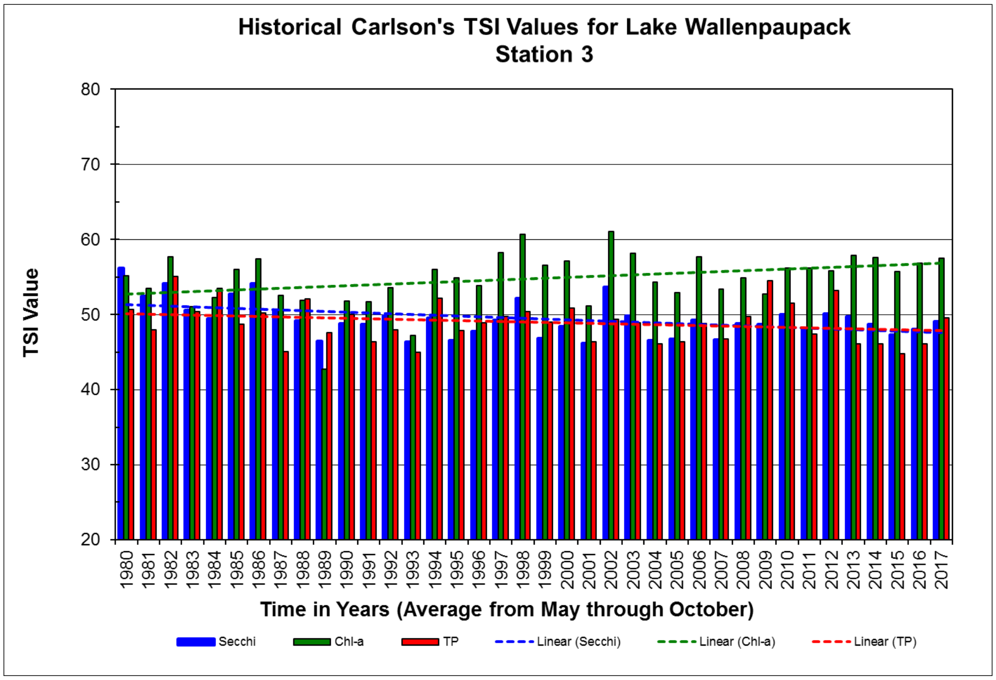


Figure 5.9 Historical Carlson's TSI Values

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 38 years. Total nitrogen concentrations in surface waters have slightly fluctuated and declined since sampling began. In contrast, total nitrogen concentrations in bottom waters slightly increased along with chlorophyll-a concentrations. Phytoplankton and zooplankton biomasses have fluctuated widely over the study period, but the overall trends have been that phytoplankton and zooplankton biomass have slightly increased and decreased, respectively.

In terms of water quality trends, it should be noted that lake water clarity (Secchi disk transparency) has generally improved even though chlorophyll-a concentrations and phytoplankton biomass have slightly 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. In addition, the general trend of decreasing zooplankton biomass may be related to more intense grazing pressure of larger zooplankton by predators (planktivorous fish and aquatic insects).

Since 2010, total phytoplankton biomass has generally remained below 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 from the unusually high 2016 level. The 2017 biomass more closely corresponds to a typical biomass historically. The inflated biomass observed in 2016 appears to be an anomaly after seeing 2017 zooplankton biomass levels returning to more typical levels. However, more data needs to be obtained to confirm that the 2016 biomass values were in fact an anomaly and not a new typical level.

6. Conclusions and Recommendations

The water quality of Lake Wallenpaupack was considered fair to good with respect to trophic state and its overall appearance in 2017. Water clarity was good from May through August and began to decline in September due to increased quantities of phytoplankton (microscopic, free-floating algae). In terms of trophic state, Lake Wallenpaupack is best classified as a slightly eutrophic reservoir in 2017. The mean Carlson TSI (Trophic State Index) values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 49, 58, and 50, respectively, for 2017.

On an annual basis, lake water clarity in terms of Secchi disk transparency tends to decrease in late summer and early fall. The lowest Secchi disk transparencies (lake water clarity) generally occur in September and October when phytoplankton biomass tends to peak. As expected, increases in phytoplankton biomass agree well with increases in chlorophyll-a concentration. The most prevalent group of algae in late summer and fall are blue-green algae (Cyanophyta).

In 2017, phytoplankton data once again indicate that blue-green algae (Cyanophyta) were most dominant during the months of July through October. The most common genera were *Dolichospermum*, formerly known as *Anabaena*, and *Aphanizomenon*. Overall, zooplankton biomass values between May through October of 2017 somewhat lower than past years. Furthermore, zooplankton biomasses were considered fairly well distributed among the taxa during the 2017 study period.

The lake was already thermally stratified in May and continued to remain stratified through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified. As in the past, the dissolved oxygen levels rapidly decreased within deeper lake waters (hypolimnion). The thermocline (the point where the greatest temperature change occurs within the lake water colunm) divides the epilimnion (surface waters) and the hypolimnion (bottom waters). The thermocline was located at a water depth of approximately 5 to 10 meters (16.4 to 32.8 feet) during the months of May through September. In October, the lake mixed and eventually thermally destratified. This process is commonly referred to as the fall turnover period in lakes.

Based upon trend analysis, the water quality of Lake Wallenpaupack has generally improved since 1980 even though there appears to be a significant annual warming trend in Northeastern Pennsylvania (Section 3). Total phosphorus concentrations in surface and bottom waters and Secchi transparency (water clarity) have gradually improved over the past 38 years. Total nitrogen concentrations in surface waters have been relatively steady since sampling began. In contrast, total nitrogen concentrations in bottom waters slightly increased along with chlorophyll-a concentrations. Phytoplankton and zooplankton biomasses have fluctuated widely over the study period, but the overall trends have been that phytoplankton and zooplankton biomass have slightly increased and decreased, respectively.

In terms of water quality trends, it should be noted that lake water clarity (Secchi disk transparency) has generally improved even though chlorophyll-a concentrations and phytoplankton biomass have slightly 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. In addition, the general trend of decreasing zooplankton biomass may be related to more intense grazing pressure of larger zooplankton by predators (planktivorous fish and aquatic insects).

Since 2010, total phytoplankton biomass has generally remained below 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 from the unusually high 2016 level. The 2017 biomass more closely corresponds to a typical biomass historically. Additional zooplankton biomass data collected over the next several years will aide in determining if the sharp increase in zooplankton biomass observed in 2016 is a new shift in the plankton dynamics in the lake or simply a single, one-year anomaly like what was observed in 2012.

Based upon the above conclusions, Aqua Link offers the following recommendations to the Lake Wallenpaupack Watershed Management District (LWWMD):

1. The District should continue to retain Aqua Link 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 is recommending that additional lake data analysis be performed in the Winter 2018-19 to determine if annual lake water temperatures are rising and whether global warming may be responsible for increased levels of primary production in Lake Wallenpaupack. Rising lake water temperatures are expected to be related to observed increases in phytoplankton biomass and chlorophyll-a concentration. In general, blue-green algae (Cyanophyta), which often are problematic in lakes, tend to become most dominant in warmer, nutrient-enriched waters.

3. The District should continue to retain Aqua Link to assist in all future lake monitoring activities. As in 2017, Aqua Link would be responsible for collecting all *insitu* water quality data using our instrumentation and data loggers.

4. The District should continue to retain ECM, Inc. 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.

5. 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.

6. 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.

7. 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 surface samples. Zooplankton samples should be collected as vertical tows of the entire water column with a 80 micron plankton net.

8. The District and Brookfield Renewable should consider lowering the lake water level in November as opposed to September if possible. By doing so, it is plausible that extent of algal blooms occurring in the fall (September and October) may be reduced. It is suspected that hypolimnetic (deep) water releases in September is allowing the lake to thermally destratify and mixing sooner than it would occur naturally – likely in mid to late November. In turn, this pre-mature mixing allows for nutrient enriched, colder, deeper lake waters to mix with warmer, shallower surface lake waters. These additional nutrients may be sufficient to promote those blue-green algal blooms occurring in September and October.

   An aquatic macrophyte (aquatic vascular plant) survey should be performed to identify what species of aquatic plants are present along with their overall abundance.

This survey should also accurately delineate the location and relative abundance of any non-native, invasive aquatic plants that are found for later control and/or eradication. Many of these plants tend to be very aggressive and spread quickly by out-competing other native plant species. Controlling the spread of these aquatic plants can be very costly if not detected early.

Based upon this survey, an aquatic macrophytes map should be developed showing the locations and relative abundances of all major plant species found throughout the entire lake basin. This map should also include the locations where any non-native, invasive aquatic plants were found.

9. The District with the assistance of Aqua Link should develop invasive aquatic species monitoring and educational programs. Monitoring for invasive aquatic plants would be accomplished by implementing Item 8. Invasive species monitoring should also be performed for aquatic animals including zebra mussels, quagga mussels and others. Also, an educational program should be developed for the public regarding species identification and how to stop the introduction and spread of invasive species to and within the lake.

10. The District and its watershed partners should continue to reduce both point source and nonpoint sources to the lake. This should be accomplished by implementing lake, watershed, and institutional best management practices throughout the 14 townships in the Lake Wallenpaupack watershed.

Many of our recommendations, as discussed above, will require a high level of expertise in the field of lake management. In some instances, our recommendations may require obtaining state permits prior to implementation. Aqua Link is a nationally recognized consulting firm specializing in pond and lake management and we are fully capable of implementing all of the recommendations offered in this report.

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APPENDIX A

Glossary of Lake & Watershed Management Terms

APPENDIX B

Primer on Lake Ecology & Watershed Concepts

APPENDIX C

Lake Water Quality Data