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WATER QUALITY OF UNION LAKE IN PROXIMITY TO DIFFERING LAND USE

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ABSTRACT. Union Lake in Rice County, Minnesota is an impaired, hypereutrophic water body with low clarity due to excessive algae. Poor water quality makes the lake unsuitable for swimming and likely impacts aquatic species composition. Characteristic of the usual difficulty in determining nonpoint source pollution, however, it is not concretely determined which of the various land use types surrounding the lake contribute to the impairment and at what magnitude. In this study, water sampling sites were placed relative to different land use types (agricultural, forested, and residential), with the possibility of seeing higher nutrient concentrations and poorer water quality at some sample locations. Water quality was assessed chemically and with macroinvertebrates. A significant difference across sample sites was found only in pH and nitrates, with the latter's greatest mean occurring at the forested site. Macroinvertebrates found were species less reliant on dissolved oxygen, and therefore of a high tolerance level. Despite a lack of variation by site, measured turbidity does not meet standards, and high pH levels give way to heightened ammonia levels. Overall, results suggest that water quality is homogeneous across sites, but confirmation of poor water quality underlines the need for cumulative consideration of land use impacts on Union Lake and other lakes.

INTRODUCTION

The more than 10,000 lakes of Minnesota have not gone uninhabited; lakeside homes and cabins are a cultural norm and other functions - commercial, agricultural, or otherwise - have their share of lakefront property. Land use surrounding lakes has the ability to impact water quality, whether by fertilizers and other substances carried in runoff or by leaching through the ground. Multiple water bodies within Rice County, Minnesota are labeled "impaired" by the MPCA for failing to meet water quality standards for nutrients, including nitrogen and phosphorous, and *E. coli*. When standards are not met, the body of water is deemed "no longer drinkable, swimmable, fishable, or useable in other, designated ways" (MPCA). Poor water quality will also impact organisms and the overall species composition of an aquatic ecosystem.

Union Lake is one example of these impaired waters; MPCA records of water chemistry data for Union Lake show years of high nutrient levels and low clarity due to excessive algae. This correlates to the lake's classification as hypereutrophic. High trophic states have been associated with nearby agricultural practices (Detenbeck 1993). Given that the presence of wetlands can somewhat buffer the anthropogenic impacts to lake water quality, the portion of a watershed put to agricultural use can be explanatory of water quality in watershed lakes (Nielsen 2012). With this in mind, standards are put in place to regulate land use around lakes, including minimum distances of certain land practices from the shoreline (Rice County Planning and Zoning 2012). However, these regulations are not foolproof; although they regulate the proximity of differing land usage, agricultural fields, residential development, and other land activity are generally never fully prohibited on Recreational Development Shoreland (RDS) lakes.

When surveyed for their general impressions, 26% of Rice County property owners "[felt] that agricultural runoff [was] a pressing problem on the lakes" (Neu 2001). The excess nutrients provided by agricultural runoff, specifically phosphorous and nitrogen, are known to foster an increase in algae. Thriving populations of algae culminate in algal blooms that may leave a lake in a state of hypoxia, with conditions now unsupportive of native organisms that rely on good water quality. Union Lake has been recorded to have these setbacks. Algal blooms and assorted suspended material have kept transparency very low and in some years has led to winter fish kills from the lack of oxygen. Additionally, conductivity readings have been alarmingly high (Scheurle 1986). To address the poor water quality of Union Lake, we look toward land use around the shoreline and the need for healthier land management practices. Characteristic of the usual difficulty in determining nonpoint source pollution, however, it is not concretely determined which of the various land use types surrounding the lake contribute to the impairment and at what magnitude. This study aimed to gain insight, with the following main objectives:

1. Determine whether there is a significant difference in water chemistry measures and macroinvertebrate composition at different sample sites.
2. Draw inferences about land use impacts based on the correlation of each sampling site to a different land use type.

While this study is localized to a single lake, conclusions are likely applicable to other impaired lakes. Underlining the magnitude of negative impact from each land use type can lead to better practices in shoreline land management and could inform policy-making and regulation. A lake characterized by algal blooms and oxygen-deprived fish populations could be given a chance to recover if effective changes in surrounding land use practices were made.

METHODS

Union Lake is located in Rice County, Minnesota and is part of the Cannon River watershed. It is connected to the Cannon River by Heath Creek, which runs from the lake downstream to the river. Union Lake has a surface area of 400 acres and a maximum depth of 10 feet (MPCA). Its 5 miles of shoreline are composed of differing land use types, including residential, recreational (Albers park), agricultural, and forested.

I placed four shallow water sampling sites in proximity to different land use types (two at agricultural, one each at forested and residential), with the possibility of seeing higher nutrient concentrations and poorer water quality at some sample locations (Table 1, Figure 1). I selected a fifth sample site located away from the shoreline, allowing the analysis of parameters across lake depth. I marked site locations with a GPS receiver for ease of return across three sampling days within the fall season. I accessed all sites with a canoe.

I evaluated water quality with both chemical analysis and macroinvertebrate sampling. I performed in-lake chemical analysis using handheld meters for pH, temperature, dissolved oxygen (DO), and conductivity. I recorded water depth at each site, and measured turbidity at the deep site using a Secchi disk. At each site, I filtered water into an acid-washed vial. At the deep site, I collected water at incremental depths (0.5, 1, 1.5, and 2 meters) using a Van Dorn. I took the collected samples back to the lab for later analysis by St. Olaf's SmartChem machine, giving concentrations of nitrates and ammonia. Using an ANOVA test, I compared the means of each measure, revealing whether there were statistically significant differences between sites.

I used a kick net to collect macroinvertebrates, which were then preserved in a 70% ethanol solution for later identification in the lab. Using the found macroinvertebrate species as bioindicators, I compared water quality as indicated by macroinvertebrates across sites.

Results

Conductivity, DO, and temperature were not found to have significantly different means across sites (Tables 2, 3, and 4). Nitrates and pH did show a statistical difference between sites (Tables 3 and 4). Most notable were the maximum nitrates and minimum pH values at Site S3 (forested) (Figures 2 and 3). An analysis of variance (ANOVA) was not performed for ammonia due to a lack of samples with levels detectable by the SmartChem. Surface water readings were only available for the last sampling day. Algae were visible at Sites S3 and S4 during separate sampling days (Figure 4). Sampling at site D1 revealed very similar values across depths for all measures.

Across surface water (shallow sites and D1(0)), the average nitrate concentration was 0.42, with a maximum of 1.6 mg/L. Surface ammonia readings, measurable from third day samples only, averaged 0.12 mg/l with a maximum of 0.20. The average conductivity across all sites was 349 µS/cm, with a maximum of 486 µS/cm. Secchi depth readings averaged 0.4m, however readings ranged up to 1.1m. pH reached a minimum of 8.3 and a maximum of 9.2.

Only eight macroinvertebrates, including five different species, were found across all three sampling days (Table 3). The only site in which no macroinvertebrate individuals were found was Site S2 (agriculture).

DISCUSSION

For the most part, means of the various water quality measures did not differ across sites. Although nitrates and pH did, only one site, Site S3, stood apart from the rest. Contrary to hypothesis that agricultural Sites S1 and S2 would display proxies of poorest water quality, Nitrates were highest (and pH lowest) at the forested site. Unfortunately, with limited detected values, ammonium measurements provided no additional clues to water quality differences between sites.

A pamphlet on nitrogen in waters, written by Dave Wall of the MPCA (2013), outlines a number of Minnesota state water quality standards. Measured Union Lake nitrate concentrations fell safely below the standard of 10 mg/L. This is surprising given the lake's historically poor water quality. If not nitrates, what is contributing to current impairment? A high pH is a warning sign, for as it increases above 8, the ammonia (NH_3) to ammonium (NH_4) ratio increases

(Wall 2013). This is alarming because ammonia is the more toxic form. "In the rare situation that a natural water pH exceeds [or] reaches 9," as was found to be the case for Union Lake, "ammonia and ammonium would be nearly equal" (Wall 2013). This hypothesis rooted in pH is confirmed by potentially high ammonia values, of which 0.20 mg/L maximum is above the 0.016 mg/L standard. Ammonia, sourced from human and animal waste, poses the largest threat of all inorganic nitrogeneous compounds toward aquatic life (Wall 2013). Detrimental effects on fish include "reduced blood oxygen carrying capacity, depletion of ATP in the brain, damage to the gills, liver and kidney, and increased susceptibility to bacterial and parasitic diseases (Carmargo and Alonso 2006 as cited in Wall 2013).

While the average Secchi depth met the 1-meter standard of shallow lakes, maximum measurements did reach 1.1m. High turbidity equates to less light penetrating the water column, resulting in reduced rates of photosynthesis and consequently less available DO (Bruckner 2017). Although "alarming" conductivity levels have been previously recorded for Union Lake (Scheurle 1986), healthy fish populations have been found in a wide range of conductivity levels, from 150 μS/cm to 800 μS/cm (Huron River Watershed Council 2013). The average 349 μS/cm of Union Lake under this study suggests the current conductivity, in itself, should not inhibit the presence of fish.

All but one macroinvertebrate species found have high tolerance to poor water quality. This tolerance is often rooted in less dependence on dissolved oxygen to breathe. Instead, such macroinvertebrates exhibit some sort of "snorkel" apparatus to use oxygen from the water's surface (Hadley 2017). The water boatman (family Corixidae) found in Union Lake breathes from an air bubble trapped under its wings, "which must be renewed periodically by breaking to the surface of the water" (Bouchard, Jr. 2004).

It remains uncertain whether water quality within Union Lake may differ with proximity to different land use types. Therefore, very little insight for other northern temperate lakes is gained from this study. The water of this lake and others may be too homogenous to find any quantifiable difference between proximity to one length of shoreline and another across the lake. Since sites hardly differed, a next step could entail moving inland to soil samples, potentially coming closer to pollution sources. In the case that future measurements do differ substantially across sites on a lake, such conclusions could support the findings of Detenbeck et al. in that agricultural land use could be most correlated with the highest nutrient levels and with macroinvertebrates indicating poor water quality. In the meantime, some conclusions about the lake and surrounding land uses as a whole can be made.

High pH, hints at toxic concentrations of ammonia, highly tolerant macroinvertebrates, and visible algae build the story of a lake impaired by excess nutrients from surrounding land use. While measured DO levels seem to be healthy, contrary to characteristics of the macroinvertebrates present, the above factors suggest partial inhibition of healthy populations of fish and other aquatic organisms.

With future studies, revealing which land use types have the highest magnitude of harmful impact on water quality would be valuable in forming plans to improve lakes' health. Within a land use type, there are likely steps that can be taken to alter encompassed practices to the benefit of the aquatic environment. Knowing where to focus land use management efforts can most effectively give hope for improved water quality in Union Lake and beyond.

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TABLES & FIGURES

Table 1. Site coordinates and characteristics.

SITE	FULL NAME	COORDINATES	DESCRIPTION
S1	Shallow 1	N 44˚28.068' W 093˚18.034'	agriculture, far right by branch
S2	Shallow 2	N 44˚28.100' W 093˚18.110'	agriculture, left of dock (lake perspective) between 2 branches
S3	Shallow 3	N 44˚28.044' W 093˚18.326'	forested, just to the right of the sandbar, tree stump at point
S4	Shallow 4	N 44˚27.285' W 093˚18.335'	residential, out from rock retaining wall
D1(X)	Deep 1(depth)	N 44˚27.861' W 093˚18.309'	center area in northern half of Union Lake

Figure 1. Map of Union Lake provided by Google Maps, with sampling sites marked.

Table 2. ANOVA results of conductivity across sample sites, revealing no significant difference in means.

conductivity (uS)	D(0)	S1	S2	S3	S4
means	319.2000	334.3333	338.9000	429.9333	322.0000
standard deviations	37.02702	43.90277	27.38193	60.86455	39.93845
p-value	0.05287				

Table 3. ANOVA results of dissolved oxygen (DO) across sample sites, revealing no significant difference in means.

DO (mg/L)	D(0)	S1	S2	S3	S4
means	11.58333	12.95667	12.80667	11.31000	13.28000
standard deviations	0.6693529	0.9152231	0.1167619	2.6254904	1.1258774
p-value	0.3581				

Table 4. ANOVA results of temperature across sample sites, revealing no significant difference in means.

temperature (˚C)	D(0)	S1	S2	S3	S4
means	10.000000	10.633333	10.583333	9.283333	10.383333
standard deviations	6.591092	6.929165	6.625393	6.597032	6.709198
p-value	0.999				

Table 5. ANOVA results of nitrates across sample sites, revealing a significant difference in means.

NO_3 (ppm)	D(0)	S1	S2	S3	S4
means	0.06336667	0.21225000	0.37520000	1.15220000	0.11265000
standard deviations	0.09100617	0.06201326	0.41799932	0.43345783	0.09015611
p-value	0.01544				

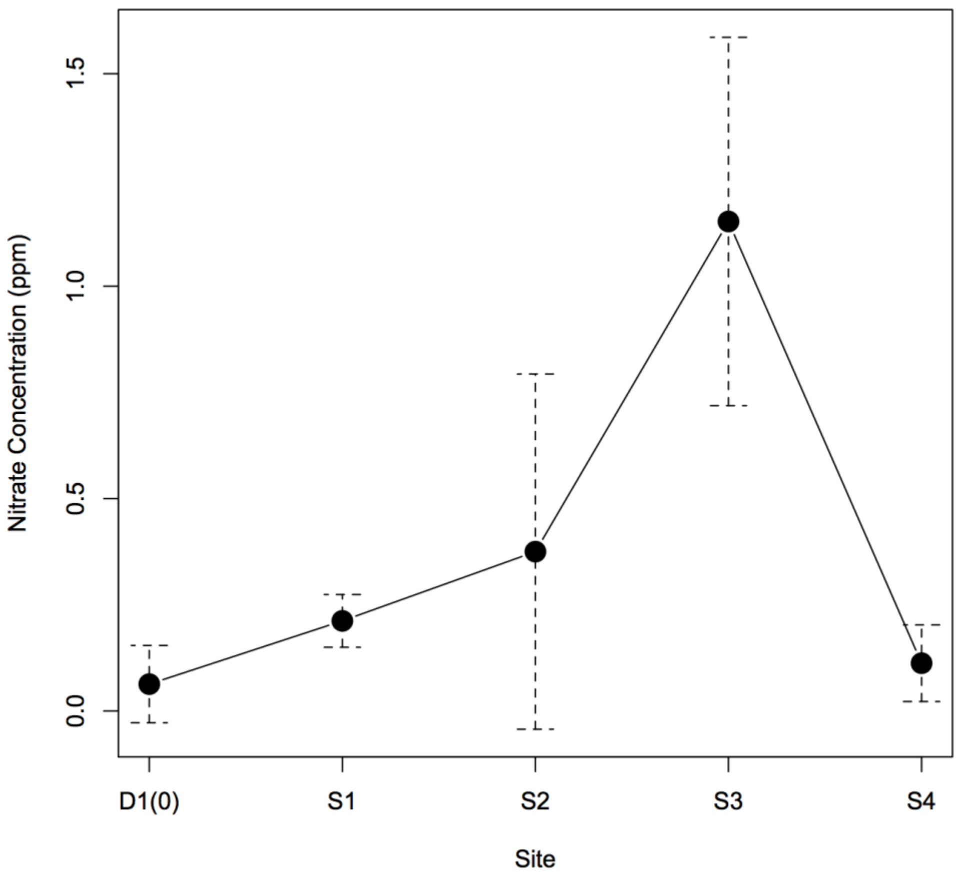

Figure 2. Mean of nitrate concentration for each site, with bars representing the standard deviation.

Table 6. ANOVA results of pH across sample sites, revealing a significant difference in means.

pH	D(0)	S1	S2	S3	S4
means	8.966667	8.766667	8.866667	8.366667	9.033333
standard deviations	0.23094011	0.23094011	0.25166115	0.05773503	0.20816660
p-value	0.02059				

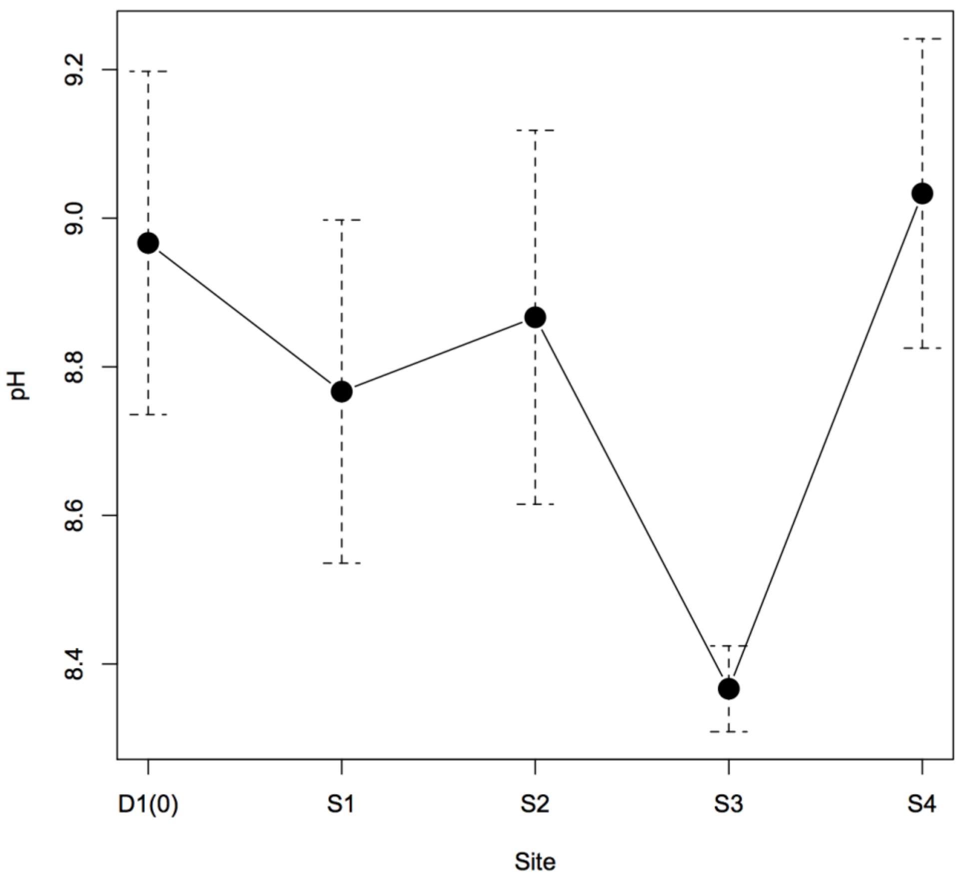

Figure 3. Mean of pH for each site, with bars representing the standard deviation.

Figure 4. Visible algae at Site 4 on November 8th, 2017.