2018 FINAL REPORT

Lake Wallenpaupack Water Quality Monitoring Program

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 2018, 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 2018 data to the historical data collected from 1980 through 2017 to determine whether lake water quality has improved or degraded over the past 39 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 in order to be more cost-effective while still providing high quality data for various key lake parameters (Aqua Link 2012).

The water quality of Lake Wallenpaupack in 2018 improved slightly when compared to 2017 with respect to trophic state and its overall appearance. Climatologic factors such as higher than average air temperatures and precipitation likely caused some decline in water quality. Water clarity was good from May through August and declined significantly in September due to a substantial phytoplankton bloom (microscopic, free-floating algae). Improvement in water clarity was observed in October, when the bloom was subsided. In terms of trophic state, Lake Wallenpaupack was classified as a highly mesotrophic reservoir in 2018. The mean Carlson TSI (Trophic State Index) values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 48, 54, and 45, respectively, for 2018. The lake was thermally stratified in 2018 from May through September. In turn, the dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified.

Phytoplankton biomass was largely dominated by genera from Bacillariophyta and Chrysophyta in May through June of 2018. From July through October, two genera from the phyla Cyanophyta (Cyanobacteria or blue-green algae), *Dolichospermum*, formerly known as *Anabaena*, and *Aphanizomenon* were most dominant. Biomass values for 2018 ranged from 1,647 ug/L (micrograms per liter) to 15,224 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 2018 study period.

Overall, zooplankton biomass values between May through October of 2018 were slightly 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 2018. Furthermore, zooplankton biomass values were considered fairly well distributed among the taxa during the 2018 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 decreased slightly since sampling began. Total nitrogen concentrations in bottom waters have been relatively consistent. 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 when compared to relatively consistent 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).

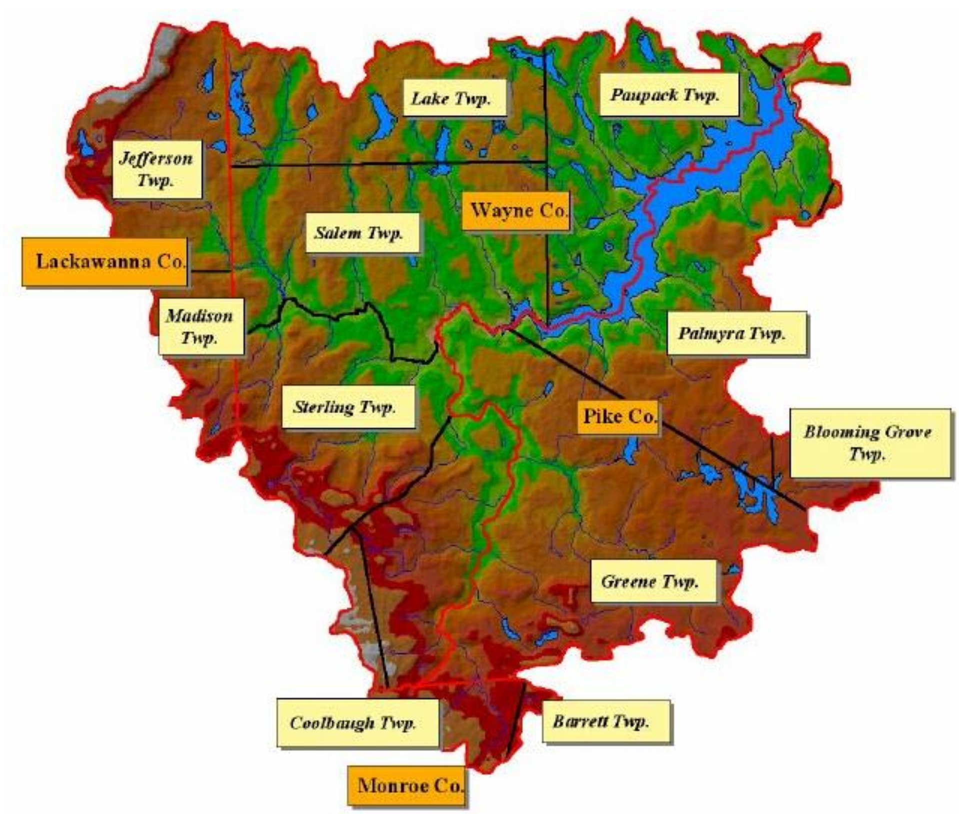


Figure 1.1 Lake Wallenpaupack Watershed

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 2018, 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 2018. Aqua Link also compared the 2018 data to the historical data collected from 1980 through 2017 to determine whether lake water quality has improved or degraded over the past 39 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 2018. The lake was monitored at Stations 3 and 5 in 2018 (Figure 2.1). These monitoring stations were monitored once a month during May through October.

In 2018, *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 2018, 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.

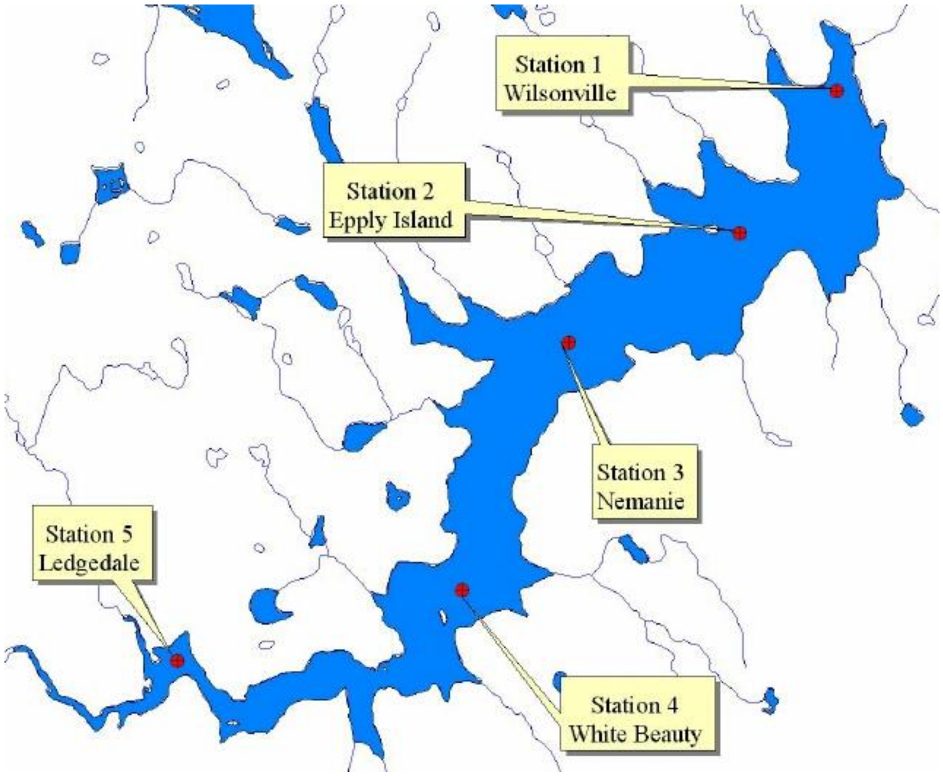


Figure 2.1 Lake Monitoring Stations

2.2. Field Observations

The overall water clarity at Station 3 at Lake Wallenpaupack was somewhat consistent from May through July in 2018, with a moderate decline in visibility observed in August. During May and June, the water was fairly clear, but slightly turbid with a light brownish tint. From July through August, water appearance was still mostly clear, but changed to a slightly greenish tint with a more planktonic appearance. At Station 3, the overall water clarity was best from May through July of 2018. 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 1.0 meters or 3.3 feet) was observed at Station 3 in September.

As noted previously, lake water clarity first began to deteriorate in August. This deterioration was more pronounced especially in September and 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 4.1 and 4.2). Overall, temperatures in 2018 were considered to be well above average with well above average precipitation when compared to data presented over the previous 38 years. In fact, both the mean temperature from May through October and the mean precipitation for all of 2018 were both the highest values since monitoring for these parameters began in 1980.

Figure 3.1 shows the average (mean) air temperatures for the growing season (May through October) from 1980 through 2018. 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 39 years, only eleven times has the annual mean air temperature exceeded 62 degrees and seven of these years occurred recently from 2010 through 2018 (nine year period). This annual warming trend in the NE PA may be adversely impacting lake water quality 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 2018. 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 2018. 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. However, a sharp increase was observed in 2018. 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 or higher hydraulic loadings (lower or higher volumes of incoming water to the lake via streams and shallow groundwater) to the lake.

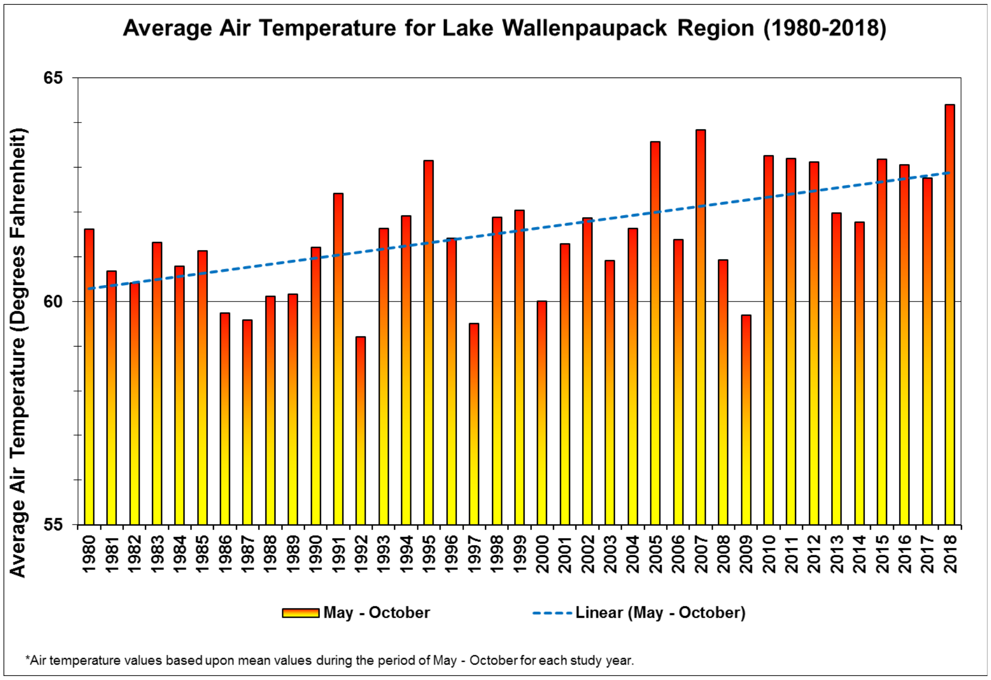


Figure 3.1 Historical Air Temperature Data in the Lake Wallenpaupack Region

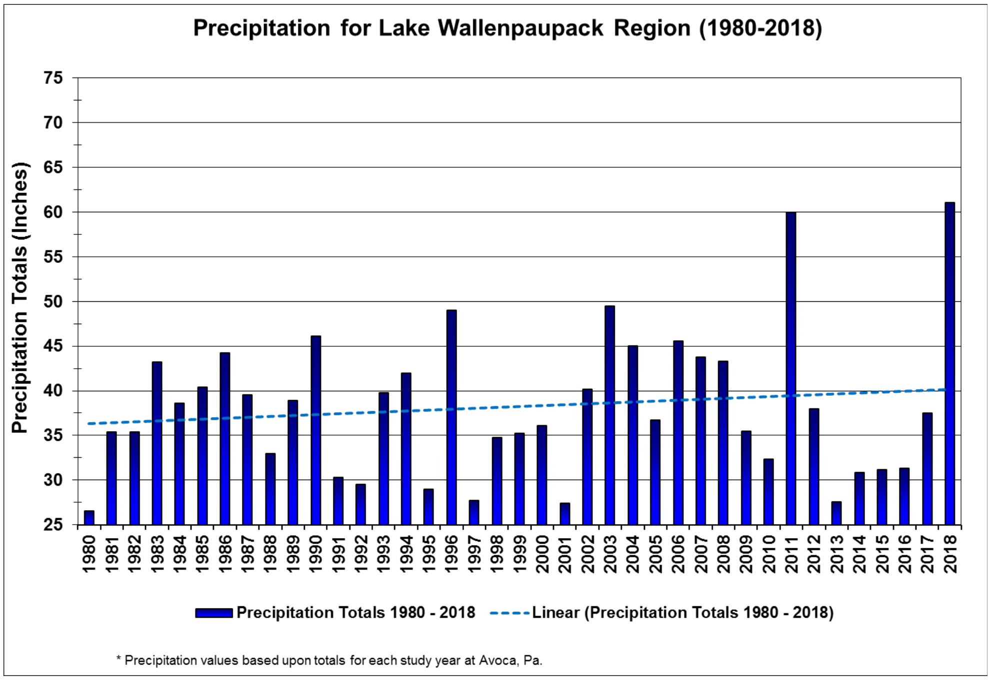


Figure 3.2 Historical Precipitation Data in the Lake Wallenpaupack Region

4. Lake Water Quality Data Results for 2018

The water quality data for Lake Wallenpaupack in 2018 are presented in this section of the report. As discussed in Section 2, the lake was monitored at Stations 3 and 5 in 2018 (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 2018 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).

<u>Lake Wallenpaupack</u>

The 2018 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 13.1 meters (43.0 feet) in 2018. 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.

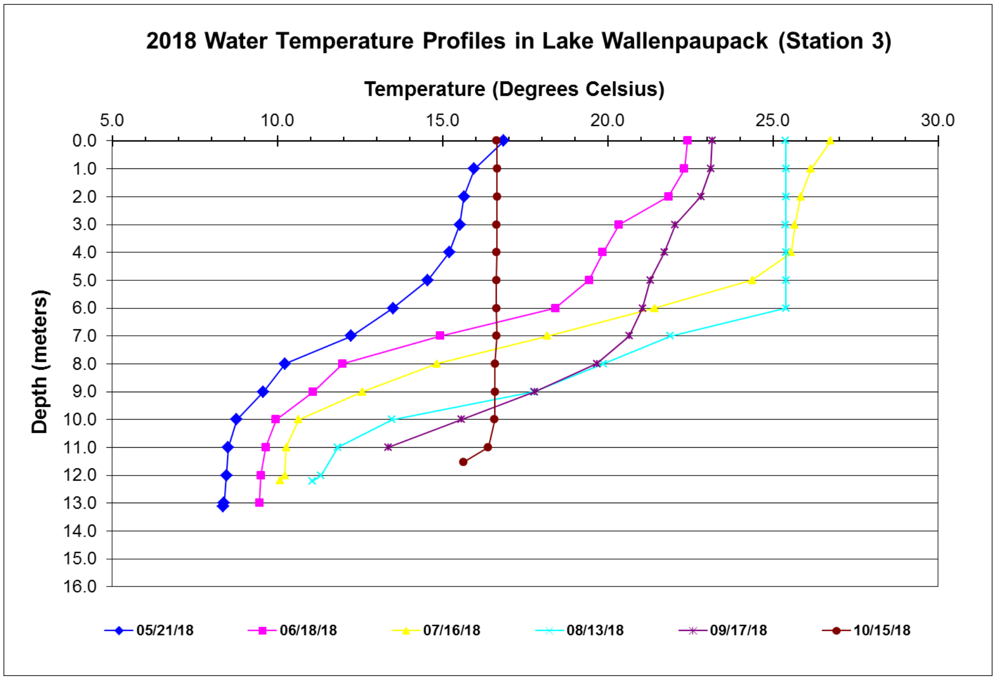


Figure 4.1 Water Temperature Profiles at Station 3 in 2018

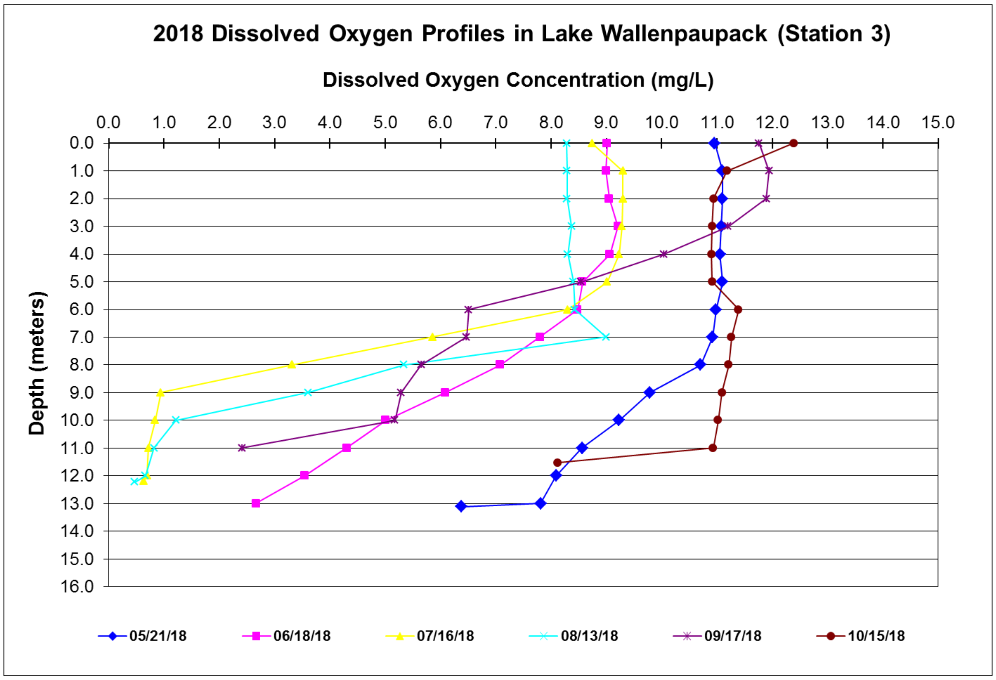


Figure 4.2 Dissolved Oxygen Profiles at Station 3 in 2018

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 2018 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 2018 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 2018

Year	pH (standard units, s.u.)		Alkalinity (mg/l as $CaCO_3$)	
	Surface	Bottom	Surface	Bottom
2018	6.47	6.12	22.3	22.6

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 2018 mean total phosphorus concentrations for surface and bottom waters were 0.017 mg/L and 0.042 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 2018.

The 2018 mean dissolved reactive phosphorus concentrations for surface and bottom waters were 0.003 mg/L and 0.017 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 2018

Year	Total Phosphorus (mg/L as P)		Dissolved Reactive Phosphorus (mg/L as P)	
	Surface	Bottom	Surface	Bottom
2018	0.017	0.042	0.003	0.017

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 2018 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 2018 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 2018

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
2018	0.250	0.367	0.170	0.180	0.080	0.187	0.017	0.052

Based upon the Nurnberg criteria (2001), the mean total nitrogen concentrations for surface waters are at a low level and thereby suggesting that Lake Wallenpaupack was classified as oligotrophic in 2018.

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 2018 mean Secchi disk transparency value for Lake Wallenpaupack was 2.25 meters (7.4 feet). Secchi disk transparency values ranged from 1.0 to 3.2 meters (3.3 to 10.5 feet) for all study dates. Based upon Nurnberg (2001), the lake is classified as highly mesotrophic.

The 2018 mean chlorophyll-a concentration in Lake Wallenpaupack was 11.1 ug/L. Chlorophyll-a concentrations ranged from 2.4 ug/L to 22.7 ug/L during the study period. According to the Nurnberg criteria, the mean chlorophyll-a concentration indicates slightly 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 of 2018.

Table 4.4 Mean Secchi & Chlorophyll-a Values at Station 3 in 2018

Year	*Secchi Disk Transparency (m)*	*Chlorophyll-a (ug/l)*
2018	2.25	11.08

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 2018 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 2018

Year	*Total Suspended Solids (mg/l)*	
	Surface	*Bottom*
2018	5.8	6.8

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 2018 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 1,647 ug/L (micrograms per liter) to 15,224 ug/L for 2018, as shown in Figure 4.3. The highest phytoplankton biomass value was reported in September of 2018. 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 by *Asterionella* (Bacillariophyta) and *Cyclotella* (Bacillariophyta) in May of 2018, as shown in Figure 4.3. A shift was observed in June when *Dinobryon* (Chrysophyta) became solely dominant. During July, *Dolichospermum* (Cyanophyta) and *Aphanizomenon* (Cyanophyta) were largely dominant, but with relatively low biomass, followed distantly by *Woronichinia* (Cyanophyta). During August, overall biomass increased with *Dolichospermum* dominating followed by *Aphanizomenon* and followed distantly by *Tabellaria* (Bacillariophyta). In September, the biomass of *Dolichospermum* (Cyanophyta) dramatically increased and continued to be the most dominant followed distantly, but also with a high biomass was *Aphanizomenon*. In October, a shift and overall reduction in biomass occurred when *Aphanizomenon* became most dominant followed by *Dolichospermum*. As previously mentioned, biomass values for 2018, ranged from 1,647 ug/L (micrograms per liter) to 15,224 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 2018 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 2018 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 2018 were slightly 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 2018.

Furthermore, zooplankton biomass values were considered fairly well distributed among the taxa during the 2018 growing season as shown in Figure 4.4. Copepods were most dominant taxa from May and July through October while Cladocerans were most dominant in June of 2018.

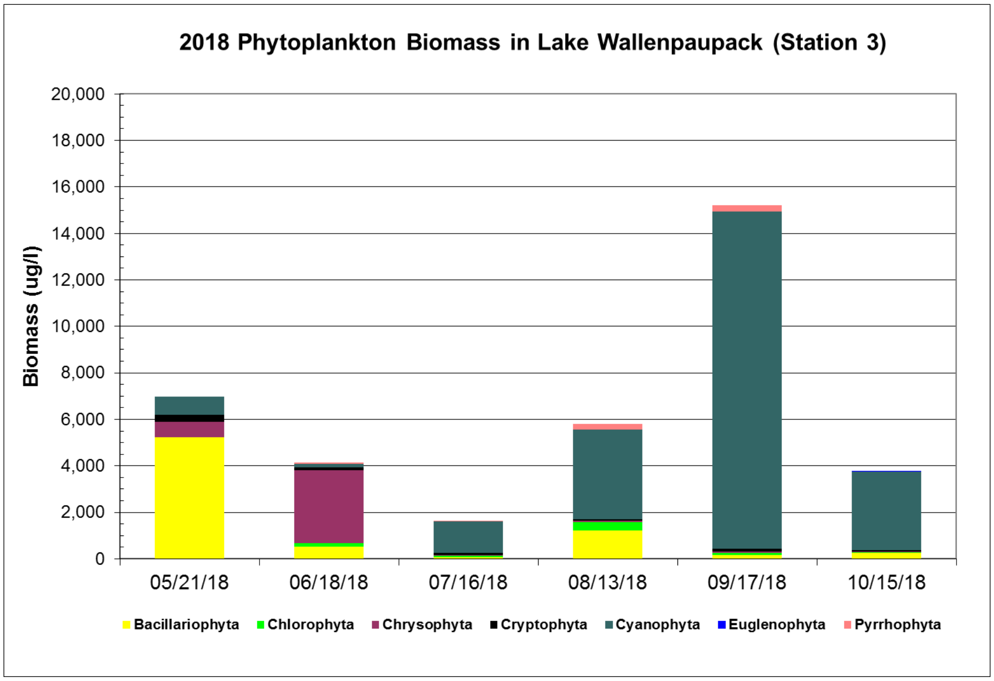


Figure 4.3 Phytoplankton Biomass at Station 3 in 2018

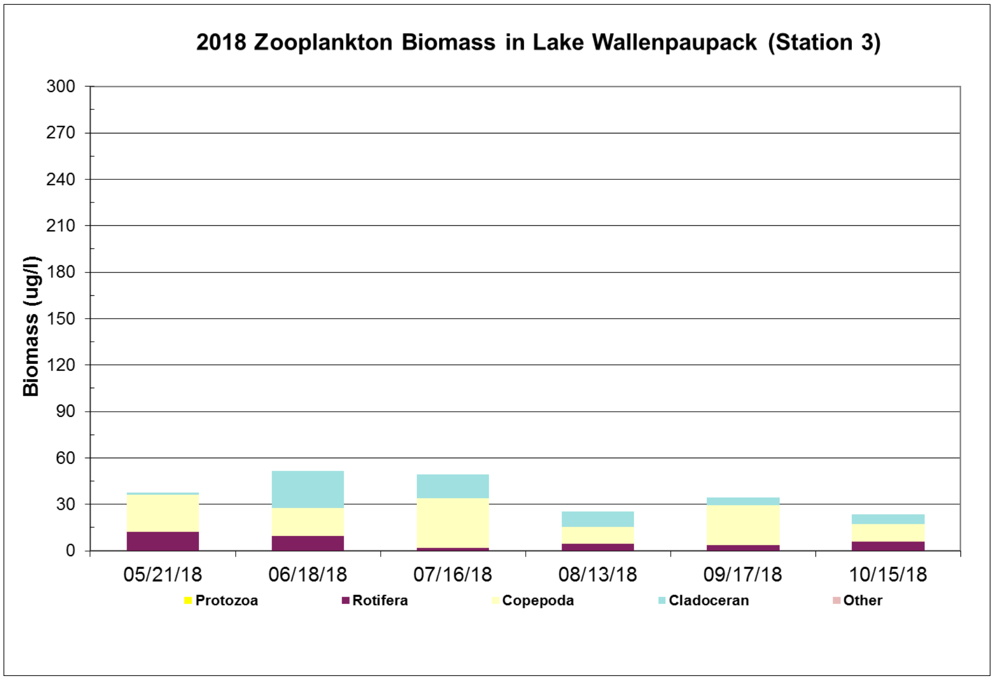


Figure 4.4 Zooplankton Biomass at Station 3 in 2018

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 2018 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 moderately eutrophic conditions, while the TSI value for total phosphorus suggests moderately mesotrophic conditions. Based upon the above, Lake Wallenpaupack is best classified as a highly mesotrophic reservoir in 2018.

Table 4.6 Mean Carlson's TSI Values at Station 3 in 2018

Year	Trophic State Index (TSI) Values		
	Secchi Depth	Chl-a	Total P
2018	48	54	45

Note: Mean TSI values determined by averaging the individual TSI values for each parameter during the 2018 study period.

4.9. Summary of Lake Assessment Data

Lake Wallenpaupack was classified as a highly mesotrophic reservoir in 2018. The mean Carlson TSI values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 48, 54, and 45, respectively, for 2018. The Secchi depth transparency TSI value suggests highly mesotrophic conditions, the chlorophyll-a TSI value suggests moderately eutrophic conditions, while the TSI value for total phosphorus suggests moderately mesotrophic conditions

The lake thermally stratified in 2018 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 2018. 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 *Dolichospermum*, formerly known as *Anabaena*, and *Aphanizomenon*, with the exception of May and June of 2018, 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 2018. 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 2018 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 decreased slightly in 2018 over the 2017 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 2018 for surface and bottom waters are shown in Figures 5.3 and 5.4, respectively. The total nitrogen levels in surface and bottom waters decreased moderately in 2018 over the 2017 mean values.

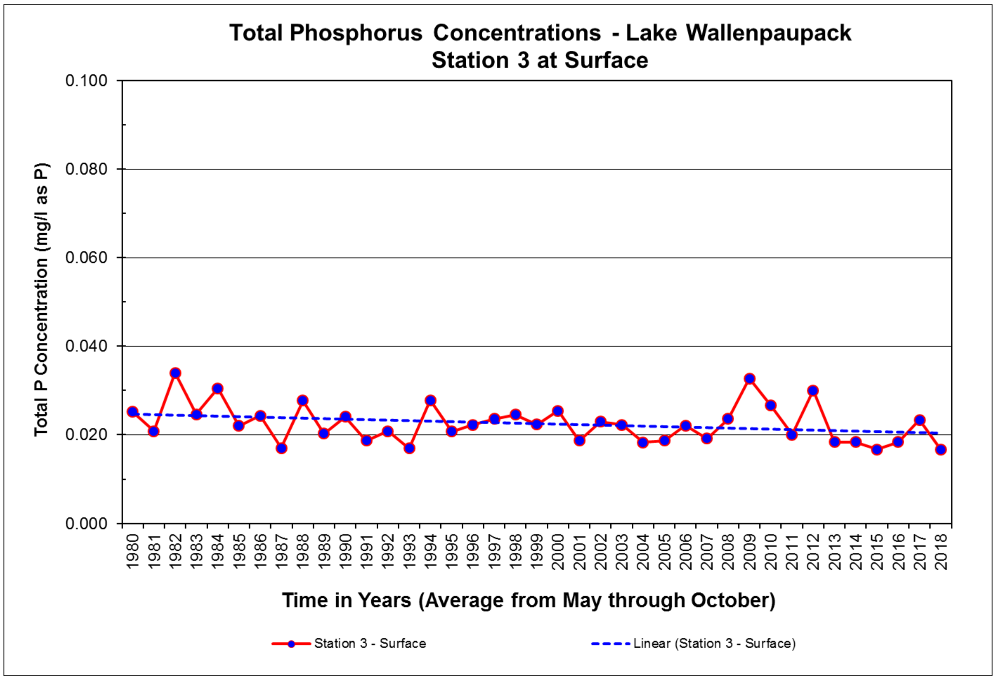


Figure 5.1 Historical Total Phosphorus Concentrations in Surface Waters

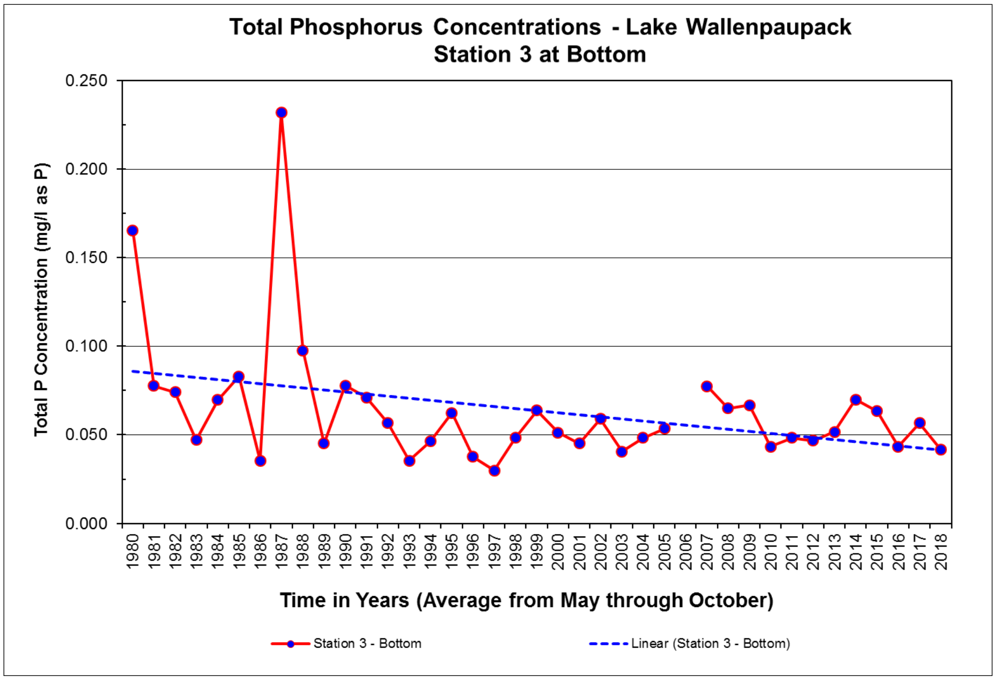


Figure 5.2 Historical Total Phosphorus Concentrations in Bottom Waters

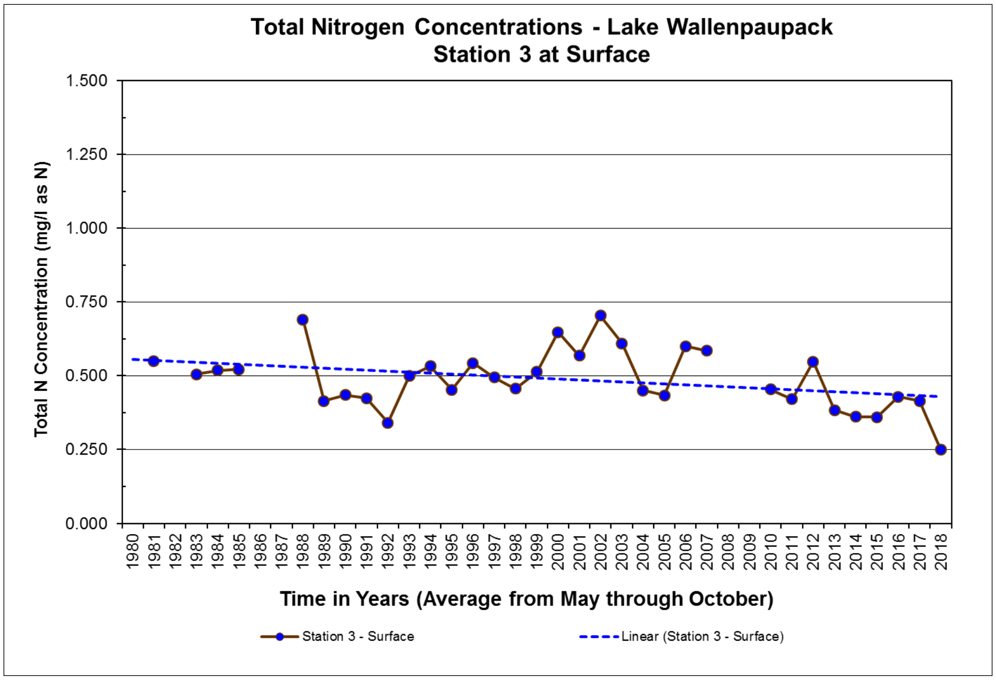


Figure 5.3 Historical Total Nitrogen Concentrations in Surface Waters

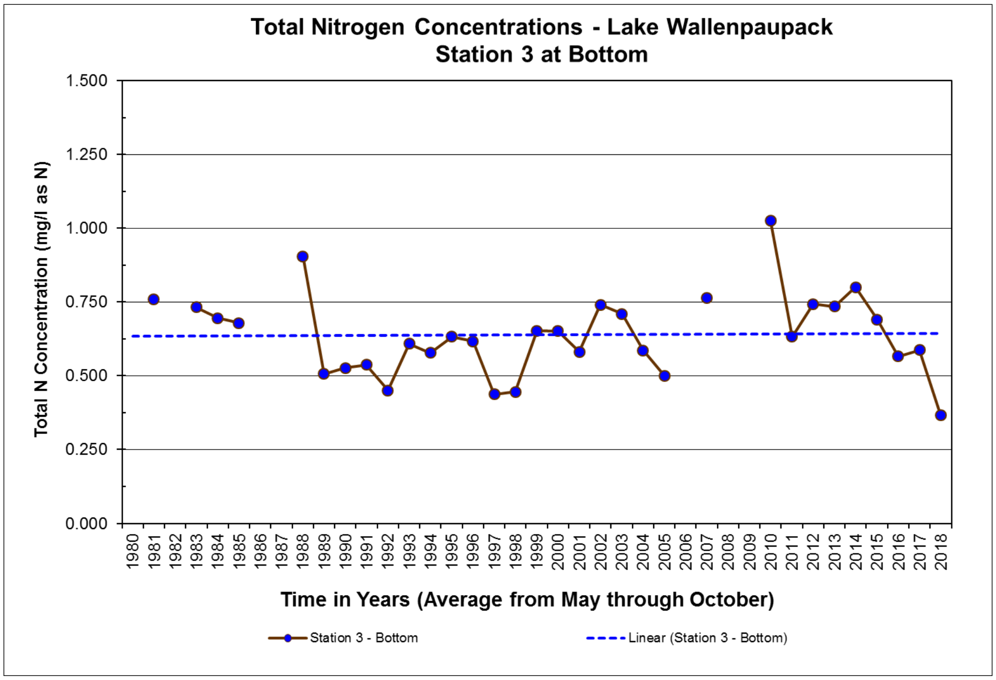


Figure 5.4 Historical Total Nitrogen Concentrations in Bottom Waters

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 slightly while total nitrogen concentrations near the bottom waters have remained relatively consistent since 1980.

5.3. Secchi Transparency

The mean Secchi disk transparency from 1980 through 2018 is shown in Figure 5.5. The mean Secchi depth increased slightly from 2017 to 2018. 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 2018 are shown in Figure 5.6. The mean chlorophyll-a concentration in 2018 decreased moderately from the concentration observed in 2017. Although this decrease was observed, the decrease was only moderate 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 and zooplankton biomass values increased slightly in 2018. 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 moderately decreased, respectively.

Since 2010, total phytoplankton biomass has been relatively consistent at approximate values of 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 and 2018 from the unusually high 2016 level. The 2017 and 2018 biomass values more closely correspond to typical biomass historically.

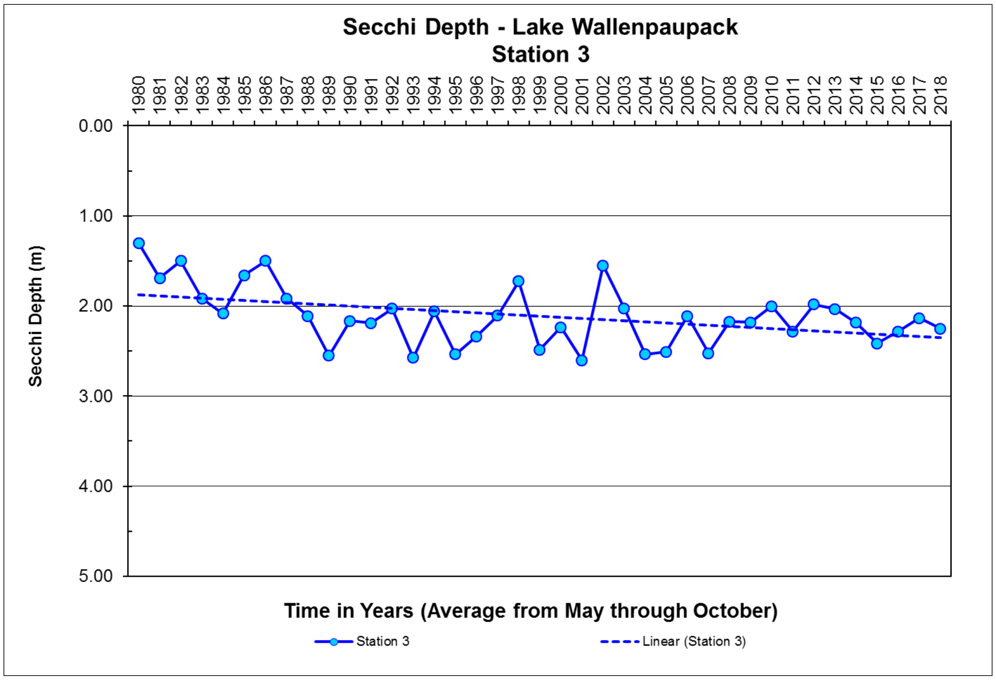


Figure 5.5 Historical Secchi Disk Transparency

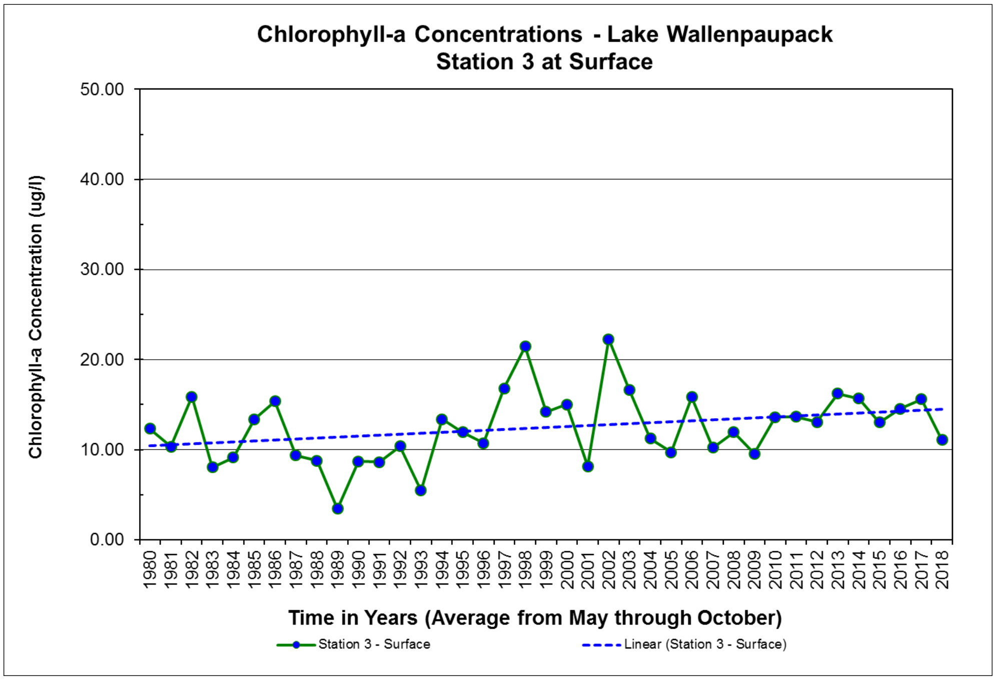


Figure 5.6 Historical Chlorophyll-a Concentrations

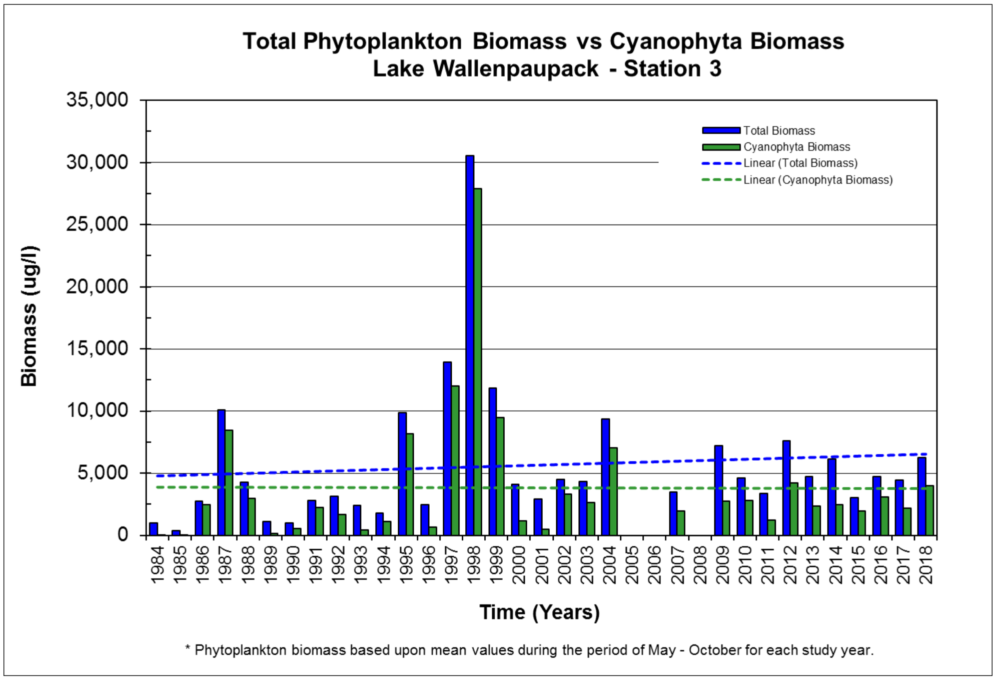


Figure 5.7 Historical Phytoplankton Biomass

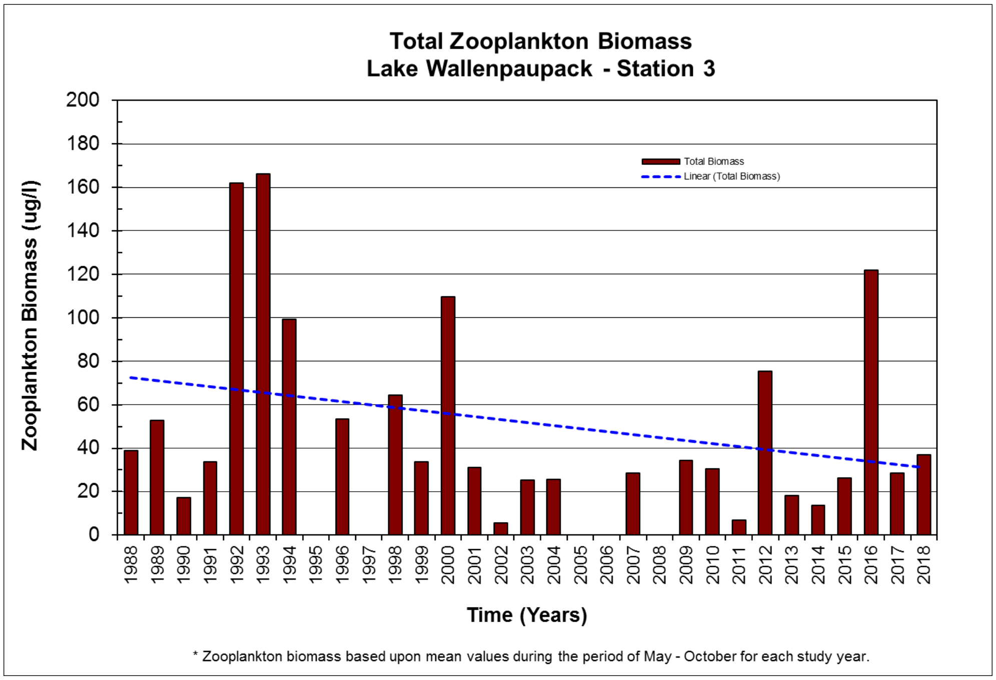


Figure 5.8 Historical Zooplankton Biomass

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 2018 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 39 years.

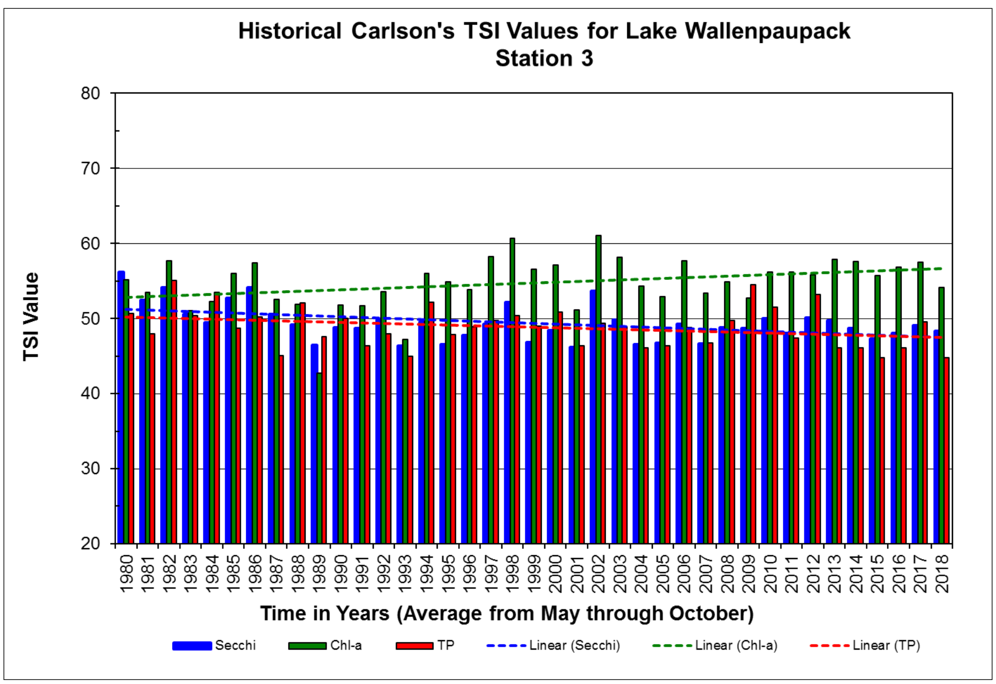


Figure 5.9 Historical Carlson's TSI Values

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 39 years. Total nitrogen concentrations in surface waters have slightly fluctuated and declined since sampling began. In contrast, total nitrogen concentrations in bottom waters increased very slightly along with a slight increase in 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 moderately 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 when compared to relatively consistent 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 been relatively consistent at approximate values of 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 and 2018 from the unusually high 2016 level. The 2017 and 2018 biomass values more closely correspond to typical biomass historically. The inflated biomass observed in 2016 appears to be an anomaly after seeing 2017 and 2018 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 overall water quality of Lake Wallenpaupack was considered good with respect to trophic state and its overall appearance in 2018. Water clarity was good from May through August and declined significantly in September due to a substantial phytoplankton bloom (microscopic, free-floating algae). This algal bloom may be attributed to or at least partially attributed to very warm air temperatures during the 2018 growing season (May through October). The warmest average season air temperature for the growing season since 1980 was recoreded in 2018. Thereafter, improvement in water clarity was observed in October when the bloom was subsided. In terms of trophic state, Lake Wallenpaupack is best classified as a highly mesotrophic reservoir in 2018. The mean Carlson TSI (Trophic State Index) values for Secchi disk transparency, chlorophyll-a, and total phosphorus were 48, 54, and 45, respectively, for 2018.

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 2018, 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 2018 slightly lower than past years. Furthermore, zooplankton biomasses were considered fairly well distributed among the taxa during the 2018 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 39 years. Total nitrogen concentrations in surface waters have decreased very slightly, while total nitrogen concentrations in bottom waters has remained relatively consistent since sampling began. In contrast, Chlorophyll-a concentrations have increased slightly. 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 relatively consistent 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 been relatively consistent at approximate values of 5,000 ug/L. In contrast, zooplankton biomass decreased dramatically in 2017 and 2018 from the unusually high 2016 level. The 2017 and 2018 biomass values more closely correspond to 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 2019-20 to determine if annual lake water temperatures are rising and whether global warming may be responsible for increased levels of primary production (algal growth) 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 2018, 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 an 80 micron plankton net.

8. Monitoring of cyanotoxins caused by harmful algal blooms should begin in 2019. It is recommended to concentrate efforts on swimming areas, primarily, or other areas where there is the most physical human contact with the water. As more information is being discovered concerning harmful algal blooms, it is becoming evident that some toxins, even in very small amounts, can be toxic to even the healthiest individuals.

Based on the results, swimming or other recreational advisories could be addressed once toxins reach a certain level.

9. 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.

10. 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. Areas such as boat ramps, other high boat traffic areas, and inlets should be looked at most thoroughly, as these are locations where invasive plants are often initially discovered in a lake.

    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.

11. 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 10. 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.

12. 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.

7. Literature Cited

Amand, A. S. and K. W. Wagner. 1999. Collection, Identification and Ecology of Freshwater Algae. 19th Annual Symposium for Lake and Reservoir Management. North American Lake Management Society. Madison, WI.

Aqua Link, Inc. 2011. The Lake Wallenpaupack Water Quality Monitoring Program for 2008-09 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2012. The Lake Wallenpaupack Water Quality Monitoring Program for 2010 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2012. The Lake Wallenpaupack Water Quality Monitoring Program for 2011 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2013. The Lake Wallenpaupack Water Quality Monitoring Program for 2012 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2014. The Lake Wallenpaupack Water Quality Monitoring Program for 2013 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2015. The Lake Wallenpaupack Water Quality Monitoring Program for 2014 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2016. The Lake Wallenpaupack Water Quality Monitoring Program for 2015 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2017. The Lake Wallenpaupack Water Quality Monitoring Program for 2016 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2018. The Lake Wallenpaupack Water Quality Monitoring Program for 2017 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Aqua Link, Inc. 2019. The Lake Wallenpaupack Water Quality Monitoring Program for 2018 Final Report. Prepared for the Lake Wallenpaupack Watershed Management District (LWWMD).

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Carlson, R. E. 1980. International Symposium on Inland Waters and Lake Restoration. EPA 440/5/81/010.

Nurnberg, G. 2001. Eutrophication and Trophic State. Lake Line, Vol. 21, No. 1. North American Lake Management Society (NALMS), Madison, WI.

U.S. EPA. 1980. Clean lakes program guidance manual. Report No. EPA-440/5-81-003. U.S. EPA, Washington, D.C.

U.S. EPA. 1990. The Lake and Reservoir Restoration Guidance Manual, Second Edition. Report No. EPA-440/4-90-006. U.S. EPA, Washington, D.C.

U.S. EPA. 1993. Fish and Fisheries Management in Lakes and Reservoirs - Technical Supplement to Lake and Reservoir Restoration Guidance Manual. Report No. EPA-841-R-93-002. U.S. EPA, Washington, D.C.

APPENDIX A

Glossary of Lake & Watershed Management Terms

Glossary

Algae - Mostly aquatic, non-vascular plants that float in the water or attach to larger plants, rocks, and other substrates. Also called phytoplankton, these individuals are usually visible only with a microscope. They are a normal and necessary component of aquatic life, but excessive numbers can make the water appear cloudy and colored.

Alkalinity - The acid-neutralizing capacity of water. It is primarily a function of the carbonate, bicarbonate, and hydroxide content in water. The lower the alkalinity, the less capacity the water has to absorb acids without becoming more acidic.

Ammonia (NH3) - A nitrogen-containing substance which may indicate recently decomposed plant or animal material.

Benthos - The communities of aquatic life which dwell in or on the bottom sediments of a water body.

Chlorophyll - Pigments (mostly green) in plants, including algae, that play an important part in the chemical reactions of photosynthesis. A measurement of chlorophyll-a (one type of chlorophyll) is commonly used as a measure of the algae content of water.

Conductivity (Cond) - A measure of water's capacity to convey an electric current. It is related to the total amount of dissolved charged substances in the water. Therefore, it can be used as a general indicator of the quality of the water and can also suggest presence of unidentified material in the water. It is often used as a surrogate for salinity measurements.

Combined Sewer Overflow (CSO) -Discharges of combined sewage and stormwater into water bodies during very wet or storm weather. These discharges occur to relieve the sewer system as it becomes overloaded with normal sewer flow and increased storm run-off. The term is also used to denote a pipe that discharges those overflows.

Dissolved oxygen (DO) - Oxygen that is dissolved in the water. Certain amounts are necessary for life processes of aquatic animals. The oxygen is supplied by the photosynthesis of plants, including algae, and by aeration. Oxygen is consumed by animals and plants at night, and bacterial decomposition of dead organic matter (plant matter and animal waste).

Effluent - Liquids discharged from sewage treatment plants, septic systems, or industrial sources to surface waters.

Epilimnion - The warmer, well-lit surface waters of a lake that are thermally separated from the colder (hence denser), water at the bottom of the lake when a lake is stratified.

Eutrophication - The acceleration of the loading of nutrients to a lake by natural or human-induced causes. The increased rate of delivery of nutrients results in increased production of algae and consequently, poor water transparency. Human-induced (cultural) eutrophication may be caused by input of treated sewage to a lake, deforestation of a watershed, or the urbanization of a watershed.

Fecal Coliform Bacteria - Bacteria from the intestines of warm-blooded animals. Most of the bacteria are not in themselves harmful, so they are measured or counted as an indicator of the possible presence of harmful bacteria.

Groundwater - Water stored beneath the surface of the earth. The water in the ground is supplied by the seepage of rainwater, snowmelt, and other surface water into the soil. Some groundwater may be found far beneath the earth surface, while other groundwater may be only a few inches from the surface. Groundwater discharges into lowland streams to maintain their baseflow.

Hydrology -The science dealing with the properties, distribution and circulation of water. The term usually refers to the flow of water on or below the land surface before reaching a stream or man-made structure.

Hypolimnion - The dark, cold, bottom waters of a lake that are thermally separated from the warmer (hence less dense) surface waters when a lake is stratified.

Invertebrates - Animals without internal skeletons. Some require magnification to be seen well, while others such as worms, insects, and crayfish are relatively large. Invertebrates living in stream and lake sediments are collected as samples to be identified and counted. In general, more varied invertebrate communities indicate healthier water bodies.

Limiting nutrient - The nutrient that is in lowest supply relative to the demand. The limiting nutrient will be exhausted first by algae which require many nutrients and light to grow. Inputs of the limiting nutrient will result in increased algal production, but as soon as the limiting nutrient is exhausted, growth stops. Phytoplankton growth in lake waters of temperate lowland areas is generally phosphorus limited.

Limnology - Scientific study of inland waters.

Littoral zone - portion of a water body extending from the shoreline lakeward to the greatest depth occupied by rooted plants.

Loading rate - Addition of a substance to a water body; or the rate at which the addition occurs. For example, streams load nutrients to lakes at various rates as in "500 kilograms per year (500 kg/yr)" or "227 pounds per year (227 lb/yr)."

Macrophytes - rooted and floating aquatic plants, larger (macro-) than the phytoplankton.

Mesotrophic - A condition of lakes that is characterized by moderate concentrations of nutrients, algae, and water transparency. A mesotrophic lake is not as rich in nutrients as a eutrophic lake, but richer in nutrients than an oligotrophic lake.

Monomictic - A lake which has one mixing and one stratification event per year. If a lake does not freeze over in the winter, the winter winds will mix the waters of the lake. In summer, the lake resists mixing and becomes stratified because the surface waters are warm (light) and the bottom waters are cold (dense). Deep lakes in the Puget lowlands are monomictic lakes.

Nitrate, nitrite (NO3, NO2) - Two types of nitrogen compounds. These nutrients are forms of nitrogen that algae may use for growth.

Nitrogen - One of the elements essential as a nutrient for growth of organisms.

Non-point source pollution - Pollution that originates from diffuse areas and unidentifiable sources, such as agriculture, the atmosphere, or ground water.

Nutrients - Elements or compounds essential for growth of organisms.

Oligotrophic - A condition of lakes characterized by low concentrations of nutrients and algae and resulting good water transparency. An oligotrophic lake has less nutrients than a mesotrophic or eutrophic lake.

Pathogens -Microorganisms that can cause disease in other organisms or humans, animals, and plants. Pathogens include bacteria, viruses, fungi, or parasites found in sewage, in runoff from farms or city streets, and in water used for swimming. Pathogens can be present in municipal, industrial, and nonpoint source discharges.

Pelagic Zone - Deep, open water area of a lake away from the edge of the littoral zone towards the center of the lake.

pH - Measure of the acidity of water on a scale of 0 to 14, with 7 representing neutral water. A pH less than 7 is considered acidic and above 7 is basic.

Phosphorus - One of the elements essential as a nutrient for the growth of organisms. In western Washington lakes, it is usually the algae nutrient in shortest supply relative to the needs of the algae. Phosphorus occurs naturally in soils, as well as in organic material. Various measures of phosphorus in water samples are made, including total-phosphorus (TP) and the dissolved portion of the phosphorus (orthophosphorus).

Photic zone - The lighted region of a lake where photosynthesis occurs.

Phytoplankton - Floating, mostly microscopic algae (plants) that live in water.

Point-source Polution - An input of pollutants into a water body from discrete sources, such as municipal or industrial outfalls.

Primary Treatment - The first stage of wastewater treatment involving removal of debris and solids by screening and settling.

Pump Station -A structure used to move wastewater uphill, against gravity.

Regulator -A structure that controls the flow of wastewater from two or more input pipes to a single output. Regulators can be used to restrict or halt flow, thus causing wastewater to be stored in the conveyance system until it can be handled by the treatemnt plant.

Salmonids - Salmon, trout, char and whitefish species of fish.

Secchi depth - Measure of transparency of water obtained by lowering a 10 cm black and white disk into water until it is no longer visible.

Secondary Treatment - Following primary treatment, bacteria are used to consume organic wastes. Wastewater is then disinfected and discharged through an outfall.

Separation -A method for controlling combined sewer overflow whereby the combined sewer is separated into both a sanitary sewer and a storm drain, as is the practice in new development.

Sewage -That portion of wastewater that is composed of human and industrial wastes from homes, businesses, and industries.

Standard - A legally established allowable limit for a substance or characteristic in the water, based on criteria. Enforcement actions by the appropriate agencies can be taken against parties who cause violations.

Stratification of lakes - A layering effect produced by the warming of the surface waters in many lakes during summer. Upper waters are progressively warmed by the sun and the deeper waters remain cold. Because of the difference in density (warmer water is lighter), the two layers remain separate from each other: upper waters "float" on deeper waters and wind induced mixing occurs only in the upper waters. Oxygen in the bottom waters may become depleted. In autumn as the upper waters cool, the whole lake mixes again and remains mixed throughout the winter, or until it freezes over.

Stormwater -Water that is generated by rainfall and is often routed into drain systems.

Thermocline - Depth in a stratified lake where the greatest change in temperature occurs. Separates the epilimnion from the hypolimnion

Total suspended solids (TSS) - Particles, both mineral (clay and sand) and organic (algae and small pieces of decomposed plant and animal material), that are suspended in water.

Toxic -Causing death, disease, cancer, genetic mutations, or physical deformations in any organism or its offspring upon exposure, ingestion, inhalation, or assimilation.

Transparency - A measure of the clarity of water in a lake, which is measured by lowering a standard black and white Secchi disk into the water and recording the depth at which it is no longer visible. Transparency of lakes is determined by the color of the water and the amount of material suspended in it. Generally in colorless waters of the Puget lowland, the transparency of the water in summer is determined by the amount of algae present in the water. Suspended silt particles may also have an effect, particularly in wet weather.

Trophic status - Rating of the condition of a lake on the scale of oligotrophic-mesotrophic-eutrophic (see definition of these terms).

Turbidity - Cloudiness of water caused by the suspension of minute particles, usually algae, silt, or clay.

Wastewater -Total flow within the sewage system. In combined systems, it includes sewage and stormwater.

Water Column - Water in a lake between the surface and sediments. Used in vertical measurements used to characterize lake water.

Watershed - The areas that drain to surface water bodies, including lakes, rivers, estuaries, wetlands, streams, and the surrounding landscape.

Water of Statewide Significance - Legal term from the state Shoreline Management act, which recognizes particular bodies of water and sets criteria and standards for their protection.

Zooplankton - Small, free swimming or floating animals in water, many are microscopic.

Source: King County, Washington (http://dnr.metrokc.gov/wlr/waterres/lakes/glossary)

APPENDIX B

Primer on Lake Ecology & Watershed Concepts

Primer on Lake Ecology & Watershed Dynamics

Prepared by:

Aqua Link, Inc.

The water quality of a lake is often described as a reflection of its surrounding watershed. The term lake collectively refers to reservoirs (man-made impoundments), natural lake systems and smaller ponds (man-made or naturally created). Water from the surrounding watershed enters a lake as streamflow, surface runoff and groundwater. The water quality of these water sources is greatly influenced by the characteristics of the watershed such as, geology, soils, topography and land use. Of these characteristics, changes in land use (e.g., forested, agriculture, silviculture, residential, commercial, industrial) can significantly alter the water quality of lakes.

Nutrients (e.g., phosphorus, nitrogen, carbon, silicon, calcium, potassium, magnesium, sulfur, sodium, chloride, iron) are primarily transported to lakes via streamflow, surface runoff and groundwater, while sediments are mainly conveyed by streamflow and surface runoff. As streamflow and surface runoff enter a lake, their overall velocity decreases, which allow transported sediments to settle to the lake bottom. Many of these incoming nutrients may be bound to sediment particles and subsequently will also settle to the lake bottom. Very small sediment particles such as, clays, may resist sedimentation and subsequently pass through the lake without settling.

Once within the lake, water quality is further modified through a complex set of physical, chemical and biological processes. These processes are significantly affected by the lake's morphological characteristics (morphology). Some of the more important morphological characteristics of lakes are surface area, shape, depth, volume and bottom composition. In addition, the hydraulic residence time (i.e., the lake's flushing rate) also greatly affects these processes and is directly related to the lake's volume and the annual volume of water flowing into the lake.

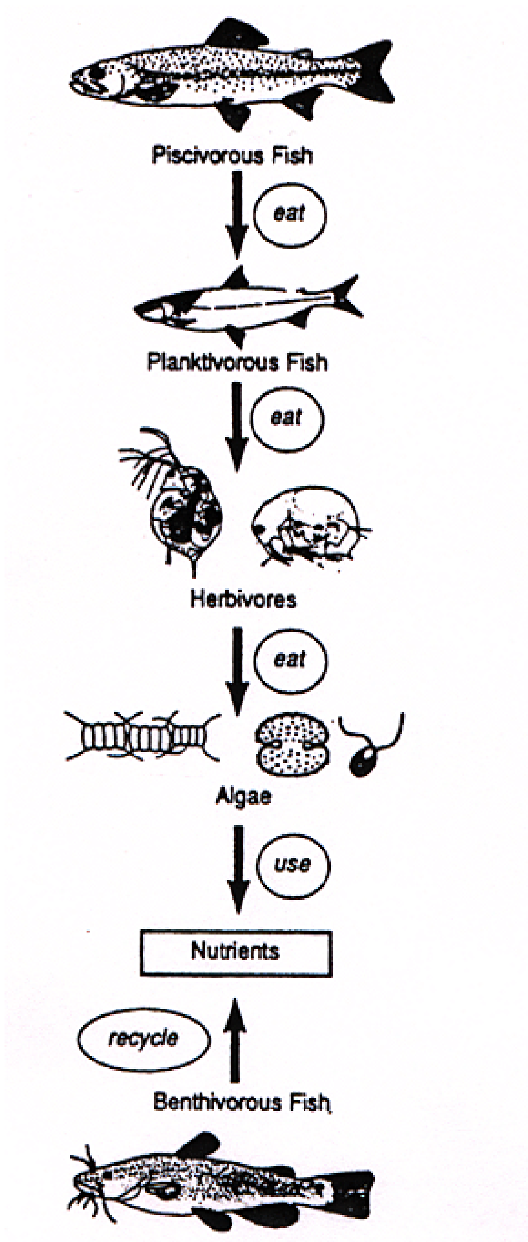
With respect to nutrients, phosphorus and nitrogen are generally considered the most important nutrients in freshwater lakes. Phosphorus and, to a lesser degree, nitrogen typically determine the overall amount of aquatic plants present. Aquatic plants adsorb and convert available nutrients into energy, which is then used for additional growth and reproduction. In lakes, aquatic plants are mainly comprised of phytoplankton (free-floating microscopic plants or algae) and macrophytes (higher vascular plants). The most readily available form of phosphorus is dissolved orthophosphate (analytical determined as dissolved reactive phosphorus), while ammonia (NH_3-N) and nitrate (NO_3-N) are the most readily available forms of nitrogen.

The transfer and flow of energy in lakes is ultimately controlled by complex interactions between various groups of aquatic organisms (both plants and animals). A simplistic diagram of these interactions among aquatic organisms is shown as Figure 1. In Figure 1, algae (phytoplankton) and aquatic macrophytes (plants) capture energy from the sun and convert this energy into chemical energy through the process known as photosynthesis. During photosynthesis, carbon dioxide, nutrients, water and captured sunlight energy are used to produce organic compounds (chemical energy), which are then used to support further growth and reproduction.

Energy continues to flow upward through the food chain. Algae are primarily grazed upon by zooplankton. Zooplankton are tiny aquatic animals that are barely visible to the naked eye. Next, zooplankton serve as prey for planktivorous (plankton-eating) fish and larger invertebrates (macroinvertebrates). In turn, plankitvores are consumed by piscivorous (fish-eating) fish. Overall, these aquatic organisms (zooplankton, macroinvertebrates and fish) derive energy by breaking down organic matter through the process known as respiration. During respiration, organic matter, water and dissolved oxygen are converted into carbon dioxide and nutrients.

At the bottom of the food chain (Figure 1), particulate organic waste products (excrement) from aquatic organisms along with dead aquatic organisms settle to the lake bottom and are subsequently feed upon by other organisms. Organisms that live or reside along the lake bottom are referred to as benthivores. After settling to the lake bottom, dead organic materials and organic waste products are now called detritus. Some benthivorous fish (catfish and carp) and microorganisms (bacteria, fungi and protozoans) feed upon detritus. Aquatic organisms that feed upon detritus in lakes are referred to as decomposers. Decomposers obtain energy by breaking down detritus (dead organic matter) via the process of respiration. During decomposition, some of the nutrients are recycled back into lake water and can now once again be used by algae and aquatic plants for growth and reproduction. Any unused detritus will accumulate and eventually become part of the lake sediments, thereby increasing the organic content of these sediments.

Ultimately, the amount of nutrients in lakes controls the overall degree of aquatic productivity (Figure 1). Lakes with low levels of nutrients and low levels of aquatic productivity are referred to as oligotrophic. Oligotrophic lakes are typically clear and deep with low quantities of phytoplankton and rooted aquatic plants. In these lakes, the deeper, colder waters are generally well-oxygenated and capable of supporting coldwater fish such as trout. Conversely, lakes with high nutrient levels and high levels of aquatic productivity are referred to as eutrophic. Eutrophic lakes are generally more turbid and shallower due to the deposition of sediments and the accumulation of detritus. If deep enough, the bottom waters of eutrophic lakes are generally less oxygenated or may be devoid of dissolved oxygen (anoxic). Eutrophic lakes are often capable of supporting warmwater fish such as bluegill and bass. Mesotrophic lakes lie somewhere in between oligotrophic and eutrophic lakes. These lakes contain moderate levels of nutrients and moderate levels of aquatic productivity.



Zooplankton plus others: macroinvertebrates (clams, snails & aquatic insects) & grazing minnows

Phytoplankton (def) : microscopic free-floating algae

Plus, microorganisms like bacteria, fungi & protozoans

Figure 1 Aquatic Food Chain

In some instances, the flow of energy through the food web may be disrupted. In hyper-eutrophic (highly eutrophic) lakes, aquatic productivity is extremely high and is dominated by very large numbers of a few, undesirable species. The phytoplankton community is typically comprised largely by blue-green algae during the summer months. Many species of blue-green algae are not readily grazed upon the zooplankton community. Under these conditions, the blue-green algae community is allowed to flourish due to the lack of predation, while the zooplankton community collapses. Decreases in zooplankton biomass in a lake may in turn adversely affect the lake's fishery. In addition, shallow lake areas may be completely infested with dense stands of aquatic macrophytes and dominated by common carp, catfish or other rough fish.

APPENDIX C

Lake Water Quality Data

LWWMD Laboratory Water Quality Monitoring Database **Prepared by Aqua Link, Inc.**
ALI Customer No. 1157-14

Key to Water Quality Parameters and Units of Measure

Parameter:	Units of Measure:
pH (pH)	Expressed in Standard Units (s.u.)
Alkalinity (Alk)	Expressed in milligrams per liter as calcium carbonate(mg/l as CaCO3)
Hardness	Expressed in milligrams per liter as calcium carbonate(mg/l as CaCO3)
Conductivity (Cond)	Expressed in micromhos per cm (umhos/cm)
Conductivity (Cond)	Expressed in microsiemens per cm (uS/cm)
Specific Conductance (Sp Cond)	Expressed in micromhos per cm (umhos/cm) @ 25.0 degrees Celsius
Total Phosphorus (TP)	Expressed as milligrams per liter as phosphorus (mg/l as P)
Dissolved Reactive Phosphorus (DRP)	Expressed in milligrams per liter as phosphorus (mg/l as P)
Nitrate (NO3)	Expressed in milligrams per liter as nitrogen (mg/l as N)
Nitrite (NO2)	Expressed in milligrams per liter as nitrogen (mg/l as N)
Ammonia nitrogen (NH3)	Expressed in milligrams per liter as nitrogen (mg/l as N)
Total Kjeldahl Nitrogen (TKN)	Expressed in milligrams per liter as nitrogen (mg/l as N)
Total Suspended Solids (TSS)	Expressed in milligrams per liter (mg/l)
Turbidity	Expressed in ntu's (nephelometric turbidity units)
Color	Expressed in Pt/Co Units
Oil & Grease	Expressed in milligrams per liter (mg/l)
Iron (Fe) total/dissolved	Expressed in milligrams per liter (mg/l)
Manganese (Mn) total/dissolved	Expressed in milligrams per liter (mg/l)
Dissolved Oxygen (Dissol Oxy)	Expressed in milligrams per liter (mg/l)
Temperature (Temp)	Expressed in degress Celsius (degrees C)
Secchi Disk Depth	Expressed in meters (m)
Chlorophyll-a	Expressed in micrograms per liter (ug/l)
Fecal coliform bacteria (FC)	Expressed as number of organisms per one hundred milliliters (No./100 ml)
Fecal streptococcus bacteria (FS)	Expressed as number of organisms per one hundred milliliters (No./100 ml)
Phytoplankton	Expressed as number of organisms per liter (No.per ml)
Phytoplankton	Expressed as biomass in micrograms per liter (ug/l)
Zooplankton	Expressed as number of organisms per liter (No.per liter)
Zooplankton	Expressed as biomass in micrograms per liter (ug/l)

Notes:

TN denotes total nitrogen and is the sum of total Kjeldahl nitrogen, nitrite, and nitrate nitrogen
NO2/NO3 (nitrate + nitrite nitrogen) can be determined directly by laboratory or by summing nitrate & nitrite concentrations
(b) denotes below detection limit, therefore data reported as the detection limit
(*) indicates calculated value
(**) indicates *in-situ* field data collected on the study date (also refer to *in-situ* data)
(^) Analysis performed out of holding time due to late arrival of samples.

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
05/21/18	9:47:50	3	0.0	16.85	113.1	10.96	83	99	6.12	0.1	0.05	89	0.0	62.3
05/21/18	9:49:12	3	1.0	15.96	112.4	11.10	82	99	6.20	0.1	0.05	77	3.3	60.7
05/21/18	9:49:47	3	2.0	15.65	111.7	11.10	84	102	6.18	0.1	0.05	77	6.6	60.2
05/21/18	9:50:12	3	3.0	15.52	111.1	11.08	80	97	6.16	0.1	0.05	78	9.8	59.9
05/21/18	9:50:43	3	4.0	15.20	110.1	11.05	83	102	6.13	0.1	0.05	82	13.1	59.4
05/21/18	9:51:04	3	5.0	14.56	109.0	11.10	79	98	6.09	0.1	0.05	85	16.4	58.2
05/21/18	9:51:33	3	6.0	13.50	105.4	10.98	77	99	6.04	0.1	0.05	88	19.7	56.3
05/21/18	9:51:54	3	7.0	12.24	101.9	10.92	80	106	6.00	0.1	0.05	91	23.0	54.0
05/21/18	9:52:20	3	8.0	10.24	95.4	10.70	75	105	5.96	0.1	0.05	93	26.2	50.4
05/21/18	9:52:47	3	9.0	9.58	85.9	9.79	71	100	5.91	0.1	0.05	96	29.5	49.2
05/21/18	9:53:09	3	10.0	8.77	79.5	9.23	73	106	5.91	0.1	0.05	96	32.8	47.8
05/21/18	9:53:30	3	11.0	8.52	73.2	8.56	71	103	5.87	0.1	0.05	98	36.1	47.3
05/21/18	9:53:51	3	12.0	8.46	69.1	8.09	72	105	5.81	0.1	0.05	101	39.4	47.2
05/21/18	9:54:15	3	13.0	8.39	66.6	7.81	74	109	5.81	0.1	0.05	68	42.7	47.1
05/21/18	9:54:30	3	13.1	8.36	54.3	6.38	81	119	5.82	0.1	0.06	39	43.0	47.0
<<insert>>														
	Min		0.00	8.36	54.3	6.38	71	97	5.81	0.06	0.05	39	0.0	47.0
	Max		13.12	16.85	113.1	11.10	84	119	6.20	0.08	0.06	101	43.0	62.3
	Max - Min		13.12	8.49	58.8	4.72	13	22	0.39	0.01	0.01	62	43.0	15.3
	Count		15	15	15	15	15	15	15	15	15	15	15	15

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions Depth (feet)	Conversions Temp (Degrees F)
06/18/18	9:47:32	3	0.0	22.42	103.9	9.01	101	106	6.60	0.1	0.05	77	0.0	72.4
06/18/18	9:48:03	3	1.0	22.32	103.5	8.99	100	105	6.56	0.1	0.05	72	3.3	72.2
06/18/18	9:48:33	3	2.0	21.84	103.2	9.05	94	100	6.54	0.1	0.05	70	6.6	71.3
06/18/18	9:48:56	3	3.0	20.34	102.0	9.21	94	103	6.53	0.1	0.05	69	9.8	68.6
06/18/18	9:49:19	3	4.0	19.85	99.4	9.06	96	107	6.52	0.1	0.05	70	13.1	67.7
06/18/18	9:49:56	3	5.0	19.44	93.3	8.57	94	105	6.47	0.1	0.05	73	16.4	67.0
06/18/18	9:50:17	3	6.0	18.42	90.4	8.48	90	103	6.41	0.1	0.05	79	19.7	65.2
06/18/18	9:50:44	3	7.0	14.93	77.2	7.80	87	108	6.35	0.1	0.05	86	23.0	58.9
06/18/18	9:51:11	3	8.0	11.98	65.7	7.08	81	108	6.26	0.1	0.05	91	26.2	53.6
06/18/18	9:51:31	3	9.0	11.09	55.3	6.09	78	106	6.19	0.1	0.05	93	29.5	52.0
06/18/18	9:51:56	3	10.0	9.96	44.4	5.01	80	112	6.13	0.1	0.05	93	32.8	49.9
06/18/18	9:52:12	3	11.0	9.65	37.8	4.30	77	110	6.10	0.1	0.05	93	36.1	49.4
06/18/18	9:52:33	3	12.0	9.50	31.0	3.54	79	112	6.02	0.1	0.05	95	39.4	49.1
06/18/18	9:53:15	3	13.0	9.46	23.2	2.66	80	113	5.94	0.1	0.05	49	42.7	49.0
<<insert>>														
	Min		0.00	9.46	23.2	2.66	77	100	5.94	0.06	0.05	49	0.0	49.0
	Max		13.00	22.42	103.9	9.21	101	113	6.60	0.07	0.05	95	42.7	72.4
	Max - Min		13.00	12.96	80.7	6.55	24	13	0.66	0.01	0.00	46	42.7	23.3
	Count		14	14	14	14	14	14	14	14	14	14	14	14

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
07/16/18	9:31:52	3	0.0	26.74	109.1	8.74	115	111	6.42	0.1	0.05	84	0.0	80.1
07/16/18	9:32:23	3	1.0	26.15	115.0	9.30	111	109	6.44	0.1	0.05	68	3.3	79.1
07/16/18	9:33:32	3	2.0	25.84	114.3	9.30	111	109	6.51	0.1	0.05	61	6.6	78.5
07/16/18	9:34:09	3	3.0	25.66	113.6	9.28	109	107	6.57	0.1	0.05	61	9.8	78.2
07/16/18	9:34:40	3	4.0	25.55	112.9	9.23	104	103	6.58	0.1	0.05	63	13.1	78.0
07/16/18	9:35:05	3	5.0	24.37	107.8	9.01	112	113	6.60	0.1	0.05	68	16.4	75.9
07/16/18	9:35:35	3	6.0	21.42	93.9	8.30	99	107	6.56	0.1	0.05	79	19.7	70.6
07/16/18	9:36:06	3	7.0	18.17	62.0	5.85	93	107	6.50	0.1	0.05	94	23.0	64.7
07/16/18	9:36:34	3	8.0	14.83	32.7	3.31	87	108	6.39	0.1	0.05	107	26.2	58.7
07/16/18	9:37:38	3	9.0	12.58	8.8	0.94	81	106	6.11	0.1	0.05	121	29.5	54.6
07/16/18	9:38:05	3	10.0	10.64	7.5	0.84	86	119	6.03	0.1	0.06	68	32.8	51.2
07/16/18	9:38:48	3	11.0	10.27	6.4	0.72	87	121	5.90	0.1	0.06	42	36.1	50.5
07/16/18	9:39:03	3	12.0	10.23	6.1	0.69	84	117	5.89	0.1	0.06	36	39.4	50.4
07/16/18	9:39:33	3	12.2	10.09	5.6	0.63	98	138	5.92	0.1	0.07	-20	40.0	50.2
<<insert>>														
	Min		0.00	10.09	5.6	0.63	81	103	5.89	0.07	0.05	-20	0.0	50.2
	Max		12.19	26.74	115.0	9.30	115	138	6.60	0.09	0.07	121	40.0	80.1
	Max - Min		12.19	16.65	109.4	8.67	34	35	0.71	0.02	0.02	141	40.0	30.0
	Count		14	14	14	14	14	14	14	14	14	14	14	14

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

													Conversions	
Date M/D/Y	**Time hh:mm:ss**	**Site**	**Depth m**	**Temp C**	**DO% %**	**DO Conc mg/L**	**Cond uS/cm**	**SpCond uS/cm**	**pH s.u.**	**TDS mg/L**	**Salinity ppt**	**ORP mV**	**Depth (feet)**	**Temp (Degrees F)**
08/13/18	9:57:52	3	0.0	25.38	100.9	8.28	110	109	6.34	0.1	0.05	99	0.0	77.7
08/13/18	9:58:25	3	1.0	25.39	101.0	8.29	108	108	6.40	0.1	0.05	90	3.3	77.7
08/13/18	9:58:57	3	2.0	25.39	101.0	8.29	111	110	6.44	0.1	0.05	84	6.6	77.7
08/13/18	9:59:25	3	3.0	25.38	102.0	8.37	106	105	6.47	0.1	0.05	82	9.8	77.7
08/13/18	10:00:28	3	4.0	25.39	101.2	8.30	109	108	6.53	0.1	0.05	77	13.1	77.7
08/13/18	10:00:55	3	5.0	25.39	102.4	8.40	104	103	6.56	0.1	0.05	75	16.4	77.7
08/13/18	10:01:16	3	6.0	25.39	102.8	8.43	106	105	6.58	0.1	0.05	74	19.7	77.7
08/13/18	10:01:37	3	7.0	21.90	102.6	8.99	89	95	6.64	0.1	0.04	77	23.0	71.4
08/13/18	10:02:04	3	8.0	19.87	58.6	5.34	90	99	6.58	0.1	0.05	93	26.2	67.8
08/13/18	10:02:23	3	9.0	17.77	38.0	3.61	95	110	6.50	0.1	0.05	78	29.5	64.0
08/13/18	10:02:58	3	10.0	13.47	11.6	1.21	99	127	6.35	0.1	0.06	-116	32.8	56.2
08/13/18	10:03:26	3	11.0	11.83	7.6	0.82	95	127	6.29	0.1	0.06	-138	36.1	53.3
08/13/18	10:03:50	3	12.0	11.32	6.0	0.66	98	132	6.26	0.1	0.06	-149	39.4	52.4
08/13/18	10:04:22	3	12.2	11.06	4.3	0.47	156	213	6.17	0.1	0.10	-169	40.1	51.9
<<insert>>														
	Min		0.00	11.06	4.3	0.47	89	95	6.17	0.06	0.04	-169	0.0	51.9
	Max		12.22	25.39	102.8	8.99	156	213	6.64	0.14	0.10	99	40.1	77.7
	Max - Min		12.22	14.33	98.5	8.52	67	118	0.47	0.08	0.06	268	40.1	25.8
	Count		14	14	14	14	14	14	14	14	14	14	14	14

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
09/17/18	9:29:48	3	0.0	23.16	137.6	11.76	102	105	7.53	0.1	0.05	52	0.0	73.7
09/17/18	9:30:25	3	1.0	23.12	139.6	11.94	105	109	7.71	0.1	0.05	51	3.3	73.6
09/17/18	9:30:52	3	2.0	22.82	138.2	11.89	105	109	7.75	0.1	0.05	56	6.6	73.1
09/17/18	9:31:29	3	3.0	22.04	128.2	11.20	97	103	7.72	0.1	0.05	69	9.8	71.7
09/17/18	9:32:03	3	4.0	21.71	114.1	10.04	98	105	7.62	0.1	0.05	81	13.1	71.1
09/17/18	9:32:33	3	5.0	21.29	96.4	8.54	102	110	7.53	0.1	0.05	88	16.4	70.3
09/17/18	9:33:55	3	6.0	21.05	73.1	6.51	96	104	7.30	0.1	0.05	105	19.7	69.9
09/17/18	9:34:20	3	7.0	20.65	72.0	6.47	99	108	7.26	0.1	0.05	107	23.0	69.2
09/17/18	9:34:45	3	8.0	19.67	61.8	5.65	89	99	7.24	0.1	0.05	110	26.2	67.4
09/17/18	9:35:06	3	9.0	17.79	55.7	5.29	79	92	7.23	0.1	0.04	111	29.5	64.0
09/17/18	9:35:38	3	10.0	15.57	51.9	5.17	100	122	7.03	0.1	0.06	-111	32.8	60.0
09/17/18	9:36:01	3	11.0	13.36	23.1	2.41	138	178	6.85	0.1	0.08	-164	36.1	56.0
<<insert>>														
	Min		0.00	13.36	23.1	2.41	79	92	6.85	0.06	0.04	-164	0.0	56.0
	Max		11.00	23.16	139.6	11.94	138	178	7.75	0.11	0.08	111	36.1	73.7
	Max - Min		11.00	9.80	116.5	9.53	59	86	0.90	0.06	0.04	276	36.1	17.6
	Count		12	12	12	12	12	12	12	12	12	12	12	12

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 3

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
10/15/18	10:06:25	3	0.0	16.64	127.3	12.39	79	94	5.45	0.1	0.04	109	0.0	62.0
10/15/18	10:07:04	3	1.0	16.65	114.9	11.18	76	90	5.49	0.1	0.04	115	3.3	62.0
10/15/18	10:07:52	3	2.0	16.65	112.4	10.94	80	95	5.53	0.1	0.04	119	6.6	62.0
10/15/18	10:08:46	3	3.0	16.64	112.0	10.91	77	91	5.56	0.1	0.04	123	9.8	62.0
10/15/18	10:09:08	3	4.0	16.64	111.9	10.90	78	93	5.57	0.1	0.04	125	13.1	62.0
10/15/18	10:10:07	3	5.0	16.63	112.0	10.91	83	98	5.61	0.1	0.05	126	16.4	61.9
10/15/18	10:13:43	3	6.0	16.63	116.9	11.39	77	92	5.66	0.1	0.04	141	19.7	61.9
10/15/18	10:14:08	3	7.0	16.64	115.7	11.26	80	95	5.68	0.1	0.04	140	23.0	62.0
10/15/18	10:14:26	3	8.0	16.59	115.1	11.21	76	91	5.68	0.1	0.04	141	26.2	61.9
10/15/18	10:14:45	3	9.0	16.59	113.8	11.09	75	89	5.67	0.1	0.04	141	29.5	61.9
10/15/18	10:14:59	3	10.0	16.58	113.0	11.02	78	93	5.68	0.1	0.04	141	32.8	61.8
10/15/18	10:15:14	3	11.0	16.39	111.7	10.93	69	83	5.68	0.1	0.04	141	36.1	61.5
10/15/18	10:15:39	3	11.5	15.64	81.7	8.12	95	115	5.57	0.1	0.05	-30	37.8	60.2
<<insert>>														
	Min		0.00	15.64	81.7	8.12	69	83	5.45	0.05	0.04	-30	0.0	60.2
	Max		11.52	16.65	127.3	12.39	95	115	5.68	0.07	0.05	141	37.8	62.0
	Max - Min		11.52	1.01	45.6	4.27	26	32	0.23	0.02	0.01	171	37.8	1.8
	Count		13	13	13	13	13	13	13	13	13	13	13	13

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
05/21/18	9:06:53	5	0.0	16.29	101.1	9.91	77	93	6.19	0.1	0.04	114	0.0	61.3
05/21/18	9:08:08	5	1.0	15.63	97.5	9.70	86	104	5.94	0.1	0.05	106	3.3	60.1
05/21/18	9:08:44	5	2.0	14.85	97.6	9.88	61	76	5.94	0.0	0.03	105	6.6	58.7
05/21/18	9:09:22	5	3.0	14.53	97.5	9.93	60	75	5.84	0.0	0.03	109	9.8	58.2
05/21/18	9:10:01	5	4.0	14.06	97.3	10.02	67	85	5.67	0.1	0.04	114	13.1	57.3
05/21/18	9:10:29	5	5.0	13.65	97.4	10.12	61	79	5.63	0.1	0.04	115	16.4	56.6
05/21/18	9:10:56	5	6.0	13.32	97.9	10.24	63	81	5.59	0.1	0.04	116	19.7	56.0
05/21/18	9:11:20	5	7.0	12.89	98.1	10.36	65	85	5.55	0.1	0.04	117	23.0	55.2
05/21/18	9:11:38	5	7.2	12.66	97.0	10.30	76	99	5.51	0.1	0.05	116	23.5	54.8
<<insert>>														
	Min		0.00	12.66	97.0	9.70	60	75	5.51	0.05	0.03	105	0.0	54.8
	Max		7.16	16.29	101.1	10.36	86	104	6.19	0.07	0.05	117	23.5	61.3
	Max - Min		7.16	3.63	4.1	0.66	26	29	0.68	0.02	0.02	12	23.5	6.5
	Count		9	9	9	9	9	9	9	9	9	9	9	9

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
06/18/18	9:16:25	5	0.0	22.10	110.3	9.63	100	106	6.56	0.1	0.05	60	0.0	71.8
06/18/18	9:17:17	5	1.0	21.55	108.9	9.60	97	104	6.42	0.1	0.05	64	3.3	70.8
06/18/18	9:17:59	5	2.0	20.74	105.0	9.41	95	104	6.25	0.1	0.05	73	6.6	69.3
06/18/18	9:18:46	5	3.0	20.07	102.1	9.27	91	101	6.13	0.1	0.05	79	9.8	68.1
06/18/18	9:19:18	5	4.0	19.68	100.1	9.15	99	111	6.10	0.1	0.05	81	13.1	67.4
06/18/18	9:19:58	5	5.0	19.05	93.5	8.66	93	105	6.03	0.1	0.05	86	16.4	66.3
06/18/18	9:20:20	5	6.0	18.36	91.7	8.62	99	113	5.99	0.1	0.05	88	19.7	65.0
06/18/18	9:20:56	5	7.0	16.89	73.3	7.10	93	111	5.98	0.1	0.05	92	23.0	62.4
06/18/18	9:21:29	5	8.0	13.91	52.8	5.45	87	111	5.90	0.1	0.05	94	26.2	57.0
06/18/18	9:21:56	5	8.6	12.75	39.2	4.15	84	109	5.92	0.1	0.05	46	28.3	54.9
<<insert>>														
	Min		0.00	12.75	39.2	4.15	84	101	5.90	0.07	0.05	46	0.0	54.9
	Max		8.61	22.10	110.3	9.63	100	113	6.56	0.07	0.05	94	28.3	71.8
	Max - Min		8.61	9.35	71.1	5.48	16	12	0.66	0.01	0.00	47	28.3	16.8
	Count		10	10	10	10	10	10	10	10	10	10	10	10

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions: Depth (feet)	Conversions: Temp (Degrees F)
07/16/18	8:57:50	5	0.0	26.99	111.3	8.86	119	114	6.16	0.1	0.05	106	0.0	80.6
07/16/18	8:58:58	5	1.0	26.11	112.3	9.09	116	114	6.23	0.1	0.05	96	3.3	79.0
07/16/18	8:59:25	5	2.0	25.82	112.5	9.15	115	113	6.27	0.1	0.05	94	6.6	78.5
07/16/18	9:00:16	5	3.0	25.11	98.1	8.09	112	112	6.28	0.1	0.05	98	9.8	77.2
07/16/18	9:00:48	5	4.0	24.35	87.5	7.31	115	117	6.26	0.1	0.05	102	13.1	75.8
07/16/18	9:01:18	5	5.0	23.18	67.3	5.75	124	128	6.22	0.1	0.06	106	16.4	73.7
07/16/18	9:02:01	5	6.0	20.97	34.8	3.10	112	121	6.23	0.1	0.06	109	19.7	69.7
07/16/18	9:02:36	5	7.0	17.86	14.3	1.36	105	122	6.17	0.1	0.06	5	23.0	64.1
07/16/18	9:03:11	5	8.0	14.43	8.7	0.89	106	133	6.06	0.1	0.06	-83	26.2	58.0
07/16/18	9:03:55	5	8.4	13.98	6.5	0.67	117	148	5.96	0.1	0.07	-185	27.4	57.2
<<insert>>														
	Min		0.00	13.98	6.5	0.67	105	112	5.96	0.07	0.05	-185	0.0	57.2
	Max		8.35	26.99	112.5	9.15	124	148	6.28	0.10	0.07	109	27.4	80.6
	Max - Min		8.35	13.01	106.0	8.48	19	36	0.32	0.02	0.02	293	27.4	23.4
	Count		10	10	10	10	10	10	10	10	10	10	10	10

LWWMD Water Quality Data - 2018
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Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date	Time		Depth	Temp	DO%	DO Conc	Cond	SpCond	pH	TDS	Salinity	ORP	Conversions Depth	Conversions Temp
M/D/Y	hh:mm:ss	Site	m	C	%	mg/L	uS/cm	uS/cm	s.u.	mg/L	ppt	mV	(feet)	(Degrees F)
08/13/18	9:23:16	5	0.0	25.43	104.9	8.60	108	107	5.87	0.1	0.05	118	0.0	77.8
08/13/18	9:23:57	5	1.0	25.45	107.4	8.80	109	108	5.99	0.1	0.05	106	3.3	77.8
08/13/18	9:24:36	5	2.0	25.45	108.8	8.91	109	108	6.06	0.1	0.05	100	6.6	77.8
08/13/18	9:25:11	5	3.0	25.45	108.9	8.92	101	101	6.13	0.1	0.05	96	9.8	77.8
08/13/18	9:25:38	5	4.0	25.43	108.8	8.92	110	109	6.18	0.1	0.05	93	13.1	77.8
08/13/18	9:26:07	5	5.0	24.91	105.7	8.75	133	133	6.15	0.1	0.06	95	16.4	76.8
08/13/18	9:26:41	5	6.0	23.52	95.1	8.08	114	117	6.27	0.1	0.05	92	19.7	74.3
08/13/18	9:27:07	5	7.0	22.00	91.9	8.04	97	103	6.32	0.1	0.05	63	23.0	71.6
08/13/18	9:27:36	5	7.1	21.69	63.9	5.62	100	106	6.24	0.1	0.05	-56	23.2	71.0
<<insert>>														
	Min		0.00	21.69	63.9	5.62	97	101	5.87	0.06	0.05	-56	0.0	71.0
	Max		7.08	25.45	108.9	8.92	133	133	6.32	0.09	0.06	118	23.2	77.8
	Max - Min		7.08	3.76	45.0	3.30	36	32	0.45	0.02	0.01	173	23.2	6.8
	Count		9	9	9	9	9	9	9	9	9	9	9	9

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Insitu Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date M/D/Y	Time hh:mm:ss	Site	Depth m	Temp C	DO% %	DO Conc mg/L	Cond uS/cm	SpCond uS/cm	pH s.u.	TDS mg/L	Salinity ppt	ORP mV	Conversions Depth (feet)	Temp (Degrees F)
09/17/18	8:53:44	5	0.0	22.55	146.4	12.67	99	104	7.05	0.1	0.05	105	0.0	72.6
09/17/18	8:54:26	5	1.0	22.51	145.5	12.60	97	102	7.23	0.1	0.05	103	3.3	72.5
09/17/18	8:55:22	5	2.0	22.37	139.2	12.09	96	101	7.28	0.1	0.05	108	6.6	72.3
09/17/18	8:56:26	5	3.0	21.92	132.3	11.58	97	103	7.25	0.1	0.05	118	9.8	71.5
09/17/18	8:57:02	5	4.0	20.83	124.8	11.16	103	112	7.17	0.1	0.05	126	13.1	69.5
09/17/18	8:57:30	5	5.0	19.64	116.4	10.66	84	94	7.21	0.1	0.04	129	16.4	67.4
09/17/18	8:57:55	5	5.3	19.57	107.3	9.84	80	89	7.14	0.1	0.04	-38	17.3	67.2
<<insert>>														
	Min		0.00	19.57	107.3	9.84	80	89	7.05	0.06	0.04	-38	0.0	67.2
	Max		5.29	22.55	146.4	12.67	103	112	7.28	0.07	0.05	129	17.3	72.6
	Max - Min		5.29	2.98	39.1	2.83	23	23	0.23	0.01	0.01	167	17.3	5.4
	Count		7	7	7	7	7	7	7	7	7	7	7	7

Database Last Modified: 12/07/18
Staff Initials: arl

Insitu Water Quality Data - Station No. 5

Date	Time		Depth	Temp	DO%	DO Conc	Cond	SpCond	pH	TDS	Salinity	ORP	Conversions	
M/D/Y	hh:mm:ss	Site	m	C	%	mg/L	uS/cm	uS/cm	s.u.	mg/L	ppt	mV	(feet)	(Degrees F)
10/15/18	9:22:39	5	0.0	14.96	120.3	12.14	63	78	5.49	0.1	0.04	175	0.0	58.9
10/15/18	9:23:25	5	1.0	14.97	112.4	11.34	62	77	5.40	0.0	0.04	170	3.3	58.9
10/15/18	9:23:53	5	2.0	14.93	111.3	11.24	67	83	5.38	0.1	0.04	167	6.6	58.9
10/15/18	9:24:22	5	3.0	14.75	110.5	11.20	67	83	5.38	0.1	0.04	166	9.8	58.5
10/15/18	9:25:03	5	4.0	13.45	114.1	11.90	76	97	5.33	0.1	0.05	164	13.1	56.2
10/15/18	9:25:33	5	5.0	11.94	117.7	12.70	57	77	5.46	0.0	0.04	159	16.4	53.5
10/15/18	9:26:02	5	6.0	11.81	121.6	13.16	54	72	5.42	0.0	0.03	159	19.7	53.3
10/15/18	9:26:41	5	7.0	11.79	124.1	13.44	62	83	5.38	0.1	0.04	91	23.0	53.2
<<insert>>														
	Min		0.00	11.79	110.5	11.20	54	72	5.33	0.05	0.03	91	0.0	53.2
	Max		7.00	14.97	124.1	13.44	76	97	5.49	0.06	0.05	175	23.0	58.9
	Max - Min		7.00	3.18	13.6	2.24	22	25	0.16	0.02	0.02	84	23.0	5.7
	Count		8	8	8	8	8	8	8	8	8	8	8	8

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Laboratory Water Quality Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: 12/07/18
Staff Initials: arl

Lab ID: ECM (Environmental Compliance Monitoring Inc.)

Ref ID	Lab ID	Year	Date	Station	Layer Code	Layer	Depth (m)	SpCond** (uS/cm)	pH** (s.u.)	ALK (mg/L)		SRP (mg/L)	TP (mg/L)		NO3 (mg/L)		NO2 (mg/L)	NO2/NO3* (mg/L)		NH3 (mg/L)		TKN (mg/L)	TN* (mg/L)		TSS (mg/L)	Ref ID	Notes
3242	ECM	2018	05/21/18	3	1	S		99	6.20	22.5	b	0.002	0.010		0.150		0.003	0.153	b	0.010	b	0.160	0.313		13.0	3242	
3243	ECM	2018	05/21/18	3	3	B		105	5.81	20.5	b	0.002	0.010		0.230		0.002	0.232	b	0.010	b	0.160	0.392		10.0	3243	
3244	ECM	2018	05/21/18	5	1	S		104	5.94	23.5	b	0.002	0.030		0.230		0.008	0.238		0.030	b	0.160	0.398		7.0	3244	
3245	ECM	2018	05/21/18	5	3	B		81	5.59	23.0	b	0.002	0.030		0.310		0.010	0.320		0.030	b	0.160	0.480		11.0	3245	
3246	ECM	2018	06/18/18	3	1	S		105	6.56	21.0		0.003	0.010		0.060		0.002	0.062	b	0.010	b	0.160	0.222		3.0	3246	
3247	ECM	2018	06/18/18	3	3	B		112	6.02	20.0	b	0.002	0.020		0.190		0.006	0.196	b	0.010	b	0.160	0.356	b	3.0	3247	
3248	ECM	2018	06/18/18	5	1	S		104	6.42	21.0	b	0.002	0.020		0.100		0.007	0.107	b	0.010	b	0.160	0.267	b	3.0	3248	
3249	ECM	2018	06/18/18	5	3	B		111	5.90	21.5	b	0.002	0.020		0.300		0.018	0.318	b	0.010	b	0.160	0.478		5.0	3249	
3250	ECM	2018	07/16/18	3	1	S		109	6.44	24.0	b	0.002	0.010		0.070	b	0.002	0.072	b	0.010	b	0.160	0.232	b	3.0	3250	
3251	ECM	2018	07/16/18	3	3	B		121	5.90	20.0	b	0.002	0.020		0.130		0.003	0.133		0.050	b	0.160	0.293		5.0	3251	
3252	ECM	2018	07/16/18	5	1	S		114	6.23	25.0	b	0.002	0.020		0.140	b	0.002	0.142	b	0.010	b	0.160	0.302	b	3.0	3252	
3253	ECM	2018	07/16/18	5	3	B		122	6.17	21.5	b	0.002	0.050		0.140		0.006	0.146		0.300		0.320	0.466		10.0	3253	
3254	ECM	2018	08/13/18	3	1	S		108	6.40	22.0		0.002	0.020		0.080	b	0.002	0.082		0.030		0.220	0.302	b	3.0	3254	
3255	ECM	2018	08/13/18	3	3	B		127	6.29	26.0		0.075	0.130		0.250		0.006	0.256		0.120		0.280	0.536		5.0	3255	
3256	ECM	2018	08/13/18	5	1	S		108	5.99	20.0		0.003	0.080		0.140		0.002	0.142		0.010		0.180	0.322	b	3.0	3256	
3257	ECM	2018	08/13/18	5	3	B		117	6.27	22.0		0.004	0.100		0.210		0.004	0.214		0.030		0.220	0.434		5.0	3257	
3258	ECM	2018	09/17/18	3	1	S		109	7.71	20.0	b	0.002	0.010		0.020		0.002	0.022		0.010	b	0.160	0.182		5.0	3258	
3259	ECM	2018	09/17/18	3	3	B		122	7.03	21.0		0.004	0.020		0.150		0.004	0.154		0.080	b	0.160	0.314		7.0	3259	
3260	ECM	2018	09/17/18	5	1	S		102	7.23	20.0	b	0.002	0.040		0.030		0.003	0.033		0.020	b	0.160	0.193		6.0	3260	
3261	ECM	2018	09/17/18	5	3	B		112	7.17	21.0		0.002	0.040		0.210		0.003	0.213		0.080	b	0.160	0.373		5.0	3261	
3262	ECM	2018	10/15/18	3	1	S		90	5.49	24.0	^	0.008	0.040	^	0.070		0.019	0.089		0.030	b	0.160	0.249		8.0	3262	*^ = Analysis performed out of holding time due to late arrival of samples.*
3263	ECM	2018	10/15/18	3	3	B		93	5.68	28.0	^	0.019	0.050	^	0.140	^	0.012	0.152		0.040	b	0.160	0.312		11.0	3263	*^ = Analysis performed out of holding time due to late arrival of samples.*
3264	ECM	2018	10/15/18	5	1	S		77	5.40	23.0	^	0.009	0.030	^	0.240		0.005	0.245		0.010	b	0.160	0.405		14.0	3264	*^ = Analysis performed out of holding time due to late arrival of samples.*
3265	ECM	2018	10/15/18	5	3	B		72	5.42	23.0	^	0.012	0.040	^	0.240	^	0.004	0.244		0.020	b	0.160	0.404		17.0	3265	*^ = Analysis performed out of holding time due to late arrival of samples.*

<insert>

Notes:
TN denotes total nitrogen and is the sum of total Kjeldahl nitrogen, nitrite, and nitrate nitrogen
NO2/NO3 (nitrate + nitrite nitrogen) can be determined directly by laboratory or by summing nitrate & nitrite concentrations
Total Kjeldahl nitrogen (TKN) determined by adding nitrate, nitrite and ammonia nitrogen fractions
(b) denotes below detection limit, therefore data reported as the detection limit
(*) indicates calculated value
(**) indicates *in-situ* field data collected on the study date (also refer to *in-situ* data)
(^) Analysis performed out of holding time due to late arrival of samples.

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

Secchi Depth & Lab Chla Data - Lake Wallenpaupack - All Stations
Prepared by Aqua Link, Inc.

Database Last Modified: **12/07/18**
Staff Initials: **arl**

Lab ID: ECM (Environmental Compliance Monitoring Inc.)

Ref	Lab	Year	Date	Station	Secchi Depth (m)	Sampling Depth (m)	Chlorophyll a (ug/L)		Pheophytin (ug/L)	Ref
1149	ECM	2018	05/21/18	3	2.50		6.00			1149
1150	ECM	2018	05/21/18	5	1.60		5.30			1150
1151	ECM	2018	06/18/18	3	2.90		2.40			1151
1152	ECM	2018	06/18/18	5	1.80		5.70			1152
1153	ECM	2018	07/16/18	3	3.20		8.30		4.20	1153
1154	ECM	2018	07/16/18	5	2.40		3.20		4.20	1154
1155	ECM	2018	08/13/18	3	2.00		16.40	b	0.50	1155
1156	ECM	2018	08/13/18	5	1.20		25.40	b	0.50	1156
1157	ECM	2018	09/17/18	3	1.00		22.70	b	0.50	1157
1158	ECM	2018	09/17/18	5	0.60		84.50	b	1.00	1158
1159	ECM	2018	10/15/18	3	1.90		10.70	b	0.30	1159
1160	ECM	2018	10/15/18	5	1.00		2.80	b	0.30	1160

LWWMD Water Quality Data - 2018
ALI Customer No. 1157-14

TSI Data - Lake Wallenpaupack - Station 3 May through October
Prepared by Aqua Link, Inc.

Carlson's Trophic State Index

Lab ID: ECM (Environmental Compliance Monitoring Inc.)

Station	Date	Secchi (meters)	Chl-a* (ug/l)	TP* (mg/l as P)	TSI Values Secchi	TSI Values Chl-a	TSI Values TP	Mean TSI Values Secchi	Mean TSI Values Chl-a	Mean TSI Values TP
3	05/21/18	2.50	6.00	0.010	46.8	48.1	37.4	48.3	54.2	44.7
3	06/18/18	2.90	2.40	0.010	44.6	39.2	37.4			
3	07/16/18	3.20	8.30	0.010	43.2	51.3	37.4			
3	08/13/18	2.00	16.40	0.020	50.0	58.0	47.4			
3	09/17/18	1.00	22.70	0.010	60.0	61.2	37.4			
3	10/15/18	1.90	10.70	0.040	50.7	53.8	57.4			
<<insert>>										
	Min	1.00	2.40	0.010	43.2	39.2	37.4			
	Max	3.20	22.70	0.040	60.0	61.2	57.4			
	Mean	2.25	11.08	0.017	------	------	------			
	Median	2.25	9.50	0.010	------	------	------			
	Stds	0.79	7.38	0.012	------	------	------			
	Std	0.72	6.74	0.011	------	------	------			
	Count	6	6	6	6	6	6			

Note(s): (*) indicates data reported for surface (1.0 m)

Plankton Identification & Enumeration

Kenneth Wagener, Ph.D.

Algae – Phytoplankton

Sample Collection

Samples are normally received by mail or courier. If collected by K. Wagner, samples are either grab samples collected about 1 ft below the surface or are composite samples from a flexible tube lowered to a depth equal to twice the Secchi transparency or the depth of the thermocline, whichever is least. Samples are collected in straight sided plastic containers with a volume of 125 to 1000 ml. Sample bottles are filled to the shoulder of the bottle (straight sided part is filled, air space left by not filling the neck). Samples are preserved in either gluteraldehyde (0.3 to 0.5% by volume) or Lugol's solution (1 to 2% by volume), depending upon client preference. With the use of gluteraldehyde, samples should froth slightly when shaken. For Lugol's solution, the sample should have a weak tea color. If algae appear dense, a little more preservative (up to about double) may be warranted. Samples are labeled with waterbody name, station, date and type of preservative.

Sample Processing

Preserved samples are allowed to stand undisturbed for at least 3 days and normally for 1 week. Each sample is viewed for visual signs of algal density (amount of material accumulated on the container bottom or floating at the surface). Unless the sample obviously contains visually large amounts of algae, the supernatant is decanted or siphoned from the middle to concentrate the sample by a factor of 2 to 6, depending upon how easy it is to remove supernatant without disturbing settled particles (this is a function of container geometry). The remaining sample is then vigorously shaken for 1 minute and 50 mL of sample is poured into a 50 mL graduated test tube.

Test tubes are clear cylinders with a height to diameter ratio of 5:1, with a conical bottom containing approximately 5 mL. Tubes are labeled to match the original sample bottles. Samples in the tubes are allowed to stand undisturbed for at least 3 days and normally for 1 week, after which the concentration process described for the original sample is repeated. Final concentrate volume is typically about 10 mL, concentrating the sample in the tube by a factor of approximately 5. Final concentration factors are therefore typically on the order of 10 to 30, although samples with high algal density may not be concentrated at all and samples with very low density may be concentrated by factors up to 100.

Sample Examination

The concentrated sample is shaken vigorously for about 1 minute to homogenize the contents, then 0.1 mL is pipetted into a Palmer-Maloney style counting chamber. This circular chamber has a depth of 0.04 cm and a diameter of 1.75 cm. The slide is allowed to stand for 5-15 minutes. The slide is then scanned at 200X power (20X objective and 10X oculars) under phase contrast optics and a list of all encountered algal taxa is constructed. Viewing at 400X is conducted if necessary to identify taxa. Using a standard microscope slide and a separate sample aliquot, it is also possible to view specimens at 1000X under oil immersion if necessary. Identifications are made from a variety of reference books as needed, relying mainly on Wehr and Sheath 2003. Actual counting (see below) is performed at 400X.

Sample Enumeration

Counts of algal cells are made along complete transects across the slide; these transects are called strips. A strip count involves recording the cells of each taxon (usually genus) encountered along the transect. To avoid overcounting, cells partially visible on the left side are counted, while those partially visible along the right side are ignored. If appropriate to the project, natural units, colonies, filaments, or other cell groupings may be counted, but in all cases an average number of cells per algal grouping is obtained to allow calculation of density as cells/mL. Based on cell measurements, cells of each taxon are recorded as small, medium or large specimens of the corresponding taxon. The size categories are genus-specific; a large specimen of one taxon with typically smaller cells may be smaller than a small specimen of another taxon with typically larger cells. At least two strips are counted, after which results from each strip are compared. If the increase in taxa is more than 10% of the total or the abundance of any two possible dominants (genera comprising more than 20% of the total count) differs by more than 10%, additional strips are counted until the "10% rule" is satisfied.

Calculations

All counts are recorded in a spreadsheet file. A multiplication factor is established as the inverse of the product of the fraction of 1 mL viewed and the sample concentration factor. For example, if one tenth of the slide was viewed, with that slide representing one tenth of a mL, and the sample had been concentrated by a factor of 10, the multiplication factor would be 1/(0.1X0.1X10), or 10. Multiplication factors are typically between 6 and 30. The cell count for each taxon is multiplied by this factor and recorded in a separate portion of the spreadsheet for easy printing, as cells/mL. Cell counts are tallied by genus, ecologically significant groupings within algal divisions (e.g., flagellated greens, filamentous blue-greens), algal division (e.g., blue-greens, greens, diatoms) and as a grand total.

Based on the number of cells of each taxon in each corresponding size category, a biomass estimate is calculated. Each size category for each taxon is assigned a biomass per cell, based on the average cell dimensions for that category and a specific gravity of 1.0. Multiplication of the genus and size specific factor by the number of cells in that taxon and size category yields both a biovolume and biomass estimate. The sum for each genus (three possible size categories) is reported as ug/L. The sum for each ecologically significant grouping, algal division and the grand total are reported as well.

If requested, a conversion to algal standard units (ASU) is also made. The average area (two dimensional) of each cell for each genus and size category is multiplied by the corresponding number of cells and divided by 400 square microns to derive an ASU value for each taxon. The ASUs are summed for each ecologically significant grouping, algal division and as a grand total as well.

The total number of taxa per ecologically significant grouping, algal division and per sample is also reported, simply as a summation of the taxa observed. Shannon-Weiner Diversity (S) is calculated by the appropriate formula based on the number of cells recorded for each taxon and for the biomass of each taxon. Pielou's Evenness (J) is also calculated, based on S divided by the maximum possible S value for the number of taxa observed, yielding a value between 0 and 1. Additional indices can be calculated as warranted.

Quality Control

Approximately one sample in every ten is subjected to re-analysis. Samples for QC checks are chosen randomly from samples available at the time of analysis. Differences of 10-20% are typical for phytoplankton samples counted by the same analyst and considered acceptable for use in evaluating aquatic conditions.

Algae – Periphyton

Sample Collection

Samples are normally received by mail or courier. If collected by K. Wagner, samples are collected by scraping a defined area of natural or artificial substrate. Enough distilled water is added to create a mixture of appropriate density for microscopic analysis of an aliquot of well-mixed sample. Samples are preserved in either gluteraldehyde or Lugol's solution, depending upon client preference, but as algal density is likely to be high, double the amount of preservative used for phytoplankton samples (1% gluteraldehyde, 2-4% Lugols). Container shape is not critical, but small size (125-250 ml) plastic bottles are preferred, as periphyton samples tend to be very concentrated to begin with. Samples are labeled with waterbody name, station, date and type of preservative, plus the area that was sampled in square centimeters.

Sample Processing, Examination and Enumeration

Samples should not require any concentration, but may be diluted by addition of distilled water. If necessary, concentration by settling is performed as described for phytoplankton analysis above. Examination and enumeration follow the phytoplankton analysis protocols above.

Calculations

All counts are recorded in a spreadsheet file. A multiplication factor is established in the same manner as for phytoplankton, except that the factor for converting cell count to cells/mL is then multiplied by the number of mL of sample and divided by the square centimeters of substrate sampled to yield a measure of cells/cm^2. All other calculations follow the phytoplankton analysis procedures.

Zooplankton

Sample Collection

Samples are normally received by mail or courier. If collected by K. Wagner, samples are concentrates obtained by towing a plankton net with a 53 um mesh size through at least 30 m of water (multiple shorter tows as needed). The net is typically retrieved at an oblique angle after allowing it to settle to within 1 m of the bottom of the lake. Care is taken to avoid tows long enough to cause net clogging. Samples are preserved in either formalin (2%) or gluteraldehyde (2%) or Lugol's solution (strong tea color, usually about 4%), depending upon client preference. Container shape is not critical, but small size (125-250 ml) plastic bottles are preferred, as zooplankton tow samples tend to be very concentrated to begin with. Samples are labeled with waterbody name, station, date and type of preservative, plus the length of the tow and the diameter of the net used.

Sample Processing

Samples are allowed to stand undisturbed for at least 10 minutes and normally for several hours. Each sample is viewed for visual signs of zooplankton density (amount of apparent zooplankton and other particles accumulated on the container bottom). The supernatant is decanted or siphoned until the concentrated sample will fit into a 50 mL graduated test tube. This may require multiple episodes of settling and transfer, depending upon container geometry and the quantity of algae present, to get a zooplankton sample that can be properly viewed at an appropriate concentration. Where considerable algae are present, siphoning is timed to remove as much algae as possible without losing zooplankton; zooplankton settle faster than most algae. Multiple refills with distilled water, with repeat of the settling/siphoning process, are used to clear the sample of algae to the extent necessary to facilitate unobstructed viewing of zooplankton.

Test tubes are clear cylinders with a height to diameter ratio of 5:1, with a conical bottom containing approximately 5 mL. Tubes are labeled to match the original sample bottles. Final concentrate volume is typically 20 to 50 mL, representing 500 to 1000 L of filtered lake water, depending upon net diameter. Final concentration factors are therefore typically on the order of 20,000 to 30,000.

Sample Examination

The concentrated sample is shaken vigorously for about 30 seconds to homogenize the contents, then 1 mL is pipetted into a Sedgewick-Rafter style counting chamber. This rectangular chamber has a depth of 0.1 cm, a length of 5 cm and a width of 2 cm. The slide is then scanned at 40X power (4X objective and 10X oculars) under brightfield optics and a list of all encountered zooplankton taxa is constructed. Viewing at 100X or higher power is conducted as necessary to identify taxa. Identifications are made from a variety of reference books as needed.

Sample Enumeration

Counts of zooplankton individuals are made along complete transects across the slide; these transects are called strips. A strip count involves recording the individuals of each taxon (usually genus) encountered along the transect. To avoid overcounting, individuals partially visible on the top side are counted, while those partially visible along the bottom side are ignored. Based on body length measurements, individuals of each taxon are recorded as small, medium or large specimens of the corresponding taxon. The size categories are genus-specific; a large specimen of a small-bodied taxon may be smaller than a small specimen of a large-bodied taxon. At least two strips are counted, after which results from each strip are compared. If the increase in taxa is more than 10% of the total or the ratio of any two possible dominants (genera comprising more than 20% of the total count) is greater than 10%, additional strips are counted until the "10% rule" is satisfied. The slide is refilled with fresh sample if more than 3 strips are needed.

Calculations

All counts are recorded in a spreadsheet file as individuals/L. A multiplication factor is established by dividing the sample volume in mL by the product of the fraction of 1 mL viewed and the number of liters of water filtered. For example, if half of the slide was viewed, with that slide representing 40 mL of concentrated sample, and the concentrated sample represented 800 liters, the multiplication factor would be 40/(0.5X800), or 0.1. The specimen count for each taxon is multiplied by this factor and recorded in a separate portion of the spreadsheet for easy printing, as individuals/L. Counts are tallied by genus and zooplankton group (e.g., rotifers, copepods, cladocerans, etc.), and as a grand total.

Based on the number of individuals of each taxon in each corresponding size category, a biomass estimate is calculated. Each size category for each taxon is assigned a biomass per individual, based on the average body length for that category and standard regressions for body weight as a function of length. Multiplication of the genus and size specific factor by the number of individuals in that taxon and size category yields a biomass estimate. The sum for each genus (three possible size categories) is reported as ug/L. The sum for each zooplankton group and the grand total are reported as well.

The total number of taxa per zooplankton group and per sample is also reported, simply as a summation of the taxa observed. Shannon-Weiner Diversity (S) is calculated by the appropriate formula based on the number of individuals recorded for each taxon. Pielou's Evenness (J) is also calculated, based on S divided by the maximum possible S value for the number of taxa observed, yielding a value between 0 and 1.

A size distribution is also generated, based on the observed body lengths. Average body length for all zooplankton is reported in mm, as well as the average body length for crustacean zooplankton (primarily copepods and cladocerans).

Quality Control

Approximately one sample in every ten is subjected to re-analysis. Samples for QC checks are chosen randomly from samples available at the time of analysis. Differences of 10-20% are typical for zooplankton samples counted by the same analyst and considered acceptable for use in evaluating aquatic conditions.

PHYTOPLANKTON DENSITY (CELLS/ML)

TAXON	LWWMD 3 05/21/18	LWWMD 3 06/18/18	LWWMD 3 07/16/18	LWWMD 3 08/13/18	LWWMD 3 09/17/18	LWWMD 3 10/15/18
BACILLARIOPHYTA						
Centric Diatoms						
Aulacoseira	128.0	115.2	0.0	0.0	76.0	357.0
Cyclotella	256.0	51.2	0.0	0.0	0.0	20.4
Urosolenia	25.6	12.8	11.6	11.6	45.6	0.0
Araphid Pennate Diatoms						
Asterionella	4019.2	76.8	0.0	0.0	0.0	0.0
Fragilaria/related taxa	256.0	64.0	116.0	1160.0	0.0	0.0
Synedra	1126.4	38.4	0.0	11.6	30.4	112.2
Tabellaria	192.0	256.0	46.4	1078.8	60.8	0.0
Monoraphid Pennate Diatoms						
Biraphid Pennate Diatoms						
Nitzschia	0.0	0.0	0.0	0.0	0.0	10.2
CHLOROPHYTA						
Flagellated Chlorophytes						
Eudorina	0.0	0.0	0.0	92.8	0.0	0.0
Coccoid/Colonial Chlorophytes						
Ankistrodesmus	0.0	76.8	34.8	0.0	30.4	20.4
Elakatothrix	0.0	0.0	69.6	0.0	0.0	0.0
Golenkinia	0.0	0.0	23.2	0.0	0.0	0.0
Scenedesmus	0.0	0.0	92.8	0.0	0.0	81.6
Tetraedron	0.0	0.0	0.0	0.0	0.0	20.4
Filamentous Chlorophytes						
Desmids						
Closterium	0.0	0.0	0.0	0.0	15.2	0.0
Mougeotia/Debarya	0.0	0.0	0.0	104.4	0.0	0.0
Staurastrum	0.0	0.0	11.6	11.6	45.6	0.0
Staurodesmus	0.0	12.8	11.6	11.6	15.2	0.0
Teilingia/related taxa	0.0	0.0	0.0	92.8	0.0	0.0
Xanthidium	0.0	0.0	0.0	11.6	30.4	0.0
CHRYSOPHYTA						
Flagellated Classic Chrysophytes						
Chromulina	1049.6	0.0	0.0	0.0	0.0	0.0
Dinobryon	153.6	1049.6	11.6	23.2	15.2	10.2
Synura	204.8	0.0	0.0	0.0	0.0	0.0
Non-Motile Classic Chrysophytes						
Haptophytes						
Tribophytes/Eustigmatophytes						
Raphidophytes						
CRYPTOPHYTA						
Cryptomonas	409.6	115.2	127.6	81.2	136.8	102.0
CYANOPHYTA						
Unicellular and Colonial Forms						
Microcystis	0.0	0.0	1160.0	0.0	0.0	2040.0
Woronichinia	2560.0	0.0	17400.0	12760.0	15200.0	10200.0
Filamentous Nitrogen Fixers						
Aphanizomenon	1280.0	1024.0	4176.0	10440.0	27360.0	20808.0
Dolichospermum	0.0	128.0	3132.0	11600.0	53960.0	2448.0
Filamentous Non-Nitrogen Fixers						
Limnothrix	53760.0	0.0	0.0	0.0	0.0	0.0
Planktolyngbya	0.0	0.0	0.0	0.0	0.0	3570.0
Planktothrix	3840.0	0.0	0.0	4640.0	0.0	0.0
EUGLENOPHYTA						
Trachelomonas	0.0	0.0	0.0	0.0	0.0	51.0
PYRRHOPHYTA						
Ceratium	0.0	0.0	0.0	11.6	15.2	0.0
Peridinium	0.0	38.4	11.6	23.2	15.2	0.0

PHYTOPLANKTON DENSITY (CELLS/ML)

DENSITY (CELLS/ML) SUMMARY						
BACILLARIOPHYTA	**6003.2**	**614.4**	**174.0**	**2262.0**	**212.8**	**499.8**
Centric Diatoms	409.6	179.2	11.6	11.6	121.6	377.4
Araphid Pennate Diatoms	5593.6	435.2	162.4	2250.4	91.2	112.2
Monoraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	0.0
Biraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	10.2
CHLOROPHYTA	**0.0**	**89.6**	**243.6**	**324.8**	**136.8**	**122.4**
Flagellated Chlorophytes	0.0	0.0	0.0	92.8	0.0	0.0
Coccoid/Colonial Chlorophytes	0.0	76.8	220.4	0.0	30.4	122.4
Filamentous Chlorophytes	0.0	0.0	0.0	0.0	0.0	0.0
Desmids	0.0	12.8	23.2	232.0	106.4	0.0
CHRYSOPHYTA	**1408.0**	**1049.6**	**11.6**	**23.2**	**15.2**	**10.2**
Flagellated Classic Chrysophytes	1408.0	1049.6	11.6	23.2	15.2	10.2
Non-Motile Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0	0.0
Haptophytes	0.0	0.0	0.0	0.0	0.0	0.0
Tribophytes/Eustigmatophytes	0.0	0.0	0.0	0.0	0.0	0.0
Raphidophytes	0.0	0.0	0.0	0.0	0.0	0.0
CRYPTOPHYTA	**409.6**	**115.2**	**127.6**	**81.2**	**136.8**	**102.0**
CYANOPHYTA	**61440.0**	**1152.0**	**25868.0**	**39440.0**	**96520.0**	**39066.0**
Unicellular and Colonial Forms	2560.0	0.0	18560.0	12760.0	15200.0	12240.0
Filamentous Nitrogen Fixers	1280.0	1152.0	7308.0	22040.0	81320.0	23256.0
Filamentous Non-Nitrogen Fixers	57600.0	0.0	0.0	4640.0	0.0	3570.0
EUGLENOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**51.0**
PYRRHOPHYTA	**0.0**	**38.4**	**11.6**	**34.8**	**30.4**	**0.0**
TOTAL	**69260.8**	**3059.2**	**26436.4**	**42166.0**	**97052.0**	**39851.4**
CELL DIVERSITY	**0.43**	**0.79**	**0.47**	**0.68**	**0.44**	**0.58**
CELL EVENNESS	**0.36**	**0.69**	**0.39**	**0.54**	**0.37**	**0.49**
NUMBER OF TAXA						
BACILLARIOPHYTA	**7**	**7**	**3**	**4**	**4**	**4**
Centric Diatoms	3	3	1	1	2	2
Araphid Pennate Diatoms	4	4	2	3	2	1
Monoraphid Pennate Diatoms	0	0	0	0	0	0
Biraphid Pennate Diatoms	0	0	0	0	0	1
CHLOROPHYTA	**0**	**2**	**6**	**6**	**5**	**3**
Flagellated Chlorophytes	0	0	0	1	0	0
Coccoid/Colonial Chlorophytes	0	1	4	0	1	3
Filamentous Chlorophytes	0	0	0	0	0	0
Desmids	0	1	2	5	4	0
CHRYSOPHYTA	**3**	**1**	**1**	**1**	**1**	**1**
Flagellated Classic Chrysophytes	3	1	1	1	1	1
Non-Motile Classic Chrysophytes	0	0	0	0	0	0
Haptophytes	0	0	0	0	0	0
Tribophytes/Eustigmatophytes	0	0	0	0	0	0
Raphidophytes	0	0	0	0	0	0
CRYPTOPHYTA	**1**	**1**	**1**	**1**	**1**	**1**
CYANOPHYTA	**4**	**2**	**4**	**4**	**3**	**5**
Unicellular and Colonial Forms	1	0	2	1	1	2
Filamentous Nitrogen Fixers	1	2	2	2	2	2
Filamentous Non-Nitrogen Fixers	2	0	0	1	0	1
EUGLENOPHYTA	**0**	**0**	**0**	**0**	**0**	**1**
PYRRHOPHYTA	**0**	**1**	**1**	**2**	**2**	**0**
TOTAL	**15**	**14**	**16**	**18**	**16**	**15**

PHYTOPLANKTON BIOMASS (UG/L)

TAXON	LWWMD 3 05/21/18	LWWMD 3 06/18/18	LWWMD 3 07/16/18	LWWMD 3 08/13/18	LWWMD 3 09/17/18	LWWMD 3 10/15/18
BACILLARIOPHYTA						
Centric Diatoms						
Aulacoseira	38.4	34.6	0.0	0.0	22.8	107.1
Cyclotella	640.0	128.0	0.0	0.0	0.0	51.0
Urosolenia	30.7	15.4	13.9	13.9	54.7	0.0
Araphid Pennate Diatoms						
Asterionella	803.8	15.4	0.0	0.0	0.0	0.0
Fragilaria/related taxa	76.8	19.2	34.8	348.0	0.0	0.0
Synedra	3481.6	122.9	0.0	9.3	24.3	89.8
Tabellaria	153.6	204.8	37.1	863.0	48.6	0.0
Monoraphid Pennate Diatoms						
Biraphid Pennate Diatoms						
Nitzschia	0.0	0.0	0.0	0.0	0.0	8.2
CHLOROPHYTA						
Flagellated Chlorophytes						
Eudorina	0.0	0.0	0.0	37.1	0.0	0.0
Coccoid/Colonial Chlorophytes						
Ankistrodesmus	0.0	7.7	3.5	0.0	3.0	2.0
Elakatothrix	0.0	0.0	7.0	0.0	0.0	0.0
Golenkinia	0.0	0.0	4.6	0.0	0.0	0.0
Scenedesmus	0.0	0.0	9.3	0.0	0.0	8.2
Tetraedron	0.0	0.0	0.0	0.0	0.0	12.2
Filamentous Chlorophytes						
Desmids						
Closterium	0.0	0.0	0.0	0.0	60.8	0.0
Mougeotia/Debarya	0.0	0.0	0.0	104.4	0.0	0.0
Staurastrum	0.0	0.0	9.3	9.3	36.5	0.0
Staurodesmus	0.0	128.0	7.0	7.0	9.1	0.0
Teilingia/related taxa	0.0	0.0	0.0	185.6	0.0	0.0
Xanthidium	0.0	0.0	0.0	3.5	9.1	0.0
CHRYSOPHYTA						
Flagellated Classic Chrysophytes						
Chromulina	52.5	0.0	0.0	0.0	0.0	0.0
Dinobryon	460.8	3148.8	34.8	69.6	45.6	30.6
Synura	163.8	0.0	0.0	0.0	0.0	0.0
Non-Motile Classic Chrysophytes						
Haptophytes						
Tribophytes/Eustigmatophytes						
Raphidophytes						
CRYPTOPHYTA						
Cryptomonas	297.0	94.7	106.7	65.0	112.5	77.5
CYANOPHYTA						
Unicellular and Colonial Forms						
Microcystis	0.0	0.0	11.6	0.0	0.0	20.4
Woronichinia	25.6	0.0	174.0	127.6	152.0	102.0
Filamentous Nitrogen Fixers						
Aphanizomenon	166.4	133.1	542.9	1357.2	3556.8	2705.0
Dolichospermum	0.0	25.6	626.4	2320.0	10792.0	489.6
Filamentous Non-Nitrogen Fixers						
Limnothrix	537.6	0.0	0.0	0.0	0.0	0.0
Planktolyngbya	0.0	0.0	0.0	0.0	0.0	35.7
Planktothrix	38.4	0.0	0.0	46.4	0.0	0.0
EUGLENOPHYTA						
Trachelomonas	0.0	0.0	0.0	0.0	0.0	51.0
PYRRHOPHYTA						
Ceratium	0.0	0.0	0.0	201.8	264.5	0.0
Peridinium	0.0	80.6	24.4	48.7	31.9	0.0

PHYTOPLANKTON BIOMASS (UG/L)

PHYTOPLANKTON BIOMASS (UG/L) SUMMARY						
BACILLARIOPHYTA	**5225.0**	**540.2**	**85.8**	**1234.2**	**150.5**	**256.0**
Centric Diatoms	709.1	177.9	13.9	13.9	77.5	158.1
Araphid Pennate Diatoms	4515.8	362.2	71.9	1220.3	73.0	89.8
Monoraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	0.0
Biraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	8.2
CHLOROPHYTA	**0.0**	**135.7**	**40.6**	**346.8**	**118.6**	**22.4**
Flagellated Chlorophytes	0.0	0.0	0.0	37.1	0.0	0.0
Coccoid/Colonial Chlorophytes	0.0	7.7	24.4	0.0	3.0	22.4
Filamentous Chlorophytes	0.0	0.0	0.0	0.0	0.0	0.0
Desmids	0.0	128.0	16.2	309.7	115.5	0.0
CHRYSOPHYTA	**677.1**	**3148.8**	**34.8**	**69.6**	**45.6**	**30.6**
Flagellated Classic Chrysophytes	677.1	3148.8	34.8	69.6	45.6	30.6
Non-Motile Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0	0.0
Haptophytes	0.0	0.0	0.0	0.0	0.0	0.0
Tribophytes/Eustigmatophytes	0.0	0.0	0.0	0.0	0.0	0.0
Raphidophytes	0.0	0.0	0.0	0.0	0.0	0.0
CRYPTOPHYTA	**297.0**	**94.7**	**106.7**	**65.0**	**112.5**	**77.5**
CYANOPHYTA	**768.0**	**158.7**	**1354.9**	**3851.2**	**14500.8**	**3352.7**
Unicellular and Colonial Forms	25.6	0.0	185.6	127.6	152.0	122.4
Filamentous Nitrogen Fixers	166.4	158.7	1169.3	3677.2	14348.8	3194.6
Filamentous Non-Nitrogen Fixers	576.0	0.0	0.0	46.4	0.0	35.7
EUGLENOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**51.0**
PYRRHOPHYTA	**0.0**	**80.6**	**24.4**	**250.6**	**296.4**	**0.0**
TOTAL	**6967.0**	**4158.7**	**1647.2**	**5817.4**	**15224.3**	**3790.3**
BIOMASS DIVERSITY	**0.77**	**0.48**	**0.72**	**0.78**	**0.38**	**0.50**
BIOMASS EVENNESS	**0.66**	**0.42**	**0.60**	**0.62**	**0.31**	**0.42**

	05/21/18	06/18/18	07/16/18	08/13/18	09/17/18	10/15/18
PHYTOPLANKTON BIOMASS (UG/L) SUMMARY						
BACILLARIOPHYTA	5225.0	540.2	85.8	1234.2	150.5	256.0
CHLOROPHYTA	0.0	135.7	40.6	346.8	118.6	22.4
CHRYSOPHYTA	677.1	3148.8	34.8	69.6	45.6	30.6
CRYPTOPHYTA	297.0	94.7	106.7	65.0	112.5	77.5
CYANOPHYTA	768.0	158.7	1354.9	3851.2	14500.8	3352.7
EUGLENOPHYTA	0.0	0.0	0.0	0.0	0.0	51.0
PYRRHOPHYTA	0.0	80.6	24.4	250.6	296.4	0.0

ZOOPLANKTON DENSITY (#/L)

TAXON	LWWMD 3 5/21/18	LWWMD 3 6/18/18	LWWMD 3 7/16/18	LWWMD 3 8/13/18	LWWMD 3 9/17/18	LWWMD 3 10/15/18
PROTOZOA						
Ciliophora	0.0	0.0	0.0	0.0	0.0	0.0
Mastigophora	0.0	0.0	0.0	0.0	0.0	0.0
Sarcodina	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA						
Asplanchna	7.9	0.0	0.0	1.1	0.0	1.4
Conochilus	0.0	0.0	0.8	0.0	18.9	0.0
Filinia	0.7	1.9	0.0	0.0	0.0	0.0
Kellicottia	0.0	0.0	0.8	0.0	4.2	0.0
Keratella	27.7	44.2	5.7	10.5	16.8	4.3
Ploesoma	0.0	2.9	0.0	0.0	0.0	0.0
Polyarthra	16.5	44.2	11.5	11.6	9.5	23.8
Trichocerca	0.0	5.8	0.4	1.7	2.1	5.0
COPEPODA						
Copepoda-Cyclopoida						
Cyclops	5.6	2.4	1.6	0.6	0.0	0.7
Mesocyclops	0.3	5.8	3.3	1.7	2.1	1.4
Copepoda-Calanoida						
Diaptomus	0.3	0.0	0.0	0.6	2.1	0.0
Other Copepoda-Nauplii	3.6	1.9	7.0	2.8	8.4	2.9
CLADOCERA						
Bosmina	0.7	20.6	6.2	4.4	2.1	2.9
Ceriodaphnia	0.0	1.0	2.9	1.7	1.1	0.7
Chydorus	0.7	1.4	0.4	0.6	0.0	0.7
Daphnia ambigua	0.0	0.0	0.8	0.0	0.0	0.7
OTHER ZOOPLANKTON						

ZOOPLANKTON DENSITY (#/L)

TAXON	LWWMD 3 5/21/18	LWWMD 3 6/18/18	LWWMD 3 7/16/18	LWWMD 3 8/13/18	LWWMD 3 9/17/18	LWWMD 3 10/15/18
SUMMARY STATISTICS						
DENSITY						
PROTOZOA	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA	52.8	98.9	19.3	24.8	51.5	34.6
COPEPODA	9.9	10.1	11.9	5.5	12.6	5.0
CLADOCERA	1.3	23.0	10.3	7.2	3.2	5.0
OTHER ZOOPLANKTON	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ZOOPLANKTON	64.0	132.0	41.4	37.4	67.2	44.6
TAXONOMIC RICHNESS						
PROTOZOA	0	0	0	0	0	0
ROTIFERA	4	5	5	4	5	4
COPEPODA	4	3	3	4	3	3
CLADOCERA	2	3	4	4	2	4
OTHER ZOOPLANKTON	0	0	0	0	0	0
TOTAL ZOOPLANKTON	10	11	12	12	10	11
S-W DIVERSITY INDEX	0.67	0.72	0.89	0.84	0.83	0.72
EVENNESS INDEX	0.67	0.69	0.83	0.78	0.83	0.69
MEAN LENGTH (mm): ALL FORMS	0.20	0.17	0.27	0.22	0.17	0.19
MEAN LENGTH: CRUSTACEANS	0.52	0.37	0.41	0.41	0.39	0.39

ZOOPLANKTON BIOMASS (UG/L)

TAXON	LWWMD 3 5/21/18	LWWMD 3 6/18/18	LWWMD 3 7/16/18	LWWMD 3 8/13/18	LWWMD 3 9/17/18	LWWMD 3 10/15/18
PROTOZOA						
Ciliophora	0.0	0.0	0.0	0.0	0.0	0.0
Mastigophora	0.0	0.0	0.0	0.0	0.0	0.0
Sarcodina	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA						
Asplanchna	7.9	0.0	0.0	2.2	0.0	2.9
Conochilus	0.0	0.0	0.0	0.0	0.8	0.0
Filinia	0.1	0.2	0.0	0.0	0.0	0.0
Kellicottia	0.0	0.0	0.0	0.0	0.2	0.0
Keratella	2.5	4.0	0.5	0.9	1.5	0.4
Ploesoma	0.0	0.8	0.0	0.0	0.0	0.0
Polyarthra	1.9	4.0	1.0	1.2	0.9	2.1
Trichocerca	0.0	0.6	0.1	0.1	0.2	0.6
COPEPODA						
Copepoda-Cyclopoida						
Cyclops	13.7	5.9	4.0	1.3	0.0	1.8
Mesocyclops	0.4	7.2	9.9	2.1	2.6	1.8
Copepoda-Calanoida						
Diaptomus	0.2	0.0	0.0	0.3	1.0	0.0
Other Copepoda-Nauplii	9.6	5.1	18.5	7.3	22.3	7.6
CLADOCERA						
Bosmina	0.6	20.2	6.0	4.3	2.1	2.8
Ceriodaphnia	0.0	2.5	7.5	4.3	2.7	1.9
Chydorus	0.6	1.4	0.4	0.5	0.0	0.7
Daphnia ambigua	0.0	0.0	1.3	0.0	0.0	1.2
OTHER ZOOPLANKTON						

ZOOPLANKTON BIOMASS (UG/L)

TAXON	LWWMD 3 5/21/18	LWWMD 3 6/18/18	LWWMD 3 7/16/18	LWWMD 3 8/13/18	LWWMD 3 9/17/18	LWWMD 3 10/15/18
SUMMARY STATISTICS						
BIOMASS						
PROTOZOA	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA	12.4	9.5	1.7	4.5	3.5	6.0
COPEPODA	23.9	18.1	32.4	11.0	25.9	11.2
CLADOCERA	1.3	24.1	15.2	9.7	4.8	6.6
OTHER ZOOPLANKTON	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ZOOPLANKTON	37.6	51.8	49.3	25.2	34.2	23.7