Oakdale Lake Final Report: AQUATOX Modeling, Sediment Characterization, and Lake Management Recommendations

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EXECUTIVE SUMMARY

Data collected during the Oakdale Lake Watershed Amelioration and Assessment Project indicates that Oakdale Lake is moderately eutrophic but appears to be a functioning ecosystem capable of cycling nutrients and supporting aquatic life. Water quality within the lake is impaired by nutrient loading from internal sources, such as excess aquatic vegetation growth followed by decomposition, and external sources, such as stormwater runoff.

In 2020 and 2021, total phosphorus (TP) exceeded 0.03 mg/L, which is the point at which a body of water is considered eutrophic, nearly 50% of the time, and in 2021, TP exceeded this threshold in more than 80% of lake samples indicating eutrophication. Second year water quality data from within Oakdale Lake showed a four-fold increase in P concentrations in the fall compared to the same time in the first year of sampling, suggesting a buildup of P in the system and worsening water quality. In addition, water quality samples taken during rain events at three stormwater drains upstream of Oakdale Lake contained high concentrations of P indicating stormwater inputs may be increasing eutrophication within Oakdale Lake. Without implementation of management actions to reduce internal and external nutrient loading, Oakdale Lake could experience an increase in frequency and magnitude of nuisance algal blooms, impacts to fish and other lake biota, and recreational use impairments.

For this reason, a water quality management approach that addresses both internal and external nutrient loading should be implemented simultaneously. Several short- and long-term management actions are recommended for Oakdale Lake and its surrounding watershed. In the short term (to be implemented within the next year, and beyond), we suggest the following to address internal nutrient loading:

1) Seasonal Submerged Aquatic Vegetation (SAV) harvesting;
2) Barley straw application; and,
3) Air diffuser aeration.

To implement management actions at the watershed level, we recommend an additional hydrologic study to understand nutrient transport between the three stormwater drains above Power Spring and Oakdale Lake, nutrient loading within the lake, and the interactions between groundwater, stormwater, and the lake that may be increasing the risk of eutrophication. As a first step, we recommend Friends of Oakdale Lake work with the City of Hudson to determine and confirm the source of water from the three storm drains. Following the determination and confirmation of the source of water, several watershed or landscape-scale management actions are recommended to control external nutrient loading in the lake, including, but not limited to:

1) Installation of stormwater detention ponds and swales in critical intercept areas to be determined through confirmation of source water from the storm drains;
2) Consideration of green infrastructure approaches for new and existing residential and commercial developments with the potential for phytoremediation actions which use vegetation to remove contaminants, and wetland enhancement within Power Spring;
3) Municipal street cleaning and litter control;
4) Promoting water conservation measures for surrounding landowners, such as xeriscaping and natural lawn care; and,
5) Community outreach and educational program to inform landowners of the risks of over- fertilization of lawns.

In the long-term (several years out, depending on the outcome of short-term internal management actions, results of ecosystem monitoring, and

funding availability) the following approaches may be warranted to control internal nutrient cycling in Oakdale Lake:

1) Aluminum sulfate (“floc and lock”) treatment; and/or
2) Dredging of soft, organic soils in the vicinity of the bathing beach.

The time frame for the long-term management alternatives could be stepped up should recreation and or aesthetic concerns and the availability of funds dictate a more aggressive approach to improving the Oakdale Lake ecosystem. Additionally, lake management decisions would benefit from ongoing, long-term monitoring to better understand changing conditions in the lake. Monitoring would include continuation of the citizen-scientist water quality monitoring with the addition of year-round dissolved oxygen monitoring and periodic surveys of aquatic life including phytoplankton, SAV, zooplankton, benthic macroinvertebrates, and fish. This approach to monitoring would help determine if the food web at Oakdale Lake is truly characteristic of a eutrophic system and identify opportunities for nutrient reduction and or system improvements that would better support the ecosystem of the lake as a whole.

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1.0 INTRODUCTION

Great Ecology was contracted by Friends of Oakdale Lake (FOL) to conduct a comprehensive watershed assessment for Oakdale Park and the five-acre Oakdale Lake (FIGURE 1). Funding for the project was provided through the Environmental Protection Fund as administered by the New York State Department of Environmental Conservation (NYSDEC), with fiscal sponsorship and project guidance from the Columbia Land Conservancy.

Project components included environmental database analysis, watershed mapping, field reconnaissance, and conducting a bathymetric survey of the lake. In addition, Great Ecology worked with FOL to develop and implement a citizen science water quality monitoring program and conducted ecosystem modeling of the lake's response to nutrient loading and possible future management alternatives.

This is the first time the Oakdale Lake watershed has been mapped. The boundary was mapped based on surface water connections as determined through topography and City of Hudson stormwater infrastructure mapping. A groundwater connection with a known aquifer that overlaps with the western portion of the lake (FIGURE 1) is also suspected to contribute water to Oakdale Lake although this connection was not confirmed as part of the scope of this project. Further refinement of the boundary may be needed as more data becomes available.

The following report presents the detailed results of ecosystem modeling based on 'dry-' and 'wet-weather' water quality data collected in 2020 and 2021 by citizen scientist and Great Ecology staff, a limited biological survey completed by Great Ecology in 2020 which included benthic macroinvertebrate community sampling and submerged aquatic vegetation (SAV) sampling as well as hydrology data obtained from desktop analysis. This report also presents the results of the 2020 sediment sampling effort and outlines recommended management recommendations for Oakdale Lake moving forward.

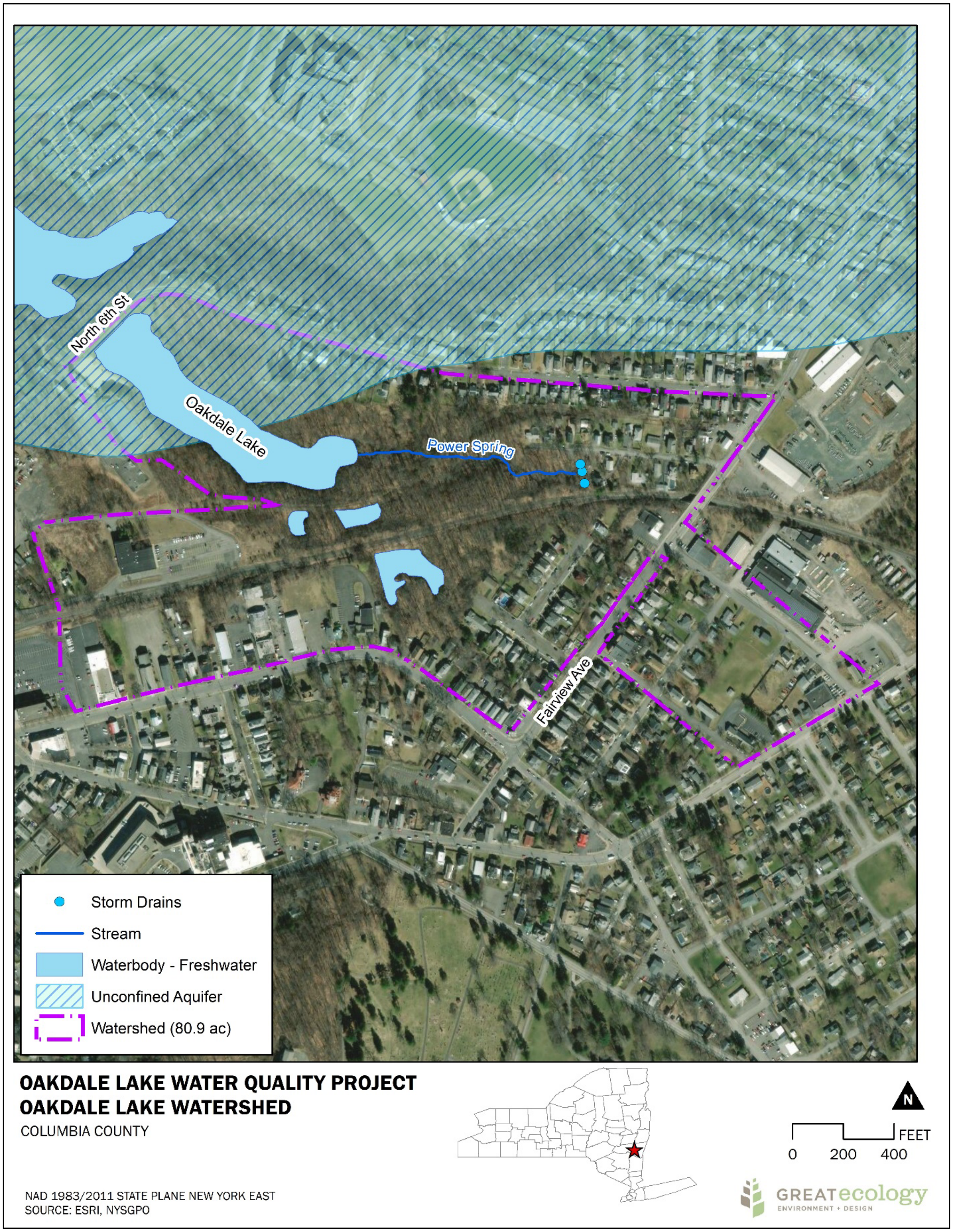


Figure 1: Oakdale Lake Watershed

2.0 METHODS

2.1 Ecosystem Modeling

A time-variable ecosystem model, AQUATOX, was selected to model the interactions of nutrients, contaminants, and other inputs to Oakdale Lake. The model is designed to simulate the biological, physical, and chemical processes within a unit volume of water in response to stressors or management actions. An ecosystem model consists of multiple components requiring different data inputs. These are the abiotic and biotic state variables or compartments being simulated.

In AQUATOX, the biotic state variables may represent multiple species grouped based on their feeding habits or "guilds," or individual species. The model also requires input of "driving" variables, such as temperature, light, and nutrient loading, which force the system to behave in certain ways such as when different algal groups may bloom in a lake in response to seasonal warming. In some instances, the external loadings of state variables, such as phytoplankton carried into a lake from an upstream tributary, may function as driving variables, and a driving variable, such as temperature, could be considered a dynamic state variable when changing in response to a simulated management action. Nutrient or contaminant loadings can be specified in the model for atmospheric, point-, and non-point sources.

AQUATOX utilizes differential equations to represent changing values of state variables, normally with a time step of one day. These equations require starting values or initial conditions for the beginning of the simulation. A simulation can begin with any date and may be for any length of time from a few days to decades. Once the model is set up and calibrated for a site, it is easy to represent a series of loading scenarios and determine threshold nutrient levels for impacts such as nuisance algal blooms or hypoxia, which is lack of oxygen in the water column.

The AQUATOX model was developed using physical and chemical indicators of water quality and biological data collected at Oakdale Lake. Biological parameters included aquatic plant community composition and density, algal classes (e.g., diatoms, blue-green, green, cryptophytes etc.), benthic macroinvertebrates, and fish. Where data gaps existed, Great Ecology used anecdotal observations/reports from Oakdale Lake park staff and information from scientific literature about similar lake ecosystems.

Because field data collection was limited in the first year (2020) of sampling to a period of approximately two months (end of July – end of September) and then to a period of five months in 2021 (June – October), it was not clear whether AQUATOX would be capable of properly predicting chemical and biological lake trends for a full year. For this reason, simulations were run for time periods of six months ("short" modeling period) and one year ("long" modeling period), to evaluate which of the two modeling periods was more accurate. Ultimately, it was determined that the "long" time period simulation predicted observed lake conditions reasonably well, based on notes/reports from volunteers conducting the monitoring and general agreement with the field data, determined through graphical comparisons of data versus model outputs.

2.1.1 Water Quality

Data collected during July 2020 site reconnaissance and subsequent volunteer water quality monitoring programs in 2020 and 2021 (TABLE 1) provided the water quality variables that were used to drive AQUATOX simulations. Data collected on July 27, 2020, at three sampling stations (FIGURE 2) was used to establish a baseline for the model (t = 0) and water quality data collected during subsequent sampling dates (August and September) by citizen scientists at two stations (FIGURE 3) were used to compare AQUATOX predictions and field observations. Because AQUATOX is designed to process daily values of all inputs, it automatically applied linear interpolation between sampled dates to estimate concentrations of water quality constituents for the intervening days. AQUATOX applies this method for all input data where daily values are not provided by the user. Where possible, site-specific data was used in the Oakdale Lake model runs. Where site-specific data was unavailable, an appropriate proxy (typically an example from the scientific literature) was used. In addition, during the 2021 sampling season, opportunistic stormwater samples were collected at several stations upstream of the lake during rain events on June 22 and September 15 (FIGURE 4) to better understand the potential contribution of stormwater runoff to lake eutrophication.


Photo 1 (left): Wet weather station / outlet 4
Photo 2 (right): Wet weather station / outlet 3

Photo 3: Wet Weather station/outlet 2

Table 1: 2020 and 2021 Water Quality Sampling Events, Oakdale Lake

Date	Sample Type	Sampler(s)
July 27, 2020	Dry Weather	Great Ecology
Aug. 16, 2020	Dry Weather	Citizen Scientists
Sept. 1, 2020	Dry Weather	Citizen Scientists
Sept. 17, 2020	Dry Weather	Citizen Scientists
Sept. 30, 2020	Dry Weather	Citizen Scientists
June 22, 2021	Wet Weather	Great Ecology
June 23, 2021	Dry Weather	Citizen Scientists
Aug. 31, 2021	Dry Weather	Citizen Scientists
Sept. 15, 2021	Wet Weather	Great Ecology
Oct. 4, 2021	Dry Weather	Citizen Scientists

Water quality parameters input to the Oakdale Lake model, based on data collected during the July 2020 site characterization study and subsequent volunteer water quality monitoring programs in 2020 and 2021, included the following:

- Temperature;
- Dissolved oxygen (DO);
- pH;
- Turbidity;
- Conductivity;
- Phosphorus/Phosphate;
- Nitrogen/nitrates;
- Ammonia;
- Nitrates;
- Chlorophyll-a;
- Calcium;
- Chloride;
- Carbon dioxide; and
- Algal classes.

2.1.2 Benthic Macroinvertebrate

A preliminary assessment of the benthic macroinvertebrate community within Oakdale Lake was conducted in July 2020. Great Ecology attempted to sample benthic macro-invertebrates at three stations (FIGURE 2); however, sampling at Station 2 was unsuccessful given the lake bottom composition of sand and decaying leaves. Benthic macroinvertebrates were collected at Station 1 using a "petite Ponar" grab (2400 ml volume; 0.025 m^2 area) while samples at Station 3 were collected using a two-inch diameter Wildco sediment corer because the presence of very soft, watery sediments made the use of the grab sampler difficult. In total, benthic samples were collected at two of the three sampling stations (Station 1 and Station 3). Volunteers assisted in washing, sorting, and picking individual invertebrates from the benthic samples in the field. In the laboratory, macroinvertebrates were identified to Family and measured (total length/width, in mm). Length–mass relationships were established to estimate body mass from body dimensions for each Family (Mährlein et al. 2016, Méthot et al. 2012). The results were used in the development of AQUATOX simulations.

2.1.3 Submerged Aquatic Vegetation

The aquatic plant community was characterized by collecting three 1 m^2 quadrats in three areas of the lake with SAV in July 2020 (FIGURE 1). Following collection, each SAV sample was blotted to remove excess water and a wet weight (gms) was taken. The samples were then air-dried and re-weighed. The average dry weight (gms) was then calculated for each station. The results of the sampling effort were used to drive AQUATOX simulations.

Photo 4: SAV Sample from Oakdale Lake

2.1.4 Hydrology and Bathymetry

Hydrology data, including precipitation, evapotranspiration, and wind conditions were obtained from the closest weather station to the site (Station ID: US1NYGR0009 (ATHENS 2.2 NNW); Latitude: 42.3 / Longitude: -73.83; TABLE 2). Lake water volume was calculated using the Oakdale Lake Bathymetry Survey conducted in July 2020 (TABLE 2).

Table 2: Calculation of Oakdale Lake Volume Based on Bathymetry

Depth from top contour line (ft)	Depth from top contour line (m)	Contour Area (m^2)	Water Volume between contour lines (m^3)
0.00	0.00	20,329.42	0.00
1.00	0.30	19,529.86	6,074.55
2.00	0.61	18,499.58	5,795.69
3.00	0.91	17,184.05	5,438.19
4.00	1.22	15,615.96	4,998.72
5.00	1.52	13,900.79	4,498.35
6.00	1.83	12,420.81	4,011.41
7.00	2.13	10,917.03	3,556.69
8.00	2.44	9,325.32	3,084.93
9.00	2.74	7,782.77	2,607.27
10.00	3.05	6,460.09	2,170.61
11.00	3.35	5,374.87	1,803.65
12.00	3.66	4,473.69	1,500.92
13.00	3.96	3,624.62	1,234.18
14.00	4.27	2,550.42	941.08
15.00	4.57	1,479.88	614.22
16.00	4.88	687.57	330.32
17.00	5.18	25.45	108.66
		Total surface volume	**48,769.45**

2.2 Sediment Sampling

Vegetation growth within Oakdale Lake was historically managed through the application of algicides (i.e. copper sulfate) and, more recently (2017-2019), enzyme treatments. The historical use of copper sulfate is an important consideration in the evaluation of potential future management action (i.e. dredging). Elemental copper binds to sediment particles and may be ingested by invertebrates, fish, and other wildlife, accumulating in organs and other tissues. For this reason, Great Ecology conducted sediment sampling in July 2020 by collecting cores at three locations within Oakdale Lake (FIGURE 2). Samples were collected to a depth of up to 12-inches below the sediment-water interface using a stainless steel Wildco hand corer (and 15-foot extension pole). Each sample was homogenized using decontaminated stainless-steel bowls and spoons, placed in appropriate sampling containers (provided by the lab), labeled, and submitted to Envirotest Laboratories. Samples were analyzed for the presence of copper as well as other common heavy metals (arsenic [As], cadmium [Cd], chromium [Cr], lead [Pb], mercury [Hg]) in the lake substrate. Additional sediment parameters tested included particle-bound phosphorus (P), nitrogen (N), percent solids, total organic carbon (TOC), and sulfides.

Photo 5: Oakdale Lake Sediment Cores

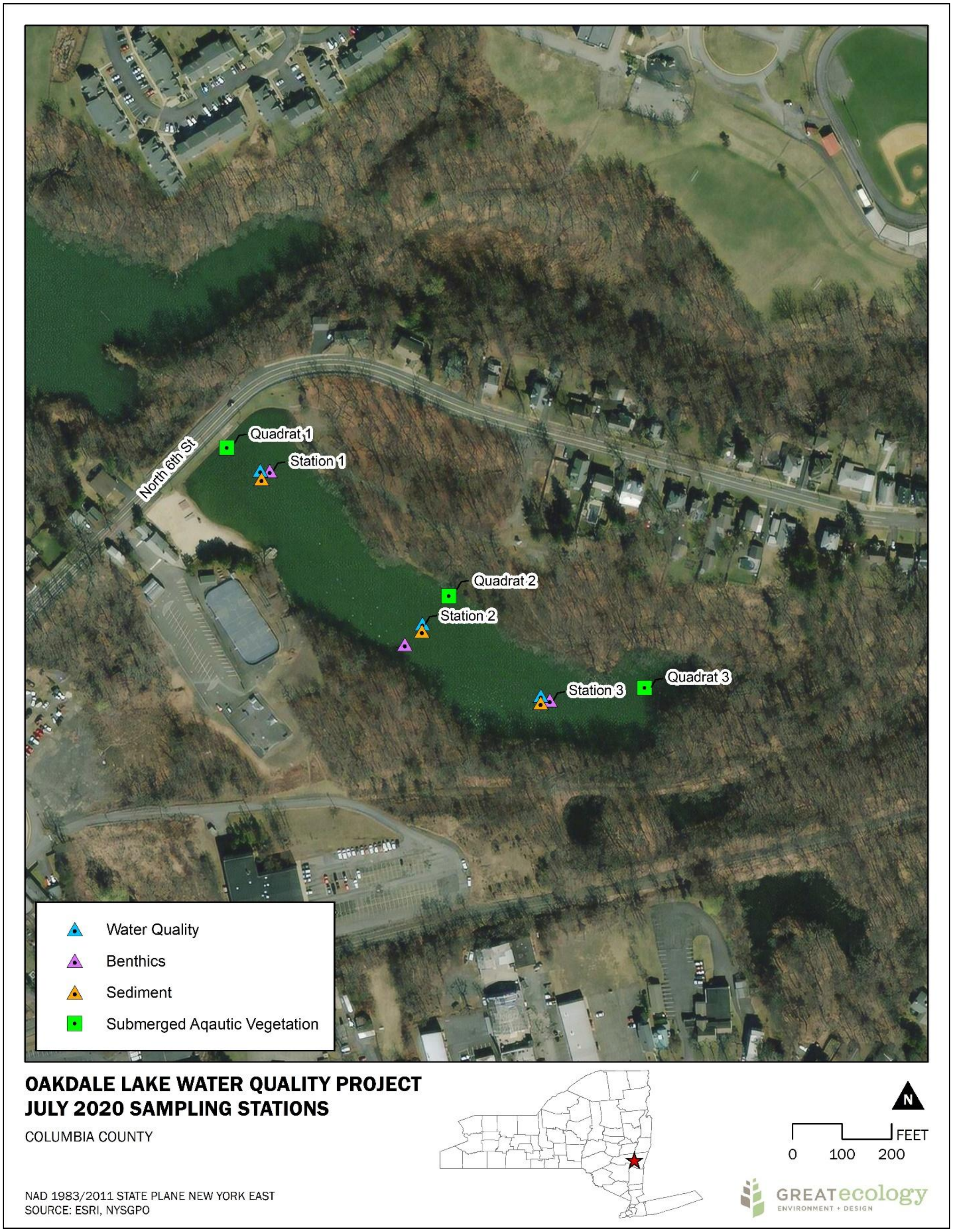


Figure 2: July 2020 AQUATOX Model Sampling Stations

Figure 3: Citizen Scientist Water Quality Sampling Stations

Figure 4: Wet Weather Water Quality Sampling Stations

3.0 Results and Discussion

The following sections detail the findings from two years of data collection and analysis. These findings inform the management alternatives presented in Section 4.0.

3.1 AQUATOX Model Results

3.1.1 Nutrients (Nitrogen and Phosphorus)

Inorganic N and P strongly influence the growth of algae and vascular plants in freshwater systems. P is often the limiting element, and its control is of prime importance in controlling lake enrichment, or eutrophication (Figure 5).

Maximum total nitrogen (TN) detected at the lake (during both 2020 and 2021) was 0.68 mg/L; well below the threshold level for eutrophication (5 mg/L). TN concentrations increased from June to October. Grab samples collected during 'wet weather' events from June and September indicated TN loads ranging between 1.6 – 3.1 mg/L and 0.33 – 1.12 mg/L, respectively. These loads were higher than those observed in 'dry weather' lake samples, indicating that stormwater runoff can potentially contribute to increased N loads within the lake. AQUATOX simulations showed a tendency for dissolved (water-column) N concentrations to increase during winter, followed by a sharp decline in spring (Figure 6). The Environmental Protection Agency (EPA) has set the acceptable level of nitrate in drinking water to be 45 mg/L, which is far higher than the highest level of nitrate measured at Oakdale Lake.

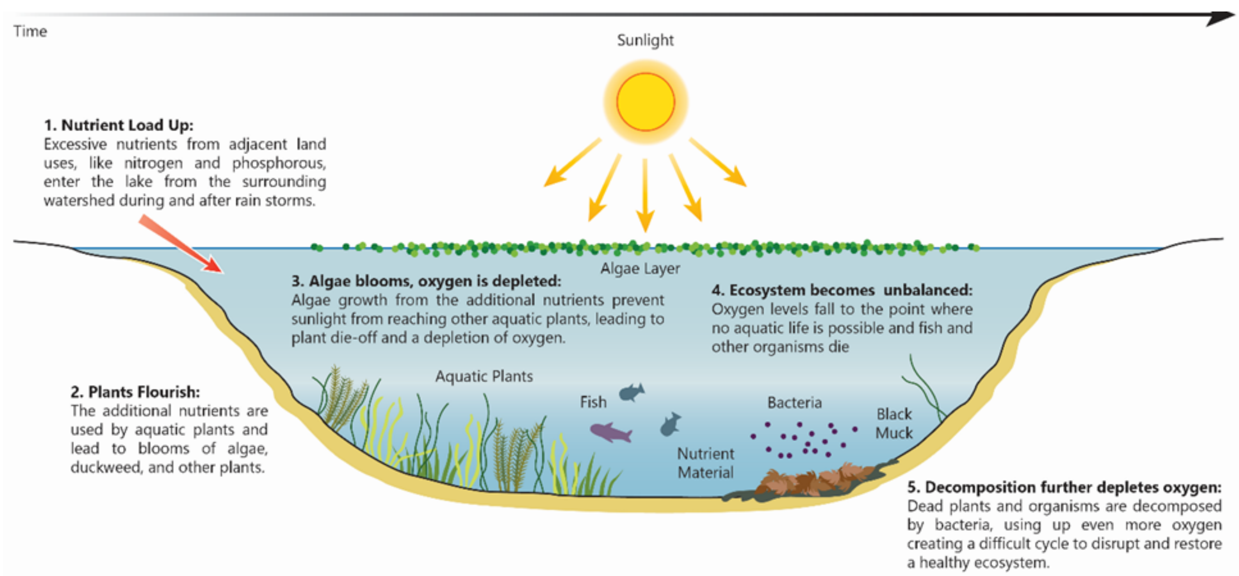


Figure 5: Eutrophication Cycle in Oakdale Lake

Ammonia levels in late summer and early fall 2021 were 2 and 5 times higher, respectively, than in late summer and early fall 2020. Despite the higher values observed, ammonia concentrations are still below the EPA´s recommended Ambient Water Quality Criteria (AWQC) threshold for protection of human health and aquatic life (EPA 2015. AQUATOX long-term projections also suggest ammonia concentrations within the lake may remain low and relatively steady over time (FIGURE 6). High oxygen concentrations in the lake under certain conditions (i.e. associated with seasonal phytoplankton blooms and/or SAV photosynthesis) may favor nitrification which is the biological oxidation of ammonia to nitrite followed by the oxidation of the nitrite to nitrate, therefore ensuring proper N cycling within the lake.

Total phosphorous (TP) levels in 2020 and 2021 indicate P is building up in the lake putting the systems at risk of eutrophication. In 2020, TP exceeded 0.03 mg/L, which is the point at which a body of water is considered eutrophic, nearly 50% of the time, indicating the lake may be undergoing eutrophication, especially during peak photosynthetic activity. In 2021, TP exceeded 0.03 mg/L in more than 80% of lake samples further supporting the findings from 2020. TP concentrations were greater in early fall in 2021 than in summer, shifting from 0.03mg/L in June to 0.15 mg/L in October. Values collected in early fall 2021 were four times higher than those corresponding to the same period in 2020. Overall, results indicate P is building up in the lake which is driving eutrophication.

Data collected during 'wet-weather' events in 2021 indicate that stormwater runoff plays a role in the accumulation of P at Oakdale Lake. Wet weather samples (collected at or close to stormwater outfalls) in June and September 2021 indicated TP loads ranging between 0.06 – 0.25 mg/L and 0.09 – 0.48 mg/L, respectively. These concentrations are between 3 and 15 times greater than TP concentrations found in the 'dry weather' lake samples, which suggests that stormwater runoff is a contributor to Oakdale Lake's eutrophication. Urban stormwater runoff contains P from fertilizers that are used on lawns and in gardens and parks, from pet and wild animal waste, from detergents (e.g., car washing) and from soil (naturally occurring). Oakdale Lake likely receives some benefits and buffering against P laden stormwater from Power Spring and its associated wetlands; however, an additional study to determine contaminant transport and nutrient loading in Oakdale Lake would confirm this hypothesis.

The source of water flowing from the two of the three storm drains (Station 2 and 3; FIGURE 4) sampled during rain events is unknown at this time. The source of Station 4 (FIGURE 4) is suspected to be from Jenkins Parkway, Bayley Boulevard, Graham Avenue, Aitken Avenue, and Storm Avenue based on the City of Hudson's Public Works Department stormwater infrastructure mapping. Great Ecology contacted the City to find out additional information about the storm drains, but the City did not have any records for any of the drains. The City suggested that their proximity to the railway line may indicate that they are related to the existing CSX line or the abandoned B&A line or the drains could be left over stormwater infrastructure from developments around Jenkins Parkway and Bayley Boulevard (pers. comm. Robert Perry). It should be noted that 'wet weather' Station 2 was not flowing during the September 15th sampling event, suggesting that the outlet may not convey stormwater.

Based on the 2021 'wet-weather' data, additional investigations should be conducted to determine the source of the water from these storm drains to properly implement upstream management actions. A simple, low-cost option for this is a dye tracing exercise where the City adds dye to the storm drains upstream of Oakdale Lake during a rain event to see if the dye drains into Power Spring.

Groundwater inputs from the nearby unconfined aquifer (FIGURE 1) is another potential source of P at Oakdale Lake. Groundwater investigation is beyond the current scope of work but could be further explored if current recommendations do not result in improved conditions in Oakdale Lake. The aquifer feeding the lake is made of glacial and alluvial deposits, with fine to medium sand. This implies a long contact time of water with sediment which can cause significant mineral dissolution of chemical compounds, such as P. Fertilizers, pesticides, and undetected septic leaks in the surrounding area can also percolate and reach the aquifer, increasing P loads at Oakdale Lake.

Despite the increase of TP observed in 2021, dissolved P concentrations at the lake were within the same range of those observed in 2020, and temporal trends predicted by AQUATOX (FIGURE 6) were similar to 2020: dissolved P may accumulate during winter and start to drop at the beginning of spring.

These results suggest the system still has capacity to buffer and store P inputs within the lake, and according to AQUATOX projections, such buffering capacity may remain relatively steady over time. However, it is important to stress that P loads stored in lake compartments not readily available to organisms (e.g., P locked in sediments) are still an active part of the P cycle and can be released under conditions of low oxygen, low pH, and/or high temperatures.

3.1.2 Dissolved Oxygen

Eutrophication is generally indicated by oxygen depletion in the water column. The DO levels measured at Oakdale Lake throughout the monitoring period were consistently >5 mg/L, which is sufficient to maintain most aquatic life. However, episodes of high photosynthetic activity (e.g., macrophyte and/or phytoplankton blooms in late spring) may be followed by episodic reductions in DO. DO is also highly variable throughout the day, generally increasing in the daytime and then becoming depleted during the night (diel variation). Since DO is probably the most important water quality factor for lake management purposes, it is advised to monitor it continuously with a DO meter for at least an entire year to identify episodes of oxygen depletion, especially in relation to primary productivity.

3.1.3 pH

In aquatic systems, pH represents hydrogen ion concentrations in water (i.e. the number of hydrogen ions per liter), expressed as a value between 0 (acid) and 14 (base). Neutral conditions (neither acid nor base) are represented at the mid-point of the logarithmic scale, at a pH of 7.0. Most freshwater fish and invertebrates (including early life stages) prefer pH of 7.0-8.0, but some species can adapt to pH levels between 6.0-9.0, if there are no rapid fluctuations exceeding 1.0 units (100x concentration) or more. Water column pH at Oakdale Lake was slightly basic, or alkaline, ranging between 8.3 – 9.0 during the 2020/2021 monitoring program. Slightly alkaline conditions may occur in ponds and lakes during the day when photosynthesis by aquatic plants is high. The more aquatic plants in a system the higher the pH may be. As the sun sets, photosynthesis decreases along with pH (Tucker & D'Abramo 2008).
The results from Oakdale Lake indicate that low pH, which is a common problem in urban watersheds and can result in the release of P from sediments, is not an issue in Oakdale Lake. Rather, the moderately alkaline conditions (likely resulting from the mineral content of the underlying native sediments and bedrock in the watershed) are protective against acidification due to runoff and acid rain as well as the mobilization, or leaching, of metals, notably aluminum, which is toxic to fish and other aquatic organisms.

3.1.4 Phytoplankton

Phytoplankton are floating, single-celled plants, representing the base of aquatic food webs. Phytoplankton populations are characterized by bloom formation, where very high cell concentrations will develop seasonally in response to bottom-up processes such as nutrient availability and/or top-down processes such as grazing by zooplankton and other aquatic organisms. Phytoplankton populations will vary greatly among seasons in a healthy pond or lake but should remain generally consistent year to year. Phytoplankton blooms are typically short-lived, lasting days to weeks. The blooms eventually die off and settle to the lake bottom, decomposing rapidly and becoming food for bacteria. This process causes a high demand for oxygen in the water column and *can* lead to chronically low DO levels. To fully understand the phytoplankton communities at Oakdale Lake and the potential for seasonal plankton blooms to occur, it would be helpful to regularly survey their populations, through routine collection of surface water samples, and laboratory taxonomic analysis. If annual phytoplankton population surveys show evidence of change, this may suggest an increased level of disturbance such as nutrient loading from excess P, or climate change (i.e. elevated average spring-summer temperatures). Certain phytoplankton species are considered eutrophication indicators (e.g., *Fragilaria, Synedra, Scenedesmus, Anabaena*) and routine surveys of their presence/absence in Oakdale Lake would help understand the extent to which the lake may be experiencing accelerated eutrophication.

Cyanobacteria (blue-green algae) blooms can occur in eutrophic systems. They would occur during mid-summer, as optimal growth temperatures for cyanobacteria are higher than that of other phytoplankton. Cyanobacteria blooms are a concern, should they arise, especially in water bodies that are used for contact recreation (swimming, paddling) or where fish consumption by anglers may be occurring. Some species of cyanobacteria (e.g., *Microcystis* sp., *Anabaena* sp.) produce toxins that can (in very high concentrations) cause irritation of exposed skin and mucus membranes, respiratory distress, organ damage, and neurological impairments in humans and animals directly exposed to active blooms via direct contact, or ingestion of natural waters (Carmichael 1994, Hitzfeld et al. 2000). Although no obvious cyanobacterial blooms were observed in Oakdale Lake during the 2020-2021 sampling program, nearby lakes in Columbia County have reported extensive, persistent cyanobacterial blooms in recent years (CSLAP 2016, 2018).

The phytoplankton community composition at Oakdale Lake is consistent with that of a moderately eutrophic water body, dominated by green algae and diatoms. Throughout the 2020 and for most of the 2021 monitoring program, Secchi disc values—a measure of water clarity, or transparency—were almost always less than two meters, another indication of eutrophic waters. Although green algae were abundant in July 2020, AQUATOX projections suggest that a shift to diatom abundance may occur in late summer and early fall (FIGURE 7,8,9). During 2021, average diatom concentrations doubled in comparison to 2020 suggesting an increase in dissolved P available for uptake in the lake. Conversely, average green algae concentration in 2021 was approximately half of that reported in 2020. Blue-green algae concentrations also decreased in 2021, while the concentration of *Cryptomonas* (a non-toxic algae) increased (FIGURE 9). Phytoplankton populations may vary seasonally but should remain generally consistent from year to year. The community composition differences observed between 2020 and 2021 suggest a slightly unbalanced phytoplankton community, which is indicative of a eutrophic, slightly unstable system-state. AQUATOX projections for phytoplankton in 2021 were similar to 2020, with diatoms representing the dominant group in late summer and early fall. In early spring of 2022, AQUATOX predicted a considerable increase in diatoms resulting from the accumulation of dissolved P in the lake over the winter (FIGURE 7). These results are indicative of a eutrophic system as those decomposing plankton cells will contribute to sediment degradation, and potentially hypoxia in deeper water areas.

3.1.5 Benthic Macroinvertebrates

A preliminary (screening-level) analysis of several sediment core samples from Oakdale Lake was performed in July 2020 to characterize the benthic macroinvertebrate community. The sample exhibited relatively low abundance and taxa richness, overall. Dominant benthic organisms present included isopods ("aquatic sowbugs"), chironomids ("non-biting midge" larvae), and gastropods (snails and clams) (TABLE 3). Overall (and based on a preliminary, single sampling event) these findings are suggestive of a stressed benthic invertebrate assemblage at Oakdale Lake. The low number of species observed, as well as an uneven pattern of abundance among samples, suggests that the lake is affected by medium-high intensity disturbances, such as episodic hypoxia, that may frequently reset the composition of the invertebrate community. This is also indicated by the presence of short life-cycle organisms (e.g., chironomids) and the absence of less tolerant invertebrates with longer life cycles (e.g., dragonflies, mayflies, or beetles). AQUATOX simulations indicate that the benthic macroinvertebrate community of Oakdale Lake may experience further decline in taxa richness, ultimately to be dominated solely by chironomids, which thrive in polluted environments with low dissolved oxygen conditions and ample organic matter present, as nutrient loading increases (FIGURE 10).

Table 3: Preliminary Benthic Macroinvertebrate Survey Data, Oakdale Lake

Station	Family	Number	Average size (mm)	Mass (mg)	Density (g/m2)	Density (mg/l)	Reference
1	Asellidae	4	4.5	0.3832	0.0204	0.2129	Mährlein et al. 2016
1	Gammaridae	3	7	1.2787	0.0511	0.5328	Mährlein et al. 2016
1	Ceratapagonidae	3	12	0.3132	0.0125	0.1305	Mährlein et al. 2016
1	Chironomidae	19	22	3.0348	0.7688	8.0086	Mährlein et al. 2016
1	Physidae	54	4	3.1353	2.2574	23.5150	Méthot et al. 2012
1	Planorbidae	14	1.5	2.6708	0.4985	5.1932	Méthot et al. 2012
3	Naididae/Tubificidae	8	8	0.1448	0.0154	0.1609	Méthot et al. 2012
3	Asellidae	6	5	0.5164	0.0413	0.4303	Mährlein et al. 2016
3	Gammaridae	4	5.5	0.6172	0.0329	0.3429	Mährlein et al. 2016
3	Coenagrionidae	1	7	0.6731	0.0090	0.0935	Méthot et al. 2012
3	Ceratapagonidae	3	11.5	0.2789	0.0112	0.1162	Mährlein et al. 2016
3	Chironomidae	9	22	3.0348	0.3642	3.7936	Mährlein et al. 2016
3	Physidae	11	5	6.1924	0.9082	9.4606	Méthot et al. 2012
3	Planorbidae	5	3.5	25.2220	1.6815	17.5153	Méthot et al. 2012

3.1.6 Submerged Aquatic Vegetation

During the 2020 sampling effort, the dominant SAV species (>99%) present was slender pondweed (*Potamogeton pusillus*). A very small percentage of the sampled SAV was made up of two other species: curly-leaf pondweed (*P. crispus*) and coontail (*Ceratophyllum demersum*).

Native coontail and slender pondweed are typical of ponds, lake shorelines, and slow-moving streams, and their presence is indicative of ample nutrient concentrations. Both species are also tolerant of moderately turbid, or murky, waters. While not abundant at the time of the initial field reconnaissance (July 2020), non-native curly-leaf pondweed forms extensive blooms throughout the lake, notably in the shallow areas just off the beach in late spring and early summer. Common duckweed (*Lemna minor*) was observed floating at the surface along the shoreline throughout the lake; however mid-summer density of this species did not appear to be excessive, in comparison to other lakes and ponds in the region.

AQUATOX results indicated very high growth of SAV (largely curly-leaf pondweed) in spring may exert some control over phytoplankton populations (FIGURE 11). Excessive growth of macrophytes such as curly-leaf pondweed can contribute significant amounts of P from sediments into the water. Once SAV beds die off, P accumulated in their tissues is released and readily available for uptake by bacteria and algae. The metabolic activity associated with bacterial production and organic matter degradation lowers dissolved oxygen – this is known as "biological oxygen demand." This can create a positive feedback system – under conditions of low oxygen release of P from sediments is enhanced. This can be ameliorated or managed to some degree through artificial aeration and SAV harvesting or treatment with chemicals.

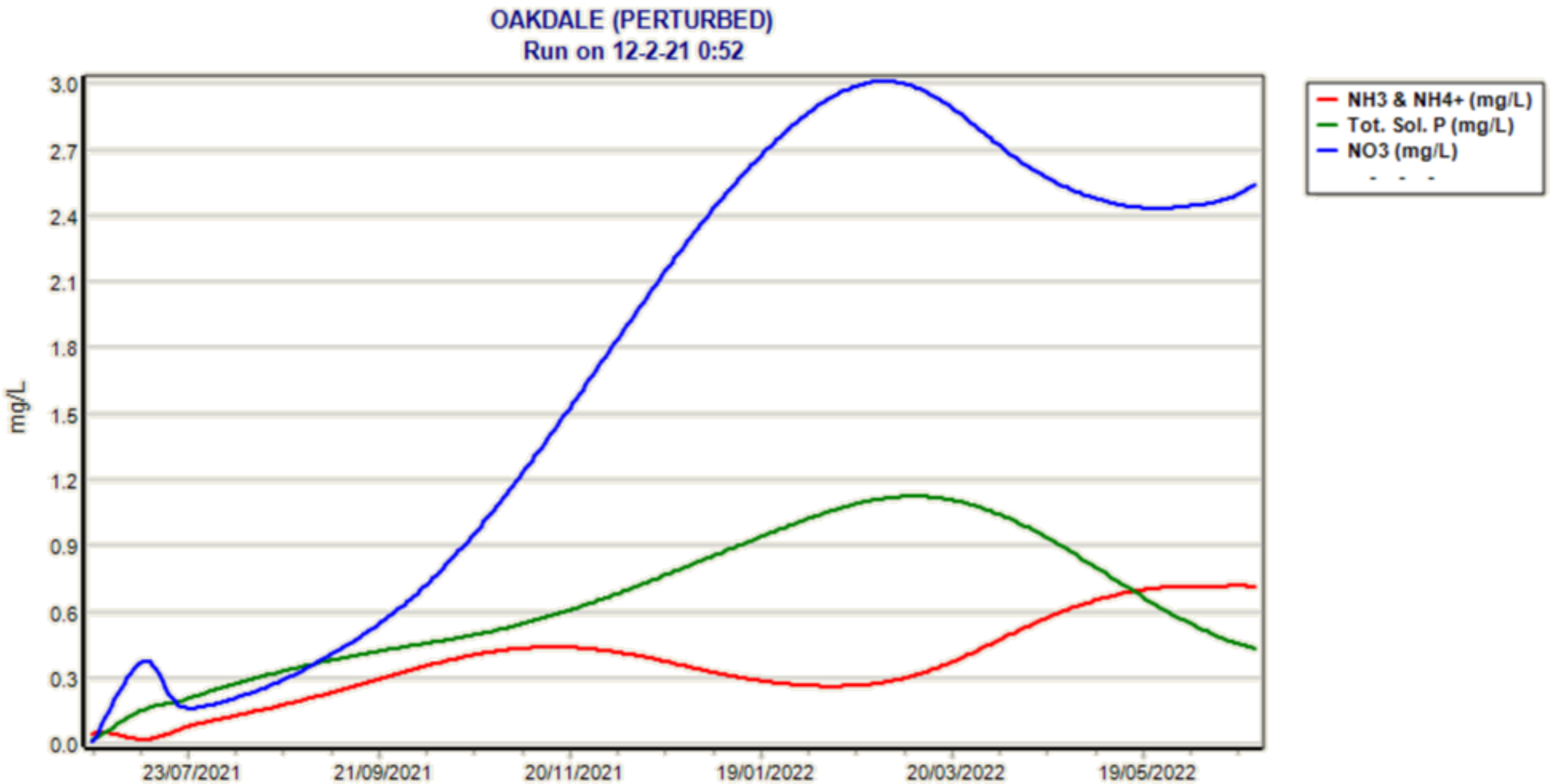
3.1.7 Fish

Oakdale Lake provides habitat for warmwater fish species including largemouth bass (*Micropterus salmoides*), rock bass (*Ambloplites rupestris*), and common "sunfish" such as pumpkinseed (*Lepomis gibbosus*) and bluegill (*L. macrochirus*), all of which are targeted by recreational anglers fishing in the lake. Sunfish are widely distributed in lakes, ponds and slow-moving streams and are moderately tolerant of pollution and habitat alteration.

Photo 6: Representative photo of largemouth bass. These fish did not come from Oakdale Lake.

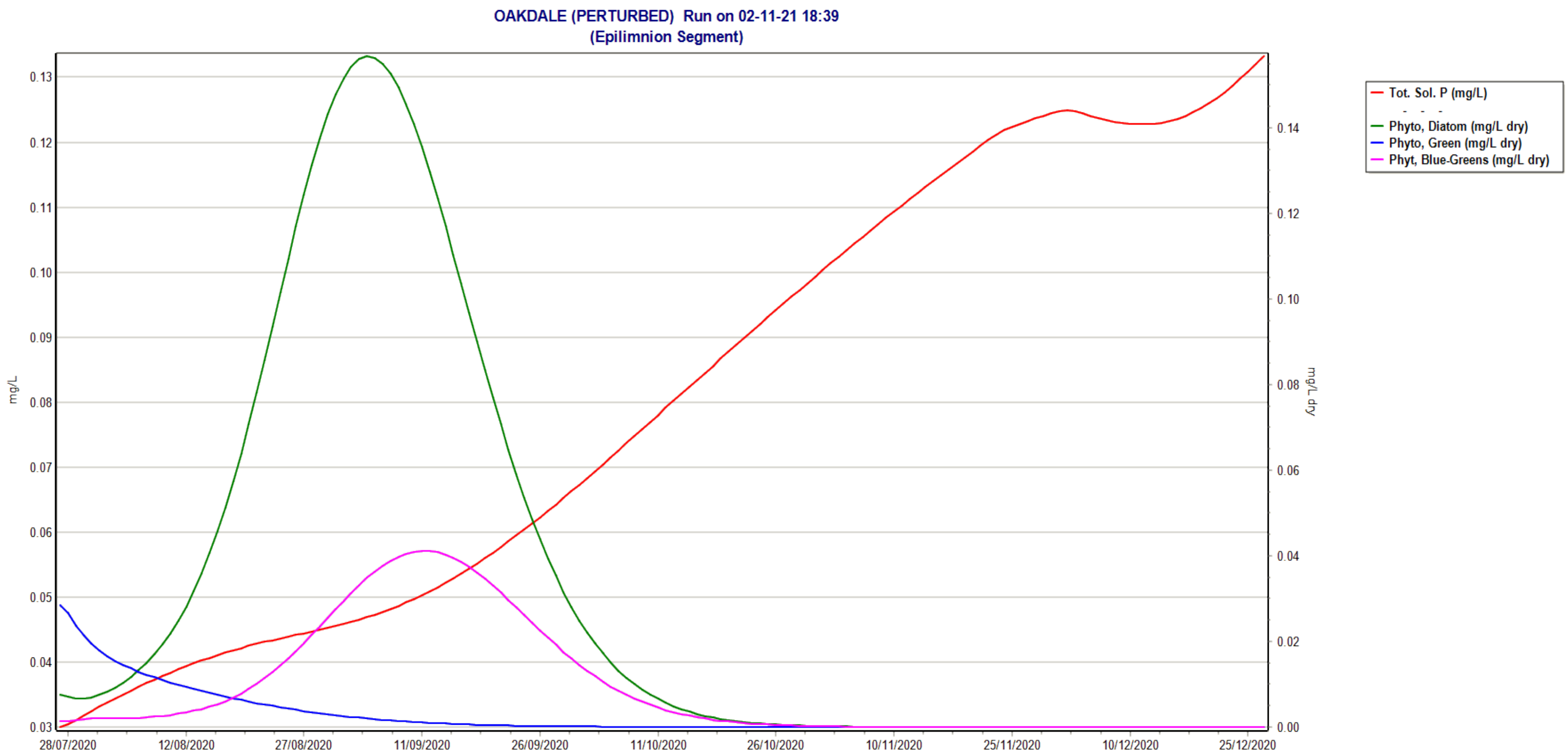
Common carp (*Cyprinus carpio*), especially tolerant of warm, turbid waters with low DO are present in the lake as well. . Due to a thermal refuge provided by cool groundwater influx in the deeper portion of the lake, stocked populations of cold-water trout species including rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) are maintained, and may be reproducing naturally. Trout generally require cool, clean, well-oxygenated water to survive and reproduce and are often the first species to disappear from polluted waters.

A comprehensive fish community survey, conducted using standard NYSDEC electro-fishing protocols developed for warmwater fish communities in lakes and ponds of New York State, would provide additional information on the species composition, age/size structure, and food web dynamics of Oakdale Lake. This information would be necessary in advance of developing any management scenarios that may involve bio-manipulation techniques to control phytoplankton production (see Management Recommendations below).



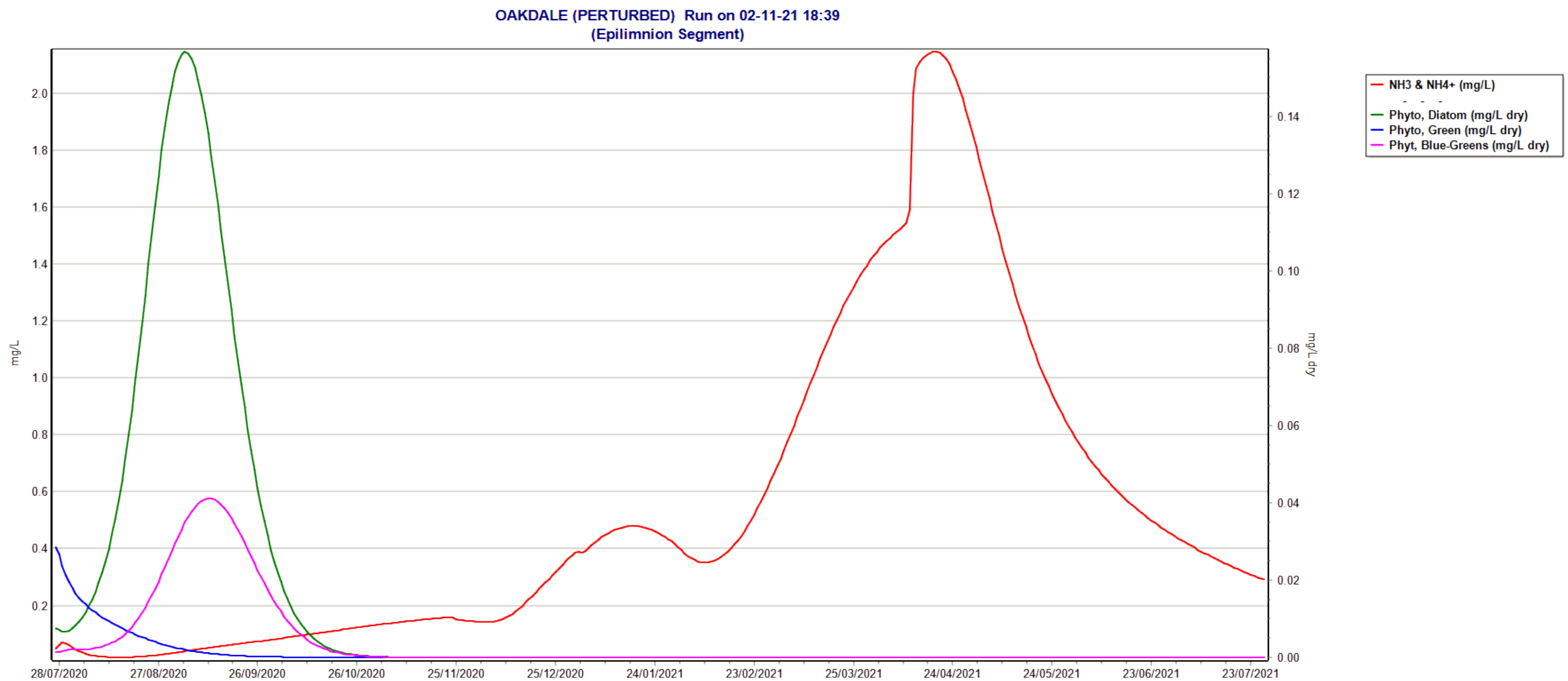
Note: Figure shows marked increase in water-column Nitrate concentration from fall to winter, while ammonia/ammonium concentrations are relatively low throughout the year.

Figure 6: AQUATOX Simulation of N and P Compounds in Oakdale Lake, 2021 – 2022



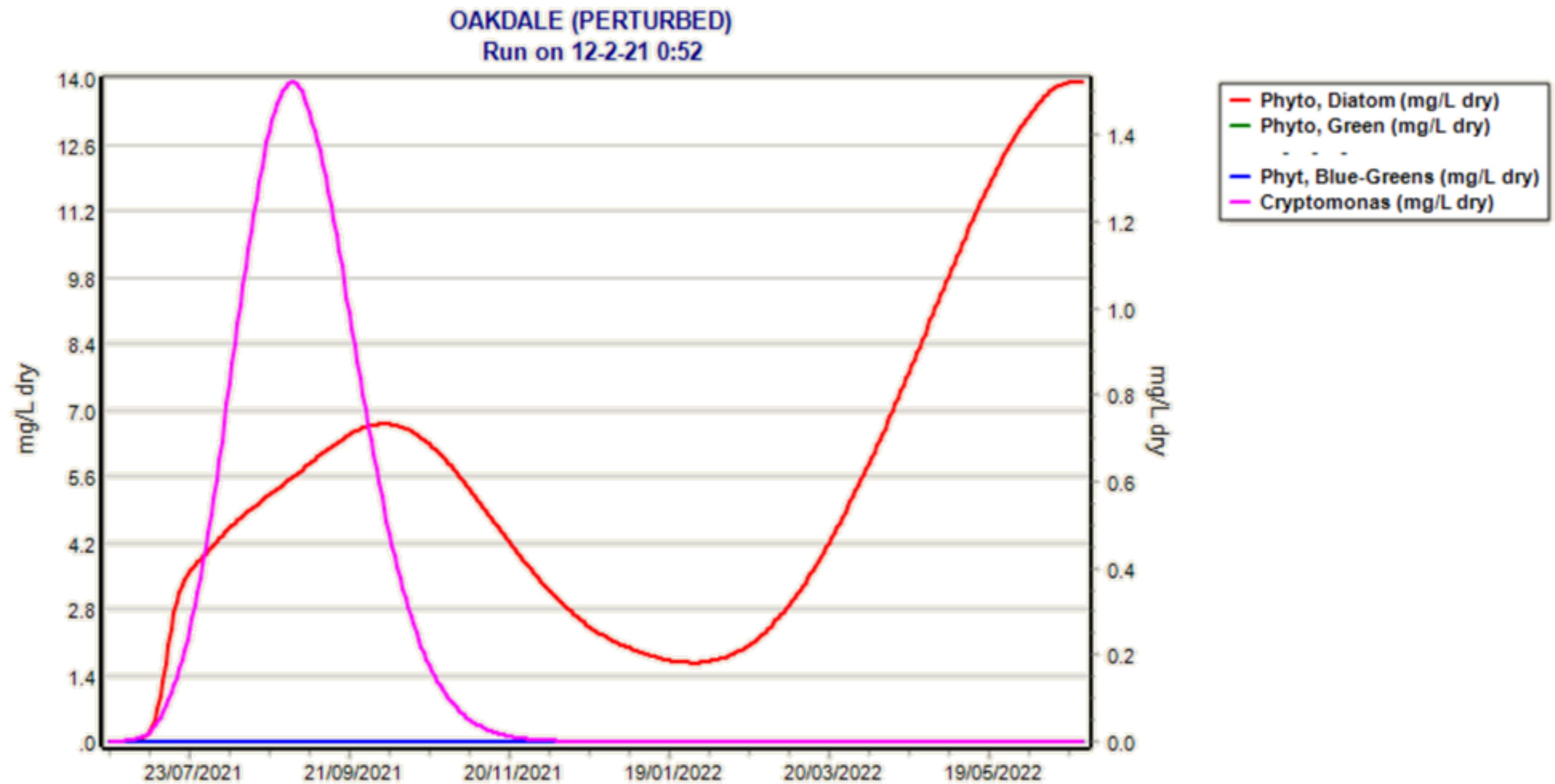
Note: Figure shows mid-summer algae bloom followed by a gradual increase in water-column P concentration from fall to winter.

Figure 7: AQUATOX Simulation of P vs. Phytoplankton in Oakdale Lake, 2020



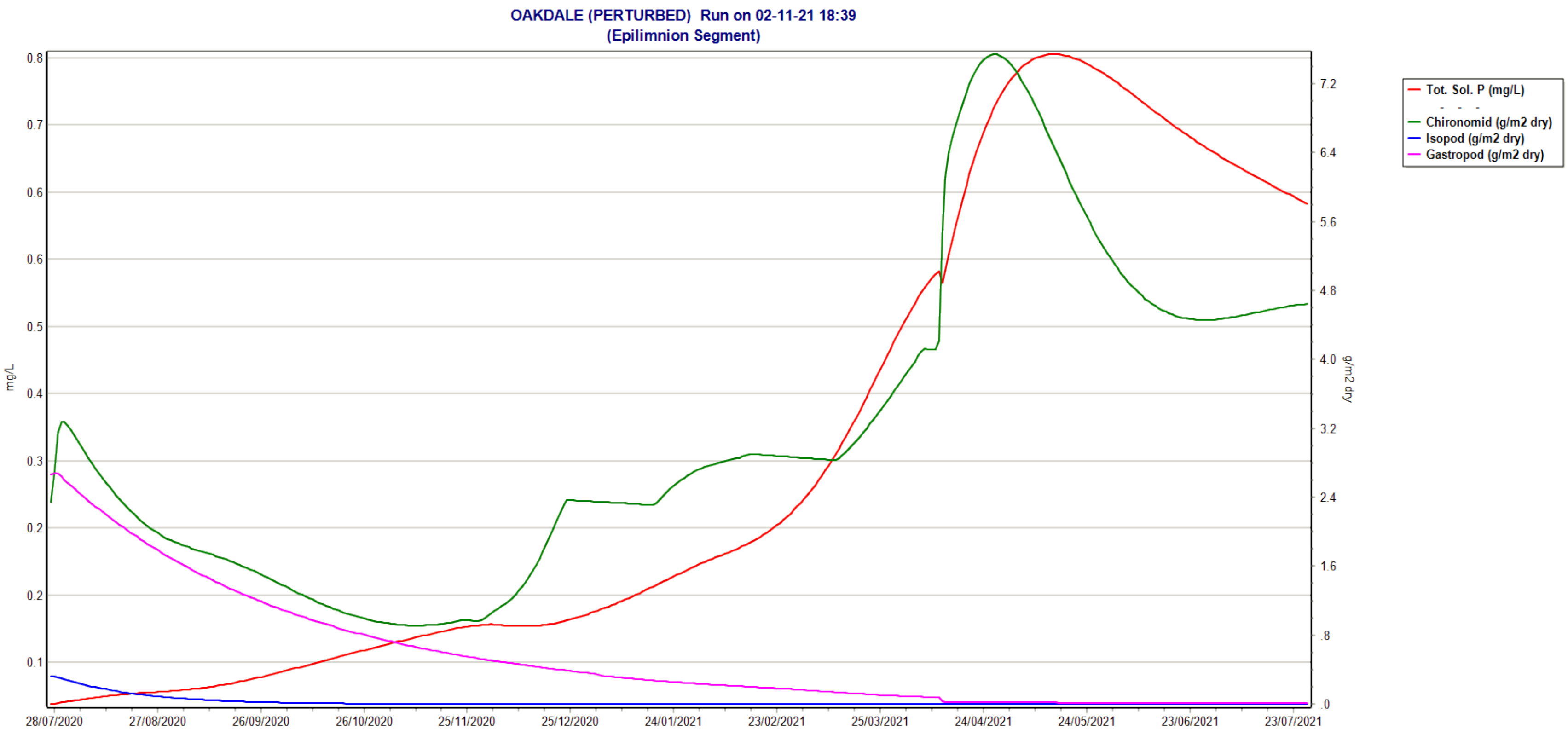
Note: Figure shows mid-summer algae blooms and mid-late winter increase in water-column N concentrations.

Figure 8: AQUATOX Simulation of N vs. Phytoplankton in Oakdale Lake, 2020-2021



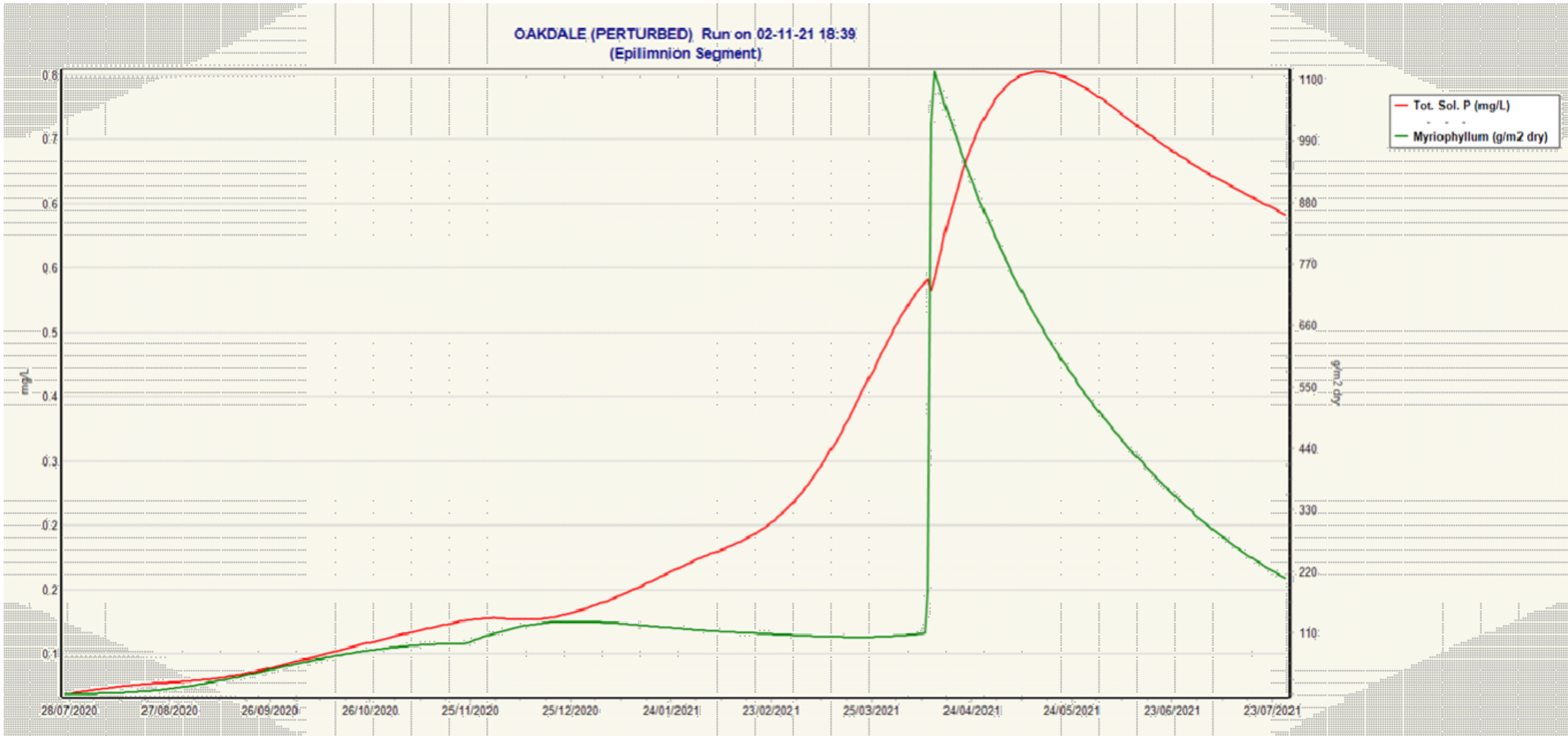
Note: Figure shows mid-summer algae blooms (*Cryptomonas*) and mid-late winter increase in water-column N concentrations.

Figure 9: AQUATOX Simulation of N vs. Phytoplankton in Oakdale Lake, 2020-2021



Note: Figure show that as P concentrations increase, the abundance of pollution-tolerant species (e.g., midge larvae) increases, while pollution-sensitive species (snails, aquatic sowbugs) decrease in abundance.

Figure 10: AQUATOX Simulation of P vs. Benthic Macroinvertebrates in Oakdale Lake, 2020-2021



Note: Figures shows that nutrient enrichment triggers a bloom of SAV production, followed by gradual senescence/decomposition.

Figure 11: AQUATOX Simulation of P vs. SAV in Oakdale Lake, 2020-2021

3.2 Sediment

Sediments collected from Oakdale Lake on July 27, 2020, were analyzed for a suite of physical and chemical parameters, including nutrients and heavy metals. Total P concentrations in sediments were high, ranging from 550-770 mg/kg. Nitrate/nitrite concentration were relatively low (1.9 – 2.3 mg/kg). Sediment percent solids were low ranging from 34.4 – 39.7. TOC was high ranging from 28,000 – 36,000 mg/kg. Sulfide concentrations were high, ranging from 440 – 970 mg/kg (TABLE 4). These physical and chemical characteristics are indicative of enriched, highly organic sediments, as well as prolonged hypoxia in bottom waters, notably the high TOC and sulfide concentrations.

Heavy metal concentrations in Oakdale Lake were compared to the NYSDEC's Screening and Assessment of Contaminated Sediment (2014). Heavy metals detected in Oakdale Lake sediments included arsenic, cadmium, copper lead, and mercury. Of these, only copper occurred at concentrations in excess of NYSDEC Class "C" thresholds for freshwater sediments (i.e. "highly contaminated and likely to pose a risk to aquatic life"). Arsenic and lead occurred at concentrations in excess of NYSDEC Class "B" limits (i.e. "slightly to moderately contaminated; potential risks to aquatic life"). Chromium and mercury were detected at low concentrations (e.g., NYSDEC Class "A") with little to no risk to aquatic life in Oakdale Lake (TABLE 5).

Table 4: *Sediment test results (physical/chemical attributes), Oakdale Lake*

Sample ID	Sample Date	Total Phosphorus (mg/kg)	Nitrate/Nitrite (mg/kg)	% Solids (mg/kg)	Sulfide (mg/kg)	Total Organic Carbon (mg/kg)
OL-S-1	7/27/2020	550	2.3	34.4	440	36000
OL-S-2	7/27/2020	740	1.9	39.7	450	34000
OL-S-3	7/27/2020	770	2	38.8	970	28000

Table 5: Sediment test results (metals), Oakdale Lake

Sample ID	Sample Date	Arsenic (mg/kg)	Cadmium (mg/kg)	Copper (mg/kg)	Chromium (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)
OL-S-1	7/27/2020	12	ND	610	26	100	ND
OL-S-2	7/27/2020	14	ND	190	30	52	0.13
OL-S-3	7/27/2020	12	ND	260	30	63	0.098

Notes: ND= not detected
Green indicates Class "A" sediment, yellow indicates Class "B" sediment, and red indicates Class "C" sediment per the NYSDEC's 2014 Screening and Assessment of Contaminated Sediment document.'

4.0 Management Recommendations

The following management recommendations have been separated into external management actions–meaning within the larger watershed and internal management actions, meaning within Oakdale Lake. Several management options were considered as part of this assessment but were not selected as final recommendations. We have included a discussion about these options for future reference should watershed conditions or management objectives change. The management actions presented in this section will require some level of collaboration between FOL, stakeholders, and the City of Hudson as well as consultation with the New York State Department of Environmental Conservation (NYSDEC) and the U.S. Army Corps of Engineers (USACE) to acquire the necessary approvals and permits. Internal management alternatives that require NYSDEC or USACE regulatory approvals are summarized in Table 6 along with estimated costs.

4.1 External Control of Phosphorus Loading

Based on the output of the AQUATOX model, limiting the influx of nutrients into the lake from point and non-point sources in the surrounding watershed should be the first step in reversing eutrophication in Oakdale Lake. Without first reducing nutrient inputs, further management is not likely to yield success.

To implement management actions at the watershed level, we recommend an additional hydrologic study to understand nutrient transport between the three stormwater drains above Power Spring and Oakdale Lake, nutrient loading in the lake, and the interplay between groundwater, stormwater, and the lake. As a first step FOL, should work with the City of Hudson to determine and confirm the source of water from the three stormwater drains either through dye tracing or some other appropriate method.

4.1.1 Stormwater Detention Basins

Construction of small stormwater quality control facilities (constructed ponds, or swales) can intercept and capture suspended solids and nutrients in stormwater runoff, if situated in the surrounding watershed, upgradient of the lake. Critical areas for stormwater interception include along Jenkins Parkway, Bayley Boulevard, Graham Avenue, Aitken Avenue, and Storm Avenue (Figure 12).

4.1.2 Green Infrastructure Approaches

Rainwater capture systems, green rooftops, phytoremediation, permeable pavement materials, and bio-retention gardens are examples of green infrastructure elements that can intercept and store rainwater in urban/developed watersheds. Incorporating green infrastructure into new municipal development projects or upgrading existing features within the built environment to include green infrastructure can reduce impervious surface coverage and promote water retention in the surrounding watershed. For example, some large municipalities in NY State (and elsewhere) have implemented rain barrel giveaway programs, intended to encourage residents to capture rainfall from building roofs for use in gardening and lawncare. Green rooftops have been developed on both private and public facilities throughout NY state (and worldwide), simultaneously reducing urban runoff while providing ecological benefits (habitat for birds and pollinators).

Green infrastructure approaches such as bioswales and bioretention basins would be best implemented in the southeastern portion of the watershed along Jenkins Parkway, Bayley Boulevard, Graham Avenue, Aitken Avenue, and Storm Avenue (Figure 12). Phytoremediation, which is the use of use of vegetation to remove contaminants, and wetland enhancement may also be beneficial within Power Spring especially if the source of the stormwater from the drains remains unclear (Figure 12).

Photo 7: Examples of green infrastructure in urban settings.

4.1.3 Street Cleaning and Litter Control

Municipal street cleaning can reduce sediments and many associated contaminants entering stormwater. Street cleaning is especially important when rainfall events are expected after long dry weather periods as nutrients and contaminants may accumulate on urban road surfaces, and a subsequent wet weather event will mobilize a "pulse" of these materials into downstream waters.

In addition, proper disposal of pet feces and litter throughout the surrounding Oakdale Lake watershed will also help reduce oxygen demand via decomposition of organic matter contained in stormwater.

4.1.4 Xeriscaping and Natural Lawn Care

The implementation of xeriscaping which is the use of drought-tolerant plants and natural lawn care by residential and commercial property owners and managers within the watershed would reduce the need for fertilizers and nutrient rich water entering stormwater.

4.1.5 Community Outreach and Landowner Education

A community outreach and educational campaign targeting landowners within the watershed could be implemented to inform landowners of the risks of over-fertilization as well as provide tools and resources to learn about natural lawn care techniques and xeriscaping.

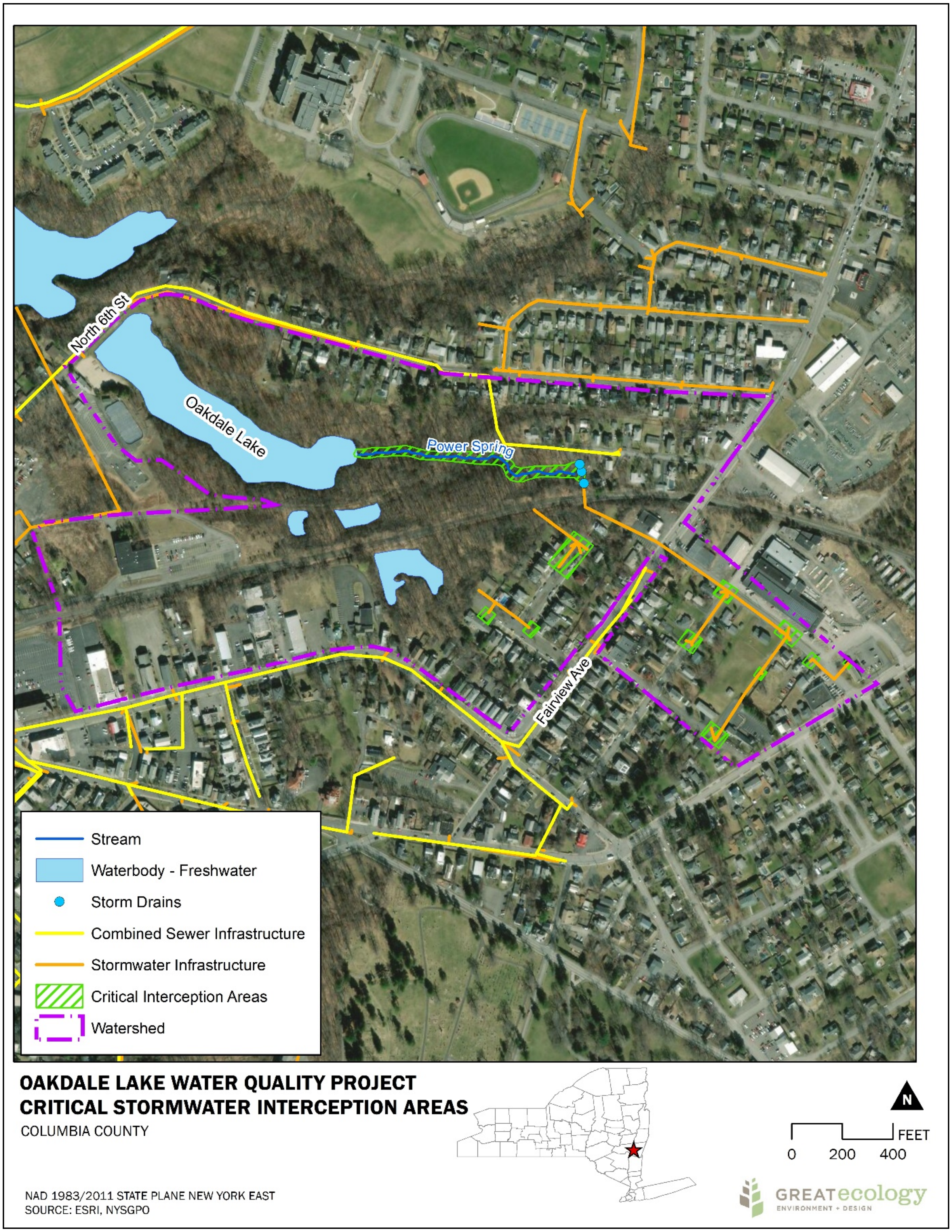


Figure 12: Critical Stormwater Interception Areas within Oakdale Lake Watershed

4.2 Internal Control of Phosphorus Loading

While curtailing external nutrient inputs is a critical first step, it is often not sufficient as a stand-alone remedy for cultural eutrophication because it does not address internal cycling of nutrients already present in the lake. Once external nutrient inputs are controlled, various methods can be implemented to suppress internal nutrient recycling.

4.2.1 Flocculating Chemicals

The most common method used to control internal nutrient recycling in ponds and small lakes is to apply flocculating chemical compounds that bind and immobilize P. Aluminum sulfate, a popular commercially available flocculant, works well and is safe for application in non-acidic waters, which is the case in Oakdale Lake. This can be an interim solution, since the "floc and lock" approach can be very effective in the short term at binding P but may require periodic re-application of chemicals over time. An initial aluminum sulfate treatment is generally effective for about five years. When implementing this action, pH should be carefully monitored once per year during early summer to coincide with maximum SAV biomass. Re-application should not occur if low pH (acidic) conditions develop in the lake, as this can result in mobilization of elemental aluminum in lake sediments, which can be toxic to fish and other aquatic organisms. A NYSDEC aquatic pesticide permit is required to apply herbicides in aquatic environments within New York State. Approximate cost for aluminum sulfate application (chemicals only) is $30-60 per acre-ft. of lake.

4.2.2 Barley Straw

Another option is to place barley straw, packed loosely in mesh bags, throughout the lake at a density of approximately 250/lbs per acre at the beginning of the summer, when conditions are starting to become favorable for algae blooms. When barley straw sits in water, decomposition by fungi cause a chemical reaction that inhibits the growth of algae and absorbs P. Decomposition requires a well-oxygenated environment, so it is best to deploy the floating bags near the shore. It can take a few weeks for the compounds that inhibit algal growth to build up, but effects are likely to last the remainder of the summer at which point the bags can be removed. Approximate cost for packed barley straw (materials only, packed in 1 lb bags) is $6,250/acre. A less expensive, but more labor-intensive option is to purchase barley straw in 25 lb bales (approximately $100 /bale). These can be placed along the lake shore at a density of 10 bales/acre ($1000/ acre), or the bales can be separated and re-packed in 1 lb mesh produce bags sourced separately.

4.2.3 SAV Harvesting and Chemical Treatment

Manual harvesting of SAV can be used to remove excess plant biomass (and associated nutrients) in confined water bodies like Oakdale Lake. The effectiveness of manual harvesting depends on several factors, including the density of SAV present at the time of harvesting, the rate or growth or recolonization of the target species, and the ability of harvest techniques to select target, nuisance species while avoiding desirable, native SAV. For larger, deeper water bodies or in deeper areas of lakes that are not wadable, such as around the dock at Oakdale Lake, powerboats can be deployed, and mechanical harvesters can be used to rapidly and effectively remove SAV. For example, a "typical" paddle-wheel aquatic weed harvester suitable for inland waters (8 ft. cutting head) can remove SAV at a rate of approximately two acres per day, at a cost of approximately $2000/acre.

For smaller lakes and ponds, manual harvesting can be effective (although labor-intensive) but is constrained to wading into shallow areas. This limits the efficacy of manual harvesting, as many nuisance SAV species can grow at water depths of up to 10 ft, depending on water column transparency and light penetration. Often, a combination of mechanical and manual harvesting is necessary to remove nuisance SAV across a range of water depths. For all SAV removal methods, it is imperative to properly dispose of the harvested plant material offsite. Leaving piles of decomposing SAV along a lake shoreline is aesthetically undesirable, and nutrients and or contaminants could leach out of harvested plant material and drain back into the treated pond or lake, especially during and immediately following a rain event.

Chemical herbicides are commonly used to control nuisance, non-native SAV in lakes and ponds. A variety of EPA and state-approved formulations and application methods are commercially available. These chemicals typically work by interfering with photosynthesis or disrupting cell walls, which leads to natural decomposition. A NYSDEC aquatic pesticide permit is required to apply herbicides in aquatic environments within New York State. A NYSDEC wetlands permit may also be required if the pond or lake to be treated is located within a state-regulated wetland. At this time, herbicide application is not recommended as an alternative for Oakdale Lake because of toxicity concerns for bathers and aquatic organisms (including fish that may be consumed by recreational anglers).

4.2.4 Water Column Aeration

Artificial aeration of surface waters, bottom waters, or both can prevent hypoxia from occurring and promote the natural processes of oxidation and organic matter decay, preventing buildup of soft, organic sediments. Often, during summer conditions, deeper areas of lakes and ponds will stratify into layers with differing temperatures – the colder, bottom depths cease to circulate and exchange with surface waters, causing hypoxia in deeper areas. When bottom layer oxygen is depleted, aquatic organisms are impacted and the normal process of oxidation / decomposition of accumulated organic matter (e.g., leaf litter, dead aquatic plants, dead algae, etc.) is interrupted. Aeration disrupts this cycle. Additional benefits of artificial aeration include control of noxious odors, typically caused by release of methane or hydrogen sulfide gas generated under low oxygen conditions, and maintenance of cool, oxygenated refuge areas for fish and other aquatic organisms during summer.

4.2.4.1 Air diffusers

Air diffusion systems are designed to be installed at the bottom of a deeper lake or pond, where circulation and aeration is required to oxygenate bottom waters and prevent stratification. In a typical configuration, an electric air compressor is situated on the shore and pumps air through a hose to a diffuser placed on the bottom of the pond. Air bubbles rush out of the diffuser to the lake surface, creating circulation and providing aeration. An additional benefit of diffused aeration is that, under oxygenated conditions, P will bind with any naturally occurring dissolved iron in bottom waters and will be unavailable for uptake by algae or aquatic plants. This is similar to the process of aluminum-P flocculation described above for aluminum sulfate treatments. Air diffusers can be configured to operate on wind or solar-generated electricity, in addition to standard household or commercial electrical systems, or portable generators. Air diffusion systems for small lakes or ponds (approximately five acres in surface area) range in price from $4,000 for a standard household/commercial electric-powered system to $15,000 for a complete solar powered system. Additional maintenance costs (approx. $1,000 per year) would be incurred over time to keep the system operational (e.g., changing air filters every six months).

4.2.4.2 Surface aerators

Surface or fountain aerators are designed for use in ponds that have a maximum depth of five feet or less. They are especially beneficial in controlling floating algae mats. As the mats are broken up, the small eddies or vortexes created by disruption of the pond surface will circulate algal cells towards the bottom. This results in decreased exposure to sunlight, reducing growth. Surface/fountain systems do not aerate the bottom portion of the water column in deeper ponds or lakes. Surface aerator systems for small, shallow lakes or ponds are generally comparable in price with air diffusers (approx. $4,000 for a five-acre lake).

4.2.5 Biomanipulation

Artificial biomanipulation of aquatic communities can be successful in small water bodies (e.g., ponds versus larger lakes). Aquatic organisms at the top of the food chain (i.e. large predators) are food limited, and organisms below them may be either predator-limited, or food-limited. Standing crops of photosynthetic organisms (e.g., algae) are regulated by zooplankton grazing. Artificial "Top-Down" control options for Oakdale Lake could include direct addition of zooplankton to the lake or controlling existing fish predators of zooplankton by introducing piscivores, larger predatory fish. In either case, prior to implementing a top-down control approach for Oakdale Lake, it would be necessary to conduct a comprehensive ecosystem characterization study, including phytoplankton and zooplankton surveys and a fish community survey to identify piscivore species and zooplankton grazers.

Another biomanipulation alternative involves implementing controls on the proliferation of rooted SAV, such as the native and non-native species of pondweeds present in Oakdale Lake. Restoring native SAV species, such as slender pondweed, can help to suppress algae blooms by creating competition for light and nutrients. After an initial treatment (e.g., alum application or barley straw, as described above) to reduce P, native SAV may increase naturally; however, eradication of non-native curly-leaf pondweed (via a seasonal manual harvesting program) might be necessary to allow native slender pondweed stands to fully develop in areas of the lake with suitable depth and light conditions.

4.2.6 Algicides

Chemical algicides are commonly used to kill unwanted algae in lakes and ponds. A variety of EPA and state-approved formulations and application methods are commercially available. These chemicals typically work by interfering with photosynthesis or disrupting cell walls, which leads to natural decomposition. A NYSDEC aquatic pesticide permit is required to apply herbicides or algicides in aquatic environments within New York State. A NYSDEC wetlands permit may also be required if the pond or lake to be treated is located within a state-regulated wetland. At this time, algicide is not recommend as an alternative for Oakdale Lake because of toxicity concerns for bathers and aquatic organisms (including fish that may be consumed by recreational anglers).

4.2.7 Dredging

At Oakdale Lake, the soft, mucky substrate located just off the bathing beach could be removed via suction dredging followed by placement of new, clean sand substrate and grading to achieve a desired bathymetric profile. This action would remove a substantial reservoir of organic matter and P-laden sediments in a portion of the lake. However, dredging the entire lake (and placing new substrate throughout) is not recommended. Oakdale Lake Park staff would need to work with an experienced dredging contractor to determine the appropriate area and volume of substrate to be removed and replaced with new substrate. This alternative would also need to be planned and implemented in consultation with local, state (NYSDEC) and federal (U.S. Army Corp of Engineers) permitting authorities. Present-day cost estimates for lake suction dredging are approximately $75,000/acre.

Dredging is expensive and disruptive, and suitable best management practices and controls must be put in place if toxic compounds (e.g., heavy metals and chlorinated hydrocarbons) are present (or suspected of being present) in the substrate to be removed. Even a relatively small-scale dredging operation requires a temporary setup and staging area for equipment and storage of the sediments removed. Identification and implementation of a suitable disposal option (e.g., disposal in a local landfill or beneficial use placement as composting or manufactured soil) is also vital. However, dredging can be a very efficient means of removing P trapped in sediments, while simultaneously improving aesthetics and promoting recreational activities such as swimming and paddling.

Table 6: Internal Management Recommendations, Permit Requirements, and Estimated Costs at Oakdale Lake

Internal Management Alternative	Agency	Permit Type	Estimated Cost for Management Alternative
Flocculating Chemicals	New York State department of Environmental Conservation (NYSDEC)	• Aquatic Pesticide Permit	• $9,000 for two years of pesticide treatment (based on SAV herbicide treatment costs)
SAV Harvesting	NYSDEC	• Article 15 Protection of Waters Permit	• $19,000 of two years of harvesting • Contractor will obtain necessary agency permits
SAV Treatment	NYSDEC	• Aquatic Pesticide Permit	• $9,000 for two years of pesticide treatment • Contractor will obtain necessary agency permits
Biomanipulation	NYSDEC	• Unknown at this time. Approach requires a meeting with the NYSDEC to determine permit requirements	• Unknown at this time.
Algicides	NYSDEC	• Aquatic Pesticide Permit	• $9,000 for two years of pesticide treatment • Contractor will obtain necessary agency permits
Water Column Aeration – Air Diffuser (installed on bottom of lakebed)	NYSDEC	• Article 15 Protection of Waters Permit	• $4,000 for a standard household/commercial electric-powered aeration • $15,000 for a complete solar powered system • $1,000 per year additional maintenance costs including filter replacement over five years
	U.S. Army Corp of Engineers (USACE)	• Nation Wide Permit (NWP) 27	
Barley Straw	N/A	• N/A	• $14,000 for materials for two years of treatment
Dredging	NYSDEC	• Article 15 Protection of Waters Permit	• $75,000/acre for suction dredging
		• Stormwater State Pollutant Discharge Eliminations System (SPDES) Permit	
	USACE	• Nation Wide (NWP) Permit 19 or NWP 27	

Note: Costs do not include consulting fees for additional biological surveys that may be required, engineering or landscape plan documents, or unless otherwise states permit preparation and submission.
Cost estimates should be refined closer to project implementation.
Consultation with NYSDEC and the U.S. Army Corps of Engineers should be carried out in the form of a pre-application meetings prior to implementation of management activities.

5.0 Conclusions and Recommendations

Eutrophic lakes can persist as one of two alternative stable states:

1) a turbid, phytoplankton dominated state; and
2) a transparent, macrophyte dominated state.

AQUATOX simulations suggest Oakdale Lake may shift between these two extremes, supporting ample growth of both submerged macrophytes (spring) and phytoplankton (mid-late summer). While eutrophic, Oakdale Lake still appears to be a functioning ecosystem capable of cycling nutrients and supporting aquatic life. Lake management decisions would benefit from a long-term comprehensive monitoring program, including continuation of the volunteer water quality monitoring, along with annual surveys of lake biota, including phytoplankton, SAV, zooplankton, benthic macroinvertebrates, and fish. This whole-ecosystem approach to monitoring would help to determine if the food web at Oakdale Lake is characteristic of a eutrophic system and identify opportunities where manipulation of the food web could result in nutrient reductions and system improvements.

Analysis of both 'wet-' and 'dry- weather' datasets illustrate that stormwater runoff is likely to contribute to the accumulation of nutrients (i.e. P, and N) in the lake. The Oakdale Lake watershed can contribute moderately high quantities of nutrients, via two contrasting pathways: P appears to be exported primarily via stormwater runoff, contributing to the direct degradation of the lake, while N compounds may percolate first to the aquifer beneath and then seep into the lake (Hobbie et al. 2017).

We recommend that FOL work with the City of Hudson to determine and confirm the source of water from the three storm drains that outlet into Power Spring as well as carry out an additional hydrologic study to understand nutrient transport and loading within the lake, and the interactions between groundwater, stormwater, and the lake. Additionally, an expanded water quality monitoring program which includes year-round DO monitoring would help confirm the observations made during the two-year project. These actions would help to better define future management strategies especially at the watershed level to ensure reduction of nutrient inputs in the lake.

Several short- and long-term management alternatives are recommended for Oakdale Lake and its surrounding watershed. In the short term (to be implemented within the next year, and beyond), we suggest the following to control internal nutrients:

1) Seasonal SAV harvesting;
2) Barley straw application; and
3) Air diffuser aeration.

Once the source of water from the storm drains is confirmed, several watershed or landscape-scale management actions are recommended for implementation along with internal management actions to control external nutrient loading in the lake, including, but not limited to:

1) Installation of stormwater detention ponds and swales in critical intercept areas to be determined through confirmation of source water from the storm drains;

2) Consideration of green infrastructure approaches for new and existing residential and commercial developments with the potential for phytoremediation actions which use vegetation to remove contaminants, and wetland enhancement within Power Spring;
3) Municipal street cleaning and litter control;
4) Promoting water conservation measures for surrounding landowners, such as xeriscaping and natural lawn care; and,
5) Educational program to inform landowners of the risks of over- fertilization of lawns.

Landscape-scale management alternatives to control external nutrient loading will require collaboration with the City of Hudson Public Works Department and their engineers.

In the long-term (several years out, depending on the outcome of short-term approaches, and results of ecosystem monitoring) the following approaches may be warranted to address internal P cycling:

1) Aluminum sulfate ("floc and lock") treatment; and/or
2) Dredging of soft, organic soils in the vicinity of the bathing beach.

The time frame for the long-term management alternatives could be stepped up should recreation/aesthetics concerns (and availability of funds) dictate a more aggressive approach to improving the Oakdale Lake ecosystem.

6.0 References

Carmichael, W. 1994. The toxins of cyanobacteria. Scientific American 270: 78-86.

CSLAP [Citizens Statewide Lake Assessment Program]. 2016. Robinson Pond, CSLAP Annual Report, Town of Copake, Columbia County, NY.

CSLAP [Citizens Statewide Lake Assessment Program]. 2018. Kinderhook Lake, CSLAP Annual Report, Town of Kinderhook, Columbia County, NY.

EPA 2015. Human Health Water Quality Criteria and Methods for Toxics | US EPA: https://www.epa.gov/wqc/human-health-water-quality-criteria-and-methods-toxics#2015

Great Ecology. 2020. Oakdale Lake Environmental Overview.

Hitzfeld, B.C., S.J. Höger, and D.R. Dietrich. 2000. Cyanobacterial toxins: removal during drinking water treatment, and human risk assessment. Environmental Health Perspectives 108: 113-122.

Hobbie, S. E., J. C. Finlay, B. D. Janke, D. A. Nidzgorski, D. B. Millet and L. A. Baker. 2017. Contrasting Nitrogen and Phosphorus Budgets in Urban Watersheds and Implications for Managing Urban Water Pollution. Proceedings of the National Academy of Sciences, U.S. 114

Mahrlein, M., M. Patzig, M. Brauns and D.M. Dolman. 2016. Length–mass relationships for lake macroinvertebrates corrected for back-transformation and preservation effects. Hydrobiologia, 786: 37-50.

Méthot, G., C. Hudon, P. Gagnon, B. Pinel-Alloul, A. Armellinand and A.M.T. Poirier. 2012. Macroinvertebrate size–mass relationships: how specific should they be? BioOne, 31: 7500-764.

NYSDEC [New York State Department of Environmental Conservation]. 2014. Screening and Assessment of Contaminated Sediment. Accessed March 2021. Available at: https://www.dec.ny.gov/docs/fish_marine_pdf/screenasssedfin.pdf

Perry, Robert (City of Hudson Public Works Department). April 22, 2021. Personal Communication.

Tucker, C.S. and D'Abramo, L.R. 2008. Managing High pH in Freshwater Ponds. Southern Regional Aquaculture Center. http://agrilife.org/fisheries2/files/2013/09/SRAC-Publication-No.-4604-Managing-High-pH-in-Freshwater-Ponds.pdf