Hutchinson

Environmental Sciences Ltd.

Watershed Health Indicators – Muskoka River Watershed

Shortlist Report

Prepared for: The District Municipality of Muskoka
Job #: J220004

November 3, 2023

FINAL

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November 3, 2023 HESL Job #: J220004

Glenn Cunnington
Manager, Watershed Programs
The District Municipality of Muskoka
70 Pine Street
Bracebridge, Ontario
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Dear Glenn:

Re: Final Shortlist Report – Watershed Health Indicators Muskoka River Watershed Project

We are pleased to submit the Final Shortlist Report for the Watershed Health Indicators – Muskoka River Watershed Project. The report summarizes the results of the shortlist survey and includes additional analysis to recommend a shortlist of indicators to monitor initially. Guidance on implementation of the shortlist is provided in a separate report.

We thank you for the opportunity to undertake this work. We hope the report provides useful information as the District develops its approach to Integrated Watershed Management.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.



Andrea Smith, Ph. D.
Senior Scientist

Signatures

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Executive Summary

The aim of the Watershed Health Indicators Project was to build on existing information and studies to identify environmental and ecological metrics to monitor watershed health in the Muskoka River Watershed. Hutchinson Environmental Sciences Ltd. (HESL) completed the first phase of the project in September 2022 by developing a longlist of 29 indicators to monitor the health of the Muskoka River Watershed. Indicators were divided into those that address Ecological Status (including biological, chemical, and physical elements of the watershed; 14 indicators) and those that address Threats to Ecological Status (15 indicators), and included several sub-categories related to Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), Landscape Condition, Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects.

As part of the second phase of the project in 2023, HESL led the development of a shortlist of indicators to be monitored initially, with the intent to monitor more as resources and capacity allow. A survey was created to gather community input on what indicators from the longlist were considered high priority for initial implementation. Guidance from other jurisdictions, as well as feedback from scientists, and our own professional judgement, were used to finalize the shortlist to 18 indicators representing all sub-categories of the original longlist except threats to biological condition.

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1. Introduction

1.1 Background

The District Municipality of Muskoka (the District) launched the Watershed Health Indicators Project in 2022, as part of its Integrated Watershed Management (IWM) Initiative. The aim of the project was to build on existing information and studies to identify environmental and ecological metrics to monitor watershed health in the Muskoka River Watershed. Hutchinson Environmental Sciences Ltd. (HESL) completed the first phase of the project in September 2022 by developing a longlist of 29 indicators. The work involved the following components:

- Review of existing knowledge of watershed health for the Muskoka River Watershed,
- Review of indicators used in other jurisdictions, and
- Consultation with local community members and scientific experts.

The 29 watershed indicators were divided into two main categories: Ecological Status and Threats to Ecological Status (Figure 1). Fourteen indicators were identified under Ecological Status, representing several sub-categories: Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), and Landscape Condition. Fifteen indicators were identified under Threats to Ecological Status, representing the following sub-categories: Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects.

The results of the first phase of the project were summarized in a report (HESL 2022a) available on the District's EnviroHub webpage[1]. The report provided guidance on how to monitor the watershed indicators and made a series of recommendations for their implementation. Among these was the recommendation that the longlist be narrowed down to a shortlist of priority indicators to be monitored initially, with the intent to eventually implement all indicators as resources and capacity allow. It was recommended that a standardized approach be used to develop the shortlist through consultation with the Community Round Table (CRT), local scientific experts, and other stakeholders, so that the shortlist addresses community needs, concerns, and priorities.

[1] *Making Waves: Integrated Watershed Management Projects:* https://www.muskoka.on.ca/en/environment/Making_Waves__Integrated_Watershed_Management_Projects.aspx#9-Develop-watershed-health-indicators

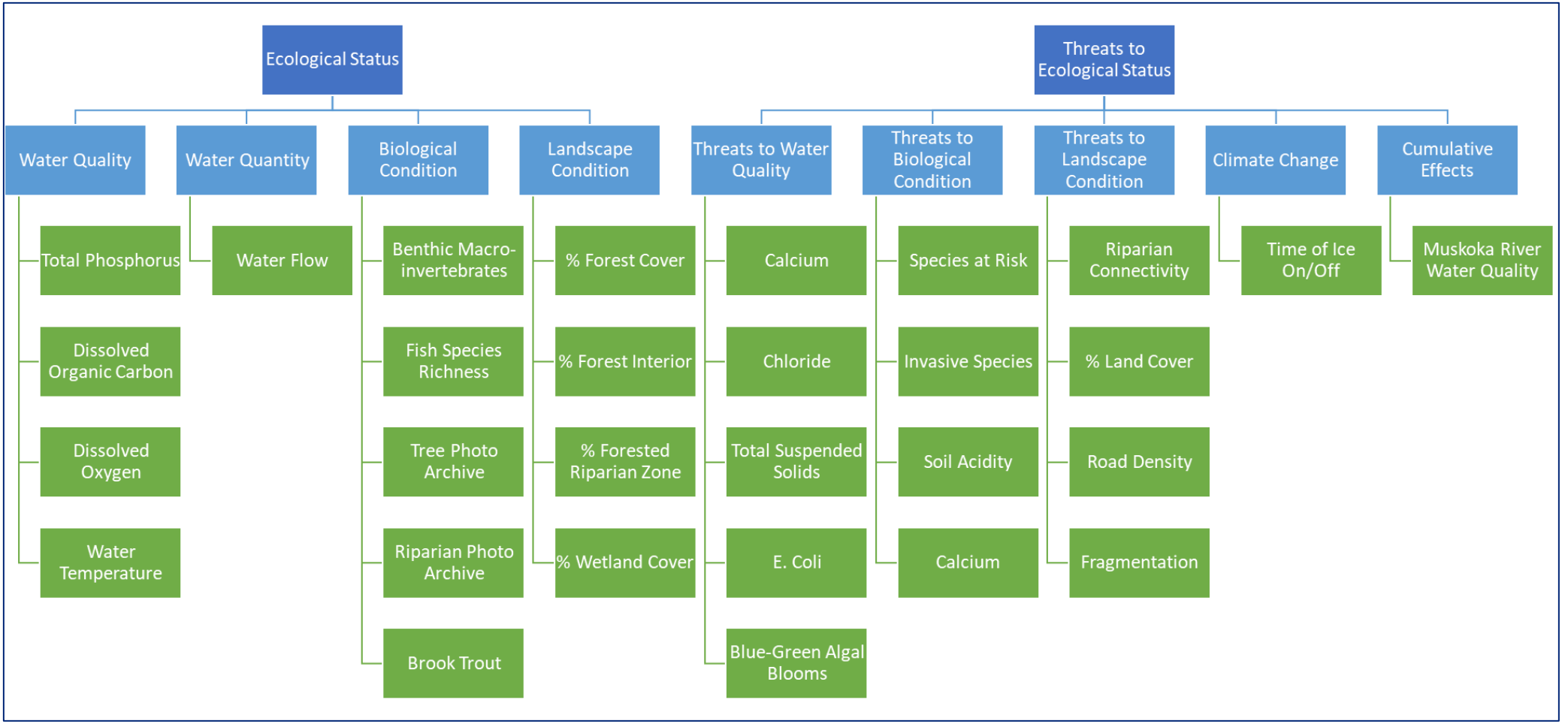


Figure 1. Longlist of 29 indicators.

1.2 Measuring Watershed Health

Watershed health refers to the ability of a watershed to support the natural features, processes, and conditions within its boundaries, including dynamic hydrologic and geomorphologic processes (within their natural range of variation), habitat of sufficient size and connectivity to support native species, and physical and chemical water quality conditions that sustain healthy biological communities (US Environmental Protection Agency [USEPA] 2022). Monitoring of watershed health assesses the current state of the system, identifies changes, and predicts risks, taking into consideration the effects of land use, climate change, and human activities (Ho et al. 2018).

Indicators are often used to measure environmental conditions because they are simplified representations of more complex ecological states and processes that are difficult to quantify. Indicators can include physical, chemical, biological, and socio-economic attributes of the watershed which convey information on underlying ecological functions (Government of Alberta 2008). Indicators can be used to document baseline environmental conditions and track changes to those conditions over time (e.g., are they improving, worsening or stable) and space. Target values of indicators (or management objectives) can be identified, and progress toward achieving targets through stewardship and management actions can be evaluated. Indicators can also have threshold levels, that serve as early warnings of unwanted change that might warrant management action. According to the USEPA, effective indicators are ones that are measurable, comparable, consistent, and relevant to the ecosystem and issues of interest (USEPA 2021). In addition, indicators should

- be easy to understand and readily available;
- be reliable, providing an unambiguous cause and effect relationship between environmental stressors and ecosystem response;
- be comprehensive, representing a range of physical, chemical, and biological attributes of the ecosystem; and
- be cost-effective to monitor (Government of Alberta 2008).

Indicators are typically selected to represent a range of watershed features (e.g., hydrology, physical habitat, water quality, biological communities) and watershed functions (e.g., base flow, flood storage and attenuation, temperature, nutrient cycling, species interactions), and to track human influence (e.g., land use, wetland alteration, invasive species introductions and spread, dam impacts, extent of impervious surfaces). Three types of indicators are generally considered:

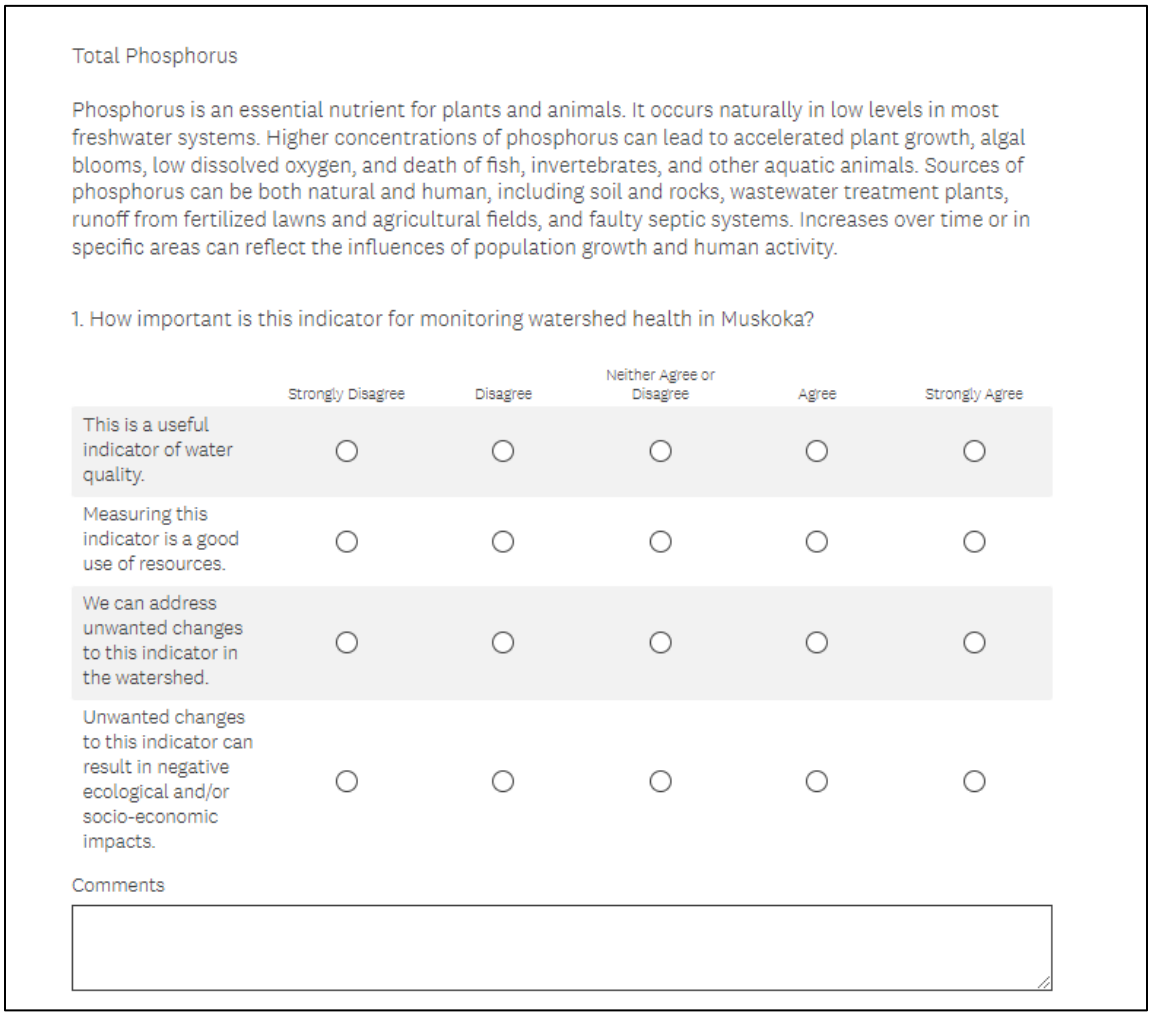
- Condition indicators, which address the state of the environment, including the quality and quantity of attributes, and the state of human and ecological health (e.g., water quality, biodiversity, riparian habitat),
- Pressure indicators, which address natural processes and human activities that could negatively impact environmental conditions (e.g., soil erosion, climate change, urban development), and
- Response indicators, which address actions to manage, mitigate, adapt to or prevent environmental damage (e.g., stewardship activities, education initiatives, municipal policy; Government of Alberta 2008).

1.3 Development of Shortlist

The second phase of the Watershed Health Indicators Project was launched in 2023 to address several of the recommendations from the 2022 report. This report highlights the development of a shortlist of watershed health indicators. We began by collecting feedback on indicator priorities through a survey, then supplemented this information with guidance from other jurisdictions and our own professional judgement to narrow down the longlist of indicators.

2. Survey

We created a survey on SurveyMonkey® to canvass the CRT, local scientific experts, and other stakeholders on what indicators should be included in the shortlist. The survey consisted of a brief description of each of the 29 indicators, followed by four statements to be rated per indicator. The statements related to whether each indicator was a useful indicator of watershed health; whether measuring each indicator was a good use of resources, whether unwanted changes to each indicator could be addressed in the watershed, and whether unwanted changes caused negative ecological and/or socio-economic impacts. Respondents were asked to record their level of agreement with each of these statements on a scale of 1 to 5, where 1 is strongly disagree, 3 is neither agree or disagree, and 5 is strongly agree. Respondents also had the option to provide comments for each indicator. An example of the survey set-up is illustrated in Figure 2. The full survey can be found in Appendix A.



Total Phosphorus

Phosphorus is an essential nutrient for plants and animals. It occurs naturally in low levels in most freshwater systems. Higher concentrations of phosphorus can lead to accelerated plant growth, algal blooms, low dissolved oxygen, and death of fish, invertebrates, and other aquatic animals. Sources of phosphorus can be both natural and human, including soil and rocks, wastewater treatment plants, runoff from fertilized lawns and agricultural fields, and faulty septic systems. Increases over time or in specific areas can reflect the influences of population growth and human activity.

1. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quality.	○	○	○	○	○
Measuring this indicator is a good use of resources.	○	○	○	○	○
We can address unwanted changes to this indicator in the watershed.	○	○	○	○	○
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	○	○	○	○	○

Comments

Figure 2. Example of survey set-up for total phosphorus indicator.

The survey was anonymous; however, respondents were given the option of indicating their affiliation (e.g., CRT, Muskoka Watershed Council, Chamber of Commerce, cottager, year-round resident) at the end of the survey.

Potential participants in the survey were selected in consultation with the District and included groups and individuals involved in the first phase of the project (developing the longlist) as well as additional contacts with scientific expertise on the Muskoka River Watershed. The survey was distributed by email to the CRT (42 members) as well as to 18 additional contacts representing academia, provincial government ministries (Ministry of Environment, Conservation and Parks and Ministry of Natural Resources and Forestry), the four local Chambers of Commerce (Bracebridge, Gravenhurst, Huntsville/Lake of Bays, and Muskoka Lakes), local land conservancy organizations (Lake of Bays Heritage Foundation and Muskoka Conservancy), Explorer's Edge (the regional tourism organization), the Muskoka Watershed Council, and Friends of the Muskoka Watershed. Participants were given three weeks to complete the survey.

Completed surveys were analyzed by first summing each individual respondent score for each of the statements per indicator, then summing these individual scores for an overall score per indicator. For example, for a particular indicator, if one person rated all four statements as *agree*, they would score a

total of 16 for that indicator (because *agree* is scored as 4). If a second person rated all four statements as *strongly disagree* for the same indicator, they would score a total of 4 for that indicator (because *strongly disagree* is scored as 1). Together, the overall score for that indicator would then be 20 for the two respondents (16 + 4). For each indicator, the highest individual score possible was 20 (a score of 5 [*strongly agree*] for each of four statements, 5 x 4) and the lowest individual score possible was 4 (a score of 1 [*strongly disagree*] for each of four statements, 1 x 4). Appendix B provides a summary of scoring for survey statements.

All comments from the surveys were recorded.

2.1 Survey Results

Seventeen responses were received. Four of these were omitted from the analysis because they were incomplete or filled out before a problem with the online survey was corrected (the problem prevented respondents from rating more than one statement per indicator).

2.1.1 Survey Scoring

The overall scoring of all 29 indicators ranged from 173 to 227. The top ten ranked indicators represented the following sub-categories from the longlist: Water Quality, Biological Condition, Landscape Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects (Table 1, Figure 2).

Table 1. Ranking of top ten indicators based on survey scores. Indicators that received the same score are grouped together.

Indicator	Score
Percent wetland cover	227
Riparian connectivity Muskoka River water quality	221
Total phosphorus	217
Benthic macroinvertebrates	214
Percent forest cover	213
Percent land cover	212
Percent forest interior Road density Habitat fragmentation	211

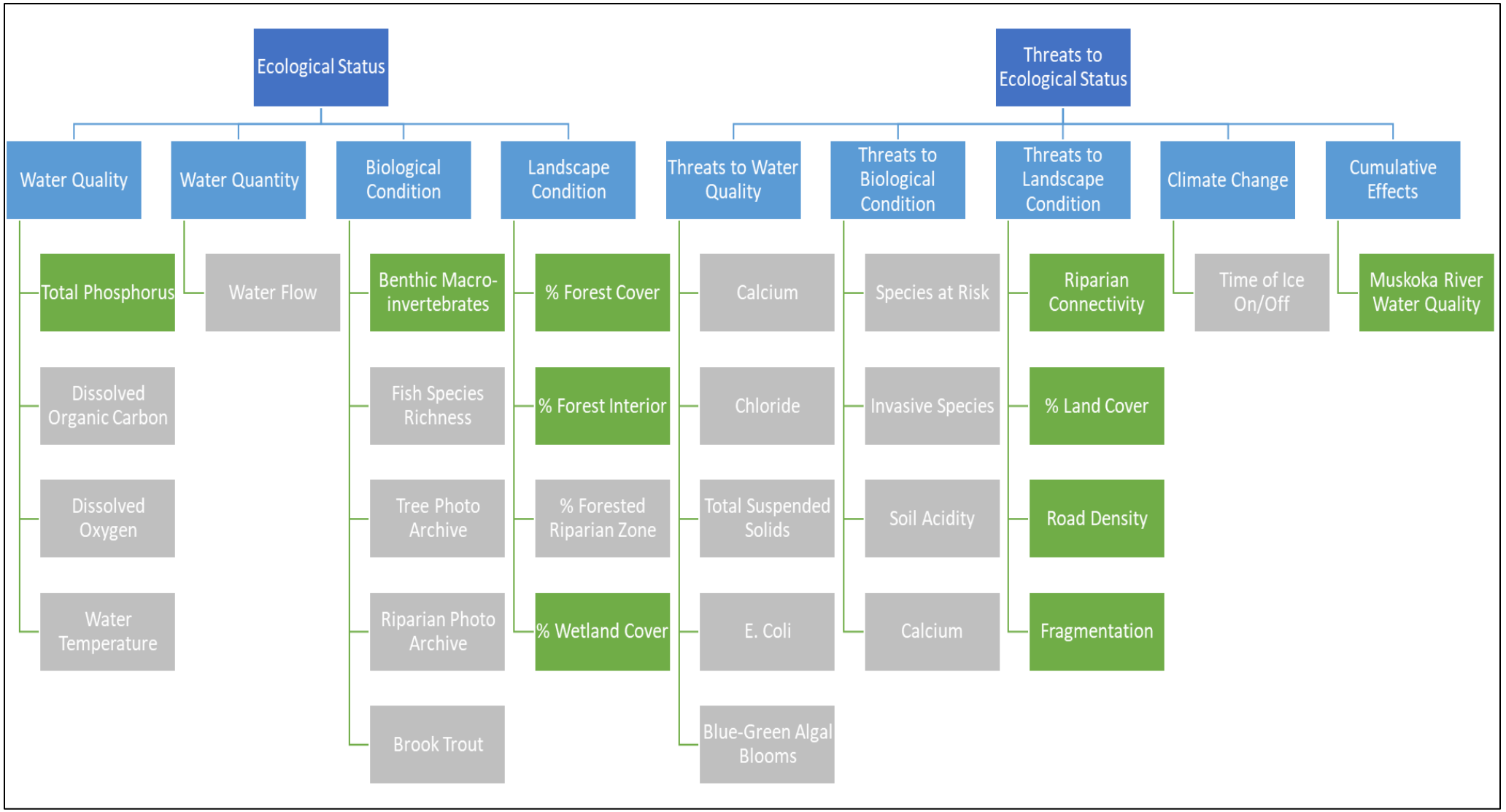


Figure 3. Distribution of shortlisted indicators from survey in relation to original longlist. Highlighted boxes (in green) were the top ten indicators selected in the survey.

2.1.2 Survey Comments

Eight participants provided comments in their survey responses. Comments focused on a variety of general themes, such as ease and cost-effectiveness of using indicators, whether indicators were useful for addressing watershed vs. local scale issues, and the ability to determine the causes of any observed changes in indicators. Comments included recommendations for additional research on indicators, and recommendations for how (when and where) to sample indicators (Table 2). Full comments can be found in Appendix C.

Table 2. Summary of survey comments.

Type of Comment	Which Indicators
Indicator is easy/inexpensive/cost-effective to monitor	Water temperature, % Land cover, % Forest cover, % Forest interior, % Wetland cover, % Forested riparian zone, Tree photo archive, Calcium, Chloride, Road density, Habitat fragmentation, Time of ice on/off
Indicator promotes citizen science/public awareness	Benthic invertebrates, Time of ice on/off
Indicator is useful in specific conditions or to track specific problems	Brook trout, Calcium, Chloride, E. coli, Total suspended solids
Indicator is a good integrator of watershed conditions	Benthic invertebrates, % Forest cover, % Forest interior, % Land cover, Road density, Time of ice on/off, Muskoka River water quality
Indicator is only useful if measured in concert with other indicators	Total phosphorus, Water temperature
Indicator can influence other indicators	Dissolved organic carbon, Water temperature, Road density
Unwanted change in indicator can be addressed locally	Riparian photo archive, % Forest cover, % Forest interior, % Forested riparian zone, % Wetland cover, Calcium, Chloride, Riparian connectivity, % Land cover, Road density, Habitat fragmentation
Indicator is complicated or labour intensive to monitor and/or interpret	Water flow, Benthic invertebrates, Total suspended solids, E. coli, Tree photo archive, Riparian photo archive, Blue-green algal blooms, Species at risk, Invasive species

Determining causes of unwanted change in indicator can be difficult to determine	Total phosphorus, Dissolved organic carbon, Brook trout, Tree photo archive, Total suspended solids, Time of ice on/off
More research is needed (e.g., to confirm source of change or to understand extent of the problem in the watershed, or to determine how the indicator correlates with other indicators, or to determine appropriate sampling methods)	Dissolved organic carbon, Dissolved oxygen, Soil acidity, Soil calcium, Road density
Specific data collection protocols should be followed to measure indicator	Total phosphorus, Dissolved oxygen, Water temperature, E. coli, Total suspended solids
Indicator should be monitored in partnership with other organizations or as part of a research-level initiative	Water flow, Blue-green algal blooms, Soil acidity, Soil calcium

Participants also had several questions and additional comments about indicators, which we address below.

1. *Is 30 m the right dimension for % Forested Riparian Zone? Is it natural forest or natural vegetation?*

   The 30 m width is the minimum natural shoreline buffer recommended by provincial and federal guidance for protection of watercourses, lakes, and wetlands (i.e., Ministry of Natural Resources 2010, Government of Ontario 2009, 2010, 2017a, 2017b, Environment Canada 2013), which are based on numerous scientific studies (e.g., Castelle et al. 1994, Zhang et al. 2010, Sweeney and Newbold 2014, and additional research reviewed in Beacon 2012).

   Conservation Ontario (2011) recommends that this indicator measure the amount of riparian zone that is forested, however, other natural vegetation could be measured as well, since all types of native vegetation (e.g., forbs, grasses, shrubs, trees) are beneficial along the shoreline.

2. *Is the amount of wetland an indicator of amount of overall intact habitat?*

   Percent wetland cover does not necessarily equate to the overall amount of intact natural habitat, but as an important component of the natural mosaic of habitats, measuring how much wetland habitat remains in comparison to historic levels can provide an indication of the degree to which the landscape has been altered.

3. *Doesn't the health unit already measure E. coli when assessing beach health?*

   The Simcoe Muskoka District Health Unit measures E. coli throughout the summer at designated public beaches. As an indicator of watershed health, E. coli could also be monitored at targeted areas along the Muskoka River.

4. *For the Riparian Connectivity indicator, a better measure would be to evaluate the extent of shoreline connected to forest or other natural habitat by riparian vegetation. A 25 to 50 m ribbon of natural riparian habitat along the shoreline does not provide connectivity if it abuts a desert.*

   Riparian Connectivity measures whether shoreline habitat is fragmented and is taken as the proportion of undeveloped shoreline 25 to 50 m inland. We agree that the connectivity of natural habitat in the surrounding landscape is also important, and this will be measured by the Habitat Fragmentation indicator.

5. *How will % Land Cover be measured? How will it be used?*

   There could be several components to measuring this indicator, such as the amount of impervious area, the amount of vegetated area by vegetation type, the amount of disturbed area by type (e.g., residential, industrial, commercial). The information can be gained by using provincial geospatial data available through the Southern Ontario Land Resources Information System (SOLRIS). Percent Land Cover could be reviewed at regular intervals in the watershed to track changes to the proportions of different land cover (and thus to track habitat loss, urbanization etc.). For example, SOLRIS data could be evaluated every 5 years to determine if there has been a gain or loss in natural cover vs. urban cover or impervious cover.

6. *For Habitat Fragmentation, it is the distribution of patch sizes, not the % of area in patches > 200 ha that is important to track. Where does the 200 ha patch size come from for this indicator?*

   Habitat fragmentation (or the breaking apart of habitat) consists of four main effects on the landscape: (i) reduction in the amount of habitat; (ii) increase in number of habitat fragments, (iii) decrease in the size of fragments; and (iv) increase in the distance between fragments (Fahrig 2003). Thus, a combination of metrics can be used to track habitat fragmentation (e.g., amount of habitat loss, number of habitat fragments, size of fragments, and distance between fragments).

   Generally, the larger the patch size the better for providing a range of biodiversity benefits. Federal guidance recommends that watersheds have at least one (and preferably several) forest patches at least 200 ha in area to maintain the long-term persistence of area-sensitive forest species, low-mobility habitat specialists, and species that are intolerant of human disturbances (Environment Canada 2013). If overall forest coverage is high in the watershed (e.g., >30-50%) then forest patch size may be less important, and many smaller patches closely spaced across the landscape may confer similar benefits. However, Environment Canada considers that multiple patches of a minimum 100 ha size each are required to maintain many biodiversity functions (Environment Canada 2013). For example, a study in the Severn Sound Area of Concern found that individual patches between 100 and 200 ha may support 79-87% of regional forest interior bird species, and that protecting several forest patches at least 200 ha would support 90-100% of the species (Environment Canada 2013).

   Fahrig (2003) suggests that measuring patch size as an indicator of fragmentation can be problematic, because both habitat loss and habitat fragmentation (independent of habitat loss) lead to smaller patches, and regions with larger patches tend to have more habitat. Thus, we

suggest that additional measures of habitat fragmentation be added to watershed monitoring in future to clarify whether observed changes are due to habitat loss, habitat fragmentation, or both.

7. *Time of Ice On/Off is one effect of climate change, but is it a good proxy of climate change?*

   The timing of lake ice formation and breakup tends to be a good indicator of climate since it is closely linked to local air temperature (although other factors such as solar radiation, snow cover and wind also influence ice phenology). A recent study of 18 lakes across the Northern Hemisphere found that warmer local air temperatures and overall climate warming over the past 200 years are the main drivers of later ice-on and earlier ice-off dates (Imrit and Sharma 2021).

8. *The Muskoka River Water Quality indicator sounds more like a description of a sampling design, not an indicator per se. We definitely need to be sampling the Muskoka River, but we need to know what data is sampled, where, when, and how.*

   We agree that this indicator is not a conventional metric, but instead represents a sampling approach to provide a composite measure of water quality along the entire Muskoka River system. The establishment of long-term water quality monitoring of rivers in the watershed was a key recommendation of another IWM initiative project focused on identifying water quality indicators (HESL 2022b). That project found that sampling of stream and river systems was under-represented in the watershed. Sampling the length of the Muskoka River system could be used to track cumulative effects within the watershed and to identify areas where increased study and/or management may be required. The specific parameters to be sampled, and the sampling design and methodology for monitoring the Muskoka River system will be determined in a separate report on the implementation of the shortlist.

2.2 Survey Limitations

The survey was intended to provide guidance on narrowing down the longlist of indicators to a manageable shortlist to be implemented initially. However, several caveats need to be considered relating to the validity of survey results. First, there was a low response rate to the survey (22%), which means that the results may not be representative of the views of the larger group invited to participate. Second, several members of the CRT expressed concern that the shortlist should be based on guidance provided by scientific experts, not from public feedback on preferences. Third, as discussed in the first phase's report, Indigenous communities in the watershed should be consulted to seek their collaboration in identifying priorities and concerns for protecting watershed health, including the identification of indicators for monitoring.

While the small sample size for the survey is not ideal, the information gained from the 13 participants is still useful in providing a general sense of indicators considered high priority for monitoring among the surveyed group. Furthermore, scientific experts contributed to the survey, and to the identification of the longlist, which was developed through extensive consideration of scientific information for the watershed, consultation with local scientific experts, and jurisdictional review of approaches to measuring watershed health elsewhere in Ontario, Canada, and North America.

3. Guidance From Other Jurisdictions

To finalize the shortlist, we supplemented survey information with guidance from other jurisdictions and our own professional judgement on indicators to monitor initially in the watershed.

Jurisdictions we reviewed in the first phase of the project (e.g., Conservation Ontario [2011], Ottawa Riverkeeper [2019]) developed shortlists through consultation, and assessment of whether indicators

- Were quantitative,
- Were scalable (e.g., applicable to sub-watersheds as well as the entire watershed), and
- Had long-term datasets available (to measure trends through time) or were feasible for long-term monitoring.

Applying these criteria to the original longlist highlights indicators that are more appropriate to be included in the initial shortlist, and others that may require additional groundwork to implement, and thus may be more appropriate to incorporate into monitoring at a later date. For example, Tree Photo Archive and Riparian Photo Archive are qualitative measures of watershed health, and methods for documenting changes over time in these indicators still need to be determined. Brook Trout (presence/absence) is restricted to coldwater stream habitat (such as headwater tributaries) and thus may not be scalable across the entire watershed (i.e., if coldwater habitat is not present in all sub-watersheds). Determining methodology (for photo archives) and targeted locations (Brook Trout) for monitoring these indicators should be determined so that they may be implemented in future.

Many of the remaining longlist indicators (i.e., related to water quality, threats to water quality, and climate change) are already measured through long-term monitoring programs underway in the Muskoka River Watershed (e.g., the District's Lake System Health Program which monitors recreational water quality and benthic aquatic communities). While the frequency, timing, and spatial extent of sampling for these parameters may need to be modified to ensure extensive watershed-level coverage, it makes sense to piggyback on existing monitoring programs to continue collecting data on these indicators. Other indicators also have historical datasets available which can be used to track trends over time. For example, indicators related to landscape condition and threats to landscape condition can be measured retrospectively by using provincial geospatial data (e.g., the Ontario Land Cover Data Base, the Ontario Watershed Information Tool) and GIS layers available through the District's GeoHub resources to monitor changes to natural and anthropogenic features, including wetland extent, forest afforestation/deforestation, habitat connectivity, and built-up areas (impervious/pervious). Most of the indicators could be monitored over the long-term, although two indicators, the number of species of risk, and the number of invasive species, are difficult to track in a comprehensive manner within the watershed. This is not to say that addressing these threats to biological condition is not important, but tracking changes in the number of species at risk and invasive species across the watershed may not be logistically feasible, and should be investigated in more detail.

Benthic macroinvertebrates can be useful indicators of watershed health. However, because they are strongly influenced by surrounding habitat, it can be difficult to discern the impacts of stressors on their community structure, especially if impacts are not pronounced. In addition, taxonomic expertise is required to identify benthic macroinvertebrates for some of the biomonitoring indices commonly used to

track changes over time and space. We thus recommend that benthic macroinvertebrates only be used as an indicator if a point source discharge needs to be assessed.

Based on these criteria and the survey results, we thus recommend that 18 indicators from the longlist be included in the shortlist of initial metrics to monitor (Figure 4, Table 3). We will provide additional guidance on implementation of the shortlist in a separate report.

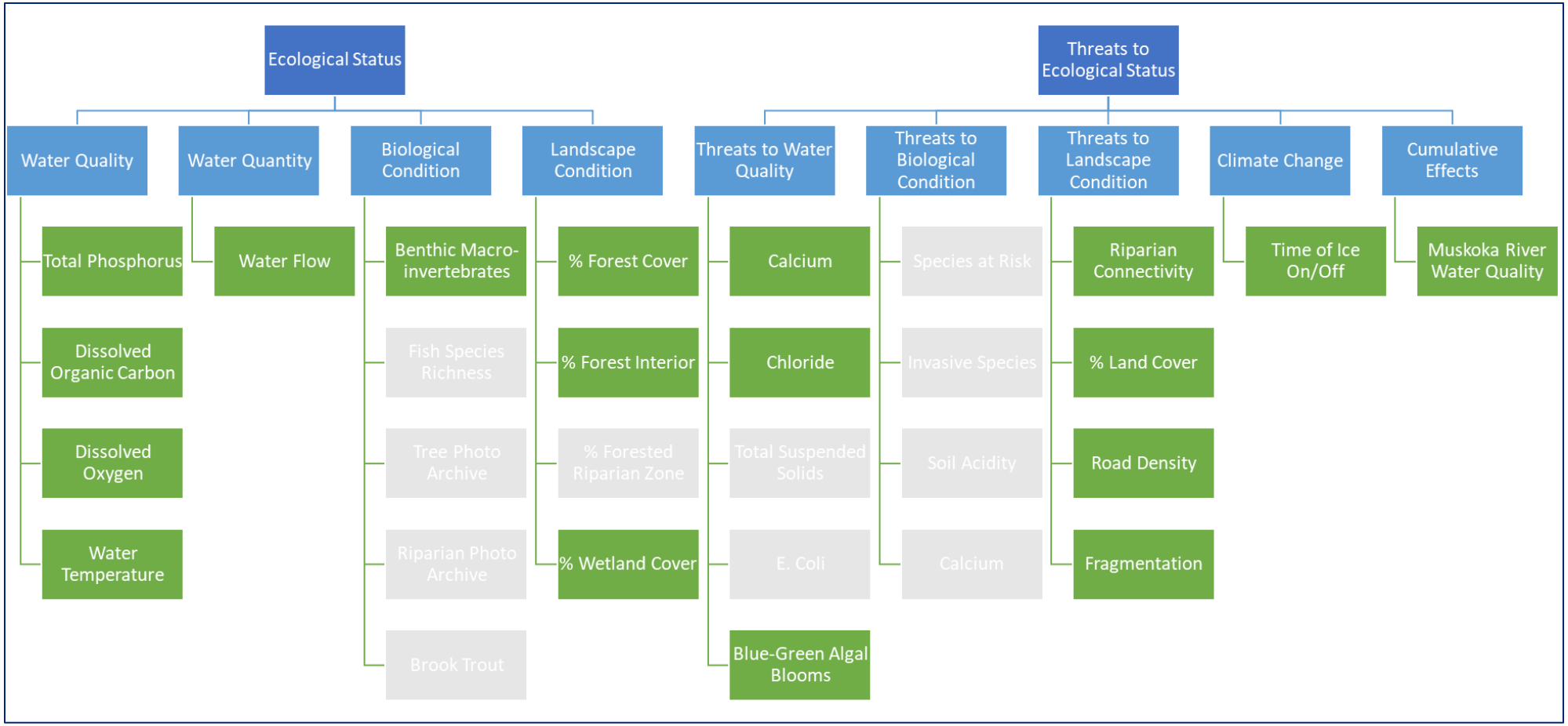


Figure 4. Recommended shortlist indicators (highlighted boxes in green) based on survey results and consideration of additional criteria.

Table 3. Rationale for recommended shortlist.

Indicator	In Shortlist?	Rationale
Water Quality		
Total Phosphorus	Yes	Quantitative, scalable, long-term data available, already monitored by the District
Dissolved Organic Carbon	Yes	
Dissolved Oxygen	Yes	
Water Temperature	Yes	
Water Quantity		
Water Flow	Yes	Quantitative, scalable, feasible for long-term monitoring
Biological Condition		
Benthic Macroinvertebrates	Yes – for assessment of point source discharges	Quantitative, scalable, long-term data available, already monitored by the District, but problematic if reference conditions are not well established
Fish Species Richness	No	Methodology needs to be determined
Tree Photo Archive	No	Qualitative, methodology needs to be determined
Riparian Photo Archive	No	
Brook Trout	No	Restricted to specific habitat (coldwater streams)
Landscape Condition		
% Forest Cover	Yes	Quantitative, scalable, long-term data available through provincial and District GIS layers
% Forest Interior	Yes	
% Forested Riparian Zone	No	Overlap with Riparian Connectivity

Indicator	In Shortlist?	Rationale
% Wetland Cover	Yes	Quantitative, scalable, long-term data available through provincial and District GIS layers
Threats to Water Quality		
Calcium	Yes	Quantitative, scalable, long-term data available, already monitored by the District
Chloride	Yes	
Total Suspended Solids	No	Highly variable and site-specific
E. coli	No	
Blue-green Algal Blooms	Yes	Quantitative, scalable, feasible for long-term monitoring
Threats to Biological Condition		
Species at Risk	No	Difficult to quantify at watershed scale
Invasive Species	No	
Soil Acidity	No	Methodology needs to be determined
Soil Calcium	No	
Threats to Landscape Condition		
Riparian Connectivity	Yes	Quantitative, scalable, long-term data available through provincial and District GIS layers
% Land Cover	Yes	
Road Density	Yes	
Fragmentation	Yes	
Climate Change		
Time of Ice On/Off	Yes	Quantitative, scalable, long-term data available, already monitored in the watershed
Cumulative Effects		

Indicator	In Shortlist?	Rationale
Muskoka River Water Quality	Yes	Quantitative, scalable, feasible for long-term monitoring

4. Conclusions

The survey identified 10 top-ranked indicators (of the original 29), representing water quality, biological condition, landscape condition, threats to landscape condition, and cumulative effects. This feedback was considered in conjunction with criteria used by other jurisdictions, and our professional judgement, to narrow down the longlist of indicators to a shortlist of initial metrics to monitor. Based on the survey results and additional criteria, we recommend that 18 indicators from the longlist be implemented initially, with the remainder to be incorporated into monitoring in the future. Guidance on implementation of the shortlist is provided in a separate report.

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Appendix A. Survey to Develop a Shortlist of Watershed Health Indicators

Survey to Develop a Shortlist of Watershed Health Indicators

Welcome to the Watershed Health Indicators Survey

In 2022, the Watershed Health Indicators Project identified a longlist of 29 ecological and environmental metrics to monitor the health of the Muskoka River Watershed. These indicators were selected through consultation with the Community Round Table (CRT) and local community members, as well as through a review of approaches taken by other jurisdictions. The longlist of indicators is divided into those that address Ecological Status (including biological, chemical, and physical elements of the watershed; 14 indicators) and those that address Threats to Ecological Status (15 indicators).

The District Municipality of Muskoka is interested in narrowing down the longlist to a more manageable shortlist (e.g., 10-15 indicators to be monitored initially, with the potential to add more as resources and capacity allow). The following survey will be used as part of that process to determine which indicators are considered most important and most effective for monitoring watershed health in the Muskoka River Watershed. The shortlist will consist of the top 10 to 15 ranked indicators from the survey.

Survey to Develop a Shortlist of Watershed Health Indicators

Survey Information

A brief description is provided for each of the 29 indicators, followed by 4 questions to be answered per indicator. Please respond to each question on a scale of 1 to 5, where 1 is strongly disagree, 3 is neutral, and 5 is strongly agree. An optional comment box is provided following the ranking questions if you have any specific comments you would like to add.

The survey should take approximately 15-20 minutes to complete. Please submit your responses by Friday July 28, 2023.

Thank you for participating in our survey. We appreciate your feedback.

Survey to Develop a Shortlist of Watershed Health Indicators

Ecological Status Indicators

Water Quality - 4 Indicators

Total Phosphorus

Phosphorus is an essential nutrient for plants and animals. It occurs naturally in low levels in most freshwater systems. Higher concentrations of phosphorus can lead to accelerated plant growth, algal blooms, low dissolved oxygen, and death of fish, invertebrates, and other aquatic animals. Sources of phosphorus can be both natural and human, including soil and rocks, wastewater treatment plants, runoff from fertilized lawns and agricultural fields, and faulty septic systems. Increases over time or in specific areas can reflect the influences of population growth and human activity.

1. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quality.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Dissolved Organic Carbon (DOC)

DOC levels in aquatic systems are influenced by decomposition of organic matter, and may arise from both aquatic (e.g., aquatic plants and algae) and terrestrial (e.g., soils, terrestrial plants) sources. DOC is an essential nutrient for microorganisms, contributes to the carbon cycle, and affects light penetration and thermal structure of lakes. Climate change can increase DOC entering aquatic systems. High levels of DOC can promote algal blooms, taste and odour issues, and calcium decline.

2. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Dissolved Oxygen (DO)

DO is essential for aquatic life (including fish, invertebrates, plants, and bacteria) and for the decomposition of organic waste. The availability of DO in freshwater is affected by factors such as excess decaying organic matter (e.g., raw sewage), wind, water temperature, and salinity. As an indicator, DO can provide information on the presence of organic pollution and nutrient enrichment.

3. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quality.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Water Temperature

Water temperature (e.g., measured as maximum annual water temperature) provides context for other indicators, such as DO, water flow, timing of ice on/off, and algal blooms, and can reflect the influence of climate change.

4. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quality.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Ecological Status Indicators

Water Quantity - 1 Indicator

Water Flow

Water flow (measured as minimum and maximum river flows, and ratio of maximum to minimum flow) provides context to other indicators, such as dissolved oxygen, algal blooms, and timing of ice on/off. It can be used to track effects of climate change and river management.

5. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of water quantity in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Ecological Status Indicators

Biological Condition (Aquatic) - 3 Indicators

Benthic Macroinvertebrates

Benthic macroinvertebrates (such as insects, aquatic worms, snails, and leeches) provide integrated information on water quality and habitat conditions in aquatic systems. Information on their community composition and abundance can reflect cumulative effects of chemical, physical, and biological factors in the watershed.

6. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of aquatic biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Fish Species Richness

Fish species richness (measured as the number of fish species present) provides integrated information on water quality and habitat conditions in aquatic systems, and can reflect cumulative effects of chemical, physical and biological factors in the watershed.

7. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of aquatic biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Brook Trout

Brook Trout are sensitive coldwater fish. Monitoring their presence or absence in coldwater streams can provide information on the health of these habitats, since Brook Trout require very clean cold water with high levels of dissolved oxygen, and are intolerant of waters that are cloudy or have low pH.

8. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of aquatic biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Ecological Status Indicators

Biological Condition (Terrestrial) - 2 Indicators

Tree Photo Archive

Photographs taken of the same trees over time can provide a long-term record of tree condition in response to environmental stressors and human activity (e.g., recovery from acid rain and calcium decline).

9. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of terrestrial biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Riparian Photo Archive

Photographs taken of the same riparian zone over time can provide a long-term record of shoreline condition in response to environmental stressors and human activity (e.g., shoreline development).

10. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of terrestrial biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Ecological Status Indicators

Landscape Condition - 4 Indicators

Percent Forest Cover

The amount of forest cover in a watershed indicates the ability of the landscape to sustain plant and animal communities. More forest cover means that the landscape is not dominated by human development and activity.

11. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Percent Forest Interior

The amount of forest interior (> 100 m from forest edge) reflects habitat quality, size, and degree of fragmentation. More forest interior indicates more habitat shielded from edge effects which are detrimental to many wildlife species.

12. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Percent Forested Riparian Zone

The amount of natural forest cover in the riparian zone (within 30 m) is a measure of shoreline health. Naturally vegetated shorelines are a hotspot for biodiversity and provide numerous ecological benefits (e.g., improve water quality, provide wildlife corridors, provide shade for aquatic species, prevent erosion).

13. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Percent Wetland Cover

The amount of wetland cover in a watershed provides a measure of how much intact natural habitat exists and an indication of the watershed's capacity to provide numerous ecological benefits, including water quality improvement, mitigation of floods and droughts, erosion reduction, shoreline protection, and provision of wildlife habitat.

14. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Threats To Ecological Status Indicators

Threats to Water Quality - 5 Indicators

Calcium

Lakes in Muskoka are experiencing calcium decline due to acid rain, with widespread negative effects on aquatic organisms (including zooplankton and crayfish). Calcium loss in aquatic systems may interact with other environmental stressors (e.g., declining phosphorus, rising chloride) to further threaten health of aquatic systems.

15. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Chloride

Chloride is a naturally occurring element, but high levels are harmful to aquatic life. Elevated concentrations can indicate the influence of human activity (e.g., use of road salt on winter roads) and can serve as a proxy for watershed hardening and alteration.

16. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Total Suspended Solids (TSS)

TSS refers to all suspended particles in water that are not dissolved, and can include sand, sediment, and plankton. Measuring TSS provides information on nutrient and contamination levels, since many of these components stick to suspended particles. TSS can thus indicate input from runoff or erosion and can be used to determine causes of high bacterial and phosphorus levels.

17. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

E. coli

High levels of the bacteria E. coli in water can indicate contamination due to sewage or animal waste and are a concern for human health.

18. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Blue-green Algal Blooms

Blue-green algal blooms are hazardous to human health and water quality. They are influenced by a variety of factors, including nutrient enrichment, low flow, water stagnation, sunlight, and temperature. Measuring the occurrence of blooms may indicate impacts of human activity and climate change.

19. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to water quality in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Threats to Ecological Status Indicators

Threats to Biological Condition - 4 Indicators

Species at Risk

Species at Risk (measured as the number of endangered, threatened, and special concern species present) indicates the effects of multiple stressors on native biodiversity in the watershed, since native species may be declining due to a myriad of threats associated with human activity (e.g., habitat loss and fragmentation, climate change, invasive species, pollution, overharvesting etc.).

20. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to biological condition in Muskoka.	○	○	○	○	○
Measuring this indicator is a good use of resources.	○	○	○	○	○
We can address unwanted changes to this indicator in the watershed.	○	○	○	○	○
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	○	○	○	○	○

Comments

Invasive Species

Invasive Species (measured as the number of non-native invasive aquatic and terrestrial species present) are a threat to native species and their habitats in the watershed. Invasive species introduced outside their native range often lack natural predators and spread rapidly, outcompeting or preying on native species, and altering habitats. Measuring the number of invasive species documented in the watershed provides an indication of the extent to which invasive species threaten native biodiversity.

21. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to biological condition in Muskoka.	○	○	○	○	○
Measuring this indicator is a good use of resources.	○	○	○	○	○
We can address unwanted changes to this indicator in the watershed.	○	○	○	○	○
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	○	○	○	○	○

Comments

Soil Acidity

Acid rain across eastern North America has led to soil acidification and increased leaching of calcium from soils. In Muskoka, this leaching, combined with the low weathering rate of Muskoka's bedrock, resulted in depletion of soil calcium levels (and ultimately declines in lake calcium concentrations). Calcium soil loss has reduced forest health, adversely affecting trees, as well as other terrestrial forest organisms, such as snails, isopods, and birds. Measuring soil acidity provides information on the legacy of acid rain and recovery from it, as well as information on the overall condition of forests in the watershed.

22. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Soil Calcium Levels

Acid rain across eastern North America has led to soil acidification and increased leaching of calcium from soils. In Muskoka, this leaching, combined with the low weathering rate of Muskoka's bedrock, resulted in depletion of soil calcium levels (and ultimately declines in lake calcium concentrations). Calcium soil loss has reduced forest health, adversely affecting trees, as well as other terrestrial forest organisms, such as snails, isopods, and birds. Measuring soil calcium levels provides information on the legacy of acid rain and recovery from it, as well as information on the overall condition of forests in the watershed.

23. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to biological condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Threats to Ecological Status Indicators

Threats to Landscape Condition - 4 Indicators

Riparian Connectivity

Natural shorelines are known as “the ribbon of life” because they are essential to maintaining healthy freshwater ecosystems through intercepting pollution, mitigating erosion, providing food, shelter and movement corridors for wildlife, and protecting aquatic ecosystems from climate change impacts.

Riparian connectivity (measured as the width of naturally vegetated habitat within 25 to 50 m inland of lakes and rivers) indicates the degree to which the shoreline provides natural connected habitat, allowing the ribbon of life to function optimally (e.g., allowing native species the ability to move unimpeded across both terrestrial and aquatic habitats).

24. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Percent Land Cover

Percent land cover refers to the proportion of the landscape comprised of different habitat types and land uses (such as forest, wetlands, urban areas, agricultural areas, industrial areas, and golf courses). It provides a measure of how land use and natural areas change over time and provides context for other indicators. It can also reveal the extent to which the watershed is covered by impervious surfaces (e.g., paved) which prevents water from infiltrating through to the ground, resulting in runoff.

25. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Road Density

Road density indicates the extent of development and habitat fragmentation across the landscape. The density of roads may be used as a proxy for the risk of road salt contamination to aquatic systems, and as an indication of how easily wildlife can move across the landscape.

26. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Habitat Fragmentation

Habitat fragmentation (measured as the percent of the watershed comprised of natural areas > 200 ha) reflects the extent of magnitude across the landscape. Large unfragmented patches of natural habitat are increasingly rare in landscapes dominated by development and human activity, but are necessary to sustain ecological processes and plant and wildlife species.

27. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of threats to landscape condition in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Threats to Ecological Status Indicators

Climate Change - 1 Indicator

Time of Ice On and Ice Off

Measuring the date ice forms on and disappears from lakes each season can provide an integrated measure of the effects of climate change (via warmer air and water temperatures, and changes in water flow) on aquatic systems over time in the watershed.

28. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of climate change in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Threats to Ecological Status Indicators

Cumulative Effects - 1 Indicator

Muskoka River Water Quality

The Muskoka River is the major artery of the watershed. A monitoring program that includes regular and systematic sampling at key points along the river, from upstream in Algonquin Park to the outflow of Lake Muskoka at Bala could detect changes over time and over space, identifying key stressors or areas of stress (e.g., influences of urban centres or highways, natural changes with location within the watershed) which could then be used to develop focused causation studies.

29. How important is this indicator for monitoring watershed health in Muskoka?

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
This is a useful indicator of cumulative effects in Muskoka.	◯	◯	◯	◯	◯
Measuring this indicator is a good use of resources.	◯	◯	◯	◯	◯
We can address unwanted changes to this indicator in the watershed.	◯	◯	◯	◯	◯
Unwanted changes to this indicator can result in negative ecological and/or socio-economic impacts.	◯	◯	◯	◯	◯

Comments

Survey to Develop a Shortlist of Watershed Health Indicators

Almost done...just one more thing!

30. This survey is anonymous, however, if you would like to provide information about your affiliation please do so below. This information will be used to track which sectors of the community responded to the survey.

Affiliation - optional (e.g., Community Round Table, Muskoka Watershed Council, Chamber of Commerce, cottager, year-round resident etc.)

Thank you very much for participating in this survey!

Survey results will be summarized in a report to the District in the fall of 2023. The final report will be posted to the District's EnviroHub (muskoka.on.ca/envirohub). If you wish to be notified when the report is available, please register for updates on the EnviroHub webpage.

Appendix B. Scoring of Survey Responses

Respondent	TP				Sum	DOC				Sum	DO				Sum
1	4	4	4	4	16	2	2	2	2	8	4	4	3	4	15
2	4	4	2	4	14	4	3	2	2	11	3	2	2	3	10
3	3	4	5	5	17	4	4	4	4	16	5	5	5	5	20
4	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
5	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	3	4	15	3	3	3	3	12	4	4	4	4	16
8	5	5	5	5	20	4	4	4	5	17	4	4	4	4	16
9	5	5	5	5	20	4	4	2	4	14	5	5	4	5	19
10	5	5	5	5	20	5	5	4	4	18	5	4	3	5	17
11	4	4	4	4	16	4	4	3	4	15	4	4	4	4	16
12	3	3	4	4	14	4	4	4	4	16	4	3	3	4	14
13	5	4	4	4	17	5	4	3	4	16	5	4	3		12
				Total	217					191					203

Respondent	Water Temperature				Sum	Water Flow				Sum	Benthic Macroinvertebrates				Sum
1	4	4	1	5	14	5	5	5	4	19	5	5	5	5	20
2	4	4	2	2	12	5	4	2	4	15	5	4	2	3	14
3	4	4	4	4	16	4	4	4	4	16	5	5	5	5	20
4	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
5	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	3	4	15	4	4	3	4	15	4	3	3	4	14
8	5	5	5	5	20	4	4	4	4	16	5	5	5	5	20
9	5	5	2	5	17	4	4	3	4	15	5	5	4	5	19
10	3	3	1	4	11	5	5	3	5	18	2	2	4	4	12
11	4	4	3	4	15	4	3	2	4	13	4	3	4	4	15
12	4	4	3	4	15	4	3	2	4	13	4	4	3	4	15
13	4	3	3	3	13	4	4	3	3	14	4	3	3	3	13
					200					206					214

Respondent	Fish Species Richness				Sum	Brook Trout				Sum	Tree Photo Archive				Sum
1	4	2	5	5	16	5	5	5	5	20	2	2	3	3	10
2	4	3	2	2	11	3	3	2	3	11	4	3	2	2	11
3	5	5	5	5	20	5	5	5	5	20	3	3	3	3	12
4	4	4	4	4	16	4	4	4	4	16	3	3	3	3	12
5	5	5	5	5	20	5	5	5	5	20	3	3	3	3	12
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	3	4	15	4	4	3	4	15	4	3	3	3	13
8	4	4	4	4	16	3	3	4	4	14	4	4	4	4	16
9	4	3	2	4	13	3	3	2	4	12	4	3	4	4	15
10	4	3	5	4	16	3	4	3	4	14	4	2	3	5	14
11	4	3	3	4	14	4	3	3	4	14	4	4	3	4	15
12	3	3	3	4	13	4	4	3	4	15	4	4	3	4	15
13	5	4	3	3	15	4	3	3	3	13	3	3	3	3	12
					201					200					173

Respondent	Riparian Photo Archive				Sum	Percent Forest Cover				Sum	Percent Forest Interior				Sum
1	4	4	4	5	17	5	5	5	5	20	4	3	4	4	15
2	4	4	2	2	12	4	3	2	2	11	4	4	3	3	14
3	5	5	5	5	20	4	4	4	4	16	4	4	4	4	16
4	5	5	5	5	20	5	5	5	5	20	4	4	4	4	16
5	3	3	3	3	12	3	3	3	3	12	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	3	3	4	4	14	4	4	4	4	16	4	4	4	4	16
8	4	4	4	5	17	4	4	4	5	17	5	5	5	5	20
9	4	3	4	4	15	5	5	5	5	20	5	5	5	5	20
10	5	3	5	5	18	5	5	5	5	20	5	5	5	5	20
11	4	4	4	4	16	4	4	4	4	16	3	3	3	3	12
12	5	4	4	4	17	5	4	3	5	17	5	4	3	5	17
13	3	3	3	3	12	3	3	3	3	12	4	3	3	3	13
					206					213					211

Respondent	Percent Forested Riparian Zone				Sum	Percent Wetland Cover				Sum	Calcium				Sum
1	5	5	5	5	20	5	5	5	5	20	4	3	3	4	14
2	3	3	2	3	11	5	4	3	3	15	5	4	4	4	17
3	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
4	4	4	4	4	16	5	5	5	5	20	2	2	2	2	8
5	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	4	3	15	4	4	3	4	15	4	4	4	4	16
8	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
9	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
10					0	5	5	5	5	20	4	4	3	4	15
11	4	4	4	4	16	4	4	3	4	15	4	4	4	4	16
12	5	4	4	5	18	5	4	3	4	16	4	4	3	4	15
13	4	4	3	3	14	4	4	3	3	14	4	4	3	3	14
					202					227					207

Respondent	Chloride				Sum	Total Suspended Solids (TSS)				Sum	E. coli				Sum
1	3	3	4	4	14	3	3	3	4	13	4	3	4	3	14
2	5	4	4	4	17	3	3	3	3	12	4	4	4	4	16
3	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
4	2	2	2	2	8	3	3	3	3	12	4	4	4	4	16
5	3	3	3	3	12	4	4	4	4	16	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	4	4	16	3	3	3	3	12	3	2	4	4	13
8	5	5	5	5	20	5	5	5	5	20	4	4	4	4	16
9	5	5	5	5	20	4	4	4	4	16	4	4	4	4	16
10	5	5	5	3	18	2	2	4	3	11	2	2	2	5	11
11	4	4	4	4	16	4	4	3	4	15	4	4	3	3	14
12	5	4	4	5	18	4	4	3	5	16	4	4	4	4	16
13	4	4	3	3	14	4	4	3	3	14	4	4	4	4	16
					209					193					200

Respondent	Blue-green Algal Blooms				Sum	Species at Risk				Sum	Invasive Species				Sum
1	4	4	3	5	16	3	2	2	3	10	2	2	2	2	8
2	5	4	2	3	14	4	3	2	3	12	4	3	2	3	12
3	5	5	5	5	20	5	5	5	5	20	4	4	4	4	16
4	3	3	3	3	12	4	4	4	4	16	4	4	4	4	16
5	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	3	4	15	3	3	3	3	12	4	3	3	4	14
8	5	5	5	5	20	4	4	5	5	18	5	5	5	5	20
9	5	5	3	5	18	4	3	3	4	14	5	5	5	5	20
10	4	3	3	4	14	3	3	3	3	12	3	2	2	3	10
11	4	4	3	4	15	4	4	3	4	15	4	4	3	4	15
12	5	5	3	5	18	4	3	3	4	14	5	4	4	5	18
13	4	4	3	4	15	4	4	3	3	14	4	3	3	3	13
					209					189					194

Respondent	Soil Acidity				Sum	Soil Calcium Levels				Sum	Riparian Connectivity				Sum
1	3	2	2	3	10	3	3	3	3	12	5	5	5	5	20
2	3	3	2	3	11	4	3	3	3	13	4	3	4	4	15
3	4	4	4	4	16	4	4	4	4	16	5	5	5	5	20
4	3	3	3	3	12	2	2	2	2	8	4	4	4	4	16
5	3	3	3	3	12	3	3	3	3	12	5	5	5	5	20
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	3	3	3	3	12	4	4	4	4	16	3	3	3	3	12
8	5	5	5	5	20	5	5	5	5	20	5	5	5	5	20
9	3	3	3	3	12	4	4	4	4	16	5	5	5	5	20
10	4	2	2	4	12	3	2	2	5	12	5	4	5	4	18
11	4	3	3	4	14	4	3	3	4	14	4	3	3	4	14
12	4	4	3	4	15	4	4	4	4	16	5	4	3	4	16
13	4	3	3	3	13	4	3	3	3	13	4	4	3	3	14
					175					184					221

Respondent	Percent Land Cover				Sum	Road Density				Sum	Habitat Fragmentation				Sum
1	4	4	4	5	17	5	5	5	5	20	5	5	4	4	18
2	5	3	4	4	16	5	4	4	4	17	5	4	4	4	17
3	5	5	5	5	20	4	4	4	4	16	4	4	4	4	16
4	2	2	2	2	8	3	3	3	3	12	4	4	4		12
5	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
6	4	4	4	4	16	4	4	4	4	16	4	4	4	4	16
7	4	4	4	4	16	4	4	4	3	15	3	3	3	3	12
8	5	5	5	5	20	5	5	4	5	19	5	5	5	5	20
9	4	4	4	4	16	4	4	4	4	16	5	5	5	5	20
10	5	5	5	5	20	5	5	5	5	20	5	5	3	4	17
11	4	4	4	4	16	4	4	3	4	15	4	4	4	4	16
12	5	4	3	5	17	5	4	3	5	17	5	4	3	5	17
13	4	4	3	3	14	3	3	3	3	12	4	4	3	3	14
					212					211					211

Respondent	Time of Ice On and Ice Off				Sum	Muskoka River Water Quality				Sum
1	4	4	2	4	14	5	5	5	5	20
2	5	4	2	2	13	4	3	2	3	12
3	5	5	5	5	20	5	5	5	5	20
4	4	4	4	4	16	4	4	4	4	16
5	4	4	4	4	16	5	5	5	5	20
6	4	4	4	4	16	4	4	4	4	16
7	4	4	3	4	15	4	4	3	3	14
8	5	4	4	4	17	5	5	5	5	20
9	5	5	1	4	15	4	4	4	4	16
10	5	5	2	4	16	5	5	5	5	20
11	4	5	4	4	17	4	4	4	4	16
12	5	5	3	5	18	5	5	3	5	18
13	4	3	3	3	13	4	3	3	3	13
					206					221

Appendix C. Survey Comments

Indicator	Comments				
Respondent	A	B	C	D	E
TP	need to be looked at in concert with a suite of variable which can be combined for overall health...	data must be collected systematically at same time of year to be comparable	An important indicator, but can be difficult to tease apart changes resulting from regional versus local impacts (e.g., recovery from acid deposition or climate change (regional) versus shoreline development (local)). Focus on spring concentrations in Shield lakes.		
DOC	A number of our lakes have background levels of DOC and yet have just as good water quality as many others	We need more research to confirm source of any changes - if DOC is responding to climate then we can have little direct influence -but DOC comes from wetlands and we can protect and manage that source	DOC is a master variable in aquatic ecosystems. However, the causes of changes in DOC are complex.	Can we address unwanted changes ?	Changes in DOC composition and concentration can affect water quality parmeters and can impact the growth and the survival of organisms found in the water
DO	Addressing changes in this WQ parameter may require extensive work	Uniform methodology focused on deep water is important	We need to collect DO data into the autumn - a mid July profile is not that useful unless lake is strongly anoxic We need more research to confirm source of any changes - if DO is responding to climate then we can have little direct influence	I suggest focusing on end of summer hypolimnetic DO concentrations, as a measure of Lake Trout habitat. MNRF may not the capacity to maintain this monitoring record at the moment. The end of summer period would be Sept 15 to Oct 15.	Can we address unwanted changes?
Water Temperature	only in concert with other variables as its easy to add to WQ sampling runs	Many water quality meters will collect temperature automatically. So it cant hurt to collect this information. It is also an important factor to be aware of when collecting water data as temperature can influence the presence/abundance of other parameters.	Difficult - an occasional measurement is not that useful - temperature needs to be collected regularly and frequently to be useful and address the noise of seasonality and year to year variation. Continuous recorders (Hobo loggers) recording at regular intervals year round would be cheap and most useful If we want to track watershed health then we need only to collect data at several key points - not for every lake (e.g. Big East River, Muskoka River at Huntsville, Port Sydney, Bracebridge, Bala	Also and important master variable and easy to track cheaply in aquatic ecosystems. You could focus on temperatures at a lake's surface (1 m depth). I recommend at least monthly readings. There are in situ sensors that can be deployed to measure temperature.	
Water Flow	bias in your question.....of course flow is a good indicator of water quantity	a key parameter to monitor although climate -related changes can only be partially managed locally	Will take an intensive monitoring program to monitor this properly....suggest partnering with MECP's DESC, as they monitor flow at a few long-term monitoring stations....although at fewer stations than they have historically.		
Benthic Invertebrates	tells a a great story of what's going on in both aquatic and terrestrial components of the ecosystem.... 'index of biotic integrity'	Need more sophisticated analysis of samples than at present, plus a properly designed sampling program	This is a great indicator to include because it can incorporate community involvement with volunteers helping to collect the invertebrates. The inverts are living in the water, they can tell you a lot about it.	DESC and residents have been monitoring benthos for several decades - we would need to know what we have learned and any evidence of change before committing resources to this given the overall influence of habitat type and seasonality on benthos it is difficult to see the data as useful in watershed management beyond the education/awareness of residents	It's important to include biological indicators, and BMIs are well-established indicators of biological condition in Ontario lakes and streams (through programs such as CABIN and the OBBN). Fairly labour-intensive, however.

Indicator	Comments				
Fish Species Richness	relatively more expensive to monitor and the benthic indices can cover the same issues	I wonder if this would be influenced by fish stocking?	Useful but there are more sensitive indicators of fish health than species richness, e.g. biochemical and physiological indicators		
Brook Trout	in areas with coldwater stream habitat, this is an excellent productive of, and indicator of high quality habitat ---- its demise means the catchment (aquatic and terrestrial) has gone downhill	Presence of this species is governed by multiple factors and simple presence/absence will not tell you much about condition of a lake	Similar to the benthic inverts, the fish live in the water and can tell you a lot about it. But inverts are extremely abundant and can tell you a variety of things about a waterbody. If brook trout only occur in certain habitats where conditions are right, monitoring might turn up a lot of nothing. But that being said, finding nothing is an answer. But it is more of a yes/no. The fish is here= good quality, the fish is absent= bad quality.	useful in cold water streams and not as a general watershed indicator - we can only manage some local influences on temperature (habitat protection) but climate change management goes beyond local efforts - we also need to account for angling pressure as a significant influence on populations	
Tree Photo Archive	Not clear how this archive would be used	Measurement and Interpretation of photos is labour intensive and how do we separate out the influence of climate change from that of Ca, acid rain etc.	Probably and inexpensive indicator to include - site selection will be important.		
Riparian Photo Archive	Not clear how the photos will be collected, so difficult to assess potential value	While interpretation of photos is labour intensive, impacts are site specific and management of the riparian zone can be directly addressed by individuals surveys and classification (i.e. degree and nature of alteration) of entire lakes can also be useful to detect trends over time, even without photo interpretations.			
Percent Forest Cover	important, easy to measure and far reaching implications	highly important integrator of forest health that is easily measured (remote sensing techniques) and which can be directly managed by local activities.	Could perhaps be done using remote sensing tools. An important macro-indicator of change in the region.		
Percent Forest Interior	possible for land use professionals to shrink forest cover as long as there's some index amount of interior mapped with the municipality. However, its important to ecosystem health	highly important integrator of forest health that is easily measured (remote sensing techniques) and which can be directly managed by local activities.			
Percent Forested Riparian Zone	Is 30 m the correct dimension? Is the measure of 'natural forest' or 'natural vegetation' -- there is a big difference?	easily measured (remote sensing techniques) and which can be directly managed by local activities. This seems to be something that is covered in other indicators - Percent Forest Cover and Riparian Photo Archive?	Maintaining a healthy, natural shoreline buffer is a relatively inexpensive way of protecting aquatic ecosystems.		
Percent Wetland Cover	Not sure that amount of wetland translates to amount of intact habitat - don't see why it should. Amount of wetland is useful indicator in its own right.	easily measured (remote sensing techniques) and which can be directly managed by local activities. This seems to be something that is covered in other indicators or in which several indicators can be measured by one method	Wetlands are important natural filters on the landscape. Percent wetland area is also a variable used in environmental impact models, such as the Lakeshore Capacity model.		

Indicator	Comments				
Calcium	specific metric for a very specific problem	easily and inexpensively measured by DMM spring surveys but we need to understand how many lakes are threatened to see how big a threat it is. Also, the damage occurred over several decades and the primary cause (acid rain) has been addressed. I see limited potential for wide scale ash addition	Yes, important to include, particularly given local wood ash projects in the watershed.		
Chloride	specific metric for a very specific problem	easily and inexpensively measured by DMM spring surveys and can be directly managed through our own efforts. The threat and damage is real for a subset of Muskoka lakes but is not widespread across all lakes	Two words....road salt.	In many of these past questions I have no idea how well we can address unwanted changes	
TSS	more useful in urban areas. Since 90% of the watershed is natural TSS may not be the best way to use resources	highly variable in response to storms and activities and requires intensive measurement to be useful very limited usefulness and application and really is only a threat on a site specific basis (storm drainage, construction activities or land clearing) that should be addressed by regulatory oversight. I see no need for a watershed -wide program of TSS measurement but it should be addressed at the level of specific activities by management controls	Not something routinely monitored, but an important input variable in some fish health models.		
E. coli	specific metric for a very specific problem -- not necessarily related to overall ecosystem health	Would be simpler to enforce proper maintenance of sewage facilities	highly variable and site specific and requires intensive sampling to be useful as a watershed program. Also is not specific to human activities as is a natural pathogen - well managed already by a) municipal programs for drinking water, b) "don't drink surface water" and c) monitoring at public beaches. I could see utility in monitoring at a few select sites on the main stem of the Muskoka RIver to get a general idea if things are getting better or worse over time with feedback to storm water management and WWTP discharges.	Health unit may already measure this when assessing beach health?	

Indicator	Comments				
Blue-green Algal Blooms	proper monitoring of HABs is a research level activity to determine causation and requires intensive monitoring effort. The problem appears to be related to climate change and so we cannot manage that pressure locally (although there are means of active management of specific blooms on lakes these are expensive and unpopular (aeration, sediment inactivation). In the absence of serious effort to curtail climate change and effective manag3ment techniques I think the status quo - is adequate - public documentation of blooms and confirmation by experts. Perhaps enough booms will convince people to act on the causation	I suggest continuing to work through MECP's algal bloom monitoring protocol...i.e., call Spills Action Centre when a blue-green algal bloom is suspected.			
Species at Risk	recording the number of species at risk known to occur does very little to inform re habitat quality. More important is whether SAR populations are thriving or dying out.	we have SAR that are SAR because they are at the limits of their range with little opportunity for management beyond the site specific level of site plan. Requires highly intensive monitoring effort which can generally only be done at the site level. Not suitable for watershed-wide monitoring. If we look after the habitat, then the SAR should be okay	An important consideration in land-use decision-making.		
Invasive Species	Ad hoc recording has enormous biases. Systematic recording would be expensive.	Requires intensive monitoring to be done in a quantitative way - otherwise we rely on observation - we can do little to manage and prevent within the watershed as they come from outside of the watershed (by definition) and once they invade, there is little evidence that they can be managed. While researchers have documented ecological changes - the "impacts" do not appear to be significant.			
Soil Acidity	we know what the impacts are, acid rain has been largely curtailed and soil Ca/acidity is highly variable across the watershed. Changes occur over decadal time scales and so the status of this indicator can be addressed at a research level at a few ongoing sites.	No doubt this is an important indicator, but work would need to be done to determine appropriate methods, and spatial and temporal sampling frequencies.			
Soil Calcium Levels	Again, details of how measurements are made will determine any value of the data	same as previous - we know what the impacts are, acid rain has been largely curtailed and soil Ca/acidity is highly variable across the watershed. Changes occur over decadal time scales and so the status of this indicator can be addressed at a research level at a few ongoing sites	At a broad scale, soil Ca can influence the P mobility from septic systems. I would be surprised if there was tremendous variability within the Muskoka River Watershed.		

Indicator	Comments				
Riparian Connectivity	Better would be an evaluation of extent of shoreline that is connected to forest or other natural habitat by riparian vegetation. 25 or 50m ribbon abutting a desert does not provide connectivity.	can be managed directly and locally and monitored cost effectively by remote sensing techniques in combination with the other forest indicators identified previously in this survey (i.e. one flight can be analysed for a variety of forest - wetland - riparian indicators.			
Percent Land Cover	How will it be measured; how will the data be used?	Land use (and accompanying economics) is the biggest threat to the Muskoka we know It can be managed directly and locally and monitored cost effectively by remote sensing techniques in combination with the other forest indicators identified previously in this survey (i.e. one flight can be analysed for a variety of forest - wetland - riparian - human indicators.)	Important to track long-term changes in land-use. This information can be used to inform future development, and are commonly used as input variables in predictive models.		
Road Density	changes in road density in areas with a high degree of connectivity or contiguous natural area is a good indicator of impending human impact on overall ecosystem health	Road density should be easy to monitor. Not yet known the extent to which it correlates to fragmentation, connectivity, or road salt contamination of lakes	Land use (and accompanying economics) is the biggest threat to the Muskoka we know It can be managed directly and locally and monitored cost effectively by remote sensing techniques in combination with the other forest indicators identified previously in this survey (i.e. one flight can be analysed for a variety of forest - wetland - riparian - human indicators - road density.)	An important predictor of chloride concentrations in lakes.	
Habitat Fragmentation	It is the distribution of patch sizes, not the percent of area in patches >200ha that will be important to track. Not sure where the focus on 200 ha comes from.	Land use (and accompanying economics) is the biggest threat to the Muskoka we know It can be managed directly and locally and monitored cost effectively by remote sensing techniques in combination with the other forest indicators identified previously in this survey (i.e. one flight can be analysed for a variety of forest - wetland - riparian - human indicators.)			
Time of Ice On and Ice Off	good use of resources is based on our knowledge of the relative effort need to monitor each variable	Not sure it tracks climate change. This is one effect of climate change and will vary among lakes due to other factors. Not a proxy for climate.	cheap, easy and effective and a clear indicator of climate change in an indicator that is directly relevant to citizens. Changes will reduce ice safety but ecological impacts of reduced ice cover are likely confined to a subset of our lakes. Management is a global effort	Easy top measure - potential for citizen-science partnerships.	

Indicator	Comments				
Muskoka River Water Quality	This has been neglected and is vital	This sounds more like a description of a sampling design. Something that is definitely needed, but cannot comment on its value without data on what is sampled, where, when and how.	The biggest benefit to this is that we could gather a great deal of useful information about the whole watershed by monitoring a small number (6-8) of sites and using the results to focus on the areas where increased management was required. I see this, and remote sensing of the suite of forest health indicators, as the most useful and cost effective monitoring approaches identified in this survey.		

Hutchinson

Environmental Sciences Ltd.

Watershed Health Indicators – Muskoka River Watershed

Implementation Report

Prepared for: The District Municipality of Muskoka
Job #: J220004

November 3, 2023

FINAL

1-5 Chancery Lane, Bracebridge ON P1L 2E3 | 705-645-0021

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Environmental Sciences Ltd.

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November 3, 2023 HESL Job #: J220004

Glenn Cunnington
Manager, Watershed Programs
The District Municipality of Muskoka
70 Pine Street
Bracebridge, Ontario
P1L 1N3

Dear Glenn:

Re: Final Implementation Report – Watershed Health Indicators Muskoka River Watershed Project

We are pleased to submit the Final Implementation Report for the Watershed Health Indicators – Muskoka River Watershed Project. A variety of reports have been completed to help develop monitoring recommendations for the Muskoka River Watershed. This report builds on those previous reports and provides guidance on implementing the 18 shortlisted indicators so that District staff have the necessary information to develop and implement a holistic monitoring plan in the Muskoka River Watershed as part of the Integrated Watershed Management Plan.

We thank you for the opportunity to undertake this work. We hope the report provides useful information as the District develops its approach to Integrated Watershed Management.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.



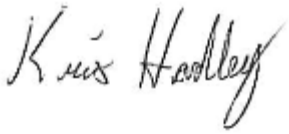
Andrea Smith, Ph. D.
Senior Scientist

Signatures

Report Prepared by:



Andrea Smith, Ph. D.
Senior Scientist



Kristopher R. Hadley, Ph.D.
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Report Reviewed by:



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Principal and Senior Aquatic Scientist

Executive Summary

The District Municipality of Muskoka (the District) launched the Watershed Health Indicators Project in 2022, as part of its Integrated Watershed Management (IWM) Initiative. The aim of the project was to build on existing information and studies to identify environmental and ecological metrics to monitor watershed health in the Muskoka River Watershed. Hutchinson Environmental Sciences Ltd. (HESL) completed the first phase of the project in September 2022 by developing a longlist of 29 indicators.

As part of the second phase of the project in 2023, HESL led the development of a shortlist of indicators through consultation with the Community Round Table, local scientific experts, and other community stakeholders, a review of approaches from other jurisdictions, and application of professional judgement to finalize the shortlist to 18 indicators from the original 29 in the longlist. The following report provides guidance on how to implement the shortlist of indicators in the Muskoka River Watershed, integrating information from the Water Quality Indicators Project (another IWM project for the District) and general guidance provided to the District on water quality monitoring.

The recommended shortlist is comprised of 18 parameters related to water quality, threats to water quality, water quantity, biological condition, landscape condition, threats to landscape condition, climate change, and cumulative effects. Many of these indicators (i.e., related to water quality, threats to water quality, and climate change) are already measured through existing long-term monitoring programs in the Muskoka River Watershed. We recommend that these parameters continue to be monitored through existing programs, although the frequency, timing, and spatial extent may need to be modified to ensure watershed-level coverage, as described below. In addition, we recommend that some water quality parameters be monitored through high frequency continuous automated sampling to address shortcomings of manual sampling. However, the technology required for automated monitoring can be expensive, and we realize this may limit its broad-scale application across the watershed. As a result, we have suggested initial targeted use of automated devices, to address the pressing issue of harmful algal blooms.

Other indicators related to landscape condition and threats to landscape condition can be measured by using geospatial datasets. We recommend that GIS data layers available through the IWM Natural Capital Inventory be used as a basis for this monitoring. Some indicators are not currently monitored systematically in the watershed (e.g., water flow, water quality throughout the Muskoka River) and we offer guidance on integrating these components into watershed health monitoring.

We make the following recommendations to implement the shortlist:

1. *Lake Monitoring*

- Continue monitoring total phosphorus (TP), dissolved organic carbon (DOC), calcium, and chloride through the Recreational Water Quality Program.

- Expand monitoring for dissolved oxygen (DO) and water temperature to include targeted sampling of lakes with low phosphorus and frequent recurring harmful algal blooms through high frequency continuous automated samplers.

- Implement high frequency automated monitoring for the early detection of algal blooms in targeted lakes (i.e., those with low phosphorus and recurring blooms) from August through October. Augment this monitoring with high frequency collection of meteorological data in the watershed to track relationships between blooms and climate trends.

- Given the confounding effects of habitat on benthic macroinvertebrate community structure, and the considerable effort required to establish reference conditions for meaningful comparison of data, only implement additional benthic macroinvertebrate monitoring if a point source discharge needs to be assessed.

- Enlist citizen scientists to monitor timing of ice on and ice off on lakes across the watershed through the IceWatch Program. Promote participation and provide an online portal on EnviroHub that participants can use to submit their data to the District.

2. *River Monitoring*

- Expand monitoring to the Muskoka River and its tributaries to track cumulative effects as water travels from the headwaters upstream near Algonquin Park to the outflow of Lake Muskoka at Bala. Monitor TP, DOC, DO, water temperature, calcium, chloride, and water flow at 17 main stations throughout the watershed, on the Hollow River, Oxtongue River, Oxbow River, Big East River, Muskoka River mainstem, North Muskoka River, South Muskoka River, Indian River, and Moon River. These sites are subject to a range of anthropogenic influences, from minimally impacted upstream locations (e.g., Oxtongue River at Oxtongue Lake outflow) to sites within and downstream of urban centres (e.g., Muskoka River at Hunter's Bay outflow, Muskoka River at Bracebridge Falls) or downstream of highways (e.g., Muskoka River at High Falls). Many of these sites overlap with locations recommended for potential monitoring of contaminants. An additional three stations could also be added at other locations recommended for contaminant sampling, representing sites downstream of urban centres, wastewater treatment plants, and agricultural lands.

- Sample river stations from spring through fall to capture spring freshet, summer baseflow, and moderate fall flow conditions.

3. *Landscape Condition*

- Use GIS datasets to measure landscape condition and threats to landscape condition.

- Measure forest conditions exclusive of lake area to avoid underestimating forest cover in an area with a high percentage of lakes.

- Differentiate different wetland types to avoid duplicating counts of wetland forest under both percent forest cover and percent wetland cover.

- Measure riparian connectivity as the amount of undeveloped shoreline within 30 m of the water's edge.

- Calculate land cover by land use type and vegetation cover type (e.g., urban, industrial, highway, golf course, agricultural field, forest, rock barren, wetland etc.).

- Measure overall road density for the watershed.

- Calculate the percent of the watershed comprised of natural areas (i) at least 100 ha and (ii) at least 200 ha in size.

4. Review and Reporting

- Review field data periodically throughout the monitoring season for quality control and assurance.

- At the end of each monitoring season (i.e., annually), conduct a more in-depth analysis of monitoring data (e.g., summary statistics) to determine if they are providing appropriate spatial and temporal resolution to discern watershed condition.

- Every two to five years, analyze field monitoring data and report on results and interpretations in a monitoring report summarizing trends and patterns in watershed health.

- For landscape condition and threats to landscape condition indicators, conduct GIS analysis, interpretation, and reporting every five years.

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1. Introduction

1.1 Background

The District Municipality of Muskoka (the District) launched the Watershed Health Indicators Project in 2022, as part of its Integrated Watershed Management Initiative. The aim of the project was to build on existing information and studies to identify environmental and ecological metrics to monitor watershed health in the Muskoka River Watershed. Hutchinson Environmental Sciences Ltd. (HESL) completed the first phase of the project in September 2022 by developing a longlist of 29 indicators. The work involved the following components:

- Review of existing knowledge of watershed health for the Muskoka River Watershed,
- Review of indicators used in other jurisdictions, and
- Consultation with local community members and scientific experts.

The 29 watershed indicators were divided into two main categories: Ecological Status and Threats to Ecological Status (Figure 1). Fourteen indicators were identified under Ecological Status, representing several sub-categories: Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), and Landscape Condition. Fifteen indicators were identified under Threats to Ecological Status, representing the following sub-categories: Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects.

The results of the first phase of the project were summarized in a report (HESL 2022a) available on the District's EnviroHub webpage[1]. The report made a series of recommendations for monitoring watershed health in Muskoka. Among these was the recommendation that the longlist be narrowed down to a shortlist of priority indicators to be monitored initially, with the intent to eventually implement all indicators as resources and capacity allow. It was recommended that a standardized approach be used to develop the shortlist through consultation with the Community Round Table (CRT), local scientific experts, and other stakeholders, so that the shortlist addresses community needs, concerns, and priorities.

As part of the second phase of the project in 2023, HESL led the development of a shortlist of indicators through consultation with the CRT, local scientific experts, and other community stakeholders, a review of approaches from other jurisdictions, and application of professional judgement to finalize the shortlist to 18 indicators from the original 29 in the longlist (HESL 2023a). The following report provides guidance on how to implement the shortlist of indicators in the Muskoka River Watershed, building on various other reports prepared for the District on watershed health indicators (HESL 2022a), water quality indicators (HESL 2022b), water quality monitoring design (HESL 2023b), the watershed health indicators shortlist (2023a), and monitoring of contaminants in the watershed (HESL 2023c).

[1] *Making Waves: Integrated Watershed Management Projects:* *https://www.muskoka.on.ca/en/environment/Making_Waves__Integrated_Watershed_Management_Projects.aspx#9-Develop-watershed-health-indicators*

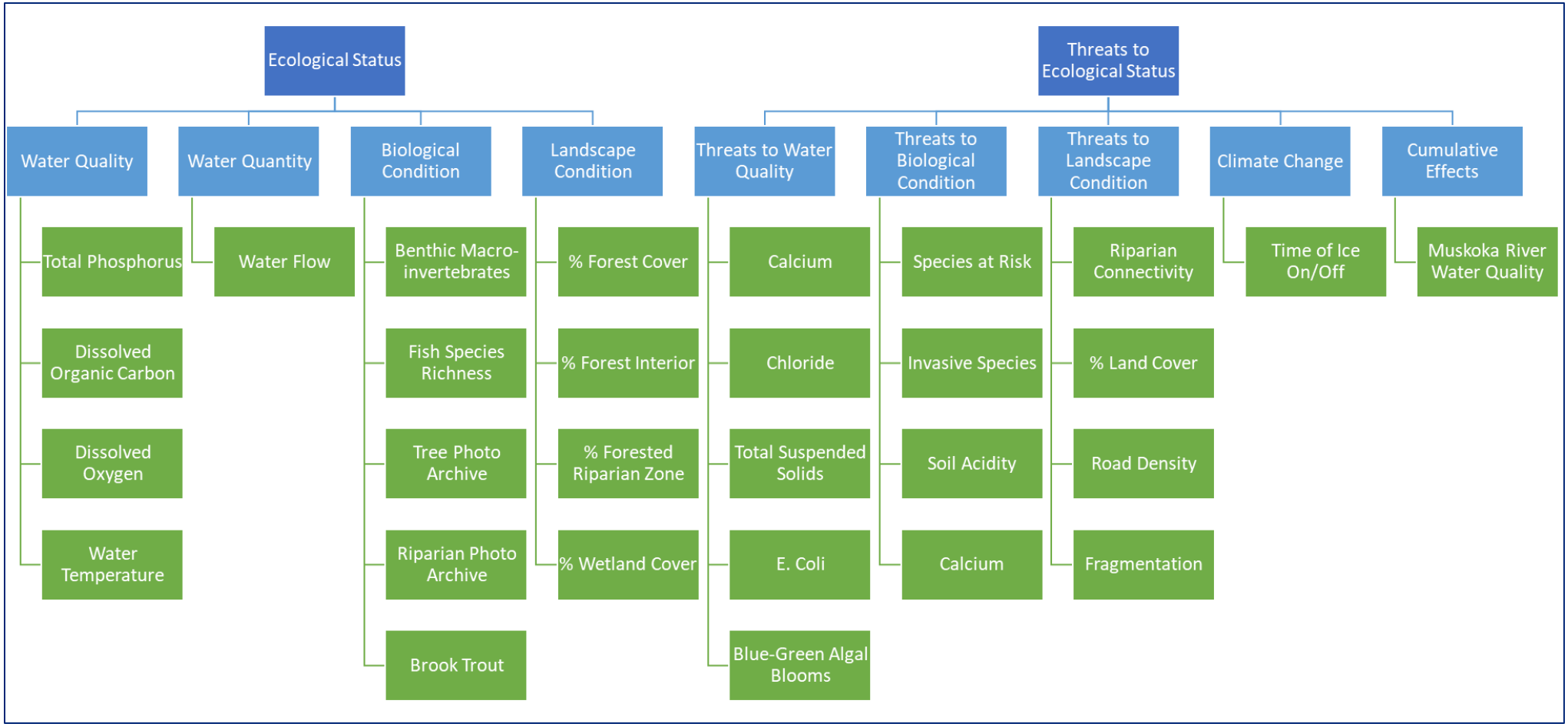


Figure 1. Longlist of watershed health indicators.

1.2 Measuring Watershed Health

Watershed health refers to the ability of a watershed to support the natural features, processes, and conditions within its boundaries, including dynamic hydrologic and geomorphologic processes (within their natural range of variation), habitat of sufficient size and connectivity to support native species, and physical and chemical water quality conditions that sustain healthy biological communities (US Environmental Protection Agency [USEPA] 2022). Monitoring of watershed health assesses the current state of the system, identifies changes, and predicts risks, taking into consideration the effects of land use, climate change, and human activities (Ho et al. 2018).

Indicators are often used to measure environmental conditions because they are simplified representations of more complex ecological states and processes that are difficult to quantify. Indicators can include physical, chemical, biological and socio-economic attributes of the watershed which convey information on underlying ecological functions (Government of Alberta 2008). Indicators can be used to document baseline environmental conditions and track changes to those conditions over time (e.g., are they improving, worsening or stable) and space. Target values of indicators (or management objectives) can be identified, and progress toward achieving targets through stewardship and management actions can be evaluated. Indicators can also have threshold levels that serve as early warnings of unwanted change that might warrant management action. According to the USEPA, effective indicators are ones that are measurable, comparable, consistent, and relevant to the ecosystem and issues of interest (USEPA 2021). In addition, indicators should have the following characteristics:

- be easy to understand and readily available;
- be reliable, providing an unambiguous cause and effect relationship between environmental stressors and ecosystem response;
- be comprehensive, representing a range of physical, chemical, and biological attributes of the ecosystem; and
- be cost-effective to monitor (Government of Alberta 2008).

Indicators are typically selected to represent a range of watershed features (e.g., hydrology, physical habitat, water quality, biological communities) and watershed functions (e.g., base flow, flood storage and attenuation, temperature, nutrient cycling, species interactions), and to track human influence (e.g., land use, wetland alteration, invasive species introductions and spread, dam impacts, extent of impervious surfaces). Three types of indicators are generally considered:

- Condition indicators, which address the state of the environment, including the quality and quantity of attributes, and the state of human and ecological health (e.g., water quality, biodiversity, riparian habitat),
- Pressure indicators, which address natural processes and human activities that could negatively impact environmental conditions (e.g., soil erosion, climate change, urban development), and
- Response indicators, which address actions to manage, mitigate, adapt to or prevent environmental damage (e.g., stewardship activities, education initiatives, municipal policy; Government of Alberta 2008).

2. Shortlist Implementation

The recommended shortlist is comprised of 18 parameters (down from 29 in the longlist) related to water quality, threats to water quality, water quantity, biological condition, landscape condition, threats to landscape condition, climate change, and cumulative effects (Figure 2). Many of these indicators (i.e., related to water quality, threats to water quality, and climate change) are already measured through existing long-term monitoring programs in the Muskoka River Watershed, such as the District's Lake System Health Program, the Lake Partner Program, and the Dorset Lakes Monitoring Program (HESL 2022b). We recommend that these parameters continue to be monitored through existing programs, although the frequency, timing, and spatial extent may need to be modified to ensure watershed-level coverage, as described below. In addition, we recommend that some water quality parameters be monitored through high frequency continuous automated sampling to address shortcomings of manual sampling. However, the technology required for automated monitoring can be expensive, and we realize this may limit its broad-scale application across the watershed. As a result, we have suggested initial targeted use of automated devices, to address the pressing issue of harmful algal blooms. Much of our guidance on implementing water quality indicators is based on recommendations we have made previously to the District on water quality monitoring program design (HESL 2023b). Detailed guidance provided in the HESL 2023b document should be followed for implementation of water quality indicators monitoring (e.g., regarding sampling frequency, number of sampling locations, technology options, and data management).

Other indicators related to landscape condition and threats to landscape condition can be measured by using geospatial datasets. However, provincial GIS data layers for the Muskoka region may not have sufficient resolution or recent enough data to be useful for watershed health analysis. Additional work may be needed to expand local GIS data layers available through Muskoka GeoHub so that the more detailed analysis of landscape condition and threats can occur. Some indicators are not currently monitored systematically in the watershed (e.g., water flow, water quality throughout the Muskoka River) and we offer guidance on integrating these components into watershed health monitoring.

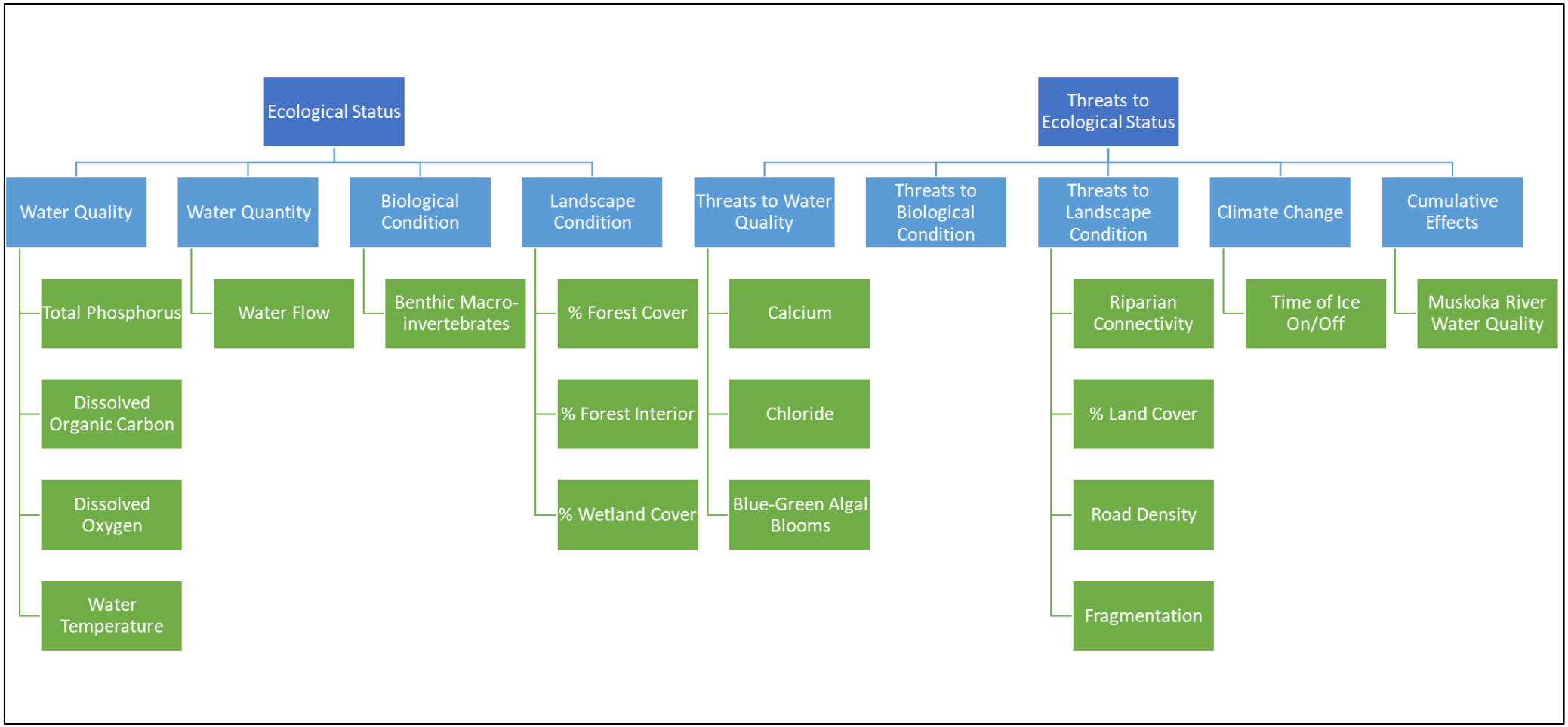


Figure 2. Shortlist of watershed health indicators

2.1 Water Quality and Threats to Water Quality Indicators

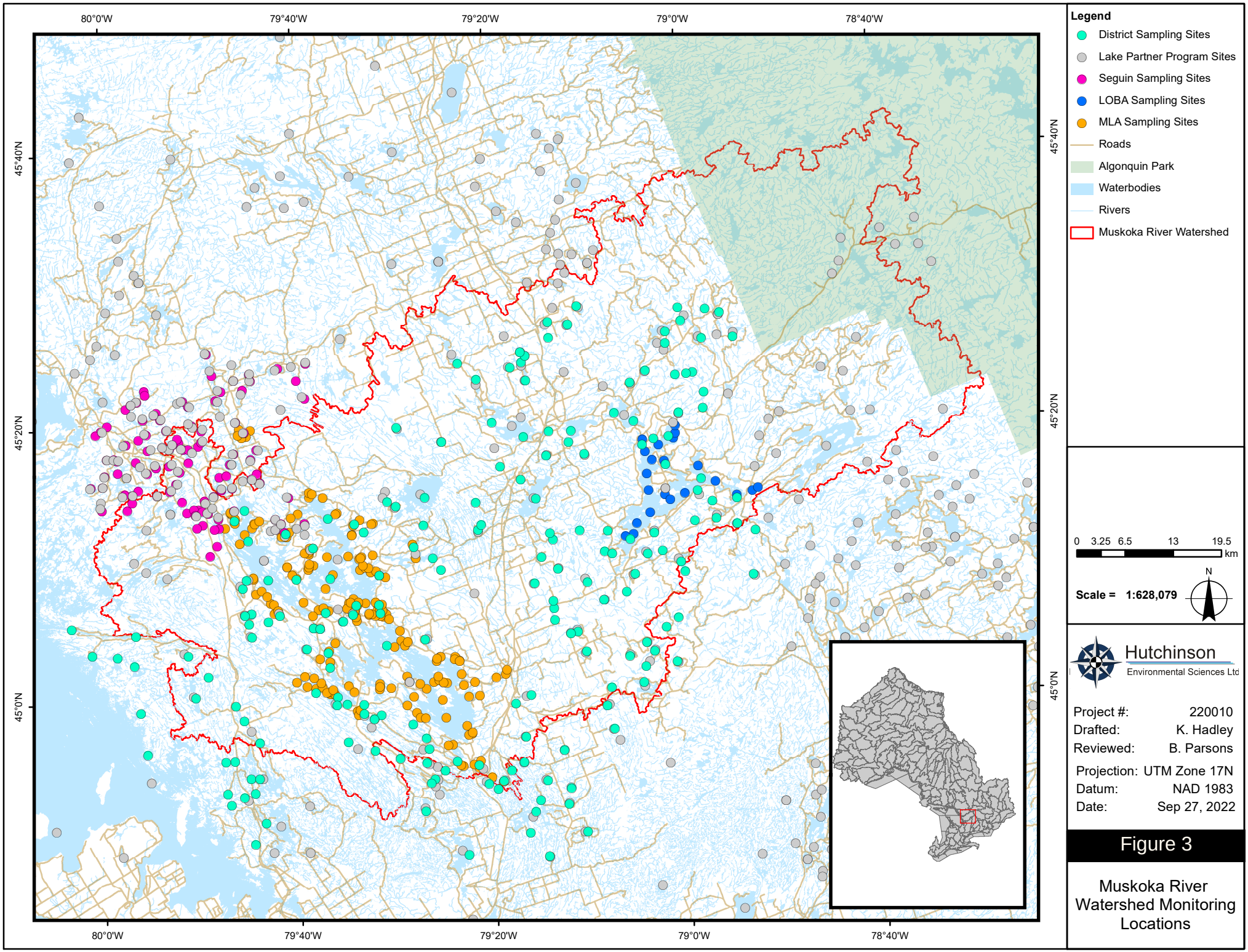
Total phosphorus (TP), dissolved organic carbon (DOC), dissolved oxygen (DO), and water temperature are currently monitored annually at lakes across the watershed through the District's Recreational Water Quality Monitoring Program. A total of 193 monitoring sites, covering 164 lakes, are sampled on a rotational basis, with approximately 80 to 85 sampled per year (HESL 2022b; Figure 3). This monitoring is complemented by data collected in the watershed through other programs, such as the Lake Partner Program (which collects TP, calcium, and chloride), the Dorset Lakes Monitoring Program (which collects TP, temperature profiles, and DO profiles), the Lake of Bays Association (LOBA) Annual Water Quality Monitoring Program (which collects TP and surface water temperature), the Muskoka Lakes Association Water Quality Initiative Program (which collects TP and surface water temperature), and the Township of Seguin Annual Water Quality Monitoring Program (which collects TP, temperature profiles, DO profiles, dissolved organic carbon [DOC], calcium, and chloride; Figure 3). Good geographic coverage thus exists for lakes monitored in the watershed and we do not recommend the addition of any new lake monitoring sites at this time.

Riverine water quality monitoring is discussed separately in Section 2.5.1.

2.1.1 Total Phosphorus (TP)

Phosphorus (P) is a natural element in the environment. It enters lakes predominantly from catchment inputs (streams and overland flow), as well as from the atmosphere (precipitation and dry deposition) and, to a lesser degree, through groundwater. Human sources to recreational lakes include stormwater runoff and erosion associated with altered land uses, fertilizers on manicured lawns, and faulty septic systems. Increases in P loads to lakes from human sources can result in increased growth of aquatic plants, algae, and cyanobacteria, which, in turn, can lead to a deterioration of water clarity and coldwater fish habitat through a decrease in deepwater oxygen concentrations. Phosphorus often limits phytoplankton growth in temperate lakes and is therefore the most commonly analyzed water quality indicator in Central Ontario. High levels of P can lead to phytoplankton blooms, and in some cases affect the habitat of coldwater fish such as lake trout. By sampling for P each year, it is possible to detect a change in the nutrient status of a lake. It is important to note that several years of data (ideally 10 years or more) should be collected to distinguish a trend from normal, year-to-year variation in P concentration. Phosphorus can occur in several forms in the environment, as organic and inorganic phosphorus, and in either dissolved or suspended (particulate) state. Total phosphorus (TP) refers to all forms of phosphorus in a water sample (e.g., dissolved and suspended orthophosphate, condensed phosphate, and organic phosphate).

TP is currently monitored by the District through spring phosphorus sampling to capture the spring turnover (i.e., between April and early June; DMM 2023). A composite water sample is collected over the deepest part of the lake at the Secchi depth measurement (the average of the depth at which the Secchi disk disappears from view on lowering and reappears on raising). Two samples are collected at each site and averaged. We recommend that this approach continue for watershed health monitoring (Table 1).


80°0'W
79°40'W
79°20'W
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78°40'W
45°40'N
45°20'N
45°0'N
Legend
District Sampling Sites
Lake Partner Program Sites
Seguin Sampling Sites
LOBA Sampling Sites
MLA Sampling Sites
Roads
Algonquin Park
Waterbodies
Rivers
Muskoka River Watershed
0 3.25 6.5 13 19.5
km
Scale = 1:628,079
N
Hutchinson
Environmental Sciences Ltd
Project #: 220010
Drafted: K. Hadley
Reviewed: B. Parsons
Projection: UTM Zone 17N
Datum: NAD 1983
Date: Sep 27, 2022
Figure 3
Muskoka River Watershed Monitoring Locations

2.1.2 Dissolved Organic Carbon (DOC)

Most of the organic carbon in lakes is present as DOC. DOC refers to the pool of hydrocarbon compounds (of varying sizes) in water that are dissolved (i.e., that will pass through a filter with pores approximately 0.5-µm in diameter). Especially in small, wetland-influenced lakes, DOC can be highly coloured and impart a “tea-stained” character to the water due to its high absorbance of short-wavelength (UV and blue) light. Thus, DOC has an influence on the aesthetic quality of water (altering its colour and clarity) and can also limit the growth of phytoplankton and/or macrophytes by controlling the quantity and quality of light available for photosynthesis. Because it originates from the breakdown of organic matter (e.g., leaf litter, aquatic plants, etc.), DOC is typically associated with macronutrients such as nitrogen and P. DOC acts as a chelating agent for iron, affecting both iron and phosphorus bioavailability in surface waters (Maranger and Pullin 2003). Likewise, DOC binds toxic metals, and has, for example, been found to control the concentration and bioavailability of total and methylmercury in Adirondack lakes (Driscoll et al. 1994). While DOC can limit primary production (Karlsson et al. 2009), it can also protect aquatic organisms from exposure to harmful UV radiation (Hansson and Hylander 2009, Harrison and Smith 2011) and directly supports the growth and metabolism of heterotrophic (non-photosynthetic) bacteria (Kalff 2002).

DOC is the dominant factor explaining TP concentrations in Precambrian Shield lakes and lakes sampled by the District of Muskoka Lake System Health Program show a significant relationship between TP and DOC (HESL 2016). Lakes with high DOC concentration (i.e., >10 mg/L) will have naturally enriched TP concentrations and may not model well for lake capacity assessment because they fall outside the range of DOC in lakes that were used to develop and calibrate the Province’s Lakeshore Capacity Model (Government of Ontario 2010).

DOC is currently monitored by the District in the spring as part of its Recreational Water Quality Monitoring Program. We recommend that this approach continue for watershed health monitoring (Table 1).

2.1.3 Dissolved Oxygen (DO)

DO has many important effects on lake ecosystems. DO solubility in lakes is primarily determined by water temperature; cold water can hold more DO than warm water. DO concentration controls habitat quality for aerobic organisms such as fish. The Provincial Water Quality Objective for DO is dependent upon temperature, ranging from 5 mg/L at 25°C to 8 mg/L at 0°C for coldwater biota such as salmonid fish communities (e.g., lake trout) and 4–7 mg/L (for 25-0°C) for warmwater biota (e.g., bass). DO is generated by photosynthesis during the day (by plants, algae, and cyanobacteria) and consumed by cellular respiration (by all organisms) during the day and night. For this reason, DO tends to vary on a 24-hour (“diel”) timescale, and the magnitude of these diel changes can provide information on lake metabolism (rates of ecosystem primary production and respiration). DO also has important indirect effects on the cycling and bioavailability of nutrients, notably phosphorus. Under oxygenated conditions, phosphate forms an insoluble precipitate with iron and sinks out of the water column to the sediments where it is not readily available to support phytoplankton growth, including cyanobacterial blooms. However, in a lake with an anoxic (oxygen-depleted) hypolimnion (bottom layer), P separates from iron and becomes soluble (dissolved) in the water where it is available for uptake by plankton. DO also mediates other aspects of sediment biogeochemistry and nitrogen cycling (e.g., nitrification and denitrification).

Monitoring programs that measure dissolved oxygen typically collect profiles in the late summer (mid to late August to mid September) to determine if low oxygen concentrations in bottom waters may result in the release of nutrients from sediments that feed phytoplankton growth and may result in cyanobacteria blooms or to characterize deepwater lake trout habitat under the most stressful period for reduced DO. Ideally, sampling should take place just prior to mixing of the water column to capture the lowest bottom water DO concentrations of the year as release of phosphorus during low oxygen conditions occurs quickly and may be missed. High frequency automated monitoring of DO (i.e., a continuous data logger) would provide the most robust DO data but at a significantly increased cost (e.g., individual loggers that measure both DO and temperature are estimated to cost approximately $3,400, while multi-parameter sondes that accommodate DO and temperature meters cost upwards of $14,000; HESL 2023b).

DO is measured in conjunction with water temperature by the District, once in May/June (to track the extent of mixing during spring turnover) and once in August (to capture minimum oxygen conditions) in lakes (DMM 2023). A DO meter is used to collect measurements at intervals throughout the water column, starting at 0.5 m below the surface, followed by 1 m below the surface, and then at 1 m intervals down to a 10 m depth. Beyond the 10 m depth, measurements are taken every 2 m down to 1 m off the bottom (DMM 2023).

We recommend high frequency continuous automated monitoring be used for watershed monitoring of DO, with sampling targeted initially to lakes having low phosphorus and frequent recurring harmful algal blooms (e.g., Three Mile Lake or Leonard Lake). As climate change increasingly alters lake systems in Muskoka, traditional sampling of DO in late summer (August or September) will likely no longer coincide with the period of minimum oxygen levels, as lakes remain ice free longer into the fall. District monitoring is carried out by trained summer staff whose contracts end in late August, creating logistical problems for extending monitoring later into the fall. High frequency monitoring of DO can help overcome this issue. The number and depth at which loggers are deployed will depend on lake-specific features (HESL 2022b). However, for Three Mile Lake[2], we recommend that data loggers be located at least in the main basin and Hammels Bay (and Green Bay if possible). Loggers should be set up in a daisy-chain configuration at 0.5 m depth intervals from the surface to lake bottom at each location. Loggers should be deployed early in the open-water season so that they capture conditions prior to stratification (i.e., as soon after ice off as possible) and be retrieved at the end of each season (i.e., after fall mixing has occurred[3]; Table 1). Using Three Mile Lake for targeted automated monitoring of DO (and water temperature) will have the added benefit of coinciding with contaminants sampling on the lake's tributaries, which may assist in elucidating the causes of blooms (HESL 2023c).

2.1.4 Water Temperature

Temperature affects the density of water, its gas solubility (e.g., how much oxygen it can hold), the speed of chemical and biological reactions (e.g., bacterial metabolism), and habitat quality for aquatic life such as fish. Vertical temperature profiles reveal if a lake is thermally stratified (i.e., has layers that do not mix vertically), and if so, what depths the layers span (Figure 4).

[2] *We recommend that the District coordinate any automated monitoring in Three Mile Lake with MECP, since the Ministry currently has an automated buoy collecting DO and temperature (among other parameters) in the lake.*

[3] *Information on timing of fall mixing can be accessed from the data loggers if using Bluetooth downloadable devices.*

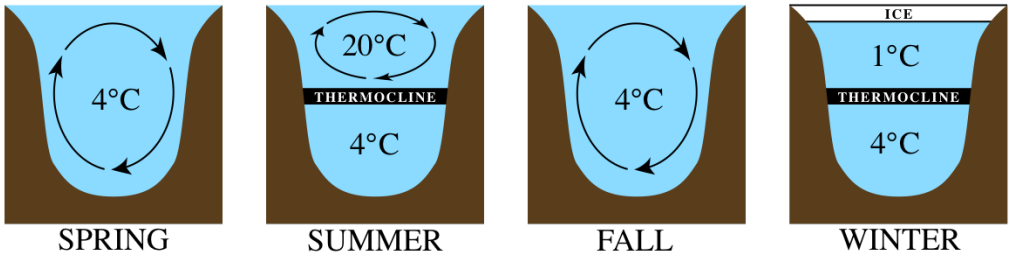


Figure 4. Simplified representation of dimictic (twice per year) lake mixing (HESL 2022b).

Climate change has resulted in increased average air temperature, is impacting lake systems in Central Ontario and is expected to continue to exert an influence on lakes globally in the coming decades. Increases in air temperatures over the past several decades in the Muskoka-Haliburton region have led to shortened ice-cover periods (e.g., Futter 2003, Yao et al. 2013), increased water temperatures, advanced onset of thermal stratification (e.g., Stainsby et al. 2011) and increased thermal stability in lakes (e.g., Stainsby et al. 2011, Hadley et al. 2014). Changes in thermal stratification and water column stability can have a major impact on physical and chemical properties in lakes, such as the redistribution of dissolved substances (e.g., nutrients and oxygen). These, in turn, may result in changes to biological communities, including the proliferation of nuisance cyanobacteria that release harmful toxins (Ferris and Lehman 2007, Paerl and Huisman 2008, O'Neil et al. 2012). The ability of certain cyanobacteria to store P, fix nitrogen and regulate their position in the water column could be particularly advantageous for these phytoplankton, as climate change brings stronger thermal stratification, sequestering nutrients outside the epilimnion.

Water temperature is measured in conjunction with DO by the District, once in May/June (to track the extent of mixing during spring turnover) and once in August (to capture minimum oxygen conditions) in lakes (DMM 2023). A DO meter collects measurements at intervals throughout the water column, starting at 0.5 m below the surface, followed by 1 m below the surface, and then at 1 m intervals down to a 10 m depth. Beyond the 10 m depth, measurements are taken every 2 m down to 1 m off the bottom (DMM 2023).

We recommend high frequency continuous automated monitoring be used for watershed monitoring of water temperature. As climate change expands the ice-free season, traditional sampling in August becomes less effective at capturing the peak water temperature and stratification in Muskoka lakes (HESL 2022b). High frequency automated monitoring of water temperature (via continuous data loggers, daisy-chained at 1 m depth intervals according to individual lake features) will help address this sampling gap, while providing high resolution data for the management of cyanobacterial blooms in low nutrient lakes where wind and bottom water anoxia likely contribute to bloom conditions (HESL 2022b). We recommend that automated monitoring of water temperature be done in combination with DO, in targeted lakes experiencing low TP and frequent recurring harmful algal blooms (e.g., Three Mile Lake or Leonard Lake), as described in Section 2.1.3 (Table 1).

2.1.5 Calcium

Calcium decline in Central Ontario lakes is a long-term consequence of acidification (Watmough et al. 2003). Acid rain caused by smelting of nickel and other metal ores stripped calcium from thin soils, which are underlain by weather-resistant granite rock. As a result, the amount of calcium moving from the watershed to freshwater lakes has decreased, as have calcium concentrations in the lake water (Watmough et al. 2003). A variety of site-specific mechanisms can also contribute to declining concentrations of calcium including local geology and timber harvesting (Kirchner and Lydersen 1995, Stoddard et al. 1999, Watmough and Aherne 2008).

Numerous biological consequences have been linked to declining calcium in lakes. For example, crayfish, like other crustaceans, depend on calcium in water, particularly during their molting period (Rukke 2002). The range of lowest hypothesized requirements for freshwater crayfish is between 2 and 10 mg/L (Greenaway 1974, France 1987, Rukke 2002, Hammond et al. 2006, Cairns and Yan 2009). In Algonquin Park, regional calcium decline has had a significant negative effect on crayfish populations resulting in the near extirpation of crayfish in four long-term study lakes (Hadley et al. 2015). Crayfish are an integral component of energy flow in aquatic food webs because they can act as detritivores, herbivores, or keystone benthic predators (Momot 1995) and they are a key element of some fish diets (Saiki and Ziebell 1976, Stein 1977). Calcium decline has also resulted in a shift in microscopic herbivore communities in softwater lakes across eastern North America. Lower calcium availability provides a competitive advantage to the zooplankton *Holopedium glacialis* (Jeziorski et al. 2015). *Holopedium* has a low calcium requirement because it has a jelly-capsule instead of a calcified carapace as its primary defence against predators (e.g., fish).

Calcium is measured by the District in Muskoka lakes in May and June. We recommend that this approach continue for watershed monitoring (Table 1).

2.1.6 Chloride

Salinization of freshwaters in Ontario is one of the most pressing environmental issues for recreational lakes near roadways. Analysis of spatial patterns in long-term chloride data from the Lake Partner Program and broad-scale monitoring data collected by the Ministry of the Environment, Conservation and Parks (MECP) has shown that proximity to urban centres and major roadways was a substantial factor in determining chloride concentrations of freshwaters; this suggests that winter road maintenance and urban land use are the primary drivers of chloride concentrations in Central Ontario lakes (Sorichetti et al. 2022). Elevated concentrations of chloride are toxic to freshwater biota, with the current Canadian Water Quality Guideline (CWQG) for the protection of aquatic life being set at 120 mg/L. However, recent research has shown that the CWQG is not sufficient to protect lake food webs and should be reassessed (Hintz et al. 2022). Development in the Muskoka River Watershed and a shift from temporary summer use to year-round use of properties has the potential to increase the need for road treatment. Monitoring of chloride concentrations should therefore be considered a high priority for water quality monitoring programs near roadways which receive winter de-icing treatment.

Chloride is measured by the District in surface waters (lakes) in May and June. We recommend that this approach continue. In addition, we recommend that chloride is analyzed in samples collected as part of the

efforts to characterize Muskoka River Water Quality as discussed in Section 2.5.1. Results will indicate the impacts of road salt use on receiving water concentrations following spring freshet and provide an idea of how concentrations decline throughout the season as characterized by summer and fall sampling (Table 1).

2.1.7 Algal Blooms

The term phytoplankton refers to a diverse group of photosynthetic organisms (algae and cyanobacteria/blue-green algae) that are suspended in the water column (i.e., are planktonic). They can exist as single cells or as substantial groups (colonies or filaments), and thus range in size from less than 1 micron to large (macroscopic) aggregations of up to several millimeters in diameter. Phytoplankton are important primary producers: they use the energy of sunlight to convert carbon dioxide into organic matter, ultimately feeding higher trophic levels (e.g., phytoplankton→zooplankton→fish→humans). Phytoplankton have existed for billions of years and are a healthy and integral component of aquatic ecosystems. However, at high biomass certain species of phytoplankton can negatively affect lakes, both as ecosystems and as resources for human use.

Harmful algal blooms (HABs)[4] are often accompanied by unpleasant odours and the production of toxins. HABs degrade the quality of water for drinking and reduce the aesthetic and recreational appeal of lakes. From an ecological perspective, HAB taxa are not generally preferred by grazers (e.g., zooplankton), and the mineralization of HAB biomass in lake sediments consumes oxygen, decreasing the quality of cold-water fish habitat and potentially causing hypolimnetic anoxia and internal phosphorus loading.

Much of the concern regarding cyanobacterial blooms is due to the ability of some taxa to produce toxins. It should be noted that cyanobacterial blooms are not always associated with detectable levels of toxins, and that the factors controlling toxin production are not fully understood. Cyanotoxins can affect the liver (e.g., microcystins), nervous system (e.g., anatoxins), and skin (e.g., lyngbyatoxins). It is not feasible to assess all types of cyanotoxins – there are over 250 different variants within the microcystin family alone (Fastner and Humpage 2021), so a small subset of parameters is typically measured, including microcystin-LR and total microcystins (the aggregate concentrations of all microcystin variants). Health Canada has established a total microcystins guideline value of 10 µg/L for “primary contact recreation” and estimates that waters may exceed this threshold where the chlorophyll-a concentration exceeds 33 µg/L (Health Canada 2022). A stricter guideline value of 1.5 µg/L has been established for drinking water (Health Canada 2021).

In recent years, Muskoka has experienced a marked increase in algal blooms in low nutrient lakes. The conventional approach to managing algal blooms, based on controlling phosphorus concentrations in the water column, is not appropriate for this type of bloom, and a better understanding of causes is needed. In addition, algal blooms are occurring later in the season in Muskoka than in the past (i.e., in the fall), after traditional monitoring programs have ended for the year. It is important that meteorological conditions in the watershed be monitored to investigate links between observed algal blooms and climate data. HESL

[4] *The term “harmful algal bloom” is something of a misnomer in the context of limnology because most phytoplankton blooms in lakes are made up of cyanobacteria (prokaryotes) not algae (eukaryotes).*

(2022b) recommended that high resolution data on air temperature and wind speed be incorporated into watershed health monitoring in Muskoka and we reiterate that recommendation here.

Algal blooms are not currently monitored by the District. The Muskoka Watershed Council (MWC) established a pilot project for algae monitoring in 2019 and 2021 on five lakes, expanding the project in 2022 to 14 area lakes (MWC 2023). The monitoring program measures the amount of chlorophyll a (found in algal cells) and phycocyanin (found in cyanobacteria cells) to track phytoplankton distribution, abundance, and seasonal variability. Samples are collected biweekly from May through mid-October at a minimum of two sites per lake: one offshore in the deepest basin of the lake (corresponding with the District's recreational water quality monitoring site if it exists on the lake) and one in the nearshore in a minimum of 2 m water depth (MWC 2023). To complement the MWC algae monitoring program and collection of high frequency climate data recommended above, we recommend that high frequency automated monitoring be used from August through October for the early detection of blooms in lakes such as Three Mile Lake and Leonard Lake. An automated system such as FlowCam or Imaging FlowCytoBot combine flow cytometry with image recognition technology to automate the identification of phytoplankton species (HESL 2023b; Table 1). High frequency automated monitoring of phytoplankton could provide important insights about the conditions that lead to algal blooms and changes in phytoplankton assemblages over time to better determine causation and inform potential management options. High frequency monitoring promises to hugely increase the efficiency of phytoplankton analysis. However, considerable resources are required to assemble the image libraries required to calibrate these instruments and their accuracy may be much lower than promised (J.W. Harrison, unpublished data from Lake George, NY). At present, manual sample identification by a professional phytoplankton taxonomist remains the "gold standard" approach.

2.2 Water Quantity

2.2.1 Water Flow

River and stream flow (or discharge) is an indicator of how much water is carried by a watercourse. Water flows provide context to water quality measurements and can reflect the influence of water management and climate change. Flow is a function of river volume and velocity, and flow dynamics are critical for supporting watershed health. Stream flow increases with water volume, affecting physical and chemical conditions (such as DO levels, water clarity and suspended sediment) and what types of organisms are present (USEPA 2012). Flow also influences how well pollution is diluted and broken down. Rapid changes in flow can have negative effects on water quality, channel stability, and biota (e.g., fish habitat and spawning, and waterbird nesting habitat). Prolonged low flows can lead to deterioration of water quality (e.g., DO), which can adversely affect aquatic conditions for aquatic life in summer (Ottawa Riverkeeper 2019).

The District does not currently monitor water flow in watershed rivers. We recommend that water flow be collected monthly at sampling sites along the Muskoka River and its tributaries (see Section 2.5.1 Muskoka River Water Quality) from spring through early fall during water quality sampling.

River flow is measured by multiplying the area of water in a channel cross section by the average velocity of water in that cross section. The following method is typically employed (USGS 2018; Table 1):

1. Extend a tape meter (or metered line) across the river or stream channel from one wetted edge to the other (Figure 5). Choose areas where water is flowing evenly, without obvious sections of turbulence or obstacles. Be sure that the line is perpendicular to the direction of flow, level, and taut.
2. Measure and record the active width of the channel (Figure 5).
3. Divide the active channel width by the number of desired flow measurement points (usually 10 to 20 depending on river size) to determine the flow measurement intervals (Figure 5).
4. Measure and record the water depth at every flow measurement interval along the transect.
5. Measure and record the river velocity at every measurement interval using a flow meter. In water depths ≤ 0.75 m, take measurements at 0.4 x the water depth. At water depths > 0.75 m, take measurements at 0.2 and 0.8 x the water depth and calculate the average. Make sure the meter is pointed towards the river flow, and that there are no obstructions (e.g., rocks, debris, people) to flow.
6. Use the area-velocity approach to calculate stream flow: (i) the area of each of the panels (measurement width x water depth) is multiplied by the measured river velocity for each panel; (ii) the panel flows are then added together to calculate the total velocity for the river.

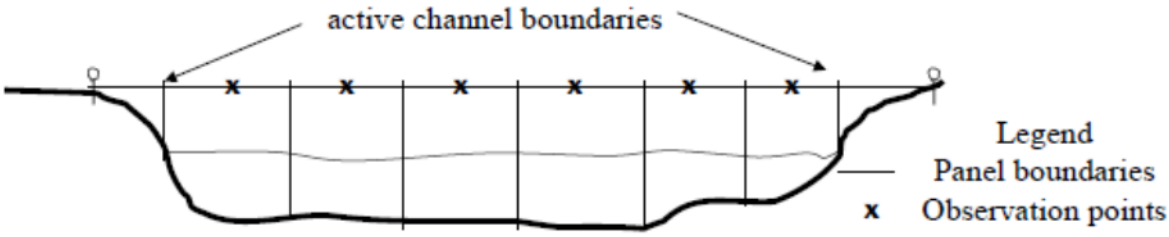


Figure 5. Typical channel cross section (from Stanfield 2010).

In shallow rivers or streams, flow can be measured by wading across the channel. For small systems, the number of measurement intervals should be increased so that any one panel does not comprise more than 10% of river flow, and panels should not be more than 1 m apart. For larger and deeper systems, flow should be measured from a boat.

At the end of each sampling season, three water flow calculations should be determined per reach from the monitoring data: minimum and maximum flow per year (including the dates on which they occurred), and the ratio of maximum to minimum flow. The timing of flow extremes will be useful to compare over time as the dataset increases, as an indicator for example, of whether climate change is advancing spring freshet (which generally coincides with maximum flow) and drought conditions (which generally coincide with minimum flow). The ratio of maximum to minimum flow can be useful for measuring the degree of river regulation, as reservoirs and dams reduce flow variability by reducing peak flows and maintaining flows during low flow periods (Ottawa Riverkeeper 2019).

2.3 Biological Condition

2.3.1 Benthic Macroinvertebrates

Benthic macroinvertebrates (which include aquatic insects, worms, mollusks, crustaceans and mites) can be useful indicators of water quality in lakes and streams because they integrate information on the cumulative effects of chemical, physical, and biological components of the watershed. Benthic invertebrates are relatively immobile and sensitive to environmental change, which means that trends and patterns in their abundance and species composition may reflect changes in water quality and habitat conditions (Conservation Ontario 2011). However, benthic macroinvertebrate community structure is shaped by a complex interplay between habitat, water chemistry, and land use, and disentangling the relative impacts of different factors can be challenging (Eimers 2016). Furthermore, while coarse-scale identification of benthos (e.g., to phylum, order or family) can be done by the layperson, finer-scale identification (necessary for some biomonitoring indices) requires taxonomic expertise.

The reference condition approach (RCA) is commonly used to account for the natural variability of benthic macroinvertebrate communities across a landscape, so that changes due to environmental stressors can then be detected and identified. The RCA establishes a series of reference sites, which are relatively undisturbed locations (where influences of human activity are minimal) in relatively good environmental condition. These reference sites should represent a range of environmental conditions throughout the watershed. Test sites are then compared to reference sites to determine if they fit within the normal range of biological condition exhibited by their predicted reference-site group (Jones et al. 2007).

Benthic macroinvertebrates are currently monitored by the District through its Biological Monitoring Program, following the Ontario Benthic Biomonitoring Network (OBBN) Protocol (Jones et al. 2007). To date, the program has mainly focused on building data on reference sites. In 2022, sampling occurred at 58 sites on 32 lakes and one river across the watershed (DMM 2023).

The reality is that benthic invertebrates can be used to determine the presence or absence of impact from a known stressor if that stressor is somewhat pronounced and the level of study is highly detailed. Benthic invertebrates are highly influenced by surrounding habitat, and it is difficult to discern habitat-related differences from the stressor of interest. Since the stressors in the watershed are anticipated to be minor and the study area is widespread, benthic invertebrate monitoring is not an ideal candidate.

We recommend that benthic macroinvertebrate monitoring only be implemented if a point source discharge needs to be assessed. If so, implement a study design to minimize the influence of habitat differences between sites that influence assemblages and limit the precision of the assessment (Table 1).

2.4 Climate Change

2.4.1 Time of Ice On/Off

The length of ice coverage on lakes in the Muskoka River Watershed is declining due to climate change. Monitoring the timing of ice formation and ice disappearance on the surface of lakes annually can provide an integrated measure of the effects of warmer air and water temperatures, and water flow, on aquatic systems (HESL 2022a).

Time of ice on and off is not currently monitored by the District but is a relatively simple metric to include in watershed health monitoring, since reliable data can be collected by the public. We recommend that ice reporting occur on lakes across the watershed by enlisting citizen scientists through NatureWatch's IceWatch Program[5]. IceWatch offers step-by-step instructions on participating in the program, including lake selection, observation of lake conditions, and collection of fall freeze and spring thaw data. We recommend that the District launch a campaign to promote participation in IceWatch across the watershed and provide an online portal on EnviroHub that participants can use to submit their data to the District (Table 1).

2.5 Cumulative Effects

2.5.1 Muskoka River Water Quality

Water quality monitoring in the Muskoka River Watershed has largely focused on lakes, while coverage of streams and rivers is disproportionately low in comparison (HESL 2022b). The District's Lake System Health Program, and other monitoring programs in the watershed address water quality in lakes (Figure 3). The only systematic monitoring of area streams and rivers was through the Provincial Water Quality Monitoring Network (PWQMN) Program, which monitored various water quality parameters at 20 to 30 stations throughout the watershed historically, however, no data has been collected since 1995 (HESL 2022b).

Monitoring of the Muskoka River could serve as an indicator of cumulative effects of the surrounding watershed. For this reason, riverine water quality monitoring was identified as a separate composite indicator of watershed health (individual measures of lake water quality to be used as watershed indicators are discussed previously in Section 2.1). We recommend that monitoring of a subset of watershed indicators occur at key points along the river and its main tributaries, from upstream near Algonquin Park to the outflow of Lake Muskoka at Bala, to detect changes over time and space (Figures 6-10). This monitoring of cumulative effects could identify key stressors or areas of stress (i.e., urban centre influences, natural changes with watershed position, highway influence) and information could then be used to develop focused causation studies (HESL 2022a). The monitoring network would consist of 17 main stations (marked as 'Potential Sampling Site' in Figures 6-10) from throughout the watershed, representing sites on the Hollow River, Oxtongue River, Oxbow River, Big East River, Muskoka River mainstem, North Muskoka River, South Muskoka River, Indian River, and Moon River. These sites are subject to a range of anthropogenic influences, from minimally impacted upstream locations (e.g., Oxtongue River at Oxtongue Lake outflow) to sites within and downstream of urban centres (e.g., Muskoka River at Hunter's Bay outflow, Muskoka River at Bracebridge Falls) or downstream of highways (e.g., Muskoka River at High Falls). Many of these sites overlap with proposed contaminant sampling sites recommended for a focused contaminants monitoring program (HESL 2023c), so that integration between the two monitoring programs can occur. An additional three stations could be added at locations recommended for contaminant sampling, representing sites downstream of urban centres, wastewater treatment plants, and agricultural lands (marked as 'Potential Contaminant Sampling Site' in Figures 6-8; HESL 2023c).

[5] *https://www.naturewatch.ca/icewatch/*

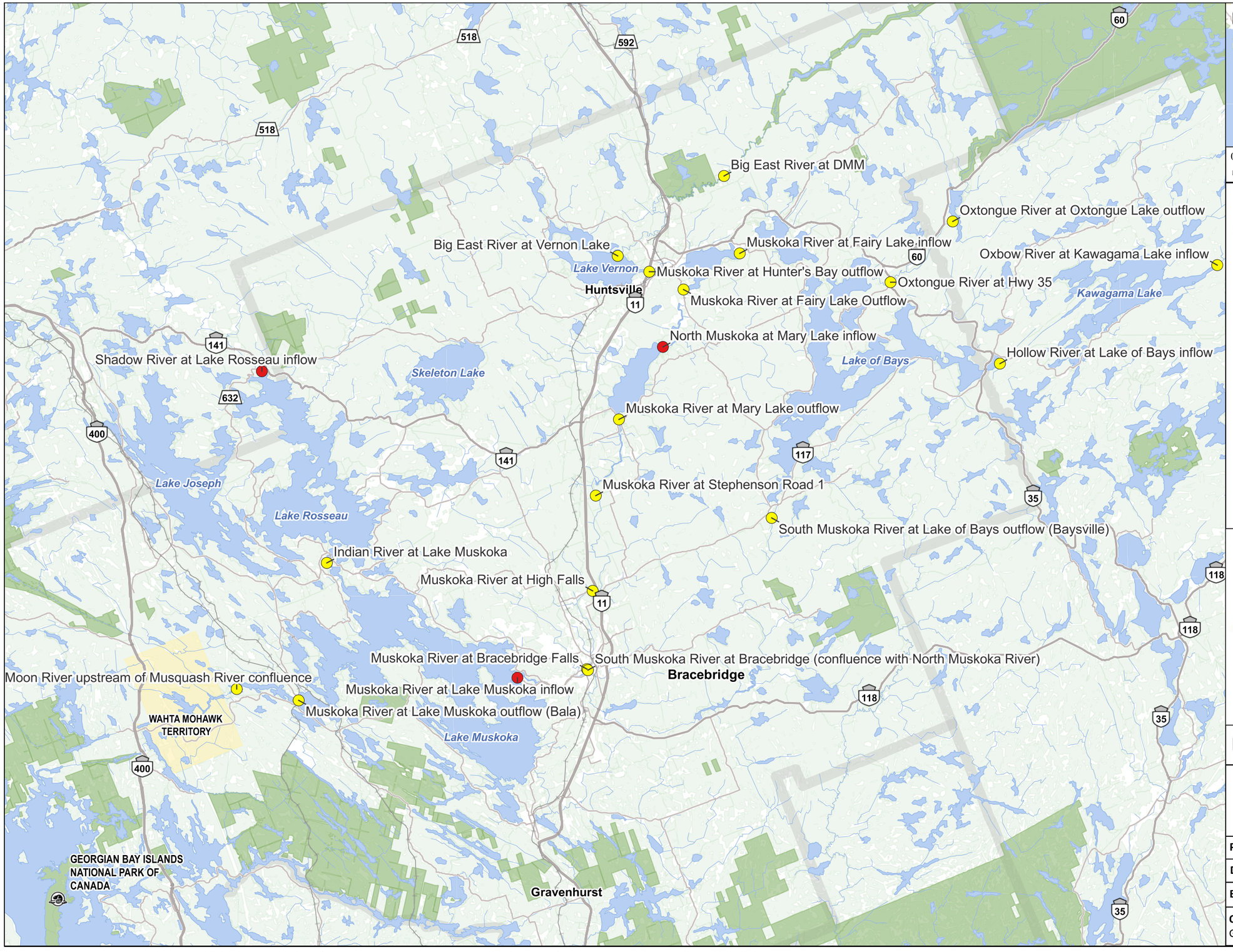
Physical and chemical sampling of streams and rivers generally follow the same procedures used for lake sampling. Sampling should be done in the centre of the channel where possible to avoid contamination from disturbance of the bank or shallow water by the people sampling (HESL 2019). Deeper and larger rivers should be sampled from a boat while smaller, shallower streams can be sampled by wading. In all cases, the sampler must take care not to contaminate the sample by disturbing sediments from the bottom of the stream or river. If multiple samples are collected within a watercourse, samples should be collected at the farthest sampling point downstream before proceeding upstream. Samples should be collected on the upstream side of the boat or bottles should be filled on the upstream side of the person completing the sampling (HESL 2019).

The following indicators should be monitored at the river stations:

- TP
- DOC
- DO
- Water temperature
- Calcium
- Chloride
- Water flow

A background on these water quality parameters and the justification for the selection of these water quality indicators was provided in Section 2.1 and 2.2.1. The utilization of additional contaminant parameters at the contaminant sampling locations is discussed in HESL 2023c.

Riverine water quality is closely related to the hydrologic flow regime. For example, water quality will be substantially different following spring freshet than during baseflow conditions in the summer following a drought. Low flows are particularly sensitive to water quality stressors while high flows increase the transport of suspended solids and pollutants such as salt from the watershed. Data on water flows and past precipitation data can provide important contextual information when interpreting water quality data but sampling should be completed to characterize riverine conditions during specific flow regimes so that data are more comparable over time and space. The Water Survey of Canada has a number of real-time hydrometric stations in the watershed. Hydrographs close to specific sampling locations or located on the same watercourses should be examined to estimate sampling dates and monitored in real-time to try and capture the flow regimes of interest. We recommend that sampling be completed following spring freshet (once water levels are safe for wading or navigating by boat) and continuing into fall (Table 1) in an attempt to capture spring freshet (April), summer baseflow (late August/early September), and moderate fall flows (October/November).



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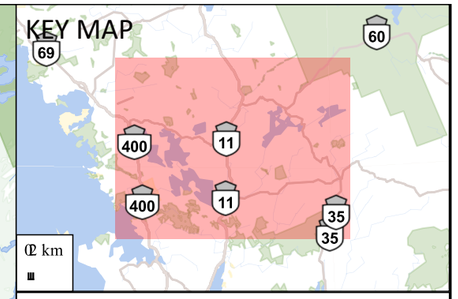

Legend

Potential Watershed Sampling Sites

- Potential Contaminant Sampling Sites
- Potential Sampling Sites

Hutchinson Environmental Sciences Ltd.

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District Municipality of Muskoka - Watershed Health Indicators

Project No.: 220004	**Figure 6:** Overview of Potential Watershed Sampling Sites
Date: 2023-11-01	
By: SA	
Orthophotograph Date: Google Earth, 2020.	

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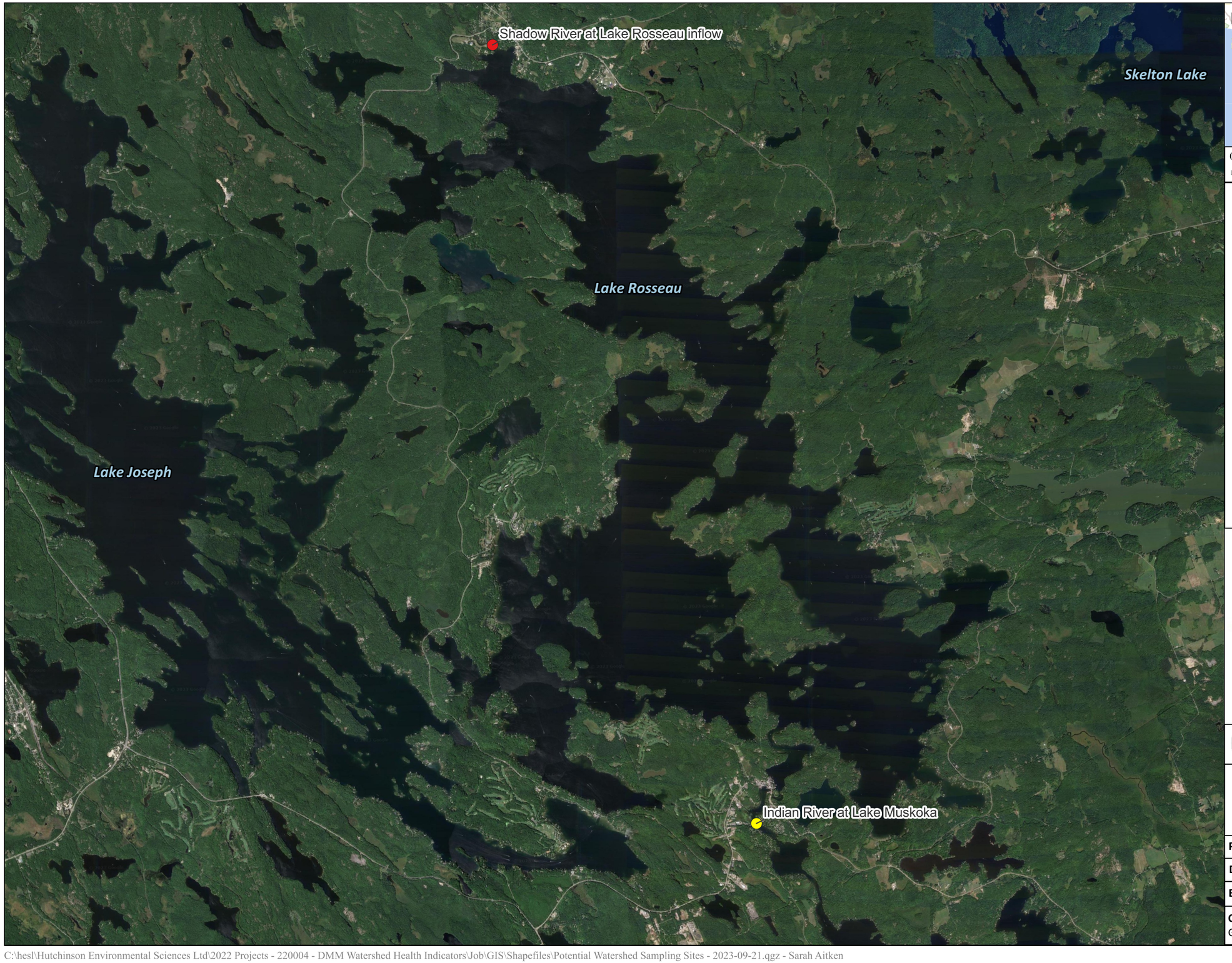

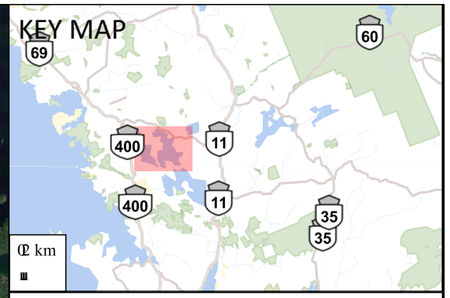

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Potential Watershed Sampling Sites

- Potential Contaminant Sampling Sites
- Potential Sampling Sites

Hutchinson ENVIRONMENTAL SCIENCES LTD.

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District Municipality of Muskoka - Watershed Health Indicators

Project No.: 220004	**Figure 7:** Potential Watershed Sampling Sites - Lower Muskoka
Date: 2023-10-31	
By: SA	
Orthophotograph Date: Google Earth, 2020.	

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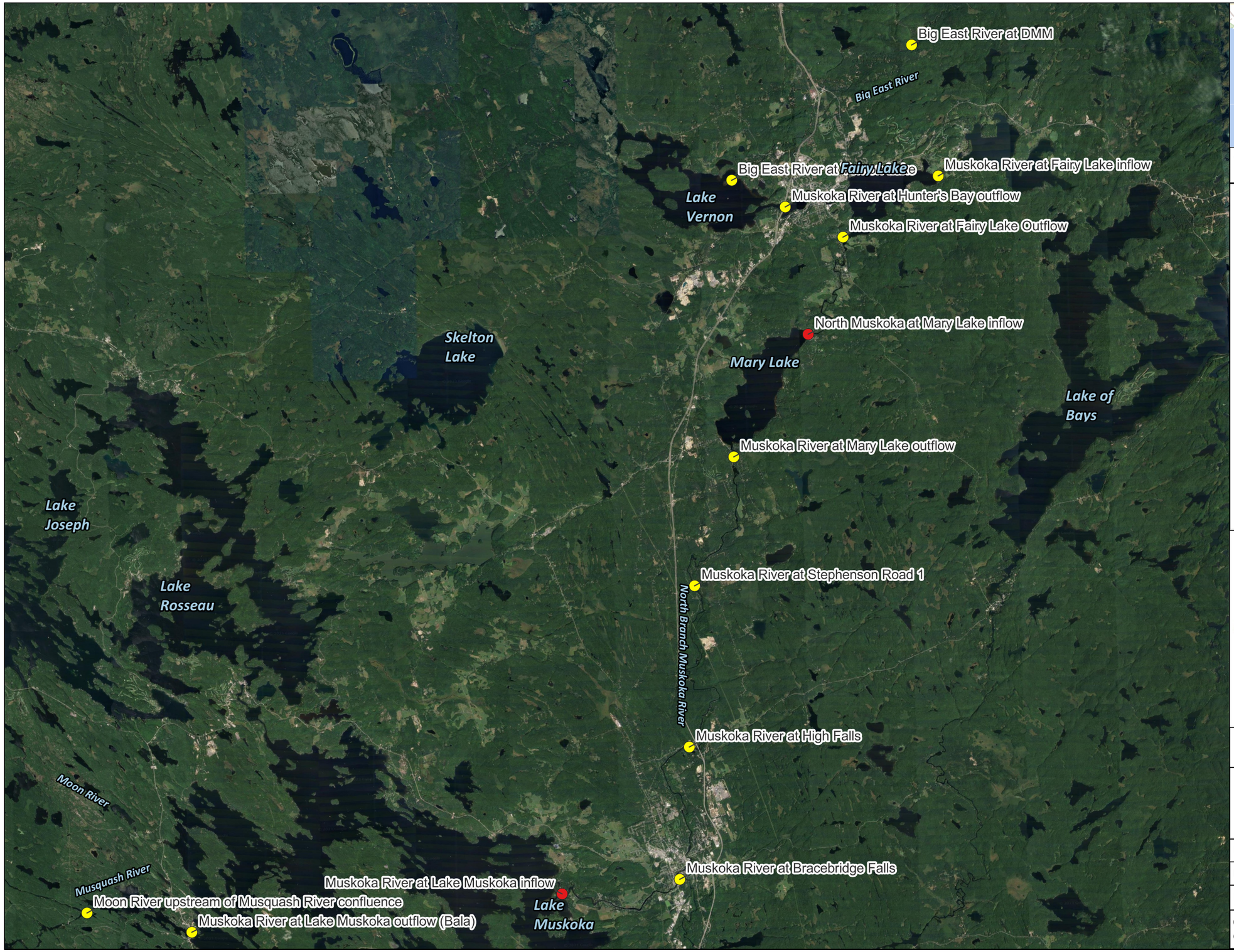

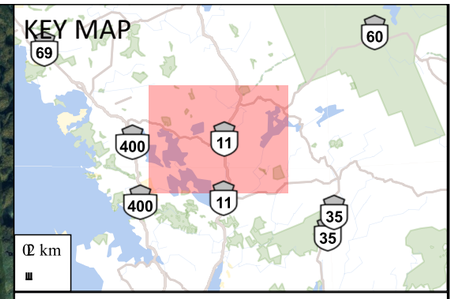

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Potential Watershed Sampling Sites

- Potential Contaminant Sampling Sites
- Potential Sampling Sites

Hutchinson Environmental Sciences Ltd.

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District Municipality of Muskoka - Watershed Health Indicators

Project No.: 220004	**Figure 8:** Potential Watershed Sampling Sites - North Branch Muskoka River
Date: 2023-10-31	
By: SA	
Orthophotograph Date: Google Earth, 2020.	

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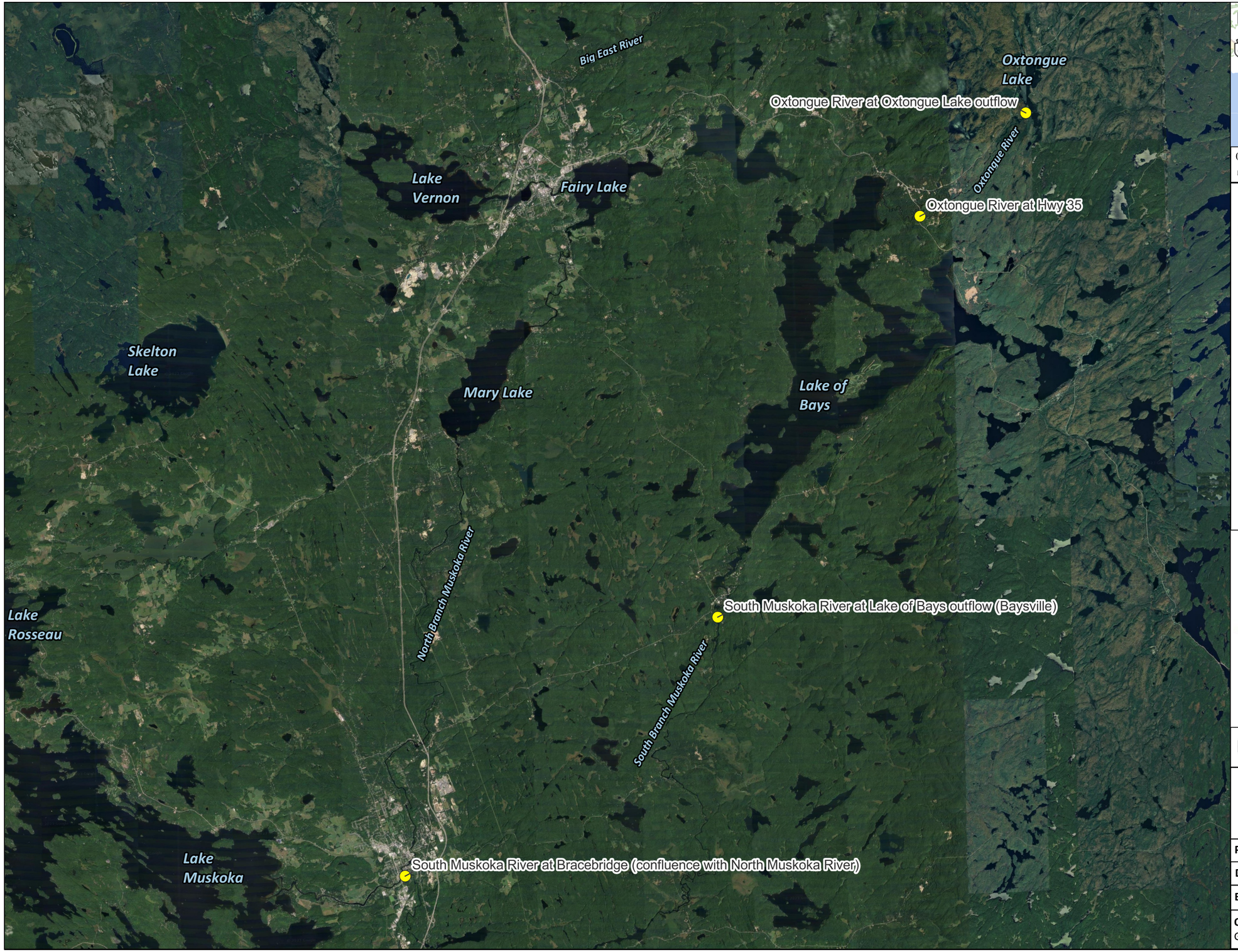

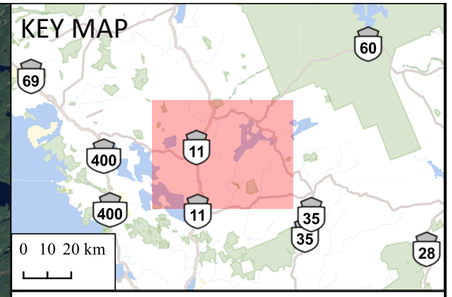

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Potential Watershed Sampling Sites

- Potential Sampling Sites

Hutchinson ENVIRONMENTAL SCIENCES LTD.

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District Municipality of Muskoka - Watershed Health Indicators

Project No.: 220004	**Figure 9:** Potential Watershed Sampling Sites - South Branch Muskoka River
Date: 2023-10-31	
By: SA	
Orthophotograph Date: Google Earth, 2020.	

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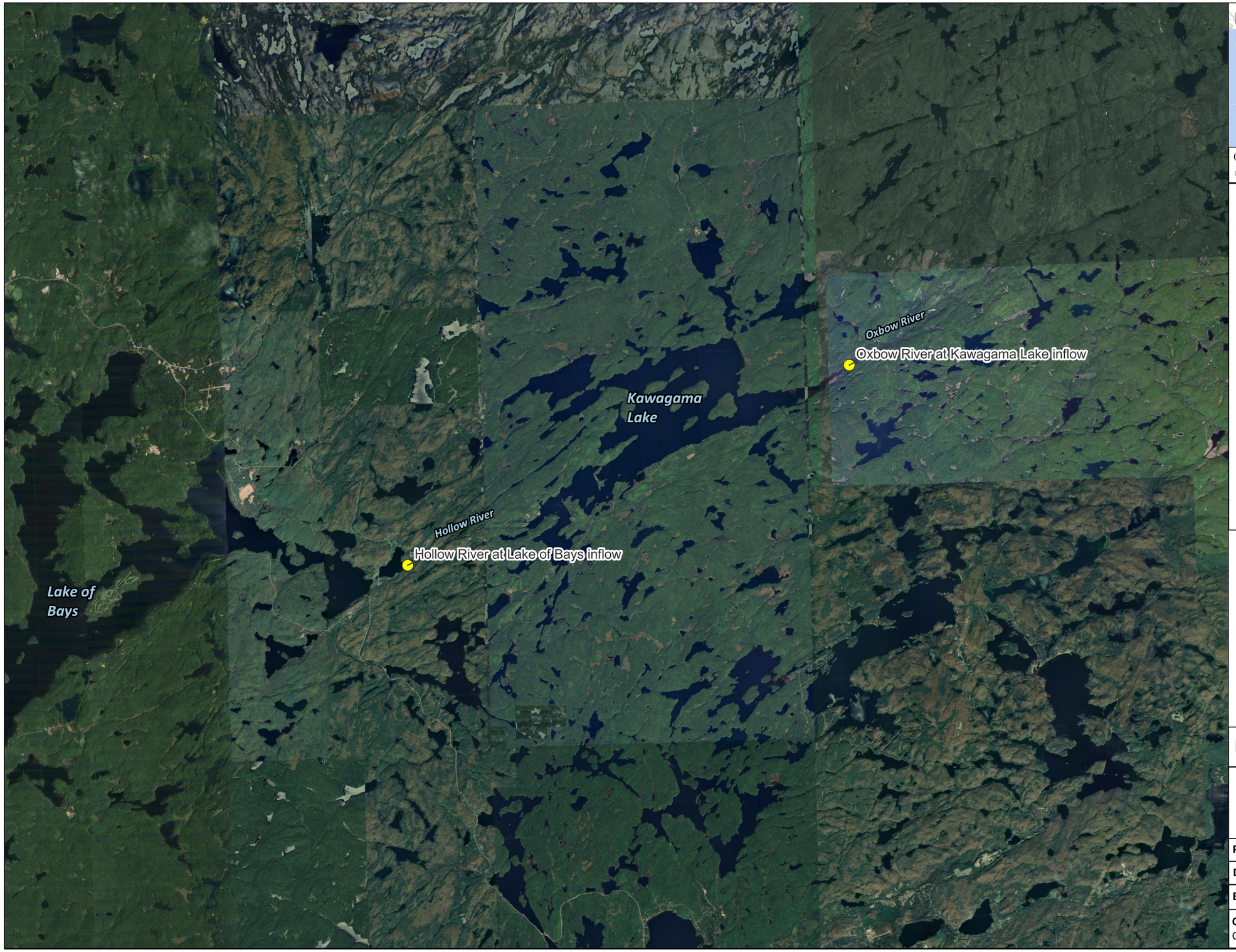

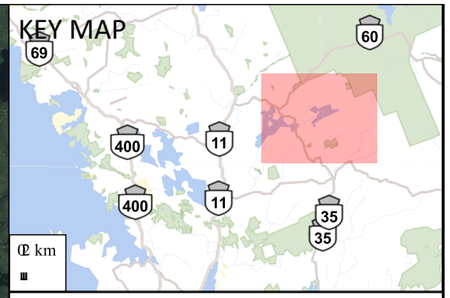

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Potential Watershed Sampling Sites

- Potential Sampling Sites

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District Municipality of Muskoka - Watershed Health Indicators

Project No.: 220004	**Figure 10:** Potential Watershed Sampling Sites - Hollow River
Date: 2023-10-31	
By: SA	
Orthophotograph Date: Google Earth, 2020.	

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2.6 Landscape Condition and Threats to Landscape Condition

All indicators of landscape condition and threats to landscape condition can be measured as a desktop exercise using GIS datasets. Conservation Ontario and its conservation authorities south of the Canadian Shield rely on the Southern Ontario Land Resources Information System (SOLRIS) to measure changes in landscape condition. However, the spatial coverage of that resource does not extend north into the Muskoka River Watershed. Northern conservation authorities, such as the North Bay Mattawa Conservation Authority, use GIS data from the Ontario Land Cover Data Base, which maps 27 broad land cover types north of the southern boundary of the Canadian Shield, including forest, wetlands, rock barrens, agricultural fields, and urban settlements, but these data have not been updated since 2002. Information on forest cover (i.e., wooded areas) is updated irregularly on the Land Information Ontario database, and wetland layers are updated based on municipal input. The Ontario Watershed Information Tool[6], which has imagery for Central Ontario spanning 2010 to 2022, may provide more up-to-date geospatial data, although incorporating the information into a watershed-level analysis would likely be laborious. The tool offers land cover information for individual sub-watersheds, which will then need to be added together for an overall calculation for the entire watershed. Information on some of the landscape condition indicators will not be attainable through this coarse-scale dataset, and more detailed GIS analysis will thus be necessary (i.e., for riparian connectivity, road density, fragmentation).

A Natural Capital Inventory was developed for the Muskoka River Watershed in 2022 as part of the District's IWM Initiative (Dougan & Associates 2022). This project focused on enhancing and updating existing geospatial datasets of natural heritage features within the watershed, including forest, wetlands, watercourses, vernal pools, and ecologically significant areas (e.g., habitat for species at risk, significant wildlife habitat, and areas that contribute to stormwater and spring runoff capacity. These data represent a valuable resource for monitoring landscape condition and threats to landscape condition over time, provided there is regular field verification and updating of remotely sensed imagery to ensure they represent current conditions. We recommend that these land cover data be used in the monitoring of landscape condition and threats to landscape condition.

We recommend that Conservation Ontario's guidance be used to calculate landscape condition indicators for percent forest cover, percent forest interior, and percent wetland cover (Conservation Ontario 2011). Ideally, landscape condition indicators should be calculated every five years in the watershed.

2.6.1 Percent Forest Cover

Forest cover is a measure of the degree of natural cover remaining on the landscape, and the extent of development. Forest cover is generally measured to include upland and wetland forest. Forest patches should be at least 0.5 ha to be included in the measurement. As recommended by Conservation Ontario, measures of forest conditions (i.e., percent forest cover and percent forest interior) in the Muskoka River Watershed should be calculated exclusive of lake area, to avoid underestimating forest cover in an area with a high percentage of lakes (Conservation Ontario 2011; Table 1).

[6] https://www.ontario.ca/page/ontario-watershed-information-tool-owit

2.6.2 Percent Forest Interior

Forest interior indicates how much forest habitat is shielded from the negative effects of forest edges (such as increased risk of disease, parasitism, and predation, unsuitable microclimate conditions, and competition from invasive species), which tend to increase with development due to habitat loss and fragmentation. Forest interior should be measured as the amount of forest at least 100 m from the outer edge of forest patches at least 0.5 ha overall (Table 1).

2.6.3 Percent Wetland Cover

Wetlands include swamps (treed and thicket), bogs, fens, and marshes. To avoid duplicating counts of wetland forest under both percent forest cover and percent wetland cover, we recommend that the amount of wetlands under each wetland type be differentiated, if possible (Table 1).

2.6.4 Riparian Connectivity

Riparian connectivity is a measure of fragmentation of natural habitat along the shoreline and is measured as the proportion of undeveloped shoreline a given distance from the water's edge (Ottawa Riverkeeper 2019). We recommend that a distance of 30 m inland be used to measure this indicator (Table 1). The 30 m width is the minimum natural shoreline buffer recommended by provincial and federal guidance for protection of watercourses, lakes, and wetlands (i.e., Ministry of Natural Resources 2010, Government of Ontario 2009, 2010, 2017a, 2017b, Environment Canada 2013), which is based on numerous scientific studies (e.g., Castelle et al. 1994, Zhang et al. 2010, Sweeney and Newbold 2014, and additional research reviewed in Beacon 2012).

2.6.5 Percent Land Cover

Land cover should be measured by land use type and vegetation cover (e.g., urban, industrial, highway, golf course, agricultural field, forest, rock barren, wetland etc.). This information can then be used to calculate impervious area, and percent of different land use types, in relation to natural areas, over time in the watershed (Table 1).

2.6.6 Road Density

Road density reflects the degree of development in an area, indicating the extent of habitat fragmentation and disruption of landscape connectivity, as well as the risk of pollution of aquatic systems from road salt and other pollutants. A high density of roads can have multiple negative effects on watershed health, including increased sediment loading to watercourses and waterbodies, increased impervious surfaces and associated peak flows and flooding, reduced biodiversity (e.g., directly via road mortality, disturbance, and pollution; and indirectly via loss of habitat, reduction in habitat quality, and barriers to dispersal and gene flow), increased risk of forest fires, and increased risk of the introduction and spread of invasive species (Ontario Biodiversity Council 2015, USEPA 2020).

We recommend that the overall road density for the watershed (measured as the total road length divided by the total watershed area be calculated for the watershed (Table 1).

2.6.7 Habitat Fragmentation

Habitat fragmentation (or the breaking apart of habitat) consists of four main effects on the landscape: (i) reduction in the amount of habitat; (ii) increase in number of habitat fragments, (iii) decrease in the size of fragments; and (iv) increase in the distance between fragments (Fahrig 2003). Thus, a combination of metrics can be used to track habitat fragmentation (e.g., amount of habitat loss, number of habitat fragments, size of fragments, and distance between fragments). We recommend that all four aspects of fragmentation eventually be measured, however, initially we recommend that the size of habitat patches be measured by calculating the percent of the watershed comprised of natural areas (i) at least 100 ha and (ii) at least 200 ha in size (Table 1).

Generally, the larger the patch size the better for providing a range of biodiversity benefits. Federal guidance recommends that watersheds have at least one (and preferably several) forest patches at least 200 ha in area to maintain the long-term persistence of area-sensitive forest species, low-mobility habitat specialists, and species that are intolerant of human disturbances (Environment Canada 2013). If overall forest coverage is high in the watershed (e.g., >30-50%) then forest patch size may be less important, and many smaller patches closely spaced across the landscape may confer similar benefits. However, Environment Canada considers that multiple patches of a minimum 100 ha size each are required to maintain many biodiversity functions (Environment Canada 2013). For example, a study in the Severn Sound Area of Concern found that individual patches between 100 and 200 ha may support 79-87% of regional forest interior bird species, and that protecting several forest patches at least 200 ha would support 90-100% of the species (Environment Canada 2013).

Table 1. Summary of recommended implementation of shortlist indicators.

Indicator	Monitoring Approach		
	Where	**When**	**How**
Water Quality			
Total Phosphorus (TP)	Lakes in Recreational Water Quality Monitoring Program	Spring turnover (April – early June)	• Composite water sample from deepest part of lake • Average of two samples per site
Dissolved Organic Carbon (DOC)	Lakes in Recreational Water Quality Monitoring Program	Once in spring	• Surface sample from deepest part of lake
Dissolved Oxygen (DO)	Initially at lakes with low TP and frequent recurring harmful algal blooms (e.g., Three Mile Lake or Leonard Lake)	Throughout open-water season – deploy as soon as possible after ice melts off lakes in the spring and retrieve after fall mixing	• High frequency continuous automated loggers • Daisy-chained at 0.5 m depth intervals from surface to lake bottom (or according to lake-specific features) • DO + temperature loggers cost ~$3,400, while multi-parameter sondes can be ~$14,000
Water Temperature	Initially at lakes with low TP and frequent recurring harmful algal blooms (e.g., Three Mile Lake or Leonard Lake)	Throughout open-water season – deploy as soon as possible after ice melts off lakes in the spring and retrieve after fall mixing	• High frequency continuous automated loggers • Daisy-chained at 0.5 m depth intervals from surface to lake bottom (or according to lake-specific features)
Threats to Water Quality			
Calcium	Lakes in Recreational Water Quality Monitoring Program	Once monthly in May and June	• Surface sample from deepest part of lake
Chloride	Lakes in Recreational Water Quality Monitoring Program	Once monthly in May and June	• Surface sample from deepest part of lake
Algal Blooms	Initially at lakes with low TP and frequent recurring harmful algal blooms (e.g., Three Mile Lake or Leonard Lake)	August - October	• High frequency continuous automated loggers • In areas of lake with known algal blooms (e.g., typically deep areas of the lake, although increasingly occurring in shallow areas also)
Water Quantity			

Indicator	Monitoring Approach		
	Where	**When**	**How**
Water Flow	Sites along Muskoka River	Monthly from spring through early fall (~April-September)	• Area-velocity approach to measure area of water x average velocity across channel cross section • 10 to 20 panels depending on river size • In ≤ 0.75 m water depths measure velocity at 0.4 x water depth • In > 0.75 m water depths measure velocity at 0.2 and 0.8 x depths and take average • Calculate minimum, maximum and ratio of maximum to minimum flow
Biological Condition			
Benthic Macroinvertebrates	Disturbed sites near development or at specific outfalls	Monthly from spring through early fall (~April-September)	• Following OBBN protocol • Only sample if point source discharge needs to be assessed
Climate Change			
Time of Ice On/Off	Lakes throughout watershed	Spring thaw and fall freeze dates	• Citizen scientist observations through IceWatch Program
Cumulative Effects			
Muskoka River Water Quality	17 main stations on the Muskoka River and its tributaries + additional 3 stations representing recommended contaminant sampling sites if desired	Monthly from spring through early fall (~April-September)	• Surface measurements of TP, DOC, DO, water temperature, calcium, and chloride • Water flow
Landscape Condition			
Percent Forest Cover	Entire watershed	Every five years	• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Include upland and wetland forest (differentiate if possible) • Include forest patches ≥ 0.5 ha • Calculate exclusive of lake area to avoid underestimating forest cover
Percent Forest Interior			• Muskoka GeoHub data and the IWM Natural Capital Inventory data

Indicator	Monitoring Approach		
	Where	**When**	**How**
			• Measure amount of forest ≥ 100 m from outer edge in forest patches ≥ 0.5 ha • Calculate exclusive of lake area to avoid underestimating forest cover
Percent Wetland Cover			• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Differentiate between treed and thicket swamps • Identify swamps, bogs, fens, marshes
Threats to Landscape Condition			
Riparian Connectivity	Entire watershed	Every five years	• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Measure proportion of natural habitat within 30 m inland of water's edge
Percent Land Cover			• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Measure land use type (e.g., urban, industrial, highway, golf course, agricultural field) and natural habitat type (e.g., forest, rock barren, wetland) • Calculate % impervious area, % of different land use types and natural habitat types
Road Density			• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Measure overall road density (total road length divided by total watershed area)
Fragmentation			• Muskoka GeoHub data and the IWM Natural Capital Inventory data • Calculate % of watershed comprised of natural areas ≥ 100 ha

Indicator	Monitoring Approach		
	Where	**When**	**How**
			• Calculate % of watershed comprised of natural areas ≥ 200 ha

3. Summary and Conclusions

We provide guidance on the implementation of monitoring for the 18 shortlisted watershed health indicators. Some indicators are already monitored in the Muskoka River Watershed, such as parameters measured under the District's Recreational Water Quality Monitoring Program (e.g., TP, DOC, temperature, calcium, chloride) and Biological Monitoring Program (benthic macroinvertebrates), which focus primarily on lake ecosystems. For many of these indicators related to water quality (and threats to water quality) we recommend that current lake monitoring approaches continue, but that additional monitoring be extended to river ecosystems (i.e., along the Muskoka River mainstem and its tributaries) to provide a more holistic picture of watershed health, and to track cumulative effects from headwaters in the north of the watershed to outflow to Georgian Bay in the south. This addition of river monitoring will also integrate with contaminant monitoring we are recommending in a separate report (HESL 2023c). We also recommend that continuous automated sampling of DO, temperature, and algal blooms be targeted toward lakes with low TP that experience frequent recuring algal blooms to help elucidate causes. In addition, we recommend that new indicators be added to field sampling programs to monitor water quantity (water flow) in rivers and climate change (time of ice on/off) in lakes. Given that benthic macroinvertebrate assemblages are strongly influenced by habitat conditions, detecting a clear cause and effect relationship between benthic macroinvertebrate measures and environmental stressors is inherently difficult. We thus recommend that benthic macroinvertebrates only be considered as a watershed health indicator for assessing point source discharge, where stressor impacts would be expected to be more obvious than in regular monitoring of nonpoint source stressors. We recommend that indicators related to landscape condition and threats to landscape condition be monitored through the District's Muskoka GeoHub and IWM Natural Capital Inventory resources.

Ongoing review and refinement of the monitoring program is essential for ensuring that it is effectively characterizing watershed health in a scientifically defensible manner. To ensure quality control and quality assurance, we recommend that data from indicators monitored in the field (i.e., water quality, threats to water quality, water quantity, biological condition, climate change, and cumulative effects indicators) be reviewed periodically throughout each monitoring season. At the end of each monitoring season (i.e., annually), we recommend a more in-depth analysis of these data (e.g., summary statistics) to determine if they are providing appropriate spatial and temporal resolution to discern watershed condition. Every two to five years, we recommend that field monitoring data be analyzed and interpreted in a monitoring report summarizing trends and patterns in watershed health. For landscape condition and threats to landscape condition indicators, we recommend that GIS analysis and interpretation occur every five years.

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Hutchinson

Environmental Sciences Ltd.

Watershed Health Indicators – Muskoka River Watershed

Boating Activity Report

Prepared for: The District Municipality of Muskoka
Job #: J220004

October 12, 2023

FINAL

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October 12, 2023 HESL Job #: J220004

Glenn Cunnington
Manager, Watershed Programs
The District Municipality of Muskoka
70 Pine Street
Bracebridge, Ontario
P1L 1N3

Dear Glenn:

Re: Final Boating Activity Report – Watershed Health Indicators Muskoka River Watershed Project

We are pleased to submit the Boating Activity Report for the Watershed Health Indicators – Muskoka River Watershed Project. The report summarizes the literature review we conducted to examine effects of recreational boating on the natural environment, ways of quantifying boating activity, and identification of potential boating indicators to monitor watershed health. Although boating impacts are well documented in the literature, separating them out from other watershed stressors is challenging. As a result, no clear indicators were identified that have been used reliably and consistently for monitoring, although several potential metrics could be developed as indicators with additional study. In addition, a variety of management tools exist to limit impacts.

We thank you for the opportunity to undertake this work. We hope the report provides useful information as the District develops its approach to Integrated Watershed Management.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.



Andrea Smith, Ph. D.
Senior Scientist

Signatures

Report Prepared by:



Andrea Smith, Ph. D.
Senior Scientist

Report Reviewed by:



Brent Parsons, M. Sc.
Principal and Senior Aquatic Scientist

Executive Summary

Recreational boating is a popular pastime across Canada, including in the Muskoka River Watershed, but the impacts of boating have not been widely studied compared to other stressors. Boating causes diverse, multi-faceted, and cascading impacts on the natural environment, which are influenced by multiple factors including boat characteristics, type of activity, water depth, shoreline vegetation, and sediment composition. Recreational boating in lakes and rivers can lead to deterioration of water quality, bank erosion, introduction of invasive species, damage to aquatic vegetation, and disturbance of wildlife populations.

Boating impact assessments are often used to determine whether lakes are at their carrying capacity (often measured as recreational, not ecological capacity) and whether they can sustain additional boating activity. The concept of carrying capacity is difficult to quantify, and influenced by site-specific factors, as well as perceptions of those using lake resources. Space standards, which are applied to different types of boats and boating activities, combined with measures of boating levels, are useful in revealing patterns of use, but this information needs to be explicitly tied to impacts on watershed health. For example, boating activity concentrated in large open areas of lakes will have fewer negative impacts on the environment than activity concentrated closer to shore.

Recreational boating has a myriad of physical, chemical, and biological impacts on the environment, but identifying indicators to track its impacts is challenging. In particular, boating may be one of many sources contributing to environmental degradation, and disentangling cumulative effects can be complicated. Some effects are obvious (e.g., noise, sediment re-suspension, erosional effects) while others are more subtle and may only be detected after prolonged boating activity (e.g., hydrocarbon accumulation in sediment, re-suspended sediments clogging aquatic insect and fish gills).

Macrophyte abundance, turbidity, total suspended solids, and bank erosion have been documented to change in response to boat traffic, suggesting that they may serve as useful indicators of boating impacts. Measurement of these parameters may require comparison of conditions at reference (undisturbed) vs. affected sites, and during peak vs. non-peak boating periods, and boating vs. non-boating season. Indirect proxies of boating activity may also reflect impacts on the environment (e.g., distance to marinas and highways, density of berths at marinas, density of docks on a lake, number of access points on a lake).

Various management approaches have been implemented in lakes and rivers to minimize negative effects of recreational boating. These include no-wake zones, speed limits, restricted areas or periods, size thresholds, limits to public access, limits to shoreline development (although public boat launches are always available), and land use zoning. Monitoring boating indicators could help to evaluate the effectiveness of these management practices. However, even if indicators are used to quantify boating activity so that it can be managed to protect watershed health, the overall carrying capacity of lakes and rivers in Muskoka will also be influenced by other associated water-based recreational activities that need to be considered as well, including onshore activities (e.g., picnicking, sightseeing, hiking).

Boating impacts on the environment are well documented but separating the effects of boating from other stressors (e.g., shoreline development, storms, wind, runoff) is particularly difficult. Consequently, there are no clear indicators that have been used to reliably monitor the impacts of recreational boating on watershed health. A few parameters offer promise for tracking boating effects, but considerable background study will be required to establish baseline conditions (i.e., in non-boating conditions), acceptable

thresholds, and desired targets. Ultimately, this information could be used to determine the ecological carrying capacity of lakes and rivers in Muskoka, which could then be used to manage shoreline development and boating activity. In the meantime, management tools are available to lessen impacts, and these should be applied to lakes and rivers based on site-specific characteristics and recreational pressures.

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1. Introduction

1.1 Background

The District Municipality of Muskoka (the District) launched the Watershed Health Indicators Project in 2022, as part of its Integrated Watershed Management Initiative. The aim of the project was to build on existing information and studies to identify environmental and ecological metrics to monitor watershed health in the Muskoka River Watershed. Hutchinson Environmental Sciences Ltd. (HESL) completed the first phase of the project in September 2022 by developing a longlist of 29 indicators. The work involved the following components:

- Review of existing knowledge of watershed health for the Muskoka River Watershed,
- Review of indicators used in other jurisdictions, and
- Consultation with local community members and scientific experts.

The 29 watershed indicators were divided into two main categories: Ecological Status and Threats to Ecological Status (Figure 1). Fourteen indicators were identified under Ecological Status, representing several sub-categories: Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), and Landscape Condition. Fifteen indicators were identified under Threats to Ecological Status, representing the following sub-categories: Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects.

The results of the first phase of the project were summarized in a report (HESL 2022) available on the District's EnviroHub webpage[1]. The report made a series of recommendations for monitoring watershed health in Muskoka. Among these was the recommendation that additional research be conducted to investigate indicators used to track boating activity and its impacts on watershed health.

The second phase of the Watershed Health Indicators Project was launched in 2023 to address several of the recommendations from the 2022 report. This report provides a synthesis of our literature review of the state of the science on identifying indicators to measure recreational boating impacts on watershed health. The report includes a description of the physical, chemical, and biological impacts of boats on the aquatic environment, followed by a discussion of boating impact studies, boating indicators, and management tools.

1.2 Measuring Watershed Health

Watershed health refers to the ability of a watershed to support the natural features, processes, and conditions within its boundaries, including dynamic hydrologic and geomorphologic processes (within their natural range of variation), habitat of sufficient size and connectivity to support native species, and physical and chemical water quality conditions that sustain healthy biological communities (US Environmental Protection Agency [USEPA] 2022). Monitoring of watershed health assesses the current state of the

[1] *Making Waves: Integrated Watershed Management Projects:* https://www.muskoka.on.ca/en/environment/Making_Waves__Integrated_Watershed_Management_Projects.aspx#9-Develop-watershed-health-indicators

system, identifies changes, and predicts risks, taking into consideration the effects of land use, climate change, and human activities (Ho et al. 2018).

Indicators are often used to measure environmental conditions because they are simplified representations of more complex ecological states and processes that are difficult to quantify. Indicators can include physical, chemical, biological, and socio-economic attributes of the watershed which convey information on underlying ecological functions (Government of Alberta 2008). Indicators can be used to document baseline environmental conditions and track changes to those conditions over time (e.g., are they improving, worsening or stable) and space. Target values of indicators (or management objectives) can be identified, and progress toward achieving targets through stewardship and management actions can be evaluated. Indicators can also have threshold levels, that serve as early warnings of unwanted change that might warrant management action. According to the USEPA, effective indicators are ones that are measurable, comparable, consistent, and relevant to the ecosystem and issues of interest (USEPA 2021). In addition, indicators should

- be easy to understand and readily available,
- be reliable, providing an unambiguous cause and effect relationship between environmental stressors and ecosystem response,
- be comprehensive, representing a range of physical, chemical, and biological attributes of the ecosystem, and
- be cost-effective to monitor (Government of Alberta 2008).

Indicators are typically selected to represent a range of watershed features (e.g., hydrology, physical habitat, water quality, biological communities) and watershed functions (e.g., base flow, flood storage and attenuation, temperature, nutrient cycling, species interactions), and to track human influence (e.g., land use, wetland alteration, invasive species introductions and spread, dam impacts, extent of impervious surfaces). Three types of indicators are generally considered:

- Condition indicators, which address the state of the environment, including the quality and quantity of attributes, and the state of human and ecological health (e.g., water quality, biodiversity, riparian habitat),
- Pressure indicators, which address natural processes and human activities that could negatively impact environmental conditions (e.g., soil erosion, climate change, urban development), and
- Response indicators, which address actions to manage, mitigate, adapt to or prevent environmental damage (e.g., stewardship activities, education initiatives, municipal policy; Government of Alberta 2008).

2. Information Sources

Two online research search engines, Google Scholar and Web of Science™, were used to identify and assemble an initial list of peer-reviewed and grey (i.e., not peer-reviewed or published through academic journals) literature related to boating activity and watershed health. We limited our review to recreational boating, with a focus on freshwater systems (although some studies found were from coastal marine settings) and impacts of motorized watercraft. Search terms included “boating capacity”, “recreational

boating impacts", "indicator", "boating activity", and "watershed health" Studies found through the search engines were supplemented with local boating impact assessment studies from the Muskoka River Watershed. A total of 45 papers (14 grey and 31 peer-reviewed) were identified, which were then screened by scanning abstracts and narrowed down to studies focused on recreational boating impacts to watershed health, and monitoring indicators to track these impacts (36 papers). All relevant literature was then read in full and key information was documented in a spreadsheet (Appendix A). The following sections of the report provide a synthesis of this literature review.

3. Effects of Boating on Watershed Health

Recreational boating is a popular pastime on Canadian lakes and rivers. In 2016, there were an estimated 8.6 million recreational boats in the country, including motorized (powerboats and personal watercraft) and non-motorized (sailboats, canoes, kayaks) watercraft, and more than 12 million people participated in recreational boating (NMMA 2017). The Muskoka River Watershed is an especially attractive location for recreational boating, offering extensive opportunities for a variety of water-based activities, including fishing, sailing, canoeing, water-skiing and wakeboarding. A 2021 survey of lake association members in Muskoka and Georgian Bay regions[2] found that 99% of respondents had one or more boats, with 91% having one or more motorized craft and 95% with one or more non-motorized craft (Spears and Seydegart 2021). Although many respondents rated their overall lake experience highly, many expressed concerns that boat traffic, boat noise, and the impact of boat wakes, were all increasing in the area (Spears and Seydegart 2021).

Despite its popularity, the environmental impacts of recreational boating have been studied less than other stressors on freshwater systems, such as shoreline development (Hunt et al. 2019). Most research is relatively short-term in scope and longer term impacts on watershed health are not well understood. Nonetheless, numerous negative impacts on watershed health have been documented, broadly divided into physical, chemical, and biological effects.

3.1 Physical Impacts

The primary physical impacts arise from disturbance of the water column, substrates, and aquatic vegetation and wildlife, caused by turbulence from the propulsion system, propeller and boat contact, and waves produced by movement (Asplund 2000). These impact mechanisms are particularly pronounced in shallow waters (less than approximately 3 m depth), where they can lead to a series of environmental effects including sediment resuspension, turbidity and reduced water clarity, bank erosion, and direct damage to aquatic plants (e.g., cutting, breaking, or uprooting) and wildlife populations (e.g., smothering of fish eggs, collision with fish, or flooding of waterbird nests; Adams 1993, Asplund 2000). Physical disturbance due to boating can also lead to multiple indirect effects. For example, turbid waters resulting from boating activity can limit aquatic plant productivity by inhibiting light penetration, while resuspended sediments can promote nutrient enrichment leading to algal blooms, and introduce pollutants, such as heavy metals, into the water column (Mosisch and Arthington 2004). Turbidity can also hinder visual feeding by fish and waterbirds and may reduce food availability if invertebrate and plant populations decline as a

[2] *5951 respondents participated in the survey, 4851 of which were from the Muskoka region.*

result (Asplund 2000). At the same time, propeller damage to aquatic plants can cause fragmentation of macrophyte beds, while simultaneously allowing more light to reach submerged plants, potentially increasing underwater plant growth (Mosisch and Arthington 2004). Jet boats (which are propelled by drawing water in and forcing it out at high velocity) such as Sea-Doos, avoid damage caused by propellers but can create pressure fluctuations which harm fish eggs (Mosisch and Arthington 2004). Motorized boats also create visual and noise disturbance which stress wildlife species, inhibiting communication, and changing behaviour, including causing avoidance or displacement from areas of high boating activity (Burgin and Hardiman 2011, Whitfield and Becker 2014).

The extent of physical damage caused by motorized boats is influenced by multiple factors, including boat speed, type, and size, hull design, power output, boat activity, water depth, density of riparian vegetation, and soil and sediment composition (Burgin and Hardiman 2011). Shallow nearshore habitats tend to be more vulnerable to boat traffic than deepwater portions of lakes, for example, because motorboats can stir up bottom sediment, disturb aquatic plants, and propagate waves which erode shorelines in shallow water (Asplund 2000). Clay sediment churned up by boats can stay suspended in the water column for weeks, while sandy sediment will settle out much faster because of its larger particle size (Burgin and Hardiman 2011). Shorelines with steep, sandy or unvegetated banks are more vulnerable to erosion (Asplund 2000). Shorelines in narrow waterways, or in areas exposed to little natural wave energy, are also more prone to bank erosion and destabilization. In Chesapeake Bay, for example, 15% of banks are experiencing high erosion rates despite being considered low energy shorelines (Bilkovic et al. 2019). High boat traffic in Chesapeake Bay has led to armouring of 25% of low energy shorelines because of erosion (Bilkovic et al. 2019).

Recreational boating can represent a significant source of waves on lakes, especially in areas with heavy boat traffic, and during peak boating periods (Bilkovic et al. 2019). Waves produced by boats differ from natural wind-induced waves because they are pulsed rather than continuous and tend to be larger, with longer periods (Whitfield and Becker 2014, Bilkovic et al. 2019). A study on Whitestone Lake (near Parry Sound) found that recreational boat wakes produced 61% of total wave energy in a busy stretch of the lake during the peak boating season (Houser et al. 2021). In addition to the initial boat wake, the study estimated that reflected waves from adjacent shorelines accounted for a further 11% of the total wave energy, suggesting that cumulative wake energy may be underestimated (Houser et al. 2021). Waves created even by relatively small boats (~4 m) 150 m out from shore can cause shoreline erosion (Bilkovic et al. 2019). Although boat waves can be as large as those created by storms, the former dissipate as they move away from the boat, while the latter increase with distance (Asplund 2000). The waves from multiple boats operating in the same area can be additive, leading to larger waves than those produced by individual craft (Houser et al. 2021). Naturally vegetated shorelines offer some protection from boat-induced waves by dissipating wave energy, although this function is reduced with frequent exposure to boat wakes (Mosisch and Arthington 2004, Bilkovic et al. 2019). Wave heights of 0.3 m or less have been found to erode vegetated shorelines (Bilkovic et al. 2019). Sheltered shorelines that experience little wind are generally more susceptible to boating induced wave effects compared with shorelines along large stretches of open water (e.g., > 300 m of open water; Asplund 2000). Similarly, small lakes are generally more sensitive than large ones, because they experience less wind-induced wave energy (Marr et al. 2022).

Many recreational boats have planing hulls which enable them to move across the top of the water's surface at high speed, creating minimal waves (Houser et al. 2021). At low speeds, however, these boats travel low

in the water, displacing significant amounts of water, and thus creating substantial wakes. The largest wake for planing hull vessels occurs as it shifts from displacement to planing mode (Beachler and Hill 2003). Furthermore, boats generate larger wakes when used for water-skiing, tubing or wakeboarding compared to when not towing (Houser et al. 2021). Wakeboats produce larger waves than conventional motorboats under both planing and wakesurfing speeds (Marr et al. 2022). Under typical wakesurfing conditions, wakeboats need more than 150 m to attenuate their waves (in terms of their height, energy, and power) to the equivalent level of waves created by conventional boats planing (Marr et al. 2022). Personal watercraft (PWC; e.g., Sea-Doo) create smaller waves than motorboats during linear travel because of their smaller size, but the typical use of PWC involves quick and frequent stops, turns and circles, which create larger waves. PWC also have very shallow drafts, allowing them to be used at high speed closer to shore than motorboats, further contributing to wave damage in the nearshore (Beachler and Hill 2003, Houser et al. 2021).

3.2 Chemical Impacts

Recreational boating contributes chemical pollution to the natural environment, primarily through fuel and oil leakage, and motor exhaust emissions (Mosisch and Arthington 2004). Two-stroke outboard engines are far less efficient than four-stroke models, producing higher emissions and releasing unburned fuel and oil into the water, which contains toxic compounds such as polyaromatic hydrocarbons, heavy metals, and phenols (Asplund 2000). It is estimated that 25 to 30% of fuel from two-stroke engines enters water unburned (Asplund 2000). The overall effect of this pollution on aquatic organisms appears to be low in most lakes because it is diluted out by the much greater lake volume, and because most hydrocarbons are volatile and rapidly dissipate (Milliken and Lee 1990, Asplund 2000). However, fuel and oil pollutants introduced into the water column can settle out in bottom sediment, causing potential harm to benthic organisms, and creating long-term storage of toxins which may be re-released in the future (Whitfield and Becker 2014). The long-term and chronic effects of pollution caused by recreational boating to aquatic ecosystems are unknown (Asplund 2000).

Sewage discharge from boats can also pollute freshwater systems, raising the risk of eutrophication, algal blooms, and pathogen contamination (Adams 1993, Whitfield and Becker 2014, Stepenuck et al. 2022). This pollution pathway has not been well studied, and the magnitude of the problem is unknown. However, a study of recreational boating in Lake Champlain (USA/Canada) estimated that the overall contribution to phosphorus loading due to improperly disposed boat sewage ranged from 7 to 73 kg/yr, representing less than 0.01% of the overall annual phosphorus load to the system (Stepenuck et al. 2022).

Recreational boats may have anti-fouling paint applied to their hulls to keep aquatic organisms (such as zebra mussels, aquatic plants, and algae) from attaching and increasing drag. Until recently, tributyltin (TBT) was widely used but was banned across Canada in 2008 because of its highly toxic, persistent and bioaccumulating properties (Antizar-Ladislao 2008). Copper compounds (e.g., copper thiocyanate) are commonly used in place of TBT, although research has shown that copper leaching from these anti-fouling agents negatively affects non-target aquatic organisms, including fish and crustaceans (Schröder et al. 2022). High concentrations of copper in surface waters of Lake Texoma (in the United States) have been linked to anti-fouling paint (Whitfield and Becker 2014).

3.3 Biological Impacts

Boating activity also contributes to the introduction and spread of invasive species. Aquatic plant fragments and invertebrates are transported on surfaces like boat hulls and propellers, boat trailers, and on fishing gear. Invasive plant cuttings from propellers can directly root in new locations when transported within and between lakes, expanding the historical range of macrophytes and leading to unfavourable conditions and limited recreational opportunities (Mcalarnen et al. 2012). Microorganisms, such as phytoplankton (algae) and spiny waterflea, are carried in bilge water and jet ski propulsion systems (Mosisch and Arthington 2004). Fishing practices, such as the use of live bait and live wells, may also lead to the inadvertent transfer of non-native species to new locations (Whitfield and Becker 2014, Hunt et al. 2019).

3.4 Case Studies

Specific impacts of recreational boating have been documented in a wide range of organisms through a variety of case studies. Across Canada, boating activity has been identified as a threat to at least 15 species at risk, including vascular plants, arthropods, birds, fish, molluscs, reptiles, and mammals, due to increased sedimentation, turbidity, erosion and siltation, disturbance, direct collision, and trampling at access points (Rosenthal et al. 2022).

Hansen and Snickars (2014) developed a macrophyte community index to measure the effects of boating in shallow soft-bottom bays of the North Baltic Sea. They found that the proportion of sensitive plant species declined with increasing boating activity, which corresponded with rising phosphorus concentrations and turbidity. The cumulative cover of macrophytes was inversely related to turbidity, suggesting that this parameter was the reason for adverse boating effects. As boating pressures rose, the macrophyte community shifted to faster growing shade-tolerant species (Hansen and Snickars 2014). A literature review of the effects of boat traffic and mooring structures on aquatic vegetation found that submerged plant abundance was reduced in boating areas (by 42%) and below docks (by 18%) compared with control locations (Sagerman et al. 2020). Docks constructed over vegetated habitats led to more than a 50% reduction in abundance, which was attributed to decreased light penetration. Floating docks were considered more harmful to submerged vegetation than elevated ones because of the stronger shading they produced underneath. Mooring buoys were documented to cause physical damage to vegetation mainly through the scouring effect of chains dragging along the bottom. It was noted that both docks and buoys are typically situated in sheltered areas that offer favourable conditions for submerged vegetation to grow (Sagerman et al. 2020).

A study examining the effects of boating activity on aquatic macroinvertebrate communities found no difference in abundance or diversity between high and low use boat ramps in South Dakota prairie pothole lakes (Smith et al. 2019). However, the authors concluded that environmental pressures operating at the regional scale likely explained the results, since macroinvertebrate assemblages in the study lakes were characterized by highly tolerant low diversity taxa already adapted to extreme conditions such as high wave action, droughts, floods, and sediment disturbance. Consequently, the relatively small-scale disturbance of localized and temporary boating activity might have little effect on these species, and thus macroinvertebrates were poor indicators of boating in the prairie pothole region (Smith et al. 2019).

The impact of recreational boating on damselflies and dragonflies was studied in islands on Georgian Bay (Hall et al. 2016). Both larvae and adults are particularly susceptible to boat waves, which can cause direct dislodgement and indirect loss or simplification of their emergent vegetation habitat. Several measures of boating pressure were used to track effects on community structure relating to the proximity to marinas, marked boating channels, and highways, the length of shoreline exposed to waves, and the speed of boats in the vicinity. Boating pressure affected species composition differently depending on life history stage. The species composition of larvae was influenced by distance to marinas and boating channels, as well as boat speeds. For adults, species composition was influenced by distance to marinas, and increasing distance corresponded to sites with increased floating vegetation cover, underscoring the detrimental impact of boat-generated waves on macrophyte habitat (Hall et al. 2016).

Northern map turtles (*Graptemys geographica*), like many other freshwater turtles, are prone to propeller injuries. A study of two populations in Ontario found that collision risk varied based on sex- and age-specific movement patterns, habitat use, and basking behaviour (Bulté et al. 2010). All turtles are vulnerable to boat collisions because they typically bask while floating on water and will surface to breathe while moving underwater. However, adult females were particularly vulnerable to collisions because they spent more time basking at the surface and more time travelling large distances over open water than males or juveniles. Adult female movements were especially extensive during the nesting period, which coincides with the peak boating season (Bulté et al. 2010). Adult females were two to nine times more likely to be injured by propellers than adult males or juveniles. A population viability analysis indicated that moderate to high boat traffic could pose a serious threat to this turtle species, predicting rapid population extinction at two locations studied if mortality risk from boat collisions exceeded 10% (Bulté et al. 2010).

Fish populations are affected by recreational boating in multiple ways. Direct strikes from boat hulls and propellers may be a problem, especially in shallow waters, but the extent of this threat to fish is unknown (Mosisch and Arthington 2004). Information is lacking on whether boating activity directly impacts fish larvae, but this sensitive stage may be prone to damage from hulls and propellers, especially at night when larvae tend to congregate in surface waters (Whitfield and Becker 2014). Fish eggs and larvae are also affected by suspension of sediment caused by boats, which may dislodge and smother eggs, promote premature larval emergence, and clog gills (Whitfield and Becker 2014). Fast-moving boats may disrupt schools of fish and cause fish to exert extra energy in avoidance behaviour (Whitfield and Becker 2014).

Noise pollution may impede fish communication and disorient fish travelling in schools as sound travels farther in water and can increase stress levels in fish. Although little research has focused on the impacts of PWCs on fish, their typical use on the water (characterized by rapid changes in speed and direction, coupled with frequent slamming of the hull and production of bubbles on the water surface) may stress and confuse fish (Whitfield and Becker 2014). Boating noise may also alter reproductive behaviour, although a study of parental care in largemouth bass (*Micropterus salmoides*) suggests that impacts may be temporary (Maxwell et al. 2017). Bass tending eggs exhibited no difference in behaviour before, during, and after exposure to a variety of boating noises (high-speed and idling combustion engines, and an electronic bow-mounted trolling motor). However, in a second experiment in which fish were exposed to high-speed motor noise only, males guarding nests during the egg-sac fry stage moved significantly less during noise treatment but returned to normal behaviour post-experiment (Maxwell et al. 2017). Fish nests occur in the nearshore, where boating activity is often concentrated. Frequent or extended exposure to boat-related

noise during sensitive egg development could thus result in negative impacts on fish reproduction (Maxwell et al. 2017).

Infrastructure associated with boating also influences fish and other aquatic organisms. Artificial structures in the nearshore, such as boat ramps, piers, docks, jetties, and breakwaters may eliminate or alter natural habitat, negatively impacting fish communities (Becker and Whitfield 2014). Hansen et al. (2019) found that recreational boating and related marina facilities (e.g., moorings) resulted in reduced abundance and structural complexity of aquatic vegetation cover available for juvenile fish in the Baltic Sea, potentially reducing fish recruitment.

4. Boating Impact Studies

The capacity for lakes and rivers to support recreational boating is often evaluated through boating impact assessments, which aim to compare the level and type of boating activity present (or predicted) with the amount the system can sustain. The foundation of this approach is the concept of carrying capacity, which can be defined as the maximum level of recreational use that can be accommodated before an unacceptable or irreversible decline in condition or value occurs (Stankey and McCool 1984). Most boating impact studies focus on recreational rather than ecological carrying capacity. As such, they tend to rely heavily on measures of user satisfaction, related to the aesthetic environment and quality of the recreational experience, instead of quantifying effects of boating activity on watershed health (Ashton and Chubb 1972, Stankey and McCool 1984). Boating capacity is typically determined by applying space standards for different types of boating activity (e.g., fishing, non-motorized boats, powerboats, water-skiing) based on a calculation of the minimum space taken up by each type of activity. These activity footprints are then used to determine how much of each type of activity can fit into a given lake or river system (Doshi 2006). The overall calculation of available space may account for areas where boating is restricted or off limits, such as along shorelines, close to swimming beaches, or within fish spawning areas (Klessig 1994, Doshi 2006). If the cumulative total of existing and proposed boating activities exceeds the boatable area of the lake, then the lake is over capacity (Doshi 2006).

Carrying capacity is notoriously difficult to quantify. As Barkham (1973) stated *"Carrying capacity is a phrase delightful in its simplicity, complex in its meaning and difficult to define, as in different situations and to different people it is understood in different ways*" (p. 218). The determination of space standards, for example, depends on a range of factors, including whether a boat is moving or stationary, how fast it is moving, and what type of activity is occurring (e.g., a boat with a water-skier takes up more space than the same boat without one; Ashton and Chubb 1972). Space standards may also be influenced by characteristics of the aquatic system and surrounding environment, such as lake size, configuration, and depth, and amount of shoreline development (Falk et al. 1992). Calculations are further complicated by user perceptions of issues such as crowding, conflict among different recreational activities, and boating safety, which can vary by user group and from lake to lake (Ashton and Chubb 1972, Stankey and McCool 1984, Doshi 2006). For example, people using sailboats may place greater value on quiet settings with fewer motorboats than those using motorized watercraft (Gray et al. 2010). Similarly, boaters on remote lakes may have lower thresholds for motorized activity than ones in more developed areas (Gray et al. 2010). Space standards are also uniformly applied throughout a lake or river, and thus may not account for areas where boating activity is more concentrated, such as around marinas or boat launches (Falk et al.

1992). It is also a challenge to establish a direct link between boating density, boater satisfaction, and boating impact in these studies (Stankey and McCool 1984). Ultimately, capacity studies should determine not only patterns of use, but also the impacts of that use (Falk et al. 1992).

For all these reasons, it is difficult to generate a universal set of boating capacity standards applicable to all lakes, and values used vary substantially among studies (Table 1).

Table 1. Examples of space standards used to determine boating capacity.

Boat Type or Activity	Area per Boat (ha)	Source
Fishing	0.25-0.50	Mosisch and Arthington 2004
Small boats (e.g., low-powered motor, row boats)	0.18-0.50	
Sailboats	0.50-1	
Powerboats	1.5-3	
Water-skiing	2-4	
All uses combined	1.6-4.4	Reviewed in Doshi 2006
Water-skiing and all other uses	16	
Water-skiing only	6-8	
Water-skiing and motorboat cruising	8	
Fishing	4	
Canoeing, kayaking, sailing	3	
All boating activities	10	
All motorized uses	12	

Variations on the simple space standard approach have been applied in different studies. Ashton and Chubb (1972) incorporated a measure of the spatial dispersion of boats (distance between boats and position of boats about a central point) in measuring boating capacity but found the timespan of their survey (one hour observations) was too short to accurately represent spatial relationships. Adams (1993) developed a consumption index to measure the impact of different craft by weighting their size and speed, combined with their movement pattern (moving or stationary) and overall density (number in the survey area) to calculate environmental load of different types on the lake. This approach accounts for user groups

which may be contributing proportionately more to environmental impacts than others (Adams 1993). A study of boating capacity in Beaver Lake, Arkansas divided the lake into zones which were assigned different recommended boating densities, based on different physical characteristics and preferential uses (CDM Smith 2017). For example, a narrow shallow section of the lake was popular for fishing, while a wide open portion of the lake attracted sailing and water-skiing (CDM Smith 2017). Similarly, RiverStone (2020) described an approach which divided a waterbody into different management components based on existing boating conditions and management objectives. Thus, an area of a lake currently experiencing low or very low boating traffic might be flagged for future restriction of development to protect its current status. An area with moderate to high boat traffic might be more appropriate for future development or might also require restrictions depending on whether increased boating would have adverse impacts (RiverStone 2020).

Correction factors may also be applied to boating assessments, for instance to account for time of observations (e.g., weekday vs. weekend), current boating levels (e.g., lakes that have many different boating activities might have lower capacity for each to avoid user conflicts among activities), and lake physical attributes (e.g., lakes with uniform shorelines may tolerate more boat traffic than ones with irregular shorelines, lakes with large open areas may tolerate more activity than ones with little open water; RiverStone 2020). Boating assessment studies may also incorporate additional data to measure boating activity, such as air photos or aerial surveys, or counts of vehicles parked at access points (Ashton and Chubb 1972, Falk et al. 1992). Establishing the carrying capacity for a lake may also involve surveys to gauge the satisfaction of user groups (e.g., different types of boaters, shoreline property owners) with current and future levels of use (Ashton and Chubb 1972, Doshi 2006, Gray et al. 2010, RiverStone 2020).

Several boating impact assessments have been conducted in Muskoka. One study evaluated potential impacts of increased boat traffic due to proposed development on Langmaid's Island in Lake of Bays (MNAL 2018). Boating activity was quantified by boat type, and whether vessels were stopped, moving at low or high speed, and towing skiers (Table 2). The boatable area was calculated as waters beyond 30 m of the shore. The study assumed that non-motorized paddle (e.g., kayaks, canoes, pedal boats, rubber rafts) and oar-powered boats (e.g., rowboats) had no capacity impacts, since they were likely to be used in the excluded nearshore zone (MNAL 2018). Boats were counted during peak boating season (summer) on both weekend and weekdays from shore or a dock to record cumulative counts (all boats moving through the study area during the day [9 am to 5 pm]) and snapshot counts (type of boat and speed/activity observed every 10 minutes during the day.

Table 2. Space standards applied in Lake of Bays Boating Impact Assessment (MNAL 2018).

Boat Type	Surface Area Required per Boat (ha)			
		Moving		
	Stopped	Slow	Fast	Skiers
Skiff	0.5	1	3	5
Runabout	0.5	1.5	6	8
Cruiser	0.5	2	2	2
Houseboat	0.5	2	2	2
Pontoon Boat	0.5	1.5	1.5	1.5
Personal Watercraft	0.5	1.5	3	6
Windsurfer	0.5	1	1	N/A
Sailboat	0.5	1	1	N/A

A similar approach was taken for a boating assessment of Wallace Bay on Lake Rosseau, with the boatable area calculated as portions of the study area greater than 10 m from shore, which generally corresponds to water depths greater than 1.4 m (RiverStone 2020). The study recommended that period counts (or cumulative counts of all traffic over a given period) be used instead of snapshot counts, because the former is more likely to capture variation in boat traffic and individual boating behaviour, and thus minimizes the risk of underestimating boating activity (RiverStone 2020). The assessment noted that a previous boating assessment of Wallace Bay conducted in 2008 applied space standards that were less than those found in the grey literature (and equivalent to those listed in Table 2) and recommended that tripling the size of these standards might be warranted for the study area (RiverStone 2020).

5. Boating Indicators

Recreational boating activity has numerous environmental impacts, but detecting and measuring them is challenging because aquatic ecosystems lack clear boundaries, impacts may derive from multiple potentially interacting types of activities or events (e.g., shoreline development, boating, fishing, storms, wind-induced waves), impacts may be hard to observe, and impacts can vary in their spatial and temporal extent (e.g., localized vs. dispersed, short-term vs. long-term; Burgin and Hardiman 2011). Identifying indicators to track how recreational boating influences watershed health is thus difficult because clear unambiguous links between cause and effect are generally lacking.

Several studies have documented a negative relationship between boat traffic and aquatic vegetation characteristics (e.g., biomass and species composition; Adams 1993, Asplund 2000, Hansen and Snickars 2014, Hansen et al. 2019). Hansen and Snickars (2014) developed a macrophyte community index comprised of plant species with varying tolerance to pollution which was a good indicator of eutrophication and boating activity in marine coastal waters. Sites were compared to a reference condition, representing what the macrophyte community would be like in the absence of any human influence (i.e., the most sensitive macrophytes would all be present). Macrophytes are generally useful as biological indicators of environmental quality because they are stationary, long-lived, integrate environmental conditions over relatively long timescales, and because some species are more sensitive to pollution than others (Hansen and Snickars 2014).

Many studies have linked boating activity to water quality changes, related to parameters such as water clarity, turbidity, and suspended solids, and to shoreline changes related to erosion and runoff (Falk et al. 1992, Adams 1993, Johnson 1994, Asplund 2000, Mosisch and Arthington 2004, Hansen and Snickars 2014, Bilkovic et al. 2019). A study of the effects of recreational boating on the Upper Mississippi River System in Minnesota found that turbidity and total suspended solids increased during peak boating periods (e.g., between noon and 3 pm on weekends and holidays from Memorial Day weekend in May to Labour Day weekend in September), while most bank erosion over a year occurred during the boating season (May-September), suggesting that these three parameters might be useful indicators of boating activity (Johnson 1994). Similarly, a study examining impacts of boat wakes in Chesapeake Bay, Virginia, found that turbidity was elevated during weekends and holidays (periods of presumed higher boat traffic) compared to weekdays from Memorial Day weekend to Labour Day weekend, and that erosion rates were high along low energy shorelines, pointing to boating as the likely cause (Bilkovic et al. 2019[3]). Glamore (2008) developed a decision support tool for calculating the relative impact of boat-generated waves compared with wind waves on inland waterways. The tool measures boat and wind waves, and shoreline erosion potential by incorporating information on boating levels, local wind data, and various shoreline characteristics relating to erosion potential (e.g., slope, channel width, upland land use, sediment type) and evaluates management options based on the results (e.g., allow additional boating, manage, or monitor boating, or restrict boating; Glamore 2008).

Measures of anthropogenic influence on a lake or river can serve as proxies of boating pressure. For example, distance to marinas and highways, density of berths at a marina, and number of vehicles parked at access points (e.g., boat ramps, marinas, and community docks) may provide insight into how much boating occurs in an area (Falk et al, 1992, Hall et al. 2016, Hansen et al. 2019). Greater lake accessibility, lake size, and shoreline development (measured by dock density) were all associated with higher levels of recreational boating in a survey of 643 lakes across Ontario (Hunt et al. 2019). Fishing related boating was higher at large lakes with tourism establishments (e.g., fishing lodges) and at lakes with greater walleye (*Sander vitreus*) biomass and lower at lakes within provincial or federal parks.

A summary of potential indicators is found in Appendix A.

[3] *A turbidity index was developed for this study to control for other environmental variables (such as sediment sources, storms, and tidal flow) that could affect turbidity measures, in which the relative change in turbidity between weekends and weekdays was compared.*

6. Management of Boating Impacts

Recreational boating pressures can be managed through a variety of tools to reduce negative impacts on watershed health (Table 3). Shallow nearshore habitat (generally less than 3 m water depth) and shorelines not exposed to high winds (generally less than 300 m of open water) are most sensitive to the physical, chemical, and biological impacts of boating, and thus protective efforts tend to focus on these areas (Asplund 2000). Common approaches include restrictions or prohibitions on boating during sensitive periods (e.g., fish spawning and wildlife nesting seasons) or in sensitive areas (e.g., critical turtle or damselfly/dragonfly habitat), speed limits, low speed periods, and no-wake zones (Klessig 1994, Asplund 2000, Beachler and Hill 2003, Doshi 2006). Lake size thresholds may also be appropriate, relating to total area and depth (Klessig 1994). For example, Mosisch and Arthington (2004) recommended that inland lakes in Australia should be at least 10 ha to handle powerboats, and at least 50 ha for water-skiing. No-wake zones may be more effective than outright speed limits and should be based on both water depth and maximum depth of plant growth, rather than just on a fixed distance from shore (Asplund 2000). Boating activity can be further managed by limiting public access (e.g., reducing parking spaces at marinas and boat launches), enacting land use zoning to limit high-density shoreline development, and applying recreational carrying capacity limits (Doshi 2006, Township of Seguin 2022).

Table 3. Summary of recommended management practices for recreational boating.

Tool	Role	Application	Source
No-wake zones	Slow boats and direct to other areas to avoid stirring up sediments, shoreline erosion, and disturbance of plants and animals in the sensitive nearshore	• Based on maximum depth of aquatic vegetation growth • Minimum 1.8 m water depth and minimum 30 m width from shore • Deeper zone may be warranted if tops of plants are within 1.5 m of surface or if fine sediments are present	Asplund 2000
Restricted areas or periods	Protect sensitive areas such as waterbird breeding habitat, turtle basking habitat, fish spawning or nursery areas, or emergent or floating-leafed plant beds	• Restrictions on motorized boats only or on all watercraft • Implemented for an area at all times or during	Doshi 2006

Tool	Role	Application	Source
		sensitive periods (e.g., during time of day or certain months)	
Speed limits	Slow boats and direct to other less sensitive areas	• Restrictions on boat speeds in certain areas (e.g., close to shore, swimming areas, or narrow channels)	Doshi 2006
Size thresholds	Prohibit motorized watercraft	• Lakes must be a certain size or depth for motorized activity (e.g., 10 ha for motorboats, 50 ha for water-skiing)	Klessig 1994, Mosisch and Arthington 2004
Limits to public access	Limit boating activity levels	• Set maximum number of parking spaces or public access points	Klessig 1994, Doshi 2006
Land use zoning	Limit boating activity levels	• Limit high density shoreline development	Doshi 2006
Enforcement and education	Ensure existing regulations are enforced and that public understands boating impacts and the importance of protecting natural shorelines, littoral zones, and aquatic ecosystems	• Monitoring of lakes and rivers by enforcement officers • Public education campaigns	Asplund 2000
Technology	Improve motors so they are more efficient, cleaner, and less noisy	• Innovations to improve two – and four-stroke engines	Asplund 2000

Waters in the Muskoka River Watershed are subject to a variety of recreational boating policies, programs and initiatives aimed at protecting the environment. Transport Canada provides guidance on reducing environmental impacts, including pollution, spread of invasive species, and shoreline erosion through its *Safe Boating Guide* (Transport Canada 2019). Boating Ontario[4] runs the Clean Marine Program in the province, which promotes environmental stewardship in recreational boating to minimize water, air, and

[4] *Boating Ontario. Clean Marine Program: https://www.boatingontario.ca/cpages/clean-marine-program*

land pollution through public education, certification of marinas, and best business practices. Other provincial organizations, such as the Federation of Ontario Cottagers' Associations and the Federation of Anglers and Hunters educate boaters on combatting invasive species (e.g., through Clean, Drain and Dry campaigns) and reducing nearshore wake (e.g., through Be #WakeAware). The Province of Ontario has a speed limit of 10 km/h within 30 m of shore on all waters (with some exceptions for recreational towing, narrow rivers, canals and buoyed channels, and areas with a different speed limit; Transport Canada 2019). Individual waters may have specific restrictions or prohibitions on boating type and activity, which are laid out in the Vessel Operation Restriction Regulations under the Canada Shipping Act, 2001. Many municipalities in Muskoka have enacted noise bylaws for boat exhaust systems.

The Township of Seguin has implemented a recreational carrying capacity policy into its Official Plan, which considers lake size, number of units surrounding the lake, and existing public access points (Township of Seguin 2022). The policy applies a density of one residential unit for every 1.6 ha net lake surface area (net lake surface area is taken as total surface area minus the area within 30 m of the shoreline) and one tourist accommodation unit for every 0.8 ha net lake surface area. Development may be permitted on over-capacity lakes less than 40 ha surface area, on the grounds that recreational boating impacts on smaller lakes may be less than on larger waterbodies.

To be truly effective, policies should ensure that the enjoyment of aesthetic and recreational opportunities and the operation of economic opportunities can occur, while preserving ecological integrity and maintaining public safety. Klessig (1994) suggested that recreational use of lakes be viewed as a type of pressure analogous to phosphorus loading, but as people loading instead, stating that "*A crowded lake where many potential users have their experience diminished by the presence and behaviour of other users is the equivalent of a eutrophic lake*" (p. 69). Just as load restrictions are applied to highways, Klessig (1994) recommended that we consider load limits for lakes to protect ecological and sociological carrying capacity. This sentiment seems to be echoed in a recent survey of lake users in the Muskoka and Georgian Bay regions. More than 66% of respondents felt that boat traffic, boat noise, and impacts of boat wakes had all increased over the past five years. Over 70% of those surveyed supported no-wake zones to protect wildlife and people in sensitive areas, and 90% believed we have a responsibility to preserve the natural states of our lakes for future generations (Spears and Seydegart 2021).

7. Summary and Conclusions

Recreational boating is a popular pastime across Canada, including in the Muskoka River Watershed, but the impacts of boating have not been widely studied compared to other stressors. Boating causes diverse, multi-faceted, and cascading impacts on the natural environment, which are influenced by multiple factors including boat characteristics, type of activity, water depth, shoreline vegetation, and sediment composition. Recreational boating in lakes and rivers can lead to deterioration of water quality, bank erosion, introduction of invasive species, damage to aquatic vegetation, and disturbance of wildlife populations (Mosisch and Arthington 2004).

Boating impact assessments are often used to determine whether lakes are at their carrying capacity (often measured as recreational, not ecological capacity) and whether they can sustain additional boating activity. The concept of carrying capacity is difficult to quantify, and influenced by site-specific factors, as well as

perceptions of those using lake resources. Space standards, which are applied to different types of boats and boating activities, combined with measures of boating levels, are useful in revealing patterns of use, but this information needs to be explicitly tied to impacts on watershed health. For example, boating activity concentrated in large open areas of lakes will have fewer negative impacts on the environment than activity concentrated closer to shore.

Recreational boating has a myriad of physical, chemical, and biological impacts on the environment, but identifying indicators to track its impacts is challenging. In particular, boating may be one of many sources contributing to environmental degradation, and disentangling cumulative effects can be complicated (Asplund 2000, Byrnes and Dunn 2020). For instance, no systematic approach to quantifying the contribution of boat-generated waves to shoreline erosion exists, although a decision support tool for comparing the relative contribution of boat vs. wind waves may be a useful method (Glamore 2008, Bilkovic et al. 2019). Furthermore, how boat-generated waves interact with natural waves, and their effect on sediment transport and aquatic vegetation is not well understood, especially for lakes of different sizes, depths, and with varied shoreline features (Marr et al. 2022). Similarly, little is known about the cumulative effects on water clarity of boats in addition to external factors, such as shoreline development, watershed runoff, and storms (Asplund 2000). Many boating impacts appear to be transient or localized, although longer term research is needed to confirm whether lasting or chronic effects exist (Asplund 2000). Some effects are obvious (e.g., noise, sediment re-suspension, erosional effects) while others are more subtle and may only be detected after prolonged boating activity (e.g., hydrocarbon accumulation in sediment, re-suspended sediments clogging aquatic insect and fish gills; Mosisch and Arthington 2004).

Macrophyte abundance, turbidity, total suspended solids, and bank erosion have been documented to change in response to boat traffic, suggesting that they may serve as useful indicators of boating impacts (Adams 1993, Johnson 1994, Asplund 2000, Hansen and Snickars 2014, Hall et al. 2016, Hansen et al. 2019). Measurement of these parameters may require comparison of conditions at reference (undisturbed) vs. affected sites, and during peak vs. non-peak boating periods, and boating vs. non-boating season. Indirect proxies of boating activity may also reflect impacts on the environment (e.g., distance to marinas and highways, density of berths at marinas, density of docks on a lake, number of access points on a lake).

Various management approaches have been implemented in lakes and rivers to minimize negative effects of recreational boating. These include no-wake zones, speed limits, restricted areas or periods, size thresholds, limits to public access, limits to shoreline development (although public boat launches are always available), and land use zoning. Monitoring boating indicators could help to evaluate the effectiveness of these management practices. However, even if indicators are used to quantify boating activity so that it can be managed to protect watershed health, the overall carrying capacity of lakes and rivers in Muskoka will also be influenced by other associated water-based recreational activities that need to be considered as well, including onshore activities (e.g., picnicking, sightseeing, hiking; Mosich and Arthington 2004).

Boating impacts on the environment are well documented but separating the effects of boating from other stressors (e.g., shoreline development, storms, wind, runoff) is particularly difficult. Consequently, there are no clear indicators that have been used to reliably monitor the impacts of recreational boating on watershed health. A few parameters offer promise for tracking boating effects, but considerable background study will be required to establish baseline conditions (i.e., in non-boating conditions), acceptable

thresholds, and desired targets. Ultimately, this information could be used to determine the ecological carrying capacity of lakes and rivers in Muskoka, which could then be used to manage shoreline development and boating activity. In the meantime, management tools are available to lessen impacts, and these should be applied to lakes and rivers based on site-specific characteristics and recreational pressures.

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Appendix A. Spreadsheet Summary

Grey Literature							
Title	**Authors**	**Year**	**Source**	**Impact**	**Indicator**	**Targets**	**Notes**
Recreational Boating: Freshwater and Foreshore, All Seasons	BC Ministry of Environment, Ecosystems Branch	Undated	https://www.env.gov.bc.ca/wld/twg/guidelines/boating.html		Water Quality	No changes over time caused by boating activities	
					Visible garbage along shorelines	No garbage along shorelines caused by boating activities.	
				Degradation of water quality	Changes to aquatic communities resulting from water quality changes.	No changes to aquatic communities caused by boating activities.	
					Water turbidity	No net change in turbidity caused by boating activities.	
				Bank erosion and siltation	Bank erosion	No increase in bank erosion caused by boating activities.	
				Introduction and spread of invasive species	Presence/absence of invasive species in waterways	No spread of invasive plants to new waterways caused by boating activities.	
				Physical damage to aquatic plant communities	Damage to rooted vegetation	No long-term damage to integrity of aquatic vegetation caused by boating activities.	
				Damage to sensitive sites	Damage to sensitive sites	No vegetation damage in sensitive sites caused by boating activities.	Sensitive sites = include habitats of rare and endangered wildlife species, nesting, and other breeding sites, rare plant communities and ecosystems that are easily damaged and/or slow to recover from disturbances, including riparian areas and wetlands
				Direct disturbance of wildlife (e.g. physiological and behavioural disruption, displacement from preferred habitats, direct mortality, habituation/sensitization	Proportion of encounters resulting in alarm response	No increase in rate of alarm responses over time caused by boating activities.	Alarm response = movement by animals, usually to safer locations
					Population abundance and distribution trends of wildlife species	No abandonment of habitats caused by boating activities.	
				Damage to fish populations and habitat			
				Special management of sensitive species (Harlequin Ducks)	Population abundance and distribution trends of species on stream reaches	No population decline or abandonment of stream reaches caused by boating activities.	
Managing Nonpoint Source Pollution from Boating and Marinas	US Environmental Protection Agency	Undated	https://archive.epa.gov/water/archive/web/html/point9.html#:~:text=Using%20a%20drop%20cloth%2C%20cleaning,chemical%20substances%20from%20entering%20waters	High toxicity in the water			
				Increased pollutant concentrations in aquatic organisms and sediments			
				Increased erosion rates			
				Increased nutrients, leading to increase in algae and decrease in oxygen (eutrophication)			
				High levels of pathogens			
				Physical destruction of sensitive ecosystems and bottom-dwelling aquatic communities (marina construction)			
Pollution Impacts from Recreational Boating: A Bibliography and Summary Review	Milliken, A. S. and V. Lee	1990	NOAA Office of Sea Grant, US Department of Commerce	Boat sewage	Biological oxygen demand (BOD)		marine focus
				Engine pollution			
				Antifouling paints			
				Plastic debris			
Recreational Boating on Delaware's Inland Bays: Implications for Social and Environmental Carrying Capacity	Falk, J., A. Graefe, E. Drogin, J. Confer, and L. Chandler	1992	Inland Bays Estuary Program, Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, University of Delaware		Number of vehicles parked at boat ramps, marinas, and residential community docks		
					On-water counts of boats passing fixed location		Impacts influenced by types of activity, type of equipment, size of group, behaviour
					Submerged aquatic vegetation		
					Dissolved oxygen		
					Turbidity		
					Loss of wildlife habitat (e.g., waterfowl nesting or fish nursery areas)		
Recreational Boating Impact Investigations - Upper Mississippi River System, Pool 4 Red Wing, Minnesota. Special Report 94-S004	Johnson, S.	1994	National Biological Survey	Shoreline erosion	Shoreline erosion assessment		
				Reduction in light penetration	Total suspended solids, turbidity		
				Disturbance of rooted aquatic plants, benthic organisms, fish, mammals, turtles, birds			
The Effects of Motorized Watercraft on Aquatic Ecosystems	Asplund, T. R.	2000	PUBL-SS-948-00	Sediment resuspension	Water clarity (e.g., Secchi disk depth, turbidity, colour, suspended solids, light extinction, chl-a [as measure of amount of algal growth])		impact of boating on water clarity vs other factors (e.g., shoreline development, watershed runoff, storm events etc.) not well known
				Water pollution	Water quality (metals, hydrocarbons, other pollutants)		studies suggest that amount of pollution from boats small in relation to overall lake volume, most hydrocarbons volatile and quickly disperse
				Disturbance of fish and wildlife			
				Destruction of aquatic plants	Submerged plant biomass		negative relationship between biomass and boat traffic due to direct cutting and uprooting of plants, scouring of sediment, increased wave action, but most research on rivers, not lakes

Title	Authors	Year	Source	Impact	Indicator	Targets	Notes
				Shoreline erosion			
				Invasive species			
Appendix G: Selecting Indicators of Watershed Health	City of Portland	2005	Framework for Integrated Management of Watershed Health	Harassment of salmon (e.g., lights from docks, noise from boats, in-water construction, human	Boat traffic (number of boats/day, large and small)		
					In-water decibels		
A Decision Support Tool for Assessing the Impact of Boat Wake Waves on Inland Waterways	Glamore, W. C.	2008	University of New South Wales	Shoreline erosion			Decision Support Tool to assess impact of boat wake waves along stretches of inland waterways
							Tool enables quantitative determination of boat wave impacts on shorelines, and based on how sensitive shoreline is to erosion, this information can be used to determine whether boats should be restricted, managed, or allowed
							Compares natural background wind-wave energy with boat-generated wave energy, incorporating information on the operating frequency of boats and the erosion potential of the shoreline
Deep Creek Lake Baseline Assessment Report	Kelsey, R. H. and S. L. Powell	2011	EcoCheck (NOAA-UMCES Partnership)		Boat density		Either no data or no established metrics for evaluating the desired boating indicators
					Sedimentation rates in shallow headwater areas		
				Negative impacts on boating access	Aquatic grasses throughout lake		
				Negative impacts on boating experience	Safety (e.g., # of boating safety violations, reported incidents of accidents, complaints, arrests)		
A Field Study of Maximum Wave Height, Total Wave Energy, and Maximum Wave Power Produced by Four Recreational Boats on a Freshwater Lake	Marr, J., A. Riesgraf, W. Herb., M. Lueker, J. Kozarek, and K. Hill	2022	St. Anthony Falls Laboratory, Health Waters Initiative, Minneapolis, Minnesota, SAFL Project Report No. 600	Shoreline erosion			Examined wave conditions of 2 non-wakesurf and 2 wakesurf boats under different conditions (speed, ballast weight, trim setting etc.) and distance from shoreline
				Impacts to aquatic vegetation			Max wave heights, total wave packet energy, and max wave poser greatest under wakesurfing/largest possible wake operation for all boats
				Sediment resuspension			Wave parameters smallest for all boats under planing conditions
				Lake water quality			Wake-surfing boats produced largest waves under all conditions
							Full ballast tanks had minor impacts on wake wave characteristics
							Under typical wakesurfing conditions, wakesurf boats require distances > 152 m to attenuate wake wave characteristics to levels comparable to non-wakesurf boats under typical planing conditions
							Propeller wash impacts not well studied (e.g., on thermocline, lake bottom, vegetation, aquatic habitats)
							Cumulative effects of boat-generated and natural waves on sediment transport, aquatic veg not well studied

Peer-reviewed Literature							
Title	**Authors**	**Year**	**Source**	**Impact**	**Indicator**	**Targets**	**Notes**
Environmentally sensitive predictors of boat traffic loading on inland waterways	Adams, C. E.	1993	Leisure Studies 12(1): 71-79	turbulence	Consumption Index considers size and speed of boat combined with movement pattern and density to calculate space consumed by craft per unit time		focus on boat characteristics, behaviour and use impacting aquatic ecology and leisure amenity on Loch Lomond
				visual and noise disturbance			inverse relationships: boat traffic vs. abundance of aquatic plants, boat traffic vs. water quality
				aquatic pollution (fuel spillage, exhaust emission, bilge pumping, sewage discharge)			
Stirring up trouble? Resuspension of bottom sediments by recreational watercraft	Beachler, M. M. and D. F. Hill	2003	Lake and Reservoir Management 19(1): 15-25	fuel and exhaust emissions			
				noise pollution			
				direct contact with plants and animals			
				hydrodynamic impacts (e.g., wake-induced shoreline erosion and turbulent prop wash)			
Impacts of recreational power-boating on freshwater ecosystems	Mosisch, T. D. and A. H. Arthington	2004	Environmental Impacts of Ecotourism	wave action (bank erosion, damage to aquatic plants)			lake carrying capacity influenced by (i) on-water activities (e.g., power-boating, water-skiing etc.), (ii) contact activities (e.g., swimming), and (iii) littoral activities (e.g., hiking, picnicking etc.)
				turbidity			
				direct boat contact (propellers, hull)			
				noise and visual disturbance			
				fuel and oil spills, exhaust fumes			
				spread of aquatic plants			
				land impacts (e.g., increased car traffic, garbage, trampling)			
Impact of recreational power boating on two populations of northern map turtles (*Graptemys geographica*)	Bulté, G., M-A. Carrière and G. Blouin-Demers	2010	Aquatic Conservation: Marine and Freshwater Ecosystems 20: 31-38	propeller injuries			
				disturbance during reproduction			
				interference with intraspecific sound communication			
				physiological disturbances			
				altered auditory sensitivity			
The direct physical, chemical and biotic impacts on Australian coastal waters due to recreational boating	Burgin, S. and N. Hardiman	2011	Biodiversity and Conservation 20: 683-701	Physical: turbulence, anchoring/drag, noise/interference/collision impacts on wildlife			Challenge detecting and measuring impacts because (i) aquatic environments lack clear boundaries, (ii) impacts may be from multiple sources (e.g., boating, swimming, fishing), (iii) impacts may be localized or dispersed
				Chemical: pollution from fuel and oil, defouling treatments, sewage discharge			Intensity of direct physical impacts influenced by boat speed, wave height, soil type, riparian vegetation density, root depth; severity of turbidity also affected by hull design, motor power output, sediment composition (e.g., clay stays suspended longer than larger particle-sized sediment)
				Biotic: introduction and spread of invasive species			
Applying macrophyte community indicators to assess anthropogenic pressures on shallow soft bottoms	Hansen, J. P. and M. Snickars	2014	Hydrobiologia 738: 171-189		Macrophyte community index	Reference condition = what ecosystem would be without any human influence, e.g. most sensistive macrophytes associated with undisturbed conditions should be present	Developed macrophyte community index and tested in response to eutrophication and boating activity in North Baltic Sea; also considered natural gradients in topographic openness, depth, and salinity
					Turbidity		Macrophyte index (proportion sensitive vs. tolerant spp.) decreased with increasing P concentration, turbidity, and boating activity

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					Number of boats/bay ha		Macrophytes are useful for assessment of environmental quality because stationary, persist over many years (integrating long-term conditions), different species have differential tolerances to human activities and pollution
					Distance from boating route/ferry traffic		
					Signs of dredging		
					Presence of natural harbour		
Impacts of recreational motorboats on fishes: a review	Whitfield, A. K. and A. Becker	2014	Marine Pollution Bulletin 83: 24-31	Direct physical impacts: fish strikes by hulls and propellers			Little information about impacts of propellers on sensitive fish larvae, especially at night when they may be concentrated at surface
				Pressure wave disturbance: displacement of fish schools as boats move by			
				Sound disturbance: hinder sound communication, disturb larval fish			
				Behavioural alteration: avoidance			
				Chemical impacts: exhaust, fuel spills, antifouling paints	Lead		Increasing lead levels = potential indicator of pollution by outboard motors, especially where lead is a fuel additive
				Introduction and spread of invasive species			
				Habitat alteration: boat wave wash on banks and littoral habitats			
Recreational boating, landscape configuration, and local habitat structure as drivers of odonate community composition in an island setting	Hall, A. M., S. J. McCauley, and M-J Fortin	2016	Insect Conservation and Diversity 8: 31-42	Water quality	Marina dock space		Indicators measured relative to odonate aquatic habitat (i.e., water distance to each of 4 marinas, average water distance to all 4 marinas, distance to nearest boating channel, distance of marinas to highway, length and % of shoreline exposed to waves)
				Damage or disturbance of plants and animals	Proximity to marked boating channels		Main boating impacts for odonates likely direct and indirect effects of increase in magnitude and frequency of waves, causing direct dislodgement of larvae and emerging adults, and altering abundance of vegetative cover
				Transport of invasive species	Proximity to major highway		Found that habitats farther from marinas had increased floating vegetative cover, likely because fewer boat-generated waves
					Frequency of boats		
					Speed of boats		
Does motor noise from recreational boats alter parental care behaviour of a nesting freshwater fish?	Maxwell, R. J., A. J. Zonderdo, R. de Brujn, J. W. Brownscombe, E. Staaterman, A. J. Gallagher, and S. J. Cooke	2017	Aquatic Conservation: Marine and Freshwater Ecosystems 28: 969-978	Changes in nest-guarding behaviour			Effect was transient (limited to when noise present)
Defining boat wake impacts on shoreline stability toward management and policy solutions	Bilkovic, D. M., M. M. Mitchell, J. Davis, J. Herman,	2019	Ocean and Coastal Management 182: 104945	Erosion of coastlines	Bank erosion rate		Impacts pronounced in narrow waterways

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	E. Andrews, A. King, P. Mason, N. Tahvildari, J. Davis, and R. L. Dixon			Turbidity	Nearshore turbidity		3 lines of evidence that boat waves contributing to shoreline erosion and poor water clarity in some creeks and tributaries of Chesapeake Bay: 1. nearshore turbidity elevated during periods of expected high boating activity 2. armoring placed along ~25% of low energy shorelines exposed to relatively high boating pressure for 3 tidal creeks examined 3. 15% of shorelines examined throughout Chesapeake Bay are low energy shorelines but subject to high erosion ($\geq$ 0.3 m/yr) not attributable to wind wave energy
Recreational boating degrades vegetation important for fish recruitment	Hansen, J. P., G. Sundblad, U. Bergström, Å. N. Austin, S. Donadi, B. Klemens Eriksson, J. S. Eklöf	2019	Ambio 48: 539-551	Reduced aquatic vegetation cover (which is important habitat for juvenil fish)			Study conducted in Baltic Sea
							Found that marinas had lower vegetation cover and height, and different species composition of fish vs. control areas, and stronger effect with increasing berth density
							Found clear positive relationship between vegetation cover and fish abundance
Predicting spatial patterns of recreational boating to understand potential impacts to fisheries and aquatic ecosystems	Hunt, L. M., D. M. Morris, D. A. R. Drake, J. D. Buckley, and T. B. Johnson	2019	Fisheries Research 211: 111-120	Physical site disturbance	Density of docks		Recreational boating activity greater on lakes with more human development (measured by density of docks)
				Chemical impacts: exhaust, fuel spills, antifouling paints	Lake accessibility		Boat fishing greater at large lakes w/ tourism establishments and walleye biomass densities, and less in lakes in parks
				Impact of boating related infrastructure (e.g., marinas, locks, dams, jetties, docks etc.)	Lake size		
				Movement of invasive species	Walleye biomass density		
Comparison of aquatic invertebrate communities in near-shore areas with high or low boating activity	Smith, B. J., S. R. Chipps, J. D. Grote, J. Mecham, T. M. Stevens and T. Rapp	2019	Journal of Freshwater Ecology 34(1): 189-198		Location and size of boat ramp access		Found no difference in macroinvertebrate assemblages between high and low use boat ramps at 5 glacial lakes in South Dakota
					Number of parking spaces at boat launch		Regional environmental variability (climate, habitat, water quality) may play greater role in structuring macroinvertebrate communities than relatively small-scale disturbance associated with boating activity
					Presence/absence of infrastructure facilities at boat launch		Macroinvertebrate assemblages in this area already characterized by low diversity and tolerant taxa
					Macroinvertebrate abundance and diversity		Conclude that in study area, macroinvertebrates may be poor indicators of shoreline disturbance due to boating
Boating- and shipping-related environmental impacts and example management measures: a review	Byrnes, T. A. and R. J. K. Dunn	2020	Journal of Marine Science and Engineering 8: 908. Doi: 10.3390/jmse8110908	Physical: anchoring and mooring activities; groundings, wrecks, abandonments; collisions and disturbances to wildlife; garbage and debris; propeller wash and vessel wake			Can be difficult to attribute effects to boating where there are multiple activities or human inputs
				Chemical: antifouling agents; gas emissions; hydrocarbons; sewage			
				Biological: invasive species; light pollution			

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Effects of boat traffic and mooring infrastructure on aquatic vegetation: A systematic review and meta-analysis	Sagerman, J., J. P. Hansen, S. A. Wikström	2020	Ambio 49: 517-530	Reduced light penetration (docks)			Docks and buoys often placed in sheltered areas which are also most suitable areas for submerged vegetation
				Scoured areas (mooring buoys due to chains dragging)			
				Propeller scarring (shallow areas)			
				Hull groundings (shallow areas)			
Environmental impacts of increasing leisure boating activity in Mediterranean coastal waters	Carreño, A. and J. Lloret	2021	Ocean and Coastal Management. 209: 1-13	Anchoring			Developed recreational boating impact rating system based on system used for recreational fishing
				Collisions			Assessment criteria: -severity of impacts -spatial scale of impact and management activities -impact probability -reversibility -complexity or difficulty of management measures to mitigate
				Sediment resuspension			
				Noise disturbance			
				Air pollution			
				Fuel and oil leaks			
				Antifouling paints			
				Transport of invasive species			
				Artificial lights			
				Grey water			
Relative importance of recreational boat wakes on an inland lake	Houser, C., A. Smith, and J. Lilly	2021	Lake and Reservoir Management 37(3): 227-234	Boat wakes: shoreline erosion and turbidity			Boat-generated waves depend on water depth, vessel design (length and hull shape), speed of vessel, amount of displacement, + presence of natural wind waves currents and other vessel-generated waves
							Hull type and boat speed influence wave height: largest waves from displacement hulls that sit in water
							Typical recreational boats have planning hulls- at low speed sit in water, at higher speeds sit on top of water (thus generating less wave)
							Larger wakes for boats towing skiiers, tubes, wakeboards vs. not towing
							Wakes may represent significant source of energy along sheltered shorelines
The impact of recreational activities on species at risk in Canada	Rosenthal, J. R. Booth, N. Carolan, O. Clarke, J. Curnew, C. Hammond, J. Jenkins, E. McGee, B. Moody, J. Roman, K. Rossi, K. Schaefer, M.	2022	Journal of Outdoor Recreation and Tourism 40: 1000567	Trampling at access points			
				Increased sedimentation, siltation, turbidity, erosion			
				Disturbance to wildlife			
				Collision with aquatic organisms			
Research note: Recreational boating, sewage production, and potential implications for phosphorus loading in Lake Champlain	Stepenuck, K. F., E. D. Roy, K. Helmer, and J. Sleigh	2022	Journal of Outdoor Recreation and Tourism 39: 100551	Improperly disposed boater-generated sewage			Sewage contribution to lake estimated to berelatively small (<0.01% of annual phosphorus load i.e., 7-73 kg/year) but potential for pathogen contamination
							Recommend funding for marinas to operate and maintain adequate pumpout facilities, and educational material and messaging to encourage use by boaters