Picture 1. Diamond Lake Loon, 4-5 August 2021

A FISHERIES, ALGAE, ZOOPLANKTON, WATER QUALITY, AND WELL SURVEY OF DIAMOND LAKE WITH RECOMMENDATIONS AND A MANAGEMENT PLAN

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INTRODUCTION

We were asked to perform a fishery investigation of Diamond Lake located north of White Cloud, MI in Newaygo County, and to develop short-term and long-term management plans for the lake. Diamond Lake is a eutrophic lake with low alkalinity and mostly shallow littoral zone with a 26 - ft deep hole in the south end of the lake. The lake is ringed with houses located around the lake, but a considerable amount of their watershed is forested. Studies done prior (Prein and Newhof 1988 – discussed briefly below) showed that the lake soils are dominated by sand, that they are on septic tanks that have leaked wastewater through that sand contaminating the ground water and entering the lake with large amounts of phosphorus and nitrogen. As a result, the lake which is mostly shallow is plagued with blooms of blue green algae (*Microcystis* – the alga that shut down the water intakes at Toledo, OH in Lake Erie) and Eurasian milfoil, an invasive macrophyte that can dominate lakes, thwart recreational activity, and cause fish stunting and destruction of spawning beds. There are no inlets or outlets, so the water budget and flow is mainly determined by ground water flow. The lake is a 171-acre lake according to MDNR.

HISTORY

Several studies were done during the 1980s studying the lake environment and the impact of septic tanks on lake water quality and macrophyte and algae proliferation (Prein and Newhof 1988, TMI 1987). Their studies included monitoring wells with water movement and water quality sampling, a nutrient budget, documentation of macrophytes and algae in the lake, plans for mitigating the algae and macrophyte problems, and recommendations for septic tank elimination and replacement with various sewage treatment facilities. They noted that many of the soils in the riparian zone are unsuitable for soil absorption systems due to high water tables, low permeability or low phosphorous absorption capacities. They noted that there are wetlands on both the east and west sides with some smaller ones located in the north. They suggested these may be areas where groundwater comes to the surface fostering ground water re charge and typical wetland plant growth. These wetlands take up many nutrients through their dense growth of plants and recycling of phosphorus. Hydrology is mainly influenced by precipitation, evaporation, and groundwater flow. Most groundwater flow leaves through the south and southwest ends of the lake, which is mainly sand, and drains into the White River. A hydrogeological investigation was done using monitoring wells (see Fig. 4 for locations and direction of flow) to measure water quality and obtain groundwater flow movements (TMI 1987). Ground water from the monitoring wells showed high levels of SRP and total phosphorus in all the samples collected. In all cases except one, concentrations were higher during the July sampling bout than during October. This correlates well with increased use during summer and less during fall. One well was placed away from the lake to establish background levels; this sample was lower than the others that were near the lake edge reflecting septic tank contamination of the groundwater. Results from the nutrient budget model showed that phosphorous loading fell between "tolerable" and "dangerous" levels as found in the general literature.

METHODS

Our study involves physical, chemical, and biological measurements and observations by professional aquatic biologists who have conducted lake management studies since 1972; we incorporated in 1974. We use specialized samplers and equipment designed to thoroughly examine all components of an aquatic ecosystem. Shallow water, deep water, sediments, animal and plant life as well as inlet and outlet streams are intensively sampled and analyzed at several key stations (sites on the lake). Some samples are analyzed in the field, while the balance is transported to our laboratory for measurements and/or identification of organisms found in samples.

After the field study, we compile, analyze, summarize, and interpret data. We utilize a comprehensive library of limnological studies, and review all the latest management practices in constructing a management plan. All methods used are standard limnological procedures, and most chemical analyses are according to Standard Methods for the Examination of Water and Wastewater. Water analyses were performed by Grand Valley State University.

STATION LOCATIONS

During any study we choose a number of places (stations) where we do our sampling for each of the desired parameters. We strive to have a station in any unusual or important place, such as inlet and outlet streams, as well as in representative areas in the lake proper. One of these areas is always the deepest part of the lake. Here we check on the degree of thermal and chemical stratification, which is extremely important in characterizing the stage of eutrophication (nutrient enrichment), invertebrates present, and possible threats to fish due to production of toxic substances due to decomposition of bottom sediments. The number and location of these stations for this study are noted in that section.

PHYSICAL PARAMETERS

Depth

Depth is measured in several areas with a sonic depth finder or a marked sounding line. We sometimes run transects across a lake and record the depths if there are no data about the depths of the lakes as we did in this study. These soundings were then superimposed on a map of the lake and a contour map constructed to provide some information on the current depths of the lake.

Acreage

Acreage figures, when desired, are derived from maps, by triangulation, and/or estimation. The percentage of lake surface area in shallow water (less than 10 feet) is an important factor. This zone (known as the littoral zone) is where light can penetrate with enough intensity to support rooted aquatic plants. Natural lakes usually have littoral zones around their perimeters. Man-made lakes and some reservoirs often have extensive areas of littoral zone.

Hydrographic Map

A map of the depth contours of the lake was prepared for Diamond Lake since there was no prior one and because the depths changed due to dredging. We secured starting and ending GPS values for transects across the lake and then ran the pontoon boat at a consistent speed and measured the depth every 5 sec until the opposite shore was reached. These depth data were recorded and later entered on each of the transect lines drawn across a copy of the lake map showing the lake shoreline outline. The distance of the transect line (in mm) was divided by the number of observations for each transect so that the depths could be assigned accurately to the line at equal intervals. Next we interpolated contour lines based on the depth contour of interest, including lines for 5, 10, 15, 20, and 30 ft. This map will assist us in making assessments of the lake and hopefully fishers who want to fish in specific depths on the lake.

Sediments

Bottom accumulations give good histories of the lake. The depth, degree of compaction, and actual makeup of the sediments reveal much about the past. An Ekman grab or dredge sampler is used to sample bottom sediments for examination. It is lowered to the bottom, tripped with a weight, and it "grabs" a 1 square foot sample of the bottom. Artificial lakes often fill in more rapidly than natural lakes because disruption of natural drainage systems occurs when these lakes are built. Sediments are either organic (remains of plants and animals produced in the lake or washed in) or inorganic (non-living materials from wave erosion or erosion and run-off from the watershed).

Light Penetration

The clarity of the water in a lake determines how far sunlight can penetrate. This in turn has a basic relationship to the production of living phytoplankton (minute plants called algae), which are basic producers in the lake, and the foundation of the food chain. We measure light penetration with a small circular black and white Secchi disc attached to a calibrated line. The depth at which this disc just disappears (amount of water transparency) will vary between lakes and in the same lake during different seasons, depending on degree of water clarity. This reference depth can be checked periodically and can reflect the presence of plankton blooms and turbidity caused by urban run-off, etc. A regular monitoring program can provide an annual documentation of water clarity changes and a historical record of changes in the algal productivity in the lake that may be related to development, nutrient inputs, or other insults to the lake.

Temperature

This is a physical parameter but will be discussed in the chemistry section with dissolved oxygen. Thermal stratification is a critical process in lakes which helps control the production of algae, generation of various substances from the bottom, and dissolved oxygen depletion rates.

Stream Flows from Inlets and Outlets

Estimation of flows in and out of a lake gives us information about ground water inputs, inputs of nutrients and toxic substances, and amount of water moving through the ecosystem. When tied to the chemical analyses described earlier, nutrient inputs and outputs can be calculated and amount of impact of these inputs evaluated.

CHEMICAL PARAMETERS

Water chemistry parameters are extremely useful measurements and can reveal considerable information about the type of lake and how nutrients are fluxing through the system. They are important in classifying lakes and can give valuable information about the kind of organisms that can be expected to exist under a certain chemical regime. All chemical parameters are a measure of a certain ion or ion complex in water. The most important elements--carbon (C), hydrogen (H), and oxygen (O) are the basic units that comprise all life, so their importance is readily obvious. Other elements like phosphorus (P) and nitrogen (N) are extremely important because they are significant links in proteins and RNA/DNA chains. Since the latter two (P and N) are very important plant nutrients, and since phosphorus has been shown to be critical and often a limiting nutrient in some systems, great attention is given to these two variables. Other micronutrients such as boron, silicon, sulfur, and vitamins can also be limiting under special circumstances. However, in most cases, phosphorus turns out to be the most important nutrient.

Temperature Stratification

Temperature governs the rate of biological processes. A series of temperature measurements from the surface to the bottom in a lake (temperature profile) is very useful in detecting stratification patterns. Stratification in early summer develops because the warm sun heats the surface layers of a lake. This water becomes less dense due to its heating, and "floats" on the colder, denser waters below. Three layers of water are thus set up. The surface warm waters are called the epilimnion, the middle zone of rapid transition in temperatures is called the thermocline, and the cold bottom waters, usually around 39 F (temperature of maximum density), are termed the hypolimnion. As summer progresses, the lowest cold layer of water (hypolimnion) becomes more and more isolated from the upper layers because it is colder and denser than surface waters (see Fig. 1 for documentation of this process over the seasons).

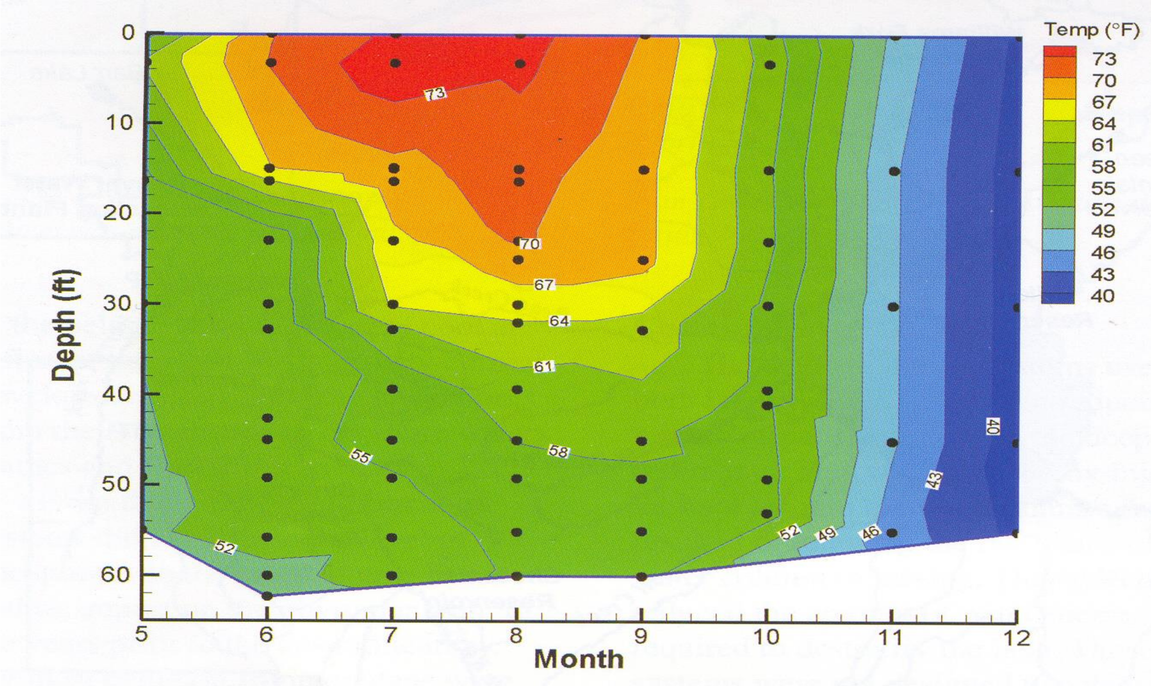

Figure 1. Depiction of the water temperature relationships in a typical 60-ft deep lake over the seasons. Note the blue from top to bottom during the fall turnover (this also occurs in the spring) and the red, yellow, and green (epilimnion, thermocline, and hypolimnion) that forms (stratification) during summer months. Adapted from NALMS.

When cooler weather returns in the fall, the warm upper waters (epilimnion) cool to about 39 F, and because water at this temperature is densest (heaviest), it begins to sink slowly to the bottom. This causes the lake to "turnover" or mix (blue part on right of Fig. 1), and the temperature becomes a uniform 39 F top to bottom. Other chemical variables, such as dissolved oxygen, ammonia, etc. are also uniformly distributed throughout the lake.

As winter approaches, surface water cools even more. Because water is most dense at 39 F, the deep portions of the lake "fill" with this "heavy water". Water colder than 39 F is lighter and floats on the denser water below, until it freezes at 32 F and seals the lake. During winter decomposition on the bottom can warm bottom temperatures slightly.

In spring when the ice melts and surface water warms from 32 to 39 F, seasonal winds will mix the lake again (spring overturn), thus completing the yearly cycle. This represents a typical cycle, and many variations can exist, depending on the lake shape, size, depth, and location. Summer stratification is usually the most critical period in the cycle, since the hypolimnion may go anoxic (without oxygen--discussed next). We always try to schedule our sampling during this period of the year. Another critical time exists during late winter as oxygen can be depleted from the entire water column in certain lakes under conditions of prolonged snow cover.

Dissolved Oxygen

This dissolved gas is one of the most significant chemical substances in natural waters. It regulates the activity of the living aquatic community and serves as an indicator of lake conditions. Dissolved oxygen is measured using an YSI, dissolved oxygen-temperature meter or the Winkler method with the azide modification. Fixed samples are titrated with PAO (phenol arsene oxide), and results are expressed in mg/L (ppm) of oxygen, which can range normally from 0 to about 14 mg/L. Water samples for this and all other chemical determinations are collected using a device called a Kemmerer water sampler, which can be lowered to any desired depth and like the Ekman grab sampler, tripped using a messenger (weight) on a calibrated line. The messenger causes the cylinder to seal and the desired water sample is then removed after the Kemmerer is brought to the surface. Most oxygen in water is the result of the photosynthetic activities of plants, the algae and aquatic macrophytes. Some enters water through diffusion from air. Animals use this oxygen while giving off carbon dioxide during respiration. The interrelationships between these two communities determine the amount of productivity that occurs and the degree of eutrophication (lake aging) that exists.

A series of dissolved oxygen determinations can tell us a great deal about a lake, especially in summer. In many lakes in this area of Michigan, a summer stratification or stagnation period occurs (See previous thermal stratification discussion). This layering causes isolation of three water masses because of temperature-density relationships already discussed (see Fig. 2 for demonstration of this process).

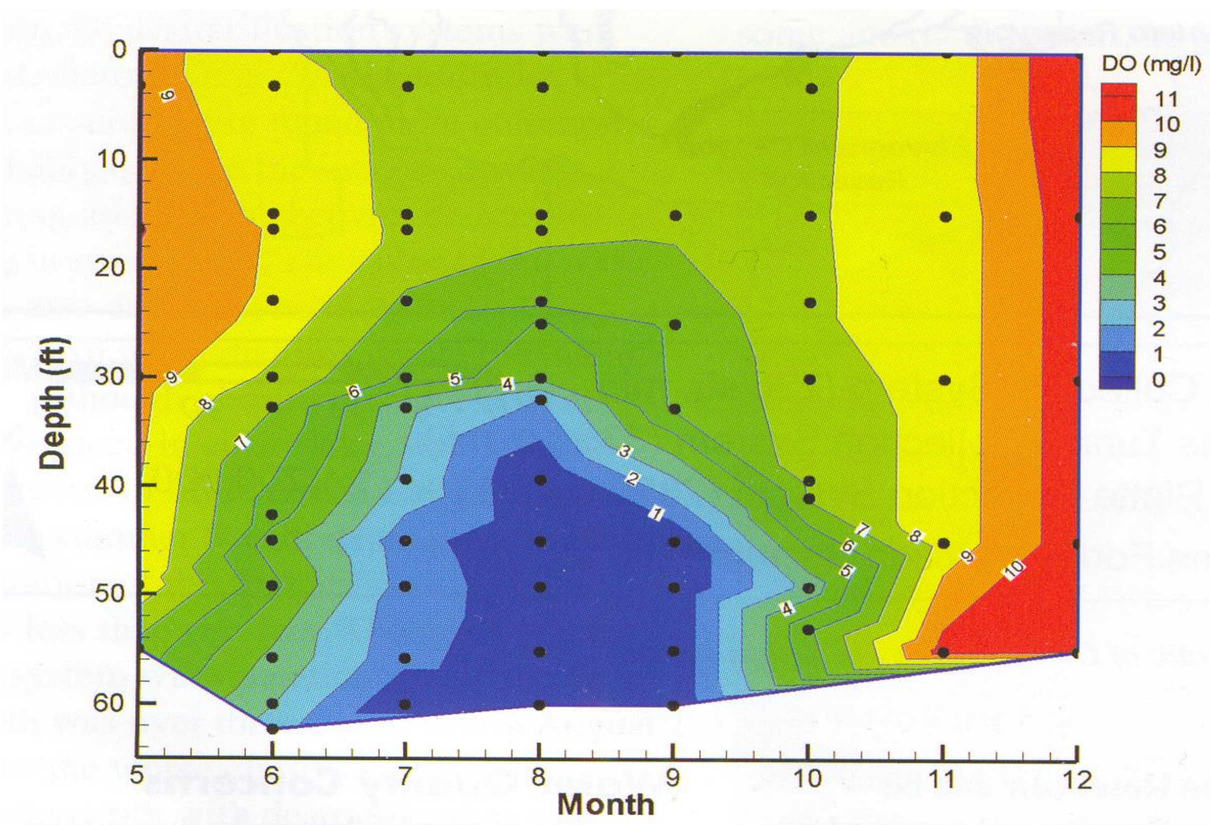

Figure 2. Dissolved oxygen stratification pattern over a season in a typical, eutrophic, 60-ft deep lake. Note the blue area on the bottom of the lake which depicts anoxia (no dissolved oxygen present) during summer and the red section in the fall turnover period (there is another in the spring) when the dissolved oxygen is the same from top to bottom. Adapted from NALMS.

In the spring turnover period dissolved oxygen concentrations are at saturation values from top to bottom (see red area which is the same in the spring – Fig. 2). However, in these lakes by July or August some or all of the dissolved oxygen in the bottom layer is lost (used up by bacteria) to the decomposition process occurring in the bottom sediments (blue area in Fig. 2). The richer the lake, the more sediment produced, and the more oxygen consumed. Since there is no way for oxygen to get down to these layers (there is not enough light for algae to photosynthesize), the hypolimnion becomes devoid of oxygen in rich lakes. In non-fertile (Oligotrophic) lakes there is very little decomposition, and therefore little or no dissolved oxygen depletion. Lack of oxygen in the lower waters (hypolimnion) prevents fish from living here and changes basic chemical reactions in and near the sediment layer (from aerobic to anaerobic).

Stratification does not occur in all lakes. Shallow lakes are often well mixed throughout the year because of wind action. Some lakes or reservoirs have large flow-through so stratification never gets established.

Stratified lakes will mix in the fall because of cooler weather, and the dissolved oxygen content in the entire water column will be replenished. During winter the oxygen may again be depleted near the bottom by decomposition processes. As noted previously, winterkill of fish results when this condition is caused by early snows and a long period of ice cover when little sunlight can penetrate the lake water. Thus, no oxygen can be produced, and if the lake is severely eutrophic, so much decomposition occurs that all the dissolved oxygen in the lake is depleted.

In spring, with the melting of ice, oxygen is again injected into the hypolimnion during this mixing or "turnover" period. Summer again repeats the process of stratification and bottom depletion of dissolved oxygen.

One other aspect of dissolved oxygen (DO) cycles concerns the diel or 24-hour cycle. During the day in summer, plants photosynthesize and produce oxygen, while at night they join the animals in respiring (creating CO2) and using up oxygen. This creates a diel cycle of high dissolved oxygen levels during the day and low levels at night. These dissolved oxygen sags have resulted in fish kills in lakes, particularly near large aquatic macrophyte beds on some of the hottest days of the year.

pH

The pH of most lakes in this area ranges from about 6 to 9. The pH value (measure of the acid or alkaline nature of water) is governed by the concentration of H (hydrogen) ions which are affected by the carbonate-bicarbonate buffer system, and the dissociation of carbonic acid (H2CO3) into H + ions and bicarbonate. During a daily cycle, pH varies as aquatic plants and algae utilize CO2 from the carbonate-bicarbonate system. The pH will rise as a result. During evening hours, the pH will drop due to respiratory demands (production of carbon dioxide, which is acidic). This cycle is similar to the dissolved oxygen cycle already discussed and is caused by the same processes. Carbon dioxide causes a rise in pH so that as plants use CO2 during the day in photosynthesis there is a drop in CO2 concentration and a rise in pH values, sometimes far above the normal 7.4 to values approaching 9. During the night, as noted, both plants and animals respire (give off CO2), thus causing a rise in CO2 concentration and a concomitant decrease in pH toward a more acidic condition. We use pH as an indicator of plant activity as discussed above and for detecting any possible input of pollution, which would cause deviations from expected values. In the field, pH is measured with color comparators or a portable pH/conductivity meter and in the laboratory with a pH meter.

Alkalinity

The amount of acid (hydrogen ion) that needs to be added to a water sample to get a sample to a pH of 4.5 (the endpoint of a methyl-orange indicator) is a measure of the buffering capacity of the water and can be quantitatively determined as mg/L or ppm as calcium carbonate (CaCO3). This measurement is termed total alkalinity and serves as an indicator of basic productivity and as an estimate of the total carbon source available to plants. Alkalinity is a measure of hydroxides (OH-), carbonates (CO3=) and bicarbonates present. Plants utilize carbon dioxide from the water until that is exhausted and then begin to extract CO2 from the carbonate-bicarbonate buffer system through chemical shifts. As discussed before, this decrease in CO2 concentrations causes great pH increases during the day and a pH drop during the night. There are two kinds of alkalinity measured, both based on the indicators, which are used to detect the end-point of the titration. The first is called phenolthalein alkalinity (phth) and is that amount of alkalinity obtained when the sample is titrated to a pH of 8.3. This measurement is often 0, but can be found during the conditions previously discussed; that is, during summer days and intense photosynthesis. Total alkalinity was noted above and includes phenolthalein alkalinity.

Hardness

Like alkalinity, hardness is also a measure of an ion, though these are divalent cations, positive double charged ions like calcium (Ca++) and magnesium (Mg/L++). Again, the units of hardness are mg/L as CaCO3. A sample of water is buffered and then an indicator is added. Titration to the indicator endpoint using EDTA completes the analysis. As with all our analyses, for more detail, consult Standard Methods. Alkalinity and hardness are complementary, so that comparing the two readings can give information about what ions are present in the system and confirm trends seen in other data. Alkalinity and hardness are complementary because every calcium ion must have a bicarbonate ion or other such divalent negative ion and vice versa; each carbonate or hydroxide ion must have a divalent or monovalent anion associated with it. For example, we might find high chlorides from street run-off in a particular sample. Since chlorides are probably applied as calcium chloride (CaCl2), we would confirm our suspicions when hardness (a measure of Ca++ ions) was considerably higher than alkalinity. If alkalinity were higher than hardness it would indicate that some positive anion like potassium (K+) was present in the lake, which was associated with the bicarbonate and carbonate ions but was not measured by hardness. High alkalinity and hardness values are associated with a greater degree of eutrophication; lakes are classified as soft, medium, or hard-water lakes based on these values.

Chlorides

Chlorides are unique in that they are not affected by physical or biological processes and accumulate in a lake, giving a history of past inputs of this substance. Chlorides (Cl-) are transported into lakes from septic tank effluents and urban run-off from road salting and other sources. Chlorides are detected by titration using mercuric nitrate and an indicator. Results are expressed as mg/L as chloride. The effluent from septic tanks is high in chlorides. Dwellings around a lake having septic tanks contribute to the chloride content of the lake. Depending upon flow-through, chlorides may accumulate in concentrations considerably higher than in natural ground water. Likewise, urban run-off can transport chlorides from road salting operations and bring in nutrients. The chloride "tag" is a simple way to detect possible nutrient additions and septic tank contamination. Ground water in this area averages 10-20 mg/L chlorides. Values above this are indicative of possible pollution.

Phosphorus

This element, as noted, is an important plant nutrient, which in most aquatic situations is the limiting factor in plant growth. Thus, if this nutrient can be controlled, many of the undesirable side effects of eutrophication (dense macrophyte growth and algae blooms) can be avoided. The addition of small amounts of phosphorus (P) can trigger these massive plant growths. Usually the other necessary elements (carbon, nitrogen, light, trace elements, etc.) are present in quantities sufficient to allow these excessive growths. Phosphorus usually is limiting (occasionally carbon or nitrogen may be limiting). Two forms of phosphorus are usually measured. Total phosphorus is the total amount of P in the sample expressed as mg/L or ppm as P, and soluble P or Ortho P is that phosphorus which is dissolved in the water and "available" to plants for uptake and growth. Both are valuable parameters useful in judging eutrophication problems.

Nitrogen

There are various forms of the plant nutrient nitrogen, which are measured in the laboratory using complicated methods. The most reduced form of nitrogen, ammonia (NH3), is usually formed in the sediments in the absence of dissolved oxygen and from the breakdown of proteins (organic matter). Thus, high concentrations are sometimes found on or near the bottom under stratified anoxic conditions. Ammonia is reported as mg/L as N and is toxic in high concentrations to fish and other sensitive invertebrates, particularly under high pHs. With turnover in the spring most ammonia is converted to nitrates (NO3=) when exposed to the oxidizing effects of oxygen. Nitrite (NO2-) is a brief form intermediate between ammonia and nitrates, which is sometimes measured. Nitrites are rapidly converted to nitrates when adequate dissolved oxygen is present. Nitrate is the commonly measured nutrient in limnological studies and gives a good indication of the amount of this element available for plant growth. Nitrates, with Total P, are useful parameters to measure in streams entering lakes to get an idea of the amount of nutrient input. Profiles in the deepest part of the lake can give important information about succession of algae species, which usually proceeds from diatoms to green algae to blue-green algae. Blue-green algae (an undesirable species) can fix their own nitrogen (some members) and thus out-compete more desirable forms, when phosphorus becomes scarce in late summer.

BIOLOGICAL PARAMETERS

Algae

The algae are a heterogeneous group of plants, which possess chlorophyll by which photosynthesis, the production of organic matter and oxygen using sunlight and carbon dioxide, occurs. They are the fundamental part of the food chain leading to fish in most aquatic environments.

There are several different phyla, including the undesirable blue-green algae, which contain many of the forms, which cause serious problems in highly eutrophic lakes. These algae can fix their own nitrogen (a few forms cannot) and they usually have gas-filled vacuoles which allow them to float on the surface of the water. There is usually a seasonal succession of species, which occurs depending on the dominant members of the algal population and the environmental changes, which occur.

This usual seasonal succession starts with diatoms (brown algae) in the spring and after the supply of silica, used to construct their outside shells (frustules), is exhausted, green algae take over. When nitrogen is depleted, blue-green algae can fix their own and become dominant in late summer.

The types of algae found in a lake serve as good indicators of the water quality of the lake. The algae are usually microscopic, free-floating single and multicellular organisms, which are responsible many times for the green or brownish color of water in which they are blooming. The filamentous forms, such as *Spirogyra* and *Cladophora* are usually associated with aquatic macrophytes, but often occur in huge mats by themselves. The last type, *Chara*, a green alga, looks like an aquatic macrophyte and grows on the bottom in the littoral zone, sometimes in massive beds. It is important to understand the different plant forms and how they interact, since plants and algae compete for nutrients present and can shade one another out depending on which has the competitive advantage. This knowledge is important in controlling them and formulating sensible management plans.

Algae samples were collected on 29 August 2021 from station A in Diamond Lake with an integrator tube that collects a sample of the algae living in the top 2 m (6.5 ft) of the water column. Algae samples were preserved with gluteraldehyde, kept from light and in the refrigerator until delivered to Dr. M. Edlund for analyses. Measured subsamples of preserved algae (~120-135 mL) were allowed to settle for a minimum of 1 week, and the algae concentrated to a volume of 10-20 mL for microscopical analysis. Well-mixed subsamples of 0.1 mL were distributed in a Palmer counting chamber and analyzed with an Olympus BX50 or Leitz Ortholux compound microscope using the Minnesota Rapid Algal Assessment method (Lindon and Heiskary 2007). In short, the sample is quickly scanned at low magnification to identify the primary algal species that are present. The sample is then counted at higher magnification (in this study, at 200x and phase contrast or oblique illumination) more slowly to estimate the biovolume of the major species present (normally those making up >5% of the assemblage). For most samples this entails counting about 400 functional algal units (i.e., cells, colonies, or filaments). For each species, a measurement of the algal biovolume is estimated based on measurements of cell or colonies using a calibrated ocular micrometer and simple shape formulas. Algal identification used standard guides (e.g., Prescott 1962, Hindák 2008). Data are reported as cells per volume of water (cells/mL) by algal groups (e.g., cyanobacteria, diatoms, green algae), total algal biovolume per volume of water (μm^3/mL) presented as algal group (e.g., cyanobacteria, diatoms, green algae), and a table of dominant types.

Macrophytes

The aquatic plants (emergent and submersed), which are common in most aquatic environments, are the other type of primary producer in the aquatic ecosystem. They only grow in the euphotic zone, which is usually the inshore littoral zone up to 6 ft., but in some lakes with good water clarity and with the introduced Eurasian water-milfoil (*Myriophyllum spicatum)*, milfoil has been observed in much deeper water. Plants are very important as habitat for insects, zooplankton, and fish, as well as their ability to produce oxygen. Plants have a seasonal growth pattern wherein over wintering roots or seeds germinate in the spring. Most growth occurs during early summer. Again, plants respond to high levels of nutrients by growing in huge beds. They can extract required nutrients both from the water and the sediment. Phosphorus is a critical nutrient for them. The aquatic plants and algae are closely related, so that any control of one must be examined considering what the other forms will do in response to the newly released nutrients and lack of competition. For example, killing all macrophytes may result in massive algae blooms, which are even more difficult to control.

Zooplankton

This group of organisms is common in most bodies of water, particularly in lakes and ponds. They are very small creatures, usually less than 1/8 inch, and usually live in the water column where they eat detritus and algae. Some prey on other forms. This group is seldom seen in ponds or lakes by the casual observer of wildlife but is a very important link in the food web leading from the algae to fish. They are usually partially transparent organisms, which have limited ability to move against currents and wave action, but are sometimes considered part of the 'plankton' because they have such little control over their movements, being dependent on wind-induced or other currents for transport.

Zooplankton is important indicators for biologists for three reasons. First, the kind and number present can be used to predict what type of lake they live in as well as information about its stage of eutrophication. Second, they are very important food sources for fish (especially newly hatched and young of the year fish), and third, they can be used to detect the effects of pollution or chemical insult if certain forms expected to be present are not. These data can be added to other such data on a lake and the total picture can then lead to the correct conclusions about what has occurred in a body of water.

Zooplankton is collected by towing a No. 10 plankton net through the water and the resulting sample is preserved with 10% formaldehyde and then examined microscopically in the laboratory. Qualitative estimates of abundance are usually given.

Benthos

The group of organisms in the bottom sediments or associated with the bottom is termed benthos. These organisms are invertebrates (lacking a backbone) and are composed of such animals as aquatic insect larvae and adults, amphipods (fairy shrimp), oligochaetes (aquatic worms), snails, and clams. The importance of this group for fish food and as intermediates in the food chain should be emphasized. Because of the tremendous variety of animals in each group and their respective tolerances for different environmental conditions, this group is a very important indicator of environmental quality. One of those organisms is called *Hexagenia*, the large mayfly that hatches in late July and precipitates much trout fishing in our local trout streams. This organism has a 2-yr life cycle; the larval form (naiad) lives in thick organic muds making a U-shaped burrow, so it can take in algae and detritus on which it feeds. It always requires high dissolved oxygen and good water quality to survive, so when present it indicates excellent water quality is present. We examine samples from deep water stations for the presence of organisms, as certain types live in low to no dissolved oxygen conditions, whereas other kinds can only exist when their high dissolved oxygen needs are satisfied.

These benthic organisms are collected using a special sampler called an Ekman dredge or Ekman grab sampler. It is lowered to the bottom in the open position, a messenger sent down the line and tripped. This results in about an l square foot section of bottom being sampled. The sample is washed through a series of screens to remove the fine mud and detritus, leaving only the larger organisms and plant material behind. The sample is then picked in the field or lab and the organisms found identified.

Fish

The top carnivores in most aquatic ecosystems, excluding man, are the fish. They are integrators of a vast number and variety of ever-changing conditions in a body of water. They, unlike the zooplankton and benthos, which can reflect short-term changes, are indicative of the long-range, cumulative influences of the lake or stream on their behavior and growth. The kind of fish, salmon or sunfish, can tell us much about how oligotrophic (low productivity) or eutrophic (high productivity) a lake is. We collect fish with seines, gill nets and from lucky fishermen on the lake. Most fish are weighed, measured, sexed, and their stomach contents removed and identified. Fish are aged using scales, and breeding condition is observed and recorded. The catches from our nets and age information on the fish will document how your length-at-age data compare with state averages and whether fish growth is good. Another problem, "stunting", can be detected using these sources of information.

Stomach contents of fish document whether good sources of food are present and help confirm age and growth conclusions. Imbalances in predator-prey relationships are a closely related problem, which we can usually ascertain by examining the data and through discussions with local fishermen. From studying the water chemistry data and supportive biological data, we can make recommendations, such as habitat improvement, stocking of more predators, and chemical renovation. We can also predict for example, the effects of destroying macrophytes through chemical control. All elements of the ecosystem are intimately interrelated and must be examined to predict or solve problems in a lake.

RESULTS

WATERSHED

Diamond Lake is located in Newaygo County and is in the Muskegon River watershed. The local watershed is composed of the land surrounding the lake which has many houses located on it. There is a county park on the north shore. The houses are on septic tanks and so we are concerned about septic tank effluent, which depending on soil type, could end up seeping into the lake through groundwater. There is also Eurasian milfoil in the lake which can expand and cover large areas of the substrate if conditions are optimal.

The local riparian zone is very important also, especially that band right at the lake (see Appendix 1 for lawn care and other recommendations). Things that can be done to inhibit entry of undesirable and deleterious substances into the lake are: planting greenbelts (thick plants that can absorb nutrients and retard direct runoff into the lake) along the lake edge, reducing erosion where ever it occurs, reducing or eliminating use of fertilizers for lawns, cutting down on road salting operations, not feeding the geese or ducks, no leaf burning in the watershed, prevention of leaves and other organic matter from entering the lake, and care in household use of such substances as fertilizers, detergents to wash cars and boats, pesticides, cleaners like ammonia, and vehicle fluids, such as oil, gas, and antifreeze (summarized in Appendix 1).

STATION LOCATION

Diamond Lake is a 171-acre lake located north of White Cloud, MI. We established five types of stations on Diamond Lake for sampling various parameters in this study (Fig. 3, 4 and Tables 1, 2). Water chemistry was taken at the deep basin site (station A), zooplankton were sampled at two sites (station A – 26 ft deep and station B (10 ft shallow), algae was sampled at station A, wells were sampled at four sites (N, S, E, W sides of the lakes), while places and times for sampling fish were set up in various locations around the lake to maximize catch of fishes (Table 2). Fishes were collected using seines at stations S1, S2, S3, and S4, gill nets at stations G1 and G2, and trap nets at stations T1, T2, and T3 (Fig. 4).

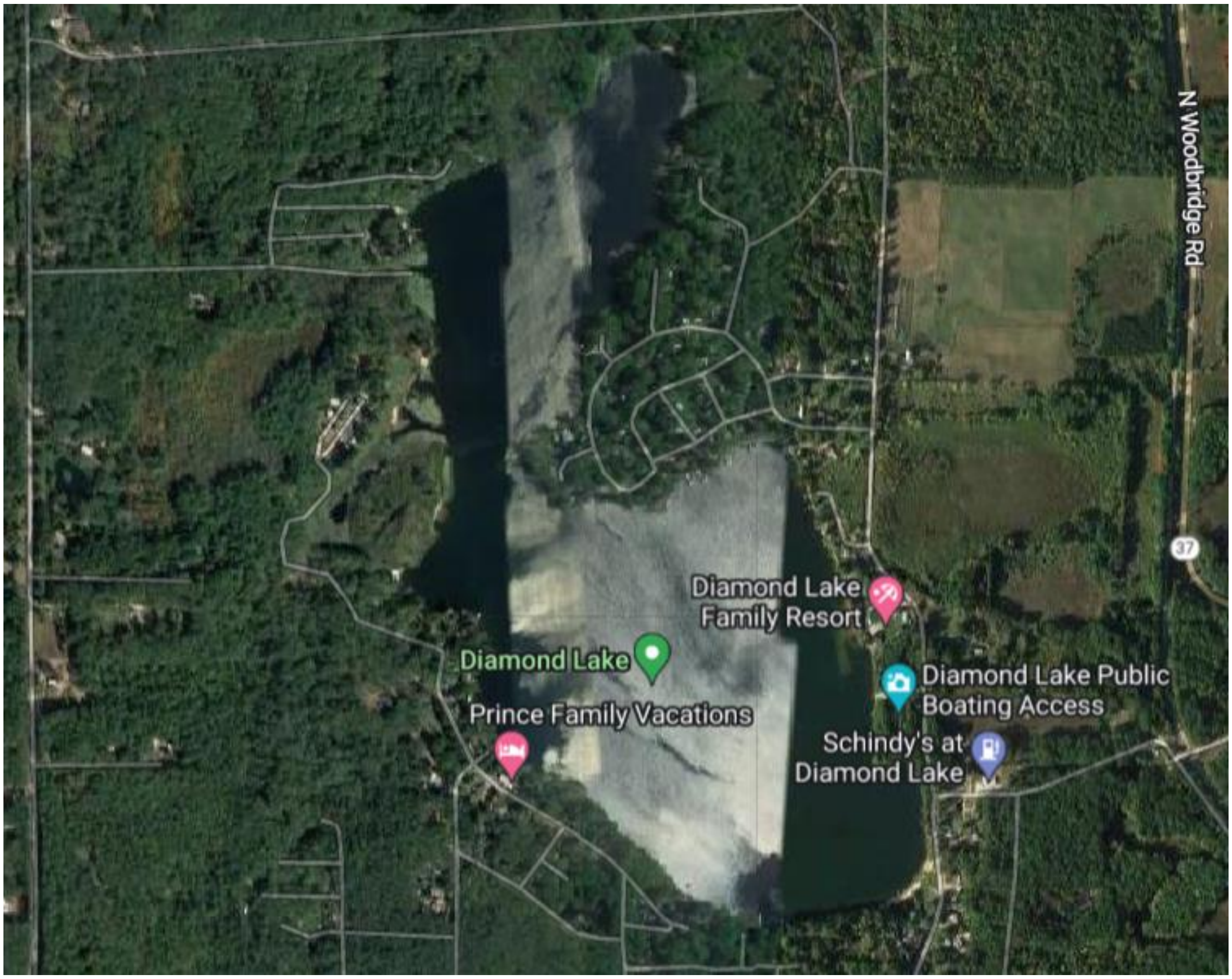

Figure 3. Google map of Diamond Lake showing the extensive areas of forested land, modest development in houses around the lake, and some agricultural activity in the east side.

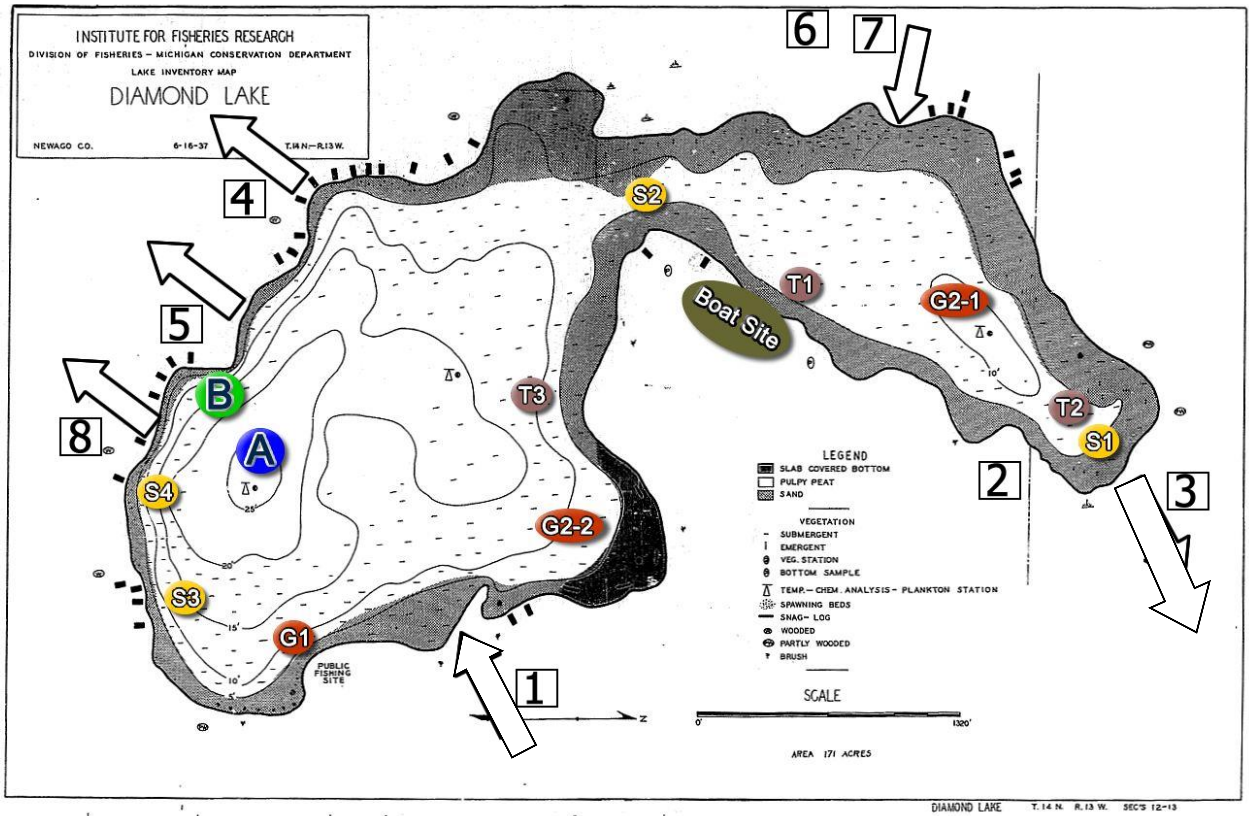

Figure 4. Map of Diamond Lake showing the water quality 26-ft deep sampling station (A - see Table 1 for description), station A and B, where zooplankton samples were collected, and fish sampling sites for seining (S1, S2, S3, S4), gill netting (G1, G2), and trap netting (T1, T2, T3). G2-1 and G2-2 were the same gill net that was moved to another location for the overnight set. Note that resident well samples from the N, S, E, and W sides of the lake were also collected and analyzed for water quality parameters. Arrows are showing direction of groundwater flow and the well numbers correspond to water quality data in Table 6. Taken from Prein and Newhof (1988).

Table 1. Location and description of sampling stations where various water quality and biological samples were collected in Diamond Lake, Newago Co., Michigan, 2021. See Fig. 4 for map of locations and Fig. 3 for google map.

Station Letter	Description/Location
A	In the southern basin, depth = 26 ft
B	In the southern basin, depth = 10 ft
S1	Seining station, north end

S2	Seining station mid lake, east 4 ft
S3	Seining station south basin west shore
S4	Seining station south basin east shore
G1	Gill netting in south basin east shore, 11.5-12.9 ft
G2-1	Gill netting in south basin east shore, 11-14 ft
G2-2	Gill netting in south basin, east shore, 11-12 ft
T1	Trap net set in north basin along the east shore, 5-7 ft
T2	Trap net set in the north basin, north shore, 4-7 ft
T3	Trap net set in south basin, north shore, 11 ft

PHYSICAL PARAMETERS

Depth

Most eutrophic lakes we work on are shallow including Diamond Lake; its deepest basin is in the southern part of the lake in about 26 ft (Fig. 4). The littoral zone is extensive and highly vegetated.

Acreage

Diamond Lake is 171 acres, is heavily forested, has modest development and some agricultural land on the east side. It has a public access site and residents are on septic systems. It has a considerable amount of sandy soil (Prein and Newhof, 1987), which allows seepage of septic effluent into the ground water probably contaminating the lake. We also worry about the safety of well water (we sampled well water and will discuss below).

Light Penetration

The Secchi disc (measure of water transparency) readings during 4 August 2021 at station A was 2.1 m (6.9 ft), which is not a particularly good reading, but it does indicate high productivity in the lake (eutrophic status). This reflects the high concentrations of nutrients measured in the lake which results in growth of algae and plants. Historical data showed that Secchi disk values ranged from 5.5 to 15 ft, so the 2021 value of 6.9 is in that range. Those values (from TMI 1987) included: 21 August 1975 – 5.5 and 8 ft, 30 March 1977 – 9 ft, 25 April 1978 – 9 ft, 11 June 87 – 15 ft, and 9 July 1987 – 10.5 ft.

Temperature/Dissolved Oxygen

Water temperature is intimately associated with the dissolved oxygen profiles in a lake. The summer profile is the one that most characterizes a lake, and the stratification impacts are very important. A lake goes through a series of changes (see introductory material-Temperature) in water temperature, from spring overturn, to summer stratification, to fall over turn, to winter conditions. During both summer and winter rapid decomposition of sediments and detritus occurs when bottom waters are fertile and can cause degraded chemical conditions on the bottom (to be discussed). Because the lake is essentially sealed off from the surface when it is stratified during summer, no dissolved oxygen can penetrate to the bottom and anoxia (no dissolved oxygen conditions- a dead zone) can result. This has implications for the aquatic organisms (fish will not go there) and chemical parameters (phosphorus is released from the sediments under anoxic conditions, which then contribute these nutrients to the lake during the fall overturn).

During early summer 2021, when we measured the temperature/oxygen profile, water temperatures were very warm at the surface at the deep basin station A (25.3 C – 77.5 F), there was a thermocline (rapid change between warm and cool water temperatures) between 4 and 6 m and little or no dissolved oxygen (0.4-0.6 mg/L) at or below 7 m (Fig. 5). This has two consequences: it effectively makes the entire water volume below 16 ft unavailable to fish and we expect the lake bottom to go anoxic later in summer, which will promote phosphorus and ammonia regeneration from bottom sediments. We measured this profile prior to maximum stratification, so we expect conditions will get much worse before summer ends. This finding indicates the lake has some fertile mud or other organic material on the bottom of the lake, which degraded the oxygen levels. Some of this material (algae and aquatic plants) was most likely generated by septic leakage into the lake. Most warm water fishes require at least 3 mg/L while cool water fish, such as northern pike and walleye require 5 mg/L. Hence these fish will be subject to the squeeze noted in Fig. 6: warm temperatures in surface water forces them downward, while no dissolved oxygen in the preferred bottom cool waters of the lake forces them into too warm surface waters. This point is important for fish management considerations.

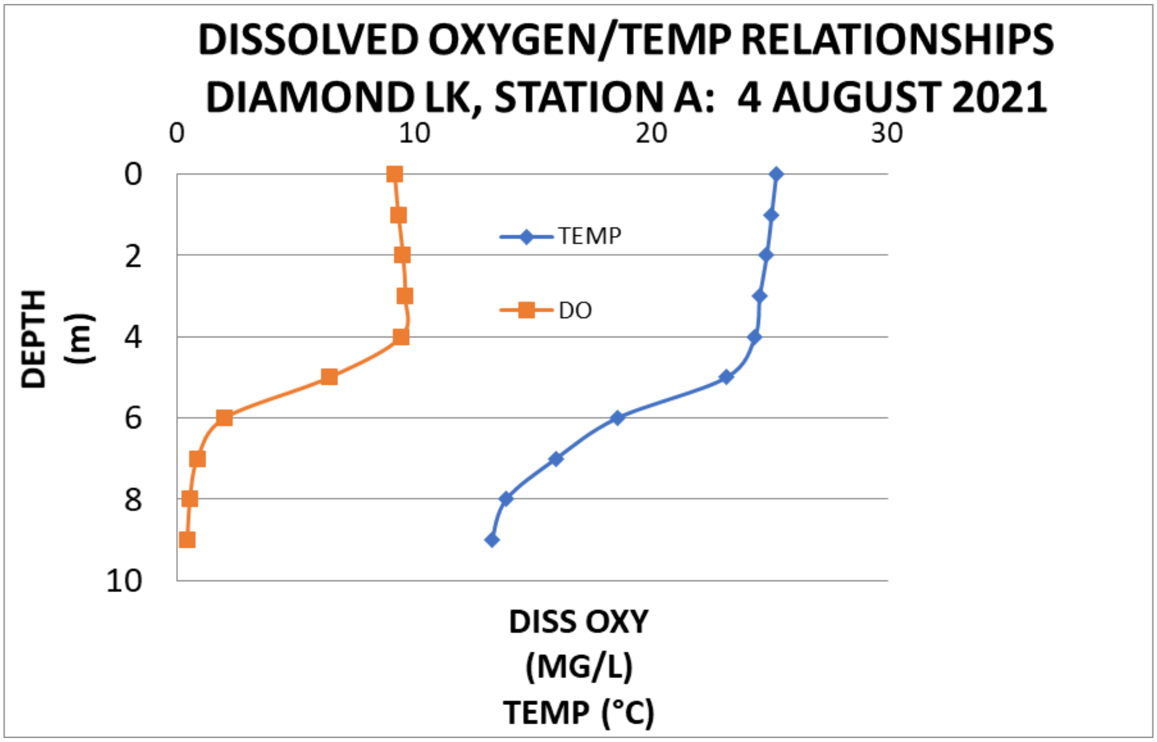

Figure 5. Dissolved oxygen-temperature relationships for Diamond Lake station A, 4 August 2021. Note depth is in m.

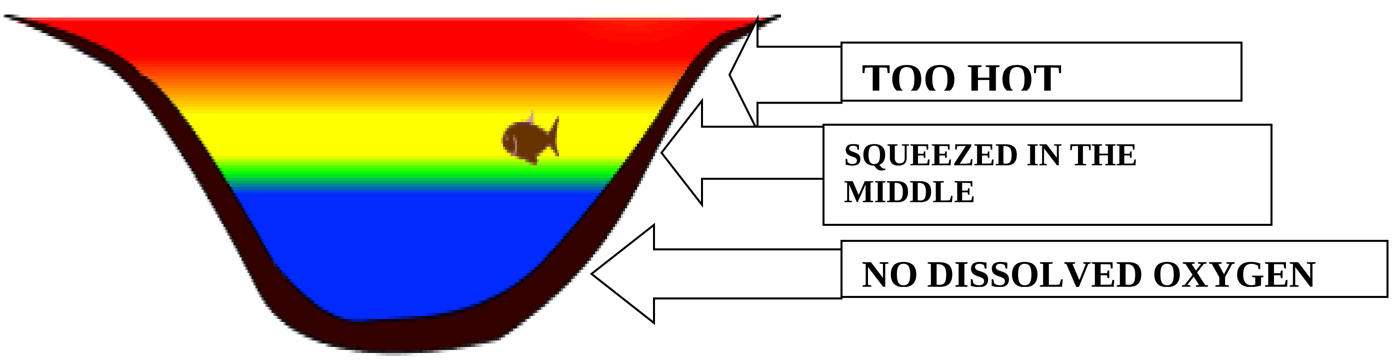

Figure 6. Depiction of the dissolved oxygen concentrations in a stratified lake, showing the surface layer (epilimnion) where warmest temperatures exist, the thermocline area where water temperatures and dissolved oxygen undergo rapid changes, and the bottom layer, where the coolest water exists, but has no or very low dissolved oxygen present. Cool water fishes, such as northern pike and walleyes are "squeezed" between these two layers and undergo thermal stress during long periods of summer stratification.

There are historical data below with which we can compare our 2021 data. During 21 August 1975 there was no dissolved oxygen below 15 ft (Fig. 7). During 11 June 1987, which is early for anoxia, there was no dissolved oxygen below about 22 ft. These data show that for the last 34 years there was probably anoxia on the bottom of the deep basin in Diamond Lake.

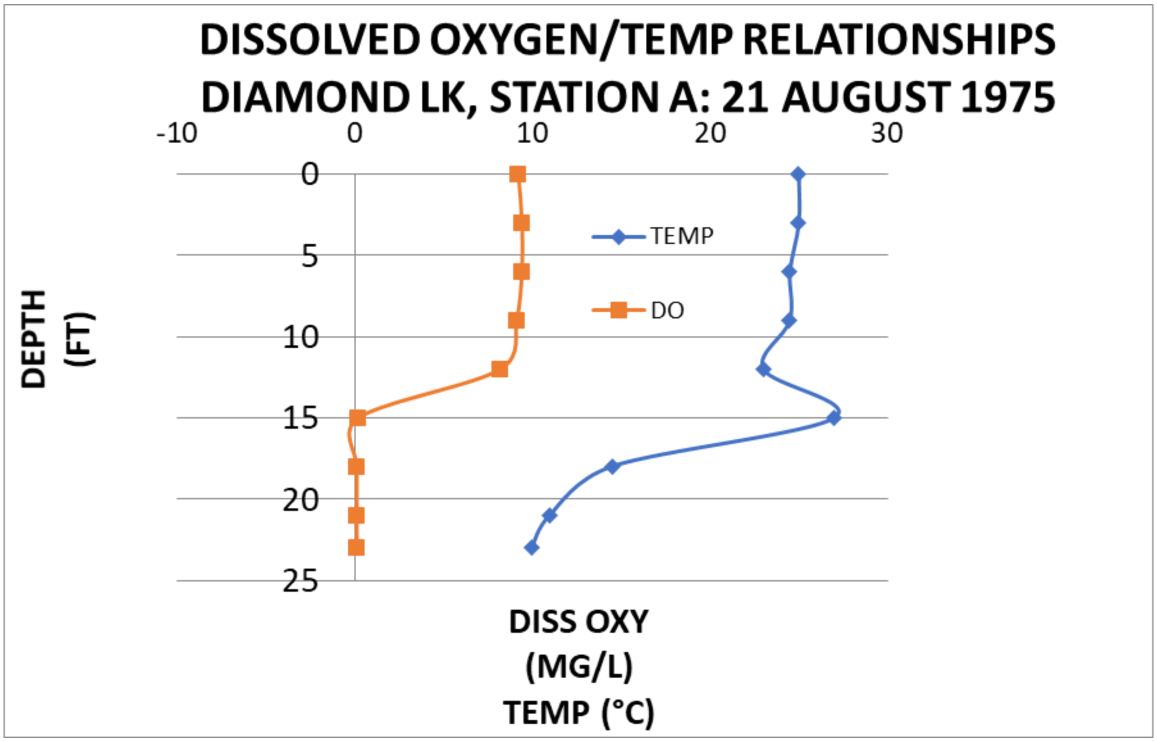

Figure 7. Dissolved oxygen-temperature relationships for Diamond Lake station A, 21 August 1975. Note depth is in ft.

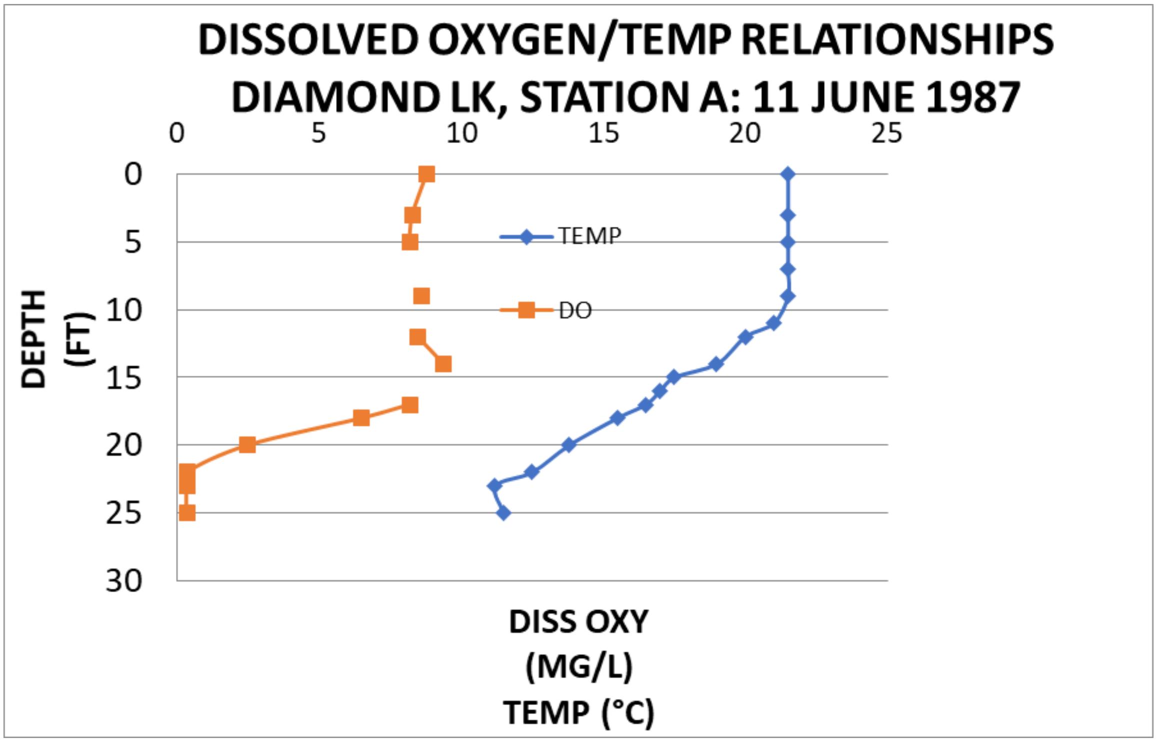

Figure 8. Dissolved oxygen-temperature relationships for Diamond Lake station A, 11 June 1987. Note depth is in ft.

CHEMICAL PARAMETERS

pH

The pH (how acid or alkaline water is) for Diamond Lake during 4 August 2021 at station A (26 ft) showed a typical pattern matching the expected situation. The pH was highest at the surface (8.59) where algal and aquatic plant growth remove carbon dioxide and increase pH, while it is lowest on the bottom (7.39) where decomposition of bottom sediments increases the CO_2 produced and reduces pH (Table 2). The very low pH of 7.39 on the bottom may reflect the very low alkalinity (34-46 mg/L – Table 3), which would not buffer the production of acidic products from decomposition of bottom sediments like it does in most Michigan lakes where alkalinity is usually much higher (hard water lakes). In addition, it needs to be noted that pH data collected by MDNR in past years (1975-1978) are also not consistent with expected pH values in most Michigan inland lakes. The pH during 21 August 1975 was 9.33 at the surface at station A, which may be the highest pH we have ever seen in an inland lake surface water. This is followed by pHs of around 6.7 at mid depth and the bottom, while the pH at another site in the north end of the lake was more reasonable – 7.8 (Table 3). During 30 March 1977, pH was much more reasonable at station A, albeit still low (7.4-7.5), while during 25 April 1978, pH was 6.4 at all three depths where pH was measured. Again, we have never seen a pH that low during all our lake studies, especially during the spring turnover period when these pHs were measured. Low alkalinity may be partially responsible for these anomalous readings since rain water is very acidic, and is probably a major source of water input to Diamond Lake. Little can be done about it, but it can help explain some findings here.

Table 2. Conductivity (uSiemens), pH, chlorides (CL), nitrates (NO3), ammonia (NH3), and soluble reactive phosphorus (SRP), and total phosphorus (TP) for station A in Diamond Lake, 4 August 2021. See Table 2, Fig. 5 for location of station A. All water quality concentrations are in mg/L.

Depth (m)	pH	COND	CL	NO3	NH3	SRP	TP
0	8.59	136	11	0.02	<0.01	<0.005	0.020
4	8.29	140	10	<0.01	<0.01	<0.005	
8	7.39	422	10	0.04	<0.01	<0.005	0.025

Table 3. Michigan Department of Natural Resources water quality data for Diamond Lake, 21 August 1975, 30 March 1977, and 25 April 1978. Data from Prien and Newhoff (1988). See Fig. 4 for station (A, G2) locations. Water quality parameter concentrations in mg/L, conductivity in micromhos, Secchi disk in feet, and Chlor A in ug/L. Bottom = 25 ft.

Parameter				
			21-Aug-75	
	A-Surface	**A- 15 FT**	**A-Bottom**	**G2-1-5 ft**
pH	9.33	6.7	6.68	7.8
Alkalinity	35	37	46	35
Hardness	48	48	52	48
Conductivity	110	110	120	105
Secchi (ft)	5.5			8
Chlor A	9.8			8.8
NO3+NO2	0.01	0.02	0.04	0.01
NH3+NH4	0.003	0.013	0.37	0.02
TP	0.008	0.009	0.018	0.014
SRP	0.001	0.001	0.002	0.001
Chloride	9.9	9.7	9	15

			30-Mar-77
	A-Surface	**A- 15 FT**	**A-Bottom**
pH	7.5	7.5	7.4
Alkalinity	37	37	38
Hardness	45	45	45
Conductivity	110	110	110
Secchi (ft)	9		
Chlor A	4.7		
NO3+NO2	0.12	0.13	0.12
NH3+NH4	0.05	0.05	0.07
TP	0.015	0.017	0.017
SRP	0.001	0.001	0.001
Chloride	7.6	7.6	7.6

			25-Apr-78
	A-Surface	**A- 15 FT**	**A-Bottom**
pH	6.4	6.4	6.4
Alkalinity	35	35	34
Hardness			
Conductivity			
Secchi (ft)	9		
Chlor A	7.4		
NO3+NO2	0.14	0.14	0.14
NH3+NH4	0.002	0.002	0.003
TP	0.012	0.012	0.012
SRP	0.001	0.001	0.001
Chloride			

Chlorides

Chloride concentrations in Diamond Lake were surprisingly low during our sampling during August 2021 and ranged from 10 to 11 mg/L (Table 2), which is a very low chloride concentration. Chloride ions are conservative ions, which mean they are not altered by biological or chemical activity; they can only change with evaporation or input of water of differing concentrations of chlorides. They can derive from septic tank effluent, road salt runoff, or can be naturally occurring. Therefore, they accumulate in a lake and give a good impression of the history of inputs of that ion, as well as co-occurring substances from runoff, such as nutrients, toxic substances, and sediment. This low a concentration indicates almost pristine conditions with no or very low suggestion of septic tank or road salt runoff getting into the lake. However, this picture is complicated when we review historical datasets. The MDNR data set (Table 3) shows that their chloride measurements during 1975 at station A (range: 9-15 mg/L) and 1977 (range: 7.6 mg/L) were close to and often lower than values measured during 2021. The largest deviation we found was in our resident well sample (Table 5) which had values of 9, 10, and an outlier of 47 mg/L from a well on the east side. This is a clear indication of contamination of the groundwater in that area with high salt concentrations, which is probably not related to road salting, but may be either high concentrations in the soil or from septic tank leakage.

Phosphorus

We are interested in phosphorus (P) because P is generally the limiting nutrient for plant growth and the level of concentrations can indicate the trophic state or amount of enrichment in the lake. Soluble reactive phosphorus (SRP) measures only that P, which is dissolved in the water, which is the form that is readily available for algal and plant growth. Total P would be all the P in the water, dissolved and that tied up in algae or other detritus. During summer, SRP values were at trace levels (<0.005 mg/L) in all depth samples from station A, because algae and aquatic plants take up all the phosphorus for growth (Table 2). Sometimes we see production of higher concentrations on the bottom in lakes with severe anoxia (no dissolved oxygen) on the bottom, but there apparently was enough oxygen to prevent any buildup of SRP in bottom waters, a good sign. Phosphorus is probably limiting algae and macrophyte growth currently in Diamond Lake. There were two other historical datasets that measured SRP that can contribute knowledge about phosphorus dynamics in Diamond Lake. The lake measurements done by MDNR (Table 3) during August 1975, March 1977, and April 1978 showed the same results as we found during 2021: the SRP was at trace levels during all these times. However, the monitoring well data collected during 1987 (Table 4) showed very high concentrations of SRP in all wells sampled near the lake with a mean of 0.090 mg/L and range of 0.047 to 0.173 mg/L during July, while the mean during October (fewer residents) was 0.021mg/L and the range was 0.007-0.028 mg/L. This is a difference in mean concentrations between these two periods of 0.069 mg/L, reflecting the high number of residents using the lake during summer and the increased input of phosphorus into the ground water from septic tank use. These high levels are fertilizer, the readily available for algal growth kind, that is seeping into the lake ground water and probably responsible for a high proportion of the algae and aquatic plant growth in your lake, assuming similar leakage of sewage is continuing today. Monitoring well no. 5 (see map, Fig. 4) which had the highest concentration (0.173 mg/L) is located on the SW corner of the lake.

Total phosphorus concentrations were measured at the surface (0.020 mg/L) and bottom (0.025 mg/L) of station A during our 4 August 2021 study and designate the lake as eutrophic (enriched), since the criteria for these designations are: oligotrophic – TP <0.010 mg/L, mesotrophic (0.10-0.20 mg/L), and eutrophic (>0.020 mg/L). Historical MDNR data (Table 3) showed TP during August 1975 ranged from 0.008 to 0.018 mg/L, with highest values on the bottom at station A. During March 1977 TP ranged from 0.015 to 0.017 mg/L and during April 1977 values were 0.012 m/L at all depths. These values categorized the lake as oligotrophic to mesotrophic, so in the intervening years the lake has shifted to mostly eutrophic, an indication of ongoing lake ageing and nutrient enrichment. The monitoring well data for TP is even more surprising than the SRP data since values were extremely elevated. The concentrations during July 1987 were: mean=0.709 mg/L, Range=0.479-1.33 mg/L and October 1987 were: mean=0.530 mg/L, Range=0.094-0.659 mg/L (Table 4). The difference between mean values between July and October, like SRP, reflect resident use of septic systems, and was 0.179 mg/L lower in late fall. These data like SRP show clearly how septic tanks are contaminating ground water with phosphorus, the key nutrient that fuels plant growth in Diamond Lake during summer.

We concluded two things from these data: first, P is limiting in the lake in surface waters during summer and will stop or slow growth of algae and plants until more phosphorus enters the lake (limiting nutrient concept). Nutrients are entering the lake during the summer critical period in the groundwater from septic systems, from fertilization of lawns, and from the air. Another way for that to happen is excessive water skiing or wave boats on the lake, since the connection between the north and south basin goes through a narrow isthmus, putting the boats close to shore, which can stir up bottom sediments, resulting in the release of phosphorus from groundwater and flocculant sediments and promotion of more algal and macrophyte growth. Second, it confirms the finding that the bottom waters in the station A basin are inhospitable to fish during summer stratification because of the low dissolved oxygen there. Decomposition of sediments probably accelerates during late summer when we assume the lake bottom waters go anoxic. This will result in an accumulation of nutrients (phosphorus and ammonia) on the bottom called internal loading and mixing these into the lake during turnover periods in spring and fall every year. One way to reduce the effect of internal loading is to treat the sediments and water with alum, but this is expensive and will only address one of the nutrient sources in Diamond Lake. Residents need to do all they can to prevent nutrients from entering the lake to preserve the current water quality they do enjoy. This would especially include pumping septic tanks every 2 yr. or every year if occupation is over a long period and many people are visiting. Lawn fertilization should be avoided, or at least only nitrogen-based fertilizer used. See Appendix 1 for more suggestions.

Table 4. Monitoring well data from around Diamond Lake from 9 July 1987 and 30 October 1987. Well no. 1-5 and 7-8 were located near the lake, while well no. 6 was 2,250 ft west from lake to act as a control (see Fig. 4 for site locations and groundwater flow arrows). Well data, which excluded well no. 6 – the control, for Means, Ranges, and Differences (difference in chemical parameters between times when residences on septic systems were in high use (July) vs. times (October) when use was much less) are also provided. SRP=soluble reactive phosphorus, TP=total phosphorus, NH3=ammonia, and NO3=nitrate. Data from Prein and Newhof (1988) - Table 3). All concentrations in mg/L.

Well no.	SRP		TP		NH3		NO3	
	July	October	July	October	July	October	July	October
1	0.087	ND	0.54	0.421	2.1	1.35	1.55	1.55
2	0.053	ND	0.479	ND	1.6	ND	8.02	
3	0.047	0.028	1.05	1.65	1.6	0.68	8.75	0.5
4	0.087	0.007	0.182	0.094	0.4	0.42	0.87	0.29
5	0.173	0.042	1.33	0.157	0.5	0.5	0.12	0.3
6	0.047	ND	0.119	0.063	0.5	0.19	0.12	0.11
7	0.093	0.014	0.266	0.196	0.4	0.82	0.2	0.58
8	0.093	0.014	1.117	0.659	1.1	0.51	1.34	0.32

Mean*	0.090	0.021	0.709	0.530	1.1	0.713	2.98	0.59
Difference*		0.069		0.179		0.387		2.39
Range*	.047-.173	.007-.028	.479-1.33	.094-.659	.40-1.6	.42-1.35	.12-8.75	.32-1.55

Nitrates

Nitrate is very important since it too is a critical plant nutrient as well as P; however, blue-green algae can generate their own nitrogen, favoring them when nitrate concentrations are depleted, usually during fall. Nitrates in Diamond Lake during 4 August 2021 ranged from trace in surface waters to 0.04 mg/L on the bottom (Table 2). These are very low values. We usually see trace concentrations of nitrates in the surface waters as we observed with SRP, so it appears that nitrates are also low in concentrations in Diamond Lake during summer. The MDNR dataset for the lake during August 1975 had nitrates that ranged from 0.01-0.04, from March 1977 that ranged from 0.12-0.13, and April 1977 that were 0.14 mg/L, all values similar to or slightly larger than concentrations we measured during 2021. The monitoring well data from 1987 were also illuminating. The July dataset on ground water had a range of 0.12 to a dangerous 8.75 mg/L nitrates- 10 mg/L nitrates in drinking water can cause a condition termed methemoglobinemia (blue baby disease). The mean concentration was 2.98 mg/L in these wells, highly indicative of pollution from septic systems in a mostly forested area; note that the control site 6 well water (see Fig. 4) away from septic fields had around 0.11-0.12 mg/L during both July and October, which is in the range we found in the lake proper. This was certainly a problem back in 1987 and we saw little that has changed during 2021 and would expect similar results today. Stations 2 and 3 had 8.02-8.75 mg/L nitrates, the highest of all values measured; these stations are on the north end of the lake, which only has a county park, and the rest is heavily forested. Never-the-less this area represents one of the biggest threats to polluting ground water around the lake. The second-largest concentration was 1.55 mg/L at station 1 (see Fig. 4) which is on the east side of the lake, near where we found an elevated concentration of chlorides in a resident well sample. Obviously the ground water here contains large amounts of nitrates, probably derived from septic tanks, since this area is dense with cabins and houses. Station 8 also had elevated nitrate concentrations and this station is on the SW side of the lake which is also an area of many cabins and houses.

Ammonia

Ammonia is also a plant nutrient, but it can be toxic to fish in high concentrations. Usually in the eutrophic lakes we sample, especially those with anoxic bottom waters, large amounts of ammonia are produced on the bottom during summer stratification. To Diamond Lake’s benefit, we surprisingly during 4 August 2021 found low (trace concentrations) of ammonia throughout the water column. Apparently there is still enough dissolved oxygen on the bottom during early August to prevent the lake from going anoxic and prevented the production of large amounts of ammonia (Table 2). The historical MDNR dataset of 21 August 1975 showed the normal pattern of ammonia distribution with depth, with 0.002-0.003 in the two surface samples, 0.013 in the mid depth sample, and 0.370 mg/L in the bottom sample (Table 3). The May 1977 and April 1978 samples reflected mixed water conditions and contained low concentrations of ammonia (0.002-0.070 mg/L). We usually see low ammonia concentrations in surface waters because ammonia is converted to nitrates in the presence of dissolved oxygen and plants readily take up ammonia for plant growth. The monitoring well data of 1987 confirmed the earlier findings of high concentrations of chemicals (SRP, TP, nitrates) associated with septic tank leakage into ground water. Ammonia is created under anaerobic conditions in septic tanks and concentrations during July 1987 in monitoring wells around Diamond Lake had a mean concentration of 1.1 mg/L with a range of 0.4-1.6 mg/L, which are extremely high concentrations of an important nutrient that is usually in low concentrations in inland lakes because of take up by aquatic plants. During October, the mean concentration declined from July levels of 1.1 mg/L to 0.7 mg/L, a difference of 0.4 mg/L, while the range decreased to 0.42-1.35 (Table 4), showing the effect that increased residence during summer had on increasing ammonia concentrations in the ground water. There were four monitoring well stations with high ammonia levels. Station 1 had 2.1 mg/L and is located on the east side where high concentrations of chlorides were measured. Stations 2 and 3, which also had high nitrate concentrations, are on the north end of the lake, where there are no houses. Station 8 is located on the SW side where high nitrates were also documented; there are many residences there.

Conductivity

Conductivity is a measure of the ability of water to conduct current and is proportional to the dissolved solutes present. During our early summer survey during 2021, conductivity stratified at 136 uS at the surface, 140 uS at mid depth, but a large value of 422 uS was measured on the bottom (Table 2). Surface values are very low values, compared with other lakes, partially explained by the low chlorides, low alkalinity, and lack of anoxia on the bottom creating products of decomposition. However, the 4-fold increase to 422 uS on the bottom is difficult to explain. One possibility is the encroachment of that nutrient-laden groundwater documented from the monitoring well data (Table 4). It would enter the lake and being cold would sink or stay on the bottom and because the lake is stratified, once it flowed downslope to the deep basin, would stay there and accumulate. Support for this hypothesis was low if one considers that MDNR data from 21 August 1975 showed that conductivity was 110 uS on the surface and only 120 uS on the bottom. One other possibility is that during the spring turnover the groundwater that accumulated in the lake would be mixed throughout the lake. That might provide a high conductivity value throughout the lake. Then after the lake stratified, rainwater could enter and dilute the epilimnion (surface) waters and dilute the conductivity there while leaving a higher value on the bottom. However, we have MDNR data from 30 March 1977 (turnover period) which provided conductivity measurements and they were only 110 uS from surface to bottom (Table MDNR). One conclusion from these data is that conductivity in surface waters have only increased slightly from 110 uS (data from August 1975 and March 1977) to 136-140 uS in 2021. A good finding since it supports little runoff or groundwater flow entering the lake and accumulating over time. Obviously there are high concentrations of some solute (perhaps sulfates?) that we are not measuring but are contributing to high conductivity on the bottom of Diamond Lake.

Chlorophyll A

Chlorophyll A is a surrogate for measuring algae in the water. It was measured by MDNR and was 8.8-9.8 ug/L during August 1975, 4.7 ug/L during March 1977, and 7.4 ug/L during April 1978 (Table 3). Criteria for Chlor A are: oligotrophic – values <2.2 ug/L, mesotrophic – 2.2-6 ug/L, and eutrophic - >6 ug/L making two of the measurements eutrophic and one mesotrophic. The value of 9.8 ug/L during summer 1975 is a high value and indicates that there were some dense algal blooms during that period and probably other summers when conditions were optimal. The Prein and Newhof (1988) report notes that blue-green algae (*Microcystsis* spp.) has been a problem in the past. Our algae data collected on 4 August 2021 (see discussion in Algae section) showed that the algae were mostly cyanobacteria (blue-green algae) and green algae, but the blue-green algae were not nuisance forms nor were they at nuisance levels. Part of the reason for this is that it was early August and some of the more nuisance blue-green blooms occur later in the summer.

Resident well samples

To determine if there are problems with groundwater input of nutrients, we collected three samples of water from wells on the lake before they ran through water softeners. These came from resident wells on the W, S, and E sides of the lake. Data from these samples (Table 5) showed that a sample from the south had pH of 8.07 and conductivity of 550 uS, considerably higher than the lake surface value of 136 uS. Recall that conductivity is merely the ability of water to conduct electricity or high concentrations of negative ions, such as chlorides or sulfates. The western sample had pH of 7.89 and conductivity of 445 uS, which is also much higher than surface values in the lake. The last site east had pH of 7.5 but conductivity was very high at 909 uS. This value was the highest of all values. Chlorides have been low in the lake during 2021 (range 10-11 mg/L – Table 2), during 1975 (range 9-15 mg/L -Table 3), and 1977 (7.6 mg/L – Table 3). Low values were also found (9-10 mg/L) in two of the well water samples but the third from the eastern side of the lake contained the highest value measured way above all other measurements, suggesting this well is contaminated with chloride-laden groundwater. Nitrates were also high at this well, reaching a surprising 1.54 mg/L, which also suggests contamination from either septic tank effluent or agricultural contamination of the groundwater. An examination of the area (see Fig. 4) shows that there is a concentration of houses in that eastern sector and in addition there is a large expanse of agricultural land immediately adjacent to the houses. A lot of the soils surrounding Diamond Lake are sand and groundwater probably flows toward the lake (Fig. 4 – see station 1 ground water flow arrow), so contamination of groundwater from agricultural sources is certainly a distinct possibility. Obviously, some additional well testing should occur in this area for water quality and bacterial presence.

Table 5. Water quality parameters (in mg/L) for three wells from the W (line 1), S (line 2), and E (line 3) sides of the lake.

pH	COND	CL	NO3	NH3	SRP
8.07	550	10	0.05	<0.01	<0.005
7.89	445	9	0.03	0.69	<0.005
7.5	909	47	1.54	<0.01	<0.005

BIOLOGICAL PARAMETERS

Algae

The algae consist of many biological groups of organisms that do not represent a single lineage on the evolutionary tree of life, but are linked by function—freshwater algae are generally small, photosynthetic, and do not have organized tissues like higher plants (flowers and trees). From an ecological perspective the algae are critical to the functioning of the earth (algae account for about 50% of the photosynthesis—hence half the oxygen we breathe) and form the base of the food web in most lake and river systems. The different algal groups are separated based on their cell structure (bacterial type or prokaryotes—the Cyanobacteria; or true cells or eukaryotes—the rest of the algal groups), storage products (starch, lipids, proteins), pigments, cell wall or membrane structure, cellular organization, and life history types. The major groups of algae that we encountered at the deep sampling station in Diamond Lake in August 2021 (Table 6) included:

Cyanobacteria—the blue-green algae are photosynthetic bacteria and are common in lakes, streams, and even wet soils. The blue-green algae are well adapted to living in lakes that have a wide range of nutrients. They have the ability to adjust their buoyancy in the water column (get light and nutrients as needed), they often grow in large colonies that are not preferred food by zooplankton, and they are most notorious for their production of toxins under certain growth conditions (e.g., cyanobacteria in Lake Erie caused the shutdown of the Toledo water supply in 2015). Cyanobacteria made up nearly 27% of Diamond's deep station algal biomass in August 2021. The algae was mostly small-celled, non-nuisance forms (e.g., *Aphanocapsa, Aphanothece*, Fig. 9A).

Green algae or Chlorophytes—the green algae range in size from single cells to large filamentous forms that are common on rocks and logs along the shorelines of many lakes. The green algae are often common in mid-summer in deep water, and can also produce nuisance accumulations in the spring following ice-out. In Diamond Lake, a filamentous green alga called

Mougeotia was common composing 72% of the algal biomass at the deep water quality station A in August.

The late summer algal flora of Diamond Lake (sampled 4 August 2021) was dominated by green algae and secondarily by cyanobacteria; Fig. 9B and 9C). Algal biomass in August 2021 was about 270,000 μm^3/mL at the deep station (for comparison, really nasty lakes often have 2-5 million μm^3/mL biomass of algae) which included over 13,800 cells per ml of mostly cyanobacteria by cell number but dominated in biomass by the green alga *Mougeotia*. Other cyanobacteria were present at lower abundance that could be of concern, particularly a *Dolichospermum* species. This cyanobacterium can produce cyanotoxins under some environmental conditions and sometimes increases in abundance in the fall. A good rule of thumb is when water clarity is low and there is a blue-green hue to the water, lake users should be cautious. They may experience skin sensitivity, should avoid ingesting any water, and should not allow pets in the water.

Table 6. Predominant (>5% of total algal biovolume, μm^3/mL) algal species or genera in Diamond Lake, 4 August 2021. Abbreviations of algal groups are: CY = cyanobacteria, BA = diatoms, GR = greens, DI = dinoflagellates, CH = chrysophytes, CR = cryptomonads, EU = euglenoids.

Diamond Lake	**Dominant algae**
August 2021	*Aphanocapsa* (CY), *Aphanothece* (CY), and *Mougeotia* (GR).

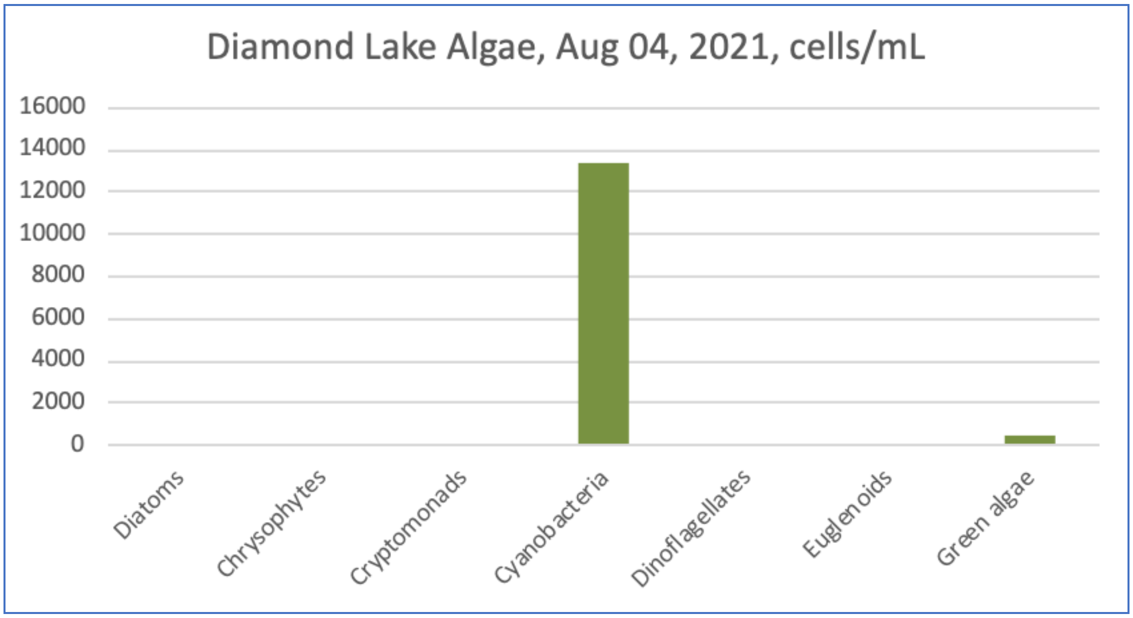

Figure 9A. Abundance of algae (cells/mL) by algal group for Diamond Lake, deep station, 4 August 2021.

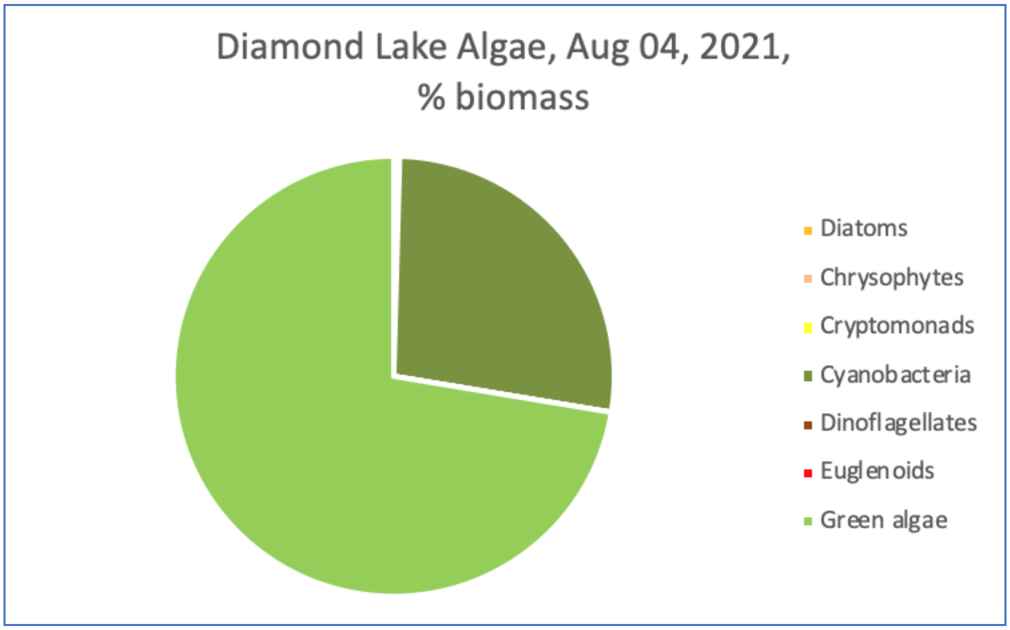

Figure 9B. Proportion of algal biovolume or biomass by algal group for Diamond Lake, deep station, 4 August 2021.

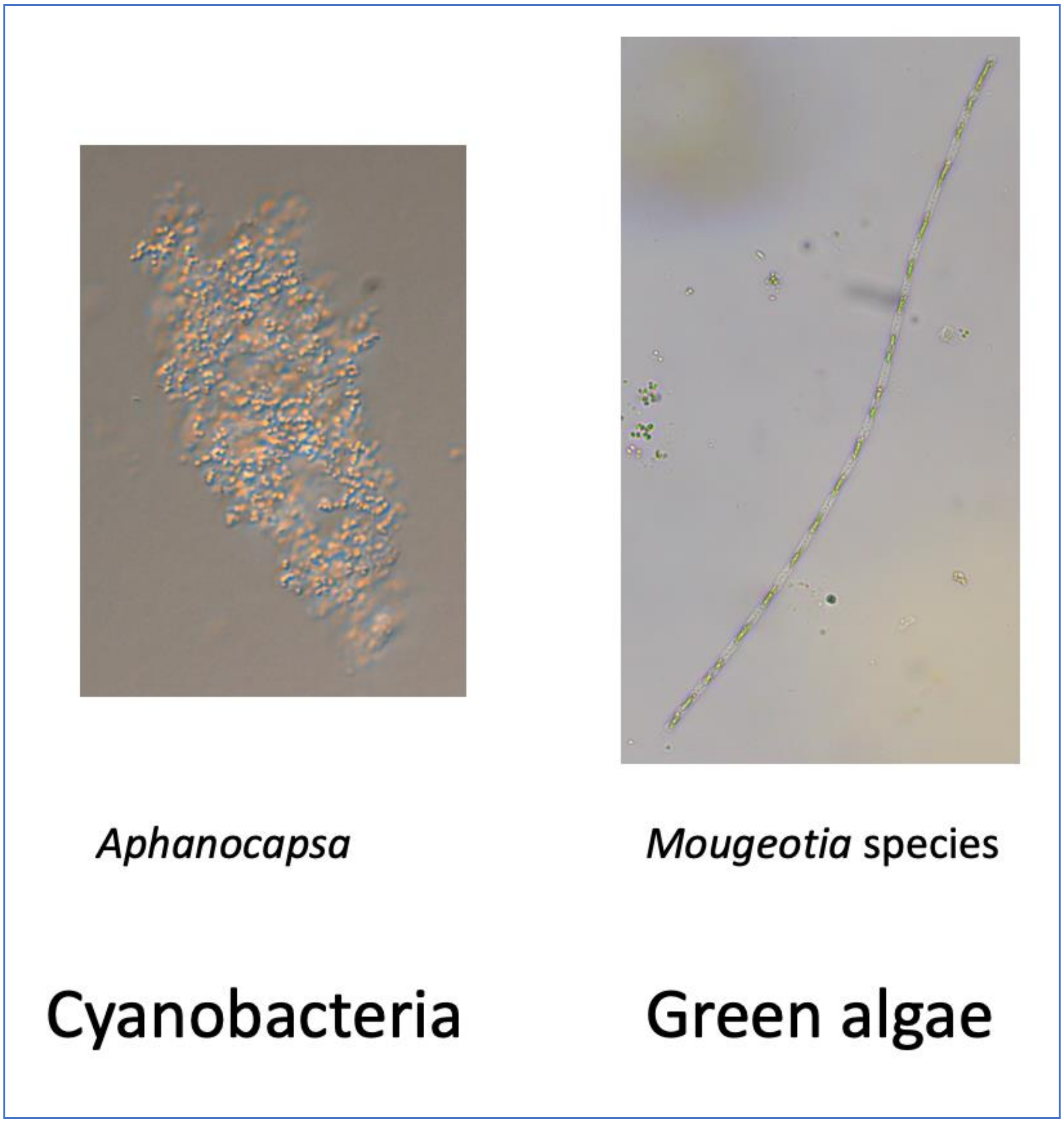

Figure 9C. Predominant algae in Diamond Lake were the cyanobacteria including small-celled non-nuisance forms (*Aphanocapsa*), and especially a green alga, a probable *Mougeotia* species.

Lastly, we wanted to ensure that residents be on the lookout for an exotic species, called starry stonewort (Picture 2), which has been observed in many Michigan lakes in the past few years. Note this species is an alga, and is a very destructive plant. It looks a lot like *Chara*, another green alga, but is somewhat different. If seen, it should be reported to the board and follow up studies done to confirm identification and begin treatment before it reaches nuisance levels.

Picture 4. Starry stonewort, an alga.

Aquatic Macrophytes

Diamond Lake was populated with many species of macrophytes based on observations during the 2021 study. They are a very important component of the lake ecosystem serving several functions. They are shelter and nurseries for young fish, they are spawning substrates for some species (e.g., minnows), they produce many insects which are important food for fishes, and help to retard wave action from re-suspending sediments from currents generated by boat activities. Those aquatic plants (not an exclusive list) include one invasive species: Eurasian milfoil *(Myriophyllum spicatum)* and several native species including: lily pads *Nymphaea*, cattails *Typha*, bulrushes *Scirpus*, eel grass *Valliseneria*, and thin-leafed naiads N*aijas* spp. We also found the alga *Chara*, which looks a lot like an aquatic macrophyte. The previous study in the lake done by TMI (1987) noted the presence of several species of pondweeds *Potamogeton* spp., coontail *Ceratophyllum*, and bladderwort *Utricularia*, with the most common alga being the blue-green alga *Microcystsis* (the alga that shut down the Toledo water intake in Lake Erie). *Microcystsis* is a bloom-producer and can form toxins under the right conditions. Macrophytes, especially Eurasian milfoil, have been a problem since the 1980s and have been treated chemically to reduce their numbers up to the present time.

Zooplankton

Zooplankters are small invertebrates present in most lakes and ponds (See Picture 3 for an example of a copepod). They are critical connectors between plants (they eat algae) and fish, since they are important as food for larval fish and other small fishes in the lake and are indicators of the amount of predation that fish exert on these organisms. Zooplankton we collected from the deep basin (26 ft) and from a shallow station (10 ft) (Table 7) was comprised of 13 species, indicating that there is a diverse group of these organisms in Diamond Lake. The dominant species included: *Daphnia* (see Picture 4), *Mesocyclops, Diaptomus,* and *Diaphanosoma*. First, one of the things we look for is the presence of the large species of zooplankton: *Daphnia* especially. *Daphnia* is slow, energy-rich, large, and an easy target for fishes. We found large quantities of these large zooplankters present in the lake at deep basin station A (20.3% by number), while there were *Daphnia* in lesser percentages (almost half) in shallow water (11%). It indicates two conclusions: first, that at least during summer fish predation is not so intense as we sometimes find, when no *Daphnia* are present, being eaten by planktivores (zooplankton eaters), such as small bluegills, yellow perch, and black crappies, which were eating zooplankton in Diamond Lake. Second, there were almost twice as many out deep compared with the shallow station, which is related to the near anoxia or hypoxia (no to low dissolved oxygen) present in the deep basin and more fish predation nearshore compared with offshore. Zooplankton perform a diel, vertical migration, staying in the oxygen - poor water where fish cannot go during the day and rising to surface waters during the night to feed on algae. Hence, there are more out deep than shallow where there is no anoxia refuge. *Bosmina* and *Eubosmina* are two other important groups (cladocerans) that are often eaten by planktivores; they composed 0-8% of the zooplankton at stations A (deep) and B (shallow).

Second, *Daphnia* is more efficient than copepods (a smaller, faster group of zooplankton – *Diaptomus and Diaphanosoma* were examples that were abundant at both stations – 6.6-25.7%) at filtering algae from the water column. Since *Daphnia* were moderately abundant, they are helping to control algae in surface waters. Copepods are also not fed on as often by fish since they are faster, unless other large zooplankters are rare.

Table 7. A listing of the abundance (% composition based on counting a random sample of 100 or more organisms) of zooplankton species (see Picture 3-4) collected from station A (26 ft) and station B (10 ft) in Diamond Lake, 4-5 August 2021 (see Fig. 5 for station locations).

	DIAMOND - A		DIAMOND - B	
	NO.	%	NO.	%
Tropocyclops prasinus ♂	2	0.7		
Mesocyclops Imm.	26	9.0	7	6.4
Mesocyclops edax ♂	1	0.3		
Mesocyclops edax ♀	11	3.8	5	4.6
Diaptomus Imm.	67	23.1	22	20.2
Diaptomus ashlandi ♂	19	6.6	28	25.7

Diaptomus ashlandi ♀	41	14.1	23	21.1
Epischura lacustris ♂	1	0.3		
Epischura lacustris ♀	1	0.3		
Bosmina longirostris	8	2.8	2	1.8
Daphnia Spp.	59	20.3	12	11.0
Eubosmina coregoni	2	0.7		
Diaphanasoma spp.	52	17.9	10	9.2
TOTAL	290	100	109	100.0

Picture 3. A copepod (zooplankter).

Picture 4. *Daphnia*, a large zooplankter, adept at eating algae.

Fish

Fish Species Diversity

We collected fish using three trap nets (stations T1, T2, T3) (Fig. 4, see Picture 5) with some of the resulting fish shown in Picture 6. A 50-ft seine (stations S1, S2, S3, S4 – Fig. 4, Picture 6), and two gill nets (shown as stations G1 and G2 – Fig. 4, Picture 7) were also deployed in the lake. The nets were used during the daytime on 4 August 2021 (see Table 8 for times); the gill net G2 was picked up and reset overnight, while the trap nets were left overnight along with gill net G1. Seining with a 50-ft seine was done at four sites on the lake in different habitats. Most fish were released; we kept enough for an adequate sample for ageing and diet analyses. We never want to kill too many fish, especially top predators, as they are so important to fish community balance in a lake. We could have used a few more large fish (especially largemouth bass), but the ones we did catch provided a good sample for some basic information on the lake.

The lake has a low diversity of fish species based on the number of species we collected (Table 8, 9). We collected 10 species in our sampling efforts in August 2021 (Table 2) which includes northern pike *Esox lucius* which were reported to us as being in the lake, but we caught none. There appears to be large numbers of largemouth bass, which are very efficient predators, probably reducing the number of species that would be in the lake with their predatory efforts. In addition, there are five other important top predators in the lake: northern pike, black crappie, yellow perch when they are large, brown bullhead, and yellow bullhead. Our sampling also reflected a dearth of larger yellow perch (largest one caught was 4.4 in) which would also be expected with the large population of largemouth bass and the few northern pike in the lake.

In addition to a moderate suite of top predators, the lake also contains a good population of bluegills and black crappies. A few pumpkinseeds were also documented. As noted, yellow perch sizes appear to be truncated, but there were some young of the year (YOY) indicating some reproduction, but few yellow perch appear to be making it to larger sizes. There is little that can be done about that when predation is the probable cause. There were also two species of minnows captured that appeared to be uncommon in the lake: bluntnose and spotfin shiners. Overall, we expected to collect a larger number of fishes, more species, and larger sizes of top predators. Part of the reason for this was how hot the summer of 2021 was. This may have concentrated the fishes in areas where we did not sample, since we had reports of good catches of largemouth bass and other predators on the lake.

It appears that there is adequate spawning substrate for yellow perch and largemouth bass (sandy, gravel areas) and a diversity of habitats that support the other species of sunfish, minnows, and bullheads. Northern pike are present in the lake, but we caught none. Three factors probably do not act in their favor. First, there are no inlets our outlets where spawners could go and reproduce, so they will be limited to shoreline spawning which is not as productive. Second, the lake is not favorable for cool-water species, since they would be stressed during summer stratification when there is hot water at the surface and no dissolved oxygen on the bottom in the deep basins where they would go for optimal conditions (see fish squeeze – Fig. 6).

Picture 5. One of the trap nets used in (see Fig. 5, Table 1) Diamond Lake, 4-5 August 2021.

Picture 6. Deployment of the 50-ft seine in the near shore zone.

Picture 7. Experimental gill net with fish being brought into the boat.

Table 8. Date, time, GPS, and depth of stations where various gear were deployed on Diamond Lake, Douglas County, MI, 4-5 August 2021. T = trap net, S = seine, G=gill net. See Table 9 for definition of fish codes. ZZ=no fish caught, zoop=zooplankton. See Fig. 4 for station locations.

STA	TIME START	TIME END	DEPTH (FT)	FISH SPECIES CAUGHT
A	4-Aug	4-Aug	26	WATER QUALITY SAMPLE, ALGAE, ZOOP
T1	4-Aug	5-Aug		
	1535	1010	5-7	ZZ
T2	4-Aug	5-Aug		
	1550	1050	4.5-7	1 BG
T3	4-Aug	5-Aug		
	1605	1000	11	1 MAP TURTLE, 1 LB
S1	5-Aug	5-Aug		
	1630	1650	4	HY, BG,LB,PS
S2	5-Aug	5-Aug		
	1720-	1740	4	YP, PS, BM, BG
S3	5-Aug	5-Aug		

	1745	1800	4	BG, PS, YP ,BM, LB
S4	5-Aug	5-Aug		
	1810	1840	4	SF, BG, LB, YP
G1-1	4-Aug	4-Aug		
	1450	2042	11.5-12.9	1 BC, 3 BG
G1-2	4-Aug	5-Aug		
	2055	955	11.5-12.9	1 BG
G2-1	4-Aug	4-Aug		
	1505	2020	14-Nov	2 LB, 2 BG
G2-2*	4-Aug	5-Aug		
	2040	950	11-12	3 BN, 2 YB

*RESET IN DIFFERENT SITE

Table 9. List of 10 fish species collected or deemed present P) in Diamond Lake, 4-5 August 2021. A=ABUNDANT, C=COMMON, R=RARE, P=present based on fisher's reports.

Fish Code	**Taxon**	**Scientific Name**	**Abundance**
BN	BROWN BULLHEAD	*Ameiurus nebulosus*	R-C
BC	BLACK CRAPPIE	*Pomoxis nigromaculata*	R-C
SF	SPOTFIN SHINER	*Cyprinella spiloptera*	R
YP	YELLOW PERCH	*Perca flavescens*	R
BG	BLUEGILL	*Lepomis macrochirus*	A
YB	YELLOW BULLHEAD	*Ameiurus natalis*	C
LB	LARGEMOUTH BASS	*Micropterus salmoides*	C
NP	NORTHERN PIKE	*Esox lucius*	P
PS	PUMPKINSEED	*Lepomis gibbosus*	C
BM	BLUNTNOSE MINNOW	*Pimephales notatus*	R
HY	HYBRID SUNFISH	GREEN X BLUEGILL CROSS	R

Fish Diets

The diet of small (1-3 in) bluegills was zooplankton, insect larvae (chironomids), and isopods (invertebrates that look like pill bugs) (Table 10). As we discussed we sample zooplankton in the lake to determine if there is stunting, since too many small fish can depress zooplankton, typically exemplified by the abundance of *Daphnia*. We found that *Daphnia* composed about 11% of the population in shallow water, while it was 20% in deeper water where we expect fish predation to be less. Hence, it appears we got validation, since bluegills in shallow water were feeding on zooplankton and presumably reducing their abundance in the near shore zone. However, 10-20% is still a good number of *Daphnia* to both provide food for prey fish and to eat algae reducing them and maintaining good water clarity. Fish from 3.3 to 6.4 in were mostly insectivorous, eating mayflies (Baetidae), chironomids, caddisflies, and dragonflies. They were also eating several other organisms including: crayfish (unusual), zooplankton, snails, and fairy shrimp *Hyalella*. This is a diverse supply of prey for this species, and we expect their populations are doing well in the lake. It was unfortunate that we did not catch any large individuals, but it was part of the problem we noted above that we did not catch the number and sizes of fishes we expected. The large bluegill can move offshore during summer and may have been concentrated in parts of the lake we did not sample.

Table 10. Listing of the species collected, length, weight, sex, and diet information for fishes from Diamond Lake, Newaygo County, MI 4-5 August 2021. NA = not available, ZOOP = zooplankton, M = male, F= female, 1= poorly developed gonads. I = immature, MT = empty stomach, CHIR = Chironomidae, MT = empty stomach, XX = unknown. See Table 6 for a definition of fish species codes.

SPECIES	LEN (IN)	WT (OZ)	DIET
	BLACK CRAPPIE		
BC	4.4	0.2	ZOOPLANKTON
	BLUEGILL		
BG	1.0		
BG	1.2		
BG	1.2		
BG	1.2		
BG	1.9	0.1	
BG	2.1	0.1	
BG	2.4	0.1	
BG	2.5	0.1	ZOOPLANKTON
BG	2.7	0.1	3 CHIRONOMIDS,WATER MITES
BG	2.8	0.1	ZOOPLANKTON
BG	2.8	0.1	MT
BG	2.8	0.1	
BG	2.8	0.1	MT
BG	2.9	0.1	MT
BG	3.0	0.1	ZOOPLANKTON, ISOPODS
BG	3.3	0.1	MT
BG	3.4	0.1	8 BAETIDAE (MAYFLIES)

BG	4.0	0.1	CHIRONOMID, CADDISFLIS
BG	4.8	0.2	ZOOPLANKTON
BG	4.8	0.2	DRAGONFLY, CHIRONOMIDS, 3 BAETIDAE
BG	5.5	0.2	CHIRONOMIDS, DRAGONFLY
BG	5.5	0.2	SNAILS, CHIRONOMIDS, INSECT PARTS, PLANTS
BG	5.6	0.2	INSECT PARTS, PLANTS, SNAIL
BG	5.7	0.2	CHIRONOMIDS, INSECT PARTS,PLANTS
BG	5.7	0.2	DRAGONFLY
BG	5.8	0.2	DRAGONFLY, TERRESTRIAL FLY,INSECT PARTS
BG	6.0	0.2	DAMSELFLY, HYALELLA, 1 CHIRONOMID, 3 BAETIDAE (MAYFLIES)
BG	6.1	0.2	DRAGONFLY, INSECT PARTS, PLANTS, SNAIL
BG	6.3	0.2	CHIRONOMIDS, DRAGONFLIES, CADDISFLIES
BG	6.3	0.2	CADDISFLY, CRAYFISH, INSECT PARTS, SNAILS
BG	6.4	0.2	DRAGONFLY, INSECT PARTS
	BLUNTNOSE MINNOW		
BM	1.1		
BM	1.7	0.1	
	BROWN BULLHEAD		
BN	10.7	0.4	MT
BN	10.8	0.4	CRAYFISH, UNKNOWN FISH 75 MM
BN	11.3	0.4	MT
	HYBRID SUNFISH		
HY	5.1	0.2	2 CRAYFISH
HY	5.2	0.2	CRAYFSH
	LARGEMOUTH BASS		
LB	1.6	0.1	
LB	1.6	0.1	
LB	1.8	0.1	
LB	1.9	0.1	
LB	1.9	0.1	
LB	1.9	0.1	
LB	1.9	0.1	INSECT PARTS
LB	1.9	0.1	
LB	1.9	0.1	
LB	1.9	0.1	
LB	2.0	0.1	MT
LB	3.1	0.1	MT
LB	3.1	0.1	XX FISH

LB	3.1	0.1	MT
LB	3.2	0.1	MT
LB	3.3	0.1	
LB	3.4	0.1	MT
LB	3.5	0.1	MT
LB	3.5	0.1	MT
LB	3.7	0.1	DRAGONFLY
LB	3.7	0.1	DRAGONFLY
LB	4.2	0.1	XX FISH
LB	4.4	0.2	XX FISH
LB	4.4	0.2	YP
LB	4.8	0.2	DRAGONFLY, XX FISH
LB	5.4	0.2	XX FISH
LB	6.0	0.2	CRAYFISH, XX FISH
LB	6.2	0.2	INSECT PARTS
LB	8.9	0.3	YP 81 MM
LB	9.9	0.4	BG 54 MM
LB	10.9	0.4	
	PUMPKINSEED		
PS	4.0	0.1	MT
PS	4.1	0.1	INSECT PARTS
PS	4.6	0.2	MT
PS	5.0	0.2	MT
PS	5.2	0.2	PLANTS
PS	5.2	0.2	SNAILS
PS	5.6	0.2	SNAILS, HYALELLA, CADDISFLIES, DRAGONFLIES
PS	5.9	0.2	CRAYFISH, INSECT PARTS
PS	5.9	0.2	MT
PS	6.1	0.2	SNAIL, *GRYAULUS*
PS	6.4	0.2	INSECT PARTS
PS	6.5	0.2	INSECT PARTS
PS	6.6	0.2	MT
PS	6.7	0.2	DRAGONFLY, SNAIL *GYRAULUS*
PS	6.8	0.2	DRAGONFLY, LARGE; 3 BAETIDAE
	SPOTFIN SHINER		
SF	3.0	0.1	
SF	3.2	0.1	
SF	3.2	0.1	
SF	3.3	0.1	

	YELLOW BULLHEAD		
YB	9.9	0.4	YP 78 MM
YB	10.1	0.4	CRAYFISH
	YELLOW PERCH		
YP	3.3	0.1	CHIRONOMID, DRAGONFLY
YP	3.3	0.1	ZOOPLANKTON
YP	3.5	0.1	INSECT PARTS
YP	3.5	0.1	3 BAETIDAE, 1 SNAIL
YP	3.6	0.1	DRAGONFLY
YP	3.8	0.1	DRAGONFLY
YP	4.1	0.1	DRAGONFLY
YP	4.4	0.2	4 DRAGONFLIES, 1 BAETIDAE, 3 CADDISLFIES

Pumpkinseeds were less abundant than bluegills; we saved 15 that ranged from 4 to 6.8 inches (Table 10). Pumpkinseeds are ecologically adapted to eat mollusks and we did observe snails in the diet of three of the ten fish that had eaten. They mostly ate insects (caddisflies, dragon flies, and mayflies – Baetidae) and one ate some macrophytes. They also ate *Hyalella*, the fairy shrimp and crayfish. The presence of the mayfly in the family Baetidae is further confirmation that a fragile organism, that requires high water quality (high dissolved oxygen and good water clarity) is present and flourishing in Diamond Lake.

Largemouth bass appear to be quite common in the lake and we collected fish ranging from 1.6 to 10.9 inches (Table 10). We always have difficulty catching larger individuals, since they do not appear in trap nets and do not get caught in gill nets very well either. There seems to be great spawning substrate (gravel and sand) both for sunfish and largemouth bass, which build and guard nests during spring-early summer. There was ample evidence of many young-of-the-year (YOY), since they were common to abundant in the seine hauls (Table 10). YOY bass from 1.6 to 3 inches were eating insects. Like bluegills, there is an excellent and diverse benthic fauna present for largemouth bass (and bluegills as we have already seen) in the littoral zone, available to promote good growth of the small sizes of largemouth bass.

Largemouth bass from 4.1 to 6.2 inches switched from eating exclusively insects to being predators on fish and crayfish as they grew older (Table 10). These fish were still eating some insects, such as dragonflies, while others ate crayfish and unknown fishes. The two largest bass, 8.9 -10.9 in were eating yellow perch (81 mm) and bluegill (54 mm), typical of what we would expect for this predator. This is excellent information, since it indicates that largemouth bass are consuming bluegills and that these prey items are apparently plentiful enough in the lake to sustain the intense predation largemouth bass can exert on prey populations in a lake. Unfortunately, they are also eating yellow perch which seem to be heavily preyed on based on their lack of survival to larger sizes. Some yellow perch predation is probably also occurring by northern pike, which appear to be uncommon in the lake based on our gill netting activity.

Interestingly, we caught two hybrid sunfish in our sampling around 5 in and they were both eating crayfish, which is unusual for panfish (Table 10).

Black crappies appeared to be uncommon in the lake, since we only caught one specimen, which was only 4.4 in. It was eating zooplankton, which is common for this species (Table 10). Larger specimens have been substantial predators on small bluegills in other lakes we studied.

Another species that appears to be rare in the lake, but might be more abundant than is indicated from our sampling efforts, was the brown and yellow bullheads, which can be important piscivores in the lake ecosystem. We collected three brown bullheads that were eating crayfish and an unknown 75-mm fish (Table 10). The two yellow bullheads (9.9-10.1 in) were eating crayfish and a 78-mm yellow perch (another predator eating yellow perch).

Yellow perch appear to be uncommon in Diamond Lake based on the data (eight fish) we collected; they were 3.3-4.4 in. The yellow perch we caught were eating zooplankton, snails, and insects (mayflies Baetidae, chironomids, dragonflies, and caddisflies) (Table 10), certainly a diverse and rich diet for this species. The low abundance of large yellow perch as observed in Diamond Lake is undoubtedly due to predation by the largemouth bass, bullheads, and northern pike in the lake. The low abundance of yellow perch is unfortunate, since they are great fish to catch and provide outstanding table fare.

The panfish community in the lake is comprised of bluegills, pumpkinseeds, and largemouth bass, all members of the sunfish family. This complex is the backbone of any warm-water lake fish community and is usually self-sustaining, since the largemouth bass have adequate spawning substrate (gravel and sandy shores) and can usually control the panfish and prevent stunting. The high diversity of prey is being consumed by the bluegills, black crappies, pumpkinseeds, and small largemouth bass along with help from bullheads and yellow perch, so it appears that a considerable amount of your prey resources are being efficiently converted into fishable biomass.

We only collected two species of cyprinids (minnow family) in our nets: the bluntnose minnow and spotfin shiner. Minnow species are an excellent addition to the fish fauna, since they utilize resources that none of the other fish consume (algae and detritus and probably some insects) and they add an important forage fish for top predators, such as yellow perch, northern pike, and largemouth bass. These species contribute to the species diversity we noted in the fish community, which is important for maintaining stability under the different stressors of the environment and varying population swings of the predators in the lake. The analogy to a diverse stock portfolio is apt here. The mayfly in the family Baetidae was found in stomachs of many fish species in Diamond Lake during 2021 (Table 10). The water quality in the near shore zone must be adequate to support them (high dissolved oxygen), despite the lack of dissolved oxygen in the deep area during summer stratification.

Lastly, there is another common species that is probably confused with minnows in the lake called the brook silversides. They have a 2-year life cycle, grow up to 2-3 inches, and can be seen feeding at the surface, sometimes jumping out of the water when they are chased by predators. Again, this is another good member of the fish community adding another prey species to the wide diversity in the lake.

It appears that there are no common carp or at least low numbers in the lake. This is a destructive species and should be killed or removed if found.

Mercury in fish

As noted, mercury is a problem in most of Michigan's inland lakes. Most mercury comes to the watersheds of lakes through deposition from the air with most coming from power plants burning coal. The elemental mercury is converted to methyl mercury through bacterial action or in the guts of invertebrates and animals that ingest it. It becomes rapidly bioaccumulated in the food chain, especially in top predators. The older fishes, those that are less fatty, or those high on the food chain will carry the highest levels. Studies we have done in Michigan lakes and studies by the MDNR have shown that large bluegills, largemouth bass, black crappies, northern pike, and walleyes all contain high levels of mercury. This suggests that fishers should consult the Michigan fishing guide for recommendations on consumption, limit their consumption of large individuals, and try to eat the smaller ones. It also suggests that a trophy fishery be established for largemouth bass, northern pike, and some of the larger individual black crappies and bluegills in the lake.

Fish Growth

Growth of the fishes we collected was determined by ageing a sample of fish of various sizes using multiple scales and comparing the age of fish from Diamond Lake with Michigan DNR standards (Latta 1958, DNR pamphlet no. 56). Bluegills are common in Diamond Lake and those we aged (n=31) were all growing at state averages (Table 11, Fig. 10). The largest fish we caught was 6.1 inches and it was 4 years old. We usually catch larger sizes of fish, but they apparently were concentrated in areas we did not sample. The scattered aquatic plant beds present in the lake, the good diversity and abundance of benthos, and abundance of large zooplankton are apparently providing food and good habitat for bluegill shelter and sufficient food for adequate growth. In addition, there was an abundance of YOY, suggesting good reproduction as well. Since there are few northern pike in the lake, we would have expected more larger bluegills present in our sampling gear.

Table 11. Growth of selected fishes collected from the Diamond Lake, Newaygo Co., 4-5 August 2021. Fishes were collected in seines, gill nets, and trap nets, scales removed, aged, and total lengths at various ages compared with Michigan state mean lengths for various fishes at those same ages (see Latta 1958). Shown is the age (years) of the fish, its total length (inches) based on MDNR state of Michigan mean lengths, and the mean length-at-age of Diamond Lake fishes along with sample size (N) in parentheses. See Figs. 11-13 for graphical display of these same data.

AGE (yr)	**MDNR Len (in)**	**DIAMOND Len (in)**

BLUEGILL

0	2.1	1.9(10)
1	2.9	3(7)
2	4.3	4.4(2)
3	5.5	5.6(7)
4	6.5	6.1(5)
5	7.3	
6	7.8	
7	8	
8	8.5	
9	8.5	
10	9.2	

BLACK CRAPPIE

0		
1		4.4(1)
2	5.9	
3	8	
4	9	
5	9.9	
6	10.7	
7	11.3	
8	11.6	

YELLOW PERCH

0	3.3	3.5(3)
1	4	3.8(5)
2	5.7	
3	6.8	
4	7.8	
5	8.7	
6	9.7	
7	10.5	
8	11.3	
9	11.7	

PUMPKINSEED

0	2	
1	2.9	
2	4.1	4.1(1)
3	4.9	4.9(5)

4	5.7	5.7(3)
5	6.2	5.7(3)
6	6.8	6.3(2)
7	7.3	6.6(4)
8	7.8	
LARGEMOUTH BASS		
0	3.3	2.6(20)
1	6.1	4.7(8)
2	8.7	8.9(1)
3	10	10.4(2)
4	12.1	
5	13.7	
6	15.1	
7	16.1	
8	17.7	
9	17.9	

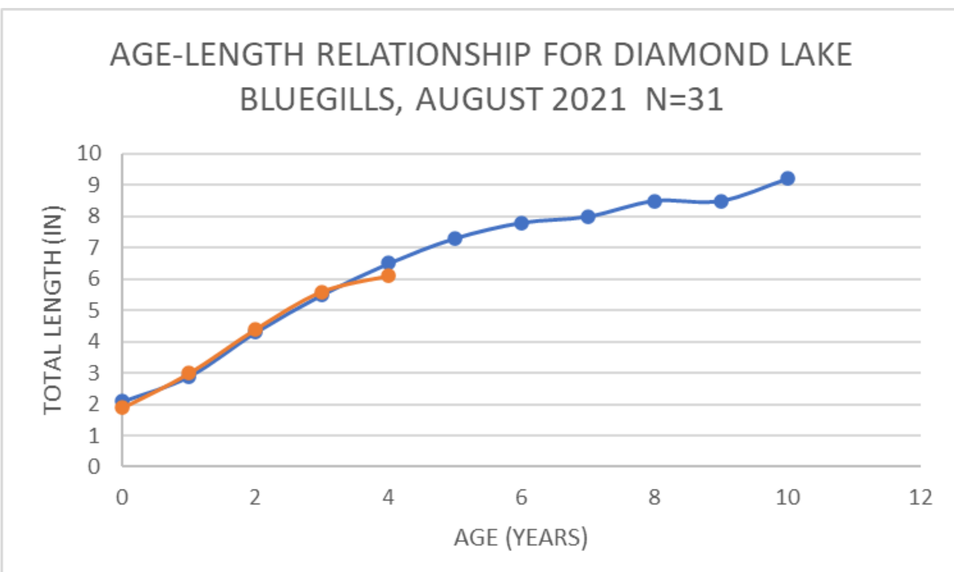

Figure 11. Growth of bluegills in Diamond Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958), 4 August 2021. See Table 8 for raw data.

Largemouth bass were also common in Diamond Lake, especially YOY, but we never caught very many very large fish. Fish collected ranged from 1.6 to 10.9 inches (Table 11). The age-length relationship for Diamond Lake bass (Fig. 11) was mostly similar to the growth rates of Michigan DNR's fish, so there do not appear to be any growth issues with your fish. This species is one of the keystone predators in your lake and responsible for keeping the bluegills in check, so the big fish should be left in the lake to the degree possible. Those foul-hooked should of course be kept. The other reason, as noted elsewhere, is that large individuals are probably contaminated with mercury and should not be eaten anyway. We concluded the following: first, they are generally growing at state averages, and second, based on our findings of large numbers of young-of-the-year fish caught (personal observations; Table 10), we think that largemouth bass are reproducing adequately in the lake. We explored the near shore zone in the lake, and there definitely was considerable gravel/sand bottom along shore that is good spawning substrate for the sunfish family members, including largemouth bass. Because there is adequate growth, abundant habitat for spawning, and good reproduction of this species and bluegills, no stocking of these species would improve the abundance of larger individuals. However, as we will note in recommendations, we do advocate for more restraint in keeping fish, because of the vastly improved fishing technology now deployed to locate and catch fish. Keep some for a meal, but allow enough large individuals to survive so they can continue producing large year classes for future exploitation.

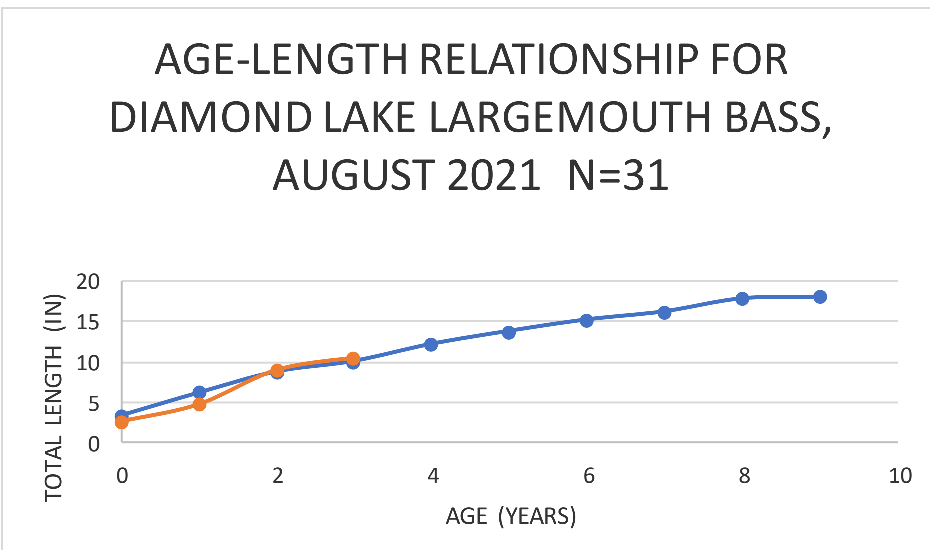

Figure 11. Growth of largemouth bass in Diamond Lake (red squares) compared with Michigan state averages (blue circles) (see Latta 1958), 4-5 August 2021. See Table 8 for raw data.

Yellow perch seem to be scarce in the lake based on our collections and fisher's reports. Yellow perch because of their opercles are very susceptible to gill nets, yet we caught none in the nets. Those we did catch ranged from 3.3 to 4.4 inches (N=8) were growing at or above Michigan DNR averages (Table 11, Fig. 12). Yellow perch are important prey fish that are usually not too susceptible to bass predation, and are outstanding table fare for people. Hence, we would like to have seen more of them in the lake. We do not think stocking yellow perch would contribute much to increasing the population with the abundance of predators currently inhabiting the lake.

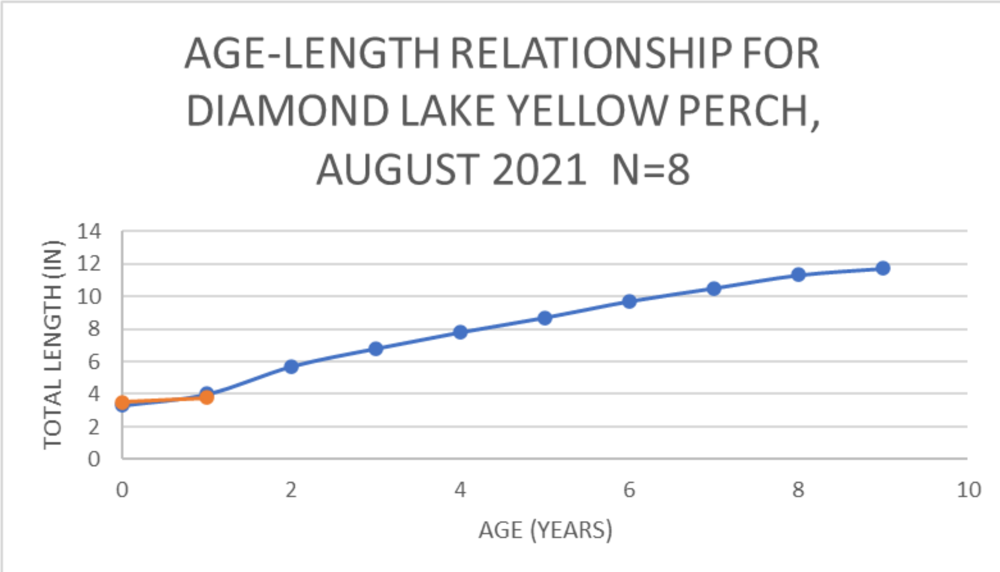

Figure 12. Growth of yellow perch in Diamond Lake (red squares) compared with the Michigan state averages (blue circles) (see Latta 1958), 4-5 August 2021. See Table 11 for raw data.

We collected a number of pumpkinseeds (n=16), and many were of large size (4.1-6.8 in). They were growing at MDNR's average lengths at ages 2-4, but they were below averages for those 5-7 years old (Fig. 13, Table 11). It was strange that we did not collect any YOY, usually the most abundant age group in most collections. The diet information showed that they were eating diverse and common prey items, including snails and insects. Treatment of the lake with copper sulfate if done for algae, can kill snails and have an impact on pumpkinseed growth.

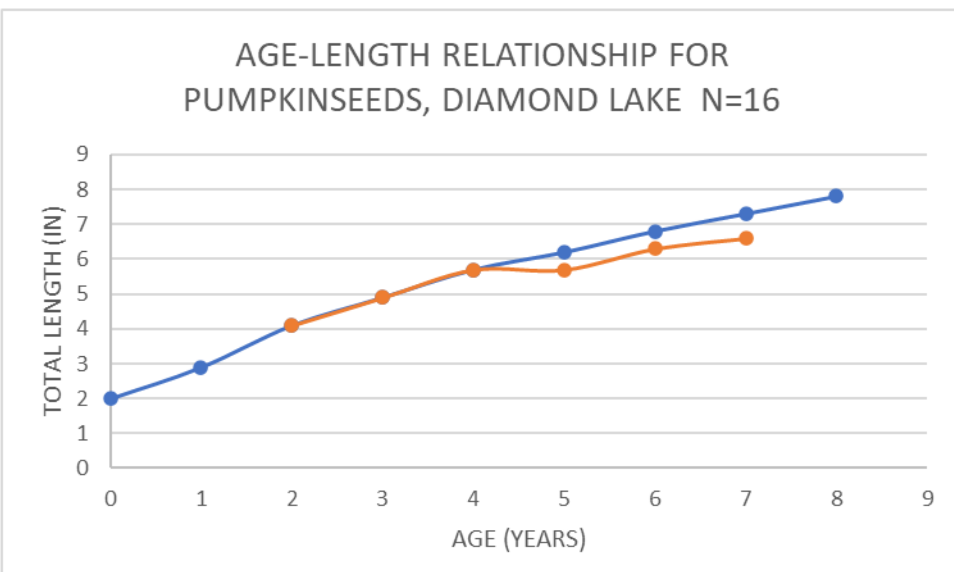

Figure 13. Growth of pumpkinseeds in Diamond Lake (red squares) compared with Michigan state averages (blue circles) (see Latta 1958), 4-5 August 2021. See Table 11 for raw data.

We caught two hybrid sunfish (mean length=5.2 in); they were both 3 year old. Also, we caught one black crappie that was 4.4 in; it was 1 year old.

Northern pike appear to be rare in Diamond Lake. We collected none in our nets, but they are reported to be present in the lake by sport fishers. We suspect that these fish, cool water species, would grow slowly during summer because of the warmer temperatures and low dissolved oxygen in their optimal habitat in the deep basin.

Fish Management Recommendations

Fish management strategies emanating from these data include the following. First, we do not think northern pike stocking (or walleye) would be productive even though it appears that reproduction is obviously limited for northern pike. The conditions during summer are restrictive, since these cool water fish need cool temperatures with at least 3 mg/L dissolved oxygen and the profile in the lake during summer does not allow for any viable habitat that has these characteristics (see Fig. 6 – fish squeeze).

Second, we recommend catch and release of the bigger largemouth bass, say those > 15 inches, so they can control the prey fish population. We always encourage people to put back large predators to maintain good fish community balance. This allows the larger, mature predators that have made it through the mortality gauntlet to spawn successfully, promotes good growth of bluegills and prevents fish stunting in the lake, and they are probably contaminated with high concentrations of mercury any way (see M*ercury in Fish* for a discussion).

Third, there was good spawning by the bluegills, largemouth bass, and yellow perch. Hence, because of the favorable substrate (sand and gravel) for sunfish spawning, there is no need for stocking any of these species. As we noted, we did not catch many large bluegills or yellow perch, and no YOY pumpkinseeds. It takes 8 years to grow an 8-in bluegill. They are a wonderful resource and usually easy to catch. With our modern society, people have larger boats, fancy depth finders that can identify fish during summer and winter, GPS units to locate "hot spots", and a myriad of different baits to catch fishes. May we suggest fishers of bluegills and pumpkinseeds exercise restraint in keeping these fish. A few for a meal is acceptable; no need to catch a limit every time someone goes out. We believe the lack of large yellow perch is due to predation, but this is a weak argument since there do not appear to be many northern pike in the lake, a major predator of this species. The lack of any YOY pumpkinseeds is perplexing, obviously they had a reproductive failure during 2021, unlike bluegills.

Fourth, live bait use (minnows, crayfish) should be discouraged or banned because of the threat of introduction of exotic species (e.g., goldfish) and VHS (viral hemorrhagic septicemia) which killed many muskies and other species in many lakes, including Lake St. Clair. As noted above, any stocking should be done with a guarantee from the stocker that the fish are VHS-free. Any stocking by individuals should be banned for this very reason: introduction of fish from other water bodies may bring in parasites and diseases, including VHS, that could have a devastating effect on the fish community of Diamond Lake.

DISCUSSION AND RECOMMENDATIONS

To summarize, Diamond Lake is a eutrophic lake with one 26-ft deep basin in the south end of the lake. That deep area during summer stratification probably generates an anoxic, dead zone near bottom devoid of dissolved oxygen and this zone can generate products of decomposition, including high concentrations of nutrients (soluble reactive phosphorus and ammonia) as well as carbon dioxide rendering this area off limits to fishes. Most earlier data sets show anoxia on the bottom, but our 2021 data documented some oxygen on the bottom during early August, but we believe it would go entirely anoxic before summer is over. Interestingly, chlorides, an indicator of septic tank leakage and road salt runoff was extremely low in the lake, a sign of excellent water quality. The most surprising finding limnologically, was that alkalinity was only in the range of 34 mg/L, which is very low; most lakes are hardwater lakes with alkalinity in the 150-200 mg/L range. This has two implications: First, alkalinity is linked closely with productivity, so we would expect lower productivity in the lake as a result. Second, the calcium carbonate system is the major buffering system in a lake and protects the lake from becoming acidic from acid rain which is highly acid. Therefore, there could be times when there is excessive rainfall on the lake and in the watershed, which could reduce the pH to low levels, threating organisms in the lake. MDNR data from the 25 April 1987 showed that pH was an astounding 6.4 throughout the water column. Our data from 2021 were at acceptable levels.

Unfortunately, the buildup of nutrients on the bottom contributes to the eutrophication (nutrient enrichment) in the lake each year after spring and fall turnover, fueling algae and the extensive macrophyte beds that ring the littoral zone. Riparians also contribute to the lake's enrichment through fertilization of lawns and septic tank seepage into the ground water which apparently is a serious problem (discussed below). To reduce the footprint of residents, sewers would be the logical solution. Until that happens, at a minimum, septic tanks should be pumped at least once every 2 year and more often if there is high use at a residence. Remove the nutrients before they seep into ground water and contaminate wells and fertilize the lake. There should be no lawn fertilization, but if necessary only nitrogen-based fertilizer should be used. See Appendix 1 for other suggestions to reduce nutrient input.

The remainder of the lake has variable depths, while the littoral zone is shallow with extensive plant beds, including lily pads, bulrushes, and submerged aquatic plants. The bottom has extensive areas of sand and gravel which act as good spawning substrate for sunfish, especially largemouth bass. The algae data showed the lake to have low abundances of green and blue-green algae, but most were not nuisance forms. Earlier studies have noted that *Microcystis* has been a problem in the past. Our zooplankton (small invertebrates in the water column) sample showed that a large species, *Daphnia*, composed over 20% of the zooplankton present in the deep sample and 10% in the shallow sample. This indicates that there is probably reduced predation on the zooplankton over the deep hole, since lakes with an abundance of planktivores, such as small, stunted bluegills, usually consume most of the *Daphnia* present, leaving only smaller species. We also noted the presence of a mayfly (Baetidae) in diets of fishes sampled, indicating that Diamond Lake is a high water quality lake with adequate dissolved throughout the year, probably in the near shore zone where there is abundant organic sediments.

We collected 9 species of fishes and another, the northern pike, avoided being collected but is reported present in the lake. This is one of the fewest number of species we have seen in an inland lake in Michigan. Members of the sunfish family (Centrarchidae – largemouth bass, bluegills, black crappies, and pumpkinseeds) dominated the species collected, while other predators included bullheads (brown and yellow). In addition, there were two species of minnows also found in the lake, including spotfin shiners and bluntnose minnows. Diets of fishes reflected the species, life stage, and feeding strategy of each fish species. Small fishes were feeding on zooplankton and benthos, while the large specimens of predaceous fishes were feeding on bluegills, yellow perch, and sometimes crayfishes. Apparently, largemouth bass and northern pike predation is probably having a depressing effect on yellow perch survival, since large individuals appeared to be uncommon in the lake. Growth of the fishes we examined generally was at MDNR state averages for a given age.

Prein and Newhof (1988) noted that their eight monitoring wells situated around the lake contained high concentrations of both phosphorus and nitrogen making Diamond Lake the reservoir of these nutrients and contributing to its eutrophication (nutrient enrichment problem). But more importantly, TMI (1987) stated that "it would appear that Diamond Lake has a problem with at least some failed or inadequate on-site sewage disposal systems. It also appears that these systems are having a negative impact on the lake by feeding the macrophytes and algae with elevated nutrient inputs." This highlights a potentially public health problem: the lake residents have not resolved to bring in sewers to remove sewage from entering the ground water, possibly contaminating some house's wells and contributing to the ageing of Diamond Lake. Things have apparently not changed some 34 years later, since the few well water samples we collected from three wells in the watershed strongly indicate that at least on the eastern side there is excessive concentrations of nitrates (1.54 mg/L), conductivity (909 uS), and chlorides (47 mg/L) present. These values are much higher than any other comparable measurements we made with these parameters and the high nitrates certainly are indicative of agricultural contamination from the farm field adjacent to this area of Diamond Lake. The high chlorides are a bit perplexing; all the other measurements of chlorides from the 1970s-1980s and our sampling suggest the highest values were only 15 mg/L and most were much lower. The value in the well was 3-fold higher than any other measurement in the past and from our data. Usually, high chlorides are attributed to road salting operations, but they can be from septic tanks or naturally occurring, but the fact that they were so low everywhere else suggest they were not naturally present in the soils. Obviously, more sampling by public health officials is in order from a public health perspective and to eventually curtail nutrient input to Diamond Lake.

From the data we collected we make the following recommendations.

First, septic tanks may be contaminating wells and contributing nutrients to the ground water which ends up in Diamond Lake. Sewers are the obvious solution from a eutrophication standpoint and for public health reasons. In addition, residents in the watershed should reduce nutrient input to the lake by reducing or eliminating lawn fertilization, no burning of leaves in the watershed, clean septic tanks at least once/2 yr and more often if the residence is a high use one, and plant greenbelts (see Michigan Natural Shoreline Protection website to get guidance on how to retard runoff and initiate sensible shoreline protection (see Appendix 1 for more suggestions).

Second, catch-and-release of large largemouth bass (>15 inches) is recommended so they can continue to control the bluegill population and they are probably contaminated with mercury anyway.

Third, the only species that would be justified in stocking is the northern pike, because they are in low abundance and spawning sites are limited in Diamond Lake. However, know that this species is a cool water species and requires cool water and adequate dissolved oxygen which only occurs in the deep basin during part of the early summer, but not later. Therefore, any cool water species, including walleyes would be expected to be stressed during this period of the year and may grow poorly as a result. If the board still wants to stock fish, be sure to use a certified VHS-free source, do not stock large numbers, and stock them at large sizes (at least >8 inches) during spring or fall. The other common species, such as largemouth bass, bluegills, and black crappies, although they may be in low abundance, should not be stocked because they are capable of good reproduction and are adapted to the Diamond Lake environments. The same is true for yellow perch which usually are limited by predation, which we believe to be the case in Diamond Lake. In fact, as we noted above, fishers are becoming considerably more sophisticated with bass boats, high-tech SONAR devices, and GPS leading to increased catches of target fishes. Most fishers already practice catch and release for top predators; we encourage those fishing for panfish to consider reducing their catches to allow some of the larger bluegills and pumpkinseeds to reproduce.

Fourth, you should consider banning bait from outside the lake (live fish, crayfish) from being used by fishers. We are worried about viral hemorrhagic septicemia (VHS)-infected bait and introduction of other non-indigenous species, such as quagga mussels or VHS, coming into the lake from outside sources. These introductions should be prevented by careful examination of boats, SCUBA gear, or bait coming from infested lakes or rivers. Any of these gear or boats should be dried for a long period or in the case of ballast water in boats, treated with chlorine to kill potential invasive species.

SUMMARY OF RECOMMENDATIONS

Recommendations are summarized more concisely below:

1. <u>Nutrient inputs</u>

Nutrients are entering Diamond Lake through septic tanks and being regenerated by anoxic sediments (termed internal loading). These sources include:

A. Septic tanks: Sewage seeps into the groundwater through permeable sand contaminating wells and the lake with nutrients. Sewers are the obvious solution; while waiting for them, have septic tanks pumped often, at least once every 2 yr and more often if the residence is a high use house. Wells should be tested to determine the extent of contamination in the watershed.

B. Sediments can generate nutrients near bottom during decomposition processes in winter and summer. Reducing nutrients from riparians will generate less organic material that will accumulate on the bottom. Expensive treatments of alum or phoslock would reduce the amount of phosphorus on the bottom.

C. Runoff, lawn fertilization, and other activities by residents contribute nutrients: Observe suggestions in Appendix 1 – greenbelts, ban pet wastes from lawns, no leaf burning at the lake, reduce impermeable surfaces, etc.

D. Waterfowl, such as Canadian geese need to be discouraged from visiting, nesting, or hanging around the lake eating lawns.

2. Northern Pike

Northern pike are uncommon in the lake, and they appear to have few optimal spawning sites. They would be a candidate for stocking, but note they will be severely stressed during the hot times of summer, reducing their growth.

3. Largemouth Bass

We recommend catch and release for all largemouth bass > 15 inches, unless fish are foul hooked and would die. They help control stunting in sunfish populations.

4. Yellow perch

Yellow perch are not very abundant, but there were quite a few young in the near shore zone. Many top predators fed on them, so not much can be done to increase numbers or sizes. Those that do escape predation should grow well, but we did not catch any large ones to document this.

5. Prevent Exotic Species from Entering Diamond Lake

Prevent exotic species, besides Eurasian milfoil which has already been introduced, from entering the lake. Consider banning bait from outside the lake to avoid the introduction of more exotic species, such as quagga mussels and VHS. Fishers and skiers need to dry out boats and gear that come from other lakes that might be contaminated with exotic species, such as zebra mussels.

Table 12. A compilation of the various physical, chemical, and biological measures for Diamond Lake and a qualitative assessment (good, bad, no problem) in general. + = positive, 0 = as expected, - = negative. "See guidelines" refers to Appendix 1 – guidelines for lake residents to reduce nutrient input into the lake. C @ R = catch and release, DO=dissolved oxygen.

Condition Documented	Qualitative assessment	Problem Potential	Action to Take
Physical			
Water Clarity	0	Moderate	Reduce nutrients
Water Depth	-/+	Sediment buildup	Reduce nutrients
Water Temp.	0	Warms up in summer	None now
Sediments	+	Gravel, sandy, organic	None

Chemical			
pH	0	None	None
Dissolved oxygen	-	Reduced DO on bottom	Monitor, reduce nutrients
Alkalinity	-	Very low	Will influence productivity
Chlorides -lake	+	None	None
-wells	-	One very high	Measure WQ and bacteria in wells
Nitrates -lake	-	Buildup in lake bottom	See Guidelines; reduce N&P
-wells	-	Some wells contaminated	Monitor wells:WQ; bacteria
Ammonia -lake	0	Buildup on bottom	See Guidelines; reduce P
-wells	-	Some wells contaminated	Monitor wells:WQ, bacteria
SRP -lake	0	Little buildup on bottom	See Guidelines; reduce P
-wells	-	Some wells high levels	Monitor wells: WQ; bacteria
Hydrogen sulfide	+	Not present in August	Monitor
Biological			
Algae	0	Some blue-greens present	Monitor later in the year
Macrophytes	-	Eurasian milfoil	Monitor; Treat if it expands
Zooplankton	+	*Daphnia* present	None
Fish			
Largemouth bass	+/-	Plenty YOY; few big adults	C @ R
Bluegill	+/-	Adequate YOY; few adults	Maintain predator balance
Yellow perch	-	Few seen	Monitor; no stocking
Minnows	0	2 species present	Monitor
Northern pike	-	Uncommon	Promote spawning

ACKNOWLEDGEMENTS

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APPENDIX

Appendix 1. Guidelines for Lake Dwellers; some may not apply.

1. DROP THE USE OF "HIGH PHOSPHATE' DETERGENTS. Use low phosphate detergents or switch back to soft water & soap. Nutrients, including phosphates, are the chief cause of accelerated aging of lakes and result in algae and aquatic plant growth.

2. USE LESS DISWASHER DETERGENT THAN RECOMMENDED (TRY HALF). Experiment with using less laundry detergent.

3. STOP FERTILIZING, especially near the lake. Do not use fertilizers with any phosphate in them; use only a nitrogen-based fertilizer. In other areas use as little liquid fertilizer as possible; instead use the granular or pellet inorganic type. Do not burn leaves near the lake.

4. STOP USING PERSISTENT PESTICIDES, ESPECIALLY DDT, CHLORDANE, AND LINDANE. Some of these are now banned because of their detrimental effects on wildlife. Insect spraying near lakes should not be done, or at best with great caution, giving wind direction and approved pesticides first consideration.

5. PUT IN SEWERS IF POSSIBLE. During heavy rainfall with ground saturated with water, sewage will overflow the surface of the soil and into the lake or into the ground water and then into the lake.

6. MONITOR EXISTING SEPTIC SYSTEMS. Service tanks every other year to collect and remove scum and sludge to prevent clogging of the drain field soil and to allow less fertilizers to enter the groundwater and then into the lake.

7. LEAVE THE SHORELINE IN ITS NATURAL STATE; PLANT GREEN BELTS. Do not fertilize lawns down to the water's edge. The natural vegetation will help to prevent erosion, remove some nutrients from runoff, and be less expensive to maintain. Greenbelts should be put in to retard runoff directly to the lake.

8. CONTROL EROSION. Plant vegetation immediately after construction and guard against any debris from the construction reaching the lake.

9. DO NOT IRRIGATE WITH LAKE WATER WHEN THE WATER LEVEL IS LOW OR IN THE DAYTIME WHEN EVAPORATION IS HIGHEST.

10. STOP LITTER. Litter on ice in winter will end up in the water or on the beach in the spring. Remove debris from your area of the lake.

11. CONSULT THE DEPT OF NATURAL RESOURCES BEFORE APPLYING CHEMICAL WEED KILLERS OR HERBICIDES. This is mandatory for all lakes, private and public.

12. DO NOT FEED THE GEESE. Goose droppings are rich in nutrients and bacteria.

From: Inland Lakes Reference Handbook, Inland Lakes Shoreline Project, Huron River Watershed Council.