Douglas Lake: 2024 Shoreline Survey

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Tip of the Mitt Watershed Council

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Table of Contents

List of Figures

List of Tables

Summary

In the spring of 2024, Tip of the Mitt Watershed Council (hereafter referred to as the Watershed Council) contracted with Douglas Lake Improvement Association (hereafter referred to as DLIA) to conduct a shoreline survey on Douglas Lake in the summer of 2024. This shoreline survey project is also funded in part by the Michigan Department of Environment, Great Lakes, and Energy's (EGLE) Nonpoint Source Program by the United States Environmental Protection Agency. In 2021, the Watershed Council acquired funding from EGLE to address poor shoreline management and weak water resource protection ordinances within the Burt Lake Watershed. Thus, through funding generously provided by DLIA and EGLE, the shoreline of Douglas Lake was fully surveyed and assessed for algal growth and density, erosion severity, degree of parcel development, shoreline alterations, and greenbelt status. Documenting this data, on an individual parcel status, expedites the understanding of inland lake shoreline conditions and their subsequent impact on water quality. The invaluable lake data generated via the shoreline survey can be used to assess long-term trends in shoreline health and protect and maintain the high-quality waters of Douglas Lake.

Introduction

The shoreline survey conducted on Douglas Lake was partially funded by a Nonpoint Source Pollution Control project through the Michigan Department of Environment, Great Lakes, and Energy's Nonpoint Source Program by the United States Environmental Protection Agency under assistance agreement 2020-0025 to Tip of the Mitt Watershed Council for the project titled *Protecting High-Quality Water Resources in the Burt Lake Watershed*. The contents of the document do not necessarily reflect the views and policies of the United States Environmental Protection Agency or the Department of Environment, Great Lakes, and Energy, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use. A shoreline survey was last conducted on Douglas Lake in 2015.

Background

During the summer of 2024, a shoreline survey was conducted on Douglas Lake by Tip of the Mitt Watershed Council to fully survey the shoreline conditions on a parcel-by-parcel basis. The shoreline conditions surveyed included those that could potentially affect the water quality of Douglas Lake, and its surrounding watershed, in negative ways. The parameters surveyed function as indicators of poor or declining water quality, and include the following: *Cladophora* growth, erosion severity, shoreline alterations, greenbelt presence/absence, parcel development status, and tributary inlets/outlets. This report will compare the 2024 survey results to the 2015 report to assess changes in lake-wide riparian management, track the progression of shoreline parcel development, and determine appropriate next steps for the best management of the shoreline of Douglas Lake.

The 2024 survey provides a comprehensive dataset documenting the shoreline conditions of Douglas Lake. This dataset not only serves as a tool for future lake management, but provides a valuable point of comparison as lake shoreline conditions inevitably continue to change. The results of the shoreline survey, in combination with localized restoration and water quality protection efforts, can identify and address lake water quality issues. Addressing identified issues is often simple and inexpensive; actions such as installation of greenbelts or rain gardens, reducing or eliminating the use of fertilizers and pesticides, and practicing proper septic system maintenance can mitigate shoreline degradation and support healthy waters. Furthermore, by publicizing the shoreline survey results, and making individual property owners aware of their shoreline conditions, further shoreline damage can be prevented. Finally, repetition of lake shoreline surveys is recommended every 5-10 years so that problem sites can adequately be addressed, long-term trends in development can be tracked, and implemented solutions to shoreline and water quality problems can be properly evaluated.

Shoreline Development Impacts

Lake shorelines serve as the intersection between the land and water—they represent the crux between human impact and delicately balanced aquatic ecosystems. When shorelines undergo development for myriad uses, the landscape and lakes experience change. Natural vegetation is removed, permeable surfaces decrease, erosion susceptibility increases, and large structures/utilities become the point of focus. Furthermore, development of Douglas Lake, and of northern Michigan's watersheds in general, has risen in recent decades. The previously more remote region of Michigan's northern lower peninsula has experienced increased use, whether from permanent settlement or tourism. This change in development and land use is notable, and should be kept in mind when considering impacts on aquatic ecosystems and the overall health of the environment. Higher levels of development will inevitably bring increased human activity. These activities have consequences – nutrient pollution and algal blooms, erosion of riparian zones, stormwater runoff, contamination from oils, gases, and road salts, pet waste, and even septic system leachate – are all potential issues resulting from shoreline degradation.

Elevated Nutrients and Aquatic Plant Growth

While nutrients such as phosphorus and nitrogen are essential within freshwater ecosystems, concentrations of these elements in excess can stimulate unwanted, and unnatural, algal and aquatic plant growth. Aquatic macrophytes (i.e. large plants that can be seen with the naked eye, whether floating, emergent, or submergent) may become more abundant, causing issues with recreational activities. Unnatural plant or algal growth may also affect habitat availability, composition of food sources, and levels of dissolved oxygen in the water column. Furthermore, unchecked algal blooms can become hazardous if they contain cyanotoxins that are harmful to human and animal health. Some toxic algal blooms produce hepatotoxins (toxins that damage the liver) and others can produce neurotoxins (toxins that damage the brain and spinal cord). In addition to posing health risks, algal blooms can be unsightly and a nuisance to recreational activities. Chemical changes to inland lakes can occur when dissolved oxygen concentrations are affected. Uncontrolled growth of both aquatic macrophytes and algae can deplete dissolved oxygen levels, as all living organisms within a lake compete for limited oxygen sources. Though Douglas Lake is relatively large (with a surface area of 3,727 acres), and is thus less susceptible to nutrient pollution/excessive plant growth occurring at the macroscale, elevated concentrations and growth can still exist at the shoreline, and should be properly addressed when and if they do.

Cladophora

Biologically, nutrient pollution can be detected along the lake shore by noting the presence of Cladophora algae. *Cladophora* is a branched, filamentous green algal species that occurs naturally in small amounts in northern Michigan lakes. While not harmful to humans or wildlife, its occurrence is dependent on specific conditions. *Cladophora* requires shallow waters, stable substrate (rocks, logs, seawalls, etc.), and warmer water temperatures (50-70° F). It typically blooms during the summer months in Michigan, and proliferates in response to elevated nutrient influx. Thus, it is an optimal bioindicator of nutrient pollution along the shoreline.

Erosion and Greenbelts

Erosion can occur as a direct result of shoreline degradation. Decreased stabilization of soils occurs when deep-rooted vegetation is removed or natural areas transition to impervious surfaces. Additionally, stormwater runoff that flows through eroded soils can bring with its numerous contaminants and spur sedimentation. Sedimentation causes issues for wildlife – it can obstruct gill function of fish and macroinvertebrates, blanket fish spawning habitat, and increase turbidity – hindering organismal function. Fortunately, much of the issues caused by erosion and stormwater runoff can be reduced or prevented through the presence of greenbelts.

Greenbelts are strips, or buffers, of vegetation occurring along lake shorelines. They are typically composed of native plants with intricate, lengthy root systems. Greenbelts stabilize soils, capture stormwater runoff, filter nutrients and other contaminants before they reach the water, and protect against wave energy and icy conditions. Greenbelts provide wildlife habitat, attract pollinators, and deter nuisance species such as geese. They even add aesthetic value to riparian properties. Greenbelts were just one of many shoreline parameters examined in the Douglas Lake shoreline survey due to their potential for minimizing shoreline degradation.

Presence of Tributaries

Tributaries carry waters from the surrounding geographic region, or watershed, into lakes. While tributaries demonstrate how interconnected our water resources truly are, they also have the potential to contribute polluted waters to previously healthy aquatic ecosystems. Shoreline surveyors look for presence of tributaries to understand if waters with elevated nutrients or stormwater contaminants could be affecting the health of a particular parcel.

Study Area

Douglas Lake is a relatively large, well-known lake located in northwestern Cheboygan County in the northern half of Michigan's lower peninsula (Figure 1). Douglas Lake is known as a kettle lake, meaning it was formed by the retreat of glaciers thousands of years ago. The lake is part of the larger Cheboygan River Watershed, which encompasses 900,000 acres of freshwater resources and is the largest watershed in the Watershed Council's service area. Douglas Lake has a surface area of 3,727 acres and a shoreline that is 15 miles in length. It reaches a maximum depth of 80 feet (Figure 2). Established populations of Zebra and Quagga mussels can be found within the Douglas Lake's waters. No aquatic invasive plant species have been identified thus far.

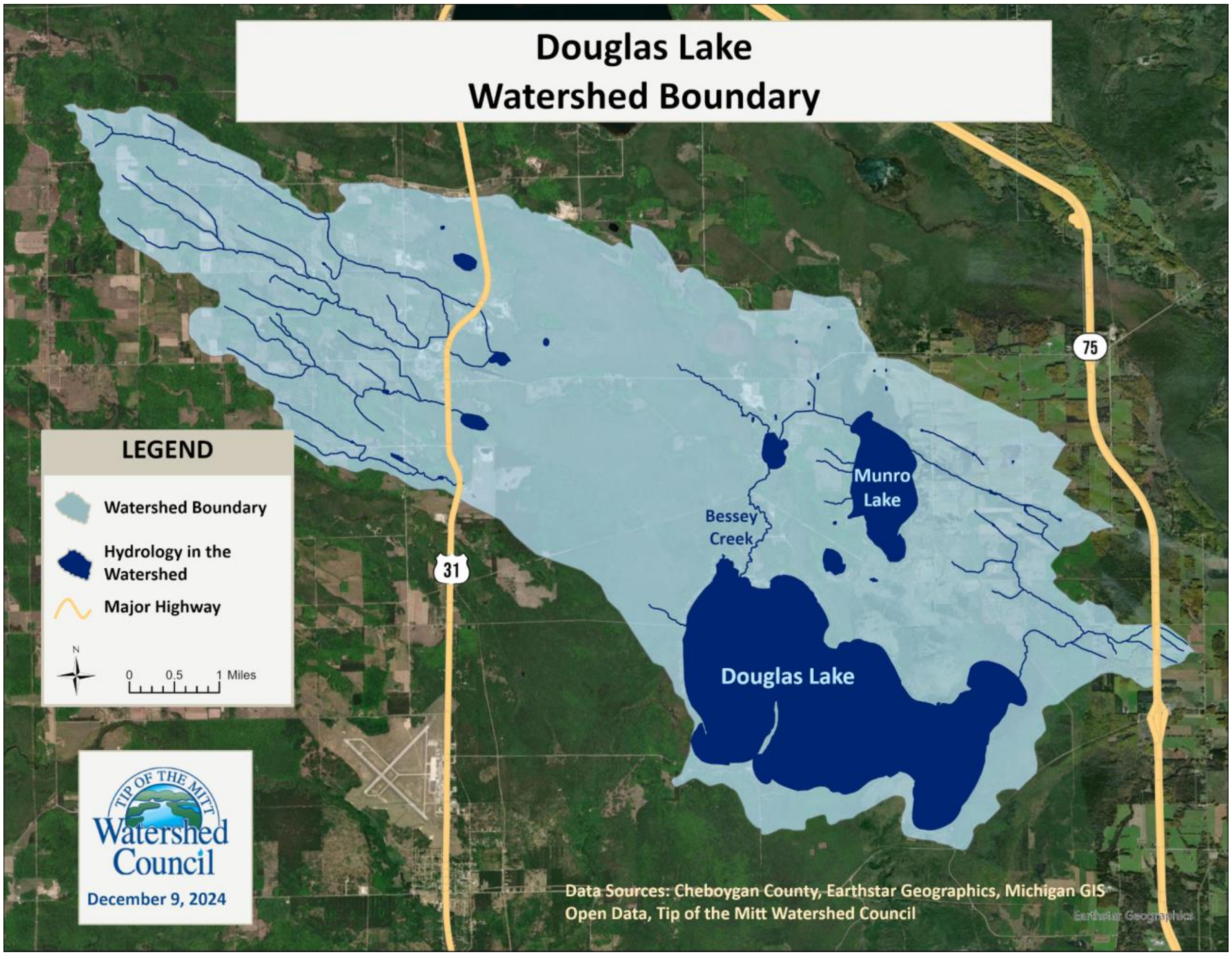


Figure 1. The Douglas Lake Watershed.

Notable landmarks of Douglas Lake include Marl and Maple Bays to the west, Pell's Island, and North and South Fishtail Bays to the east. Major tributaries of Douglas Lake include Bessey Creek and Beavertail Creeks to the northeastern and northwestern shores, respectively, and the East Branch of the Maple River. Douglas Lake is developed along the western shoreline, but relatively untouched in the Fishtail Bay areas. Douglas Lake is also home to the University of Michigan Biological Station, a scientific research facility that investigates topics ranging from limnology to ethnobotany.

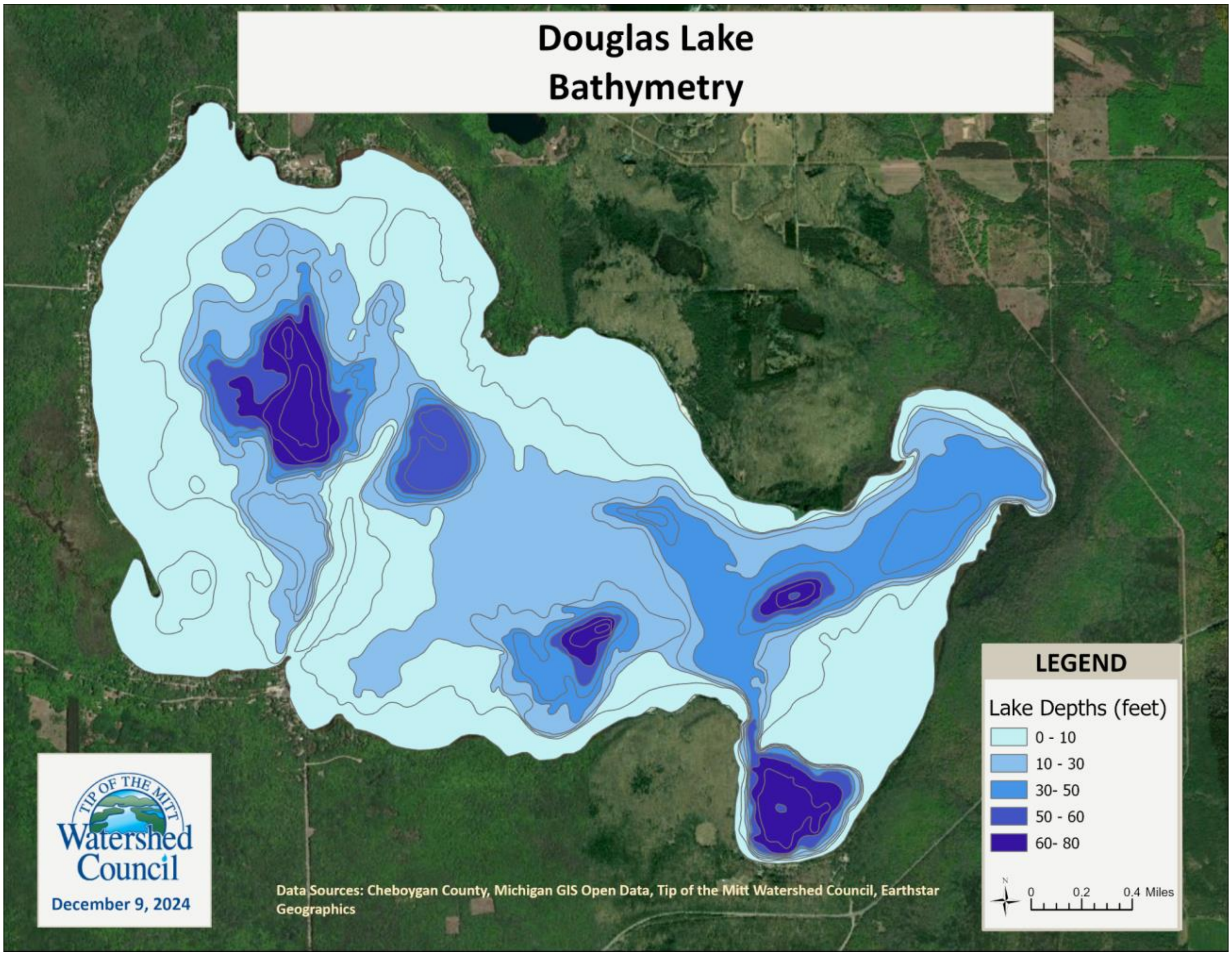


Figure 2. A Bathymetric Map of Douglas Lake.

Land cover in the Burt Lake Watershed (of which the Douglas Lake Watershed is a subwatershed of) has remained relatively unchanged over 31 years (1985-2016, Table 1). Land cover classifications such as 'Water', 'Wetland', 'Urban Development', and 'Barren' have changed only minimally. 'Forest/Grassland/Shrub' land coverage increased by 1%, and 'Agricultural' land coverage decreased by 2%.

Table 1. Land Cover Change in the Burt Lake Watershed, 1985-2016.

Land Cover Change				
	1985		2016	
Class Name	Acreage	%	Acreage	%
Agriculture	4853.256	17.73602	4361.953	15.94057
Barren	21.51625	0.07863	51.65526	0.188772
Forest/Grassland/Shrub	8505.444	31.08278	8822.485	32.24139
Urban Development	418.6159	1.529814	502.6465	1.8369
Water	4433.45	16.20185	4450.175	16.26298
Wetland	9131.563	33.37091	9174.931	33.52939
Total	**27363.85**		**27363.85**	

Comprehensive Water Quality Monitoring

Douglas Lake has been monitored every three years from 1987-2022 through the Watershed Council's Comprehensive Water Quality Monitoring (CWQM) Program for dissolved oxygen, temperature, specific conductivity, pH, total nitrogen, total phosphorus, and chloride levels.

Phosphorus, Nitrogen, and Chloride

Aquatic nutrients, such as total phosphorus and total nitrogen, are important chemical parameters that form the foundation of all freshwater ecosystems. Total phosphorus is an essential aquatic nutrient required by algae and rooted aquatic plants to facilitate their growth and reproduction. Total phosphorus predicts both biological productivity and current trophic states of freshwater bodies. It can be used to determine whether nutrient pollution is occurring, and to what extent. Nutrient pollution can not only cause increased aquatic plant and algal growth, but can contribute to decreased water clarity, depleted levels of dissolved oxygen, mucky lake bottoms, unstable food chains, hypoxic zone formation, and death of benthic organisms.

Total nitrogen is another essential nutrient found in aquatic ecosystems. Nitrogen contributes to the growth of algae and plants, which provide wildlife habitat. Similar to total phosphorus, excess levels of nitrogen are indicative of a eutrophic ecosystem. Nitrogen-heavy waters may reflect environmental disturbances or anthropogenic activities, such as fertilizer use, stormwater runoff, or wastewater leakage from malfunctioning septic systems.

Chloride occurs naturally in freshwater, and is needed by aquatic organisms to carry out basic life functions. However, excess levels of chloride (whether from road salting, brining, drilling of gas and oil wells, or runoff) can pollute freshwater in many ways. For example, chloride can contaminate drinking water, can destabilize aquatic plant community structure, and can be toxic to amphibians and fish. Furthermore, chloride may cause soil to be more sensitive to erosion by affecting its ability to retain water, can corrode infrastructure, and may even cause death if ingested by wildlife.

Comprehensive Water Quality Monitoring Assessment Criteria

Below are the assessment criteria used for nutrient parameters sampled through the Watershed Council's CWQM program (Table 2). The assessment criteria are derived from the United States Environmental Protection Agency's (EPA) ambient water quality recommendations and the State of Michigan. Standard parameter values vary based on classification of waterbodies (i.e. lake or stream), type of parameter (i.e. type of nutrient, type of physical parameter, etc.), and EPA ecoregions and subecoregions. An ecoregion refers to specific areas where ecosystems are generally similar. A subecoregion refers to an ecoregion, but on a smaller geographic scale. Douglas Lake falls within subecoregion 50.

Table 2. Aquatic parameters measured as part of the Watershed Council's CWQM program.

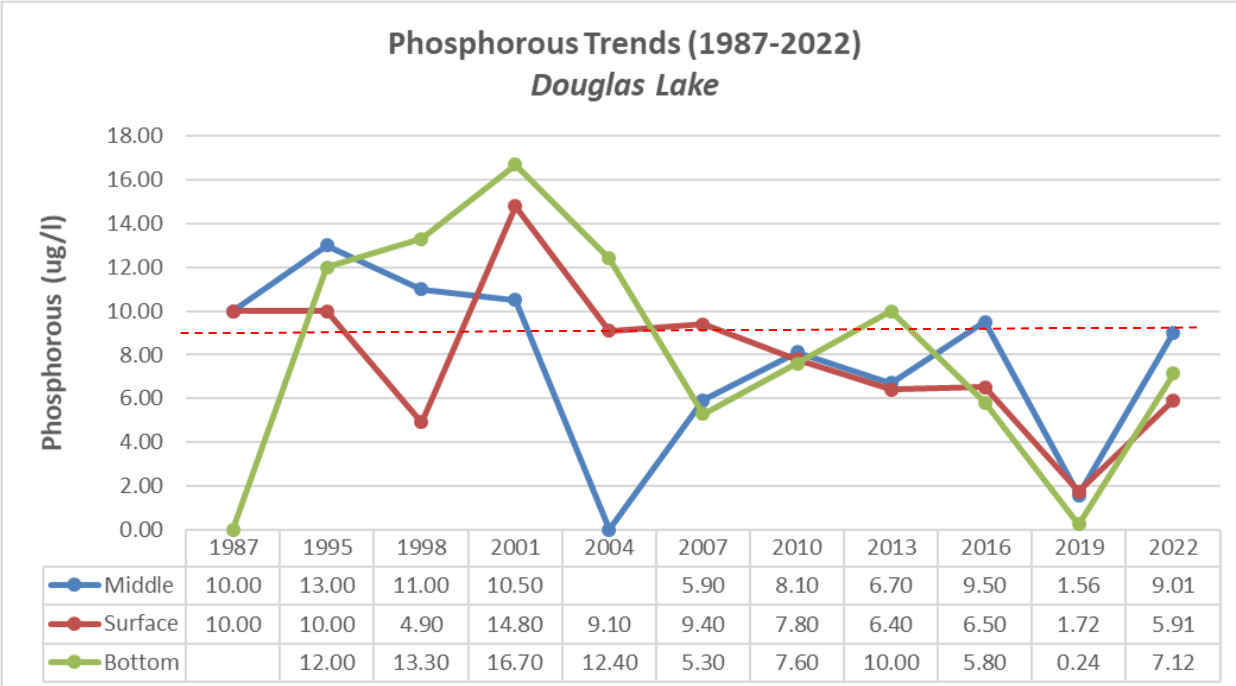
Total Phosphorus (micrograms per liter, or ug/L)	**Subecoregion 50:** 12 ug/L streams, 9.7 ug/L lakes
Total Nitrogen (micrograms per liter, or ug/L)	**Subecoregion 50:** Streams: 440 ug/L streams, 400 ug/L lakes
Total Chloride (milligrams per liter, or mg/L)	Aquatic Maximum Value: 320 mg/L

Comprehensive Water Quality Monitoring Results

Below are the results of water quality monitoring on Douglas Lakes through the CWQM program. Table 3 features the most recent physical data (i.e. depth, temperature, dissolved oxygen, specific conductivity, and pH) collected on both lakes in the year 2022 (the last time CWQM was conducted in the Cheboygan River Watershed). Figures 3-6 provide insight into long-term water quality trends on Douglas Lake beginning in the year 1987.

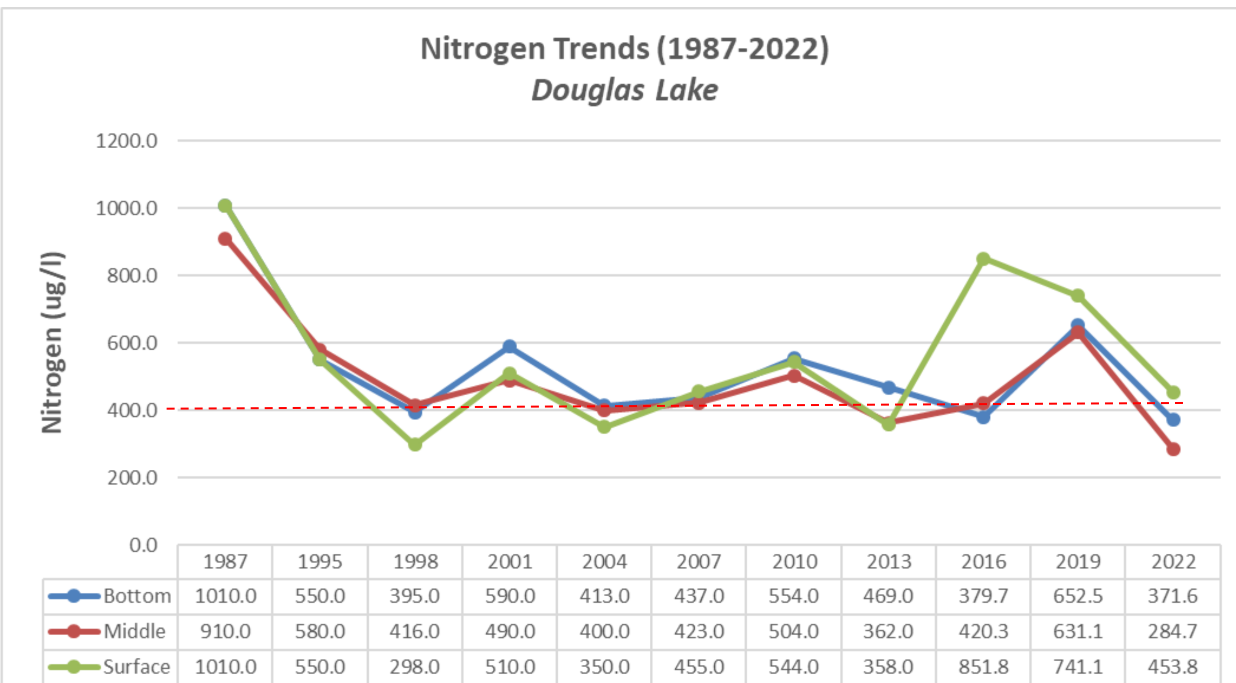
Table 3. Results of Comprehensive Water Quality Monitoring on Douglas Lake, 2022.

CWQM Site Name	Date	Depth (m)	Class	Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductivity (uS/cm^2)	pH
Douglas Lake	5/18/2022	0.61	Surface	15.50	10.87	224.70	8.45
Douglas Lake	5/18/2022	13.31	Middle	8.99	10.70	223.80	7.89
Douglas Lake	5/18/2022	24.52	Bottom	7.44	3.33	246.10	7.22



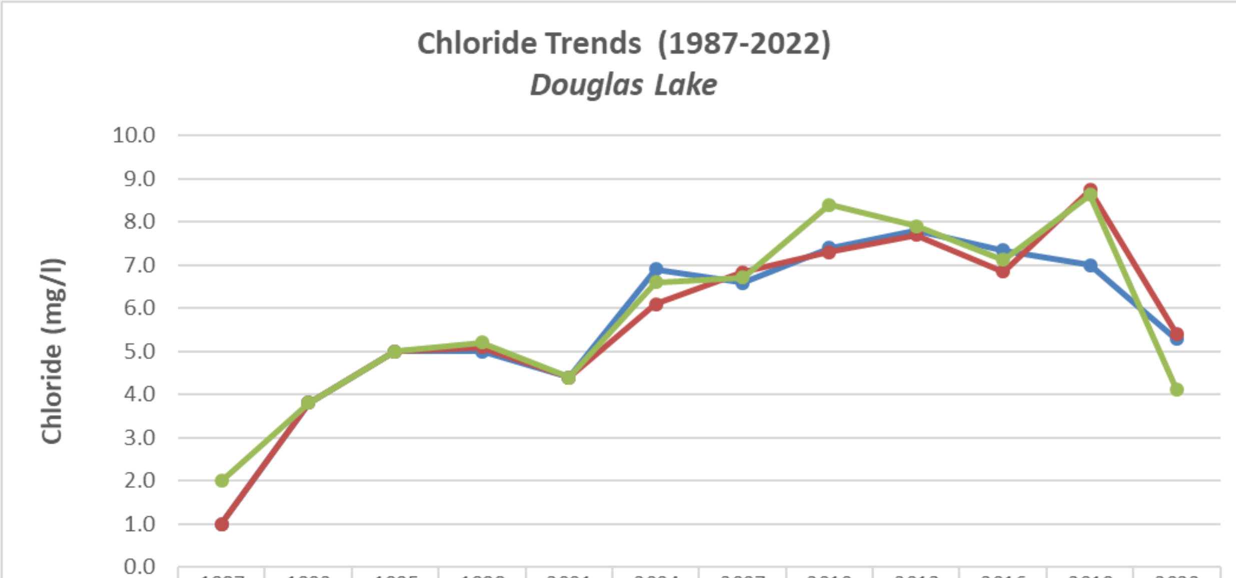
	1987	1995	1998	2001	2004	2007	2010	2013	2016	2019	2022
Middle	10.00	13.00	11.00	10.50		5.90	8.10	6.70	9.50	1.56	9.01
Surface	10.00	10.00	4.90	14.80	9.10	9.40	7.80	6.40	6.50	1.72	5.91
Bottom		12.00	13.30	16.70	12.40	5.30	7.60	10.00	5.80	0.24	7.12

Figure 3. Phosphorus trends in Douglas Lake, from 1987 - 2022, collected through the Comprehensive Water Quality Monitoring Program. Note: Red dashed line indicates EPA recommended maximum value (9.7ug/L).



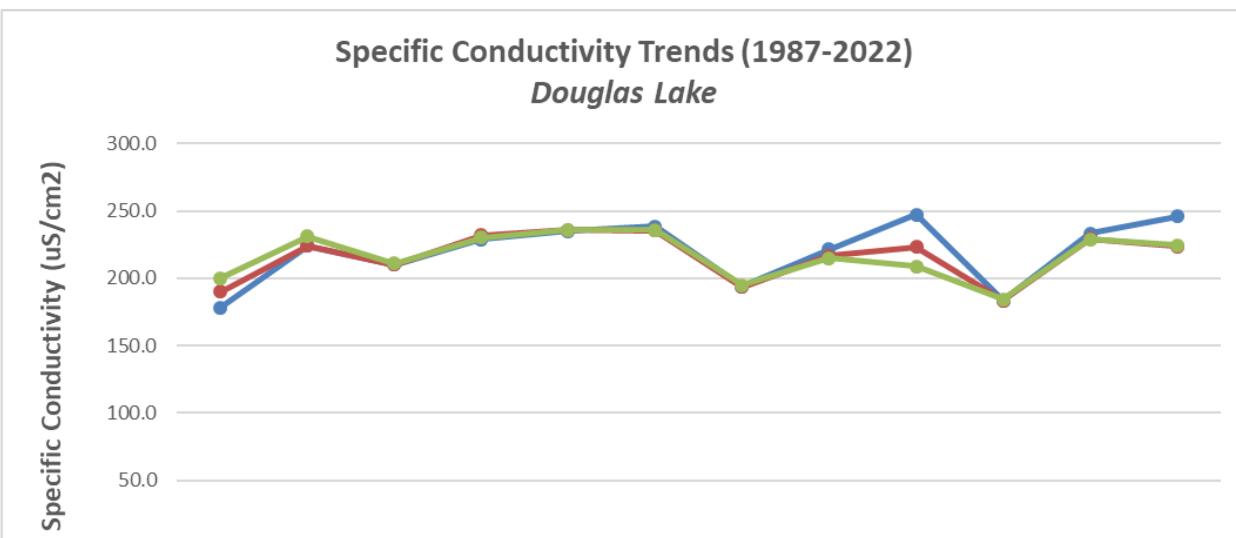
	1987	1995	1998	2001	2004	2007	2010	2013	2016	2019	2022
Bottom	1010.0	550.0	395.0	590.0	413.0	437.0	554.0	469.0	379.7	652.5	371.6
Middle	910.0	580.0	416.0	490.0	400.0	423.0	504.0	362.0	420.3	631.1	284.7
Surface	1010.0	550.0	298.0	510.0	350.0	455.0	544.0	358.0	851.8	741.1	453.8

Figure 4. Nitrogen trends in Douglas Lake, from 1987 - 2022, collected through the Comprehensive Water Quality Monitoring Program. Note: Red dashed line indicates EPA recommended maximum value (400 ug/L).



	1987	1992	1995	1998	2001	2004	2007	2010	2013	2016	2019	2022
Middle	1.00	3.80	5.00	5.00	4.40	6.90	6.59	7.40	7.80	7.35	7.00	5.28
Surface	1.00	3.80	5.00	5.10	4.40	6.10	6.84	7.30	7.70	6.85	8.74	5.41
Bottom	2.00	3.80	5.00	5.20	4.40	6.60	6.71	8.40	7.90	7.12	8.63	4.12

Figure 5. Chloride trends in Douglas Lake, from 1987 - 2022, collected through the Comprehensive Water Quality Monitoring Program. Note: Not noted by red line as levels are nowhere near the maximum (320 mg/L).



	1987	1988	1992	1995	2001	2004	2007	2010	2013	2016	2019	2022
Bottom	178.0	224.0	210.0	229.0	235.0	238.7	193.9	221.5	247.1	183.6	233.1	246.1
Middle	190.0	224.0	210.0	232.0	236.0	235.6	193.7	216.7	223.4	183.3	229.3	223.8
Surface	200.0	231.0	211.0	230.0	236.0	235.9	194.9	214.8	208.7	184.5	229.0	224.7

Figure 6. Conductivity trends in Douglas Lake, from 1987 - 2022, collected through the Comprehensive Water Quality Monitoring Program. Note: A suitable conductivity range to support freshwater fish populations is 150 - 800 uS/cm².

Based on the nutrient data collection from 1987 - 2022, phosphorus levels in Douglas Lake have shown improvement over time. Though there were multiple exceedances beginning with data collection in the 1980s, levels have fallen as time went on. Levels did fall below the recommended maximum in the year 2019. Nitrogen levels in Douglas Lake have also consistently breached the recommended maximum. The levels were relatively consistent from 1998 onwards until a large spike was observed. Chloride levels have increased from 1987 - 2019, with a recent decline in 2022. Chloride levels never approached the recommended maximum of 320 mg/L. Conductivity levels in Douglas Lake were within an acceptable range throughout the course of data collection for freshwater organisms. There was a small spike for surface, middle, and bottom-level conductivity around 2013, with levels reaching around 250 uS/cm^2.

Volunteer Lake Monitoring

Douglas Lake is also monitored on an annual basis for water clarity (Secchi) and chlorophyll-*a* data through the Watershed Council's Volunteer Lake Monitoring (VLM) Program. Secchi disks are used to measure water clarity, or transparency, of a lake. Water clarity relates to overall nutrient levels and biological productivity (i.e. the clearer the water, the more nutrient-poorer), and thus, Secchi disks are used for general assessment of lakes worldwide. For example, clear, nutrient-poor lakes may have Secchi disk depths reaching up to 50 feet or more, and nutrient-heavy lakes with excess algal blooms may be invisible just a few feet below the water's surface.

Chlorophyll-*a* is a photosynthetic pigment found in all green plants, including algae. Chlorophyll-*a* concentrations can be used as a measure of algal biomass in freshwater ecosystems, and can provide an estimate of overall biological productivity, and thus, trophic state. Trophic state essentially refers to the level of biological productivity, and overall nutrient levels, observed in water bodies. Trophic state is commonly classified into four distinct categories: oligotrophic (nutrient-poor), mesotrophic (moderate nutrient levels), eutrophic (nutrient-enriched), and hypereutrophic (extreme nutrient enrichment). The median value of the summer chlorophyll-*a* monitoring results is used to calculate the Carlson Trophic Status Index (TSI) value for the lake, which is compared with the Secchi disk and total phosphorus TSI values for trophic status determination. The Carlson TSI uses an equation to calculate overall biological productivity and trophic state for any given waterbody (Table 5). Below are the assessment criteria used for all aquatic parameters sampled through the Watershed Council's VLM program (Table 4).

Table 4. Aquatic parameters measured as part of the Watershed Council's VLM program.

Parameter	Standard Value(s)
Chlorophyll-*a* (maximum value reported, in ug/L)	Oligotrophic = < 2.2 ug/L Mesotrophic = 2.2 - 6.0 ug/L Eutrophic = 6.0 - 22.0 ug/L Hypereutrophic = >22.0 ug/L
Water Clarity (Carlson Trophic Status Index (TSI))	Oligotrophic = ● Secchi disc depth: > 15.0 ft ● Chlorophyll-*a*: < 2.2 ug/L Mesotrophic = ● Secchi disc depth: 7.5 - 15.0 ft ● Chlorophyll-*a*: 2.2 - 6.0 ug/L Eutrophic = ● Secchi disc depth: 3.0 - 7.5 ft ● Chlorophyll-*a*: 6.0 - 22.0 ug/L Hypereutrophic: = ● Secchi disc depth: < 3.0 ft ● Chlorophyll-*a*: > 22.0 ug/L

Table 5. Trophic State and Corresponding Carlson TSI Values.

Trophic State	Carlson TSI
Oligotrophic	<38
Mesotrophic	38-48
Eutrophic	48-61
Hypereutrophic	>61

Below are the results of water quality monitoring on Douglas Lake through the VLM program. Figures 7-9 provide insight into long-term water quality trends on Douglas Lake beginning in the year 1986.

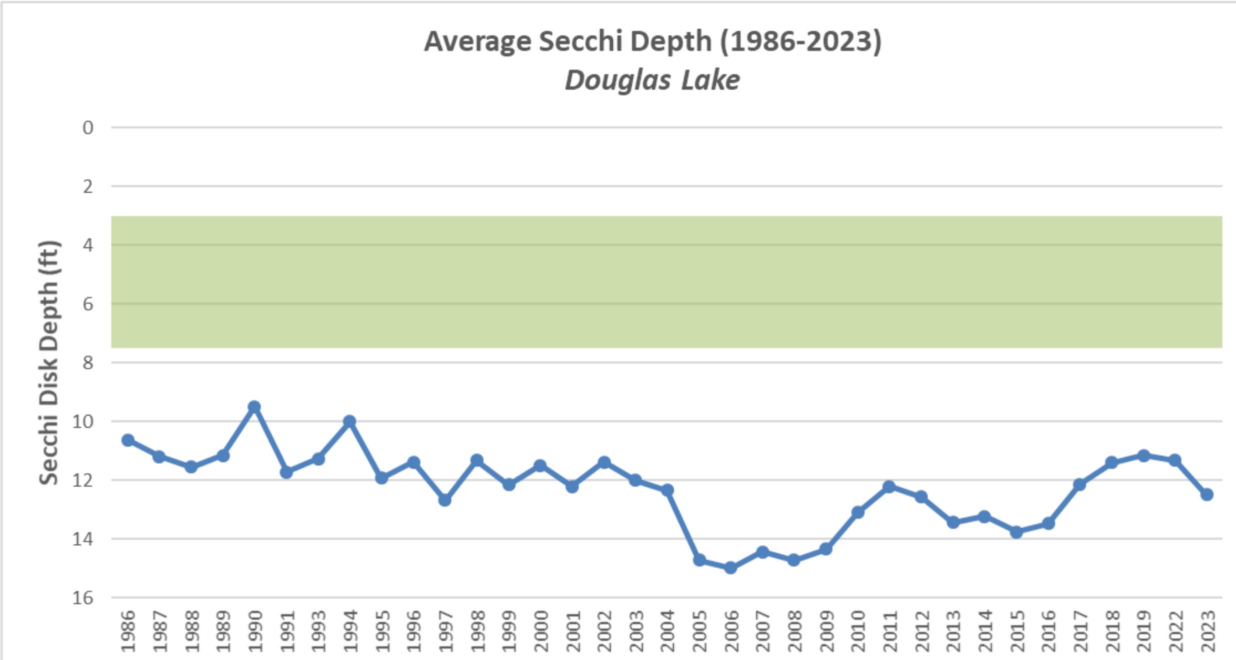


Figure 7. Secchi disc depth trends in Douglas Lake, from 1986 - 2023, collected through the Volunteer Lake Monitoring Program. Note: Green shaded region indicates a eutrophic ecosystem (Secchi depth readings of 3.0 feet to 7.5 feet). Readings less than 3.0 feet are indicative of a hypereutrophic ecosystem.

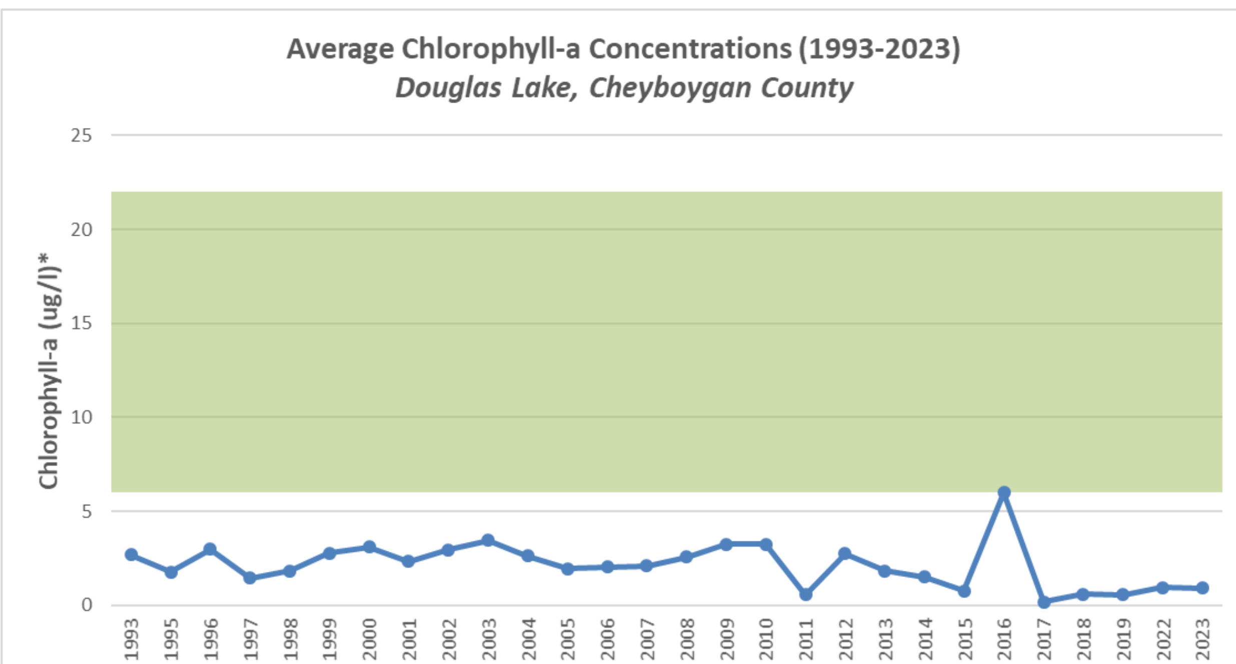


Figure 8. Chlorophyll-a trends in Douglas Lake, from 1993 - 2023, collected through the Volunteer Lake Monitoring Program. Note: Eutrophic conditions are indicative of chlorophyll-a concentrations at 6.0 ug/L and above (green shaded region). Levels exceed this threshold for this lake in the data reflected above.

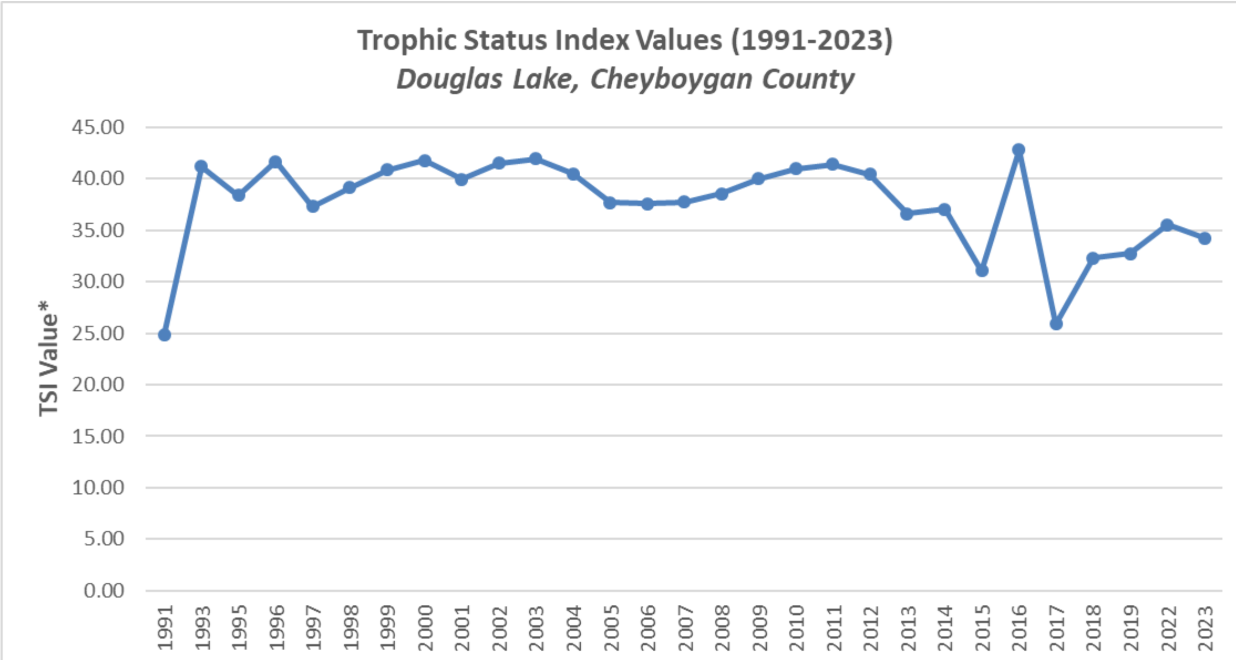


Figure 9. Trophic status index trends in Douglas Lake, from 1991 - 2023, collected through the Volunteer Lake Monitoring Program. Note: Eutrophic conditions are associated with a Trophic Status Index value of 48 or higher. Levels do not exceed this threshold for this lake in the data reflected above.

Secchi depth readings have increased since 2005 onwards, with depths reaching around 15 feet below the water's surface. Secchi depth data did not indicate eutrophic or hypereutrophic conditions throughout the entirety of data collection. Chlorophyll-*a* levels showed a spike in 2016 that just barely breached the threshold for eutrophic conditions (6.0 ug/L). However, levels were otherwise below the threshold, with a notable dip in the year 2011. Trophic Status Index values were below 48 for Douglas Lake, but values spiked in both 1993 and 2016. Aside from the spikes in the data, levels remained relatively steady.

Methodology

During the summer of 2024, the entire shoreline of Douglas Lake was surveyed to comprehensively document shoreline conditions. Shoreline conditions were surveyed by kayaking adjacent to the lake shorelines parcel-by-parcel. The following parameters were surveyed: *Cladophora* growth, substrate type, erosion, greenbelt status, shoreline alterations, and tributary presence. Data was recorded on iPads using ArcGIS FieldMaps. The data was linked with parcel data obtained from Cheboygan County equalization records.

Development

Parcels were categorized as 'developed', 'partially developed', or 'undeveloped'. Developed parcels were those with buildings, houses, or other permanent structures. These structures included roadways, boat launches, or recreational sites. Partially developed parcels referred to land with non-residential structures (driveways, sheds, etc.). Undeveloped parcels were those with no permanent structures and natural conditions.

Cladophora

Cladophora is able to be detected by the human eye, without the aid of a microscope, due to its distinct appearance, texture, color, and attachment to substrate. These were the only criteria on which identification of *Cladophora* was based upon. When *Cladophora* was noted, it was described by its length of occurrence along the shoreline, its relative density (Table 6), both of which were considered subjective estimates. Growth density was estimated by examining the percentage of substrate covered with *Cladophora* using the following categorization system:

Table 6. Categorization system for Cladophora density.

Density Category	Field Notation	Substrate Coverage
Very Light	VL	A green shimmer
Light	L	Up to 25% coverage
Light to Moderate	LM	25-49% coverage
Moderate	M	50-59% coverage
Moderate to Heavy	MH	60-74% coverage
Heavy	H	75-90%
Very Heavy	VH	90-100%

Cladophora growth is dependent on the presence of suitable substrate. Substrate types were examined and recorded during the shoreline surveys. Substrate types were recorded according to the following categories: M = soft muck or marl, S = sand, G = gravel (0.1” to 2.5” diameter), R = rock (2.5” to 10” diameter), B = boulder (>10” diameter), W = woody debris (logs, sticks), and MTL = steel bulkhead, barrels, etc. If a suitable substrate was present, or partially present, it was noted in FieldMaps.

Greenbelts

Greenbelts, i.e. strips of (typically) native vegetation, were characterized based on the length of shoreline they occupied, and the depth (in feet) that they extended from the shoreline landward into the parcel. Ratings for length ranged from zero to four while depth ranged from zero to three (Table 7). Overall scores were based on the following categorizations:

Table 7. Greenbelt Scoring Chart.

Score	Length (%)	Depth (feet)
0	Absent	Absent
1	<10%	<10
2	10-25%	10-40
3	25-75%	>40
4	>75%	N/A

Greenbelt ratings for the length and depth of the vegetation were summed to produce an overall score describing the status, or health, of the greenbelt. Scores of 0 were considered very poor, 1-2: poor, 3-4: moderate, 5-6: good, and 7: excellent.

Shoreline Alterations

Shoreline alterations were surveyed and recorded according to the abbreviations below. A bulkhead is a man-made structure, existing parallel to the shoreline, that contributes to shoreline hardening. Rip-rap is essentially a collection of rocks, or even large boulders, distributed among the shoreline.

Shoreline alterations were noted according to the categorizations below:

- SB = steel bulkhead (i.e., seawall)
- BB = big boulder rip-rap/bulkhead
- CB = concrete bulkhead
- RR = rock rip-rap
- G = groin (rock, concrete in water)
- BR = mixed boulder and rock rip-rap
- WB = wood bulkhead
- BS = beach sand
- BH = permanent boathouse
- DP = discharge pipe

Erosion

Erosion was noted based on visible evidence of undercut banks, crumbling or bare soils, visible tree roots, leaning or fallen trees, shoreline scalloping, recession, removal of vegetation for beach sand (fill or grooming), slumping sod, or even gullies from runoff. Erosion was categorized based on length of extent and severity (i.e. light, moderate, or heavy).

Tributaries

Tributaries were noted (Y = yes, N = no) on the field data sheets depending on presence/absence. Tributary presence was necessary to record, as tributaries may contribute to unwanted nutrient or stormwater pollution to Douglas Lake.

Aquatic Plants

Aquatic plants along the shoreline were documented for the following reasons: 1) they provide stability and prevent erosion, 2) they can provide wildlife habitat, and 3) they can indicate an issue with nutrient pollution if present in excessive amounts. Any aquatic plants growing within 20 feet of the shoreline were noted and categorized according to the following labels:

- E = emergent plants (ex. bulrushes, cattails, arrowhead, or pickerelweed)
- F = floating leaved plants ex. (white water lily or yellow pond lily)
- S = submergent aquatic plants (ex. pondweeds, watermilfoils, chara)

Comments

Additional information regarding parcel features, shoreline features, or any field notes recorded during surveying was entered into the database for future reference.

Data Processing

Within a software program called ArcGIS Pro, a feature class containing shoreline property outlines, along with ownership information, was obtained from Cheboygan County. Shoreline parcels were selected via the use of a 150-foot buffer around a shapefile of Douglas Lake. Fields for each survey parameter (i.e. erosion, greenbelt presence, shoreline alterations, etc.) were created within an attribute table. The created feature layer was uploaded to ArcGIS Online so that a form for offline data collection could be created. This offline data could then be accessed using ArcGIS FieldMaps – an extension of ArcGIS. Within the field, shoreline property parameters were comprehensively surveyed by taking photos of each parcel and noting all shoreline features in FieldMaps on Watershed Council iPads. Physical descriptions of each parcel were noted –

intended to describe notable physical features of specific parcels (e.g. large pine trees, a white, two-story house with a brick chimney, etc.).

When data collection in the field was completed, the data was synced to ArcGIS Online and then downloaded into ArcGIS Pro. Any existing discrepancies were resolved during data processing by reviewing comments from the field days. Any 'Null' values were changed to 'None' or '0' to facilitate data interpretation.

Results

A total of 328 parcels were surveyed on the perimeter of Douglas Lake in 2024.

Development

292 out of 328 total surveyed parcels (89.02%) were classified as 'Developed'. 31 parcels (9.45%) were categorized as 'undeveloped', and 5 parcels (1.52%) as 'partially developed' (Figures 10, 11).

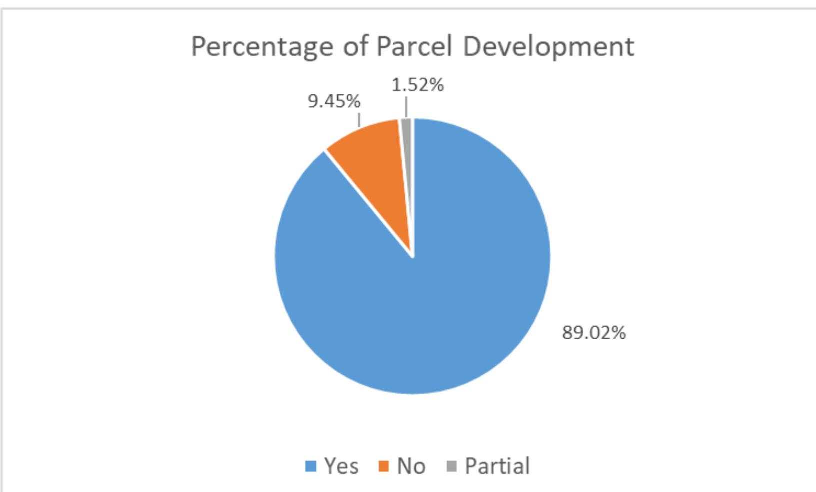


Figure 10. Parcel Development (Percentages) on Douglas Lake, 2024.

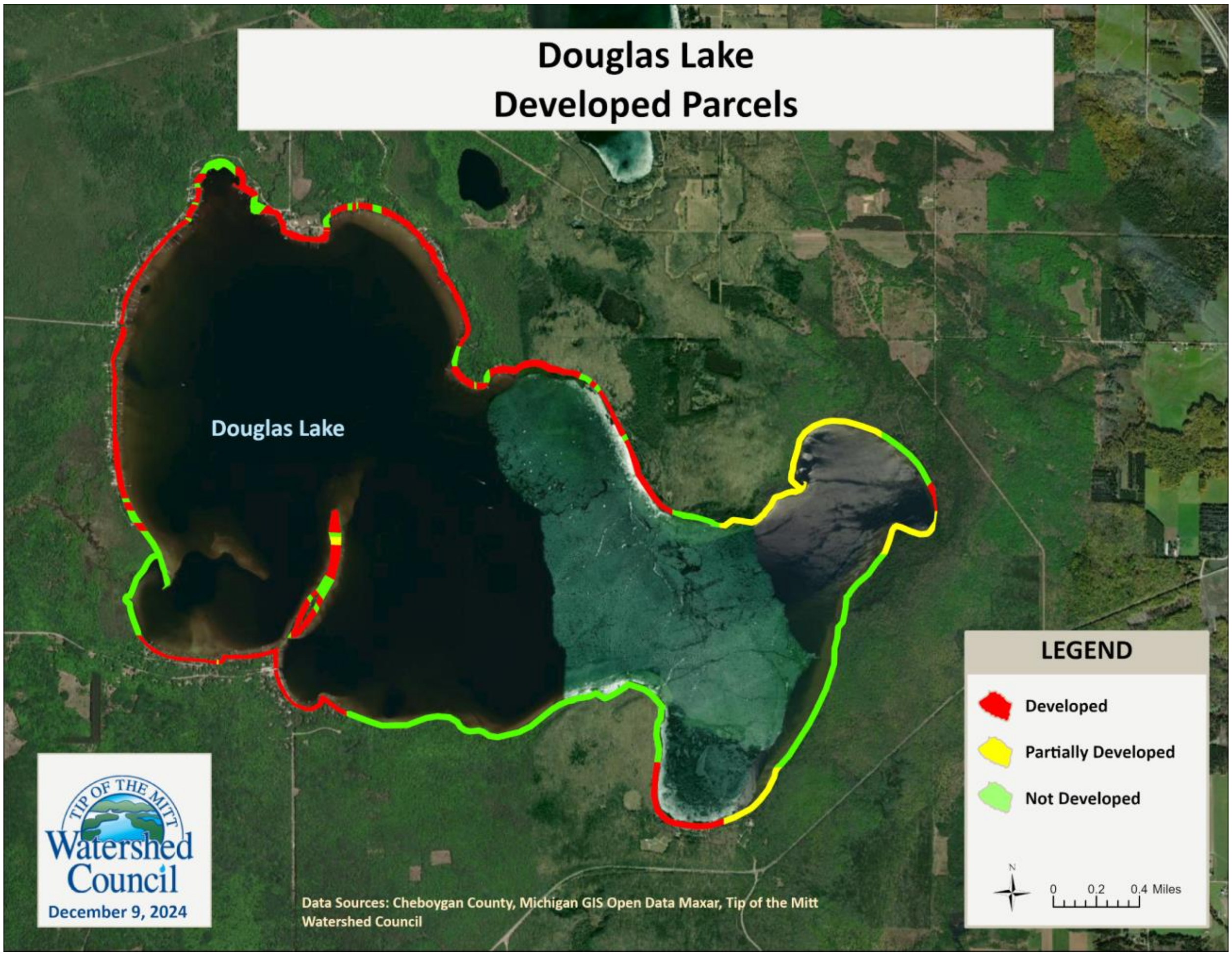


Figure 11. Parcel Development (Map) on Douglas Lake, 2024.

Cladophora

The majority of surveyed parcels (85.06%) did not have *Cladophora* present (Table 8). For parcels with *Cladophora* presence, the most common density was 'Very Light' (9.15%). Overall, less than 15% of Douglas Lake's shoreline had *Cladophora* growth (Figure 12).

Table 8. Cladophora density categorizations and frequencies.

Cladophora Density		
Density	Frequency	%
Heavy	1	0.30%
Moderate to Heavy	2	0.61%
Moderate	0	0.00%
Light to Moderate	5	1.52%
Light	11	3.35%
Very Light	30	9.15%
None	279	85.06%

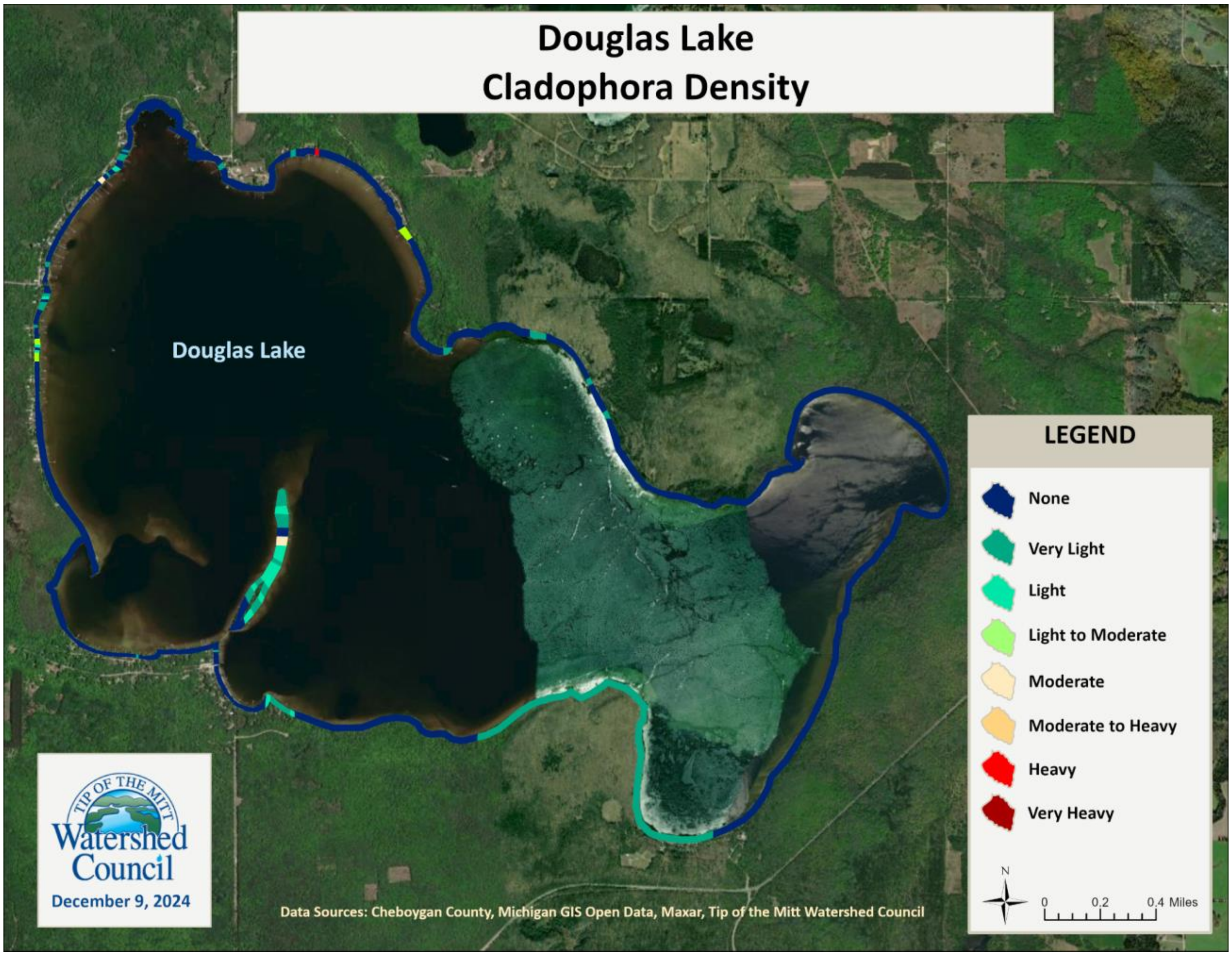


Figure 12. Cladophora Density (map) on Douglas Lake, 2024.

As *Cladophora* requires a hard surface to grow, the varying types of substrate present across Douglas Lake were recorded (Table 9). Substrate type was helpful in determining if suitable habitat for *Cladophora* growth was available. Substrate types that allow for *Cladophora* growth include rock, boulder, woody debris, gravel, and steel bulkheads. The most common type of substrate identified on Douglas Lake was 'Sand' (68.60%), followed by 'Rocks' (between 2.5"-10" in length, 20.43%). Interestingly, the only type of solid substrates identified that could support *Cladophora* growth were 'Gravel' and 'Rocks' (Table 9). This data indicates that nearly 80% of parcels surveyed did not have substrate that would allow for growth of *Cladophora*.

Table 9. Substrate categorizations and frequencies.

Substrate Type		
Substrate Type	Frequency	%
Gravel (0.1"-2.5")	1	0.30%
Muck-soft or marl	35	10.67%
Rocks (2.5"-10")	67	20.43%
Sand	225	68.60%

Greenbelts

Of the 328 total parcels, an encouraging ~40% of parcels had a greenbelt rating of ‘Good’, indicating a score of 5-6 (high length/depth scores in regards to greenbelt coverage, Table 10). Furthermore, 17.07% of parcels surveyed had a greenbelt rating of ‘Excellent’, indicating dense vegetation and extended shoreline coverage. However, it should be noted that 27.44% of surveyed parcels received a score of ‘Very Poor’, indicating greenbelt absence (Figures 13, 14).

Table 10. Greenbelt scores (0-7) and frequencies.

Greenbelt Score		
Score	Frequency	%
Very Poor (Absent)	90	27.44%
Poor (1-2)	8	2.44%
Moderate (3-4)	44	13.41%
Good (5-6)	130	39.63%
Excellent (7)	56	17.07%

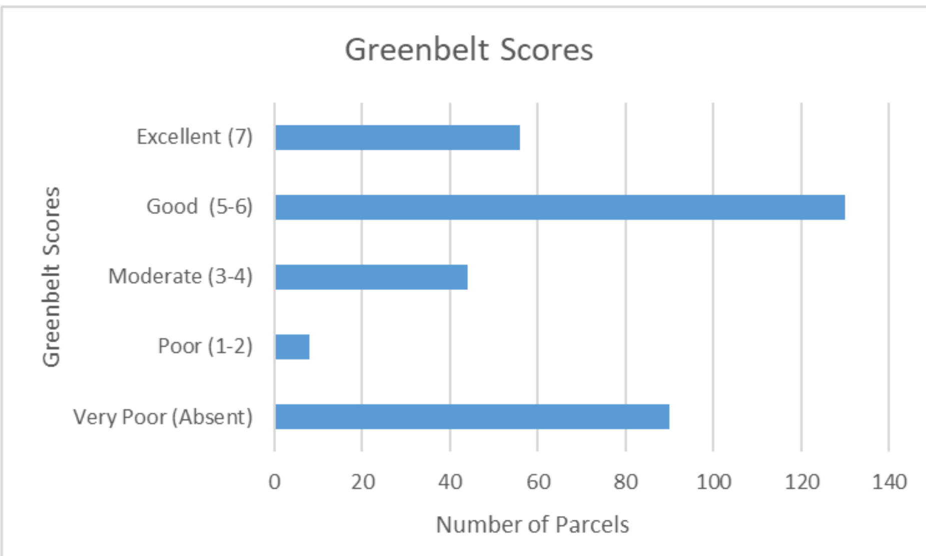


Figure 13. Greenbelt scores (0-7) on Douglas Lake parcels.

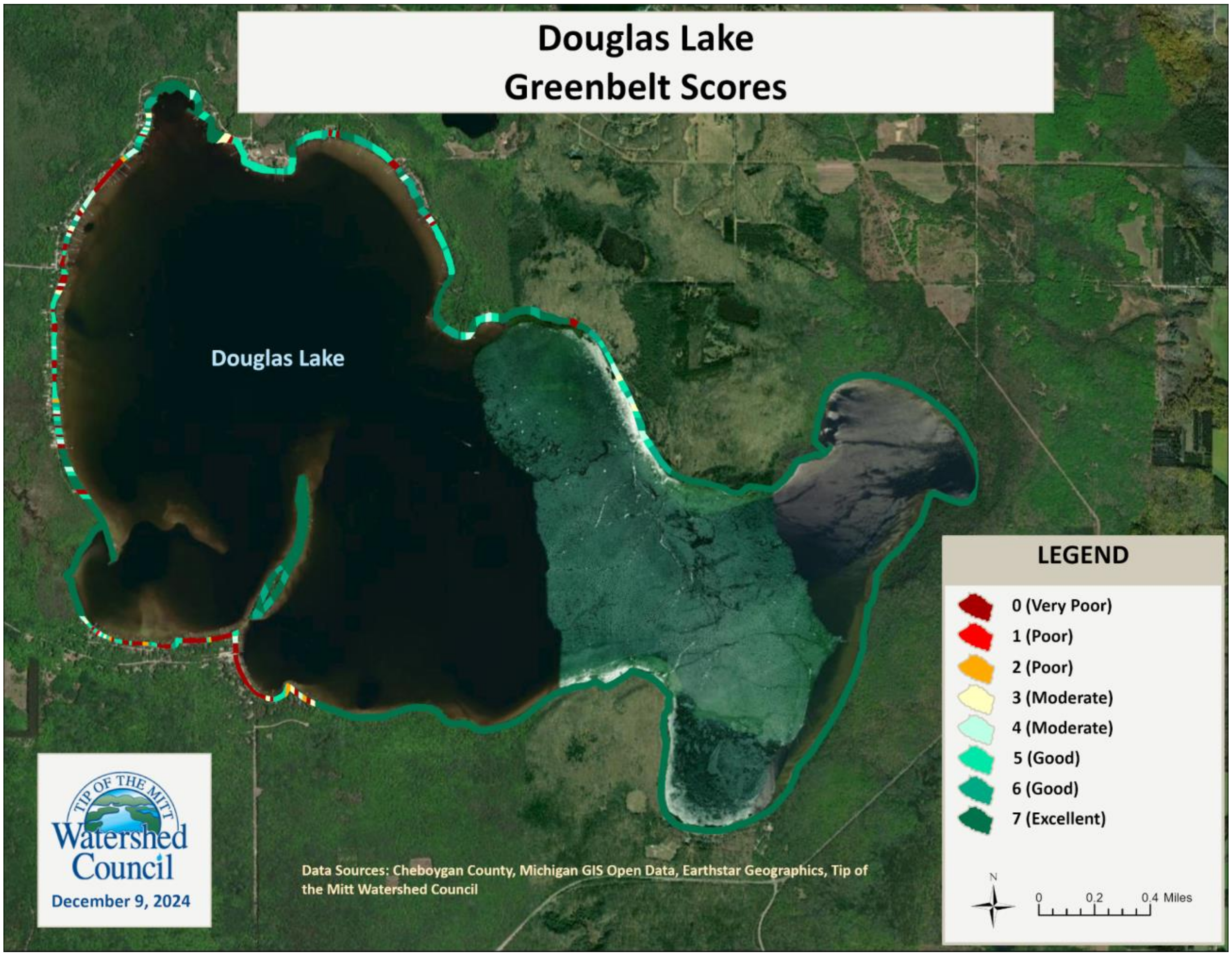


Figure 14. Greenbelt scores (map) on Douglas Lake, 2024.

Shoreline Alterations

Of the shoreline alterations recorded, the majority of parcels (51.52%) had only 1 alteration recorded (Table 11). 43% of surveyed parcels had zero alterations present, and a negligible percentage of parcels had 2-3 shoreline alterations. There were no parcels with 4 alterations.

Table 11. Alterations per parcel and frequencies.

Number of Alterations Per Parcel		
# of Alterations	Frequency	%
0	141	42.99%
1	169	51.52%
2	16	0.05%
3	2	0.01%
4	0	0%

The shoreline alteration types along Douglas Lake were also recorded. The most commonly recorded type of shoreline alteration was rock rip-rap (37.20%), followed by mixed boulder and rock rip-rap (9.45%, Table 12)). Other types recorded (though in small percentages) included big boulder rip-rap/bulkhead, beach sand (whether from fill or grooming), and concrete bulkhead (Figure 15). Other alteration types recorded were present at extremely small frequencies (Table 12, Figure 15).

Table 12. Alteration type categories and frequencies.

Alteration Types		
Type	Frequency	%
big boulder rip-rap/bulkhead	12	3.66%
boat launch	2	0.61%
mixed boulder and rock rip-rap	31	9.45%
beach sand (from fill or grooming)	12	3.66%
concrete bulkhead	4	1.22%
drainage pipe	1	0.30%
None	141	42.99%
rock rip-rap	122	37.20%
steel bulkhead (seawall)	1	0.30%
wood bulkhead	2	0.61%

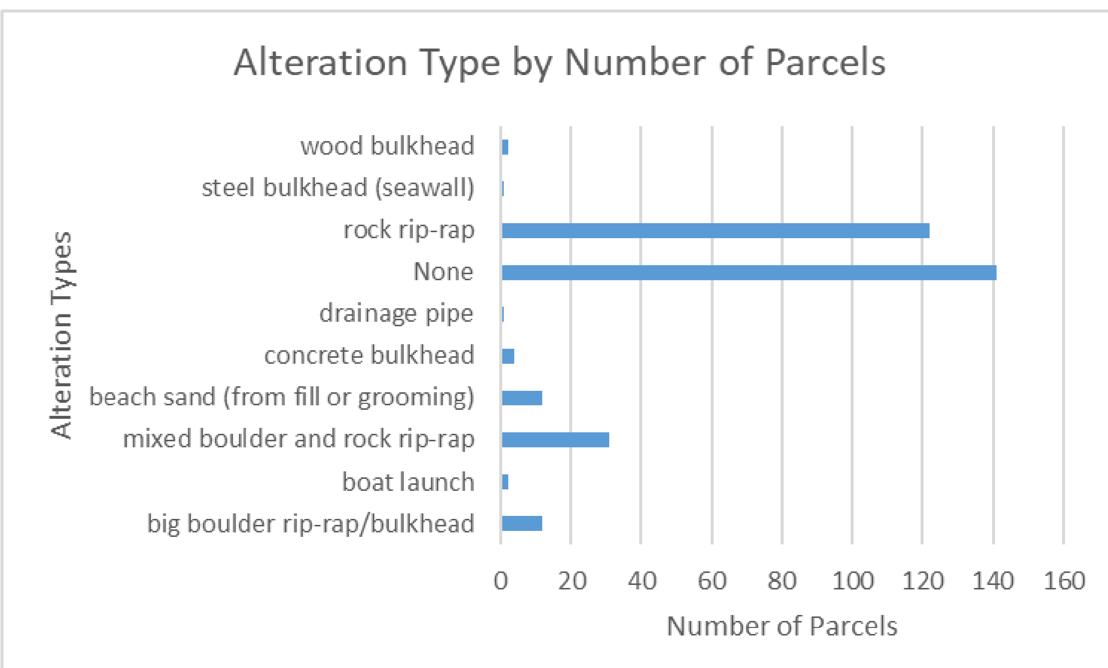


Figure 15. Percentage of parcels per alteration type on Douglas Lake.

Erosion

Of the 328 parcels surveyed, the majority (76.83%) showed no evidence of erosion (Table 13, Figure 16). Where erosion was documented, 9.45% of parcels were categorized as having 'Moderate' erosion, and 7.93% of parcels had 'Heavy' erosion. Less than 6% of parcels had 'Light' erosion (Table 13).

Table 13. Erosion severity and frequencies.

Erosion Severity		
Severity	Frequency	%
Light	19	5.79%
Moderate	31	9.45%
Heavy	26	7.93%
None	252	76.83%

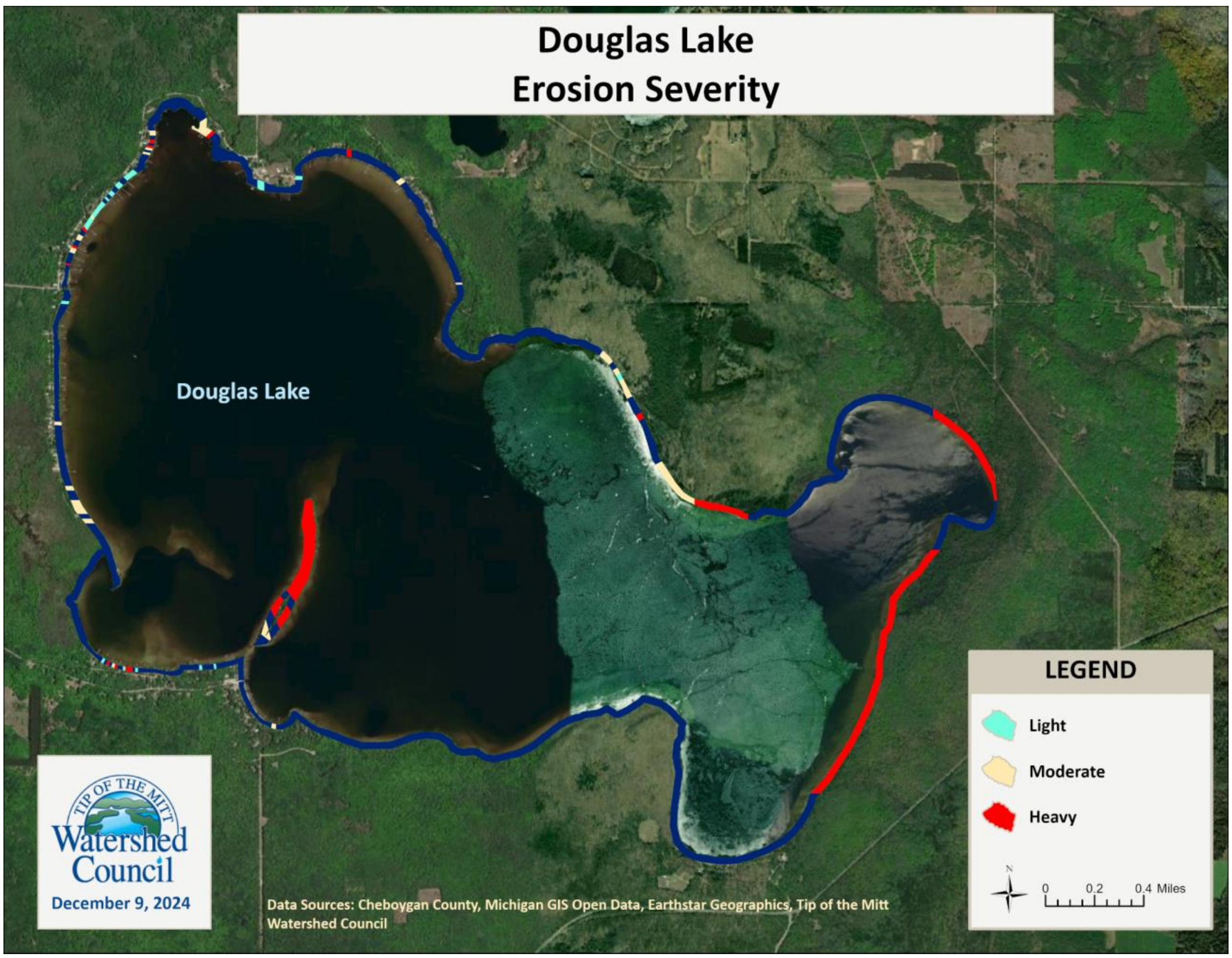


Figure 16. Erosion severity map (by parcel) on Douglas Lake.

Discussion

Conducting a comprehensive shoreline survey of Douglas Lake provides information on water quality issues that the lake itself may be experiencing and/or is susceptible to. For example, the greater the degree of shoreline development, subsequent declines in water quality and overall ecosystem health are noticeable. Shoreline parcel development removes natural vegetation buffers, increases the coverage of impervious surfaces, facilitates the process of shoreline hardening, increases soil susceptibility to erosion, and can contribute to an influx of nutrients and *E. coli* into precious water resources. The following discussion will compare the results of the 2015 shoreline survey on Douglas Lake to the results of the 2024 survey and will also reference the Burt Lake Watershed Management Plan in regards to previously identified critical and priority areas.

Development

According to the 2015 Shoreline Survey conducted on Douglas Lake (346 properties surveyed), 83% of the parcels were categorized as 'Developed'. Compared to the 2024 percentage of developed parcels (89%), we see an increase of 6% in the frequency of developed parcels. This 6% increase in development indicates that, although the vast majority of parcels were developed in 2015, development trends continued in the past 9 years. Douglas Lake has become increasingly popular for residential living and building of permanent structures – a trend that is noticeable among many inland lakes in Northern Michigan in recent decades. It is likely that this trend will continue in the coming years. However, with increased education, outreach, and water protection efforts, shoreline development can occur with regard to ecosystem health and water quality.

It should be noted that the number of parcels in 2015 compared to the number in 2024 was higher by 18. Any differences in percentage calculations would be marginal.

Cladophora

Cladophora growth was documented as absent, or 'none', at 73% of parcels in the 2015 Douglas Lake Shoreline Survey, and 85% of parcels in the 2024 Shoreline Survey. This indicates a decrease in *Cladophora* growth along the perimeter of Douglas Lake parcels by an encouraging 12%. The number of parcels categorized with 'Heavy', 'Moderate to Heavy', 'Light to Moderate', and 'Light' *Cladophora* growth decreased from 2015 to 2024 (Figure 17). There were no parcels categorized as having 'Moderate' *Cladophora* growth in 2024, and there was an increase in the number of parcels categorized with 'Very Light' *Cladophora* growth (by 17 parcels) from 2015 to 2024.

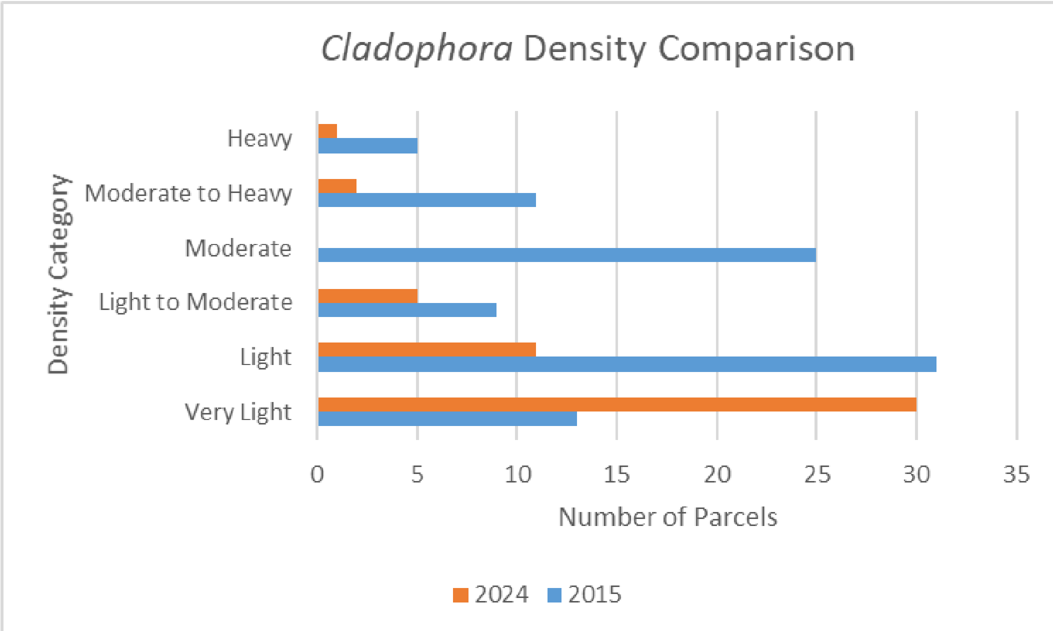


Figure 17. Cladophora Density Comparison by Number of Parcels from 2015 to 2024 on Douglas Lake.

Overall, the increase in the percentage of parcels with no evidence of *Cladophora* growth, combined with the decreases in the majority of density categories over the past 9 years, indicates a decrease in nutrient influx reaching Douglas Lake. Aquatic nutrients that contribute to *Cladophora* growth, such as phosphorus and nitrogen, come from a multitude of sources. These sources include stormwater runoff, excess use of fertilizers or other phosphorus-containing agents, malfunctioning septic systems, or loss of riparian vegetation. Based on the decline in algal growth, it is possible that the results of the 2015 shoreline survey encouraged riparian owners to a) be more mindful of their fertilizer and/or pesticide use, b) practice proper septic system maintenance, or c) decrease the amount of impervious surface coverage by planting greenbelts, rain gardens, or allowing natural vegetation to grow unchecked.

While the decrease in the percentage of parcels with *Cladophora* growth is an excellent sign, the percentage of parcels with 'Very Light' *Cladophora* growth did increase by ~5%. While this percent increase may seem minimal, it may be helpful to revisit properties with algal growth to attempt to determine the source, or recommend practices to property owners that could help keep Douglas Lake in an oligotrophic to mesotrophic state.

Greenbelts

Based on the results of the greenbelt score comparison between 2015 and 2024, the most noticeable change was that the number of parcels with a 'Very Poor' (completely absent) greenbelt increased from 41 parcels in 2015 to 90 parcels in 2024 (12% to 27% in 9 years, Figure 18). This supports the trend of increasing shoreline development along Douglas Lake, and many other inland lakes, in northern Michigan. The unfortunate decrease in greenbelt presence may be due to the removal of shoreline vegetation to make room for shoreline alterations (rip-rap, beach sand, seawalls, etc.) or maximize lake viewing opportunities. With the removal of these vegetation buffers, Douglas Lake becomes more vulnerable to nutrient pollution, stormwater runoff, erosion, and even bacterial and viral contamination from septic leachate that could not be filtered and/or infiltrated into riparian soils before reaching the lakefront(s). It is important to note that, despite the low percentage of parcels with *Cladophora* growth identified in 2024, nutrient influx and stormwater runoff are common threats to water quality on any lake, and stripping natural vegetation from the shoreline increases the likelihood of nutrient pollution.

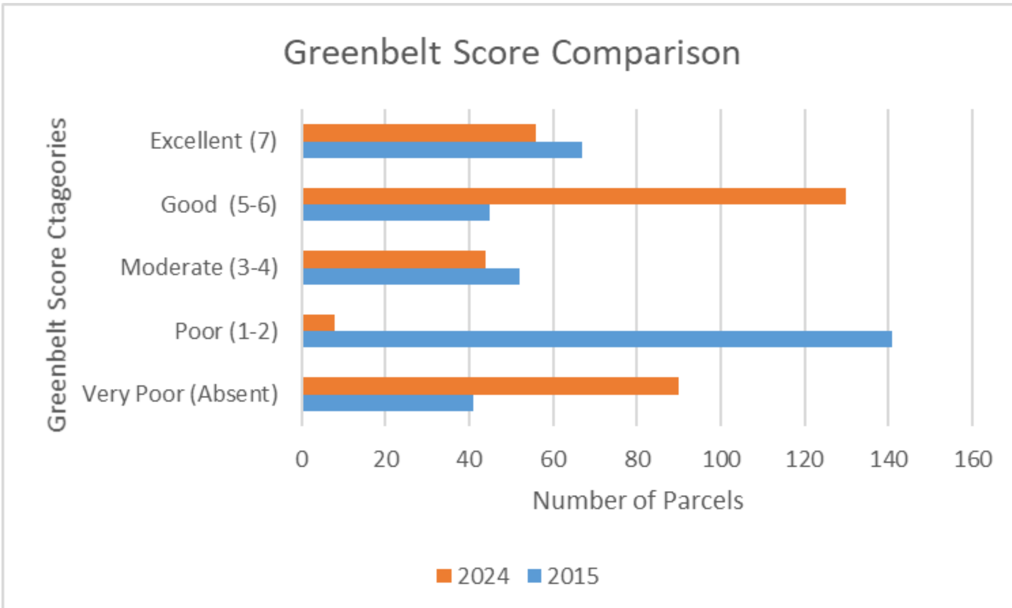


Figure 18. Greenbelt Scoring by Number of Parcels from 2015 to 2024 on Douglas Lake.

Although the number of parcels with absent greenbelts increased, there was an increase in the number of parcels classified as having a 'Good' greenbelt. From only 45 parcels classified as 'Good' (score of 5-6) in 2015 to 130 in 2024, there was a percent increase from 13% to 40%. This is a notable improvement from the 2015 Shoreline Survey results and should not be discounted. Furthermore, this increase in 'Good' greenbelts may be directly correlated with the sharp decline in the number of greenbelts categorized as 'Poor' (score of 1-2). From 141 parcels with a 'Poor' rating in 2015, to only 8 parcels in 2024, it is safe to suggest that previously existing greenbelts that may have been shorter in length and/or less dense were allowed to flourish and properly establish themselves within the riparian zone(s) of each lake.

Greenbelts can ascend the categorical 'ladder' if they increase in length and/or density (in feet). Refraining from mowing or pulling of native shoreline vegetation can have numerous benefits for riparian landowners and their properties – allowing for less yard maintenance, providing natural filtration of stormwater runoff, keeping their lakefront clear of nuisance algae, and stabilizing lakefront property banks. In addition to these valuable services, greenbelts deter unwanted species (geese) and attract pollinators.

Erosion

Upon comparison of parcels categorized by erosion severity from 2015 to 2024, the two notable differences over the 9-year period would be the decline in parcels categorized as having 'Light' erosion (73 parcels compared to 19 parcels) from 2015 to 2024 (Figure 19). Furthermore, the number of parcels that demonstrated no evidence of erosion whatsoever increased from 215 (2015) to 252 (2024). Though these trends are encouraging, it should be noted that there was a slight increase in the number of parcels classified as having 'Heavy' erosion (11 parcels in 2015 to 26 parcels in 2024, Figure 19).

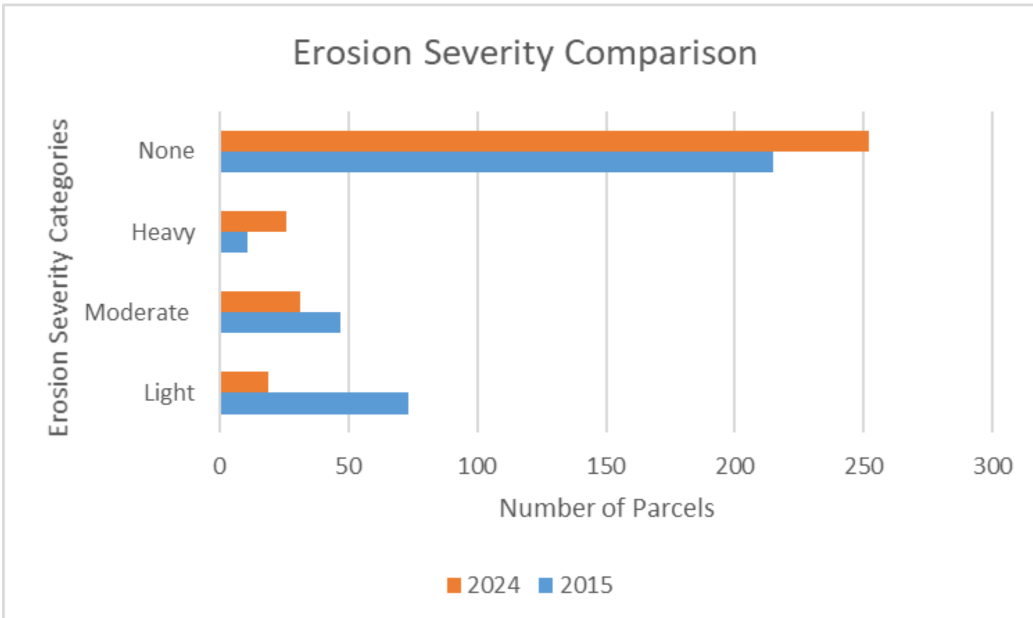


Figure 19. Erosion Severity Scoring by Number of Parcels from 2015 to 2024 on Douglas Lake.

The decrease in erosion on Douglas Lake indicates that there has likely been a change in either 1) riparian landowner behaviors in regards to implementation of Best Management Practices (BMPs), 2) inland lake shoreline conditions that have contributed to a decrease in erosion or 3) all of the above. Based on the results of the 2015 Douglas Lake Shoreline Survey, it is again possible that riparian landowners took it upon themselves to comply with shoreline BMPs - including, but not limited to greenbelt installation, methods for controlling stormwater, and even bioengineering projects that include deep-rooted plants and placement of coir logs/mats. Projects such as these can stabilize shoreline soils and riparian banks without compromising the surrounding aquatic ecosystem. Many of these practices are sustainable and/or biodegradable. Preventing erosion can protect native wildlife, reduce sedimentation, maintain water clarity, and support habitat availability for native fishes and other aquatic organisms.

While the erosion trends are overall positive, the slight increase in the number of parcels with 'Heavy' erosion severity should be further investigated. Re-examination of the specific parcels with more severe erosion can help determine parcels that would be good candidates for greenbelts, rain gardens, or bioengineering projects. Overall, the decline in parcels with evident erosion should be considered a success for the shoreline resiliency and ecosystem health of Douglas Lake.

Shoreline Alterations

In 2015, some form of shoreline alteration was documented at 60% of parcels surveyed, compared to 57% in 2024. This is only a slight decrease, but still shows that the number of parcels with altered shorelines declined. In 2015, rip-rap accounted for 59% of shoreline alterations, while seawalls, including seawalls combined with rip-rap or other structures, accounted for 33%. Beach sand, whether from fill or vegetation and topsoil removal to expose underlying sand, was documented at 17 properties, compared to 12 properties in 2024. Rip-rap was still the most commonly installed shoreline alteration across both survey years (59% in 2015 compared to 37% in 2024). Interestingly, steel bulkheads (seawalls) only accounted for 0.30% of shoreline alterations in 2024, compared to 33% in 2015 (though it should be noted that the 33% included seawalls combined with rip-rap and other existing structures). Unfortunately, a direct comparison between seawalls combined with other structures (i.e. rip-rap, beach sand) cannot be made between 2015 and 2024, as the 2015 survey grouped shoreline alteration types into different categories using outdated protocols.

A decrease in the presence of shoreline alterations across all parcels is encouraging, as it demonstrates that previously installed alterations (i.e. seawalls, rip-rap, beach sand) may have been removed to make way for more natural features such as greenbelts and growth of native vegetation. Generally, removal of shoreline alterations can have numerous benefits. These benefits include increased shoreline stability, erosion prevention, wildlife habitat, pollution filtration, algal growth prevention, and more. Educating riparian landowners about the advantages of keeping their shorelines as natural as possible is the best way to ensure that the water resources of Douglas Lake can be enjoyed for generations to come.

Burt Lake Watershed: Critical and Priority Areas

The Burt Lake Watershed Management Plan, approved in 2018, identified critical and priority areas within the watershed(s) throughout water quality monitoring and resource inventories (Burt Lake Watershed Management Plan). A critical area is one that needs restoration actions, whereas a priority area is one that needs protective actions.

Critical areas identified through the creation of this plan included shoreline degradation occurring on the western shore of Douglas Lake, which is highlighted as in need of restoration due to natural shoreline loss. This identified critical area, situated directly on Douglas Lake, emphasizes the need for remedial action related to shoreline restoration. Without addressing this natural shoreline loss, Douglas Lake and its surrounding watershed is left susceptible to algal growth/harmful blooms, erosion, sedimentation, pollution, wildlife loss, and so much more.

In addition to the identified critical areas, priority areas falling within the geographic range of the Douglas Lake Watershed were identified due to their need for protection of wetlands and maintenance of natural shorelines/biodiversity. Though not directly related to shoreline degradation, maintenance of functional wetlands in the larger Burt Lake Watershed can help keep the water resources of northern Michigan healthy. Wetlands act as nature's kidneys – filtering unwanted contaminants, mitigating extreme weather events, and providing habitat for a plethora of native wildlife species.

In direct opposition to the identified critical area on Douglas Lake's western shoreline, the eastern/central portion of Douglas Lake was identified as a priority area due to the presence of natural shorelines and diverse wildlife populations. This can be seen in the Douglas Lake parcel development map (Figure 11), which shows undeveloped/partially developed shoreline on the eastern shore of the lake, and developed parcels to the west. Protecting these natural shorelines decreases the risk of pollution, algal blooms, wildlife loss, and the loss of ecosystem services, and ensures that Douglas Lake can be preserved for future use. Adherence to the Burt Lake Watershed Management Plan allows for better understanding of our water resources, and gives us the tools to restore, protect, and enjoy them.

Conclusion

Overall, responsible, low-impact, lake shoreline property management is paramount for protecting water quality. Maintaining a healthy greenbelt, regular septic tank pumping, treating stormwater with rain gardens, addressing erosion sites, and eliminating fertilizer, herbicide, and pesticide application are among many low-cost best management practices that minimize the impact of shoreline properties on lake water quality. Responsible stewardship on the part of shoreline property owners and living in harmony with the lake is vital for sustaining a healthy and thriving lake ecosystem. Stewardship starts with taking science-based action – steps which can be referred to in the 'Recommendations' section.

Recommendations

Fully documenting shoreline conditions at inland lakes provides invaluable data that is used to determine appropriate next steps for shoreline management, riparian landowner education, and best practices to either 1) prevent aquatic ecosystem damage or 2) rectifying existing water quality and shoreline issues. The following is a list of professional recommendations from the Watershed Council regarding how to best utilize the results of the Douglas Lake 2024 Shoreline Survey. These results can be used to maximize positive environmental impact and ensure the lifelong protection of the water resources of Douglas Lake and its surrounding watershed.

*Note: "Recommendations" #1 and #2 must be completed according to grant specifications (EGLE 319). These are actions that will be completed rather than recommendations.

1. **Make specific results available online at www.watershedcouncil.org.** Keep the specific results of the survey confidential (e.g., do not publish a list of sites where *Cladophora* algae were found) as some property owners may be sensitive to publicizing information regarding their property. Property owners will be able to access their specific, individualized results using a unique identifying code that will be sent to them via mail. This mailing is included as a step in the contract between the Watershed Council and DLIA.
2. **Make this shoreline survey report publicly available at www.watershedcouncil.org.** Douglas Lake residents, along with any interested parties/individuals, can access the full background information, methodology, general results, and interpretation of the results/comparison to previous data (discussion).
3. **Share general results of the survey** in DLIA's newsletter/publications, the Watershed Council's newsletter/publications, present findings to the Burt Lake Watershed Advisory Committee, and present findings in the form of an educational slideshow when requested/relevant.
4. **Promote and encourage landscape contractors and designers to attend bioengineering workshops and Certified Natural Shoreline Professional certification classes (Michigan Natural Shoreline Partnership - Home).**
5. **Hold greenbelt workshops to educate shoreline homeowners about the importance of greenbelts for protecting water quality**. Share a summary of the survey results at the workshops.
6. **Encourage landowners to sign up and take a self-assessment for MI Shoreland Stewards (Be a Shoreland Steward - Michigan Shoreland Stewards).**
7. **Use shoreline survey data to advocate for stronger greenbelt ordinances in Cheboygan County.**
8. **Encourage use of Best Management Practices (BMPs) that advocate for low-cost, low commitment, yet highly effective, preventative measures that riparian landowners can take to prevent shoreline and water quality damage.** These measures include, but are not limited to:
    a. Reducing use of fertilizers, herbicides, and pesticides, and avoiding products that are phosphorus-based.
    b. **Allow for the growth of shoreline vegetation rather than mowing to the water's edge.** Changing mowing and cutting practices encourages growth of native plants, attracts pollinators, deters geese, stabilizes the shoreline bank, prevents erosion and sedimentation, and filters pollutants and contaminants before they reach aquatic ecosystems of inland lakes.
    c. **Promote/engage in rain garden installation and/or planting native plant species.** Rain gardens add aesthetic value to properties while functioning as mitigators of stormwater runoff/pollution.

   d. **Practice proper septic system maintenance by having systems pumped and/or inspected by a septic professional every 3-5 years.** Areas of lush, green grass, flooding, or toilet backups should be promptly investigated and addressed.
   e. **Limit the installation of shoreline alterations (i.e. rip-rap, seawalls/bulkheads, filling with beach sand, etc.).** These shoreline alterations negatively impact water quality by altering natural inland lake processes and hardening the shoreline.
9. **Repeat the shoreline survey periodically (ideally every 5-10 years).**
10. **Consult the Burt Lake Watershed Management Plan (**[Watershed Management Planning - Tip of the Mitt Watershed Council]) in further detail to a) consider the full realm of existing water quality data for the watershed and for Douglas Lake and b) use this data, along with knowledge of identified critical and priority areas, to prioritize the remediation and protection of crucial water resources.
11. **Continue to identify chronic problem sites along the lake's** shoreline and either a) determine the root cause of the issue(s) and/or b) address the existing water quality issue(s) through the most appropriate actions (BMPs, nutrient or *E. coli* monitoring, policy implementation, education, etc.).
12. **Continue to support the Tip of the Mitt Watershed Council Volunteer Lake and Stream Monitoring programs** by providing volunteer support.
13. **Continue water quality data collection on Douglas Lake through the Comprehensive Water Quality and Volunteer Lake Monitoring Programs.** Long-term datasets are extremely useful in evaluating trends in water quality through the context of changing environmental conditions.

References

Amick, R. S., & Burgess, E. H. (2000). Exfiltration in sewer systems. EPA/600/R-01/034. United States Environmental Protection Agency. Cincinnati, OH.

Carlson, R. E. (1977). A trophic state index for lakes. *Limnology and Oceanography, 22*(2), 361-369.

Department of Environment, Great Lakes, and Energy. (n.d.). Rule 57 water quality values. SOM - State of Michigan. https://www.michigan.gov/egle/about/organization/water-resources/glwarm/rule-57-water-quality-values

Domka, M., Johnson, E., & Watson, A. (n.d.). Lake Charlevoix septic study report 2023. Retrieved July 2, 2024.

Domka, M., Watson, A., & Keson, C. (n.d.). Quality assurance project plan for Tip of the Mitt Watershed Council volunteer stream monitoring (VSM) and Watershed Academy (WA) programs. Retrieved 2024.

Domka, M., Watson, A., & Keson, C. (n.d.). Tip of the Mitt Watershed Council volunteer lake monitoring program: Quality assurance project plan. Retrieved July 3, 2024.

Fondriest Environmental, Inc. (2013, November 19). pH of water. *Fundamentals of Environmental Measurements.* Retrieved from https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

Fondriest Environmental. (2014, June 13). Turbidity & total suspended solids: Water clarity. Fondriest Environmental. Retrieved November 25, 2024, from https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/

Huron River Watershed Council. (2013). Conductivity. https://www.hrwc.org/wp-content/uploads/2013/09/Conductivity.pdf

Kronk, K., & Myers, D. (2015). Douglas Lake shore survey report. Watershed Council. https://watershedcouncil.org/wp-content/uploads/2023/04/douglaslakeshoresurvey2015_report_tomwc.pdf

Kurtz, J., Griffith, M. B., Morrison, M. A., & Hornig, C. E. (n.d.). Nutrients. EPA. https://www.epa.gov/caddis-vol2/nutrients

Michigan Department of Environment, Great Lakes, and Energy. (2022). 2022 integrated report: Water quality in Michigan's lakes, rivers, and streams. Michigan Department of Environment, Great Lakes, and Energy. https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Programs/WRD/GLWARM/IR/2022-Integrated-Report.pdf

Missouri Department of Natural Resources. (n.d.). Chloride. *Chloride | Missouri Department of Natural Resources*. https://dnr.mo.gov/water/hows-water/pollutants-sources/chloride#:~:text=Chloride%20occurs%20naturally%20in%20lakes

National Oceanic and Atmospheric Administration (NOAA). (2006). Coastal Great Lakes land cover project. NOAA Coastal Services Center. Charleston, SC. http://www.csc.noaa.gov/crs/lca/greatlakes.html

Sportsman's Connection. (2002). Northwestern Michigan fishing map guide. Superior, WI. http://www.sportsmansconnection.com/

Spur, S. H., & Zumberge, J. H. (1956). Late Pleistocene features of Cheboygan and Emmet counties, Michigan. *American Journal of Science, 25*(1), 96-109.

Tip of the Mitt Watershed Council. (2017, November). Burt Lake watershed management plan. https://watershedcouncil.org/wp-content/uploads/2023/02/burt_lake_watershed_management_plan_final.pdf

Tip of the Mitt Watershed Council. (2024, January 30). Shorelines & streambanks. Tip of the Mitt Watershed Council. https://watershedcouncil.org/our-work/watershed-protection/shoreline-streambanks/

United States Environmental Protection Agency. (2001, December). Ambient water quality criteria recommendations. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA05.pdf

United States Environmental Protection Agency. (2019, February 4). The issue | Nutrient pollution. *EPA*. https://19january2021snapshot.epa.gov/nutrientpollution/issue_.html

United States Environmental Protection Agency. (2021, July). E. Coli parameter fact sheet. *EPA*. https://www.epa.gov/awma/e-coli-parameter-factsheet

United States Environmental Protection Agency. (2024, May 29). Indicators: Conductivity. *EPA*. https://www.epa.gov/national-aquatic-resource-surveys/indicators-conductivity#:~:text=What%20is%20conductivity%3F

United States Environmental Protection Agency. (2024, June 6). Ecoregions. *EPA*. https://www.epa.gov/eco-research/ecoregions#:~:text=Ecoregions%20are%20areas%20where%20ecosystems

United States Environmental Protection Agency. (2024, February 29). pH. *EPA*. https://www.epa.gov/eco-research/ecoregions#:~:text=Ecoregions%20are%20areas%20where%20ecosystems

United States Environmental Protection Agency. (2024, July 16). Frequent questions on septic systems. *EPA*. https://www.epa.gov/septic/frequent-questions-septic-systems-failing

United States Environmental Protection Agency. (2024, June 5). How to care for your septic system. *EPA*. https://www.epa.gov/septic/how-care-your-septic-system-inspect

U.S. Environmental Protection Agency. Method detection limit (MDL) procedure found in Title 40 Code of Federal Regulations Part 136 (40 CFR 136, Appendix B, revision 1.11).

United States Environmental Protection Agency. (1979). Methods for chemical analysis of water and wastes. E.P.A.-600/4-79-020. Government Printing Office, Washington, D.C.

Watershed Council. (n.d.). Douglas Lake, Cheboygan County. Watershed Council. https://watershedcouncil.org/waterbody/douglas-lake-cheboygan-county/

Watershed Council. (n.d.). *Harmful algal blooms*. Watershed Council. https://watershedcouncil.org/shoreline-streambanks/greenbelts/harmful-algal-blooms/

Water Rangers. (2024, July 11). pH in freshwater. *Water Rangers*. https://waterrangers.com/testkits/tests/ph-in-freshwater/?v=0b3b97fa6688

Water Wise Group. (2017, January 18). Greywater and septic systems. *Water Wise Group*. https://waterwisegroup.com/greywater-septic-systems/

Watson, A. (n.d.). Burt Lake shoreline survey 2022. Retrieved October 23, 2024.

Wisconsin Department of Natural Resources. (n.d.). Nuisance algae (Cladophora) in Lake Michigan. *Wisconsin DNR*. https://dnr.wisconsin.gov/topic/GreatLakes/Cladophora.html

Withers, P. J., Jordan, P., May, L., Jarvis, H. P., & Deal, N. E. (2014). Do septic tank systems pose a hidden threat to water quality? *Frontiers in Ecology and the Environment, 12*(2), 123-130.

Withers, P. J. A., May, L., Jarvis, H. P., Jordan, P., Doody, D., Foy, R. H., ... & Deal, N. (2012). Nutrient emissions to water from septic tank systems in rural catchments: Uncertainties and implications for policy. *Environmental Science & Policy, 24*, 71-82.