Summary of Results from the 2017 Citizen- Based Water Quality Monitoring Campaign in Tug Lake, WI

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Introduction

Tug Lake is a 151- acre lake located in Rock Falls, WI (Lincoln County). It is within the Lilly Hay Meadow Creek watershed (USGS hydrologic unit # 070700020305) draining an area of approximately 12 square miles consisting of primarily forest (54%), wetland (22%), and agriculture (10%) (Figure 1). Over 60 residential homes are built on its shores with a mix of cottage and year around dwellings. Tug is a highly recreational lake used for boating, fishing and swimming. Over the last several years, homeowners have raised concerns over deteriorating water quality and the occurrence of large accumulations of algae or algal blooms primarily during summer and fall. Tug Lake has been listed as an impaired waterway by the Wisconsin Department of Natural Resources since 2010 due to mercury contamination of fish (Wisconsin Department of Natural Resources 2018). It remains a low priority lake in the Total Maximum Daily Loads program for mercury contamination. The Wisconsin DNR also considers it a eutrophic lake.

A meeting was convened with members of the Tug Lake Task Force and the Miller Laboratory in the spring of 2017 in order to formulate a citizen- based monitoring campaign for the summer of 2017. These activities were planned in conjunction with a larger water quality study conducted by Cason & Associates (Berlin, WI). Our primary goals for the field season were to 1) determine the species of algae causing blooms in Tug Lake, 2) quantify the temporal

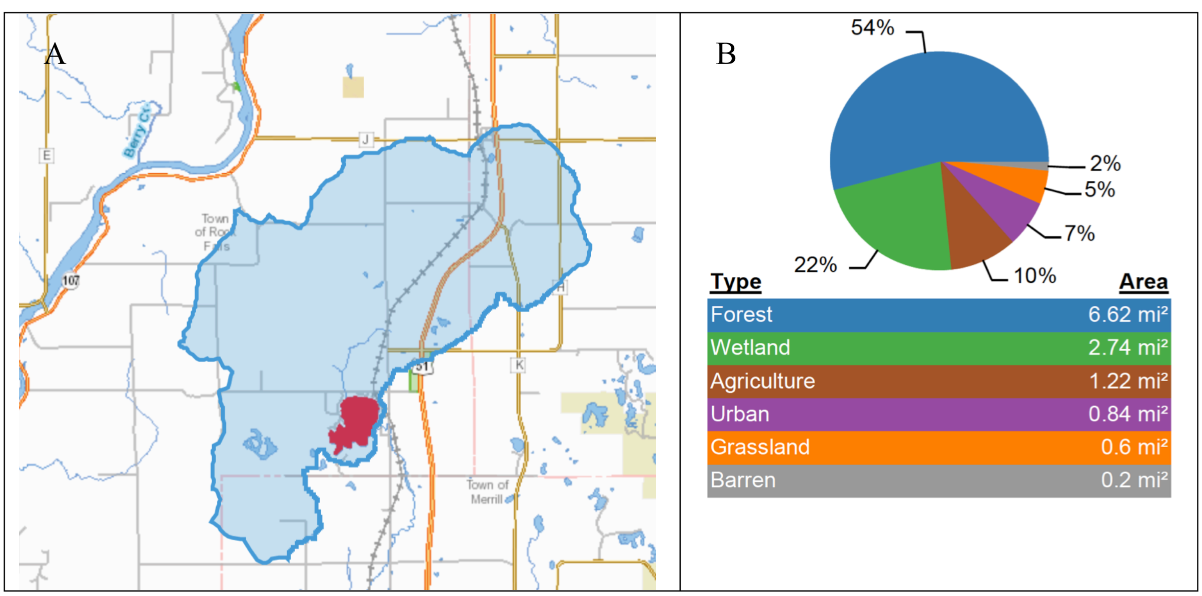

Figure 1. A) Tug Lake (red) and its watershed (blue). B) Land types in Tug Lake's watershed.

and spatial distribution of any toxins associated with the algae, and 3) deploy a continuous monitoring station capable of measuring water quality parameters in near- real time. Results from these project goals were to be compared with other water quality monitoring activities conducted by Cason & Associates.

Methods

Sampling. Water sampling was conducted at the deep hole (DH) on a weekly basis and at other locations when algal blooms were present (Figure 2). Water was collected from the surface ("glug") in certified cleaned amber glass bottles filling the bottle half way, and stored frozen within two hours. Samples were then shipped frozen to the Miller Laboratory at the University of Wisconsin – Milwaukee in batches throughout the summer.

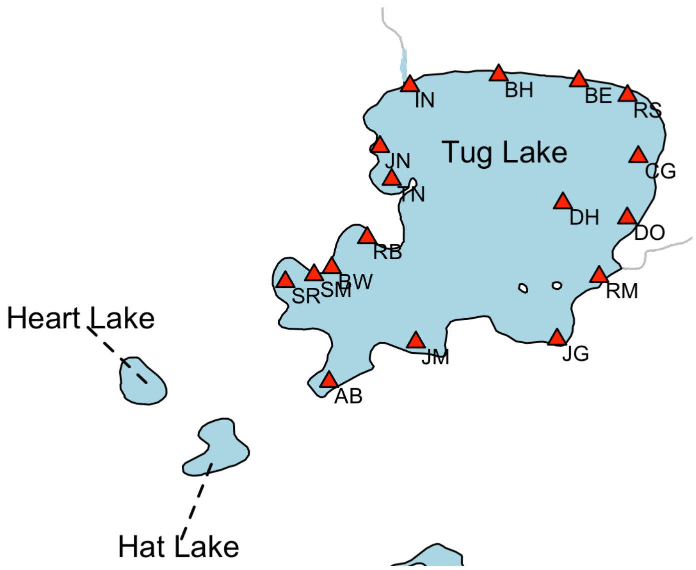

Figure 2. Sampling locations in Tug Lake

Identification of Bloom Species. Frozen samples were thawed at 4°C and qualitatively inspected under the microscope to identify the most abundant algae. While freezing is not an ideal preservation method for algae, given limited resources this allowed for identifying the most likely species causing blooms.

Algal Toxin Analysis. The most common species capable of producing toxins of human health concern in freshwater lakes are cyanobacteria or "blue- green algae." As such 17 different toxins produced by cyanobacteria were quantified in thawed water samples using liquid chromatography tandem mass spectrometry (LC-MS/MS) following chemical extraction in methanol as previously described (Beversdorf et al. 2017). Toxins targeted included

Table 1. Algal toxins targeted in this study

Cyanobacterial Toxins	Target Organ	Acute Effects	Chronic/Sub-Acute Effects
Microcystins (11 different types), Nodularin	Liver	Diarrhea, vomiting, rash, joint pain	Tumor promoter/cum. liver damage
Anatoxin-a/ & homoanatoxin-a, Saxitoxin & Neosaxitoxin	Nerve Synapse	Limb twitching, paralysis	Unknown
Cylindrospermopsin	Liver/ Kidneys	Diarrhea,vomiting, kidney failure	Mutagen and possible tumor initiator

the liver toxins microcystins, neurotoxins including saxitoxin, anatoxin-a and homoanatoxin-a, and the kidney toxin cylindrospermopsin (Table 1).

Total Phosphorus. Total phosphorus (TP) was measured in thawed samples using the ascorbic acid method after digestion with Valderrama's reagent (Valderrama 1981). TP was only measured in samples from the DH location.

Water Quality Monitoring Buoy. A continuous monitoring buoy (Nexsens CB-450 Data Buoy, Fondriest Environmental) equipped with water quality sensors was deployed at the DH location on July 7th, 2017. The sensors include a custom- made thermistor chain measuring water temperature at five depths (0 – 4 m), chlorophyll and phycocyanin algal pigment sensors (Turner C7), and an air temperature sensor. Water temperature data from the thermistor chain was recorded by a custom- made data logger and transmitted to a CR1000 Campbell Scientific data logger. All data was then sent to a computer in the Smith Laboratory at the University of Wisconsin – Milwaukee via cellular communication (Verizon network). All electronics are powered by a 55 amp-hour marine battery, which is charged daily by three 10- watt solar panels.

Results

Sampling effort. Sampling officially began on June 15 at site DH, however, a large bloom of *Dolichospermum* (formerly known as *Anabaena*) was observed two days earlier on June 13 with highest biomass located in and around site AB and JM (Figure 3). As such a sample of this bloom was taken from these sites on June 13th. A total of 39 samples were taken for laboratory analyses. Of these, 26 were weekly samples from the DH location. Others were near shore bloom samples at sites indicated in Figure 2, however not all sites were sampled. These sites may be sampled in future studies.

Figure 3. Algal bloom caused by *Dolichospermum* in AB ("Airplane Bay") on June 13, 2017.

Table 2. Summary of Microcystin Detections at Sites in Tug Lake 2017 (red = detected)

Site	#	Date(s)	Mean or Amount (µg/L)	Microcystin Types Detected									
				dm LR	LA	LF	LR	RR	LY	LF	LW	YR	Hil R
DH	26	6/15 – 10/11	27	■	■	■	■		■				
AM	1	6/13	17.7		■								
BH	3	6/16/, 6/19, 7/6	10.0		■								
JG	1	6/13	52.0		■		■	■				■	
AB	1	6/13	6.3		■								
Dock	1	8/29	4,261		■	■	■		■		■		■
CG	1	9/13	44.6		■		■		■				
JM	1	9/10	3,905	■	■	■	■		■		■		■
DO	1	9/7	2,860	■	■		■		■	■	■		■
TN	1	8/29	42.7		■		■		■				
BayRd	1	6/21	52.0		■		■	■				■	

Toxins Detected. Of the 17 toxins targeted, 9 were detected in at least one sample and all were one of several types of microcystin liver toxins (Table 2). Total microcystin concentrations ranged from 6 to >4,000 µg/L. The greatest diversity and highest concentration of toxins was detected in bloom samples from three near shore sites (Dock, JM, and DO). The majority of samples were taken from the DH location, which allows for a temporal analysis at this site. Concentrations of microcystin at the DH were relatively low when sampling began in early June (Figure 4). The mean concentration from June through mid- August was approximately 2.5 µg/L. In mid- August the concentration of microcystin at the DH location increased rapidly over a two week period to over 20 µg/L and remained relatively high over 4 µg/L for the remainder of the sampling season until sampling ended on October 11th, 2017. One sample during this period was an outlier at over 500 µg/L microcystin on September 9th.

The United States Environmental Protection Agency's draft recreational water quality limits for microcystin in lakes is 4 µg/L. Swimming is not recommended in waters above this limit and any lake with concentrations above this limit for 10% or more of the recreational season (generally Memorial Day to Labor Day in temperate lakes) are considered impaired for recreation. During the 2017 recreational season 34% of sampling days in Tug Lake had greater than 4 µg/L microcystin and the average concentration of microcystin at all locations was above 4 µg/L indicating that Tug Lake is impaired for recreation due to the presence of algal toxins. As such in-water activities where accidental ingestion may occur (e.g. swimming, water skiing, jet skiing) is not warranted.

Results from the Data Buoy. The buoy was deployed and recording data from July 7th until October 2nd and made 125,517 sampling events resulting in over 3 million data points (Figure 5). During the initial period when the buoy was deployed the lake was strongly stratified for several weeks from July 7th until the end of July. The lake rapidly mixed between August 3rd and August 4th. Soon afterwards the lake quickly stratified again on August 5th and remained weakly stratified for much of August until a strong mixing event occurred again on September 6th. The lake slowly re-stratified throughout much of September before decreasing air temperatures resulted in the fall mixing event beginning on September 29th.

Chlorophyll and phycocyanin algal pigments as recorded by the buoy fluorometer sensors indicated that approximately 4 bloom events occurred. One bloom was in progress when the buoy was deployed and algal pigments were decreasing. Dolichospermum likely caused this bloom. A small brief bloom of *Microcystis* was recorded on or around July 28th. A larger and longer lasting bloom of *Microcystis* occurred August 18 – September 4th before the largest bloom of *Microcystis* beginning on approximately September 22nd.

Microcystin toxin concentrations largely vary with the algal pigment data. However, there were some notable discrepancies. For example, toxins were nearly undetectable on July 13th, but algal pigments were still moderately high and as pigments were decreasing on July 21st microcystin toxin concentrations increased to nearly above the EPA recreational limit. Perhaps most importantly, the highest recorded microcystin toxin concentration at the DH location occurred during a non- bloom period.

Total Phosphorus. TP at the DH location was highly variable. For the majority of sampling dates TP was less than 0.1 mg/L. However, on three occasions TP increased to well above 0.5 mg/L on August 13th, August 29th, and September 7th. All three of these occasions occurred after the first mixing event was recorded by the buoy. This may indicate that mixing played a role in delivering phosphorus from bottom waters to the surface waters at the DH location.

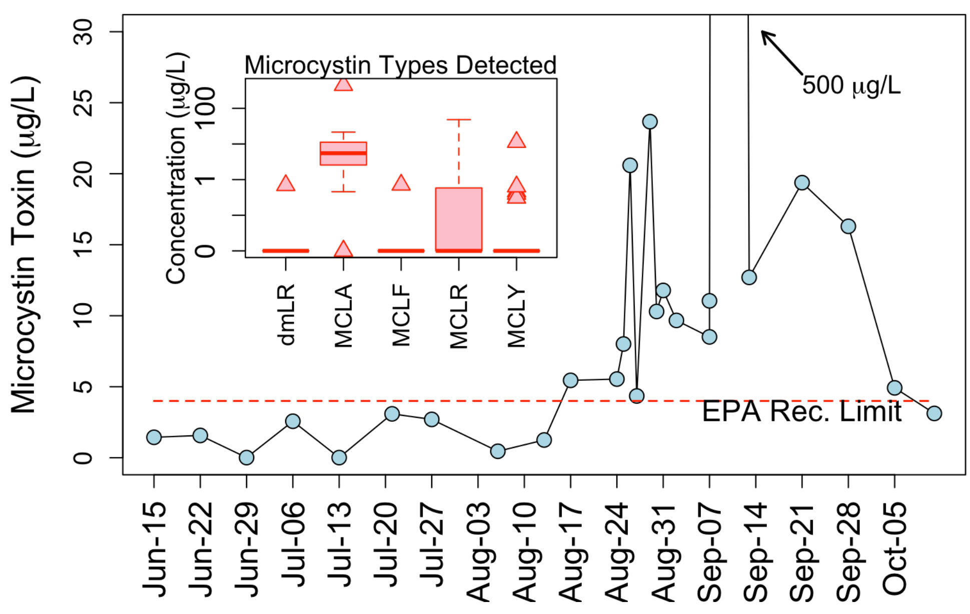

Figure 4. Trends in microcystin concentrations in Tug Lake at the Deep Hole location. Results indicate the sum of all microcystin types detected. The inset

Discussion

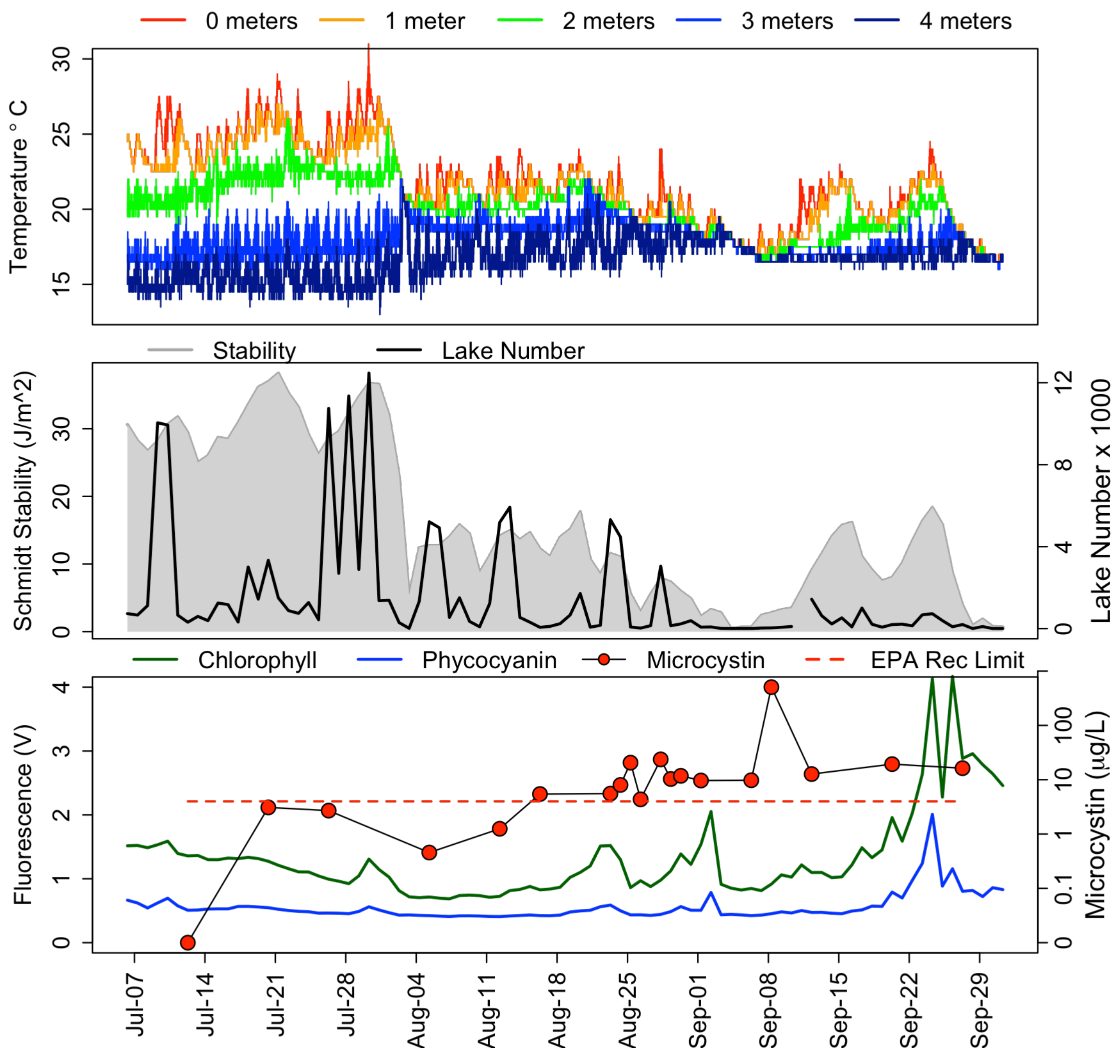

Figure 5. Top) Water temperature at five depths, Middle) Stability indices Schmidt Stability or energy required to mix the lake and Lake Number, which indicates if the lake is mixing. Higher numbers for both indicate lake stratification, Bottom) Algal pigment fluorescence and microcystin toxin concentrations.

The occurrence of cyanobacterial toxins is often related to other factors occurring in the lake including the amount of algae and type of species present, water temperature, water temperature by depth or water column stratification, and the presence of nutrients for algal growth such as nitrogen and phosphorus. Some of these environmental factors may change rapidly over the course of minutes to hours. These changes would typically be missed when manually sampling by boat. The data buoy was deployed in an attempt to measure some of these environmental factors in near – real time, continuously.

Water temperature measured at depths from the surface down to below the thermocline indicate the degree to which the lake is stratified or mixed. When lake water is warmer at the surface compared to deeper waters the lake is said to be thermally stratified setting up a density gradient. When there is a strong temperature difference, particularly in eutrophic lakes or stained lakes like Tug, bottom waters (i.e. the hypolimnion) may become oxygen depleted (hypoxic), anoxic (no oxygen), or anaerobic (no oxygen and no nitrate). In order for the lake to become

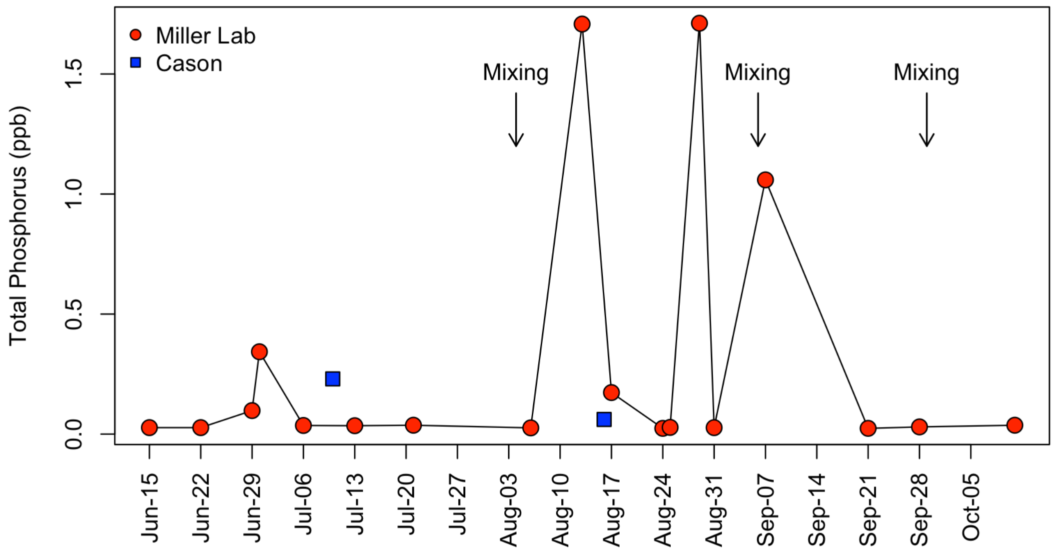

Figure 6. Trends in total phosphorus concentrations at the Deep Hole location.

mixed and de-stratified energy must be applied, usually in the form of wind and waves, or rapid cooling of surface waters, such as occurs in the fall. The amount of energy required to mix the lake can be expressed in units as Joules per cm squared and is given by the Schmidt Stability equation (see Figure 5).

The results of the buoy thermistor data indicate that Tug Lake is a polymictic lake, mixing more than two times per year. Most lakes in temperate environments undergo mixing events in spring due to ice and snowmelt whereas the fall mixing event occurs due to decreasing sunlight and air temperatures. Lake mixing that occurs between the spring and fall mixing events could be due to one of many factors including strong wind speed, waves, and rainfall. Neither wind speed nor storm events or precipitation correlate with the two mixing events recorded by the buoy thermistor chain in Tug Lake in 2017. However, several strong thunderstorms did occur during the deployment period with heavy rains and wind. It's possible mixing occurred due to a surge in groundwater seepage, but only after aquifers are fully recharged. In general groundwater seepage into lakes is correlated with rainfall (Downing and Peterka 1978). Alternatively, it's also possible that changes in cloud cover and solar irradiation may be important drivers of these mixing events.

Mixing may be a mechanism to bring nutrients from the bottom waters in the lake up into sunlit layers where they feed algae. Insufficient quantities of nutrients including nitrogen and phosphorus are most often responsible for limiting algal growth in lakes. Since some cyanobacteria have the ability to obtain nitrogen from air, their growth is most often limited by a lack of phosphorus. If sufficient quantities of phosphorus enter the lake then algal growth may ensue assuming other conditions are optimal (such as water temperature). If enough phosphorus is supplied and conditions are optimal then an algal bloom may occur. Since increases in TP occurred after the first mixing event it is possible that the large spikes in TP (Figure 6) originated from the bottom waters of Tug Lake. The lake had been well stratified for several weeks or longer. The data from Cason & Associates suggests this resulted in bottom water oxygen depletion and increases in phosphorus release from sediments due to diagenesis.

Conclusions:

1. *Microcystis* and *Dolichospermum* were the dominant species present in algal blooms in Tug Lake. While Tug Lake is stained with tannic acids, the pH data recorded by Cason & Associates is still within an optimal range for growth of these cyanobacteria. Given this and the eutrophic nature of the lake the occurrence of blooms of these two species is not remarkable.
2. The liver toxin, microcystin was the dominant toxin detected. Concentrations varied from 6 - >4,000 µg/L, well above the EPA recreational guideline value of 4 µg/L. Over 10% of sampling days had concentrations above this limit. As such Tug Lake is impaired for in-water recreational activities. Fish consumption may also carry some risk, but this has not been evaluated.
3. The lake mixed at least three times during the open water season indicating that it is a polymictic lake.
4. Total phosphorus spiked to above 0.5 ppb on at least three occasions after the first mixing event recorded by the buoy.

Recommendations:
The data from Cason & Associates study does not indicate that phosphorus from surface runoff in spring is a significant source of eutrophication in the lake. Under-sampling in the Cason study likely underestimated chlorophyll concentrations and the full extent of algal bloom activity in Tug Lake, which is not uncommon since blooms can form rapidly and decay. Photos of algal blooms in the lake taken by residents (Figure 3) in conjunction with the very high microcystin concentrations are evidence that toxic algal blooms in the lake are problematic, despite a lack of high spring phosphorus input. It should be noted that nitrogen concentrations reported by the Cason & Associates study does not suggest that cyanobacterial growth would be limited by nitrogen. Thus, since phosphorus in this case is the key nutrient fueling algal blooms, it is likely that another source of phosphorus is entering the lake at times other than during the spring snowmelt and from sources other than runoff.

There are two other obvious sources of phosphorus to investigate. These include 1) internal phosphorus release from sediments during periods of thermal stratification of the water column, and/or 2) phosphorus within groundwater seepage into the lake. The former was detected in the Cason study but not fully characterized. It is not clear what percentage of algal growth can be attributed to phosphorus release from sediments. In the latter, seepage may contain phosphorus that entered groundwater from various surface water sources. In the absence of intense agricultural land usage in the watershed (Figure 1) the most obvious source of phosphorus in groundwater seepage is from residential activities around the lake (e.g. lawn fertilizers, grey water input) or from wastewater as a result of faulty septic systems. Given these conclusions the following recommendations are offered:

<u>Recommendation 1</u>: Characterize the extent of bottom water oxygen depletion and phosphorus release from sediments in combination with the mixing regime of the lake.

<u>Recommendation 2</u>: Quantify the concentration of wastewater indicators in Tug Lake relative to a nearby control lake lacking a significant amount of septic systems such as Heart or Hat Lake.

The goal of these recommendations is to identify potential sources of nutrients to the lake that are responsible for causing toxic algal blooms.

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