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Environmental Sciences Ltd.

Watershed Health Indicators – Muskoka River Watershed

Comprehensive Summary Report

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

September 23, 2022

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September 23, 2022 HESL Job #: J220004

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

Dear Glenn:

Re: Final Comprehensive Summary Report for the Watershed Health Indicators – Muskoka River Watershed Project

We are pleased to submit the Final Comprehensive Summary Report for the Watershed Health Indicators – Muskoka River Watershed Project. The report summarizes the results of our review and analysis of, and consultation on, what metrics should be used to document current watershed health and monitor watershed changes over time, and incorporates comments received by the District and Community Round Table on our August 2022 draft report.

We thank you for the opportunity to undertake this interesting and important assignment. 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 Muskoka River Watershed is recognized as a “jewel to be protected” because of its rugged natural beauty and many pristine lakes, rivers, forests, wetlands, and rock barrens. Compared to watersheds to the south, which are dominated by urban and agricultural landscapes, the Muskoka River Watershed retains large expanses of natural areas. The health of the watershed is critical to protect not only for its own intrinsic value, and because it supports rich biodiversity (including many species at risk), but also because a well-functioning watershed provides many important ecosystem goods and services humans depend on, including regulation of water flow, soil formation, carbon storage, and nutrient cycling. The vast forests and clean lakes that characterize Muskoka are also a major tourism attraction, and tourism is a major economic driver in the region. Degrading or destroying this natural jewel is thus counterproductive on many levels.

Before we can adequately protect the watershed, we need to understand its current condition, what elements are changing, and why. Watershed indicators are effective tools for documenting watershed health because they provide a simplified approach to describing an inherently complicated system, acting as surrogates or proxies of multiple watershed features and functions that are more difficult or impossible to quantify. Tracking watershed health depends on determining baseline conditions (so that change over time can be measured) and identifying targets (to measure progress toward a goal) and thresholds (to warn of the need for management action). Watershed indicators selected for use should be measurable, comparable, consistent, and relevant to the watershed being monitored, as well as

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

We sought to identify indicators best suited to the Muskoka River Watershed based on the above criteria and a review of

- existing knowledge of the health of the Muskoka River Watershed,
- approaches to measuring watershed health used by other jurisdictions,
- priority environmental, economic, and social issues and management goals identified by local community members and scientific experts.

Our review identified a range of indicator types, encompassing physical, chemical, biological and socio-economic attributes of watersheds. Inclusion of a broad array of indicators from across these categories will provide a comprehensive picture of watershed health that more accurately captures the dynamics and complexity of the system, and the stressors acting on it.

The key natural features that define the Muskoka River Watershed are water, forest, wetlands, and biodiversity. Climate change and development are the overarching stressors influencing these natural features and their ecological functions, manifested through the additional (and interactive) pressures of algal blooms, road salt, calcium decline, invasive species, biodiversity loss, habitat loss and fragmentation, and land use change. Monitoring of watershed health should thus attempt to encompass the main environmental components of the watershed, and the main environmental stressors.

Based on our assessment of watershed conditions and priority issues, and review of approaches used elsewhere, we generated a longlist of 29 watershed indicators. We divided the indicators into two main categories: Ecological Status and Threats to Ecological Status. We identified 14 indicators under Ecological Status, representing Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), and Landscape Condition. We identified 15 indicators under Threats to Ecological Status, representing Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects. We provided guidance on how to monitor the watershed indicators and recommended that the longlist be narrowed down to a shortlist of priority indicators through consultation with the Community Round Table, local scientific experts, and other stakeholders.

We conclude our report with 21 recommendations for monitoring watershed health in Muskoka, relating to the identification of a shortlist of indicators, reconciliation with local Indigenous communities, outreach and public education, collaboration, funding and support, citizen science, research on indicators, targeted monitoring, and archiving of samples.

List of Abbreviations

CBR	Criteria-based ranking
CCME	Canadian Council of Ministers of the Environment
CRT	Community Round Table
DESC	Dorset Environmental Science Centre
DOC	Dissolved organic carbon
eDNA	Environmental DNA
ENMs	Engineered nanoparticles
GCMs	Global climate models
IBI	Index of Biotic Integrity
IPCC	Intergovernmental Panel on Climate Change
IWM	Integrated Watershed Management
LRCA	Lakehead Region Conservation Authority
MECP	Ministry of Environment, Conservation and Parks
MNRF	Ministry of Natural Resources and Forestry
MRWIP	Muskoka River Watershed Inventory Project
MWAG	Muskoka Watershed Advisory Group
MWC	Muskoka Watershed Council
NBMCA	North Bay – Mattawa Conservation Authority
PFAS	Per- and polyfluoroalkyl substances
PGMN	Provincial Groundwater Monitoring Network
PWQMN	Provincial Water Quality Monitoring Network
RPS	Recovery Potential Screening
SOLRIS	Southern Ontario Land Resources Information System
USEPA	US Environmental Protection Agency

VECs	Valued Ecosystem Components
WISKI	Water Information Systems software by KISTERS

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Integrated Watershed Management (IWM) is increasingly being recognized as an effective way to sustainably manage human activities and protect the natural environment. IWM takes a holistic approach to environmental management and land use planning, incorporating environmental, social, and economic considerations into a continuously adaptive process. It provides a science-based framework for community planning and decision-making, which acknowledges that ecosystem features and functions are complex, inter-connected, and best addressed at meaningful ecological scales, such as watersheds[1], rather than based on political boundaries. IWM further acknowledges that watershed health[2] is influenced by a dynamic interplay of environmental (e.g., water quality, biodiversity etc.) and socio-economic (e.g., human health, economic activities) factors. Promoting watershed health thus requires a collaborative process, which depends on participation from a broad cross-section of society, so that community interests and concerns are fully represented, and inform the identification of issues, goals, and actions, and the subsequent implementation of plans and strategies.

In 2020, the Muskoka Watershed Council (MWC) released a report entitled *The Case for Integrated Watershed Management in Muskoka* (Sale et al. 2020), recommending that IWM be applied to all aspects of environmental management and land use planning in the Muskoka River Watershed. The report emphasized that IWM was particularly needed to address climate change in the watershed, which, among other impacts, has led to more variable water flow both spatially and temporally, challenging traditional approaches to flow regulation. The report illustrated the iterative adaptive management nature of IWM (Figure 1).

In 2021, the Province of Ontario provided funding to the District to support a series of IWM initiatives to reduce the impacts of flooding in, and protect the health of, the Muskoka River Watershed. The following twelve projects were identified for funding:

- Develop a baseline hydrological model for the watershed,
- Examine infrastructure flood mitigation approaches for flood-prone areas,
- Expand floodplain mapping,
- Undertake a natural capital inventory,
- Identify the data and information needed to support potential changes to water management plans,
- Examine watershed-scale flood mitigation options,
- Review land use policy to improve consistency and watershed-scale approaches,
- Identify areas of shoreline erosion and strategies to remediate and limit shoreline damage,
- Identify public access points throughout the watershed,
- Conduct a siltation and bathymetry study for the management of sediment at the delta of the Muskoka River entering Lake Muskoka,

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[1] *A watershed is defined as the area of land that drains precipitation to a river, lake, or stream (US EPA 2022).*

[2] *A healthy watershed has the ability to support the biological, physical and chemical features, processes and conditions which naturally occur within it (USEPA 2022).*

- Develop water quality indicators, and
- Develop watershed health indicators.

Figure 1. The IWM iterative process. IWM typically proceeds by describing the watershed, identifying local issues, developing plans and strategies to address those issues, implementing actions locally, monitoring for changes and responses to management actions, and refining or modifying the approach based on monitoring results (from Sale et al. 2020).

1.2 Purpose

The aim of the Watershed Health Indicators project is to support the implementation of IWM through the identification of environmental and ecological metrics for the Muskoka River Watershed, and the development of a plan to use those metrics for monitoring the watershed in the future. The selected watershed health indicators should build on existing information and studies available for the watershed. The Watershed Health Indicators project thus fits into the first two steps of the IWM cycle: "Characterize the System" and "Set Management Objectives" (as presented in Figure 1).

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. The selection of indicators to evaluate watershed health is thus critical. 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 Scope of Work

There are four main components to the project:

- Review of existing information and research on watershed health for the Muskoka River Watershed to document current conditions, and review of indicators used in other jurisdictions to gain an understanding of current metrics used to measure watershed health elsewhere which might be applicable to the Muskoka River Watershed;
- Public consultation with the Community Round Table (CRT) and community members to identify environmental, social and economic goals for the watershed;
- Preparation of a comprehensive summary report of efforts and findings; and
- Presentation of project results to the CRT and Community and Planning Services Committee.

In this report, we present a comprehensive summary of the project research, consultation, and findings, which incorporates feedback from the District and CRT. While the focus of the project is on identifying environmental and ecological indicators for the watershed, such an exercise necessarily requires an understanding of the socio-economic conditions shaping human activity within the watershed as well. Public consultation was thus key to documenting the socio-economic conditions shaping influencing watershed health.

2. Summary of Existing Knowledge of the Health of the Muskoka River Watershed

2.1 Overview of the Muskoka River Watershed

The Muskoka River Watershed is located in central Ontario on the Canadian Shield (Figure 2). It stretches over 5100 km^2, from the headwaters of the Muskoka River in the Algonquin Highlands (on the western slopes of Algonquin Park) to the shores of Georgian Bay, over 200 km to the southwest. The watershed has three main drainage systems: the North Branch and South Branch (which both originate in Algonquin Park and flow southwest, converging south of Bracebridge before discharging to Lake Muskoka) and the Lower Muskoka (which flows from the west, receiving inflow from both the North and South Branches, as well as Lakes Joseph and Rosseau, and flows into the Moon and Musquash Rivers, ultimately discharging to Georgian Bay). The watershed contains over 2000 lakes (occupying approximately 13% of the landscape) and is mainly forested (approximately 66% of land cover), with wetlands (11% of landcover) and rock barrens and outcrops (2% of landcover) being prominent features on the landscape (Muskoka River Watershed Inventory Project [MRWIP] 2007). Much of the watershed is underlain with granitic bedrock from the Canadian Shield, and overlying soils tend to be shallow and sandy (MRWIP 2007).

The watershed lies within Ontario Shield Ecozone Ecoregion 5E (Georgian Bay Ecoregion). At the southern boundary of the Canadian Shield, and the northern boundary of the St. Lawrence Lowlands, the watershed forms part of a unique transitional ecological zone known as the ‘Land Between’, where coniferous forests in the north give way to deciduous forests in the south (Marsh and Dale 2018, Muskoka Watershed Advisory Group [MWAG] 2020). Forests are characterized by mixed hardwood (Maple, Birch, Oak) and coniferous (White and Red Pine, Spruce, Tamarack and Hemlock) tree species. The Land Between ecotone supports rich native biodiversity represented by northern species at their southern limit, and southern species at their northern limit. Aquatic ecosystems support 30 fish species, representing mainly cool- and cold-water fish species, including Walleye, Northern Pike, and Smallmouth Bass (cool-water species) in the lower watershed and Lake Trout, Brook Trout, and Whitefish (cold-water species) in the upper watershed (MWC 2022). A wide variety of wildlife species typical of the Canadian Shield ecozone occur in Muskoka, including almost 50 mammal species (e.g., Moose, White-tailed Deer, Black Bear, American Beaver), more than 250 bird species (e.g., Common Loon, Blue Jay, Broad-winged Hawk, Ruby-throated Hummingbird) and 25 species of reptiles and amphibians (e.g., Eastern Massasauga Rattlesnake, Eastern Hog-nosed Snake, Blanding’s Turtle, Spring Peeper; Muskoka Water Web undated).

The Muskoka River Watershed has a cool to moderate climate and receives relatively large amounts of precipitation compared with other parts of the province (MWAG 2020). Approximately 50% of the precipitation flows through the watershed to Georgian Bay, while the remainder cycles back to the atmosphere through evaporation and transpiration (Sale et al. 2016). Regulation of the large quantity of water moving through the watershed is a critical ecosystem service provided by Muskoka's soils, forests, grasslands, and wetlands (Sale et al. 2020). Water flow within the watershed varies over time and space, influenced by precipitation patterns, soil conditions (mostly shallow), bedrock, vegetation, wetlands, and human modifications to the landscape (Sale et al. 2020).

The Muskoka River Watershed has been inhabited by Indigenous Peoples for thousands of years. The Muskoka region is on the traditional territory of the Anishnaabeg, which includes the Ojibwe, Odawa, and Potawatomi Nations (collectively known as the Three Fires Confederacy). The Huron-Wendat and the Haudenosaunee Nations have also lived in Muskoka. The region is covered by the Williams Treaty (of 1923), the Robinson Huron Treaty (of 1850) and the J. Collins land purchase (of 1785). Today, three sovereign nations are found in Muskoka: Wahta Mohawks First Nation, Moose Deer Point First Nation, and the Moon River Métis (DMM 2021).

European settlement in the Muskoka River Watershed began in the mid to late 1800s, driven largely by the burgeoning forestry industry in the area. Dams were constructed along many waterways to transport timber to sawmills (MWC 2022). Following the peak of timber production in the late 1800s, many of these dams were converted for hydroelectric power production. Today, 10 hydroelectric generating stations are located in the watershed, which are also used by the Ontario Ministry of Natural Resources and Forestry (MNRF) to control and manage water flow on the Muskoka River and the water levels of Muskoka's largest lakes (Sale et al. 2020; MWC 2022).

Settlement since the 1800s has centred around the three main towns in the watershed: Bracebridge, Gravenhurst, and Huntsville, linked by the Highway 11 corridor. Four upper tier municipalities occur within the watershed: the District Municipality of Muskoka (62% of the watershed), the District of Parry Sound (15%), the County of Haliburton (11%) and the District of Nipissing (10%). Approximately 50% of the watershed is Crown land, while 48% is privately owned. The remaining 2% belongs to First Nations and other federal lands (MRWIP 2007).

The watershed has been a popular destination for tourists and seasonal cottagers since the late 1800s and the tourism and recreational sectors are now the primary economic drivers in the region, bringing in $400 million a year to the local economy (MWAG 2020, Government of Ontario 2021). At the same time, however, the region is characterized by marked economic disparities. In 2018, the median employment income for the Muskoka region was 21% below the provincial level and 13% of residents lived below the poverty line (Muskoka Community Foundation 2018). Lack of affordable housing, increasing home prices and the cost of living outpacing household income create considerable challenges for many households in the watershed (Muskoka Community Foundation 2021).

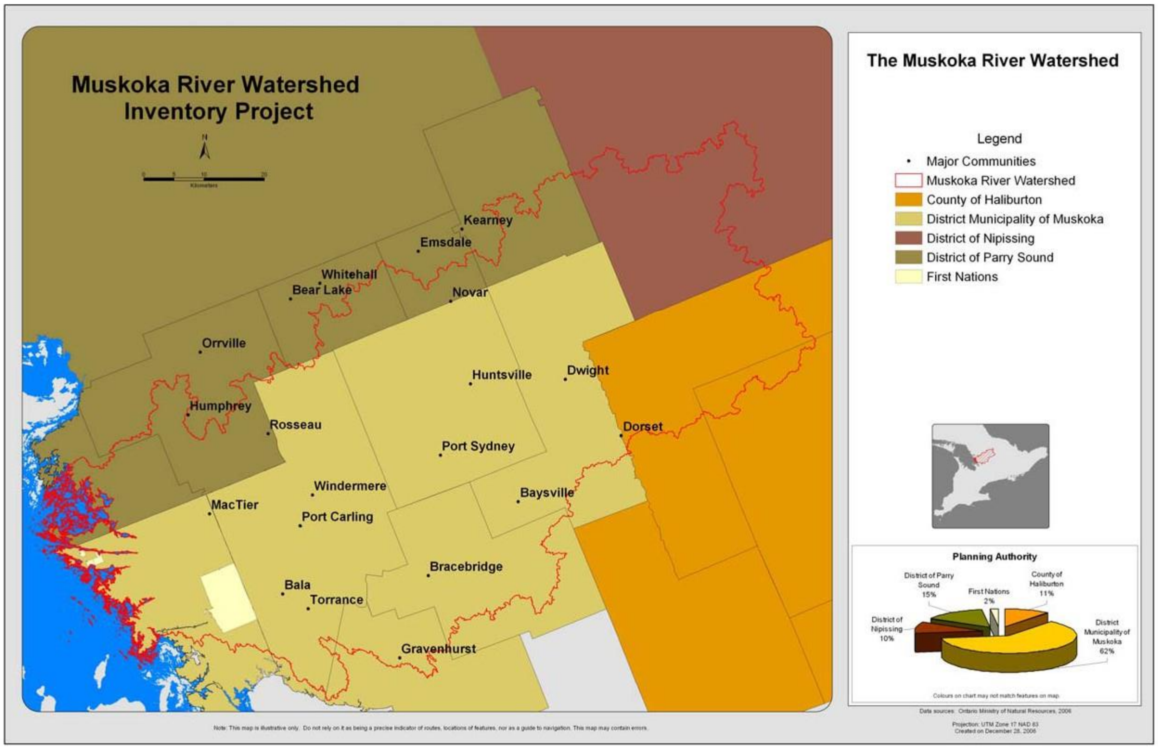

Figure 2. Muskoka River Watershed (from MRWIP 2007).

2.2 Health of the Muskoka River Watershed

The Muskoka River Watershed is recognized as an exceptional part of the province because of its rugged natural beauty and many pristine lakes, rivers, forests, wetlands, and other natural features (MRWIP 2007). Compared to Southern Ontario, where natural areas tend to be islands of green surrounded by non-natural areas, much of Muskoka can be described as "islands of green within a sea of green" (p. 68, MRWIP 2007). Indeed, as of 2005, only 4% of the watershed consisted of developed areas (i.e., settlement areas, agricultural land and golf courses; MRWIP 2007[3]). Unlike more urbanized areas, the Muskoka River Watershed still contains vast expanses of interconnected high quality natural habitat, which support important ecological processes and rich biodiversity (including many species at risk; MWAG 2020). However, the watershed is not immune to anthropogenic stressors, and watershed health is threatened by population growth and associated development pressures, working in conjunction with climate change (Sale et al. 2020).

A considerable amount of environmental research has been conducted in the Muskoka River Watershed relating to watershed health. The following sections provide a summary of recent studies in the area.

2.2.1 The Muskoka River Watershed Inventory Project

The Muskoka River Watershed Inventory Project[4] was initiated in 2005 to identify ecologically significant aquatic and terrestrial ecosystems within the watershed and to determine which areas were under stress due to human activity. Natural areas were identified based on representation, ecological function, diversity, special features, and condition. Under each of these criteria, one or more objectives were used to evaluate the state of the watershed, and a series of indicators were developed to represent each objective (Table 1). Natural features were then scored on each indicator. Criteria were weighted based on their relative importance or significance to the overall score (with ecological function given 60% of the score, diversity 5%, special features 15%, and condition 20%; representation was not scored since it was used to identify ecosystems to evaluate). Natural features were assigned higher scores if they had higher potential for sustaining ecological processes, and lower scores if they had limited potential to contribute to a healthy functioning watershed. Natural areas were also assessed based on stressor impacts, scoring higher if they had no or limited impacts, and scoring lower if they were significantly stressed and highly degraded (MRWIP 2007, 2009). Individual scores were then amalgamated to produce a final scored dataset for the watershed.

[3] In 2018 MWC reported that 18% of the watershed was "extensively modified for human uses" but did not define those uses (MWC 2018a). The discrepancy between the MRWIP and MWC values could be due to the inclusion of additional types of developed areas in the MWC calculation, such as road, trail and railway networks.

[4] The Muskoka River Watershed Inventory Project was a collaborative effort of the Muskoka Heritage Foundation, Muskoka Watershed Council, District Municipality of Muskoka, and the Ontario Ministry of Natural Resources.

Table 1. Framework for assessment used in the Muskoka River Watershed Inventory Project (MRWIP 2007, 2009).

Goal	Criterion	Objective	Indicator
Identify ecosystems and protected areas	Representation	a) Identify all terrestrial and aquatic ecosystems within the watershed and their protection status	(i) Terrestrial landform and vegetation associations (ii) Existing protection areas (iii) Aquatic ecological units
Identify areas of high ecological importance	Ecological Function	a) Identify natural areas that exhibit high degrees of integrity and resiliency	(i) Size of discrete terrestrial ecosystems and aquatic ecological units (ii) Presence of old growth forests (iii) Interior size of discrete terrestrial ecosystems
		b) Identify wetlands	(i) Presence of wetlands
		c) Identify riparian areas	(i) Riparian of stream/rivers, inland lakes, and Great Lakes shoreline
		d) Identify recharge areas	(i) Highly permeable areas
	Diversity	a) Identify habitat diversity	(i) Diversity of terrestrial habitats and aquatic ecological units
	Special Features	a) Identify species element occurrences, vegetation communities, and other significant wildlife habitat	(i) Species and vegetation community occurrences

Goal	Criterion	Objective	Indicator
			(ii) Important habitat areas
Identify stresses on ecosystems and processes	Condition	a) Identify condition/quality of the watershed	(i) Percentage natural cover (ii) Influence of settled areas (iii) Influence of open cleared areas (iv) Influence of pits and quarries (v) Influence of hydro lines (vi) Influence of railways (vii) Influence of roads (viii) Influence of trails (ix) Invasive species (aquatic only) (i) Indicator species (aquatic only) (ii) Road and railway crossings (aquatic only) (iii) Water quality (aquatic only) (iv) Influence of dams (aquatic only)

The Inventory found that over 50% of the terrestrial portion of the watershed was under some form of protection, ranging from the highest level of protection in national and provincial parks, conservation reserves and land trusts (18% of the watershed), to intermediate protection in Crown land, Muskoka Heritage Areas, conservation easements, and provincially significant wetlands (31% of the watershed), to the lowest level of protection through municipal Official Plan and comprehensive by-law provisions (14% of the watershed). Most protected areas were concentrated at the northeast and southwest corners of the watershed, coinciding with Algonquin Provincial Park, roadless areas of the Township of Algonquin Highlands, and Crown land (Figure 3; MRWIP 2007). In contrast, less than 10% of aquatic systems (streams, lakes, wetlands) were within protected areas (MRWIP 2009).

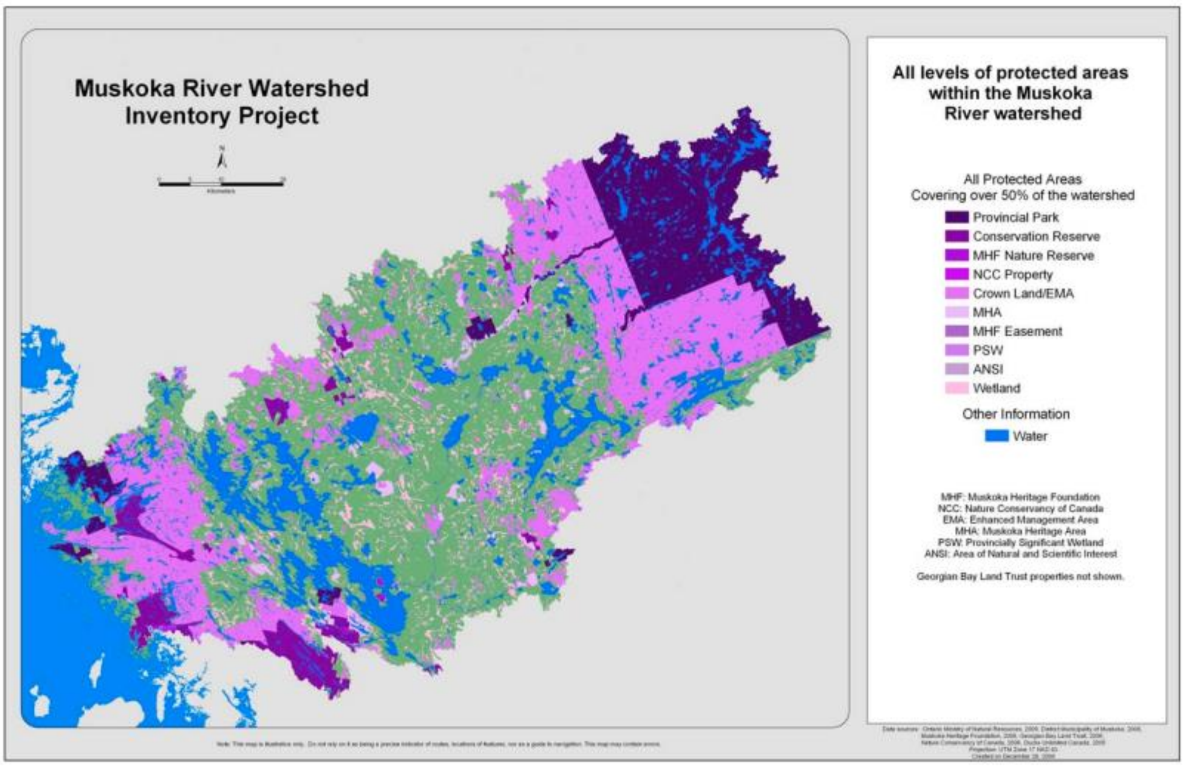

Figure 3. Protected areas within the Muskoka River Watershed (from MRWIP 2007).

The Inventory documented a high percentage of natural cover throughout much of the watershed, but the influence of roads, and to a lesser degree trails, was evident across the region, particularly in association with the three main towns and the Highway 11 corridor (Figures 4-6). Open and cleared areas (representing agricultural lands and golf courses) also influenced natural areas, particularly within the central part of the watershed (Figure 7). Much of the watershed was determined to be in very good condition, with high potential for sustaining ecological processes, except for areas close to major roads and within urban centres (Figure 8). The Inventory recommended that future development be restricted to existing urban and settled areas to protect and maintain areas in the rest of the watershed having higher ecological value (MRWIP 2007).

Significant natural core areas (which were defined as natural areas scoring very high for the final combined score of ecological importance and condition) were identified as being high quality habitat with high potential to maintain and sustain important ecological processes. Significant natural linkage areas (defined as also scoring high for the final combined score) were identified based on their ability to connect or enlarge the natural core areas. Such connectivity is essential for the healthy functioning of natural systems (MRWIP 2007). Approximately 22% of the identified core areas received no protection, while 52% of high quality linkage areas and 33% of medium quality linkage areas were unprotected in the watershed (Figure 9; MRWIP 2007).

The impact of aquatic invasive species was assessed by examining the spread of the Spiny Waterflea (*Bythotrephes*) in Muskoka lakes, which was prevalent throughout the watershed, but particularly in the large lakes to the southwest and the smaller lakes to the northeast of the watershed (Figure 10). Water quality was assessed based on whether lakes sensitive to phosphorus were above or below modeled and measured phosphorus concentration thresholds. Most lakes were below the threshold and thus classified as having high water quality for recreational purposes (Figure 11).

The Muskoka River Watershed Inventory Project provided a comprehensive snapshot of the state of the Muskoka River Watershed in the early 2000s. However, the information is almost 20 years old, and over that time it is likely that the watershed stressors documented by the project have intensified in Muskoka, as human populations have risen, development has increased, and climate change has continued to occur across the watershed.

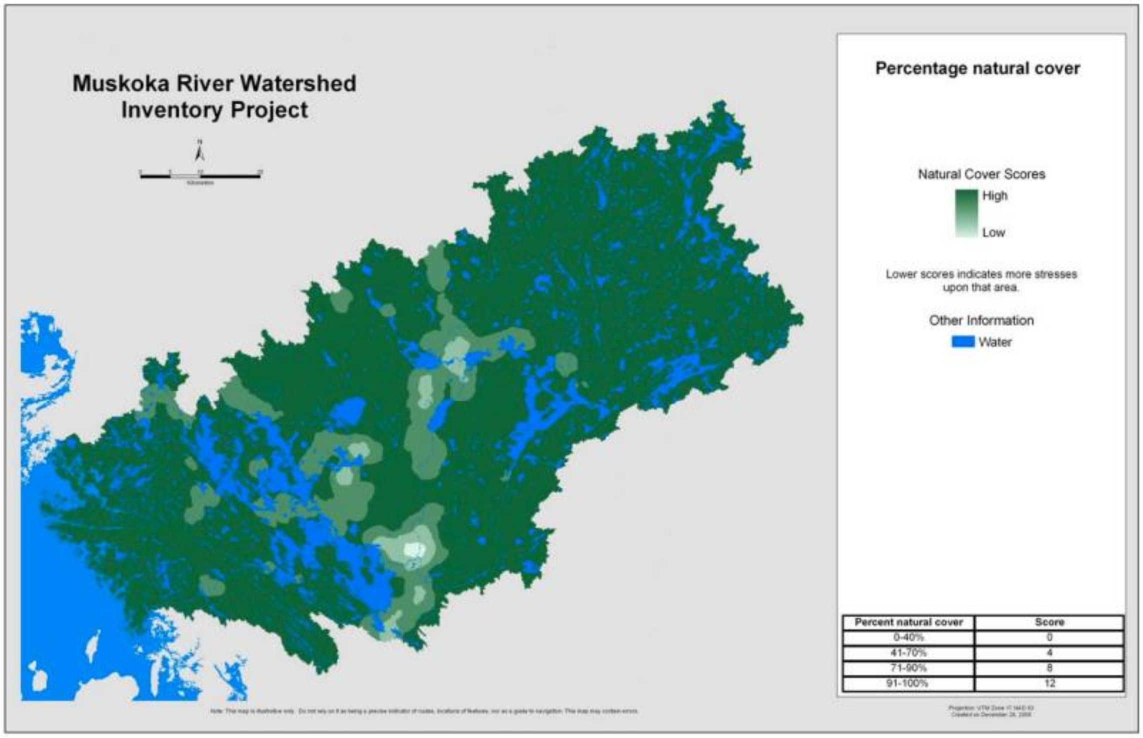

Figure 4. Percentage natural cover (from MRWIP 2007).

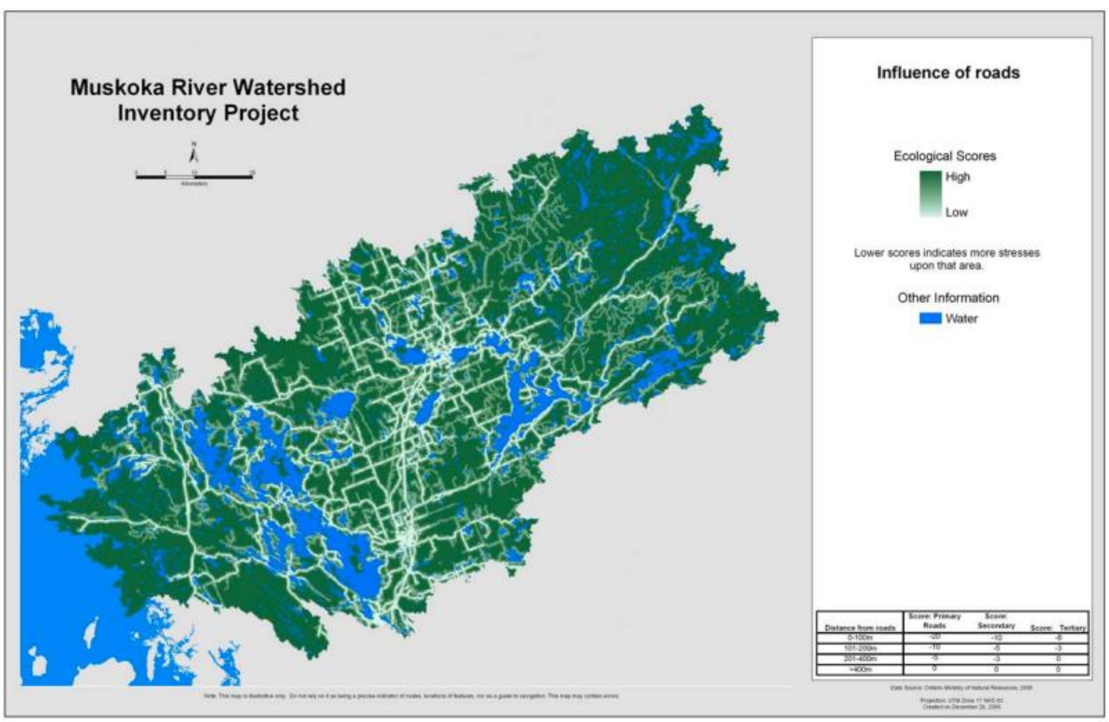

Figure 5. Influence of roads (from MRWIP 2007).

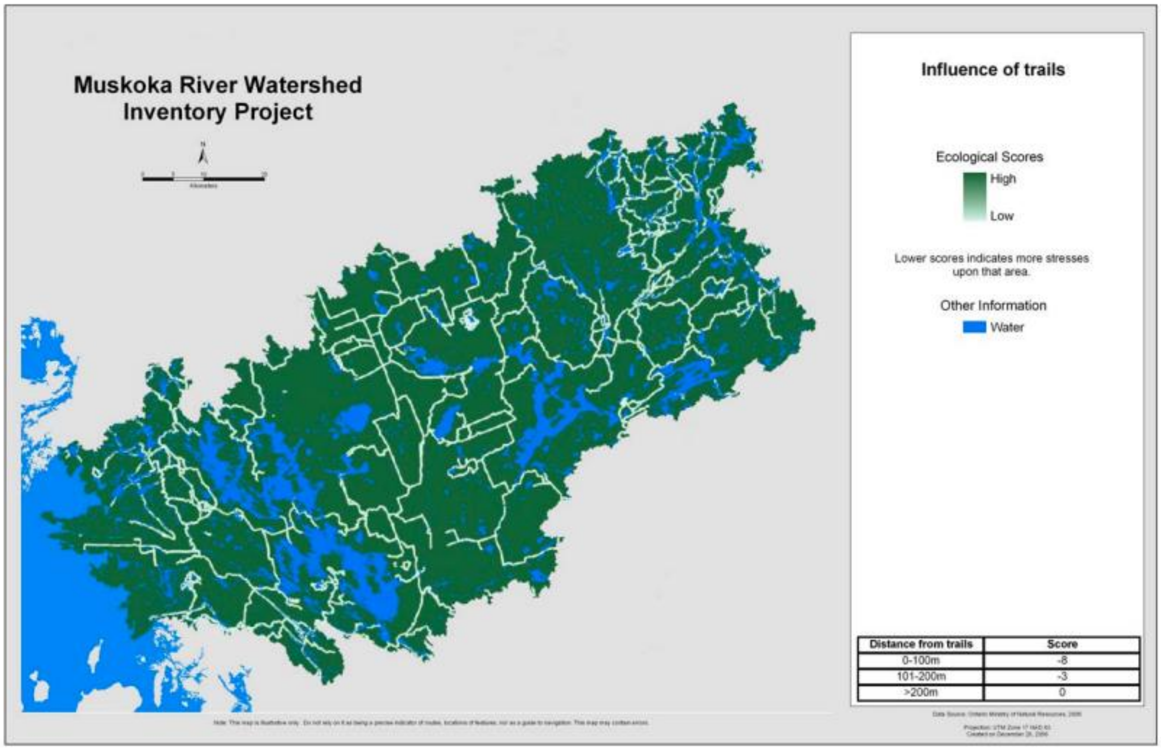

Figure 6. Influence of trails (from MRWIP 2007).

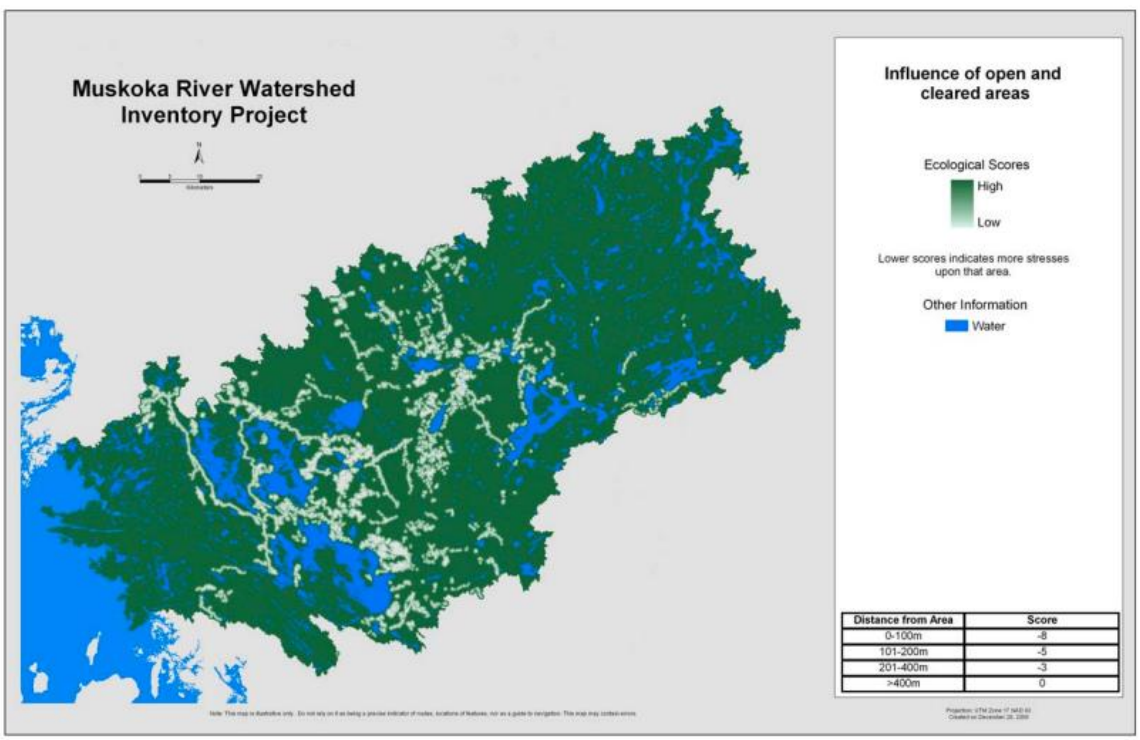

Figure 7. Influence of open and cleared areas (from MRWIP 2007).

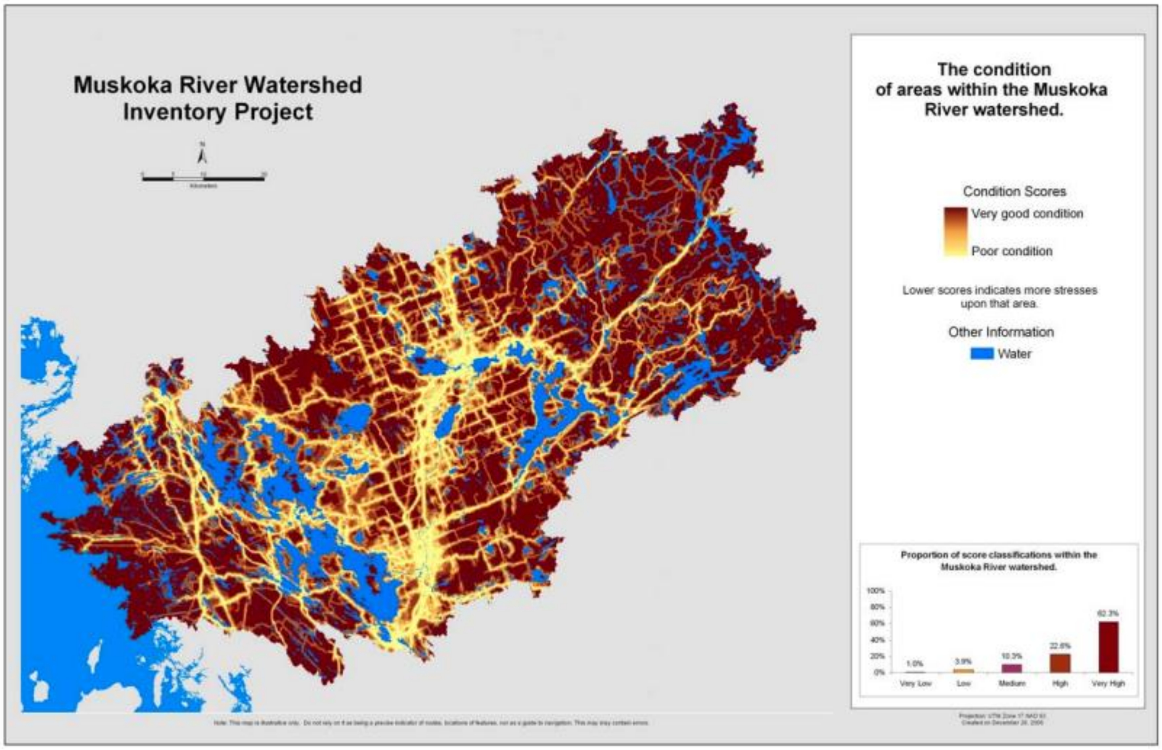

Figure 8. Overall condition of areas within the watershed (from MRWIP 2007).

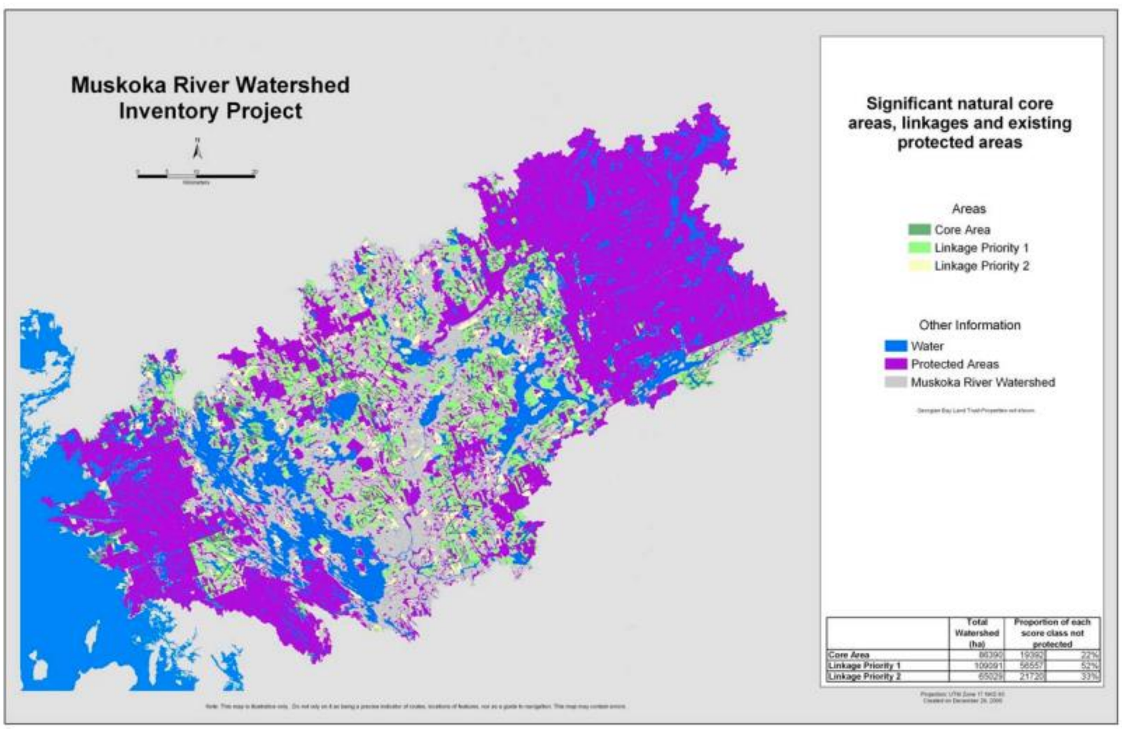

Figure 9. Significant natural core areas and linkages and their protected status (from MRWIP 2007).

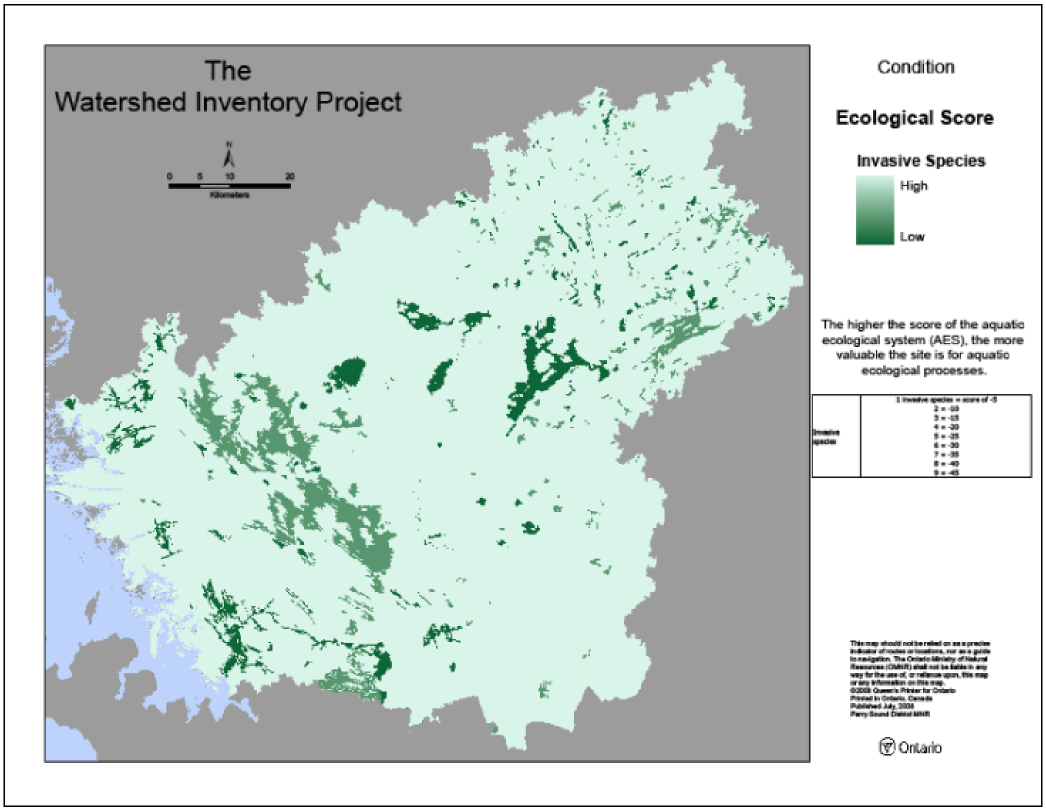

Figure 10. Occurrence of Spiny Waterflea in Muskoka lakes (from MRWIP 2009).

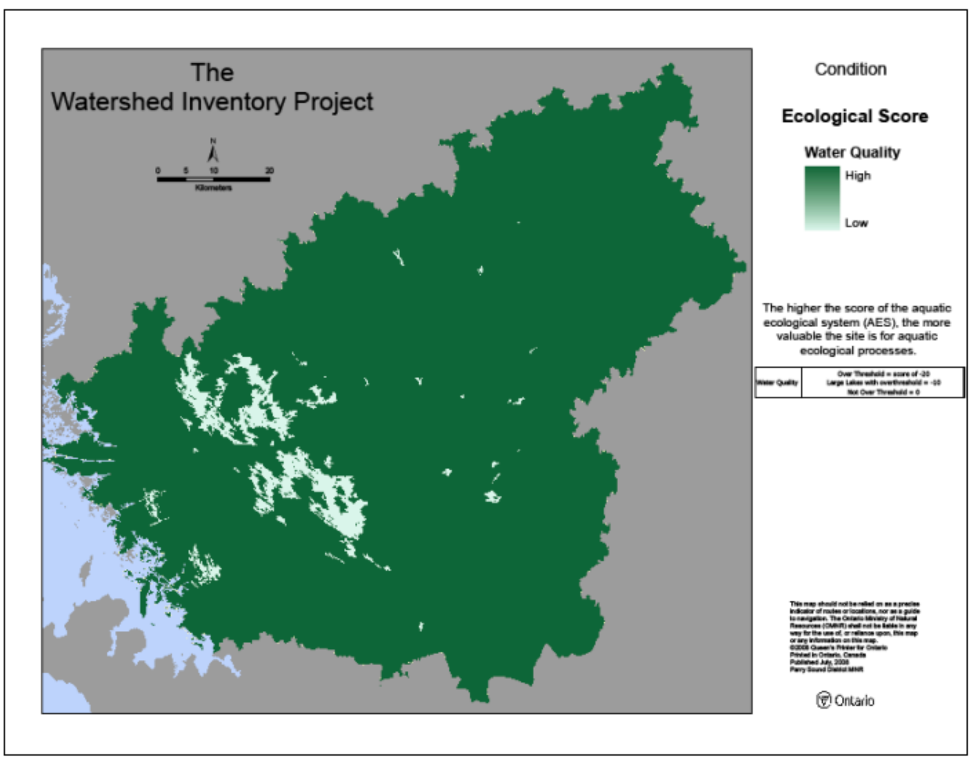

Figure 11. Water quality condition of Muskoka lakes (from MRWIP 2009).

2.2.2 Muskoka Watershed Report Cards

In 2002, the Muskoka Watershed Council (MWC) developed its first set of watershed health indicators, based on the Pressure-State-Response model. This approach identifies what is happening in the environment (state or condition), why it is happening (pressure), why it is significant (effects), and what humans should do to address it (response; MWC undated). The first Muskoka Watershed Report Card was released in 2004, which documented conditions under six categories through a series of indicators (Table 2). Since then, report cards have been published every four years (in 2007, 2010, 2014, and 2018).

Table 2. Indicators used in the 2004 MWC Report Card (from MWC 2004a).

Condition		Example Indicators
Swimmability	*Bacteria*	
	i)	Supervised public beaches meet provincial standards for swimming
	ii)	Natural background *E. coli* levels in all inland lakes and along Georgian Bay coastline (i.e., <5 counts/100 ml)
	Nutrient Enrichment	
	i)	Lakes are free of nuisance algal blooms
Drinkability	i)	Clean treatable groundwater
	ii)	Clean treatable surface water
	iii)	Good municipal water source
Fishability	i)	No restrictions on eating local fish
	ii)	Healthy fish populations (e.g., Lake Trout)
Air Quality	i)	No cases of poor air quality (i.e., smog advisories)
	ii)	Industrial and automotive emissions are in a healthy range
	iii)	Acid rain reduction that will allow full recovery of lakes and forests
Healthy Natural Areas	i)	Large natural areas with connecting corridors
	ii)	Quality natural habitat
	iii)	Maintenance of naturally forested environment
	iv)	Naturally vegetated shorelines and adjacent areas
	v)	Adequately protected wetlands
Community Stewardship	i)	All farms have an Environmental Farm Plan
	ii)	All marinas participate in the 'Clean Marine' program
	iii)	Strong environmental ethic and responsible civic attitude among residents
	iv)	60% waste diverted to recycling by 2008

The 2004 Report Card also identified key indicator species to monitor for information on habitat quality. Birds were recommended as indicators because they tend to be sensitive to environmental change and relatively easy to monitor (MWC 2004b). For example, many forest bird species are sensitive to habitat fragmentation and loss of interior forest habitat (e.g., warblers). Top predators, such as hawks, are sensitive to bioaccumulation of contaminants in the food web, while waterbirds, such as loons, are sensitive to shoreline development and boating activity. The Brown-headed Cowbird, meanwhile, thrives in more disturbed habitat, and is thus a good indicator of habitat fragmentation. Several mammal species were also recommended as indicators: American Marten (which requires mature forest), and moose and deer (which both use younger forests). In particular, deer rely on coniferous cover in winter, which is often associated with shorelines, and thus deer wintering habitat may be threatened by shoreline development. Moose rely on wetlands and shallow bays of lakes for feeding on aquatic plants in spring and summer, which also may be impacted by shoreline development (MWC 2004b).

The 2004 Report Card found that overall, the watershed was in good health, but was experiencing pressure from many human-caused stressors, including gray water dumping and faulty septic systems, removal of shoreline vegetation, loss of wetlands, poor logging practices, climate change, invasive species, shoreline development, and industrial emissions from beyond the watershed (elsewhere in Canada and the United States; MWC 2004a).

Subsequent report cards have focused on similar categories as the 2004 Report Card to describe watershed condition and stressors, with an emphasis on aquatic habitats and water quality, air quality, ecosystem protection (e.g., large natural areas, representation of all habitat types, interior forest), wetland and shoreline protection, and development impacts (e.g., impervious surfaces, road density). Report cards continue to show that the Muskoka River Watershed is in relatively good shape, with water quality above provincial guidelines for recreational use, high levels of natural cover, and many intact wetlands. However, climate change, invasive species, species at risk, and calcium decline have emerged as major issues in the watershed over the years (MWC 2007, 2010, 2014).

The 2018 Report Card assessed four measures of watershed health (total phosphorus, calcium, benthic macroinvertebrates, and interior forest) and four measures of threat (climate change, species at risk, invasive species, fragmentation; MWC 2018a). Indicators were selected based on data availability and the recommendations of scientists, with the intent to provide a broad overview of watershed health, continuity with previous report cards, and consideration of emerging issues. Each of the 19 sub-watersheds in the watershed were assessed for each indicator (and in most cases graded; MWC 2018b; Table 3).

Table 3. Indicators used in the 2018 MWC Report Card (criteria reported on a sub-watershed level; MWC 2018b).

Indicator	Grade	Criteria
Total Phosphorus	•Not Stressed •Vulnerable •Stressed	• <25% of lakes vulnerable or stressed • 25 to 50% of lakes vulnerable or stressed • >50% of lakes vulnerable or stressed
Calcium	•Not Stressed •Vulnerable •Stressed	• ≥50% of lakes have calcium concentration >2.0 mg/L • ≥50% of lakes have calcium concentration of 1.5 to 2.0 mg/L • ≥50% of lakes have calcium concentration <1.5 mg/L

Benthic Macroinvertebrates	•Typical •Atypical •Extremely Atypical	• ≥50% of lakes are classified as typical • ≥50% of lakes are classified as atypical • ≥50% of lakes are classified as extremely atypical
Interior Forest	•Not Stressed •Vulnerable •Stressed	• ≥50% of landscape is interior forest • 20 to 50% of landscape is interior forest • <20% of landscape is interior forest
Climate Change	All sub-watersheds are considered vulnerable	
Species at Risk	Not graded	
Invasive Species	•Not Stressed •Vulnerable •Stressed	•Total score (invasiveness ranking x abundance) < 5000 •Total score 1000 to 5000 •Total score >10,000
Fragmentation	•Not Stressed •Vulnerable •Stressed	• >90% of landscape comprised of natural areas >200 ha • 60 to 90% of landscape comprised of natural areas >200 ha • <60% of landscape comprised of natural areas >200 ha

The 2018 Report Card found that

- Phosphorus levels have generally stabilized in Muskoka lakes,
- 56% of sampled lakes have calcium concentrations below 2.5 mg/L (the threshold for stress to Daphnia populations),
- Benthic macroinvertebrate communities are typical across most of the watershed,
- 46% of the watershed is interior forest,
- Surface water temperatures are increasing and the length of ice coverage on lakes is declining,
- 46 species at risk occur in the watershed,
- Seven invasive species of concern are found in the watershed, and
- 82% of the watershed is natural area (including lakes, wetlands, forest, rock barrens, and other natural ecological communities).

While the 2018 Report Card examined individual stressors, it was also acknowledged that stressors (such as urban development, agricultural practices, industrial activities, and climate change) are linked and interact to have cumulative impacts on the watershed (MWC 2018b).

2.2.3 Muskoka Watershed Council Position Papers

The MWC has released two recent position papers addressing threats to watershed health, one focused on climate change (Sale et al. 2016) and a second focused on the need for IWM to address climate change and development pressures (Sale et al. 2020).

2.2.3.1 Climate Change in the Muskoka River Watershed

The MWC forecasted what Muskoka's climate would look like in a typical year mid-century (i.e., 2041-2070), using global climate models (GCMs) compiled by the Intergovernmental Panel on Climate Change (IPCC). A central location within the watershed (near High Falls in Bracebridge) was selected as the study area, and climate models were sampled under two scenarios: (i) a significant shift away from fossil fuels occurs globally, resulting in global mean temperature increase limited to 2ºC by 2100, and (ii) business as usual, in which the world continues to use fossil fuels as the main source of energy (Sale et al. 2016).

The analysis found that at mid-century, Muskoka will likely be warmer (by 3 to 4ºC each month) and slightly wetter (by about 10%) than today. Precipitation is expected to occur in fewer more pronounced storm events, concentrated in the winter and spring, with drier summer and fall seasons. From November to April, 17% more precipitation will likely fall, mostly as rain, rather than snow. Increased rates of evaporation and transpiration from May to October will lead to drier soils, reduced water flow in streams and rivers, and some wetlands completely drying up. At the same time, altered precipitation patterns in winter will have far-reaching effects, potentially reducing snowpack and spring thaw, which in turn will further reduce flow in summer and fall. Lakes will have shorter periods of ice cover, will warm more during the open water season, and will be more productive, potentially leading to more algal blooms and water quality concerns. Climate change will alter lake ecology, affecting phytoplankton, zooplankton, and fish community structure and composition (Sale et al. 2016).

Droughts and wildfires will be more common in Muskoka at mid-century, as well as flooding, violent storms, and heat waves. Summer recreational opportunities will likely increase, but winter recreation will be curtailed in many years. While a longer growing season will benefit plant growth (and farming, if water is available in summer and fall), many tree species native to Muskoka will experience climatic stress and will become less common or disappear in the watershed. Forest insect pests and pathogens will increase under a warmer and seasonally drier climate. Human diseases such as Lyme and West Nile will also become more prevalent, as will new diseases traditionally associated with tropical zones (e.g., malaria, dengue fever). Vulnerable populations (such as the elderly and those with underlying health conditions) will be at greater risk of heat-related death (Sale et al. 2016).

Ongoing and increasing development in the watershed adds further strain to the health of the watershed, exacerbating the impacts of climate change. More impervious surfaces will reduce the watershed's capacity to regulate water flow to Georgian Bay, leading to increased risk of flooding (Sale et al. 2020). Development pressures are also interacting with climate change to increase the risk of erosion and siltation, and to threaten water quality, biodiversity and natural habitat in Muskoka (MWAG 2020).

The MWC Position Paper on Climate Change made a series of recommendations to improve our understanding of Muskoka's environment and to strengthen our response to climate change in the watershed, including

- Building on existing water quality monitoring programs to develop a coordinated citizen-driven, science-based water monitoring program which encompasses lakes, wetlands, and streams to track climate-driven changes in water quality and aquatic biota,
- Researching causes and management of algal blooms in Muskoka lakes,
- Researching the effects of road salt on aquatic systems,
- Researching the interactive effects of calcium decline and climate change on Muskoka forests, and
- Reviewing active management strategies to protect Muskoka wetlands from increasing drought (e.g., through passive conservation, active maintenance, and protection for beavers).

2.2.3.2 Major Issues in the Muskoka River Watershed

The MWC Position Paper on the need for IWM identified the following challenges facing the Muskoka River Watershed (Sale et al. 2020):

- Road salt,
- Species at risk,
- Algal blooms,
- Calcium loss,
- Climate,
- Invasive species,
- Floods,
- Natural capital,
- Ecosystem services,
- Education,
- Health,
- Population, and
- Sustainability.

This list is supported by a recent review on emerging threats to freshwater biodiversity which identified twelve global ecological stressors deemed responsible for global freshwater biodiversity decline (Reid et al. 2019). While the researchers noted that this list is not exhaustive of all threats to freshwater biodiversity, they sought to highlight the most pressing concerns based on their expert opinion and the literature available at the time of writing. Threats identified included changing climate, harmful algal blooms, invasive species, emerging contaminants, microplastic pollution, light and noise, salinization, declining calcium, engineered nanomaterials and cumulative impacts (Reid et al. 2019).

Across the Northern Hemisphere, climate change has exerted discernible effects on lake ecosystems, inducing changes in their physical, chemical and biological conditions. For example, increases in annual-mean air temperature in south-central Ontario have resulted in significant increases in the duration of the ice-free period since the mid-1970s (Futter 2003). Reid et al. (2019) noted that changing climate is expected to continue and is anticipated to exacerbate other emerging threats to water quality including invasive species (Rahel and Olden 2008), harmful algal blooms (Huisman et al. 2018), salinization (Henman and Poultier 2008), and eutrophication (Elliot 2012).

Climate, eutrophication, brownification (i.e., increased dissolved organics) and changes to hydrology have resulted in conditions conducive to the proliferation of nuisance and harmful algal blooms. In the Muskoka River watershed, this includes a marked recent increase in algal blooms in low nutrient lakes. The existing scientific body of literature suggests that the conventional understanding and management of algal blooms, that is based on controlling phosphorus concentrations in the water column, is not adequate to manage the development of oligotrophic blooms in nutrient-poor lakes (Reinl et al. 2021).

Invasive species are not a novel threat to freshwater biodiversity. Research on invasive mussels, aquatic plants, fish and invertebrates in the Muskoka River Watershed has been ongoing for decades (e.g., Hincks and Mackie 1997, Yan et al. 2002, Strecker and Arnott 2005, Edwards et al. 2014). Many past invasions have been associated with ballast water releases to the Great Lakes, leading to new regulations to control invasions. However, Reid et al. (2019) identified e-commerce as an emerging novel vector of concern for species invasions, noting that direct unregulated purchase of exotic species through the internet allows individuals the opportunity to import non-native plant and animal species. If released into the wild, these species often have the potential to become established and pose a substantial threat to native species.

A long-term consequence of acidification during the latter half of the 20th century by regional acid deposition from industrial smelting is that calcium concentrations in softwater lakes on the boreal shield have declined (Stoddard et al. 1999, Watmough et al. 2003). Numerous biological consequences have been linked to declining calcium in lakes. In Algonquin Park, regional calcium decline has had a significant negative effect on crayfish populations resulting in in the near extirpation of crayfish in four long-term study lakes (Hadley et al. 2015). Lower calcium availability also provides a competitive advantage to *Holopedium glacialis*, which forms a jelly-capsule instead of a calcified carapace as its primary defence against predators (Jeziorski et al. 2015). *Holopedium* blooms are a nuisance for water intakes, are a less efficient food source for fish (lower P content), and are more difficult for invertebrate predators to catch, which may alter the food web within a lake and put additional stress on fish populations.

Emerging contaminants that are most relevant in the Muskoka River watershed include active pharmaceutical ingredients, personal-care-product additives, pesticides, engineered nanomaterials and microplastics. Antibiotics, antimicrobials, antivirals and antidepressants have been demonstrated to be broadly detectable in wastewater-impacted rivers (Hughes et al. 2013), however ongoing research is required to determine the impact of these compounds on the aquatic receiving environment.

Antimicrobial compounds have been demonstrated to affect natural microbial communities (Barra Caracciolo et al. 2015), as well as algal diversity and periphyton, and some primary consumers (Nietch et al. 2013). Likewise, anti-inflammatories and antidepressants have be shown to negatively impact species abundance and the composition algal communities (B´acsi et al., 2016; Richmond et al., 2016; Reid et al. 2019).

Microplastics became a topic of discussion in the early 2000s, when Thompson et al. (2004) demonstrated that microplastic particles were common pollutants in marine environments (beaches and estuarine sediments) and suggested that recovered microplastics were a result of the degradation of larger plastic debris. Due to their small size, microplastics can easily be ingested by biota. Microplastic ingestion can cause abrasion and blockage of the gastrointestinal tract and internal bleeding in aquatic organisms (Wright et al., 2013). It has been demonstrated in laboratory studies that microplastics can adsorb environmental contaminants on their surfaces and act as vectors for these contaminants (Rochman et al., 2013; Bakir et al., 2014; Velzeboer et al., 2014).

Engineered nanomaterials (ENMs) are synthetic materials, ranging in size from 1-100 nm, that are used in a myriad of applications. A marked increase in the number of ENM products listed in various global inventories has been recently noted, showing an increase from 54 in 2005 to above 5000 in 2020 (Moli et al. 2021). The market for ENMs is currently dominated by health and fitness products, including active wear, sunscreens, cleaning supplies, cosmetics and sporting goods (Moli et al. 2021). ENMs in these products are typically surface-bound or suspended in liquid and therefore have a medium to high potential for release into water (Foss Hansen et al. 2016, Moeta et al. 2019).

2.2.4 Recent Scientific Research in the Muskoka River Watershed

Much of the environmental research conducted in the Muskoka River Watershed has stemmed from the Ontario Ministry of Environment, Conservation and Parks' (MECP) Dorset Environmental Science Centre (DESC), which has monitored the ecology and water quality of Muskoka lakes for almost 50 years. An online search of scientific papers published on the watershed (using Google Scholar and Web of Science and the search terms 'Muskoka', 'watershed health', 'indicators', monitoring', 'environmental stressors', 'water quality', and 'biodiversity') generated 14 studies from 2008 to 2020, with 11 (79%) associated with DESC, either through direct authorship or use of DESC's long-term monitoring data.

Research out of DESC shows that Muskoka lakes are impacted by multiple stressors, which interact in often complex ways to affect aquatic biota and water quality. For example, a paleolimnological study found that the cumulative effects of multiple stressors (such as acid deposition, past forestry practices, and climate change) appeared to be reducing phosphorus loading to lakes despite increased phosphorus inputs from human activity (Quinlan et al. 2008). Focusing solely on physical and chemical parameters of lake health would thus suggest that lakes were in good condition, while overlooking potential ecological effects of anthropogenic nutrient enrichment. Quinlan et al. (2008) thus emphasized the importance of combining traditional water quality measures (e.g., total phosphorus, pH) with biological monitoring (e.g., of community structure), since recovery of good water quality does not necessarily equate to biological recovery (Quinlan et al. 2008).

The water quality of Muskoka lakes has changed in recent decades due to acid deposition, climate change, and shoreline development (Palmer et al. 2011). Acid rain reached its peak in the watershed in the 1970s and Muskoka lakes were particularly susceptible to its effects, due to the impermeable granite bedrock and shallow sandy soils of the surrounding landscape (MacDougall et al. 2016). Muskoka lakes are showing signs of chemical recovery from the legacy of acid rain, but biological conditions have shifted to novel plankton communities, largely driven by the effects of climate change (Hadley et al. 2013). Acidification of the watershed also led to increased leaching of calcium from soils, initially raising calcium concentrations in surface waters. However, the naturally low weathering rate of Muskoka's bedrock, combined with atmospheric deposition, were not enough to maintain soil calcium levels during long-term acid deposition (over decades), causing depletion of soil calcium levels, and ultimately declines in lake calcium concentrations (Jeziorski et al. 2008). Lake calcium levels have decreased an average of 30% in Muskoka from 1981 and 2012 (Eimers 2016). An array of aquatic species dependent on calcium are negatively affected by this decline, including Daphnia zooplankton and crayfish, with profound consequences for pelagic food webs (Jeziorski et al. 2008, Edwards et al. 2014). At the same time, depletion of soil calcium reduced forest health, adversely affecting tree growth and overall condition, and seedling survival and regeneration (Azan et al. 2019).

A study of eight Muskoka lakes found that over the last 30 years, decreased sulphur deposition (via recovery from acid rain) has reduced lake acidity (although concurrent leaching of calcium, potassium, and magnesium from soils into lakes is hindering recovery of lake alkalinity and pH), climate warming has increased dissolved organic carbon (DOC) entering lakes, and lakeshore development is leading to increases in sodium and chloride in lakes from road salt (Palmer et al. 2011). Rising DOC levels due to climate change may counteract the benefits of decreasing sulphate deposition, by increasing organic acid concentrations in surface waters, simultaneously exacerbating calcium declines (Reid and Watmough 2016). Calcium declines are further accelerated by tree harvesting, which removes terrestrial sources from the watershed (>60% of a tree's calcium is stored in the stemwood and bark; Reid and Watmough 2016). Some Muskoka lakes have lost so much calcium they are no longer able to support keystone zooplankton species (Daphnia spp.), leading to greater risk of algal blooms, and replacement with species of lower nutrition value for planktivores (Reid and Watmough 2016).

Canadian Shield lakes, such as those in the Muskoka River Watershed, are typically oligotrophic or mesotrophic, with naturally low total phosphorus concentrations because of the low weathering rates of the granite bedrock (Pinder et al. 2014, Crossman et al. 2016). Total phosphorus levels in the watershed have been further limited by the historically low human population in the area, the lack of major agricultural and industrial activity, and the lack of large urban centres (Pinder et al. 2014). Nonetheless, in the 1970s and 1980s, Muskoka experienced widespread cottage development and associated road construction, which led to increased forest clearing and flooding of treed wetlands. These disturbances caused an increase in the decomposition of dead trees, which in turn created short-term pulses of phosphorus entering streams and downstream lakes (Pinder et al. 2014). Pinder et al. (2014)'s research highlights the important link between wetland dynamics and overall watershed health and underscores the value in protecting wetlands and riparian zones from disturbance to avoid nutrient release to waterways (Pinder et al. 2014).

Widespread application of road salt is also a problem for aquatic environments in Muskoka. Salting of roads began in the 1950s in the watershed, coinciding with a shift in the composition and abundance of zooplankton taxa in lakes adjacent to affected roadways (Valleau et al. 2020). Chloride toxicity tends to be magnified under soft water (i.e., <60 mg/L calcium carbonate) and low-nutrient conditions typical of Canadian Shield lakes (Arnott et al. 2020). Daphnia in soft water exhibited decreased reproduction and increased mortality when exposed to low levels of chloride (5-40 mg/L) that were below existing water quality guideline concentrations (120 mg/L for chronic exposure and 640 mg/L for acute exposure; Arnott et al. 2020). Zooplankton herbivores in Muskoka lakes thus likely face the cumulative effects of declining calcium and phosphorus, and rising chloride, interacting to affect food availability, reproduction, growth, and salt sensitivity (Arnott et al. 2020, Valleau et al. 2020). Most Muskoka lakes may be sensitive to rising chloride levels due to their already low nutrient status, and declining levels of calcium and phosphorus (Eimers 2016).

MacDougall et al. (2016) demonstrated that periphyton (algae which is attached to submerged surfaces in lakes and rivers) is an effective indicator of ecological condition in the Muskoka River Watershed. Periphytic diatom community composition was assessed in relation to water chemistry and anthropogenic stressors, and it was determined that periphyton composition varied in relation to road proximity and density, suggesting that factors such as use of road salt and dust suppressants, as well as road construction and maintenance activities influenced periphyton dynamics. Using periphyton diatoms as an indicator of aquatic health has numerous benefits, including that they are sensitive to environmental change, immobile, relatively easy to monitor, and they provide a continuous integrated profile of environmental conditions (vs. a snapshot provided by a single water quality measurement; MacDougall et al. 2016). The study further found that periphytic responses were non-linear, with greater changes to community composition with small rather than large increases in stressors. MacDougall et al. (2016) suggested that this response could be a confounding effect of natural variability in pH (i.e., periphytic response to stressors was reduced when pH variation was high) and recommended that periphyton monitoring be stratified to account for this possibility (in other words, data from more acidic lakes should be analyzed separately from less acidic lakes).

From 2012 to 2015, the Canadian Water Network funded a research program focused on cumulative effects assessment and monitoring in the Muskoka River Watershed, undertaken by scientists at seven universities and MECP. The researchers collected current data and reviewed historical data from the past 30 years to establish baseline conditions, identify cumulative effects, and determine causes of long-term changes over the decades (Eimers 2016). The key findings of the program were the following:

- Phosphorus levels have declined in many lakes in the watershed.
- Phosphorus levels in streams are higher in areas that experienced historical disturbance (particularly in treed wetlands).
- Calcium levels are declining in Muskoka lakes, and many lakes are approaching thresholds for sustaining calcium-dependent aquatic species (such as Daphnia and crayfish).
- Forest harvesting will exacerbate calcium loss in the watershed. Under current forest management practices, more than 50% of lakes studied in Muskoka could fall below biologically critical calcium levels.
- Chloride levels are rising in both urban and more rural waterways in Muskoka.
- Diatoms are sensitive to salt concentration, making them a good early indicator of road salt effects on water quality.
- Salt toxicity for zooplankton is exacerbated by limited food availability (algae), which in turn is caused by declining phosphorus levels.
- Dissolved organic carbon (DOC) has increased in lakes across the watershed, although there is marked natural variation (influenced by differences in nutrient levels, pH, and alkalinity).
- DOC has broad ecological effects, providing food for bacteria, and affecting light penetration and thermal structure of lakes. High levels of DOC interact with phosphorus to cause greater thermal stability, promoting cyanobacteria blooms. High levels of DOC interact with low nutrient levels to support chrysophyte algae, which can lead to taste and odour issues.
- Muskoka lakes are warming and stratifying earlier and for longer, providing ideal conditions for algal blooms.
- Benthic invertebrates (e.g., insects, aquatic worms, sow bugs, snails, and leeches) are good indicators of water quality in lakes and streams.
- Benthic invertebrate community composition appears to be influenced by a complex interplay among habitat, water chemistry, and land use factors.
- The main stressors on Muskoka waterways include acid rain, climatic variability, shoreline development, land use change, and invasive species. Other potential factors not considered by

the program include pollution from pharmaceuticals and personal care products, and dam construction for energy production.

The cumulative effects of stressors operating in the Muskoka River Watershed were summarized in the graphic:

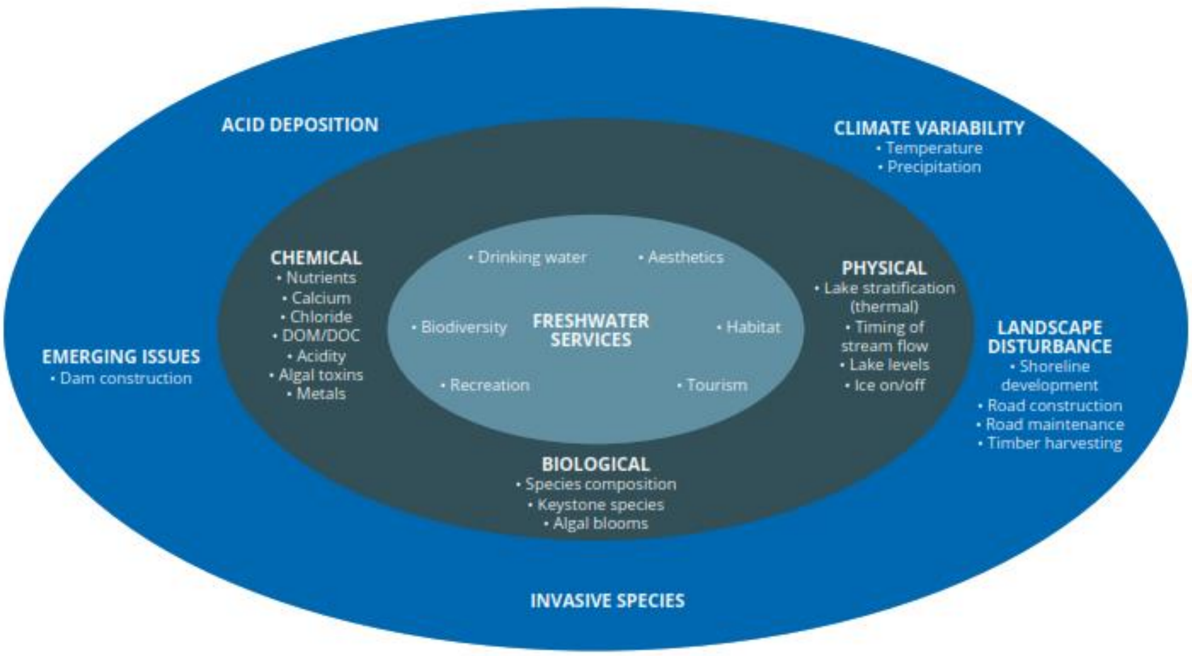

Figure 12. Cumulative effects of main stressors affecting aquatic systems in the Muskoka River Watershed (from Eimers 2016).

3. Summary of Approaches to Measuring Watershed Health in Other Jurisdictions

A review of watershed health indicators used by other jurisdictions and organizations for monitoring watershed health was conducted to gain insight on approaches that could be applicable to the Muskoka River Watershed. In selecting jurisdictions to review, we focused on areas with similar environmental and socio-economic characteristics, as these were assumed to be most relevant and easily adapted to the Muskoka context. For example, we included jurisdictions with similar watershed size and population (permanent and seasonal), that have a high percentage of natural cover, many lakes and rivers, and a tourism-based economy (or any combination of those characteristics), with a focus on jurisdictions in north and central Ontario. We also included watershed monitoring guidance from government organizations. Our review thus included the following jurisdictions/organizations:

- Conservation Ontario and four conservation authorities (Conservation Sudbury, Lakehead Region Conservation Authority, North Bay – Mattawa Conservation Authority, Otonabee Conservation),
- City of Greater Sudbury's Watershed Study,

- Ottawa Riverkeeper's Watershed Health Assessment and Monitoring Project,
- Government of Alberta resources on watershed reporting, and
- USEPA's Healthy Watersheds Program.

We gathered information through a direct review of relevant written material and through interviews with key contacts in each jurisdiction.

3.1 Ontario Conservation Authorities

Conservation Ontario, the umbrella organization representing all of Ontario's 36 conservation authorities, implemented a pilot project in 2003 to establish guidelines for watershed report cards. The project led to the development of a standardized set of indicators and associated evaluation methodology to ensure conservation authorities across the province have the same consistent approach to collecting, analyzing, and reporting data (Conservation Ontario 2011). Conservation Ontario reviews its watershed report card guidelines every five years to reflect changing priorities and to incorporate new information and indicators (it is currently updating its 2023 guidelines).

Conservation Ontario identified indicators that address conservation authority priorities of protecting and enhancing water quality and preserving and managing natural areas. The main environmental issues of concern are urbanization, cultural eutrophication, and overuse and depletion of resources. Indicators were selected that were

- Relevant and easy to understand,
- Sensitive to change,
- Quantifiable (i.e., change in indicator state could be evaluated as good, improving, or worsening),
- Broadly applicable across the watershed (with accessible and consistent data availability),
- At an appropriate scale, and
- Useful for long-term monitoring (e.g., stable and reliable, allowing statistical testing of trends).

Eight indicators were initially recommended in the 2003 pilot study, encompassing three main categories: surface water quality (total phosphorus, E. coli, benthic macroinvertebrates), forest condition (% forest cover, % forest interior, % forested riparian zone), and groundwater quality (nitrite + nitrate, chloride; Table 4). Additional optional indicators were also identified (metals, calcium, and iron concentrations under surface water quality, and % wetland cover). Groundwater quantity was also flagged as a potential future indicator, pending more research.

In 2022, chloride was also added as a surface water quality indicator, since it is affecting both surface and groundwater in southern, central, and eastern Ontario. Groundwater quantity is being considered as a new metric for 2023 as an indicator of climate change. For the 2023 update, Conservation Ontario is re-examining the current indicators used and considering updates based on enhanced technology and monitoring available to various conservation authorities. At the same time, however, Conservation Ontario recognizes that smaller conservation authorities may not have the capacity and resources to incorporate some new indicators. Conservation Ontario thus aims to establish a suite of baseline indicators that all conservation authorities can collect and report on, with the option of including additional indicators.

Targets were identified for surface water quality based on Provincial Water Quality Objectives (MECP) and CCME guidelines. Targets for forest condition (>30% forest cover and >10% forest interior to sustain plant and animal communities, 75% of riparian zone naturally vegetated and minimum 30 m wide) and wetland cover (10%) were based on Environment Canada recommendations (Environment Canada 2004). A different scoring system is recommended for watersheds in northern Ontario and on the Canadian Shield, because minimum forest coverage in those areas generally exceeds the 30% threshold set for southern Ontario (Conservation Ontario 2011).

Each indicator is assigned a point score and grade, and weighted equally. The overall grade for each category (A – Excellent, B – Good, C – Fair, D – Poor, F – Very Poor) is determined by averaging individual point scores and rounding to the nearest whole number.

The guidelines recommend some adjustments to indicator measurements based on watershed conditions. If watersheds have a high proportion of lakes, measures of forest conditions (% forest cover and % forest interior) should be calculated exclusive of lake area, to avoid underestimating forest cover across the landscape. Similarly, in watersheds with large areas of natural habitat that is not forested (such as rock barrens or wetlands), a low measure for forest cover should not be equated with overall low natural cover.

Table 4. Conservation Ontario's watershed indicators.

Category	Indicator	Rationale	Scoring		
			Value	Point Score	Grade
Surface Water Quality	Total Phosphorus (mg/L)	Key nutrient limiting aquatic primary productivity, nutrients are key pollutants in degraded waterbodies	• <0.02 • 0.02 – 0.03 • 0.031 – 0.06 • 0.061 – 0.18 • >0.18	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
	E. coli (# colonies/100 mL)	Good indicator of fecal contamination and overall aquatic health, public interest in tracking levels	• 0 - 30 • 31 - 100 • 101 - 300 • 301 - 1000 • > 1000	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
	Benthic Macroinvertebrates (Modified Family Biotic Index)	Good indicator of biological condition because they are relatively immobile (and thus exposed to environmental stresses) and are sensitive to environmental change, and because they are abundant, easy to sample and identify, and easy to store	• 0 - 4.25 • 4.26 – 5 • 5.01 – 5.75 • 5.76 – 6.50	• 5 • 4 • 3 • 2	• A • B • C • D

Category	Indicator	Rationale	Scoring		
			Value	Point Score	Grade
			• 6.51 - 10	• 1	• F
Forest Condition	Forest Cover (includes upland and wetland forest; %)	Indicates watershed's capacity to support wildlife species	• >35 • 25.1 – 35 • 15.1 – 25 • 5 – 15 • < 5	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
	Forest Interior (≥ 100 m from outside edge; %)	Reflects habitat quality, size, and fragmentation	• >11.5 • 8.6 – 11.5 • 5.6 – 8.5 • 2.5 – 5.5 • < 2.5	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
	Forested Riparian Zone (within 30 m of open watercourses; %)	Vegetated shorelines are a hotspot for biodiversity, and provide a variety of ecological benefit (e.g., improve water quality, provide wildlife corridors and shade for aquatic species, prevent erosion)	• > 57.5 • 42.6 – 57.5 • 27.6 – 42.5 • 12.5 – 27.5	• 5 • 4 • 3 • 2	• A • B • C • D

Category	Indicator	Rationale	Scoring		
			Value	Point Score	Grade
			• < 12.5	• 1	• F
Groundwater Quality	Nitrite + Nitrate (mg/L)	Nitrogen concentration in groundwater influenced by human activity (such as excessive fertilizer use and malfunctioning septic systems), both forms of nitrogen can indicate pollution (although nitrate also reflective of historical or distant source)	• 0 – 2.5 • 2.6 – 5 • 5.1 – 7.5 • 7.6 – 10 • >10	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
	Chloride (mg/L)	Although naturally occurring, elevated levels can indicate human activity (e.g., road salt, landfills)	• 0 – 62.5 • 62.6 – 125 • 125.1 – 187.5 • 187.6 – 250 • >250	• 5 • 4 • 3 • 2 • 1	• A • B • C • D • F
Optional	Wetland Cover (%)	Wetlands improve water quality, mitigate floods and droughts, reduce erosion, protect shorelines, provide wildlife habitat and are negatively affected by human disturbances (e.g., encroachment, drainage, pollution)	• > 11.5 • 8.6 – 11.5 • 5.6 – 8.5 • 2.5 – 5.5	No scores given	• A • B • C • D

Category	Indicator	Rationale	Scoring		
			Value	Point Score	Grade
			• < 2.5		• F

Monitoring generally occurs monthly in spring and summer (e.g., May-August) as part of the provincial water quality (Provincial Water Quality Monitoring Network – PWQMN) monitoring program and once annually (September-October) for the provincial groundwater (Provincial Groundwater Monitoring Network – PGMN) monitoring program. Benthic biomonitoring occurs annually during the spring. Spatial coverage for monitoring is largely determined by the provincial monitoring programs. Information on forest cover is collected from the Southern Ontario Land Resources Information System (SOLRIS) once every five years. Watershed report cards are produced every five years to minimize the effects of seasonal variation and to provide a robust dataset for analysis of trends and patterns.

The development of watershed reporting guidelines ensures consistent and comparable data collection across the province's conservation authorities, that is cost effective. Conservation Ontario is exploring additional ways to streamline watershed monitoring through potential automatic calculations and information transfers (e.g., through various script writing technology such as R, or using functions of the Water Information Systems by KISTER [WISKI] database) and would be happy to share this information following the launch of its 2023 watershed report card guidelines.

The indicators are useful for tracking cumulative effects because they are long-term datasets that relate specifically to land use changes due to anthropogenic influences. However, they are limited in their specificity, since much of the data comes from provincial monitoring programs (PWQMN and PGMN), and thus may not perfectly fit watershed-level requirements (e.g., based on representation, geology, scale etc.). They are also geared towards large-scale monitoring, which may be more difficult for smaller conservation authorities, whose capacity is limited by the size of the municipalities and amount of tax dollars within the watershed. Nonetheless, some conservation authorities may have more targeted and scoped monitoring programs focused on localized issues. For example, North Bay – Mattawa Conservation Authority (NBMCA) focuses on lake total phosphorus and dissolved oxygen because these parameters have specific objectives in the City of North Bay Official Plan.

Much of the data collected under the Conservation Ontario guidelines represents a snapshot in time (e.g., data from the PWQMN program), not an integrated long-term profile of condition. It does not consider flow or loading values, nor does it capture heavy precipitation events or wintering sampling. However, use of biomonitoring indicators, such as benthic macroinvertebrates, provides valuable information on long-term water quality conditions that is not possible from point data and other sampling methods. Conservation Ontario recognizes that there are many programs working in silos and that better coordination and integration of complimentary datasets is needed. For example, there are numerous citizen science/community science monitoring programs and university research projects that may be collecting useful data on watershed health.

The four conservation authorities reviewed have all adopted Conservation Ontario's recommended indicators, to varying degrees. For example, Lakehead Region Conservation Authority (LRCA) does not measure benthic macroinvertebrates because information is not available. However, LRCA does measure additional indicators (wetland macrophyte index, water quality index, and aesthetic appeal of surface waters). North Bay – Mattawa Conservation Authority (NBMCA) measures a suite of surface water quality parameters in addition to those recommended by Conservation Ontario (e.g., oxygen concentration, specific conductance, temperature, pH, Secchi depth, blue-green algae pigment, chlorophyll-a in surface water), but no longer measures E. coli.

The main issues of concern for the four conservation authorities include

- Blue-green algal blooms (LRCA, NBMCA),
- Water quality (e.g., source protection; LRCA, NBMCA),
- Water levels (low water and flooding; NBMCA),
- Degradation and loss of wildlife corridors, especially for fish (LRCA),
- Spread of invasive species, especially invasive plant species (e.g., Phragmites, narrow-leaved cattail, Eurasian milfoil; LRCA), and
- Urbanization.

LRCA finds that the additional indicators it monitors are excellent for tracking long-term watershed health (Table 5). The Wetland Macrophyte Index helps to evaluate the presence and degree of anthropogenic disturbance, based on the composition and abundance of aquatic wetland macrophytes in the Great Lakes. Water quality testing highlights abnormalities in the aquatic system and indicates whether it can adequately sustain aquatic life. Finally, the look and smell test of surface waters provides the most basic way to detect potential issues within a habitat and can be combined with additional methods to further understand watershed biochemistry. Foul odours may indicate degraded water quality, cyanobacteria, or the presence of sewage. If the water or surrounding environment appears to have abnormalities, it is often a clear sign of a larger issue. These indicators can be compared annually to environmental, social and economic values. LRCA identifies fishability, swimmability, and breathability as additional indicators that would be useful to monitor (but which it is not currently monitoring).

NBMCA reports that its indicators are fairly effective at tracking watershed health, as several key watershed conditions are monitored for trends over time (Table 5). However, it can be difficult to determine the source of a watershed issue based on the monitoring data alone. For example, the detection of high or rising phosphorus levels does not indicate the cause of the problem. Similarly, it may be challenging to determine if changes in a specific indicator are due to short-term effects or cumulative impacts over time. Benthic macroinvertebrate data can help elucidate whether water quality observations are due to long-term effects. NBMCA finds that phosphorus is a useful indicator for other nutrients and is effective for tracking blue-green algae issues. However, most blue-green algae blooms are being reported in the fall, after water quality monitoring has usually ended, and thus it may be necessary to extend the monitoring period to capture these events (e.g., into September or October).

NBMCA is currently installing an all-weather precipitation station and a stream gauge, both with telemetry to inform flood monitoring. As a rural agency, NBMCA is limited in its monitoring coverage. For water quality monitoring there are only so many road crossings that can be used for sampling sites. While other jurisdictions may be able to sample headwaters, mid-watershed, and near the outlet to understand changes within each sub-watershed, NBMCA only has capacity to sample nearest the outlets.

Otonabee Conservation finds that the watershed guidelines provide accessible coarse-scale information to the public on where the watershed is and where it is going (Table 5). The monitoring framework can be conducted on a limited budget and creates synergies partnering with the provincial water quality monitoring programs. However, watershed monitoring data is not easily used to evaluate development impacts, and information is lacking on habitat (e.g., ecological land classification) and wetlands across the watershed. Otonabee Conservation would like to add fish indicator species to its monitoring framework, to enable tracking of the health of aquatic communities in the watershed. It would also like to coordinate annual monitoring with information from planners to target areas of the watershed facing development. In these areas, Otonabee Conservation hopes to establish long-term monitoring stations to determine the impacts of development, including continuous monitoring of water quality indicators. It also aims to conduct wetland mapping in the watershed to gain a greater understanding of what is present and how wetlands are affected by development.

Table 5. Advantages and disadvantages of watershed indicators used by four conservation authorities.

Category	Strengths	Weaknesses
Plants	•Plants are excellent biotic indicators because they are stationary, easily sampled, their distributions can be georeferenced, and changes in plant communities can be tracked over time.	•Plant identification and verification can be difficult and should be conducted by a professional. The process can be challenging with limited staff or expertise.
Water Quality	•Water quality results are easy to understand and comparable with other datasets. Most devices are portable and easily transferable in the field.	•Water quality testing devices can be expensive and must be calibrated properly for adequate results. Devices can be costly to fix and replace if damaged. Lack of funding to obtain enough devices has also been an issue. •Secchi depth measurements may vary based on individual eyesight and water conditions (e.g., wavy vs. calm)
Aesthetics of Surface Water	•Intuition is often the first indicator that something is wrong in the environment. Foul odours may indicate degraded water quality, cyanobacteria, or the presence of sewage. If the water or surrounding environment appears to have abnormalities it is often a clear sign of a larger issue.	•Sometimes, the aesthetics test can be deceiving, and other issues may be overlooked with this method alone (it should be used in concert with other referenced indicators for a full picture of watershed conditions).
Benthic Macroinvertebrates	•Benthic macroinvertebrates are indicative of long-term water quality conditions	•Benthic macroinvertebrate identification requires expertise
Water Chemistry	•Chemical analysis is measurable.	•Inconsistencies in methods and reporting between labs for chemical analysis

3.2 Other Jurisdictions

3.2.1 The City of Greater Sudbury

The City of Greater Sudbury monitors watershed health within several of its sub-watersheds to improve water quality, reduce erosion and prevent flooding. Indicators are used to track surface water quality and wetland function (Table 6).

Table 6. Indicators used by the City of Greater Sudbury.

Category	Indicator	Rationale
Surface water quality	Chlorophyll	Indicator of overall plant biomass and nutrient enrichment (e.g., phosphorus, nitrogen)
	Phycocanin	Indicator of presence and relative abundance of blue-green algae
	Fluorescent dissolved organic matter	Indicator of levels of organic matter dissolved in water
	Conductivity	Indicator of concentration of ions in water (from dissolved salts, such as chlorides)
	Turbidity	Measure of water clarity, indicating potential pollution (e.g., caused by sedimentation, siltation)
	pH	Measure of how acidic or alkaline water is, indicating potential pollution
	Dissolved oxygen	Indicator of ability to support aquatic organisms
Wetland function	Evidence of seeps, springs, iron precipitates, coldwater vegetation (such as Jewelweed, Skunk Cabbage, Watercress) in vicinity of wetlands	Indicator that wetland connected to groundwater table, and thus of greater ecological and hydrological value than isolated wetlands
	Ratio of wetland size to catchment size	Indicator of wetland capacity for flood mitigation
	Proximity of wetland to other aquatic features	Indicator of recharge value (i.e., isolated wetlands that are groundwater fed are valuable source of recharge vs. wetlands along rivers or lakes that recharge only occasionally or during flooding)

3.2.2 Ottawa Riverkeeper

Ottawa Riverkeeper launched the Watershed Health Assessment and Monitoring Program in 2019, following an initial study to identify a set of indicators to monitor the health of the Ottawa River Watershed. Its main environmental concerns are water quality, biodiversity protection, and healthy waterways. Indicators were selected through consultation with a Watershed Health Committee (a group of volunteer water experts comprised of academics, program managers etc.), the Algonquin Nation, and other watershed stakeholders using the following guiding principles:

- A manageable number of indicators,
- A focus on tracking surface water in river systems,
- Indicators that are scientifically rigorous and informative for both scientists and the public,
- Indicators that are quantitative, enabling trends through time to be assessed,
- Indicators with historic datasets (recognizing that indicators lacking such data may still be important, e.g., ecological connectivity),
- Indicators that are scalable (i.e., applicable to smaller sub-watersheds as well as the overall watershed), and
- Availability of data.

Indicators were organized into three groups: those reflecting ecological status, those reflecting threats to ecological status, and those reflecting socio-economic conditions. The ecological status indicators were further classified as biological (i.e., plants and animals), hydro-morphological (including water flows and interactions of flow with the land, e.g., through riverbed substrate), and chemical and physico-chemical (including physical and chemical properties of water). Threats indicators were divided into threats to water quantity, threats to water quality, threats to habitat, and climate change. Socio-economic indicators encompassed human health and well-being (e.g., safe water for drinking, swimming, and fishing), and adaptation and climate resilience (e.g., flood and drought risk management, government and community preparedness). The first phase of the program, which is currently underway, is focused on developing and implementing biological, physical and chemical indicators (Ottawa Riverkeeper 2019).

Fourteen inter-related indicators were ultimately identified for monitoring in phase one, representing two biological elements, one hydro-morphological element, five chemical and physico-chemical elements, and six threat elements (Table 7). Some of these indicators are considered preliminary (e.g., maximum annual water temperature, combined sewer overflows, changes in land use), and the intent is to refine them (e.g., by developing more sophisticated metrics for sewage levels, and by adding more categories for land use change), and to develop additional indicators in all areas, as the program unfolds (Table 8; Ottawa Riverkeeper 2019).

Ottawa Riverkeeper collaborated with local Indigenous communities to design the monitoring program and is engaging citizen scientists to participate in data collection. The program is in its early stages, with only a few years of data generated so far. Ottawa Riverkeeper is now developing a grading system for indicators and will produce a report card once enough data have accumulated to assess trends and patterns.

Table 7. Ottawa Riverkeeper Watershed Indicators introduced in phase one.

Category	Element	Indicator	Rationale
Ecological Status	Biological	Benthic macroinvertebrates (Hilsenhoff Biotic Indicator)	Provides integrated information on water quality and habitat conditions for aquatic life (e.g., fish) Tolerance to environmental stressors varies by taxonomic group
		Fish species richness (number of fish species present, collected through eDNA sampling)	Information on species presence is usually easily attainable Differences among locations can indicate influence of habitat type, quality and connectivity
	Hydro-morphological	Water flow (minimum and maximum river flows [m^3/s] per year, and ratio of maximum to minimum flow)	Provides context to other indicators, such as water temperature, dissolved oxygen, algal blooms, and timing of ice on and off Date of minimum flow (typically in summer) can be used to examine trends in timing of driest period of the year over time Date of maximum flow usually coincides with spring freshet and reflects contribution of melting snow and ice Ratio reflects the degree of river management. Reservoirs and dams reduce peak flows and maintain flows during low flow periods, reducing the ratio of maximum to minimum
	Chemical and Physico-	Total phosphorus (mg/L)	Limits plant and algal growth

Category	Element	Indicator	Rationale
	chemical		Excess amounts can stem from human activities such as fertilizer use, erosion, and wastewater effluents
		Dissolved oxygen (mg/L)	Essential for aquatic life (including fish, invertebrates, plants and bacteria) and for decomposition of organic waste Availability of dissolved oxygen affected by excess decaying organic matter (e.g., raw sewage), wind, water temperature, salinity, and pressure
		Maximum annual water temperature (ºC)	Linked to many other indicators, such as flow, dissolved oxygen, timing of ice on/off, algal blooms, biological populations, and changes in land use) Can inform assessment of and predictions of changes to habitat quality under climate change
		Chlorophyll-a (mg/L)	Reflects amount of algae in water, indicating trophic state, ranging from oligotrophic (very low) to eutrophic or hyper-eutrophic (excessive)
		Water mercury (mg/L)	Naturally occurring in the water (bound up in plants and sediments). Human activity can introduce excess amounts into the water column, where it is highly toxic to aquatic life
Threats to ecological	To water quality	Combined sewer overflows (the number of sewage releases)	Sewage discharge can degrade water quality, threaten aquatic life, and be a health risk for humans

Category	Element	Indicator	Rationale
status		Blue-green algal blooms (number of blooms)	Nutrient enrichment, low flow, and water stagnation (as well as sunlight and temperature) can lead to blooms, indicating the influence of human activity
	To habitat and biota	Riparian connectivity (proportion of undeveloped shoreline 25 to 50 m inland)	Indicates whether shoreline habitat is fragmented Natural shorelines provide numerous ecological functions including nearshore habitat, filtration of runoff, stabilization of soils, erosion control, and shading of aquatic habitat
		Invasive species (number of non-native aquatic species in an area)	Disrupt ecosystems, outcompeting native species and degrading habitat quality
	To water quantity, water quality, and habitat and biota	Land use change (area of land converted from one use to another over time)	Affects quantity and quality of water in the watershed, affecting biodiversity and habitat Provides context for other indicators
	Climate change	Timing of ice on/off (date ice forms and disappears from water surface)	Provides an integrated measure of the effects of warmer air temperature, warmer water temperatures, and flow on aquatic systems

Table 8. Potential indicators to be considered by Ottawa Riverkeeper in future phases of watershed monitoring.

Category	Element	Indicator
Ecological status	Biological	Threatened and endangered or culturally significant species in the watershed
	Hydro-morphological	Ecological flow indicators
		Precipitation and snowpack indicators
	Chemical and physico-chemical	Alkalinity (as $CaCO_2$)
		pH
		Conductivity
		Salts
		Metals
		Total suspended solids or Secchi disk measurements
Threats to ecological status	To water quality	Number, location, and status of contaminated sites (e.g., remediation planned or not planned, abandoned)
		Pesticides
		Persistent chemicals (e.g., per- and polyfluoroalkyl substances, or 'PFAS')
		Road salt
Socio-economic status	Human health and well-being	E. coli and beach closures
		Liability in the watershed (i.e., economic risk of existing or proposed contaminated sites,

Category	Element	Indicator
		pipelines etc.)
	Adaptation and climate resilience	Status of floodplain mapping (e.g., % of watershed with updated floodplain mapping)

3.2.3 Government of Alberta

The Province of Alberta has developed guidance on watershed monitoring and reporting for its Watershed Planning and Advisory Councils, as well as for municipal governments and community-based watershed stewardship organizations. A suite of potential indicators is presented for consideration, with the intention that a subset of indicators will be selected for monitoring in each watershed, depending on watershed-specific conditions and concerns. The guidance emphasizes the importance of determining how often indicators will be monitored and who the target audience is when designing a watershed monitoring program (Government of Alberta 2008). Indicators should encompass major components and processes of watershed health, while being measurable at a scale and frequency that is feasible. Indices, which incorporate multiple parameters (e.g., Alberta's River Nutrient Index synthesizes information on four different nutrients, dissolved oxygen and pH into a single score) are often an effective way to assess and communicate ecological condition to the public (Government of Alberta 2008). The Province lists 42 potential indicators, relating to water quality (16 indicators), water quantity (8), landscape (12) and biological community (6; Table 9). Several indicators are indices, providing composite measures of environmental conditions, such as

- River Water Quality Index, which summarizes chemical, physical, and biological data and is calculated as the overall average of the River Metals Index, River Bacterial Index, River Nutrient Index, and River Pesticide Index,
- River Metals Index, which summarizes up to 22 heavy metal concentrations,
- River Bacterial Index, which combines fecal coliform and E. coli information,
- River Nutrient Index, which summarizes a subset of total phosphorus, total nitrogen, dissolved nitrite, total ammonia, dissolved oxygen, and pH,
- River Pesticide Index, which summarizes a subset of 17 commonly used pesticides,
- Lake Level Index, which calculates lake level elevation in comparison to a standard level, and
- Index of Biotic Integrity, which summarizes fish species richness, composition, abundance and condition for different categories (e.g., total fish species, native species, sensitive fish species etc.).

Table 9. Example indicators recommended for watershed reporting in Alberta.

Element	Indicator	What Measured	Rationale
Water quality	Lake trophic status	•Total phosphorus •Chlorophyl a •Secchi-disk visibility	Indicates lake's productivity
	Nutrients	•Phosphorus •Nitrogen	May be used to assess nutrient contamination from non-point sources
	Dissolved oxygen	•Concentration •% saturation	Provides information on factors affecting the distribution and abundance of aquatic species and release and adsorption of pollutants in sediments Reflects degree of mixing of the water column
	Sediment contamination	•Total suspended solids •Turbidity	Provides information on nutrient and contamination levels, since many of these components adhere to sediment
	Wastewater loadings (municipal or industrial)	•Nutrients •Pathogens •Total suspended solids	Indicates influence of human activity
Water quantity	Lake level index	Lake level elevation vs. a standard level	Provides context for assessing other indicators related to water quality, fisheries, and recreational opportunities

Element	Indicator	What Measured	Rationale
	Deviation of recorded flows from Instream Flow Need	Recorded flow vs. scientifically determined level needed to sustain a healthy aquatic ecosystem	Characterizes stress to the aquatic system (e.g., where, when and degree)
	Floodplain presence and flooding pattern	Area of historically connected floodplain vs. area currently connected	Indicates changes to floodplain dynamics
	Hydrograph alteration	Changes in duration, timing and magnitude of •peak flow •base flow •seasonal patterns •frequency of overbank flow	Indicates changes to natural seasonal flow patterns and potential impact on flow-dependent ecosystem functions
Landscape	Wetland inventory	•Current wetland area •Wetland area lost to human activity	Indicates land use change from natural to developed state Identifies potential changes to local hydrology and water quality
	Riparian health	•Width of vegetated zone •Species composition, age structure, and % tree canopy cover of riparian zone •Extent of impervious area •Bank condition	Characterizes human disturbance on shoreline area and potential impact to aquatic health

Element	Indicator	What Measured	Rationale
	Land cover	•Impervious area •Bare area •Vegetated area by vegetation type	Characterizes habitat types and the extent and distribution of disturbed areas Amount of disturbed area vs. size of watershed provides general assessment of watershed stress
	Land use	% industrial, commercial, residential, agricultural, protected etc. areas	Further characterizes natural vs. disturbed areas Changes in land use reflect trends in human development, and may also highlight potential pollution sources
	Terrestrial habitat connectivity	Size, shape and distribution of habitat patches and corridors	Indicates degree of human disturbance and disruption to wildlife movement, viability, and sustainability
	Stream connectivity	Number and impact of culverts or other hydraulic interruptions (e.g., dams, weirs)	Indicates degree of disturbance to natural flow conditions that could degrade natural ecosystem function
	Human population	•Population density •Dwelling unit density	Indicates the general level of human pressure on the environment
Biological Community	Macrophyte community	Species composition and abundance	Provides information on aquatic condition (e.g., eutrophication)
	Benthic macroinvertebrate community	Species composition and abundance	Provides information on the cumulative effects of chemical, physical and biological factors in the watershed

Element	Indicator	What Measured	Rationale
	Individual indicator species	Presence/absence of species sensitive to human disturbance, such as Leopard Frogs, Piping Plovers, Bull Trout etc.	Indicates degree of human disturbance
	Blue-green algae outbreaks	Record of cyanobacteria blooms	Indicates eutrophication
	Invasive species	Presence of indicator species, such as Purple Loosestrife, Eurasian Water Milfoil, Quagga Mussel, Spiny Waterflea	Indicates native species stressed by invasive species

3.2.4 US Environmental Protection Agency

The USEPA's Healthy Watersheds Program provides a strategic framework for IWM at the state, tribal and local levels across the United States, with a focus on the impacts of climate change and population increase, which are recognized as the primary threats to watershed health.

The Healthy Watersheds Program offers a variety of publicly available resources for watershed protection, including the Recovery Potential Screening (RPS) tool, which allows jurisdictions and restoration planners to compare watersheds based on ecological conditions, environmental stressors, and social factors customized to the user's needs, with more than 300 watershed indicators available for review in most states and territories. The Healthy Watersheds Program also maintains the Watershed Index Indicator Library (which informs the RPS tool) a publicly available data library of watershed indicators used for evaluating, comparing, and prioritizing watersheds. Both the RPS and Watershed Index Indicator Library are regularly updated based on new information, emerging issues and changing priorities. The latest update, in December 2021 identified 68 new indicators, covering ecological, stressor, and social issues, relating to

- Critical habitat for aquatic species,
- Projected climate and hydrologic change,
- Flood inundation risk,
- Hazardous waste and wastewater,
- Pollution loading severity,
- Soil attributes,
- Traffic density, and
- Population demographics.

The USEPA has developed a Watershed Health Index to provide an integrated measure of watershed condition incorporating six elements of watershed health: landscape condition, habitat, hydrology, geomorphology, water quality, and biological condition (Table 10). The USEPA has also developed a Watershed Vulnerability Index that aggregates risks of climate change, land use and water use change to determine the potential for future degradation of watershed health.

Table 10. Examples of indicators recommended for the USEPA Watershed Health Index.

Element	Indicator	What Measured
Landscape Condition	Extent of each habitat type or ecological system	•Area •Perimeter-to-area ratio •Core area
	Landscape Composition	•Number of habitat types •Number of patches of each habitat

Element	Indicator	What Measured
		•Presence/absence of native plant communities
Habitat	Community extent	•Extent of native ecological communities •Extent of successional states
Hydrology and Geomorphology	Pattern of surface flows (rivers, lakes, wetlands)	•Flow magnitude and variability (including frequency, duration, timing and rate of change) •Water level fluctuations in wetlands and lakes
	Distribution and extent of connected floodplain	•Distribution of plants tolerant to flooding •Area flooded by 2-year and 10-year floods
Water Quality	Nutrient concentrations	•Nitrogen •Phosphorus •Other nutrients (e.g., calcium, potassium, silicon)
	Trace metals in sediments and suspended particulates	•Copper •Zinc
	pH	
	Dissolved oxygen	
Biological Condition	Population size	•Number of individuals of species
	Population structure	•Population age structure
	Signs of disease or trauma	•Presence of parasites or pathogens (e.g., in fish) •Tree defoliation

4. Summary of Public Consultation

We held a consultation session with the Community Round Table (CRT) on May 25, 2022 to solicit local perspectives on what should be measured to determine watershed health, and how to track it over time, providing local community members with the opportunity to identify priority environmental, economic, and social issues and management goals. We also contacted local community members and scientific experts for feedback, representing Friends of the Muskoka Watershed, Explorer's Edge, and the four Chambers of Commerce in the watershed (Bracebridge, Gravenhurst, Huntsville/Lake of Bays, and Muskoka Lakes).

4.1 Community Round Table Consultation

The following questions were posed to the CRT to guide discussion on what issues and goals should be integrated into the identification of watershed health indicators. A summary of responses is provided for each question.

1. *How would you describe the Muskoka River Watershed?*

The Muskoka River Watershed is a jewel that needs to be preserved in its current state, and enhanced beyond where it is right now. Compared to southern Ontario, Muskoka still retains vast beautiful natural areas. It is a world-class resource, but it's also an ecosystem that is threatened by numerous stressors, including development, climate change (and extreme weather events), and shoreline erosion. The sustainability of Muskoka's communities is also threatened. The watershed is an eclectic mix of natural areas and small towns/cities, punctuated by areas of massively overdeveloped waterfront areas and individual properties.

Water quality is of paramount importance in Muskoka because it is a primary economic driver, supporting seasonal residents, resorts, recreation, and tourism generated around our lakes. Everything is connected – if the watershed is not healthy, the waters are not healthy. Everything travels downstream and affects us all. The effects of flooding, drought and degradation of water quality all relate to how water works in the system. The ribbon of life along the waterfront is of particular importance, and shoreline buffers are key to protecting this critical habitat from development. Access to waterways is becoming more limited in Muskoka. Continued development pressures mean continued habitat loss.

We do not have a good measure of how much of the watershed is developed or held privately, and how much is responsibly developed (e.g., tree cover maintained vs. cleared). Over time it is important that the watershed be maintained in its natural state, or as close to natural as we can, so that it can respond to stressors in its full capacity, rather than in a diminished state. We should consider how the watershed responds to stressors (such as rainfall, pollution, roads, loss of continuous forest) and how that compares to development pressure in the watershed. We need to be more progressive and aggressive in obtaining land to protect from development.

2. *What are important issues of concern in the watershed?*

Climate change is a huge concern. Muskoka has been reasonably spared from wildfire damage so far, but that is not something we can count on in the future. Increased risk of drought, combined with more people moving to the area, will mean greater threat of fires threatening property and habitat.

Municipalities have had to enact fire bans for two spring seasons in a row, which could be a sign of things to come. There is not a lot of talk about fire risk in the watershed, but the issue needs to be front and centre. Multiple stressors interact to exacerbate risk as well. For example, invasive species are killing native species, especially trees, creating a lot of dead wood ready to fuel huge fires.

There are a lot of people who do not care about the natural environment, but they do care that the forest can catch fire and be out of control. We need to make people realize that areas may be destroyed for a whole generation, and that we cannot simply rebuild, plant trees, and recreate what was there before. So, we need to be thinking of how to educate the public and bring these issues to the forefront.

The status quo management of land uses in the watershed is a massive issue that must be addressed. In most municipalities, planning does not proceed with an overall watershed perspective. More and more larger scale developments are being approved without a holistic analysis of cumulative effects. We are not addressing climate change problems at the watershed scale either (e.g., flooding). If we continue to think that the status quo approach to management and planning is good enough, we are sorely mistaken. Our current land use management approach is a huge danger for the future of the watershed.

The watershed's response to certain stressors appears to be changing. We seem to be getting more flooding, and more frequent algal blooms. Forest cover is decreasing because of development and forestry. We need to consider how these changes impact other things we are measuring in the watershed.

It is important to understand what the watershed was like prior to damming of waterways. Traditional knowledge can provide critical information on baseline conditions, adding context to assessment of watershed health.

Waterfront development seems to be the sole focus of major environmental groups and cottage associations in the watershed. The latter represent the major tax base, so their concerns are the major focus of most local councils. Additional issues of concern are climate change, and the possible connection with increase blue-green algal blooms, loss of calcium and road salt impacts on water quality.

Now that most of the waterfront has been developed or redeveloped, there is too little attention being paid to supports for those providing services for waterfront properties, such as affordable housing. Nobody wants affordable housing in their backyard, but it is a definite need in Muskoka if we want individuals working in local businesses and trades. There are economic and environmental impacts of the lack of housing, including increased number and use of vehicles (as people have to travel farther to work), over-capacity septic systems, and general welfare of people. The Provincial Policy Statement directs development to "settled" areas, but many trades people would prefer to live in rural areas, and few are able to survive in Muskoka without personal transportation. Careful planning is needed to meet this need.

Another side-effect of the over-developed waterfront is that many are now developing on rural estates on backlots, but no inventory of natural heritage areas has meaningfully considered rural development (i.e., beyond the requirement that lots are kept big and on main roads). This backlot development adds additional pressure to the survival of large open spaces in Muskoka and thus threatens many species.

The CRT identified a need to document current existing conditions to help understand the current natural heritage conditions and stressors as baseline. This would include calculating percent land cover within the watershed and using this as a metric moving forward. The following additional watershed metrics were suggested:

- Percent land cover in upstream catchments where 1st and 2nd order streams originate (including wetlands, agriculture, forest, developed etc.),
- Percent wetlands in upland catchments (noting historic percentage where data available),
- Percent of stream length by stream order with 75% riparian cover for 30 m on each side and similar metrics for vegetated shorelines on lakes,
- Percent of stream length by stream order with hardened banks or bottoms (more relevant in urban than rural areas),
- Temperature monitoring stations at confluences where 2nd and 3rd order streams join 3rd and 4th,
- Monitoring salt in surface water, groundwater, and wetlands close to selected key roads, and
- Monitoring of key species as indicators or biodiversity (e.g., sensitive cold-water fish species, such as Brook Trout, as well as turtles, species at risk).

3. *What should the watershed look like in 5 years? 10 years? 25 years? What do we need to do now to achieve those visions?*

Forest cover should be preserved and enhanced. Particular focus should be given to areas in the lower watershed, where there is discontinuous forest cover now.

Natural shoreline buffers should be restored as much as possible to improve our ability to mitigate the effects of flooding and erosion, and to maintain current biodiversity.

We need to figure out what needs to be done now to keep water clean, forests healthy, and the environmental response strong, so that when we have threats like invasive species and fluctuations in temperature the watershed remains resilient to handle them. We need to learn about water fluctuations in the Muskoka River and how they are managed. We need to avoid cumulative interactions that deplete resources and make the watershed susceptible to threats. We need to learn to respect the environment, which means no clear cutting, and no blasting of landscapes. We also need to acknowledge that environmental management is needed, particularly forest management (e.g., in response to invasive species) and water quality management (e.g., in response to road salt), if we want these ecosystems to do their ecological functions effectively in a changing world.

Indigenous participation in this type of project is regenerative, and essential for a successful project in 5, 10 and 25 years from now. We need to think differently culturally as well as environmentally. There is an increasing focus on the value of Indigenous land guardians, a type of management strategy that teaches people the need to guard and protect the lands and animals. This approach would add to the success of efforts in the watershed.

In addition to characterizing current water quality conditions, we should determine what parameters have less resilience and are the “canary in the coal mine” on which we should be focusing attention. We need to investigate what stressors have greater effects on these indicators, and what causes cascading effects.

We need to recognize the goal is not only preservation, but enhancement or regeneration of areas, to make the watershed more resilient.

Socio-economic issues are a huge concern. There is a significant divide between the haves and have nots in Muskoka. It's almost unsustainable for local people to survive here. We should consider creating an equivalent of the Gross Domestic Product on a local watershed scale to be used as an indicator of economic activity. Development is part of the economy and growth, so responsible development is critical. We need to recognize that development is inevitable and learn to live with it and go forward responsibly.

We need to remember that this exercise is about people living in the watershed, as much as it is about the ecological health of the watershed. Natural assets support social and economic elements, and this needs to be quantified. A healthy watershed supports business activity, and the business community needs to be involved in this process. Municipal official plans should focus on rural development planning based on the natural heritage inventory.

One indicator that should be considered is road density, as a surrogate for water quality, since more roads generally means more road salt. Road density also reflects the degree of habitat fragmentation on the landscape.

Development cannot be avoided, but an ideal vision for the watershed is that it has a plan to consciously protect significant natural areas, even on private property by compensating owners, and sufficient large natural areas to support the wildlife that is important to our biodiversity and enjoyment of natural areas. Some natural areas should be accessible to all, but others should be restricted. First Nations should be part of the discussion of protection of large natural areas. Overall, Muskoka should be sufficiently natural to maintain its biodiversity and be attractive to visitors and residents alike.

4.2 Community Consultation

We contacted three members of the public (representing a local lake association, Explorers Edge, and the general public) and the four Chambers of Commerce in the watershed for additional feedback on watershed health priorities and concerns. All contacted members of the public expressed interest in participating in our consultation, two requesting that our questions be sent to them by email, and one requesting an interview. Two of the Chambers of Commerce also agreed to participate, one through email response to questions, and one through an interview. We sent out interview questions in June, 2022 and interviewed participants in June and July. We did not receive responses to our email questions by the time the report was prepared.

The questions posed to community participants were similar to, but slightly different from, those presented to the CRT, as detailed below.

1. *How would you describe the Muskoka River Watershed? What are its key environmental, cultural, social, economic, and historical features?*

The watershed is why we have tourism, which has been important to the region since the 1800s. The historical and economic features go hand in hand, because tourism draws people into towns, where they visit restaurants and shops, and hopefully eventually they are motivated to move up here (which was expedited because of COVID). People realize now that they can work from home here, which has positive and negative aspects.

The Muskoka River is quite a beautiful place. Culturally, there may be many cultures that live there now, but there are still 8-10 First Nation communities that live around the watershed, and in the watershed.

Swimming, drinking, and fishing come to mind when thinking about the watershed.

Muskoka is referred to as the Hamptons of the North, which is true. It's a unique watershed and a special place for us.

Historically, the area was quite decimated due to widespread logging. It is quite significant that it has changed from that landscape to today's landscape – in some respects we have stewards of the environment, but we need to make sure we continue with that protection. We are so connected to the environment here, as an economic driver for the community, and it would be a shame to lose what makes Muskoka special.

2. *What are important issues of concern in the watershed? What needs protecting? Fixing?*

The wood ash program is important because soil health translates to water health, which is critical. We need to preserve as much of the environment as possible. We need to find a balance so that people can enjoy nature, but also be invested in it, so they feel connected to it and develop a deep love for it. Many people who live here are invested in the environment because it's a love of theirs. We need to think about getting visitors invested also in projects. We need to think of everything from protecting shorelines to protecting groundwater. Everything we do in the community is connected to our watershed health. It's very important that those kinds of lessons and information get out to the public.

Obviously, the fish need to be protected because they are indicators. Other important issues include species at risk, water quality, stormwater management, shoreline erosion, and climate change. Climate change is huge, and it's not included enough when we talk about water and protection of the environment.

3. *Are there emerging issues which are not yet a problem here, but which we should be planning to address in the future?*

There is an influx of people coming into the community and we need to think of what the effects will be on the health of our water, the influx of garbage, and the increased use of trails, impacts to plants and ecosystems. The more people that come, the more opportunity to damage natural areas. We don't want to deter people from coming, but they need to be educated and make those connections.

Issues are more intertwined in the area because we are so dependent on tourism. We are all connected to tourism. We need to make that message clear to the people that are here – tourists come up here to experience our lakes, water and trees, so we need to preserve those features.

We need to look at what's happening in the Great Lakes, because that could very soon happen in our rivers (e.g., road salt, phosphorus, plastics).

The provincial government needs a much more stringent environmental protection plan. It needs to be highlighted that the provincial government has almost completely eroded environmental protection. It's a real shame. If we don't have safe potable drinking water we don't have anything. We are 70% water and as animals we all need water, for our livelihoods, to play, work and live. We need stringent protection for water, species at risk, and the watershed. We can't just fill in watersheds and build. We must look at other ways of doing things.

4. *How do you envision the watershed ideally to be in 5 years? 10 years? 25 years? What do we need to do now to achieve those visions?*

A healthy watershed would continue to involve swimming, drinking, and fishing. It would involve ensuring that the voices of First Nations are at the table and included equally. We are on treaty land and we need to follow the United Nations Declaration on the Rights of Indigenous Peoples and also the Truth and Reconciliation Calls to Action. We live in Canada, and we are all treaty people, and we need to start looking at those responsibilities and taking those steps forward.

The watershed should be at least as healthy as it is today, if not better. If we can educate people on the environment that would be huge. A healthy watershed consists of healthy waterways, trees and soil that contribute to the waterway, and a balance between people being able to experience the outdoors and protecting the environment.

We need to start education programs and tell stories in different ways. For example, we could target tourists through the visitor's centre (Bracebridge Chamber of Commerce is happy to help with this), boat museum, or at Air BnBs with material on the Muskoka River Watershed. Also, we need to target youth through school programs, reaching them early so they become ambassadors for the environment as they grow up, and teach their parents. The wood ash program is a good model because it involves residents in solving an environmental problem. It is important for people to actually see the positive results of their involvement, rather than just having people fill out surveys. We need to reach people in innovative ways—not just reports, but videos and social media, to get them invested. People want to do better, but they just don't know where to begin.

We need to lobby our current provincial government. We need to present all this research, both Indigenous knowledge research and scientific research to show what's happening to the climate, and we need to do it now, not in another four years. If we continue to mine and build in sensitive areas, we will just continue to erode our watershed health. The watershed is everything, it protects our ecosystem. Our biodiversity is at a crisis point, and people don't recognize that. We have sustainable development indicators that we all need to be looking at. There needs to be a better way to communicate and advocate to government.

5. *What indicators should be used in the Muskoka River Watershed to monitor watershed health (i.e., which allow us to understand the current state of the watershed and to identify unwanted change)?*

Scientists need to tell us what they are doing, how to interpret the science, and what the public can do to help.

Water quality, fish and bird populations, plants, shorelines, erosion, are all important indicators to measure. Are there any indicators on how to lower emissions for boating activity? How is climate change influencing everything? We need to consider mitigation and adaptation measures and how they can be used as indicators. Upkeep of infrastructure, and asset management are huge considerations for municipalities under climate change. All that information must be shared. We need adequate funding to undertake community plans and monitor watershed health indicators.

There needs to be some sort of baseline, and it should include Indigenous knowledge systems because all those stories gained through hunting, trapping and gathering on the land will tell you how things used to be, and how things are today. We need that information to gauge how we want things to be, and how we want things to continue, and how we can live in balance with nature. It's important to hear those stories to understand when the ice is melting, what birds have disappeared, how soon do birds come back in the spring, what types of fish are no longer being caught.

Science is also critical. There should be opportunities for First Nations, and youth in schools and communities to learn about and participate in water monitoring along the Muskoka River. Funding needs to be dedicated toward giving youth that opportunity. We can have surveys and studies, but the monitoring needs to be going on all the time and include youth so they can grow up wanting to protect our source.

5. *Why do you recommend these indicators?*

It's important that we track watershed health now so that in 25 years we are not in a bad situation. Indicators should be linked to economic value to garner interest from the public and levels of government. Linking to the economy is probably the easiest way to get funding to take action. A direct link between the health of our waterways and ecosystems in general and the business health of the community is crucial. We need to point out that investments now in environmental protection are really investments in our future and paint a picture of what our watershed will look like in 25 years time if we don't take action today.

The culture here is all about the cottage. People who own cottages come up year after year and have a love for the area. How do we grow that love and make sure they have an interest in stewardship and a view to preservation? How do we connect with cottagers and get them invested? They are a big contributor to gasoline, boats, and shoreline condition.

We should investigate opportunities for collaborating and information sharing. There are a lot of organizations working on similar issues and areas, and doing great work (e.g., Swim Drink Fish, Waterkeepers, the conservation authorities). How can all that information be more readily shared, so that not everyone is working in their silos? We also need to take our time, communicating and learning about the issues. People are interested and it's just a matter of having the time to have those conversations.

4.3 Scientific Consultation

We contacted two local scientific experts and both agreed to participate in the consultation process. We sent them questions by email. One participated in an interview, and the other provided answers to the questions by email.

The questions posed to local scientific experts were similar to, but slightly different from, those presented to the CRT and community members, as detailed below.

1. *What are the main valued ecosystem components (VECs) for the Muskoka River Watershed (i.e., aspects of the ecosystem that have scientific, social, cultural, economic, historical, archaeological, or aesthetic importance)?*

One local scientific expert objected to this question, stating that, at a time when we are trying so much to understand First Nations philosophies and approaches to nature, to focus on VECs without any reference to the inherent value of living ecosystems is an enormous oversight. The focus should not be on VECs that treat nature as a commodity for humans. We must value ecosystems for their own inherent worth, not because of their worth to us.

Several scientific VECs were identified:

- The Dorset Environmental Science Centre (DESC) and its long-term set of study lakes are provincial, if not, national treasures, in terms of what they have taught us about the watershed.
- Some of the western Algonquin Park lakes that have been studied for years and have generated important datasets are extremely valuable.
- The mixed hardwood forests of the Land Between are valued ecosystems. Moving north from Toronto, these are the first large semi-intact landscapes, that have inherent value both for the life that is there and as corridors to the north for plans and animals to escape the effects of climate change.
- Water quality in its own right, is representative of a Precambrian Shield watershed, where it is a function of the unique combination of geology, wetlands and forested catchment. In turn, water quality supports the habitat of a diverse assemblage of aquatic species.

Intact mixed hardwood forests and clean lakes are the main tourism attraction in Muskoka, and tourism is our main economic driver. Water quality is the cultural centrepiece of our economy. The watershed itself could be considered a VEC, as an integrator of natural and anthropogenic influences that determine the water quality throughout Muskoka.

2. *What environmental/ecological indicators should be used in the Muskoka River Watershed to monitor watershed health?*

The first compliance indicator for the state of science in the watershed is DESC. We need stable funding and staffing of this national treasure to ensure that it can continue to do important science.

In the 1980s, the Ministry of Environment (Air Resources Branch) established large-scale forest bio-monitoring plots across the Haliburton/Muskoka/Nipissing/Parry Sound region that were sampled every few years until fairly recently to assess forest health. Numerous indicators were tracked in these plots, including a tree health index (which was a function of leaf size, leaf chlorosis, and number of dead branches). The long-term data provided useful information on watershed health, and the program should be resurrected.

One target we should aim for is that seven generations from now we still have 50% of the watershed as intact forest. Research that was conducted as part of the lake capacity research in Ontario from the 1970s found that as long as 50% of the landscape is forested, the songbird and amphibian biodiversity will be ok. This target needs to be applied at a quaternary watershed scale, so that large protected areas such as Algonquin Park do not constitute the full 50%, allowing other parts of the watershed to be completed deforested.

Drones could be used to help track the health of forests. Citizen science could also play an important role. For example, community volunteers could take standard photographs of the same trees every year for 100 years. Think of how powerful imagery was in Sudbury, showing the recovery of the landscape over time from acid rain. The same approach could be used in Muskoka to track recovery from acid rain and calcium decline, and citizens could be invited to be involved.

The key parameters to track water quality as a VEC are largely in use now but should be applied on a broader scale in a systematic fashion:

- Total phosphorus integrates stress to the watershed from a variety of natural and human sources (land clearing, wastewater discharge, urban runoff) and increases over time or in specific areas as an index of population growth coupled with management activities.
- Dissolved organic carbon (DOC) is a master variable driving phosphorus concentrations from natural sources as well as water clarity and can be linked to changes in wetland dynamics and hydrology. It is an important interpretive parameter.
- Major ions (especially calcium and chloride) indicate changes in aquatic health either through their low levels (calcium as a response to acid rain) or increases from road salting for de-icing (chloride). Chloride can almost serve as a proxy for watershed hardening and alteration (Utz et al. 2022) and has reached harmful levels in many Muskoka lakes.
- Total suspended solids indicate input from runoff or erosion as stressors and can be used to determine causes of high bacterial and phosphorus levels.
- Bacterial indicators (E. coli) should be approached with caution as their concentrations are highly variable (they occur in clumped distributions or associated with solids), they are added by natural and human sources and interpretation of the occasional sample on a routine basis (i.e., outside of a focused study) is challenging. Nevertheless, trend analysis at select places in the watershed is a useful metric.
- Trace metals are not recommended for routine monitoring in the absence of known sources or reasons for concern. Measurement is required as part of routine operations at wastewater treatment plants and occasional (annual) measurements at select places in the watershed could inform any trends over the long term.
- Organic contaminants are not recommended for routine monitoring in the absence of known sources or reasons for concern. Measurement is required as part of routine operations at wastewater treatment plants and occasional (annual) measurements at select places in the watershed could inform of any trends over the long term. While pesticides are no doubt used in the watershed there is not a large agricultural industry in Muskoka and any concerns could be better addressed by stewardship and education to landowners. A trend analysis at select places in the watershed could be a useful metric.
- Biological monitoring

    - Outside of the educational value, one local scientific expert saw little merit in routine benthic biomonitoring outside of studying specific outfalls or sources. Thirty years of benthic biomonitoring in lakes has shown us that the community varies with the habitat type and the expert was hard pressed to see that as a useful management application.

- The algal community in Muskoka has been poorly documented and is becoming increasingly important as the number of nuisance cyanobacterial blooms increase. The efforts of the Muskoka Watershed Council to develop standardized estimates of total algal and cyanobacterial abundance are useful but more specific quantification of community makeup by species and seasonality of species succession would be useful. This is probably better addressed in a research program focused on bloom causation which could develop rationale and methods for routine monitoring.
- Fish monitoring – there are two reasons to monitor fish on a routine basis: as environmental indicators and as input to sport fish management. The latter is the mandate of MNRF. For the former, there is merit in developing an environmental monitoring program focused on fish as integrators of all watershed stressors. Surveys assessing fish health indicators in small fish have been widely used in Canada and standard methods and analyses are readily available (Barret and Munkittick 2010, Gray et al. 2018). Small fish will integrate all water quality stressors on the Muskoka River system and may be especially useful as sentinels of organic contaminants (i.e., from road runoff). Unlike water chemistry indicators which look for concentrations of harmful stressors (which must then be interpreted to see if they are problematic), fisheries surveys look for direct impacts which can then lead to detailed water quality assessments to determine causation.

The standard chemistry parameters that DESC and the District Municipality of Muskoka measure in their water quality monitoring program are worthwhile for tracking long-term change (and issues that develop slowly), but they fall short in addressing rapid change, such as why we're experiencing hazardous algal blooms in the fall. There are only two locations in the watershed where we monitor frequently enough to capture such rapid events, but those locations are not in places where those datasets would be most instructive, such as shallow bays where blue-green algae proliferate. We need a completely different approach for monitoring emerging conditions and stressors.

Citizen scientists can be part of the solution with shoreline monitoring as well. For example, the public could be enlisted to take standard photographs of riparian zones over time, which would reveal details on shoreline condition.

Ice reporting is also very beneficial, spread out across the watershed. Another relatively simple indicator could be a blackfly severity index, which could reveal the extent of streamwater recovery from acidification (research shows that the incidence of blackflies rose by as much as 100-fold in streams that recovered from acid rain). Although we love to hate blackflies in Muskoka, their prevalence could be a good news story for acidification.

Other important diagnostic indicators to consider include the movement of boats, surface water temperatures (through use of automated HOBO recorders, which are relatively inexpensive), and late summer bottomwater oxygen measurements. We should also rely more on meteorological data, especially wind data, as this could help predict the risk of algal blooms (i.e., when little or no wind surface waters will not mix in lakes, creating ideal conditions for blooms to develop). We should also consider ways to measure defoliating pests (like spongy moth and fungal pathogens). Soil acidity and low calcium levels are still the biggest chemical threat to forests, so we need to be tracking those parameters, in relation to climate (e.g., drought).

Citizen science offers a tremendous opportunity to get the public more involved with studying watershed health. We need to find a way to organize efforts among various organizations monitoring emerging issues (i.e., DESC, MWC, Friends of the Muskoka Watershed, District Municipality of Muskoka, and Muskoka Lakes Association). We should probably start with hazardous algal blooms because that is a concern of cottagers.

3. *Do you have any thoughts on how to incorporate cumulative effects into watershed indicators?*

We should assume that we're going to get it wrong. We absolutely will be surprised by what happens to watershed health, so we need to prepare for those surprises. One way is to maintain sample banks that we can return to in future to review. Paleolimnology is useful that way because zooplankton and algal samples are preserved. But water and soil samples should be preserved as well in specially maintained archives (e.g., water in sealed glass ampoules). The Experimental Lakes Area did this, allowing them to go back to test samples as new questions emerged. It is important to be able to go back in time after something goes wrong or surprises us and search for answers in the archive.

A photo archive is also an important archive for looking back in time, for standard tree and riparian areas.

It's also helpful to always ensure that sampling sites are unimpacted, such as unimpacted lakes and forests, because changes year over year can then be linked to weather and long-term changes in climate, rather than other confounding factors.

The Muskoka River itself can be used as an indicator of cumulative effects if a monitoring program was designed with that as a focus. The Muskoka River is the major artery of the watershed and a river-focused monitoring program is feasible in the absence of any other significant tributaries. A monitoring program that included regular and systematic sampling at key points along the river – from upstream in Algonquin Park to the outflow of Lake Muskoka at Bala (Figure 12), would be capable of detecting changes over time and over space, and of identifying key stressors or areas of stress (i.e., urban centre influences, natural changes with watershed position, highway influence) which could then be used to develop focused causation studies.

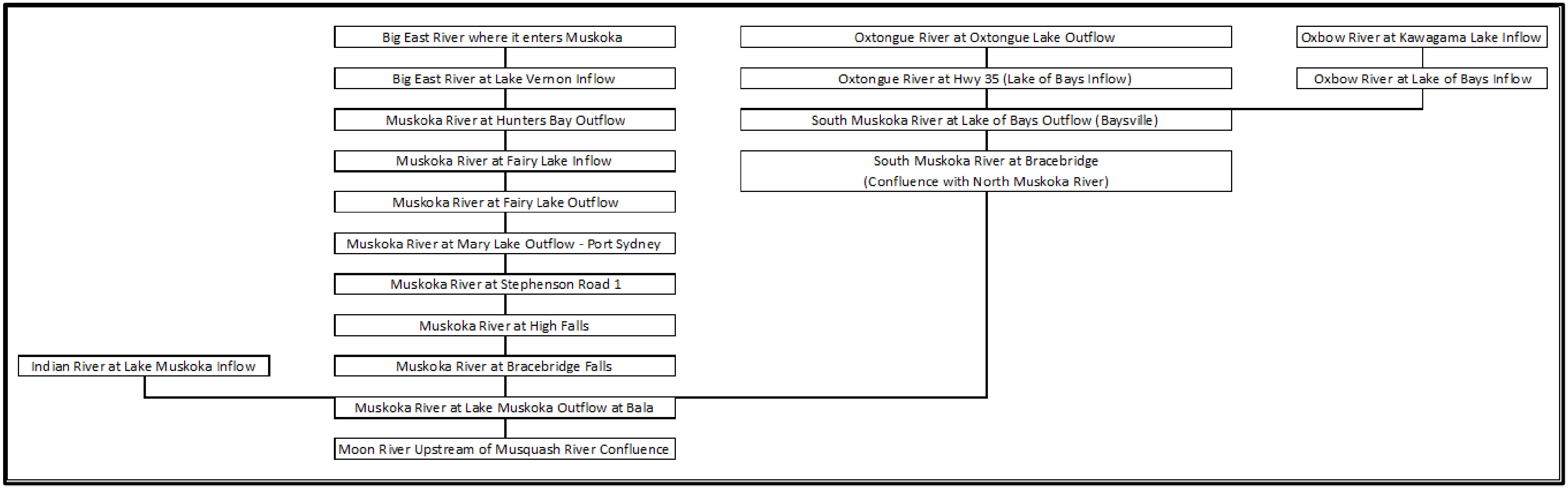

Figure 13. Potential watershed sampling sites.

4. *What are the main environmental stressors you are concerned about in the Muskoka River Watershed?*

The most serious gap and stressor is the lack of consideration of the inherent worth of nature in watershed planning and monitoring. It is inconsistent with how people are thinking these days. We need to value the inherent worth of nature and figure out how to measure it.

Climate change is the key concern, through its impact on lake dynamics (thermal stratification), ice cover, extreme heat events in shallow surface waters, algal dynamics, snow and winter rain and implications for extreme flooding, wetland health (drought and flooding), forest health and changes in the forest community, invasive species, and extreme weather events. Most of the effects of climate change are cumulative, interactive, and indirect, although some of Muskoka's lakes are getting hot enough that they are likely leading to direct mortality of organisms (e.g., Daphnia die at 28ºC and some of our brown water lakes are reaching 28-29ºC). The effects of other stressors, like road salt, calcium decline, and drought are exacerbated when it gets that hot and dry. The big cumulative effect on forests is drought in summer, and that will have a huge impact first on ground vegetation.

Unrestricted and unplanned development/land clearing is a significant problem in Muskoka. Most development planning here is done in a piecemeal fashion, on a case-by-case basis, without any kind of overarching vision of where we want to be seven generations from now. We need to be thinking of what we want our grandchildren to see on the landscape.

It is ironic that the "Muskoka lifestyle" of wealth and consumption is a major contributor to the problem. This stressor is not ecological, but social and behavioural – a combination of many people, intensive activities (loud and fast boats) and changes to the landscape wrought by large cottages, large resorts, and large-scale alterations which have urbanized the landscape and changed the character of Muskoka.

The Norwegian approach offers a good example of what we should be striving for. Every county in Norway has a county biologist whose job is to protect the local biology, and every development proposal must be approved by not only the regional economic planner, but also the regional biologist. We give lip service to biology in every regional zoning bylaw update, but we have economic planners, not biologists, on staff (although the hiring of the District's Climate Change Initiatives Coordinator is a good first step).

We need to value our forested landscape and take advantage of the fact that 85% of the watershed is forested. Why wouldn't we want that forest to do much of the heavy lifting in protecting our lakes? Take phosphorus levels as an example. Phosphorus levels in the rain are two to three times higher than in our oligotrophic lakes, so where is that extra phosphorus going? It goes to our forests. If there are no forests, then all that phosphorus will end up in our lakes, and our lakes will become mesotrophic or eutrophic. Then we will have no forests or lakes to enjoy. The two go hand in hand. If we protect the forests, we go a long way to protecting our lakes. But we don't think like that, and that's a mistake. The forest is a filter, so let's protect it and it will protect the water. The stupidest things we can do is kill our zooplankton with road salt and low calcium and cut down all our forests. That is just a guarantee of a miserable environment.

We need to recognize the importance of place. When you've been living in the same place for 5000 years you truly understand the landscape, and know that every place is unique, and everything about that place matters, and is connected to culture and history. Attachment to place is divorced from western planning, but it needs to be reintroduced into our mindset.

There are interesting spatial components of stressors in Muskoka, which vary depending on the stressor. Calcium decline affects half our lakes and all our forests. Road salt affects about 20% of our lakes, a number which is projected to increase. Calcium decline is mainly a problem in the northeastern part of the watershed and does not affect Lake Muskoka at all (because people have been adding calcium there to make up for the loss through wood ash, limestone, gardening). Salt levels, in contrast are falling in the northeast because natural levels are declining, but salt levels are increasing in other parts of the watershed where people live.

Invasive species are a problem in both forests (e.g., Emerald Ash Borer, Hemlock Adelgid) and lakes (e.g., Spiny Waterflea, bass).

5. *Are there emerging stressors which are not yet a problem here, but that we should be planning to address in future?*

Pharmaceuticals and other novel chemical mixes (e.g., 100,000 new chemicals added to the environment every year) are a concern, as well as microplastics. The rising incidence of hazardous algal blooms formed by novel causes is an emerging issue, and how these blooms are linked to climate change.

Any program should proceed from a clear and accepted statement of purpose or problem formulation such as "*Have human activities in the Muskoka River Watershed resulted in changes to the accumulated environmental state?*". Stating the problem in this manner does not presuppose the stresses that may be present but can guide the selection of indicators, the degree of change considered acceptable (significance threshold) and the spatial design of any monitoring program.

Although municipal wastewater is well managed in Muskoka, urban runoff is an unknown and ignored stressor that will become increasingly important as the population, urban areas and commercial areas and road traffic grow. A first step should be to identify and map all urban runoff outfalls to surface water and quantify the loadings of various pollutants that they represent (solids, phosphorus, chloride, hydrocarbon residues, bacteria).

5. Analysis of Key Metrics and Monitoring Approaches

The Muskoka River Watershed is recognized as a "jewel to be protected" because its many lakes, forests, wetlands and rock barrens are relatively intact and in good condition, compared with watersheds to the south, which are mainly dominated by urban and agricultural landscapes. The health of the watershed is critical to protect not only for its own intrinsic value, and because it supports rich biodiversity (including many species at risk), but also because a well-functioning watershed provides many important ecosystem goods and services humans depend on, including regulation of water flow, soil formation, carbon storage, and nutrient cycling (USEPA 2022). The vast forests and clean lakes that characterize Muskoka are also a major tourism attraction, and tourism is a major economic driver in the region. Degrading or destroying this natural jewel is thus counterproductive on many levels.

Nevertheless, Muskoka is threatened by an array of stressors, many of which interact to create additional, and often unforeseen, negative impacts. In general, threats to the watershed arise from development pressures (initially along waterfronts and in urban areas, but increasingly within inland rural areas as well) and climate change. A recurring theme from our local consultation was that the watershed needs protecting to maintain its resiliency in the face of these pressures, and that this will require a paradigm shift from the status quo approach to land use planning in the region.

Before we can adequately protect the watershed, however, we need to understand its current condition, what elements are changing, and why. Watershed indicators are effective tools for documenting watershed health because they provide a simplified approach to describing an inherently complicated system, acting as surrogates or proxies of multiple watershed features and functions that are more difficult or impossible to quantify. Tracking watershed health depends on determining baseline conditions (so that change over time can be measured) and identifying targets (to measure progress toward a goal) and thresholds (to warn of the need for management action). As stated in Section 1.2, watershed indicators selected for use should be measurable, comparable, consistent, and relevant to the watershed being monitored, as well as

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

We sought to identify indicators best suited to the Muskoka River Watershed based on the above criteria and a review of

- existing knowledge of the health of the Muskoka River Watershed,
- approaches to measuring watershed health used by other jurisdictions,
- priority environmental, economic, and social issues and management goals identified by local community members and scientific experts.

5.1 Key Considerations

While we attempted to cover a wide range of research, jurisdictions, and local opinions on watershed health in a systematic and unbiased manner, we acknowledge that our approach was not able to encompass all information or views on the subject. A criteria-based ranking (CBR) process for selecting and prioritizing watershed indicators was developed by Ho (2018) in the Muskoka River Watershed to standardize the identification of indicators so that they were broadly representative of stakeholder priorities. We recommend that the CBR process (which involves stakeholders ranking indicators based on a series of criteria; Table 11) be applied to narrow down the longlist of indicators we identify in this report to a manageable and meaningful shortlist that addresses community needs, concerns, and priorities. The CBR process allows participants to rank indicators by importance using a series of questions for each indicator (e.g., via SurveyMonkey) on a scale of 1 (least) to 5 (most). The sum of individual participants' scores for each criterion are then summed to rank indicators overall, with the highest total scores representing the higher ranked indicators. If a pre-determined number of indicators is identified for the shortlist, then these indicators can be selected based on the highest ranked scores. For example, if 10 indicators were decided as a manageable number to monitor, then the shortlist would consist of the top 10 highest scoring indicators from the longlist. Indicators can also be weighted differently if participants determine that this is warranted (Ho 2018).

Table 11. Example criteria-based ranking process to prioritize watershed indicators (Ho 2018, Ho et al. 2018). Each potential indicator is assessed through a series of criteria statements on a scale of 1 (strongly disagree) to 5 (strongly agree).

Potential Criteria	**Potential Indicators**			
	Algae	Calcium	Land Use	Wetland Cover
I would include this indicator in watershed health monitoring				
This indicator is measurable given reasonably expected resources (e.g., tools, people, funds, time)				
We have control over changes to this indicator				
We have effective mechanisms for correcting current unwanted changes to this indicator				
We have effective mechanisms for correcting future unwanted changes to this indicator				
Unwanted changes to this indicator would result in serious impacts (directly or indirectly) on ecological and human systems				
This indicator is important to me				
Total Score				
Ranking				

We also emphasize the critical importance of reconciliation with Indigenous peoples in the process of identifying and monitoring watershed indicators in the Muskoka River Watershed. As Wong et al. (2020) stated "*Reconciliation requires a new way of conducting natural science, one that includes and respects Indigenous communities, rights, and knowledge leading to better scientific and community outcomes*" (p. 769). Indigenous knowledge of the environment and observations of change over time and space provide an invaluable resource for documenting and tracking watershed health. Indigenous perspectives can enrich our understanding of the watershed, and strengthen our capacity to protect it by diversifying our knowledge base to more than just information collected through Western science. At the same time, collaboration and engagement with Indigenous communities in the monitoring of watershed health provides First Nations peoples (particularly youth) with opportunities to experience and participate in the natural sciences, a field in which they are traditionally under-represented (Wong et al. 2020). Early engagement with Indigenous communities is key to a successful process, since Indigenous knowledge, concerns, and priorities should inform the design and implementation of watershed health monitoring.

Citizen science can be an important component of a watershed health monitoring program, enabling broader and more consistent spatial and temporal coverage in a cost-effective manner. At the same time, engaging the public in monitoring can help educate people on local watershed issues and build support for and involvement in watershed protection and management (Conrad and Hilchey 2011). While not all indicators are well suited to community-based monitoring (e.g., % coverage of different land uses and habitat types gained through GIS data), many parameters of interest to watershed health can be effectively monitored with the assistance of citizen scientists, included water quality measurements (e.g., through the provincial Lake Partner Program) and forest and shoreline conditions (e.g., through photographs).

5.2 Identification of Longlist of Indicators

Our review identified all three types of indicators (condition, pressure, and response), encompassing physical, chemical, biological and socio-economic attributes of watersheds. Inclusion of a broad array of indicators from across these categories will provide a comprehensive picture of watershed health that more accurately captures the dynamics and complexity of the system, and the stressors acting on it. In particular, it is important to include a range of attributes, since biomonitoring data integrates information on long-term ecological conditions, while physical/chemical data presents only a brief snapshot (USEPA 2022). Furthermore, measuring a suite of indicators describing both conditions and stressors can help pinpoint underlying causes of unwanted changes (USEPA 2002).

The key natural features that define the Muskoka River Watershed are water, forest, wetlands, and biodiversity. Climate change and development are the overarching stressors influencing these natural features and their ecological functions, manifested through the additional (and interactive) pressures of algal blooms, road salt, calcium decline, invasive species, biodiversity loss, habitat loss and fragmentation, and land use change. Monitoring of watershed health should thus attempt to encompass the main environmental components of the watershed, and the main environmental stressors.

Based on our assessment of watershed conditions and priority issues, and review of approaches used elsewhere, we recommend the following longlist of watershed indicators (Table 12). We have divided the indicators into two main categories: Ecological Status and Threats to Ecological Status. We identified 14 indicators under Ecological Status, representing Water Quality, Water Quantity, Biological Condition (Aquatic and Terrestrial), and Landscape Condition. We identified 15 indicators under Threats to Ecological Status, representing Threats to Water Quality, Threats to Biological Condition, Threats to Landscape Condition, Climate Change, and Cumulative Effects.

Many of the parameters are already monitored within the watershed (e.g., surface water quality), but the frequency and spatial distribution of sampling may need to be adjusted to provide useful watershed-level data. For example, algal blooms are commonly reported in late summer and early fall in Muskoka, after monitoring has usually ended for the season. Predicting the occurrence of these late-season blooms has so far proved elusive, but use of high-frequency automated monitoring in key locations may help elucidate causes.

We have recommended individual metrics as indicators, however, many jurisdictions have found that indices, incorporating multiple parameters, provide a useful way to integrate numerous measures into a single indicator. For example, the Government of Alberta recommends using an Index of Biotic Integrity (IBI) to determine biological health based on community structure for a particular taxonomic group (e.g., fish, algae, macroinvertebrates, vascular plants, or a combination of these taxa). For fish, an IBI might include data on abundance (total number of fish), diversity (number of fish species), trophic interactions (e.g., number of species in different feeding guilds, such as insectivorous, piscivorous, generalist, etc.), and fish condition (e.g., number of individuals with signs of disease or abnormalities). IBIs provide a direct measurement of the impact of human activity on biological communities in the watershed because they compare observed conditions to what would be expected in the absence of human disturbance (AESRD 2012).

Indices can be effective at distilling a large amount of related information down to a single value, which can help in communicating to the public on watershed health. However, indices eliminate information on individual parameters, and possible interactions among variables, and thus may be less sensitive than individual metrics (Government of Alberta 2008). They are also typically designed to be watershed-specific, based on an assessment of individual watershed priorities and data availability. We believe that a determination of whether indices should be developed and used to monitor watershed health in the Muskoka River Watershed would be appropriate at the next stage of the project when a shortlist of indicators is selected.

Table 12. Recommended longlist of watershed indicators.

Category	Element	Indicator	Rationale	Monitoring Approach
Ecological Status	Water Quality	Total phosphorus	Reflects impacts from a variety of natural and human sources Increases over time or in specific areas reflect population growth and human activity	Throughout watershed
		Dissolved organic carbon	Influences phosphorus concentrations from natural sources and water clarity Reflects changes to wetland dynamics and hydrology	
		Dissolved oxygen	Reflects ability of aquatic system to support life Can indicate presence of organic pollution and nutrient enrichment	High frequency automated monitoring as part of targeted sampling (e.g., in lakes with low phosphorus and algal blooms initially) or at a minimum, end of summer measurements
		Water temperature	Reflects climate change Provides context for other indicators	High frequency automated monitoring in lakes throughout watershed, as well as at confluences where 2nd and 3rd order streams join 3rd and 4th order streams, respectively

Category	Element	Indicator	Rationale	Monitoring Approach
	Water Quantity	Water flow (minimum and maximum river flows, ratio of maximum to minimum flow)	Reflects influence of climate change and river management Provides context to water quality and climate change indicators	At key sites along the Muskoka River and its tributaries (e.g., see Fig. 13), from upstream (Algonquin Park) to outflow of Lake Muskoka (Bala)
	Biological Condition - Aquatic	Benthic macroinvertebrates	Integrate long-term ecological conditions Composition varies with habitat, which may confound any stressor signal	Targeted sampling at specific outfalls or sources (e.g., near development) and more widespread sampling once reference conditions determined
		Fish species richness (especially sensitive cold-water species)	Fish integrate all water quality indicators and may indicate organic contamination (i.e., from road runoff)	eDNA or netting
		Brook Trout (presences/absence)	Reflects health of coldwater habitats because species is sensitive to environmental changes Requires very clean cold water with high levels of dissolve oxygen Does not tolerate acidity or turbidity	In coldwater streams (e.g., headwater tributaries)
	Biological Condition - Terrestrial	Tree photo archive	Reflects tree condition	Citizen scientists take standardized photographs of the same trees annually throughout watershed
		Riparian photo archive	Reflects riparian condition	Citizen scientists take standardized photographs of the same riparian area annually throughout watershed

Category	Element	Indicator	Rationale	Monitoring Approach
	Landscape Condition	% Forest cover	Indicates degree of natural cover and extent of development	Throughout watershed using SOLRIS data layer
		% Forest interior	Indicates how much forest is shielded from edge effects	
		% Forested riparian zone	Indicates degree of natural forest cover along shoreline	
		% Wetland cover	Indicates degree of natural cover and extent of development	
Threats to Ecological Status	To Water Quality	Calcium	Reflects changes to aquatic health (via legacy of acid rain) Lakes in Muskoka are experiencing calcium decline affecting aquatic biota	Throughout watershed
		Chloride	Reflects increases from road salting for de-icing Represents a proxy for urban development (watershed hardening and alteration) Lakes in Muskoka are reaching harmful levels for aquatic biota Reflects changes to aquatic health (via legacy of acid rain) Lakes in Muskoka are experiencing calcium decline affecting aquatic biota	Throughout watershed in surface water, groundwater, and wetlands close to selected key roads (e.g., Highways 11, 60, 118, 141)
		Total suspended solids	Reflects input from runoff or erosion	Throughout watershed

Category	Element	Indicator	Rationale	Monitoring Approach
			Can indicate sources of high bacterial and phosphorus levels	
		E. coli	Can indicate contamination due to human activity Due to difficulties in interpretation (caused by patchy distributions), targeted sampling (at limited number of sites) for general trends recommended	Targeted sampling
		Blue-green algal blooms	Reflects nutrient enrichment and impacts of climate change A concern for water quality and human health Nuisance algal blooms may be increasing in Muskoka	High frequency automated monitoring and remote sensing for early detection from August – October (when blooms are most commonly reported) Monitoring at downwind sites and beaches (where greatest interaction of people with water)
	To Biological Condition	Species at Risk (number of endangered, threatened and special concern species)	Integrates effects of multiple stressors on native biodiversity	Throughout watershed (e.g., through surveys and review of resources such as the Natural Heritage Information Centre, NatureServe Canada, Ontario Breeding Bird Atlas, Ontario Reptile and Amphibian Atlas, eBird, iNaturalist, Fisheries and Oceans Canada Aquatic Species at Risk Map, Early Detection & Distribution Mapping System Ontario)
		Invasive Species (number of invasive aquatic and terrestrial species)	Indicates stress to native species and habitats	

Category	Element	Indicator	Rationale	Monitoring Approach
		Soil acidity	Reflects legacy of (and recovery from) acid rain Indicator of forest health	In provincial forest biomonitoring plots used to track forest health in Muskoka in the 1980s
		Calcium	Reflects legacy of (and recovery from) acid rain Indicator of forest health	
	To Landscape Condition	Riparian connectivity (width of naturally vegetated zone within 25 to 50 m inland)	Indicates degree to which natural shoreline is intact	Throughout watershed using SOLRIS data layer
		% Land cover (e.g., forest, wetlands, urban area, agriculture, golf courses, impervious vs. pervious etc.)	Indicates land use change over time Provides context for other indicators	
		Road density	Indicates magnitude of development, degree of habitat fragmentation, and risk of road salt contamination to aquatic systems	
		Fragmentation (% of watershed comprised of natural areas >200 ha)	Reflects extent and magnitude of development	
	Climate Change	Time of ice on/off	Reflects influence of climate change	On lakes throughout watershed
	Cumulative Effects	Muskoka River water quality	Integrates cumulative effects of stressors across watershed over time	Regular and systematic sampling of water quality at key sites along river, from upstream (Algonquin Park) to

Category	Element	Indicator	Rationale	Monitoring Approach
				outflow of Lake Muskoka (Bala)

6. Recommendations

We make the following additional recommendations for monitoring watershed health:

Identification of Shortlist of Indicators

1. Use a standardized approach (such as the criteria-based ranking process) to narrow down the longlist of recommended indicators to a manageable shortlist based on consultation with the CRT, local scientific experts, and other stakeholders.

Reconciliation

2. Consult with the First Nations and tribal council in the Muskoka River Watershed on opportunities to engage and collaborate with their communities on watershed monitoring and protection.

3. Seek Indigenous knowledge on baseline conditions and changes to the watershed, and Indigenous perspectives on priorities and concerns.

4. Investigate opportunities to partner with First Nations on conservation and monitoring in the watershed (e.g., through initiatives such as the Land Needs Guardians[5] campaign).

5. Investigate ways to involve Indigenous communities (especially youth) in watershed monitoring.

Outreach and Public Education

6. Consider ways to connect with tourists, cottagers, and local businesses to educate and engage with them on the importance of watershed health and how it is linked to their activities (e.g., information on watershed health and monitoring initiatives in Muskoka could be available at local visitor's centres).

Collaboration, Funding and Support

7. Consult with Conservation Ontario for information on its efforts to streamline watershed monitoring and investigate whether this approach could be applied in Muskoka.

8. Investigate opportunities to collaborate with other local organizations doing similar work, such as the Dorset Environmental Science Centre, Muskoka Watershed Council, Friends of the Muskoka Watershed, and Muskoka Lakes Association to strengthen monitoring efforts and avoid duplication.

9. Ensure sufficient resources (i.e., financial, logistical, expertise) are available to support the implementation, analysis and interpretation of the recommended indicators through securement of long-term funding and partnership arrangements.

[5] *https://landneedsguardians.ca/*

10. Recognize the crucial role that the Dorset Environmental Science Centre (DESC) plays in providing scientific expertise and resources to identify, monitor, analyze and interpret watershed health indicators in Muskoka, by ensuring it receives adequate and stable funding and staffing to continue its important scientific research over the long term.

Citizen Science

11. Involve citizen scientists in the monitoring of watershed health.

12. Support existing citizen science monitoring in the watershed, such as the MWC's Algae Monitoring Program.

Research on Indicators

13. Investigate indicators used to track emerging contaminants relevant to the Muskoka River Watershed (e.g., active pharmaceuticals, personal care product additives, pesticides, engineered nanomaterials, microplastics, and PFAS).

14. Engage with university partners to investigate the feasibility of using diatoms (either from periphyton or surface sediment samples) as a road salt indicator. While diatoms are sensitive to road salt, monitoring them is labour intensive and requires taxonomic expertise, thus partnering with academic researchers would be ideal.

15. Establish a reference condition approach to determine what benthic macroinvertebrate communities look like in minimally disturbed areas of the watershed, so that samples can be compared to these reference conditions (i.e., to determine if a site is "disturbed"). This could be achieved by sampling a range of minimally impacted sites identified through GIS and other information (e.g., presence/absence of dams or aquatic invasive species) across the watershed.

16. Identify what indicators are less resilient to stressors and should thus be closely monitored for early detection of unwanted changes.

17. Investigate indicators used to track boating activity.

Targeted Monitoring

18. Identify and map all urban runoff outfalls to surface water and document baseline conditions for various pollutants (e.g., solids, phosphorus, chloride, hydrocarbon residues, bacteria). Incorporate monitoring of runoff at these sites as an indicator of development.

19. Consider targeted monitoring (e.g., of water quality) in areas facing high levels of development (e.g., in both urban and rural areas).

20. Investigate the possibility of re-launching the large-scale forest biomonitoring program that tracked forest health on plots throughout Muskoka in the 1980s.

Sample Archives

21. Consider establishing sample archives (for water and soil samples) to allow retrospective analysis of watershed conditions as new issues, concerns, and analytical capabilities emerge in future.

7. List of Sources Contacted

Note that additional sources were contacted for feedback, but only those who responded are listed here.

Project Component	**Source**	**Date of Consultation**
Review of Muskoka River Watershed	Community Round Table (16 participants)	May 25, 2022 August 24, 2022
	Local Community Member	June 27, 2022
	Local Community Member	July 7, 2022
	Local Scientific Expert	June 23, 2022
	Local Scientific Expert	July 11, 2022
Review of Other Jurisdictions	Conservation Ontario	July 20, 2022
	Conservation Sudbury	July 15, 2022
	Lakehead Region Conservation Authority	July 14, 2022
	North Bay – Mattawa Conservation Authority	July 15, 2022
	Otonabee Conservation	July 7, 2022
	Ottawa Riverkeeper	July 20, 2022
	US Environmental Protection Agency	July 15, 2022

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