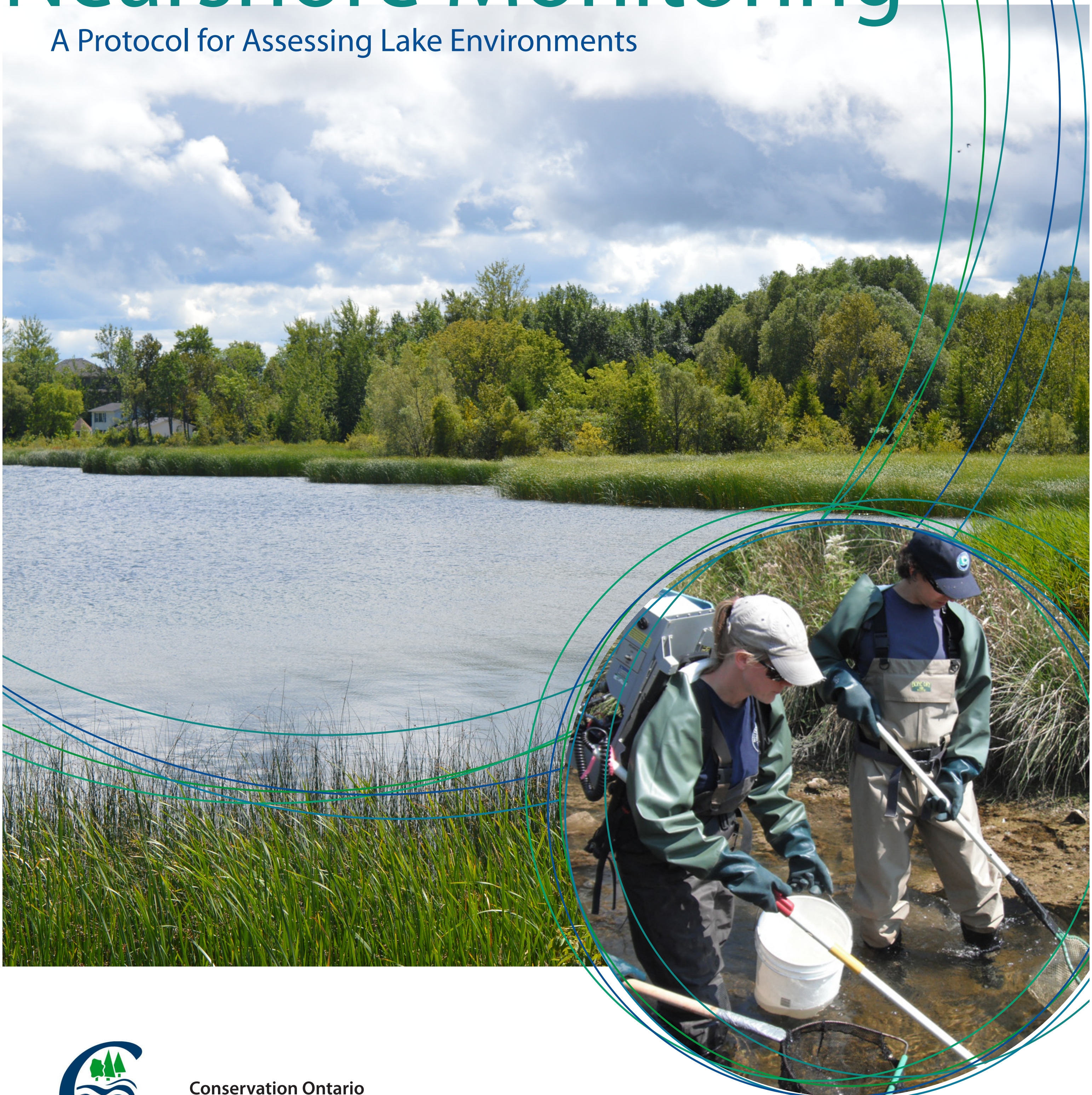
Nearshore Monitoring

A Protocol for Assessing Lake Environments



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Executive Summary

This report represents the sixth deliverable from Hutchinson Environmental Sciences Ltd. (HESL) for the Nearshore Monitoring Protocol Project, presenting the final Nearshore Monitoring Protocol. The final report is comprised of the background literature review of nearshore monitoring approaches and the development of the Nearshore Monitoring Protocol, based on the literature review, our professional knowledge and experience, as well as consultation with the Project Advisory Team, and other stakeholders and experts.

Conservation Ontario wishes to develop a Nearshore Monitoring Framework (the "Protocol") to improve environmental information for decision-making. The Protocol is intended for specific application to southeastern Georgian Bay and ultimate expansion to include the rest of Lake Huron and other parts of the Great Lakes. It includes "lessons learned" and perspectives on monitoring large lakes, particularly Lake Simcoe and the Great Lakes. The Protocol documents standard methods and recommends considerations for the development of programs to characterize the nearshore area, identify stressors and issues, and undertake field collection, data analysis and assessment. The Protocol is designed to be adaptable to localized conditions, as well as different degrees and types of impacts from the contributing watershed. Additionally, it is flexible to varying levels of capacity and expertise, which may change based on the organization or agency using it. The Protocol incorporates the concept of adaptive management, so that assessment of its effectiveness and subsequent improvements to its approach, are built in as regular parts of the process.

The development of the Nearshore Monitoring Protocol was informed by a literature review of monitoring approaches for the nearshore and guided by consultation with an Advisory Team consisting of representatives from Conservation Ontario, Ausable Bayfield Conservation Authority, Conservation Halton, Credit Valley Conservation (CVC), Essex Region Conservation Authority, Lake Simcoe Region Conservation Authority (LSRCA), Nottawasaga Valley Conservation Authority (NVCA), Toronto and Region Conservation Authority (TRCA), and the Ontario Ministry of the Environment and Climate Change (OMOECC). We also consulted with LSRCA to learn about its nearshore monitoring program. The Georgian Bay Biosphere Reserve provided comments on a draft version of the Protocol.

Over 100 documents were reviewed in the course of our research, covering approaches currently used in Ontario, Canada and internationally to monitor benthic invertebrates, zooplankton, fish, *Cladophora*, macrophytes, periphyton, phytoplankton, physical and chemical water quality, physical and chemical sediment quality, shoreline observations, tributary influence and coastal processes.

The Protocol was developed by creating a decision-making framework to guide users through a series of steps to select the best monitoring variables to use based on consideration of numerous criteria, including issues of concerns (i.e., stressors or human uses of the nearshore), habitat, nearshore characteristics, significance and sensitivity of particular variables, and capacity and resources of the monitoring organization. This framework is intended to narrow down the wide variety of monitoring choices available to users to a manageable subset representing the most effective, feasible and appropriate suite of variables recommended for their particular goals and objectives. The Protocol also provides guidance to prioritize the top variables to use in cases where there are resource or financial constraints.

Once the variables have been selected, the Protocol provides specific instructions on methods and equipment to use for monitoring. Research (both literature review and consultations) was completed on each variable to identify standardized widespread approaches that were well-tested and commonly used for monitoring. If none were available for a particular monitoring variable, approaches were selected that were at least part of a single regular monitoring program (e.g., LSRCA Standard Operating Procedures, SOPs) or research study. Where no standardized approach existed professional experience with nearshore monitoring was drawn on to highlight recommended approaches. All information was summarized into brief factsheets for each monitoring variable, discussing advantages and disadvantages, sampling methods and equipment, sampling considerations (e.g., water depth, need for boat access), habitat that can be monitored, time of year for sampling, sampling effort required, options for data assessment, quality assurance/quality control (QA/QC) procedures and how the Protocol can be adapted to meet differing levels of capacity and resources. An example scenario was provided in Appendix A to illustrate how the Protocol can be applied to real world issues.

Relatively few standardized approaches to monitoring were documented for the variables we reviewed, and none specifically designed for the nearshore environment. Our findings and recommendations fill in a major gap in research methods for the nearshore environment and reinforce the need for a consistent robust monitoring framework as human pressures on the nearshore continue to grow in the future.

Table of Contents

List of Figures

List of Tables

Abbreviations

Term	Description
AIS	Aquatic invasive species
ANOVA	Analysis of variance
AOC	Areas of concern
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
CVC	Credit Valley Conservation
EMAN	Ecological Monitoring and Assessment Network
ECCC	Environment and Climate Change Canada
GLWQA	Great Lakes Water Quality Agreement
HESL	Hutchinson Environmental Sciences Ltd.
IPZs	Intake protection zones
LSRCA	Lake Simcoe Region Conservation Authority
MDLs	Minimum detection limits
MTRI	Michigan Technical Research Institute
NOAA	National Oceanic and Atmospheric Administration
NSCIN	Nearshore Community Index Netting Program
NVCA	Nottawasaga Valley Conservation Authority
NWRI	National Water Research Institute
OABP	Ontario Algal Bioassessment Protocol
OBBN	Ontario Benthos Biomonitoring Network
OMNRF	Ontario Ministry of Natural Resources and Forestry
OMOECC	Ontario Ministry of the Environment and Climate Change
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PSQGs	Provincial Sediment Quality Guidelines
PWQOs	Provincial Water Quality Objectives
QA/QC	Quality assurance/quality control
SOPs	Standard operating procedures
SLIN	Spring Littoral Index Netting Program
SQI	Sediment Quality Index
SRP	Soluble reactive phosphorus
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TRCA	Toronto and Region Conservation Authority
USACE	US Army Corps of Engineers

Glossary

Term	Definition
Habitat	An area of the nearshore that has distinct physical features (e.g., sandy beach, exposed bedrock, wetland etc.) supporting specific ecological functions.
Indicator	A metric that provides information on an environmental variable.
Method	A specific technique used to sample a particular biotic or abiotic variable either directly in the field (e.g., grab sampler for benthos) or indirectly through surrogate measures using existing models or data (e.g., for wind speed or water levels to characterize coastal processes)
Nearshore	A zone which will vary but generally extending: • lakeward from the high water mark to beyond the breaker zone, encompassing an area of nearshore currents formed primarily by wave action, and to • the offshore depth of light penetration or the deepest depth at which the thermocline intersects with the lakebed in late summer or fall, to • the immediate riparian, to • the local contributing watershed (technically not part of the nearshore, but the Protocol needs to address its influence on the nearshore) With emphasis on: • the "wadeable" littoral area of a lake, which is easily accessible because of its proximity to shore and shallow depth, and thus can be sampled readily, and is the part of the nearshore most exposed to influences from the immediate terrestrial environment and most heavily used by humans.
Protocol	Toolbox of standardized monitoring variables and methods for collection, analysis and assessment of environmental data to identify stressors and responses and a process for their selection and use in developing programs for characterizing the nearshore and documenting the impact of anthropogenic activities in the watershed on the nearshore environment.
Stressor	An anthropogenic or natural agent of change that disturbs the structure, composition and/or function of an ecosystem.
Variables	Measurable components of the environment (biological, physical and chemical) that respond to stressors and thus provide quantitative or qualitative information on ecological condition, and the presence and impact of stressors. Examples of variables include various measures or syntheses of: benthic invertebrate community structure (biological), water quality (physical and chemical), sediment quality (physical and chemical), and shoreline observations (physical).

1. Introduction

The nearshore is a dynamic and complex area linking terrestrial and aquatic environments. The nearshore represents a transition zone, influenced both by the waters of the offshore and by land use and drainage from watersheds reporting to the nearshore either directly or through watershed influence on streams or rivers that discharge to the nearshore (Makarewicz and Howell 2012). Anthropogenic activities in the local watershed (such as urban development, agriculture and shoreline alteration) first impact a lake in its nearshore, where tributaries, surface and groundwater flows transport water, sediment and nutrients from land to water (LMANFTT 2015). Nearshore waters provide numerous goods and services to society, including safe drinking water, recreational opportunities, water withdrawals for industry and power generation, and wastewater assimilation. They also support a wide variety of plant and animal species (LMANFTT 2015).

There is a growing recognition of the environmental and socio-economic importance of the nearshore and the need to protect it from ongoing and emerging threats. The updated 2012 Great Lakes Water Quality Agreement (GLWQA), for example, committed to developing an integrated nearshore framework by 2016 to address continuing ecological degradation of Great Lakes nearshore waters, through coordinated and systematic restoration, protection and prevention activities (LMANFTT 2015). The framework aims to increase understanding of the state of the nearshore while engaging all levels of government, as well as communities and non-governmental organizations, in its stewardship. Through these actions, it is hoped that the framework will improve the resilience of the Great Lakes nearshore, reduce the cumulative effects of human activity on it, increase its sustainable use and raise awareness of its value (LMANFTT 2015).

1.1 Project Rationale and Objective

The federal Great Lakes Nearshore Framework highlights the lack of a coordinated and comprehensive approach to nearshore management as a serious threat to the health and productivity of the Great Lakes (LMANFTT 2015). Part of the problem is that monitoring of the nearshore occurs in a patchwork manner. Numerous organizations and agencies currently conduct monitoring in the nearshore of Ontario lakes (e.g., federal and provincial ministries, municipalities, conservation authorities, universities, consultants and non-governmental organizations), but no standardized approach to nearshore monitoring exists in the province. This lack of uniformity across monitoring programs makes comparison of environmental conditions, problems, trends and management approaches a challenge among projects, watersheds and jurisdictions. The patchwork approach can mean that patterns are overlooked and linkages are not made, which ultimately can translate into weak or non-existent policy (CCME 2006).

Conservation Ontario wishes to develop a Nearshore Monitoring Protocol for southeastern Georgian Bay (which is transferable to the rest of Lake Huron and to the other Great Lakes) to improve environmental information for decision-making. The Protocol is to include "lessons learned" and perspectives on monitoring large lakes, particularly those from Lake Simcoe and the other Great Lakes. The Protocol will document standard methods to characterize the nearshore area and to conduct field collection, data analysis, assessment and identification of stressors and issues. The Protocol, however, is not to be exhaustive in its review of monitoring methods applicable to the nearshore, but instead should be more selective, focusing on evaluating those methods which are commonly used, well-established and well-tested. The Protocol is to be adaptable to localized conditions, as well as different degrees and types of impacts from the contributing watershed. Additionally, it is to be flexible to varying levels of capacity and expertise, which may change based on the organization or agency using it. The Protocol should be designed to incorporate adaptive management, so that assessment of its effectiveness and subsequent improvements to its approach, are built in as regular parts of the process.

Conservation Ontario identified eleven environmental variables, which either influence or could be measured in the nearshore, to be addressed by the Nearshore Monitoring Protocol. We added the filamentous green algae *Cladophora* to the list, since it is an emerging concern in many nearshore waters of the Great Lakes, is the subject of numerous specific investigations that integrate nutrients, water clarity and benthic organisms (Dreissenid mussels) and warrants detailed attention. The full suite of environmental variables reviewed for the Nearshore Monitoring Protocol are summarized in Table 1.1.

Table 1.1. Monitoring variables reviewed for the Nearshore Monitoring Protocol.

Biotic	Abiotic
Benthic invertebrates	Physical and chemical water quality
Zooplankton	Physical and chemical sediment quality
Fish community and habitat	Shoreline observations (natural characteristics and degree of alteration
Cladophora	Tributary influence (spatial extent of physical and chemical influence)
Macrophytes	Coastal processes (e.g., circulation and currents)
Periphyton	
Phytoplankton	

1.2 Project Approach

The development of the Nearshore Monitoring Protocol was informed by a literature review of monitoring approaches for the nearshore and guided by consultation with an Advisory Team consisting of representatives from Conservation Ontario, Ausable Bayfield Conservation Authority, Conservation Halton, Credit Valley Conservation (CVC), Essex Region Conservation Authority, Lake Simcoe Region Conservation Authority (LSRCA), Nottawasaga Valley Conservation Authority (NVCA), Toronto and Region Conservation Authority (TRCA), and the Ontario Ministry of the Environment and Climate Change (OMOECC). We also consulted with LSRCA to learn about its nearshore monitoring program.

We summarized our findings from the literature review and consultation with LSRCA in the draft Literature Synthesis Report (November 13, 2015). These results were presented to the Advisory Team at a workshop on November 27, 2015. A draft Table of Contents for the Protocol was submitted to the Advisory Team (December 18, 2015). Feedback from the workshop, as well as comments on the Table of Contents, were incorporated into the development of the draft Nearshore Monitoring Protocol.

A second workshop was held in February 2016 to present the draft Protocol to the Advisory Team. The final Protocol incorporated information gained through research and consultations and was completed in March 2016. The final Protocol will be presented to lake and watershed monitoring practitioners at a third workshop in April 2016. We will develop a factsheet for the public summarizing nearshore issues and describing the final Protocol in April 2016.

1.3 Defining the Nearshore

A key first step in the development of the Nearshore Monitoring Protocol is establishing a working and defensible definition of the nearshore. The protocol must consider what techniques can be used successfully in the nearshore and proceed from a solid understanding of the processes that influence nearshore water quality and aquatic ecology. Our experience in previous projects shows that:

- offshore processes may be significant in a) diluting nearshore stressors or b) replacing nearshore waters with offshore water masses through wind, wave, current and seiche activity;
- nearshore water quality in exposed areas of the large lakes does not generally differ from offshore water quality except where rivers or large wetlands discharge to the nearshore;
- the influence of biological processes such as filtering by Dreissenid mussels may be equally or more significant than large point sources in determining nearshore water quality;
- stormwater flows from large urban areas may have significant influence on nearshore water quality over and above tributary inputs;

- large embayments of lakes may create a nearshore zone of their own and can have a direct influence on the nearshore zone of the main water body; and

- habitat structure (e.g. input of woody debris or sediment) is a strong determinant of invertebrate and fish community structure and may confound interpretation of impacts from water quality stressors.

These, and other factors, must be considered in defining the nearshore and subsequent development of the Nearshore Monitoring Protocol so that it can be used to select methods that are best suited to specific sites and concerns and to distinguish among nearshore, watershed and open water processes and responses.

We recognize that defining the nearshore is a challenging task, and that its boundaries and extent vary depending on a variety of factors. A consistent approach to identifying the nearshore is required, however, to enable spatial and temporal comparison of monitoring results. It is useful to apply a set of criteria to delineate the nearshore on a case-by-case basis to ensure standardization within and among studies.

Our working definition of the nearshore is a zone that will vary but will generally extend:

- lakeward from the high water mark, where physical stressors (e.g., shoreline hardening) may alter energy dissipation from waves or impede species access to land or water, to beyond the breaker zone, encompassing an area of nearshore currents formed primarily by wave action, and to

- the offshore depth of light penetration (the littoral zone, where stressors may alter light penetration, alter fish habitat or introduce contaminants) or the deepest depth at which the thermocline intersects with the lakebed in late summer or fall, to

- the immediate riparian zone where onshore disturbances may add solids or pollutants or alter shade or habitat structure, to

- the local contributing watershed (technically not part of the nearshore, but the Protocol needs to address its influence on the nearshore through a spatial program design centred around tributary discharges to the nearshore).

The design of an effective Nearshore Monitoring Protocol is strongly influenced by the resources available to monitoring agencies, as well as health and safety considerations. Not all agencies have the equipment or budget to sample the entire nearshore zone. Additionally, health and safety requirements may limit the spatial extent of monitoring (e.g., scuba diving may be restricted to shallow waters, larger boats mandated for deeper waters etc.). In such cases, nearshore monitoring is limited to the portion of the nearshore zone that is easily accessible. Our consultations with the Project Advisory Team indicated there the Nearshore Monitoring Protocol should have an emphasis on the wadeable portion of the nearshore, defined as:

- the part of the nearshore that is easily accessible because of its proximity to shore and its shallow depth, and thus can be sampled readily, and which is most exposed to influences from the immediate terrestrial environment and is most heavily used by humans.

The Federal Nearshore Framework considers the nearshore zone to extend from the coastal margin to a depth of approximately 30 m offshore in the Great Lakes (10 m in Lake Superior). The Framework emphasizes that the concept of the nearshore zone is a fluid one. Zones of influence (where problems originate) and zones of impacts (where problems are detected) are dynamic, constantly blurring the boundaries of the nearshore (LMANFTT 2015). The definition, as well as the protocol itself, must therefore be adaptable.

1.4 The Adaptive Monitoring Process

The main goal of the Nearshore Monitoring Protocol is to provide a toolbox of methods for assessing the impacts of watershed, shoreline and nearshore activities on the nearshore environment and a systematic means to review study objectives in order to select the most appropriate set of tools.

The Nearshore Monitoring Protocol has been designed according to the concept of adaptive monitoring, in which the toolbox of monitoring approaches is flexible and adaptable to different environments, as well as varying levels of expertise, capacity and information requirements. Adaptive monitoring is a process or roadmap which considers the receiving environment, the potential stressors and their pathways to the receiver, as well as the potentially affected receptors for any site-specific application. It then draws on a toolbox of proven methods and selects the best tool for a given problem or area of interest. The Protocol has a tiered structure, allowing users to modify it as appropriate to suit particular goals and objectives, habitats to be monitored, stressors and uses to be assessed, and capabilities and resources available. The Protocol incorporates the following guiding principles to achieve this comprehensive and adaptive design, based on the Canadian Council of Ministers of the Environment (CCME) Guidance Manual for Optimizing Water Quality Monitoring Program Design (CCME 2015):

- selection of recommended sampling methods that are rigorous, repeatable and well-documented;

- prioritization of methods based on an evaluation of significance (i.e., address goals and objectives and monitor variables most sensitive to stressor(s) of interest); cost and equipment needs, logistical demands (i.e., ease of sampling, temporal frequency and spatial coverage), health and safety requirements; and adequacy of quality assurance/quality control (QA/QC) procedures;

- ability of methods to be modified based on the technical abilities, resources and information needs of users.

Adaptive monitoring is not, therefore, a prescriptive method, but rather a structured and semi-formal process to (in the words of the Request for Proposal) *"standardize an approach to monitoring that can be adapted for localized issues in the study area".*

In addition to being adaptive in its own design, the Monitoring Protocol should be used as part of a monitoring program based on adaptive management. This approach uses monitoring as a tool to focus management goals through an iterative process (CVC 2015). Initially, monitoring generates baseline information that helps identify management goals, while ongoing monitoring then investigates whether management action is effective (CVC 2015) and increases or decreases in intensity and scope depending on the findings and the needs for follow up. Adaptive management therefore depends on a regular assessment of the success of a particular approach, and the ability to adjust the approach based on changing needs, knowledge, goals, resources and environmental conditions (CCME 2015).

We developed an adaptive monitoring flow chart to guide our design of the Nearshore Monitoring Protocol and to illustrate how the Protocol fits within the context of an adaptive management approach (Fig. 1.1). The process beings with identifying the specific nearshore environment of interest and the problem or issue of concern for that environment. The area of focus could be broad (e.g., Southeastern Georgian Bay) or fine scale (e.g., coastal wetlands, beaches or rocky shoreline) depending on the monitoring goals. Delineating this receiving environment may require a two-step approach, in which monitoring is conducted at a broader scale first to document the status, general trends and stressors of the aquatic ecosystem, followed (if needed) by finer scale monitoring to identify specific problems or areas of interest. For conservation authorities the nearshore monitoring area will obviously need to align with their area of jurisdiction, which may vary among authorities.

Once the nearshore area of interest has been identified, and the problem or issue of concern defined, the next step is to establish the goals and objectives of a monitoring program (which may be influenced by both scientific considerations and public concerns). A clear articulation of the goals and objectives is crucial for determining the overarching purpose of the monitoring program, which will guide its initial design, as well as progress and evolution over the long-term. Monitoring goals refer to broad environmental management outcomes (e.g., "protect ecological health", "identify degraded or threatened areas", "restore fish habitat" or "support aquatic recreational activities"), while objectives are more specific descriptions of the intent of these goals (e.g., “eliminate aquatic invasive species” or “maintain water quality conditions for swimming” etc.; CCME 2015).

Goals and objectives need to be realistic and quantifiable, so that the information collected directly applies to the problem or issue of concern, and leads to concrete management decisions and actions to address it. CVC (2015) recommends that goals and objectives be specific, measurable, achievable, results-oriented and applicable over the relevant time-frame (i.e., ‘SMART’). CCME (2015) further suggests that objectives be detailed enough that they can be translated into specific statistical requirements for the data (e.g., desired precision, confidence, types and amount of variability and detectable trend). Monitoring goals and objectives of conservation authorities should fit within their mandates and have the support of conservation authority boards, as well as local municipalities, for the greatest chance of success.

The next stage in the process of designing a monitoring program is to evaluate what resources are available to carry out the desired work. Resources to be considered include skills, funding, equipment and personnel. It is often beneficial to seek out partnerships to maximize the effectiveness and scope of monitoring. Collaborating with local, regional, provincial and/or federal partners can yield many advantages, including information exchange, coordination of sampling, access to equipment and personnel, and cost savings (CCME 2015). Even if partnerships are not made, communication with other agencies conducting monitoring in the same area is key to avoiding duplication and ensuring methodologies are compatible (i.e., so that results can be compared). In addition, knowledge of other monitoring initiatives in the study area can provide valuable background information on local conditions, stressors, trends and patterns, which could influence study purpose and design. Data-sharing agreements can be negotiated with other monitoring organizations to promote widespread dissemination of findings, which will help fill data and information gaps and strengthen the scientific rigour of monitoring initiatives (CVC 2015).

Once the background planning has occurred, the adaptive monitoring process moves to the toolbox of proven methods that we have identified as part of this project. At this stage, the goal is to select the best tool to monitor the problem or issue of concern in the nearshore area of interest. We have developed a decision tree to guide the user through the Protocol selection process, which is informed by what habitats are being monitored and stressors assessed, as well as additional considerations such as cost, ease of use, health and safety and QA/QC considerations. More details on Protocol selection are provided in Section 5.

Implementing the selected monitoring approach occurs next, followed by data analysis, review and interpretation of results and reporting on findings. At this point it is also important to critically review the monitoring approach by evaluating whether it meets the initial needs, goals and objective of the program. Problems and issues may change over time, as may monitoring goals, objectives and resources. The monitoring approach should be flexible enough to respond to these changes through modifications to overall monitoring design (e.g., switch to different monitoring variables, change sampling frequency or extent) or methodology (e.g., switch to different methods for a particular variable) and to incorporate new improved technology as it emerges (Lovett *et al.* 2007).

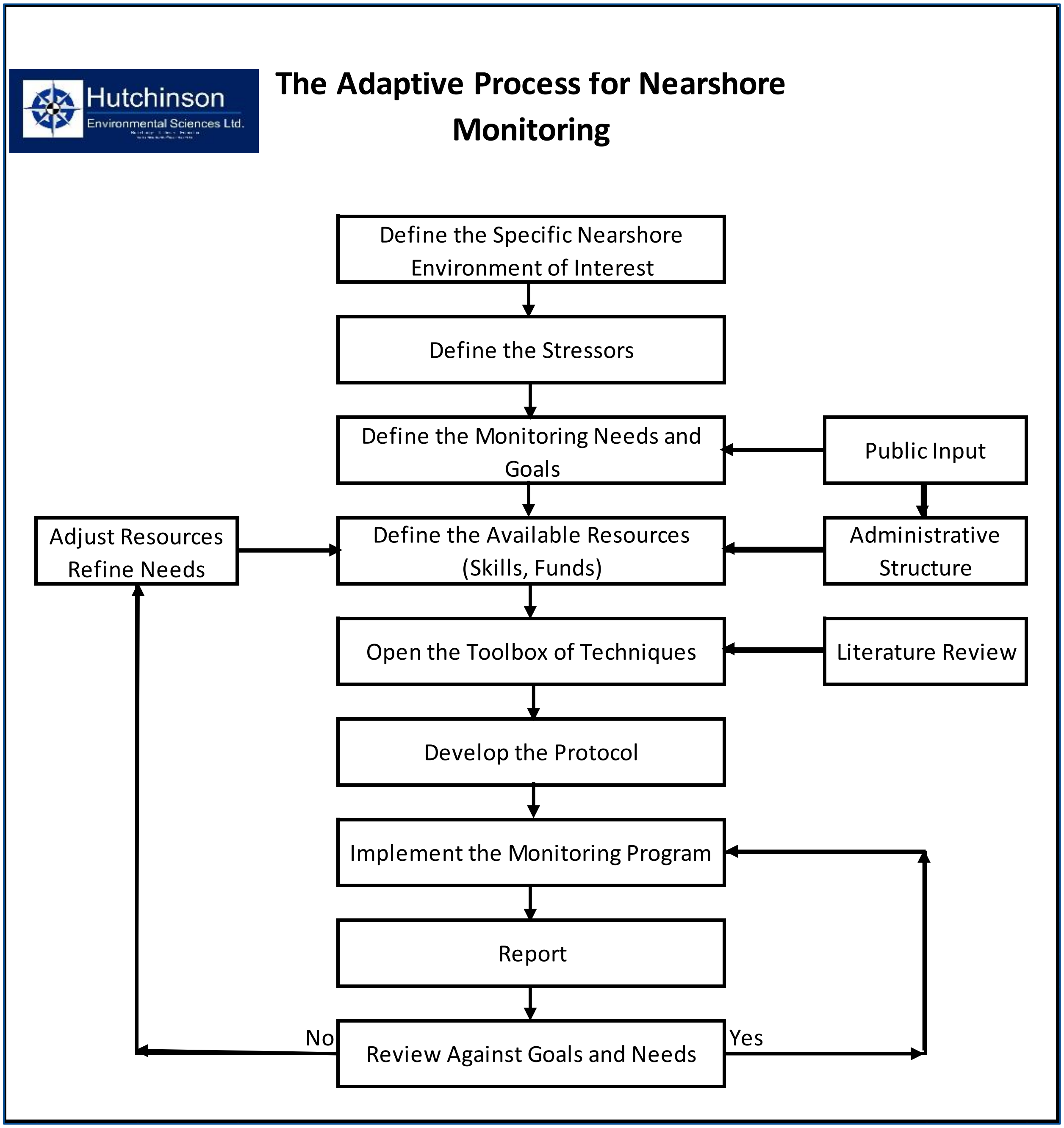

Figure 1.1. Conceptual process for the development of the Nearshore Monitoring Protocol within an adaptive management framework.

1.5 Stressor Identification

A number of primary stressors arising from anthropogenic activity can directly or indirectly impact the nearshore through a series of secondary stressors. For example, urban development (a primary stressor) can directly impact the nearshore hydrologic regime and nearshore water quality by replacing natural vegetation with impervious surfaces (a secondary stressor), leading to increased stormwater runoff and subsequent flooding, erosion, sedimentation and surface runoff contamination. This can result in impacts to the nearshore, including degraded water quality, habitat degradation and loss of biodiversity. Urban development can also create indirect impacts to the nearshore through discharge of runoff to streams in the watershed and subsequent discharge of the streams to the nearshore.

Monitoring for the effects of primary and secondary stressors requires identification of the ecosystem variables that will be impacted, and then selection of appropriate indicators or metrics to detect change in these variables. In the example given above, watershed variables affected by impervious surfaces could include water quality and quantity, which would have an impact on the nearshore that could be assessed by measuring metrics such as water quality parameters (e.g., total phosphorus, total dissolved solids, turbidity) or benthic or periphyton community structure.

The identification and selection of methods for monitoring environmental indicators is a key component of the Nearshore Monitoring Protocol toolbox. We have compiled a list of stressors, variables and indicators that the Monitoring Protocol should assess, focusing on the main issues characterizing watersheds of southeastern Georgian Bay (Table 1.2). This list helped guide our review of the literature and our identification of best techniques for monitoring the nearshore environment.

Table 1.2. Examples of stressors on the nearshore environment, variables and indicators used to measure their impacts.

Primary	Secondary	Impacts	Variables	Indicators
Land use activities directly impacting nearshore (e.g., urban, commercial, industrial development)	• increase in impervious surfaces • contaminated surface water runoff • direct discharge from municipal wastewater treatment plants • vegetation removal • erosion • sedimentation • flooding • shoreline hardening	• change in water quality • changes to biodiversity, community dynamics and structure • habitat loss or alteration • changes to hydrologic regime • changes to ice cover period • changes to water temperature	• water chemistry • flow • water quantity • sediment transport • geomorphology • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• total phosphorus, nitrate, ammonia, E. coli, turbidity, total suspended solids, pharmaceuticals, temperature, conductivity • increased extreme flows and reduced low flows • rate and amount of siltation • rate, amount and location of erosion • dredging volumes (permits) • biotic indices/metrics of community composition, richness, tolerance
Land use activities in watershed of tributary discharging to nearshore (e.g., urban development, agriculture, aggregate extraction, infrastructure)	• contaminated surface water runoff • natural vegetation removal • erosion • sedimentation • flooding • pesticide runoff • increased tile drainage • increased row cropping and mono-culture • buffer strip loss or reduction	• change in water quality • changes to biodiversity, community dynamics and structure • habitat loss • changes to hydrologic regime	• water chemistry • flow • sediment transport • water quantity • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• total phosphorus, nitrate, ammonia, E. coli, turbidity, total suspended solids, temperature, conductivity • increased extreme flows and reduced low flows • rate and amount of siltation • biotic indices/metrics of community composition, richness, tolerance

Primary	Secondary	Impacts	Variables	Indicators
Land use change – Recreational activities (e.g., ATVs, beach use etc.)	• disturbance of habitat and species • sedimentation • hardening of surfaces and increased imperviousness • introduction of invasive species • vegetation removal • contaminated surface water runoff	• changes in water quality • changes in biodiversity, community dynamics and structure • habitat loss	• water chemistry • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• total phosphorus, nitrate, ammonia, E. coli, turbidity, total suspended solids, temperature, conductivity • rate and amount of siltation • rate, amount and location of erosion • biotic indices/metrics of community composition, richness, tolerance
Land use change -Water management (e.g., diversions, enclosures, groynes, marina basins)	• low or fluctuating water levels • water level regulation • altered circulation patterns • fill and drainage of wetlands	• changes to hydrologic regime • changes to nearshore sediment composition • changes to biodiversity, community dynamics and structure • habitat loss	• flow • geomorphology • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community • water chemistry	• increased extreme flows and reduced low flows • rate and amount of siltation • rate, amount and location of erosion • dredging volumes • biotic indices/metrics of community composition, richness, tolerance
Harvesting of biological resources (e.g., logging, fishing)	• vegetation removal • erosion • sedimentation • overharvesting	• change in water quality • changes to biodiversity, community dynamics and structure • habitat loss	• geomorphology • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• turbidity, total suspended solids • rate and amount of siltation • biotic indices/metrics of community composition, richness, tolerance

Primary	Secondary	Impacts	Variables	Indicators
Invasive species	• habitat alteration • competition, predation of native species • nutrient transformation and enrichment (e.g., from mussels)	• change in water quality • changes to biodiversity, community dynamics and structure • habitat loss	• water chemistry • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• total phosphorus, dissolved phosphorus, turbidity, total suspended solids • biotic indices/metrics of community composition, richness, tolerance
Climate change	• temperature extremes • extreme winds • changes in precipitation • changes in storm magnitude, frequency, direction • increased surface water temperature • increased surface water evaporation • low or fluctuating water levels • altered circulation patterns • reduced ice cover	• change in timing of water quantity delivery • change in water quality • changes to biodiversity, community dynamics and structure • habitat alteration and loss • wetland alteration and loss	• water chemistry • water quantity • water temperature • precipitation • evapotranspiration • benthic invertebrates • zooplankton • fish community and habitat • macrophytes • periphyton • phytoplankton • riparian plant community	• total phosphorus, nitrate, ammonia, E. coli, turbidity, total suspended solids, temperature, conductivity • increased extreme flows and reduced low flows • rate, amount and location of siltation • rate, amount and location of erosion • dredging volumes (permits) • ice-free period • biotic indices/metrics of community composition, richness, tolerance

(Mackey 2012; CVC 2015)

1.6 Southeastern Georgian Bay Nearshore Environment

Conservation Ontario and NVCA plan to use southeastern Georgian Bay as a case study for application of the Nearshore Monitoring Protocol, with the intent that the Protocol will subsequently be transferable to other parts of the Great Lakes. We have interpreted southeastern Georgian Bay as extending from Owen Sound to the French River, extending the definition provided by the Lake Simcoe/South-eastern Georgian Bay Clean-Up Fund of Environment and Climate Change Canada (ECCC) to include a full diversity of nearshore environments and add areas of intensifying human development from Wasaga Beach to Owen Sound. This region is characterized by a remarkably diverse geology, ranging from limestone and granite cliffs to sand and cobble beaches, dunes, wetlands, bedrock shores and river mouths. The nearshore environment provides important habitat to a wide variety of plant and animal species, serving as feeding, spawning and nursery habitat for fish, and as key stopover habitat for migratory birds (Franks Taylor *et al*. 2010; Donnelly 2013). Nearshore habitats in Georgian Bay are considered biodiversity hotspots and are among the most productive areas in all of Lake Huron (Franks Taylor *et al*. 2010).

Much of southeastern Georgian Bay (i.e., south of Port Severn) is highly developed compared to more northern parts of the Bay, and is increasingly dominated by agriculture, urban and cottage development. As a result, anthropogenic pressures on the nearshore are growing. Critical threats to the nearshore environment include development, dredging and shoreline hardening, all of which can degrade and destroy habitat, disrupt coastal processes, alter nutrient cycles and impair water quality (Franks Taylor *et al*. 2010). Much of the Lake Huron nearshore is sensitive to eutrophication (LimnoTech 2015). Climate change and the introduction of invasive aquatic species further threaten the ecological integrity of nearshore areas of southeastern Georgian Bay (Featherstone and Fortini 2011; LMANFTT 2015). Climate change (combined with glacial rebound) has led to low water levels in the nearshore, degrading and eliminating critical fish habitat (LimnoTech 2015). Introduced Dreissenid mussels and the invasive fish species Round Goby (*Neogobius melanostomus*), meanwhile, are implicated in the redirection of energy flow from offshore to nearshore zones (referred to as the 'nearshore/benthic shunt'). The efficient filtering action of Dreissenid mussels has also led to drastic reductions in spring diatom biomass in Lake Huron, and is apparently linked to *Cladophora* infestations along the southeastern shoreline over the past 40 years (LimnoTech 2015). At the same time, persistent toxins that were prevalent in Lake Huron waters in previous decades have shown continuing declines in sediments and the food web (LimnoTech 2015).

Currently, there are no nearshore monitoring approaches specifically designed for the southeastern Georgian Bay area. A number of organizations, however, are monitoring the nearshore of southeastern Georgian Bay, using a range of variables and methods. We recommend that their work be consulted prior to the design and implementation of a nearshore monitoring program for the area, to gather background information and to ensure efforts are compatible and comparable. These organizations include:

- Georgian Bay Islands National Park;
- Township of the Archipelago;
- Township of Georgian Bay;
- Severn Sound Environmental Association;
- Ontario Ministry of Environment and Climate Change;
- Georgian Bay Islands National Park;
- Environment and Climate Change Canada.

2. Methods

The Nearshore Monitoring Protocol Project was comprised of three main components: the literature review of approaches to lake nearshore monitoring, consultation through workshops and meetings, and the development of the Nearshore Monitoring Protocol. We describe how we conducted each of these steps below.

2.1 Literature Review

As a first step to developing the Nearshore Monitoring Protocol, we conducted a literature review of approaches currently used in Ontario, Canada and internationally for each of the monitoring variables listed in Table 1.1. We compiled a list of published and grey literature to review based on our knowledge of nearshore monitoring techniques, consultation with the Project Advisory Team, and a review of the scientific literature.

The literature search generated over 100 documents to review. Many of these provided general background information, describing for example, the overall ecological status of a particular lake and its nearshore, as well as associated stressors and issues, but not actual protocols for monitoring. Other documents (generally academic papers) described methodology used to monitor over the short-term, to address a specific question or issue. Relatively few papers actually described standardized protocols that were well-tested and commonly used, underscoring the importance of developing such tools for the nearshore. In particular, we were unable to find any papers on monitoring protocols for nearshore currents and circulation. For all other monitoring types, we followed the guidance received from the Advisory Team at the Project Initiation Meeting, focusing on a few well known techniques to document, instead of an exhaustive summary of all possible techniques.

We summarized the literature review for each monitoring variable, highlighting its advantages and disadvantages, as well as details on specific methodologies used. We also incorporated lessons learned from LSRCA's monitoring program into the appropriate sections of the literature review (see Section 2.2 Workshop and Meeting Consultation).

2.2 Workshop and Meeting Consultation

We consulted with the Project Advisory Team to receive background resource material, as well as feedback and guidance on our approach to the Project. We met twice with the Project Advisory Team (at the Project Initiation Meeting, October 16 2015 and at the Literature Review Workshop, November 27 2015) and met once with Dr. Brian Ginn of LSRCA on October 27 2015 (to learn about LSRCA's nearshore monitoring program). We have also received written comments from the Project Team on previous deliverables.

We met with the Project Team at the Project Initiation Meeting to review our proposed approach to the project, including definition of the nearshore, use of an adaptive monitoring process, identification of stressors, and identification and summary of key literature. We discussed the geographic focus of the project, the need to be flexible with our nearshore definition, and the target audience for the Protocol. The Team emphasized the importance of standardized methodologies for the nearshore, which can also be adapted to site-specific conditions and applications.

A key component of protocol development is documenting lessons learned from other monitoring programs. This information is not typically included in published or grey literature, but is more likely to arise through direct consultations with organizations and people undertaking monitoring. We met with Dr. Brian Ginn to find out details about LSRCA's nearshore monitoring program and lessons learned from designing, implementing and running it. At this meeting, Dr. Ginn described the LSRCA monitoring program in detail, outlining its macrophyte, benthic invertebrate and water quality components, as well as the tributary surveys for benthic invertebrates, fish and water quality. Dr. Ginn discussed numerous aspects of the monitoring program, including sampling design, frequency and location, equipment requirements, lab and data analysis, training, quality assurance/quality control, cost, and health and safety considerations. He identified gaps in monitoring coverage (e.g., nearshore zooplankton and phytoplankton are not sampled, hard substrates are more difficult to sample), and highlighted the value of comparing results with overlapping monitoring programs to ensure accuracy. We documented these observations for consideration in the protocol development. Dr. Ginn provided us with several LSRCA technical reports and scientific publications, as well as supporting literature on methodology used in the LSRCA monitoring program.

We held a workshop with the Project Advisory Team to review and discuss the findings of our literature review. At the workshop we asked each conservation authority to describe its experience with nearshore monitoring, including the key reasons for monitoring, what issues are addressed, what questions are asked, and how the nearshore is defined. We then summarized the key findings of the literature review and received feedback from the Team on challenges and opportunities for nearshore monitoring. The Team discussed what criteria are important to consider in the design of the Nearshore Monitoring Protocol.

2.3 Protocol Development

We used the information gained from the literature review and consultations to guide our development of the Nearshore Monitoring Protocol. We began by developing a decision-making framework to help users select the best monitoring variables to use based on a consideration of numerous criteria, including issues of concerns (i.e., stressors or human uses of the nearshore), habitat, significance and sensitivity of particular variables, and capacity and resources of the monitoring organization. This framework was intended to narrow down the wide variety of monitoring choices available to users to a manageable subset representing the most effective, feasible and appropriate suite of variables recommended for their particular goals and objectives. Multiple variables may be identified as suitable at the end of this step. We recognize, however, that resource and budgetary constraints may restrict monitoring to only one or a handful of variables. We provide further guidance, therefore, on prioritizing the top variables to use out of all recommended under these circumstances.

The next step in the development of the Protocol was to provide specific instructions on recommended methods and equipment to use for each monitoring variable. We reviewed our research (both literature review and consultations) on each variable to identify standardized widespread approaches that were well-tested and commonly used for monitoring. If none were available for a particular monitoring variable, we identified approaches that were at least part of a single regular monitoring program (e.g., LSRCA standard operating procedures, SOPs) or research study. We identified when no standardized approach existed and also used our own professional experience with nearshore monitoring to highlight recommended approaches. We summarized all information into a brief factsheet for each monitoring variable, discussing advantages and disadvantages, sampling methods and equipment, sampling considerations (e.g., water depth, whether boat required), habitat that can be monitored, time of year for sampling, sampling effort required, options for data assessment, QA/QC procedures and how the protocol can be adapted to meet differing levels of capacity and resources.

3. Literature Review

3.1 Monitoring Variables

3.1.1 Benthic Invertebrate Monitoring

Benthic invertebrates are commonly used as biological indicators of overall aquatic ecosystem health because they respond rapidly to changes in water and habitat quality (Jones *et al*. 2007) and they integrate the effects of multiple stressors over time into a whole community response. They are also widespread and sedentary, making them relatively easy to sample (Environment Canada 2012). Benthic biomonitoring is a cost-effective tool for tracking trends over time and space, and is useful at assessing environmental condition at multiple scales, from individual site to subwatershed and watershed levels (LSRCA 2013). Several established long-term monitoring programs exist for benthic invertebrates in Ontario (e.g., Jones *et al*. 2007; Burton *et al*. 2008; LSRCA 2013; Environment Canada 2012, 2014; OMOECC 2014).

3.1.1.1 Ontario Benthos Biomonitoring Network (OBBN) - Nearshore

The Ontario Benthos Biomonitoring Network (OBBN) is a widely used methodology that can be applied to lakes, streams and wetlands (Jones *et al*. 2007). The OBBN provides standard sampling protocols, based on a reference condition approach, in which the benthic community at test sites is compared with those at minimally impacted reference sites. The recommended sampling method for the nearshore of lakes is the travelling-kick-and-sweep with a 500 µm mesh D-frame net. Three random lake segments encompassing the aquatic ecosystem condition of interest should be sampled with a series of transects (at least one transect per segment), from the water's edge out to a 1 m depth. Each replicate should be sampled for 10 minutes, or until at least 100 animals have been collected. If the travelling-kick-and-sweep method is not appropriate for a particular site (e.g., large rocky substrates make collection difficult), then artificial substrates can be substituted. The OBBN has not yet established design specifications and minimum colonization times for the artificial substrate method, but several references are provided in the OBBN manual for further guidance. Any season is acceptable for the OBBN protocol, as long as comparisons between test and reference sites are made within the same season (pros and cons of sampling during different seasons are provided). Descriptive habitat variables to be reported include water temperature, conductivity, pH, alkalinity, dissolved oxygen, depth, substrate, and riparian vegetation (Jones *et al*. 2007).

Benthic sampling protocols must consider sample processing and analysis as well as sampling techniques. A variety of picking methods are described for the OBBN that minimize equipment cost and processing time. The preferred method is in-lab with preserved samples, using a Marchant Box to randomly sub-sample and a microscope for assistance. Identification down to genus/species is recommended for reference sites. Generally the more detailed the identification, the higher the sensitivity to detect environmental impairment and diagnose its cause. However, detailed identification requires more time and expertise, and is also subject to greater risk of taxonomic mistakes (Jones *et al*. 2007). The OBBN offers regular training and certification programs in its sampling methods and invertebrate identification, promoting QA/QC of the protocol. It also provides an equipment checklist and field data summary sheets to further assist with consistency and standardization of technique and data collection (Jones *et al.* 2007).

The OBBN provides a comprehensive review of data analysis options to compare test sites with reference sites. The biological condition of the test sites can be summarized using a series of biological indices, such as abundance (total number of individual organisms), richness (total number of taxonomic groups), community composition (abundance in different categories, e.g., taxonomic group or feeding guild), diversity (a combination of richness and abundance metrics) and biotic (weighted summaries combine known pollution tolerances of taxa with richness or abundance metrics). Diversity and biotic indices are commonly used in biological assessments because they are easily applied and based on ecological theories (although they may not always adequately explain variability among sites; Jones *et al*. 2007). Multivariate statistics can also be used (e.g., distance or similarity scores, ordination) to test for differences between test and reference sites. The OBBN emphasizes the importance of selecting the right analytical approach for a particular study, as different biological indices assess different aspects of biological condition, and respond in different ways to stressors (Jones *et al*. 2007).

3.1.1.2 Ontario Benthos Biomonitoring Network (OBBN) - Wetlands

The travelling-kick-and-sweep method, with a 500 µm mesh D-frame net, is also recommended for coastal wetland monitoring in the Great Lakes (Burton *et al*. 2008). Sampling occurs from late July through August, with three replicates per wetland. A minimum of 150 individuals are collected per sample and are identified to the lowest taxonomic unit possible, usually genus or species. Voucher specimens are collected for identification by expert taxonomists. An index of biological integrity is used to compare sampling results against established index scores. The index is calibrated to dominant emergent vegetation types and regional differences throughout the Great Lakes to determine patterns found along a well-established gradient of human disturbance because of the importance habitat has on the composition of benthic invertebrate communities (Burton *et al*. 2008). The index is recommended for assessment in Lake Ontario coastal wetlands. It is lake-specific, however, and requires calibration before application in southeastern Georgian Bay because the strength and direction of responses varies substantially by wetland type for each lake (Brazner *et al.* 2007).

3.1.1.3 Canadian Aquatic Biomonitoring Network (CABIN)

ECCC has established the Canadian Aquatic Biomonitoring Network (CABIN), a national biomonitoring program that provides a standardized sampling protocol and recommended assessment approach for monitoring benthic macroinvertebrates in wadeable streams (Environment Canada 2012, 2014). Although it is designed for lotic systems, CABIN may be generally applicable to lake nearshore environments (with the exception of sampling site selection). As with the OBBN, a reference condition approach is adopted. A travelling-kick-and-sweep technique is used with a triangular metal frame net having a 400 µm mesh. Sampling typically occurs from late summer into fall because most taxa are in an aquatic life stage at this time, and identifiable to species level. Sampling also occurs at this time for safety reasons, since stream flow is generally reduced compared with other times of year. This consideration may not be as important for nearshore monitoring in lakes, unless sampling is occurring near tributaries (Environment Canada 2012). Microhabitats are sampled in proportion to their occurrence in the study area. Supplemental information collected includes aquatic habitat type, canopy coverage, macrophyte coverage, riparian vegetation, periphyton coverage and physio-chemical water quality parameters (e.g., temperature, pH, conductivity, turbidity, dissolved oxygen, depth, wave height, substrate, and shoreline slope; Environment Canada 2012).

CABIN processes a minimum of 300 organisms per sample (if more than 50% of sample is required to reach 300 organisms then the entire sample is processed). A Marchant box is used to aid subsampling and sorting. Specimens are identified to at least the family level, with the finest resolution possible recommended for reference sites (Environment Canada 2014). QA/QC is promoted in several ways through the CABIN program. All participants must receive standardized training, and only Project Managers can set up CABIN databases to enter and share data. The program also recommends that data review and recording occur in the field to verify findings and ensure data sheets have been filled out correctly. In the lab, QA/QC procedures include the collection of voucher specimens, which can be sent to the National CABIN Laboratory for identification, and sorting and identification audits (Environment Canada 2014). CABIN provides guidelines and training in field and laboratory safety procedures and equipment (Environment Canada 2012).

3.1.1.4 LSRCA's Nearshore Monitoring Program

LSRCA uses a petite Ponar grab for benthic biomonitoring in the littoral and profundal zones and a D-net with travelling-kick-and-sweep technique (following the OBBN) along the shoreline (LSRCA 2013). The LSRCA's monitoring program consists of 48 sites across Lake Simcoe (surface area = 72,200 ha, shoreline ~240 km) representing three depth categories: shoreline (0-1 m depth), nearshore (~7 m depth) and profundal (> 20 m depth), with three samples taken per site. Sampling occurs in October. For shoreline samples 100 organisms (or 100% of the sample) are processed, while for littoral and profundal samples 200 organisms (or 100% of the sample) are processed. A greater number of individuals are likely sampled in the profundal zone because profundal communities are less diverse and do not exhibit marked shifts in composition so a larger number of individuals are required to indicate any responses to stress. Taxa are identified into groups, except for Zebra and Quagga Mussels, which are identified to species.

The LSRCA conducts a targeted survey of invasive Dreissenid mussels every five years to monitor distribution and population trends in Lake Simcoe. Over 700 sites are sampled across the entire lake and in all habitat types using a petite Ponar grab. Mussels are counted, identified to species, and sorted into size classes based on shell length. Mussels are removed from shells and weighed to determine shell-free wet and dry weights. The number of individuals per unit area/volume and relative abundance are also calculated.

Sampling of benthic invertebrates is limited in areas of Lake Simcoe that have hard substrates. Divers have been considered, but are prohibitive because of health and safety concerns. Instead, LSRCA has used a Go-Pro camera to successfully survey for Zebra Mussels in these locations (Ginn pers. comm. 2015).

3.1.1.5 Great Lakes Index Station Network

The OMOECC's Great Lakes Index Station Network monitors benthic invertebrates across the Great Lakes basin (OMOECC 2014). A minimum of seven sites are sampled per year on a rotating basis (of 70 core sites) by a team of 15 scientific and field staff using two survey vessels. Sampling is conducted with a Ponar grab and five replicates per station in the summer to measure abundance and community composition. The percentage of the Ponar grab filled is recorded, and grabs less than 1/5 full are rejected (Howell and Benoit 2014).

3.1.1.6 US Geological Survey Guidelines

The US Geological Survey provides benthic invertebrate sampling guidelines for Ekman and Ponar grab samplers (Becker Nevers and Whitman undated). The selection of the appropriate grab sampler often depends on substrate as heavier samplers, such as the Ponar sampler, allow for collection of a deeper sample. The Ponar sampler is more suitable for larger or harder sediments, or sand, but depending on the size of the sampler a large boat and/or a winch may be required. The Ekman sampler allows water to flow through the instrument (rather than being pushed into the sediment) so that organisms are not dispersed from the sediment surface. Brief step-by-step sampling guidance is provided for the two grab samplers as well as subsequent processing instructions but information is general in nature and methods are not prescriptive (Green *et al*. 2015).

3.1.1.7 Costs and Considerations

Information on the cost of benthic biomonitoring programs is generally lacking in the literature. The OBBN provides a qualitative comparison of the cost of different approaches to monitoring. For example, the cost of identifying invertebrates to a coarse level (a 27 group mix of phyla, orders, classes and families recommended by OBBN as the minimum level of identification) will be low, to family will be moderate and to genus/species will be high. Similarly, the use of more sophisticated equipment for processing will be more costly. A key determinant of cost is sampling effort - the number of samples required to adequately characterize an area and the level of detail or precision required in the results. The OBBN offers guidance on balancing cost with sampling and processing efficiency (Jones *et al*. 2007). Burton *et al.* (2008) estimate the cost of benthic biomonitoring to be $3241 per wetland (size not specified). The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) was estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015).

Table 3.1. Summary of Benthic Invertebrate Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort	Cost
OBBN (Jones et al. 2007)	Travelling-kick -and-sweep (500 µm mesh D-frame net)	Series of biological indices: abundance, richness, community composition, diversity, biotic Descriptive habitat variables: water temperature, conductivity, pH, alkalinity, dissolved oxygen, depth, substrate, riparian vegetation	Shallow wadeable nearshore of lakes, including streams and wetlands	Water's edge to 1 m depth	Any time of year, pros and cons of different seasons discussed	3 random segments/lake, replicates within each segment sampled for 10 minutes or until minimum of 100 animals collected	Finer resolution identification of taxa more expensive
Great Lakes Coastal Wetlands Monitoring Plan (Burton *et al.* 2008)	Travelling-kick -and-sweep (500 µm mesh D-frame net)	Index of biological integrity	Coastal wetlands		Late July through August	3 replicates/ wetland, minimum 150 individuals collected/sample	$3241/wetland
CABIN (Environment Canada 2012, 2014)	Travelling-kick -and-sweep (400 µm mesh triangular frame net)	Abundance, community composition	Wadeable streams		Typically late summer and fall	3 minute sampling per site, minimum 300 individuals/ sample	
LSRCA SOPs (LSRCA 2013)	Petite Ponar grab, travelling-kick-and-sweep (500 µm mesh D-frame net)	Benthic invertebrates including Zebra and Quagga Mussels	Shoreline and littoral and profundal zones	Shoreline: 0-1 m depth, nearshore: ~7 m depth, profundal: >20 m depth	October	48 sites, 3 samples per site, 100 organisms or 100% of sample for shoreline, 200 organisms or 100% of sample for littoral and profundal zones	
Great Lakes Index Station Network (Howell and Benoit 2014; OMOECC 2014)	Ponar grab	Abundance, community composition			Summer	70 core sites, minimum 7 per year by 15 staff and 2 vessels, 5 replicates per station	
US Geological Survey Guidelines (Becker Nevers and Whitman undated; Green *et al.* 2015)	Ekman and Ponar grab samplers						

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3.1.2 Zooplankton Monitoring

Zooplankton play an important role in aquatic food webs, transferring energy from primary producers (phytoplankton) to larger invertebrates and fish and are especially important in the diet of juvenile fish. They are highly sensitive to environmental change and are therefore useful biological indicators of ecosystem health (LSRCA 2013; Green *et al*. 2015). A variety of sampling equipment and techniques are available depending on the type of zooplankton to be monitored. A pilot study is recommended before establishing a long-term monitoring program to ensure the correct approach is taken to effectively address study objectives (Paterson 2002). While there are many documented methods for zooplankton monitoring, there are few interpretive frameworks available such as biotic indices, which would serve to reduce large amounts of data into interpretable metrics. Furthermore, while individual zooplankton species may be sensitive, there is limited data or guidance available to interpret changes or to assign changes to specific stressors.

3.1.2.1 Ecological Monitoring and Assessment Network (EMAN)

The Ecological Monitoring and Assessment Network (EMAN) describes a number of collection, processing and analytical methods for monitoring freshwater zooplankton (Paterson 2002). Crustacea should be collected using a vertically-integrated sampler with a 50 µm net at a tow speed of 0.5- 1m/second. Macrozooplankton should be sampled with vertical net hauls (mouth diameter $\geq$ 0.5 m), towed at a speed of 1/3 m/second. Plankton traps, bottles or tubes work best for Rotifera, using a 10-35 µm mesh size for filtering. The number of individuals collected per sample will vary depending on study objectives, as well as financial and human resources. Samples can occasionally be combined to reduce sample processing effort. The number of sample replicates is also study-dependent (e.g., if there is high aggregation of zooplankton more replicates will be needed). Timing of collection also depends on the study purpose. Sampling should be made at approximately the same time each day so that results are not confounded by vertical migration. Ideally, sampling should span most of the ice-free season to ensure the greatest range of species are monitored (Paterson 2002). Samples should be preserved in either 95% ethanol or 5% formaldehyde and random subsampling used for analysis. Species number can be estimated from the asymptote of the species curve. Biomass is generally estimated by converting length estimates to biomass using regression. Commonly measured parameters include abundance and community composition, analyzed with univariate and multivariate statistical approaches (Paterson 2002).

3.1.2.2 LSRCA's Nearshore Monitoring Program

LSRCA has monitored zooplankton in the past, but does not currently include them in its regular monitoring program. Zooplankton were collected with a 64 µm mesh "Wisconsin" style plankton net equipped with a dolphin bottle to concentrate samples (LSRCA 2013). The net was lowered to 0.5 m above the bottom and pulled slowly and steadily back to the surface. The outside of the net was then dipped into the lake four to five times to force samples into the dolphin bottle, which was then released with a clip and drained into a plastic sample jar. In shallow water the Schindler-Patalas trap was used as an alternative sampling device. Two net hauls were carried out per site and 300 individuals collected per sample. Taxa were identified to species level and enumerated. The following parameters were collected: species present, relative abundance of each taxon, and number of individuals per unit volume (LSRCA 2013).

3.1.2.3 US Geological Survey Guidelines

The US Geological Survey provides guidelines for monitoring zooplankton using plankton nets, plankton traps (Juday plankton trap, Schindler-Patalas trap), bottles, bailers, tubes, and water pumps (Becker Nevers and Whitman undated; Green *et al*. 2015). For nets, water should be collected from a specific depth using a water sampling device such as a van Dorn sampler, and then poured through the plankton net at the surface manually. Juday samplers should be used directly in the water to sample zooplankton, then brought to the surface where the water is automatically filtered once the sample bag is lifted above the water surface (Becker Nevers and Whitman undated). Plankton tow nets or Schindler-Patalas traps are often used to collect concentrated zooplankton samples (Green *et al*. 2015). The guidelines emphasize the importance of measuring biomass and composition, and of understanding the role of zooplankton within the aquatic ecosystem (Green *et al*. 2015).

3.1.2.4 Other Methods

Vertical tows are widely used to sample zooplankton (e.g., US EPA 1982, 2003; Evans 1986; Johansson *et al*. 1991; Agy 2001; Hall *et al*. 2003; Goforth and Carman 2005; Holeck *et al*. 2008; Pothoven and Fahnensteil 2014). The United States Environmental Protection Agency (US EPA) used a vertical tow from a 10 m depth in the nearshore of Lake Michigan, with a 240 µm conical mesh net. This mesh size optimized filtration efficiency for all but the smallest zooplankton. Rotifers were collected separately with 8 L Niskin bottles at depths of 2 m depth and just above lake bottom (US EPA 1982). The US EPA SOPs for zooplankton sampling recommends sampling 2 m above the bottom in water up to 20 m in depth. Similar approaches have been used by other studies throughout the Great Lakes (e.g., Evans 1986; Johansson *et al*. 1991; Hall *et al*. 2003; Goforth and Carman 2005; Holeck *et al*. 2008; Pothoven and Fahnenstiel 2014; see Summary table below). Additional sampling techniques for monitoring zooplankton include a submersible pump (with 130 µm mesh, 1 m diameter Puget Sound closing net sampling the entire water column; Lehman and Cáceres 1993) and an optical plankton counter (taking vertical and horizontal measurements from < 2 m to a depth of 100 m towed behind a boat; Zhou *et al*. 2001).

3.1.2.5 Costs and Considerations

The US EPA SOP (US EPA 1982) includes the implementation of a calibrated flowmeter attached to the zooplankton net. Flowmeters were not discussed as part of the other protocols reviewed but are often utilized as part of quantitative assessments because the volume of water filtered can be calculated, allowing for subsequent calculation of zooplankton densities.

Several studies anesthetize zooplankton (e.g., with an antacid tablet or soda water) before preserving them (US EPA 2003; Holeck *et al*. 2008; Pothoven and Fahnensteil 2014). Preservation of samples is achieved with either sugar formalin or 95% ethyl alcohol (Johansson *et al*. 1991; Lehman and Cáceres 1993; Agy 2001; US EPA 2003; Goforth and Carman 2005; Holeck *et al*. 2008; Pothoven and Fahnensteil 2014).

No cost estimates were found in the literature for zooplankton sampling. LSRCA halted its zooplankton monitoring because of time and staff constraints (Ginn pers. comm. 2015). The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) was estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015). The EMAN protocol uses voucher specimens as QA/QC for identifying samples (Paterson 2002). LSRCA's SOPs review various health and safety considerations for sampling protocols and list required training certifications (LSRCA 2013).

Table 3.2. Summary of Zooplankton Monitoring Approaches

Method Name	Type of Gear	Species Targeted	Type of Use	Depth of Water	Time of Year	Effort
EMAN (Paterson 2002)	Vertical tow (50 µm net), plankton traps, bottles or tubes (10-35 µm mesh)	Crustacea, macrozooplankton, rotifera	Abundance, community composition, biomass	Close to deepest part of lake	Throughout ice-free season	Increase replicates if zooplankton aggregations
LSRCA SOPs (LSRCA 2013)	Wisconsin style net (64 µm mesh) with dolphin bottle (for deeper water), Schindler-Patalas trap (for shallow water)		Species present, abundance, number of individuals per unit volume	0.5 m above lake bottom to surface		2 net hauls per site, 300 individuals/ sample
US Geological Survey (Becker Nevers and Whitman undated; Green *et al.* 2015)	Plankton nets, Juday plankton trap, Schindler-Patalas trap, bottles, bailers, tubes, water pumps, van Dorn sampler		Biomass, community composition			
US EPA (1982)	Vertical net (240 µm conical mesh), 8 L Niskin bottles	Macrozooplankton and rotifera		10 m depth to surface for vertical tow, just off lake bottom and 2 m depth for bottles		
Evans (1986)	Vertical net (156 µm conical mesh, 50 cm diameter) with calibrated flowmeter		nearshore	1 m off bottom to surface		2 replicates per site
Johannson *et al.* (1991)	Vertical net(64 µm, 0.25 m, 0.3 m and 0.5 m diameters used in Canadian waters; 153 µm and 0.5 m diameter used in US waters)			Lake stratification determined depth of tow		
Lehman and Cáceres (1993)	Submersible pump (130 µm mesh, 1 m diameter closing net)			Entire water column		

Method Name	Type of Gear	Species Targeted	Type of Use	Depth of Water	Time of Year	Effort
Agy (2001)	Vertical net (153 µm conical mesh, 0.5 m diameter, 2.5 m length) with calibrated flowmeter (0.5 m/s)		nearshore	2 m above lake bottom to surface	Year-round	2 replicates per site
Zhou *et al.* (2001)	Optical plankton counter			< 2 m to 100 m		
Hall *et al.* (2003)	Vertical net (153 µm mesh, 0.5 m diameter, 2 m length)		nearshore	10 m to surface		3 replicates
SOPs for Zooplankton Monitoring (US EPA 2003)	Vertical net (63 µm mesh for 20 m depth, 153 µm mesh for 100 m depth, both 0.5 m diameter) with calibrated flowmeter (0.5 m/s)			20 m and 100 m (or 2 m above bottom if shallower) to surface		2 replicates
Goforth and Carman (2005)	Vertical net (80 µm mesh, 0.3 m diameter, 0.9 m length)		nearshore	0. 5 m above lake bottom to surface		3 replicates
Holeck *et al.* (2008)	Vertical net (64 µm, 0.5 m diameter) with a calibrated flowmeter (0.7 m/s)					
Pothoven and Fahnenstiel (2014)	Vertical net (153 µm mesh, 0.5 m diameter, 2.5 m length) with a calibrated flowmeter (0.5 m/s)		nearshore	1-2 m above bottom to surface		

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3.1.3 Fish Community and Habitat Monitoring

A variety of active and passive methodologies are used to sample fish in the nearshore, including electroshocking boats, shoreline seines, purse seines, gill nets, fyke nets, trawls and hydroacoustic devices. Of these, electrofishing and fyke netting are considered the most useful tools for describing the littoral fish community (Green *et al*. 2015) likely because they sample a wider variety of the fish assemblage than other methods. Monitoring is conducted to characterize the fish community (e.g., OMNRF 1999a), to track persistent organic pollutants in sport fish and juvenile fish (e.g., OMOECC 2014), to compare the productive capacity of natural vs. altered shorelines (e.g., Brosseau *et al*. 2005) and to assess the overall ecological health of the lake or reservoir (e.g., Green *et al*. 2015).

3.1.3.1 Nearshore Community Index Netting Program (NSCIN)

Standardized methods were developed by the Ontario Ministry of Natural Resources (OMNRF) for sampling nearshore fish communities through its Nearshore Community Index Netting program (NSCIN) and its Spring Littoral Index Netting program (SLIN) (OMNR 1999a, b). The NSCIN uses live release trap netting (1.82 m spring-haul trap nets) to evaluate fish abundance and community composition. Sample sites are randomly selected in the nearshore, with a minimum of 16 traps sampled per lake over at least two consecutive years (note that sample size will depend on the purpose of a particular study). Nets are set for 24 hour periods from August 1st until the surface water temperature drops to 13°C. The house of the trap nets are set at depths ranging from 1.7 to 3.5 m. The NSCIN protocol recommends measuring all fish so that they can be size classed by species, and sub-sampling for large catches when measuring all fish is not logistically possible. In addition, the protocol recommends recording substrate, vegetative and log cover and weather, which can be used as explanatory variables during later assessment (OMNRF 1999a).

3.1.3.2 Spring Littoral Index Netting Program (SLIN)

The SLIN focuses on spring Lake Trout sampling in Algonquin Park, but could be applicable to sampling coldwater fish in Georgian Bay in the early spring when they are closer to shore. It uses gillnets (e.g., 38 mm, 51 mm or 64 mm in mesh size) which are deployed for 90 minute intervals at least six times a day. Sampling occurs after ice melt and before surface water temperatures reach 13°C, from a 2.5 m depth perpendicular to shore out to a maximum 60 m depth. A minimum of thirty locations are sampled per lake by OMNRF area offices, compared with a minimum of 60 locations per lake for Fisheries Assessment Units. The parameters measured are fork length and round weight, scale sample, as well as sex and gonad condition if the fish dies during collection. Otoliths are also removed for ageing (OMNR 1999b).

3.1.3.3 Great Lakes Areas of Concern Surveys

Boat electrofishing was used to evaluate the status of nearshore fish communities in Great Lakes' Areas of Concern (AOC; Brosseau *et al*. 2005). Sampling was conducted at the 1.5 m depth contour along 100 m transects, as well as at several point locations along the shoreline or along transects. Surveys began one to two hours before sunset until late evening (i.e., approximately 11:00 pm to 1:00 am). Fish were identified to species and length and weight were measured. If more than 20 fish were caught for a particular species, individuals were counted and batch weighed. Habitat parameters measured included substrate, cover, water temperature, conductivity, dissolved oxygen and location. Physical water quality measurements were taken at the middle of each transect to provide additional habitat description (Brosseau *et al*. 2005).

3.1.3.4 Great Lakes Coastal Wetlands Monitoring Plan

The Great Lakes Coastal Wetlands Monitoring Plan uses boat electrofishing and fyke nets for its sampling protocol (Burton *et al*. 2008). Seven electrofishing transects are sampled in July or August or three fyke nets are used to characterize fish communities when wetland vegetation has matured. Fish larger than 25 mm are identified to species and enumerated, with 10-20 specimens randomly chosen for additional measurements such as total length, deformities, etc. The Monitoring Plan uses an index of biological integrity to compare sampling results with patterns expected for a well-established gradient of anthropogenic disturbance (Burton *et al*. 2008).

3.1.3.5 US Geological Survey Guidelines

Boat electrofishing and fyke nets are also used for the US Geological Survey's lake and reservoir sampling protocol, which assesses ecological health through measurement of fish community structure, gut contents and tissue contaminant analysis (Green *et al*. 2015).

3.1.3.6 Standard for Sampling Small-Bodied Fish in Alberta

Beach seining is used to provide a consistent method of collecting data on diversity and abundance of small bodied fish in Alberta (Alberta Parks and Environment 2013). Seining is conducted parallel to shore in water less than or equal to 1.3 m in depth at eight sites equally spaced around a lake and the first site is randomly selected. Data are assessed per number of fish captured per m^2.

3.1.3.7 Costs and Considerations

Little information is available on the estimated cost of different fish monitoring methods. We have summarized the effort required in the table below. Burton *et al*. (2008) suggest that monitoring costs $1092 per wetland. OMNRF indicates that spring-haul trap nets cost approximately $2250-2500 each and should last 15 or more years (OMNR 1999a).

QA/QC procedures used in fish monitoring include collecting reference specimens for future identification and flagging data that fall outside the normal range of variation (OMNR 1999a; Brosseau *et al*. 2005). The NSCIN and SLIN methods have been extensively tested and documented to determine the effort needed to produce a robust dataset.

Basic health and safety requirements for fish monitoring include training in first aid/CPR and safe boat and trailer operation; OMNR (1999a) details many of these health and safety procedures. Boat electrofishing requires a crew (typically of four people) trained in electrofishing procedures and standards (Brosseau *et al*. 2005).

Table 3.3. Summary of Fish Community and Habitat Monitoring Approaches

Method Name	Type of Gear	Species Targeted	Type of Use	Depth of Water	Time of Year	Effort	Cost
NSCIN (OMNR 1999a)	1.82 m trap net	Littoral zone- all species	Non-sacrificial, community composition, abundance	1.7-3.5 m	Late summer, > 13°C	16 nets, 24 hours each over 2 years	$2250-2500
SLIN (OMNR 1999b)	36/51/64 mm gill nets	Lake Trout	Non-sacrificial, abundance, morphometrics, fish health	2.5- 60 m	Spring, < 13°C	30-60 sets/lake, 90 minutes, 6x/day	
Great Lakes AOC Fish Surveys (Brosseau *et al.* 2005)	Boat electrofishing	Littoral zone- all species	Non-sacrificial, community composition, abundance	1.5 m		100 m transects + point locations, evening surveys	
Great Lakes Coastal Wetlands Monitoring Plan (Burton *et al.* 2008)	Boat electrofishing and fyke nets	Coastal wetlands- all species	Non-sacrificial, community composition, abundance, fish health		July or August	7 electrofishing transects, 3 fyke nets	$1092/ wetland
US Geological Survey Lake and Reservoir Sampling Protocol (Green *et al.* 2015)	Boat electrofishing and fyke nets	All species	Non-sacrificial, community composition, abundance, fish health, fish diet				
Standard for Sampling Small-Bodied Fish in Alberta (Alberta Parks and Environment 2013)	Beach Seining	Small-bodied fishes	Non-sacrificial, community composition, abundance	≤1.3 m	Summer >15°C	8 seine hauls equally spaced around a lake	

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3.1.4 Cladophora Monitoring

Cladophora growth has become a problem in nearshore areas of the Great Lakes where substrates are suitable and other conditions permit. The introduction of invasive Dreissenid mussels (i.e., Zebra and Quagga Mussels) can stimulate the growth of this nuisance green algae because the mussels increase water clarity, provide biologically available phosphorus in close proximity to the algae and even provide a suitable substrate for it. Numerous surveys have been conducted to monitor *Cladophora* distribution and abundance, primarily in the lower Great Lakes, Lake Simcoe and more recently parts of Lake Huron.

Cladophora distribution is strongly influenced by habitat. The algae will only grow where the substrate is suitable (i.e., hard and stable such as rock ledges or boulders or shoreline protective structures). *Cladophora* will not colonize areas with unstable sediments, such as sand or mud. Consequently, understanding the substrate is a first step in monitoring for this attached algae (Garrison *et al*. 2008; Depew *et al*. 2011; Higgins *et al*. 2012; HESL 2014).

Cladophora growth is limited by light and thus its habitat zone is generally restricted to shallow nearshore depths (e.g., maximum 20 m depths in Lake Ontario). The depth to which *Cladophora* occurs varies by lake depending on light penetration and substrate type. The *Cladophora* habitat zone in Georgian Bay, for example, may extend to greater depths than in Lake Ontario because of greater water clarity. In shallow areas with suitable substrate, the algae may be dense but its distribution tends to become inconsistent or patchy moving offshore. *Cladophora* production is influenced by a variety of factors, including tributary inputs of turbid water, shoreline erosion and reduced wave energy, and seasonal water temperatures, all of which can result in large annual variability (e.g., as observed in Lake Ontario; Depew *et al*., 2011; University of Waterloo *Cladophora* Study Team undated.). *Cladophora* growth is also limited by water temperature with optimum temperatures within the range of 13 to 17ºC with lower temperatures more limiting than higher temperatures (Tomlinson *et al*., 2010)

3.1.4.1 Surveys using Echosounders and Videography

The seasonal and spatial variability of *Cladophora* growth in the nearshore makes it challenging to design an effective monitoring program for the algae. A high-frequency echosounder in association with high resolution underwater videography was used to monitor *Cladophora* on rocky substrates of the Great Lakes (Depew *et al*. 2009; Depew *et al*. 2011). Percent cover and stand height were recorded. The methodology requires specialized equipment, training and software to correctly analyze and interpret data (Depew *et al*. 2009). However, this seems to be the most effective way to accurately measure *Cladophora* biomass.

Greb *et al*. (2004) describe using underwater videography to document percent cover of *Cladophora* in Lake Michigan. Garrison *et al*. (2008) also used a video camera to estimate bottom coverage, as well as an Ekman grab to collect *Cladophora* for productivity and biomass estimates in western Lake Michigan.

3.1.4.2 Diver Surveys

Cladophora blooms were characterized in the Lake Ontario nearshore by scuba divers using quadrats (Higgins *et al*. 2012). Seven sites on both the Canadian and US sides of the lake were selected to represent an impact gradient from highly urbanized to minimal adjacent land use. Each site spanned a 10 km distance horizontal to the shoreline 1 km offshore. *Cladophora* was sampled along two transects at Canadian sites and three transects at US sites at least twice during the height of its growth season (June-August), with three to five quadrats per depth. Quadrats covered a 0.25 m^2 area over rocky substrates. Depths along transects ranged from 0 to more than 70 m.

3.1.4.3 Remote Sensing

The Michigan Technical Research Institute (MTRI) has developed a remote sensing application to monitor *Cladophora* in the nearshore zone (MTRI 2014). The online tool uses Landsat satellite imagery to map the extent of submerged aquatic vegetation (mainly *Cladophora*) in Lakes Michigan, Huron, Erie and Ontario from 2008-2011. Starting with raw Landsat imagery, a depth correction algorithm used to eliminate radiance due to the water column, leaving just the radiance reflected from the lake bottom. By plotting multiple depth-corrected spectral bands (typically blue and green visible light) against one another, MTRI can discriminate between bottom types (sand, mud, sparse and dense submerged aquatic vegetation). The reported optical depth for this application varies from 2 to 20+ m dependent upon water clarity or transmissivity at the time of the image, which is variable. The amount of light that reaches a *Cladophora* bed depends on depth and the transparency of the water column at a particular site. As light moves through the water, some is reflected back to the surface and the balance is absorbed, resulting in a cumulative attenuation of the light received at the surface. Changes in light with depth are well described by a first order decay with an attenuation coefficient, k_e (m^{-1}). The magnitude of k_e increases as levels of dissolved colour, chlorophyll (phytoplankton) and sediment increase. Light attenuation is typically greatest at shallower depths where waves and wind mixing resuspend bottom sediment (Auer 2014).

This remote sensing technique was applied in the Ajax nearshore, where light levels at the lake bottom were highest at depths of 2.5 and 5 m at about 60% of the optimum intensity (Auer 2014). As depth increased with increasing distance from shore, light at the lake bottom decreased in an essentially exponential manner (Fig. 3.1; Auer *et al*. 2010). At depths >10 m (typical offshore distance in the Lower Lakes of ~1 km) *Cladophora* growth potential was negligible. The mapping of *Cladophora* in the Ajax nearshore may be underestimated by the remote sensing technique as compared to the sonar survey work conducted by Depew (2009) and Depew *et al.* (2009) with respect to distance offshore or depth (Fig 3.2; HESL 2014). At the same time, the density of *Cladophora* may be over-estimated by the remote sensing method in the nearshore zone although the data from these two studies are from different years and are therefore not directly comparable.

A further drawback of the remote sensing technique is that it may not be able to differentiate between different types of algae and macrophytes. Thus, ground-truthing and calibration should be an important component of any remote sensing approach.

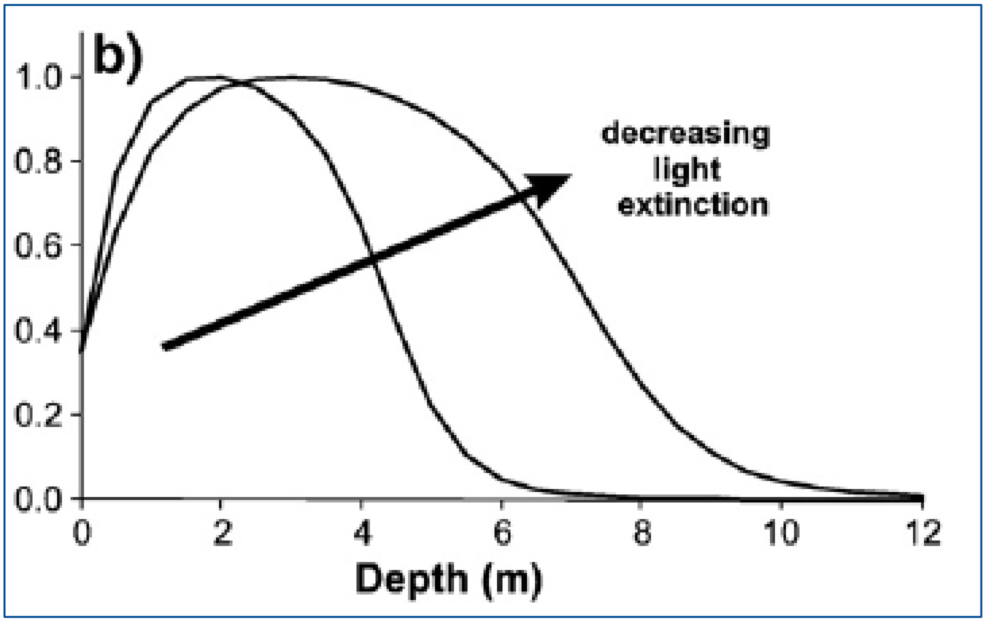

Figure 3.1 Cladophora Growth Potential. . Cladophora growth potential with change in the light extinction coefficient for two algal populations experiencing identical soluble reactive phosphorus conditions (Auer et al. 2010).

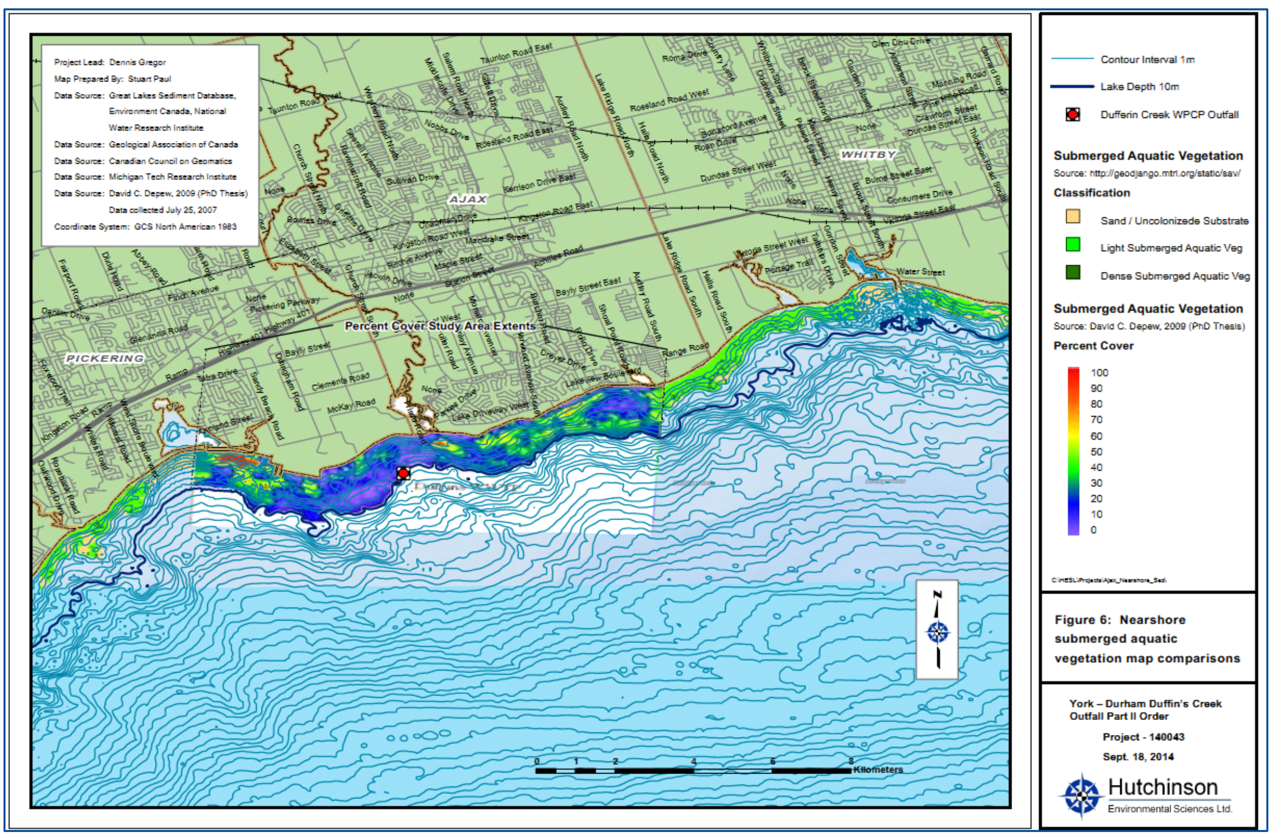

Figure 3.2. Cladophora percent cover overlain on mapping of submerged aquatic vegetation (MTRI undated; Depew 2009).

Water quality data are normally also collected as part of *Cladophora* monitoring programs. For example, Higgins *et al.* (2012) included limnological data collected with a shipboard flow-through system (chloride, conductivity, total phosphorus, soluble reactive phosphorus, and nitrate). Wet and dry mass and areal biomass of *Cladophora* were calculated and plant tissue was analyzed for phosphorus. Greb *et al.* (2004) included water column profiles of temperature, dissolved oxygen and conductivity, and water samples were analyzed for total Kjeldahl nitrogen (TKN), nitrate+nitrite, total phosphorus, total dissolved phosphorus, dissolved reactive phosphorus and chlorophyll a. Concurrent monitoring of water quality is important for understanding the causes and controls of *Cladophora* growth, but may not be necessary for routine *Cladophora* monitoring programs. The design of *Cladophora* monitoring does not tie in well with routine water quality monitoring programs as they need to be frequent during the *Cladophora* growing season and focused on the physical and chemical factors that control *Cladophora* growth.

3.1.4.4 Costs and Considerations

No cost estimates are provided for the documented *Cladophora* methods in the literature. Higgins *et al*. (2012) noted that using scuba diving for sampling was labour intensive. The estimated cost of commercial side scan sonar surveys is approximately $7,000 per day including surveying, support and interpretation of results (Gregor, HESL. pers. comm. 2015).

Growth models have been developed to predict *Cladophora* biomass (grams of *Cladophora* dry weight per m^2) in the Great Lakes. Tomlinson *et al.* (2010) have the most detailed model, as it includes data points from Lakes Erie, Ontario, Michigan and Huron. This model provides a prediction of *Cladophora* biomass based on the concentrations of soluble reactive phosphorus (SRP) in the water column. In Lake Ontario, open lake SRP concentrations are able to support extensive *Cladophora* growth (for example, at Presqu'ile Provincial Park; HESL 2015) so it is not always evident how biomass is affected by local sources of nutrients such as water pollution control plant effluent and tributaries. Numerous studies have documented the generation of biologically available phosphorus in the nearshore in the Ajax area (Martin 2010), Halton Region (Ozersky *et al.* 2009, 2012; Martin 2010) and Lake Michigan (Bootsma 2009; Dayton *et al.* 2014) by Dreissenid mussels. The direct effect of phosphorus sources on *Cladophora*, while likely important, has not been quantified.

The real socio-economic issue associated with *Cladophora* in the Great Lakes is not that it grows here (it is native to these lakes after all), but that its growth can be prolific, making it a nuisance under certain circumstances. For example, following storm events, or senescence in the early fall, *Cladophora* fouls beaches and decays, resulting in high bacterial counts and obnoxious smells (Bootsma 2009; Depew *et al*. 2011; Auer 2014; University of Waterloo *Cladophora* Study Team undated). The US Geological Survey has a simple sloughed *Cladophora* monitoring program as a part of the Avian Monitoring for Botulism Lakeshore Events program (USGS 2012). This consists of trained individuals walking along beach transects a periodic basis during the growing season and characterizing the *Cladophora* accumulation, as noted by Riley *et al.* (2015) as: "none [0]; scattered clumps [1]; isolated mats [2]; scattered continuous coverage [3]; continuous mats [4], or thick continuous mats [5]." Numerical scores were used instead of estimates of areal extent because of the challenge of accurately calculating the area or biomass of many small clumps of algae (Riley *et al.* 2015).

Table 3.4. Summary of Cladophora Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort	Cost
Cladophora Surveys of Wisconsin Nearshore Areas of Lake Michigan (Greb *et al.* 2004)	Underwater video	Percent cover	nearshore				
Western Lake Michigan Nearshore Survey (Garrison *et al.* 2008)	Underwater video, Ekman grab	Productivity, wet and dry biomass, carbon, phosphorus and chlorophyll content, supplemented with water quality data (temperature, dissolved oxygen, conductivity, TKN, nitrate+nitrite, total phosphorus, total dissolved phosphorus, dissolved reactive phosphorus, chlorophyll a)	nearshore	2 and 10 m		24 sites, 2 depths/site	
Echosounder survey (Depew *et al.* 2009)	High-frequency echosounder	Percent cover, stand height					
Lake Ontario Nearshore Survey (Higgins *et al.* 2012)	Scuba divers, quadrats, shipboard flow-through system	Wet and dry biomass, areal biomass, phosphorus content, depth, supplement with water quality data (chloride, conductivity, total phosphorus, soluble reactive phosphorus, nitrate)	nearshore	0-70 m Canadian sites: 2, 5, 10 and 20 m depths; US sites: 3, 6, 10 and 18 m	June-August	7 sites, 2 transects/site for Canada, 3 transect/site for US, 3-5 quadrats/ depth, 4 quadrats/ depth, sampled twice per season	Scuba diving is labour intensive

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3.1.5 Macrophyte Monitoring

Monitoring of aquatic macrophytes can provide information on lake trophic status, since macrophyte communities respond to changes in nutrient loading and water clarity (Stantec Consulting Ltd. 2007; LSRCA 2013; Green *et al*. 2015). Nutrient enrichment to the nearshore can promote excessive plant growth in the initial stages but, ultimately, growth of planktonic algae can reduce light availability to the lake bed and impair the growth of aquatic macrophytes. The introduction of invasive Dreissenid mussels (i.e., Zebra and Quagga Mussels) leads to increased water clarity and thus increased light conditions and habitat for aquatic plants. Longer ice free seasons due to climate change, meanwhile, extend the macrophyte growing season. Use of macrophytes as a biological indicator of lake health may be limited, however, since their community composition, distribution and biomass may also be influenced by a variety of other factors (such as changes in water clarity or water levels and increases in phosphorus in sediment) which are not always directly related to nutrient levels in the water column (Ginn 2011). Macrophytes are important for fish habitat however, and may play an important role in stabilizing nearshore sediments in low energy environments where they can accumulate and are not eroded. Consequently, macrophyte sampling is only appropriate in areas that are not exposed to currents and high wave energy (e.g., bays, protected areas).

3.1.5.1 Stantec Survey of Cook's Bay, Lake Simcoe

A macrophyte inventory of Cook's Bay, Lake Simcoe was undertaken in 2006 to compare with data collected in 1984 and 1987, and to provide information on baseline conditions to compare against future change (Stantec Consulting Ltd. 2007). Both submergent and emergent macrophyte vegetation was characterized and analyzed spatially in relation to water chemistry and substrate. Sampling occurred in August at 121 locations. Duplicate samples were taken with a Ponar grab, covering an area of 0. 1 m^2 at depths of 0.5, 1, 2, 6 and 8 m. Sampling depths were concentrated at 2 m depth and less because macrophyte diversity and density is generally higher at shallow depths. Routine water quality parameters (e.g., temperature, pH and dissolved oxygen) were recorded, and qualitative mapping of emergent vegetation was conducted. Submerged plants were collected, washed and dried, identified to species and both wet and dry weighed. The distribution of macrophytes was mapped, with dry-weight biomass values plotted as concentrations of the various species across the study area. Canonical correspondence analysis was used to explore the influences of water depth, substrate and location. Macrophyte biomass increased slightly since the arrival of Zebra Mussels in 1995, but additional information is required to understand the factors limiting growth in Cook's Bay (Stantec Consulting Ltd. 2007).

3.1.5.2 Great Lakes Coastal Wetlands Monitoring Plan

Under the Great Lakes Coastal Wetlands Monitoring Plan, macrophytes are first mapped with the use of aerial photographs to identify the following major vegetation zones: wet meadow, emergent and submergent (if present). Sampling locations are selected either by randomly overlaying a grid or three transects to cross each zone. Any obvious monoculture patches in the aerial photographs should be flagged for monitoring, as they may indicated infestations of invasive aquatic plants (Burton *et al.* 2008).

In the field, 15 1.0 m^2 sample quadrats are placed randomly within the grid or along transects 25 m apart (establishing points along transects requires less time than choosing random points, so may be preferred if budget constraints are a consideration). Within each quadrat the following measurements are recorded: percent cover for each plant species, type of substrate, organic depth, water depth and water clarity. The Plan provides standardized worksheets for recording field data and a checklist of the most common wetland macrophytes found in Great Lakes coastal wetlands.

The Plan cautions that data analysis for macrophyte monitoring is limited by the natural response of plants to water level fluctuations. As a result, it recommends that analyses be kept simple, using only a few metrics and indices (e.g., number of invasive species present, number of native species tolerant of nutrient enrichment and turbidity present, index of conservatism, i.e., number of native species/total number of species present; Burton *et al*. 2008).

3.1.5.3 Macrophyte Survey of Lake Simcoe

Submerged macrophytes were surveyed throughout Lake Simcoe to assess lake trophic status (Ginn 2011). A total of 43 transects located at 5 km intervals were sampled once between September and November at depths of 1, 3, 5 and 10 m. A Ponar grab was used at deep sites and a lake rake in shallow waters. The area sampled per site was normalized to 1 m^2. Plants were identified to species and wet and dry biomass calculated. Additional information collected included water depth, substrate, surface area of subwatershed closest to the sample site, phosphorus loading from the nearest tributary, and water quality parameters including colour, specific conductance, dissolved inorganic carbon, dissolved organic carbon, TKN, pH, total phosphorus, turbidity, alkalinity, aluminum, and calcium. Aquatic macrophyte community index and macrophyte index were calculated, as well as a trophic rating score. Trophic rating scores were calculated based on the average cumulative trophic ranking score for each macrophyte species collected at each sample site. Canonical correspondence analysis was used to determine relationships between indices and limnological information. Results indicated that macrophyte biomass was strongly related to depth, substrate, phosphorus loading from the closest tributary and size of area drained by the tributary. Increased biomass and decreased diversity were also observed in areas infested with Eurasian Milfoil. Ginn (2011) concluded that macrophytes were not an effective indicator of lake trophic status because of their sensitivity to other unrelated drivers.

3.1.5.4 LSRCA's Nearshore Monitoring Program

LSRCA conducts annual macrophyte surveys in parts of Lake Simcoe, and lake-wide surveys every five years (LSRCA 2013). Frequency of monitoring is partly driven by public demand, since increases in aquatic plant growth in the lake have led to significant concern from residents (Ginn pers. comm. 2015). The lake is divided into four areas, with five stations sampled per area in July and September every year. For the lake-wide survey every five years, surveys at 215 sites are completed. A petite Ponar grab is used in water deeper than 2 m and a lake rake in shallower waters. Plants are identified to species and wet and dry weighed. Abundance (number per sample, scaled to unit area), wet and dry weight biomass (by species for each sample, scaled to unit area), and total biomass (wet or dry weight of all species per sample, scaled to unit area) are measured (LSRCA 2013).

3.1.5.5 US Geological Survey Guidelines

The US Geological Survey describes common methods for sampling macrophytes (Green *et al*. 2015). They are typically collected by hand or with grappling hooks, rakes, oyster tongues or dredges. A quantitative description of macrophyte distribution can be obtained through careful sampling within defined quadrats, including sampling biomass from above and below the lake bottom with replicate samples.

3.1.5.6 Costs and Considerations

No cost estimates are provided for the documented macrophyte methods in the literature. The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) was estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015).

If more than one collection method is used in macrophyte monitoring (e.g., Ponar grab *vs*. hand pulling), the results should be compared to ensure QA/QC. Alternatively, one method can be used to eliminate potential variability between methods. Representative specimens of all macrophytes surveyed should be collected and stored for later reference (e.g., if there are identification problems, or for future study; LSRCA archives representative specimens in its herbarium; Stantec Consulting Ltd. 2007; Ginn 2011; LSRCA 2013).

Table 3.5. Summary of Macrophyte Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort
Macrophyte Survey of Cook's Bay, Lake Simcoe (Stantec Consulting Ltd. 2007)	Ponar grab	Macrophyte distribution, dry weight biomass, temperature, pH, dissolved oxygen	nearshore	0.5, 1, 2, 6 and 8 m	August	Duplicate samples/depth/site, 5 depths/site, 121 sites,
Great Lakes Coastal Wetland Monitoring Plan (Burton *et al.* 2008)	Aerial photographs, quadrats (1.0 m^2), Plexiglas or aluminum tube for measuring sediment depth, Secchi disk	Percent cover for each plant species, type of substrate, organic depth, water depth, water clarity	wetlands			
Macrophyte Survey of Lake Simcoe (Ginn 2011)	Ponar grab (deep sites), lake rake (shallow sites)	Species, wet and dry weight biomass, macrophyte community index, macrophyte index, trophic rating score, water depth, substrate, surface area of subwatershed, phosphorus loading, water quality parameters (e.g., specific conductance, dissolved organic carbon, pH, turbidity, etc.)	nearshore	1, 3, 5, 10 m	September-November	43 transects, 4 depths, sampled once
LSRCA SOPs (LSRCA 2013)	Petite Ponar grab (> 2 m), lake rake (< 2 m)	Species, wet and dry weight biomass, total biomass, abundance	nearshore		July and September	4 areas of lake, 5 stations sampled per area per year 215 sites lake-wide sampled every 5 years
Macrophyte Survey Techniques (Green *et al.* 2015)	By hand, grappling hook, rake, oyster tongue, dredge, sediment core, quadrats	Distribution, biomass	nearshore			

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3.1.6 Periphyton Monitoring

Periphyton are sensitive to water quality conditions, responding rapidly to environmental change because of their short life cycles (less than 24 hours; Goncalves *et al*. 2011; LSRCA 2013). The ecological optima and tolerances of these algal taxa are well documented, which makes them a useful tool for tracking short-term and localized effects of stressors on aquatic ecosystems (DeNicola and Kelly 2014). They are particularly useful indicators of nutrient status and turbidity, key stressors related to urban development. Like phytoplankton, periphyton provide an early warning of environmental change. However, while phytoplankton generally reflect conditions in the water column, periphyton indicate conditions at the interface between the water and the lake bottom (Flotemersh *et al*. 2006). Furthermore, since periphyton are stationary, their response to environmental change can provide a high degree of spatial resolution, and they may respond earlier to watershed stressors than phytoplankton (Bellinger and Sigee 2010; DeNicola and Kelly 2014). Nonetheless, periphyton also respond to many other variables beyond anthropogenic stressors (e.g., grazing, light). Teasing apart the relative contribution of different factors to periphyton community diversity, biomass and productivity in lakes is challenging because no standardized protocols yet exist in lentic environments (Thomas *et al*. 2011). Used in conjunction with other biological indicators, however, periphyton can provide an integrated assessment of lake ecosystem health (Goncalves *et al*. 2011).

3.1.6.1 New Zealand Stream and River Periphyton Protocol

A comprehensive description of key periphyton metrics and sampling protocols is provided in a guide for monitoring New Zealand streams and rivers but many of the methods, except for determination of sampling areas, are also applicable to lakes (Biggs and Kilroy 2000). A rapid assessment approach is used to record percent cover in quadrats, combined with physical measurements (e.g., water depth, substrate). Guidance is given on what protocols to use under different conditions (e.g., whole cobble sampling *vs*. scraping or brushing a sample from a defined area *vs*. underwater sampling when substrates are too large to collect) and for different substrates (e.g., sand/silt sampling with spatula blade and Petri dish). Artificial substrates are recommended when the water is too deep or substrates differ significantly between sites. Sampling surfaces commonly include etched acrylic and glass, as well as slate, brick, clay tile and filter paper (Biggs and Kilroy 2000). A reference condition approach to study design is recommended, in which multiple impact and control sites, that are representative of the entire system, are selected. The number of replicates depends on the degree of local variability and will be a balance between increasing accuracy and minimizing cost. Analysis can be semi-quantitative (i.e., relative abundance of taxa based on their contribution to sample biovolume) or fully quantitative (i.e., detailed count of the number of individuals per taxa). Measures of chlorophyll a and ash-free dry mass are recommended. The high degree of temporal and spatial variability exhibited by periphyton makes data analysis prone to complications and errors. Biggs and Kilroy (2000) recommend metrics that are simple and easily understood (such as number of individuals per taxa, proportion of individuals of different taxa, diversity indices) instead of single number community indicators (e.g., a single periphyton pollution or eutrophication index), which may obscure what is ecologically important. For example, reporting that diatom taxa associated with clean water dominate a control site, while fungus and green algae associated with polluted waters, dominate a site near a sewage discharge, will provide a more straightforward and informative message to the public and decision-makers than reporting that the pollution index is 4 vs. 8 at the two sites. A variety of univariate and multivariate statistical approaches are discussed for different applications (Biggs and Kilroy 2000).

3.1.6.2 Bioassessment of Non-wadeable Streams and Rivers

Flotemersch *et al*. (2006) provide protocols for monitoring periphyton in non-wadeable streams and rivers, but much of the protocol is transferable to lake environments such as field sampling, laboratory sampling and data analyses. A sample site is comprised of a 500 m river reach, with six transects at 100 m intervals, where each transect consists of a 10 m sample zone on each bank from shore to 1 m depth. Scraping, brushing or siphoning should be used to sample in each microhabitat, as dictated by the substrate that is sampled. The key guidance for sampling the nearshore of a lake would therefore be to sample a composite of microhabitats within each of six 10 m x 1 m band replicate sites. In erosional habitats, the substrate sample should be removed from the water and material dislodged with a brush and washed into a sample bottle. In depositional habitat, a predetermined area of soft sediment is collected, with a syringe or spoon, and transferred to a sample bottle. Rock, wood and plant substrates are preferred for sampling. Artificial substrates can be used when natural substrate is not suitable because of inaccessibility, cost of collection or safety issues, but artificial substrate collection generally results in reduced diversity that is not comparable to natural conditions (Flotemersch *et al*. 2006). Approximately 300 diatom cells are counted per sample and the samples are either combined as part of the qualitative multi-habitat assessment or assessed independently as part of the quantitative targeted habitat sampling method. Parameters measured include relative abundance, density of species, algae metrics (e.g., richness, dominance, percent cyanobacteria, chlorophyll a, ash-free dry mass, phosphatase activity, autotrophic index) and diatom metrics (e.g., number of taxa, diversity, percent community similarity, pollution tolerance index, percent sensitive diatoms, percent live diatoms; Flotemersh *et al*. 2006).

3.1.6.3 Algal Bioassessment Protocol

Ontario's Algal Bioassessment Protocol (OABP) is designed to complement the OBBN and the Provincial Water Quality Network (Goncalves *et al*. 2011). The project examined the community composition of diatoms from different substrates (rocks, sand, macrophytes) and the applicability of a three-tiered assessment of periphyton: (1) a rapid visual assessment, (2) a rapid identification under the microscope and (3) a high resolution identification to species level. Modules are provided for collection of diatoms, soft algae and a visual assessment of algae.

OABP is developed for rivers, but much of it could be applicable to lakes (except for determination of sample sites). No sampling is advised for two to three weeks following a bottom-scouring storm event. Five sample locations are selected per stream reach for collection of diatoms or soft algae (riffle areas with hard substrates are preferred), while three transects are traversed within each sample location during visual assessments. At each station, a sample area at least the size of loonie is sampled for diatom and/or soft algae using different collection methods depending on the substrate that is sampled. Hard, removable substrates are scraped and brushed, fine sediments are siphoned with a turkey baster and vigorously shaken in the sample jar and plants are rubbed to remove the algae. Effort is approximated to be 10-15 minutes for diatom sampling, 5 minutes for soft algae sampling and 30-45 minutes on visual assessment. The visual assessment consists of estimating the percent coverage of different substrate types on the streambed and identifying periphyton categories present based on colour and thickness.

Diatoms should be identified to species and indices such as species richness, diversity and the Eastern Canadian Diatom Index should be calculated. The Eastern

Canadian Diatom Index is produced by plotting species optima along a gradient using correspondence analysis and it is highly correlated with nutrients, especially phosphorus, and other water quality variables, such as chloride. Multivariate techniques such as canonical correspondence analysis can be used to arrange sites along environmental gradients. Of the three assessment protocols described, a high resolution identification of diatoms (to species level) had the strongest link to water quality (Goncalves *et al*. 2011).

3.1.6.4 Assessment of Periphyton Biomonitoring

The sensitivity of five periphyton metrics to shoreline development was compared in Precambrian Shield lakes of Ontario (Thomas *et al*. 2011). Rapid visual assessment (colour, texture, filament length, mat thickness, percent cover) collected within approximately 15 minutes per site, was combined with benthic sampling (in which rock and cobble substrate was removed and collected using a 2.6 cm internal diameter syringe sampler fitted with a toothbrush head and samples collected from sand using an inverted Petri dish and spatula). Sampling was conducted at 28 sites along the shorelines of five lakes in August. Water chemistry and benthic algae were collected along a 9 m transect positioned parallel to the shoreline at a depth of 0.4-0.6 m. Each transect was divided into nine contiguous circular plots of 1 m diameter to capture variation within a site. The five metrics compared were: (1) visual assessment, (2) biomass using chlorophyll a and ash-free dry mass, (3) community composition at a coarse taxonomic level (i.e., major algal classes), (4) quantified concentrations and composition of photosynthetic pigments (a new technique) and (5) community composition of diatom algae to the finest taxonomic level possible (e.g., species, subspecies or variety). Principal component analysis ordinations derived from the water chemistry results were used to explore bioassessment results using different approaches. The results indicated that high resolution diatom counts were most sensitive to shoreline development compared to the other approaches, revealing differences in periphyton communities according to development categories when other methods (and water chemistry) could not (Thomas *et al*. 2011). These findings may be applicable to southern Georgian Bay as well due to geographic similarity. However, larger gradients in nutrient concentrations near tributary mouths found in the Georgian Bay region may warrant the use of less sensitive metrics, such as biomass or major algae classes.

3.1.6.5 LSRCA's Nearshore Monitoring Program

The LSRCA collects periphyton samples from shoreline monitoring sites that are also used for benthic invertebrate monitoring (48 sites) at depths between 0 and 1 m. Samples are collected from all available habitats within the sites using a toothbrush to scrub substrates from a small area (roughly the size of a deck of cards; LSRCA 2013). Samples are wet mounted and observed under a compound microscope for preliminary identification soft algae and cyanobacteria. Biovolume is calculated by an algal specialist to determine community composition (LSRCA 2013).

3.1.6.6 Costs and Considerations

No cost estimates are provided for the periphyton monitoring protocols reviewed. The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) is estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015).

Use of multiple assessment methods can contribute to QA/QC by allowing comparison of effectiveness and sensitivity of different approaches (e.g., Goncalves *et al*. 2011; Thomas *et al*. 2011). Photographs of representative specimens are archived at LSRCA, as are unused portions of samples, should later consultation be necessary (LSRCA 2013).

Figure 3.3. Application of a syringe periphyton sampler in the field.

Table 3.6. Summary of Periphyton Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort
New Zealand Stream and River Periphyton Sampling Protocol (Biggs and Kilroy 2000)	Quadrats, artificial substrates, scraper, brush, spatula, Petri dish	Relative abundance, abundance, chlorophyll a, ash-free dry mass	Streams and rivers but could be adapted to lakes			
Bioassessment of Non-wadeable Streams and Rivers (Flotemersch *et al*. 2006)	Scraper, brush, sample bottles, syringe, spoon, artificial substrates	Relative abundance, species density, richness, dominance, percent cyanobacteria, chlorophyll a, ash-free dry mass, phosphatase activity, autotrophic index, number of taxa, diversity, percent community similarity, pollution tolerance index, percent sensitive taxa, percent live taxa	Streams and rivers but could be adapted to lakes	Shore to 1 m		~300 diatom cells/sample
OABP (Goncalves *et al.* 2011)	Scraper, brush, turkey baster, sample jars	Diatoms and soft algae Species richness, diversity, Eastern Canadian Diatom Index, percent cover of different substrate types, visual classification of periphyton based on colour and thickness	Rivers but could be adapted to lakes			3-tier assessment: 10-15 minutes for diatom sampling/site, 5 minutes for soft algae/site and 30-45 minutes for visual assessment/site
Assessment of Periphyton Biomonitoring (Thomas *et al*. 2011)	Syringe, toothbrush, Petri dish, spatula	Visual classification of periphyton based on colour, texture, filament length, mat thickness, percent cover, chlorophyll a, ash-free dry mass, community composition (to class, species, subspecies, variety), concentration and composition of photosynthetic pigments,	shoreline	0.4 – 0.6 m	August	28 sites across 5 lakes 9 m transect divided into 9 contiguous circular plots of 1 m diameter per site, Visual assessment: 15 minutes/site
LSRCA SOPs (LSRCA 2013)	Toothbrush, compound microscope	Diatoms and soft algae, Community composition	nearshore	0-1 m		All available habitats at 48 sites

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3.1.7 Phytoplankton Monitoring

Phytoplankton are useful biological indicators of short- and long-term environmental change that are often included in aquatic ecosystem assessments (Green *et al*. 2015). The ecological optima and tolerances of phytoplankton taxa are well documented, and they exhibit rapid response to ecological disturbance and change because of their short life spans (i.e., less than 24 hours; LSRCA 2013). The sensitivity of phytoplankton can act as an early warning system in lakes, revealing the presence and impact of environmental stressors long before they are detected through many other monitoring types (OMOECC 2014; Green *et al*. 2015).

3.1.7.1 Phytoplankton Monitoring Protocols

Findlay and Kling (2001) provide a summary of sampling and laboratory procedures, data analyses and QA/QC measures for monitoring phytoplankton in freshwater systems. For qualitative sampling, they recommend using a 10 μm

Nitex mesh net fitted with a stopcock, which is 20 cm in diameter and 35 cm in length. A van Dorn sampler or an integrated sampler is recommended for quantitative sampling so that biomass can be calculated and compared at specific water volumes. A van Dorn sampler allows the phytoplankton assemblage to be collected from a specific water depth while an integrated sampler collects phytoplankton across a desired vertical gradient (e.g., a euphotic zone composite) within the water column. Sampling sites should be located a sufficient distance from shore to prevent collection of periphyton (which could grow several meters off the bottom), ideally over the deepest part of the euphotic zone (if it falls within the nearshore). At each site three to four net pulls are recommended with each sample combined to make one composite. Sampling should occur bi-weekly or monthly, with more frequent collection during algal blooms. Mid-day sampling is recommended to optimize light transparency due to vertical movements at other times. Findlay and Kling (2001) suggest that sample counting should be conducted through a counting chamber, and that a minimum of 400-600 cells be enumerated to ensure a representative sample. Taxa should be identified to species level if possible, and wet-weight biomass based on cell volume calculated. The cells/L and biomass of each species can then be summarized and plotted to determine seasonal, annual and long-term trends. Further metrics such as species richness, species diversity and similarity index can be used to characterize community composition and track changes over time (Findlay and Kling 2001).

3.1.7.2 US EPA Phytoplankton Surveys

The US EPA has developed sampling and analytical procedures for sampling phytoplankton in the Great Lakes (US EPA 2010). The protocol provides detailed guidance on how to composite different depths using a Rosette sampler so that the phytoplankton assemblage is represented proportionately. Sampling is designed for a US monitoring vessel and would need to be adapted for use with fewer or less sophisticated equipment, such as Kemmerer bottles (US EPA 2010).

3.1.7.3 LSRCA's Nearshore Monitoring Program

LSRCA has monitored phytoplankton in the past, but does not currently include them in its regular monitoring program. Three methods were used to sample phytoplankton in the nearshore: vertical and horizontal plankton net hauls and van Dorn sampling (LSRCA 2013). The vertical net haul consisted of a 64 µm mesh net lowered to 0.5 m below the epilimnion, then pulled steadily to the surface. The horizontal haul used the same type of net towed slowly at a depth of approximately 1 m for the length of the transect. The horizontal van Dorn sampler collected data at 0.5 m below the surface or at 1 m off the bottom, and samples were then filtered through an 80 µm nylon mesh filter. Sampling occurred at 10 lake stations during the spring and fall. Locations were selected based on sites used in previous studies, and to ensure adequate spatial distribution, or to target likely sources of ecological stressors or to include a wide range of water quality (e.g., Cook's Bay is shallow, enriched and dominated by rooted aquatic plants while Kempenfelt Bay is deeper with lower nutrient levels). Collections were wet mounted and observed directly under a compound microscope for preliminary identification of "soft" algae (i.e., non-diatoms) and cyanobacteria to species level. Diatoms were slide mounted through a multi-step procedure and also enumerated under a compound microscope. Biovolumes were calculated by an algal specialist to determine community composition (LSRCA 2013).

3.1.7.4 Great Lakes Water Intake Monitoring for Trophic Conditions

The OMOECC's Great Lakes Water Intake Monitoring for Trophic Conditions provides information on where and how water quality is changing over time, and any response of biological conditions (OMOECC 2014). The monitoring program has collected over 20 years of data on nutrient concentrations in the Great Lakes as a continuation of the Great Lakes Intakes Project. Seventeen water treatment plants are sampled on a weekly to monthly basis throughout the year by collecting nutrient samples and chlorophyll a from raw intake water. The long-term scope of the monitoring program can reveal impacts of a variety of stressors not actively monitored in the aquatic environment (e.g., UV radiation, climate change), since shifts in algal species composition beyond the normal range of previous patterns can indicate underlying environmental drivers (OMOECC 2014).

3.1.7.5 US Geological Survey Guidelines

The US Geological Survey guidelines for lake and reservoir monitoring recommend sampling chlorophyll a to determine the trophic state of a waterbody (Green *et al*. 2015). It is simple to collect, and identification and enumeration of phytoplankton can provide additional useful information. Samples can be collected at the surface, at discrete depths, or through depth-integrated collection (Green *et al*. 2015).

The US Geological Survey's manual for lake monitoring recommends sampling phytoplankton with both a vertical tow (lowered to 1 m above the lake bottom and retrieved at approximately 0.5-1 m/second) and a surface horizontal tow (retrieved hand over hand, or pulled behind the boat so that the net is just below the water surface; Becker Nevers and Whitman undated). Since changes in fluctuations in nutrients, sunlight and predation pressure cause frequent changes to phytoplankton community composition, surveys should be conducted at least once a month.

3.1.7.6 Costs and Considerations

No cost estimates for phytoplankton monitoring were found in the literature. LSRCA halted its phytoplankton monitoring because of time and staff constraints (Ginn pers. comm. 2015). The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) is estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015).

Several QA/QC approaches are applied to collection and processing. Findlay and Kling (2001) suggest that having one person identify all samples provides consistency, but recommend that 10-15% of samples be double checked by others to ensure accuracy. They further recommend that replicate counts be performed on selected samples, and that results be within $\pm$ 20% of the first count. Two protocols recommend collecting voucher specimens for identification by expert taxonomists (Findlay and Kling 2001; Becker Nevers and Whitman undated). LSRCA's SOPs include archiving photographs of representative specimens, as well as unused portions of samples. The SOPs review various health and safety considerations for sampling protocols and list required training certification (LSCRA 2013).

Table 3.7. Summary of Phytoplankton Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort
Phytoplankton Monitoring Protocols (Findlay and Kling 2001)	Qualitative: 10 µm Nitex mesh with stopcock (20 cm diameter, 35 cm length) Quantitative: van Dorn or integrated sampler	Wet-weight biomass, cells/L, species richness, species diversity, similarity index	Freshwater systems	Deepest part of euphotic zone	Mid-day	3-4 pulls/site bi-weekly or monthly (more frequently when algal blooms)
US EPA Phytoplankton Surveys (US EPA 2010)	Rosette sampler			Unstratified: 1, 5, 10 and 20 m if depth > 20 m, if total depth 15 – 22 m replace 20 m sample with bottom sample, if total depth < 15 m sample at surface, mid-depth and bottom Stratified: surface, 5, 10 m and lower epilimnion		
LSRCA SOPs (LSRCA 2013)	Vertical and horizontal plankton net hauls (64 µm mesh), van Dorn sampler (80 µm mesh)	Community composition of algae and cyanobacteria	nearshore	0.5 m below epilimnion (vertical haul), 1 m below surface (horizontal haul), 1 m off lake bottom and 0.5 m below surface (van Dorn sampler)	Spring and fall	10 lake stations
Great Lakes Water Intake Monitoring for Trophic Conditions (OMOECC 2014)		Chlorophyll a	Raw intake water		Weekly to monthly all year	17 locations
US Geological Survey Guidelines (Becker Nevers and Whitman undated; Green *et al.* 2015)	Vertical tow, surface horizontal tow	Community composition	Lakes and reservoirs	1 m above lake bottom to surface (vertical tow), just below surface (horizontal tow)	monthly	

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3.1.8 Water Quality Monitoring

Numerous short- and long-term monitoring programs exist in the Great Lakes and Lake Simcoe to monitor nearshore water quality. The main objectives of these programs are to characterize spatio-temporal changes in water quality and to link them to anthropogenic activity in surrounding watersheds (e.g., Diep *et al*. 2007; Howell *et* al. 2012; LSRCA 2013; OMOECC 2014). Two studies emphasize that water quality is influenced by a complex range of factors, which must be recognized and incorporated into monitoring design (Diep *et al*. 2007; Howell *et al*. 2012). Water quality typically exhibits a large degree of spatial variability due to a diversity of geomorphic, ecological and anthropogenic drivers operating at multiple spatial scales. Additionally, water from different biogeochemical sources may mix in the nearshore. An accurate characterization of the range of water quality conditions and their drivers is thus challenging. As a result, evaluation of water quality issues requires an assessment of multiple spatial and temporal scales and an understanding of the underlying features of both the watershed and the nearshore zone affecting them (Diep *et al*. 2007; Howell *et al*. 2012).

3.1.8.1 Eastern Georgian Bay Water Quality Survey

Water quality was assessed in coastal areas of eastern Georgian Bay to characterize the natural limnological variability and dynamics of the region (Diep *et al*. 2007). Sampling occurred three times over a two year period (2003-2005) in the spring, summer and fall at 135 nearshore, offshore and embayment sites. Both composite and discrete samplers were used from the water surface to two times the Secchi depth, or the top of the metalimnion. Sampling also occurred at 1 m off the bottom if a hypolimnion was detected. The following parameters were measured in the field: Secchi depth, dissolved oxygen, conductivity, pH, turbidity, and in-situ light profiles. In the lab, chlorophyll a, chlorophyll b, total phosphorus, phosphate, total nitrogen, ammonium, nitrate, nitrite, silicate, sulphate, magnesium, chloride, calcium, potassium, dissolved organic carbon, total suspended solids, colour, turbidity, and hardness were also analyzed. Diep *et al*. (2007) recommended also recording broader physical habitat features, such as distance from land, degree of shelter and connectivity to the open waters of Georgian Bay.

3.1.8.2 Lake Ontario Water Quality Survey

The Lake Ontario coastline (Grimsby to Cobourg) was surveyed in 2008 to compare water quality conditions at four locations (Howell *et al*. 2012). A shipboard flow-through system connected to a series of sensors measured parameters continuously from a 3 m depth to 5 km offshore at each location, covering 12.8-23 km per site. Samples were also taken at 20-25 stops within each of these areas. Additional samples were collected along the shoreline (to a depth of 1.2 m) by wading from shore along 0.6-2.5 km of coastline at each location. Each site was sampled four to five times between April and November. The following parameters were measured: conductivity, pH, alkalinity, turbidity, total phosphorus, phosphate (as reactive phosphorus), ammonium, ammonia, nitrate, nitrite, TKN, silicate, chloride, calcium, dissolved organic carbon, total suspended solids and *E. coli*. Supplemental information on land use was gained from aerial photography to help with interpretation of results. Levels of solids, nutrients, major ions, dissolved organic carbon and *E. coli* were higher and more variable at tributary, embayment and shoreline (0-1.2 m depth) sites compared with open nearshore (~ 3 m – 5 km offshore) sites. Levels of these parameters declined sharply as distance from shore increased, up to 1 km offshore (Howell *et al*. 2012).

3.1.8.3 LSRCA's Nearshore Monitoring Program

LSRCA has developed standard operating procedures (SOPs) for monitoring lake health and seasonal and inter-annual changes in water quality in Lake Simcoe (LSRCA 2013). Monthly physical monitoring is conducted to coincide with the spring and fall overturn at 10 lake stations and 6 Holland River stations (as required). Sampling sites are selected based on locations used in previous studies, and to ensure adequate spatial distribution, or to target likely sources of ecological stressors or sensitive habitat (e.g., coldwater fish habitat, urban run-off, agricultural inputs). Water surface samples are collected at 0.5 m below the surface and at 1 m off the bottom using a horizontal van Dorn sampler, then filtered through an 80 µm nylon mesh filter. Parameters measured include temperature, dissolved oxygen, conductivity, pH, chlorophyll a, as well as nutrients and metals.

3.1.8.4 Great Lakes Index Station Network

OMOECC currently has three survey programs that monitor the Great Lakes nearshore: the Great Lakes Index Station Network, the Great Lakes Nearshore Mapping Surveys and the Great Lakes Water Intake Monitoring for Trophic Conditions (OMOECC 2014). The purpose of the Index Station Network is to document where and how water quality conditions change over time. Stations are situated both in locations representative of background conditions (reference stations) and in locations integrating stressors from a wide area (index stations; e.g., river mouths, depositional zones of embayments, areas where prevailing circulation patterns concentrate stressors). The network is comprised of 70 core sites, with a minimum of seven sites sampled per year on a lake-by-lake cycle. A team of 15 scientific and field staff using two survey vessels sample sites from spring through fall and various physical measurements are collected, including thermal and optical profiles of the water column, water chemistry (nutrients, major ions, solids), (OMOECC 2014). These measurements are complemented by additional monitoring of sediment chemistry, habitat characterization and biological response (i.e., benthic invertebrates, phytoplankton, zooplankton).

3.1.8.5 Great Lakes Nearshore Mapping Surveys

The Great Lakes Nearshore Mapping Surveys map spatial water quality patterns to evaluate nutrient, bacteriological, physical and aesthetic features along shoreline gradients throughout the Great Lakes (OMOECC 2014). The surveys are designed to track the status of environmental indicators in the nearshore zone, because this is the area of lakes most strongly and directly affected by land-based activities. Water quality is assessed over multiple sampling periods to characterize the typical range of conditions found in areas likely impacted by anthropogenic activity (e.g., large tributaries or harbours). Two to five study areas are surveyed every second year, with 15 sites sampled per area, from spring through fall. High resolution in site mapping of water quality parameters (e.g., conductivity, chlorophyll fluorescence, dissolved oxygen, turbidity, hydrocarbon fluorescence) is combined with ground truthed sample collection. The mapping is often used in combination with hydrodynamic modelling to assess specific abatement action scenarios (OMOECC 2014).

3.1.8.6 Great Lakes Water Intake Monitoring

The Great Lakes Water Intake Monitoring for Trophic Conditions focuses on identifying spatio-temporal trends in nutrient concentrations and is a continuation of the Great Lakes Intakes Project, which has over 20 years of monitoring data (OMOECC 2014). Seventeen water treatment plants are sampled on a weekly to monthly basis throughout the year by collecting samples from raw intake water and measuring conductivity, chlorophyll a, total phosphorus, nitrate, and chloride. The high frequency of sampling is necessary to overcome the high short-term and annual variability in parameters measured, so that meaningful seasonal and annual trends can be detected (OMOECC 2014).

3.1.8.7 Lake Ontario Nearshore Monitoring

TRCA has been monitoring water quality in the Lake Ontario nearshore around Ajax and Pickering since 2006. The monitoring area extends from Rouge River in the west to Carruthers Creek in the east, and encompasses the intake for the Ajax Water Supply Plant, as well as the outfall for the Duffins Creek Water Pollution Control Plant. The intent of the program is to understand nutrient dynamics in the region to inform management decisions. In particular, the program aims to identify practices and sources of nutrients or bacteria which could affect nearshore water quality (TRCA *et al*. 2014). The sampling design has changed several times over the course of the program, Initially it consisted of eight transects extending from shore to 3 km offshore, with surface water samples taken at 0 m, 100 m, 400 m, 1 km, 2 km, and 3 km out. Additional samples were also taken at middle and bottom depths along one of these transects. In 2011, the transect length was extended to 5 km so that shoreline water chemistry could be compared with 'background' nutrient levels, and sampling was added at middle and bottom depths along all transects. The number of transects was reduced from eight to four, with sampling stops at 100 m, 1 km, 3 km and 5 km from shore to offshore in 2011. More transects were added close to shore in 2014, and only surface samples were taken in water less than 1 km from shore (TRCA 2016).

The 2014 sampling design was found to be too labour intensive, since it could not be completed in a single day, even with two boat crews. As a result, monitoring was modified to make it manageable and focused on shore. Samples are now taken along 10 transects: at the surface only close to shore (i.e., at 0 m, 100 m and 400 m) since the entire water column is well mixed at these depths and at both the surface and bottom of the lake at 1 km, 3 km and 5 km offshore (TRCA 2016). Many of the 3 km and 5 km sampling sites were removed since ECCC's offshore surveys already provide water quality information for these locations. Collection of data from the middle of the water column was also eliminated.

Niskin water samplers are used to collect water samples. The following parameters are measured: nutrients (i.e., ammonia, ammonium nitrate, nitrite, TKN, total phosphorus, dissolved phosphorus, phosphate), general chemistry (i.e., alkalinity, pH, chloride, sulphate, conductivity total suspended solids, turbidity and dissolved organic carbon), and *E. coli* (at sites less than 400 m from the shore; TRCA *et al.* 2014).

Note: The TRCA nearshore monitoring program in the vicinity of Ajax and Pickering also represents an example of monitoring for tributary influence and thus is discussed in Section 3.1.11 as well.

3.1.8.8 US Geological Survey Guidelines

The US Geological Survey has a primer on study design and sampling strategies for a wide variety of monitoring types, including water quality (Green *et al*. 2015). Many factors are considered, including water quality concerns (e.g., erosion), linkages with possible contributing factors, types of studies and lists of parameters generally assessed, as well as those that are prioritized in reconnaissance studies. Guidance on sampling approaches is provided, such as recommended sample size and timing of collection. While the guidelines provide general background information to assist lake managers in the design of monitoring programs, the methods are not prescriptive (Green *et al*. 2015).

3.1.8.9 Costs and Considerations

No cost estimates are provided for water quality monitoring protocols in the literature. The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) is estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015). The annual cost for TRCA's monitoring of the Lake Ontario nearshore is estimated to be approximately $80,000 in 2016, or $10,000 per field survey and $20,000-30,000 per lab analysis (Bowen pers. comm. 2016).

QA/QC procedures include use of replicates (duplicates or triplicates) and linear regression of paired field and lab measured values (Diep *et al*. 2007; Howell *et al*. 2012). OMOECC collects two blanks to be submitted with field samples and employs blanks and standards in lab analyses in the Great Lakes Index Station Network (Howell and Benoit 2014). LSRCA encountered problems when its analytical lab raised detection limits (to be less sensitive) but still reported values at the lower limit, resulting in false negatives. LSRCA did not become aware of the issue until it compared some of its sample results with samples from overlapping offshore sites collected by the OMOECC, which was using a lab with more consistent and accurate analytical methods (Ginn pers. comm. 2015). Sending duplicate samples to different labs (providing other labs are using lower detection limits), or examining the precision of the analytical methods used to analyze samples, could help avoid this problem but duplication effort needs to be balanced with available resources (Ginn pers. comm. 2015).

The US Geological Survey guidelines outline standard health and safety protocols, including training and communication considerations (Green *et al*. 2015). LSCRA's SOPs provide health and safety instructions in a step-by-step manner to accompany sampling protocols and list required training certification (LSCRA 2013).

Table 3.8. Summary of Water Quality Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort
Eastern Georgian Bay Water Quality Survey (Diep *et al.* 2007)	Composite and discrete samplers	Field: Secchi depth, dissolved oxygen, conductivity, pH, turbidity, in-situ light profiles Lab: chlorophyll a and b, total phosphorus, phosphate, total nitrogen, ammonium, nitrate, nitrite, silicate, sulphate, magnesium, chloride, calcium, potassium, dissolved organic carbon, total suspended solids, colour, turbidity, hardness	Natural limnological variability and dynamics, anthropogenic impacts	Nearshore, offshore and embayment sites water surface to 2 x Secchi depth or top of metalimnion (also 1 m off bottom if hypolimnion present)	Spring, summer, fall	135 sites, 3 times over 2 years
Lake Ontario Water Quality Survey (Howell *et al.* 2012)	Shipboard flow-through system + series of sensors	Conductivity, pH, alkalinity, turbidity, total phosphorus, phosphate (reactive phosphorus), ammonium, ammonia, nitrate, nitrite, TKN, silicate, chloride, calcium, dissolved organic carbon, total suspended solids, *E. coli*	Compare water quality conditions across sites	3 m depth to 5 km offshore, shoreline to 1.2 m	April-November	4 locations with continuous sampling 3 m to 5 km offshore + 20-25 sampling stops + shoreline sampling to 1.2 m depth, 4-5 times/year
LSCRA SOPs (LSCRA 2013)	Horizontal van Dorn sampler	Temperature, dissolved oxygen, conductivity, pH, chlorophyll a, nutrients, metals	Monitoring lake health and temporal changes	0.5 m below surface and 1 m off bottom	Spring and fall overturn	10 lake stations, 6 river stations
Great Lakes Index Station Network (OMOECC 2014)		Thermal and optical profiles	Water quality changes over time		Spring, summer and fall	70 core sites, minimum 7 per year by 15 staff and 2 vessels
Great Lakes Nearshore Mapping Surveys (OMOECC 2014)		Conductivity, chlorophyll fluorescence, dissolved oxygen, turbidity, hydrocarbon fluorescence	Mapping status of water quality		Spring, summer and fall	2-5 areas every 2 years, 15 sites per area

Method Name	Type of Gear	Parameters Measured	Type of Use	Depth of Water	Time of Year	Effort
Great Lakes Water Intake Monitoring (OMOECC 2014)		Conductivity, chlorophyll a, total phosphorus, nitrate, chloride	Trends in nutrient and water quality conditions in nearshore		Year-round	17 sites on weekly to monthly basis
Lake Ontario Nearshore Monitoring (TRCA *et* al. 2014; TRCA 2016)	Niskin water sampler	Ammonia, ammonium, nitrate, nitrite, TKN, total phosphorus, dissolved phosphorus, phosphate, alkalinity, pH, chloride, sulphate, conductivity, total suspended solids, turbidity, dissolved organic carbon, *E. coli*	Nutrient dynamics (temporal and spatial)	Nearshore out to 5 km offshore	Ice-free season	10 transects, samples taken at surface at 0 m, 100 m and 400 m and at surface and bottom at 1 km, 3 km and 5 km distance from shore, sampling conducted 5-8 times per year

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3.1.9 Sediment Monitoring

Lake sediment represents an important long-term archive of overall lake conditions since it is a repository for nutrients, biological materials and pollutants from throughout the lake basin. Sampling sediment at depth intervals can thus provide a profile of the history of nutrient loading and contamination within the lake (Becker Nevers and Whitman undated). The shallow nearshore of large lakes, however, is often too turbulent to allow the accumulation of sediments. Consequently, sampling in deeper waters or quiescent embayments is necessary, where sediment usually exists as silt or clay. Suspended sediment is often measured in the water column (and referred to as total suspended solids) as part of water quality investigations to assess the impacts from a specific stressor (e.g., tributary inputs, shoreline erosion or resuspension, dredging) or to provide ancillary information for the interpretation of other water quality parameter results. In general, sediments are used for evaluating the extent of contamination from toxic and bioaccumulative metals and compounds, but sediments may also be useful for assessing nutrient inputs to the nearshore particularly from the watershed via rivers and stormwater outfalls. The physical properties of sediment can also be measured to characterize nearshore coastal processes (e.g., grain-size statistics etc.; see Section 3.1.12 for more information).

Numerous frameworks exist for assessing the degree of contamination, designing and implementing remediation operations and conducting post-remedial monitoring (e.g., Jaagumagi and Persaud 1996; Chapman 2008; USACE *et al*. 2006; Fletcher *et al*. 2008) but protocols that detail sampling and processing methodologies are less common. Sediment contamination is often first detected through other biomonitoring programs (such as fish or benthic invertebrate surveys), highlighting the important and common linkage between different benthic monitoring types (Jaagumagi and Persaud 1986).

3.1.9.1 Integrated Approach to the Evaluation and Management of Contaminated Sediments

OMOECC developed a stepwise approach to sediment assessment and management that included guidance on evaluation and remediation options (Jaagumagi and Persaud 1996). The framework recommends comparison of sediment chemistry with Provincial Sediment Quality Guidelines (PSQGs; e.g., no-effect level, lowest effect level and severe effect level) as well as background levels. Background levels can be established through information derived from core samples. Complementary data should be collected on the biological community (e.g., benthic invertebrate and fish community structure, sediment bioassays on benthic organisms such as chironomids, mayflies, oligochaetes, and fathead minnows, uptake studies on caged clams/mussels, leeches, and/or caged fish, contaminant residues in in-situ organisms such as benthic organisms or fish, bottom-feeding or young-of-the-year). The results of the data gathering and evaluation will dictate, to a certain extent, what course of action should be taken to manage the contaminated sediment, including remediation and associated monitoring (Jaagumagi and Persaud 1996).

3.1.9.2 Decision-making Framework for Assessment of Great Lakes Contaminated Sediment

A risk assessment framework has been developed to standardize evaluation of Great Lakes contaminated sediment (Chapman 2008). Guidance is intended to be sufficiently prescriptive that consistency across projects is maintained, but provides flexibility to incorporate site specific considerations. The framework only focuses on contaminants that biomagnify in fish or shellfish.

Caution should be taken when choosing sampling locations to ensure they are representative and capable of accurately documenting the ecosystem record within the accumulated sediments. The first step is to identify areas where sediment is accumulating. This occurs in low energy nearshore environments with organic rich, fine grained sediments (rather than in high energy shorelines with fine sand or coarser sediments). Embayments and river mouths are typical locations for sampling. Sediment assessment should focus on the known or anticipated contaminants for the study area, which might include nutrients (particularly phosphorus), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides, heavy metals, industrial compounds, pesticides and flame retardants. Prediction of what contaminants might be present is based on identifying possible point and non-point sources and tributary loadings (Chapman 2008). Chemistry data should be compared to PSQGs (guidelines exist for total phosphorus, total organic carbon [TOC] and TKN). Further study is warranted if one or more parameters exceed these guidelines. Complementary benthic invertebrate community assessment is recommended to assist in determining whether the system is impaired (Chapman 2008).

A Sediment Quality Index (SQI) is used in the framework to summarize and compare sediment conditions across sites in the Great Lakes (Grapentine *et al.* 2002; Marvin *et al.* 2004). The SQI is comprised of three indicators: exposure sediment toxicity (which evaluates survival of the benthic amphipod *Ampelisca abdita* exposed to almost 100 contaminant compounds), contaminant concentrations (associated with adverse biological effects), and TOC (high TOC sediments adsorb contaminants and can subsequently release them at high temperatures, under anoxic conditions or due to disturbance). A reference condition approach allows comparison and ranking of indices calculated for test sites with reference sites. If one or more of these indicators ranks as poor then the overall site is determined to have poor sediment quality (Chapman 2008).

3.1.9.3 Sediment Sampling Guidelines for the Pacific Northwest

The US Army Corps of Engineers (USACE) provide freshwater sediment sampling guidelines for the Pacific Northwest (USACE *et al.* 2006), portions of which are generally applicable to Ontario lakes. Core samplers are recommended for sampling thick sediment and for collecting sediment profiles (for determining the vertical distribution of sediment traits). Grab samplers are appropriate for finer grain sediment and to assess the horizontal distribution of sediment characteristics. Both core and grab samplers are relatively easy to operate, moderately priced and versatile for use in a variety of substrate types. Core samplers do not sample large volumes of sediment. Reliability of grab samplers should be checked to ensure sediment has not leaked out during sampling (e.g., by ensuring sampler is fully closed when retrieved and relatively full). More details on recommended sampling equipment is presented in the Summary table below.

Parameters collected with the USACE methodology include depth to mudline, sediment characteristics (e.g., texture, odour, visual), and presence of debris and/or benthos. Recommended analytical methods and quantification limits are provided for a variety of parameters (e.g., total solids, TOC, total sulfides, ammonia, grain size, metals, PCBs, PAHs, pesticides). Complementary biomonitoring is important to assess the impacts of contaminants on lake biota (e.g., availability of uptake through bioassay tests to test toxic effects on sensitive benthos like amphipods and midges; USACE *et al*. 2006).

3.1.9.4 Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario

Fletcher *et al*. (2008) provide guidance on identifying, assessing and managing contaminated sediment. Sediment chemistry parameters are compared with PSQGs and if any exceedances occur then biological assessments are conducted to quantify impairment of the aquatic environment. Recommended assessments include tests of sediment toxicity, benthic community alteration (through multivariate comparisons with reference conditions) and biomagnification potential. The results are used to develop a decision matrix to evaluate environmental risk and to determine the best management options (Fletcher *et al*. 2008).

3.1.9.5 LSRCA's Nearshore Monitoring Program

LSRCA uses sediment monitoring to track changes in nutrient concentrations and internal loading and release of phosphorus under low oxygen conditions (LSRCA 2013). A petite Ponar grab is used at 10 lake stations and 6 Holland River stations (as required) during the spring and fall overturn. The Ponar grab is preferred to the Ekman grab in Lake Simcoe because of its suitability for sampling hard packed sediments. Samples are analyzed for ammonia, moisture, orthophosphate, TKN, nitrate, nitrite, nitrate+nitrite, and acid extracted total phosphorus (LSRCA 2013).

3.1.9.6 Great Lakes Index Station Network

The OMOECC's Great Lakes Station Network program samples contaminants in surficial and suspended sediment at sites throughout the Great Lakes (OMOECC 2014). A minimum of seven sites are sampled per year (out of a total of 70 core sites) during the summer months (for surficial sediments) and spring through fall (for suspended sediments) to measure levels of PCBs, dioxins, PAHs and organochlorine pesticides. Surficial sediment is collected with a Shipek sampler (or Ponar if Shipek does not work) in the upper 3 cm of sediment. Triplicate samples are taken at each station (Howell and Benoit 2014). For suspended sediments, cylindrical acrylic tubes are used as sediment traps to collect fine grain material from the bottom of the water column. Traps are vertically deployed on the first spring survey and collected on the final fall survey (Howell and Benoit 2014).

3.1.9.7 Contaminated Sediment Assessment Program

OMOECC also conducts a more targeted survey of contaminated sediment through the Contaminated Sediment Assessment program, at designated sediment 'hotspots' throughout the Great Lakes (including Great Lakes Areas of Concern; OMOECC 2014). Benthic surveys are conducted concurrently to link contamination with biological impacts.

3.1.9.8 US Geological Survey Guidelines

The US Geological Survey's guidelines recommend using a core sampler to collect sediment and analyzing it for heavy metals, pesticides, organic and inorganic compounds (Becker Nevers and Whitman undated).

3.1.9.9 Costs and Considerations

Sediment sampling programs need to begin with a clear understanding of their intent. Sampling with Ponar grabs or Ekman grabs will provide a bulk sample of sediment up to ~ 10-15 cm depth. This will provide a composite sample of current and historic sediment characteristics but must be interpreted with some understanding of the rate of sediment accumulation. Grab type sampling is not recommended for determination of current sediment conditions except in stable environments where little change has occurred over time. Current deposition or contamination must be assessed by sampling the upper ~1 cm of sediment using a coring device or hand sampling by divers. Redox conditions and geochemistry will also change with depth of a sample and some metals will be preferentially mobilized. As a result, core profiles of contaminants may not accurately reflect an historic record of deposition.

It is increasingly acknowledged that current contaminant monitoring programs may not be sufficient for tracking many emerging pollutants (such as fluorinated surfactants, flame retardants, pesticides, pharmaceuticals and personal care products; OMOECC 2014). These toxins present new monitoring challenges, since they tend to dissolve in water rather than accumulating in sediments. Consequently, modifications will be needed to monitoring protocols in the nearshore, particularly for locations in urban areas, where runoff and sewage effluents are sources of many of these emerging contaminants (OMOECC 2014).

Sediment chemistry analysis tends to be expensive. Since sediment conditions change very slowly, annual sampling is not recommended; instead every five years should be appropriate (Becker Nevers and Whitman undated). The initial cost for establishing the LSRCA's nearshore monitoring program (covering benthic invertebrates, zooplankton, periphyton, phytoplankton, macrophytes, sediment and water quality) is estimated to be approximately $2-3 million for the first five years (Ginn pers. comm. 2015).

Many parameters measured for sediment assessment are present in trace amounts and care should be taken to avoid contamination of samples. Trip blanks should be used to detect volatile organic compound contamination, equipment rinsate blanks to monitor the decontamination process, field blanks to monitor field decontamination procedures and duplicates to assess sampling precision (more details of these QA/QC procedures are provided in USACE *et al*. 2006). For lab analysis, split samples can be used to compare results from two different labs, and a test sample (of known concentration) can be compared with lab results (Becker Nevers and Whitman undated).

Table 3.9. Summary of Sediment Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Time of Year	Effort	Cost
Integrated Approach to the Evaluation and Management of Contaminated Sediments (Jaagumagi and Persaud 1996)		Sediment chemistry, supplemented with biological assessments (e.g., benthic invertebrate and fish community structure, sediment bioassays on benthic organisms, uptake studies on cage organisms, contaminant residues in in-situ organisms)				
Decision-making Framework for Assessment of Great Lakes Contaminated Sediment (Chapman 2008)		Contaminants that biomagnify (e.g., PCBs, PAHs, chlorinated pesticides, heavy metals, industrial compounds, flame retardants), SQI, supplemented with biological assessments (e.g., on benthic invertebrates)	Low energy nearshore environments (e.g., embayments, river mouths)			
Sediment Sampling Guidelines for the Pacific Northwest (USACE *et al.* 2006)	Core samplers: gravity cores, Gus samplers, augers with spiliot spoons, hydraulic push cores, box cores, piston cores, vibracorers Grab samplers: Ekman, Peterson, Ponar, Shipeck, Van Veen	Total solids, TOC, total sulfides, ammonia, grain size, metals, PCBs, PAHs, pesticides, depth to mudline, sediment characteristics, presence of debris, presences of benthos, supplemented with biological assessments (e.g., bioassay tests on benthic invertebrates)				Core and grab samplers are moderately priced
Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario (Fletcher *et al.* 2008)		Sediment chemistry, supplemented with biological assessments (e.g., tests of sediment toxicity, benthic community alteration, biomagnification potential)				

Method Name	Type of Gear	Parameters Measured	Type of Use	Time of Year	Effort	Cost
LSRCA SOPs (LSRCA 2013)	Petite Ponar grab	Ammonia, moisture, orthophosphate, TKN, nitrate, nitrite, nitrate + nitrite, acid extracted total phosphorus		Spring and fall overturn	10 lake stations and 6 river stations	
Great Lakes Index Station Network (Howell and Benoit 2014; OMOECC 2014)	Surficial sediment: Shipek or Ponar sampler; Suspended sediment: cylindrical acrylic tubes	PCBs, dioxins, PAHs, organochlorine pesticides	Throughout Great Lakes	Surficial sediment: summer; Suspended sediment: spring through fall	Minimum 7 sites sampled, triplicates at each station for surficial sediment	
Contaminated Sediment Assessment Program (OMOECC 2014)		Sediment chemistry, supplemented with benthic surveys	Sediment hotspots (including Great Lakes Areas of Concern)			
US Geological Survey's Lake Monitoring Guidelines (Becker Nevers and Whitman undated)	Core sampler	Heavy metals, pesticides, organic and inorganic sediment			Once every 5 years	Analysis tends to be expensive

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3.1.10 Shoreline Monitoring

Large-scale shoreline surveys can provide valuable information on the spatial distribution and extent of shoreline and nearshore habitat types, as well as patterns of shoreline alteration, degradation and development (OMNR 2010; NVCA 2014). It is particularly valuable when used to develop a time series of changes. Shoreline monitoring has been used effectively in Lake Ontario and southern Georgian Bay to collect information on natural heritage features and shoreline alteration and recession, which can be used as a baseline for measuring future change (OMNR 2010; Geomorphic Solutions 2012; NVCA 2014). It has also been used to characterize predominant types of alteration, and what percentage is associated with work permits (NVCA 2014). Data from a variety of sources can contribute to a shoreline monitoring program (e.g., aerial photography, underwater video, bathymetric sounding, GIS and GPS), enabling a broad-scale quantitative assessment of current conditions (OMNR 2010; Geomorphic Solutions 2012). Whenever possible, shoreline conditions should be referenced to the Coastal Zone Atlas which documented the Canada-Ontario Great Lakes Shore Damage Survey as a result of high water levels on the Great Lakes in the late 1960s through early 1970's (Haras and Tsui, 1976). The Atlas includes detailed information on the shoreline configuration usually from the break of slope point on the shoreline as a result of wave erosion out to the 20 m depth contour. The location of profiles is placed on aerial images from the time of the survey. Information on bank and nearshore sediment composition is also provided. Changes in the shoreline, particularly with respect to hardening and reconfiguration over the past 40+ years can be determined relative to this information. Nevertheless, fully integrating these varied datasets can be a challenge (OMNR 2010).

3.1.10.1 Shoreline Development and Alteration Survey for Southern Georgian Bay

The OMNRF conducted a survey of 660 km of shoreline along southern Georgian Bay, from Port Severn to Tobermory, to develop mapping standards and a baseline map of the coastline (OMNR 2010). Aerial photography and orthophotography were used to document shoreline characteristics. Shoreline development was quantified based on the extent of altered land cover, densities of buildings, roads and docks, and land ownership and the type of shoreline alteration (e.g., groynes, dredging, marinas, bridges, hardened shoreline) was assessed. Available nearshore data, such as substrate, vegetation cover and fish (both species and habitat), were also collected. Supplementary information on natural heritage features (e.g., forest patches, coastal wetlands, migratory bird stopover habitat) was used to identify significant and vulnerable habitat. The footprint of each type of shoreline alteration was calculated and a scoring method was devised to determine the cumulative impact of each type on the shoreline environment (OMNR 2010). A large percentage (67 %) of the shoreline was developed, with the highest levels located within close commuting distance of the Greater Toronto Area and where natural conditions do not restrict development. Development density was approximately three times greater within 500 m of the shoreline than the swath of land located 501-1000 m from the shoreline.

3.1.10.2 Shorelines Alteration Assessment Project for Southern Georgian Bay

NVCA examined shoreline alteration along south-eastern Georgian Bay to determine the amount of degradation between 2002 and 2012, and what proportion of development was associated with issuance of work permits (NVCA 2014). The shoreline and nearshore were also mapped to characterize natural heritage features. Aerial imagery was compared in 2002, 2010 and 2012 for the municipalities of Blue Mountains, Collingwood, Meaford and Wasaga Beach and the townships of Georgian Bluffs, and Tiny (a total of 278 km of shoreline). Six different types of shoreline alteration were documented: groynes and breakwaters, docks, dredging, marinas, bridges, hardened shoreline). Characterization of ecological values was conducted through analysis of a wide range of habitat, natural heritage and biodiversity information cross-referenced with the aerial imagery (categories included coastal wetlands, sand beaches, cobble beaches, bedrock shores, river mouths etc.). Detailed indication of the types of habitat, natural heritage and biodiversity information was not provided in the study but is included in a separate GIS shape file. A Shoreline Habitat Zone Framework was developed but developing quantitative statistics to describe habitat impacts (e.g., percent hardened shoreline for a given water surface area) was a challenge, and it was recommended that GIS protocols be modified to allow such calculations and an accurate assessment of two sets of aerial imagery when an evaluation of temporal change is desired (NVCA 2014).

3.1.10.3 Wabamun Lake Riparian Health Assessment

The North Saskatchewan Alliance completed a riparian health assessment of Wabamun Lake using video footage captured by a drone over three days in August 2014 (NSWA 2015). Drone imagery is considered coarse-scale but offers many advantages such as: no need for permission form landowners, a permanent record can be captured in a single study and processed anytime, and it is cost-effective. A Health Assessment Scorecard was calculated based on the imagery to determine if the riparian segments were “Healthy”, “Moderately Impaired” or “Highly Impaired” based on the vegetation cover, cattail and bulrush growth in the littoral zone, abundance of woody plants, density of trees, signs of human activity and human alteration. Fifty seven percent of the riparian area was deemed to be in healthy condition, with residential development serving as the major cause of disturbance.

3.1.10.4 Costs and Considerations

The cost of running a shoreline monitoring program includes short-term observations ($12,000-14,000 per year) for the first two to three years, long-term monitoring ($4000-6000 per year) every year and offshore bathymetry and underwater video once every 15 – 20 years or as needed ($8000-10,000 per sounding; Geomorphic Solutions 2012). Commercial side scan surveys cost approximately $7000 per day, including surveying, support and interpretation of results (Gregor, HESL. pers. comm. 2015). Bad weather conditions (i.e., waters too rough) need to be factored into budget estimates, as equipment and personnel rates are still charged when they are on standby. The utilization of a drone to gather imagery is very economical as the cost to purchase a basic drone (~$1350) is approximately half the hourly cost of renting a helicopter and it can be reused for future projects (NSWA 2015). Drones in this price range, however, typically operate through line of sight controls, which may be difficult to achieve in some nearshore environments, and which may require the use of a boat.

Table 3.10. Summary of Shoreline Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Cost
Shoreline Development and Alteration Survey for Southern Georgian Bay (OMNR 2010)	Aerial photography and orthophotography, natural heritage data	Extent of altered land cover, densities of buildings, roads and docks, land ownership, type of alteration, nearshore substrate, vegetation cover, fish species and habitat, natural heritage features	Quantification of shoreline development, baseline map of coastline conditions	
Shorelines Alteration Assessment Project for Southern Georgian Bay (NVCA 2014)	Aerial photography, natural heritage data	Amount and type of alteration, proportion of development associated with work permits, mapping of natural heritage features	Comparison of alteration over 10 year period	
Riparian Health Assessment of Wabamun Lake (NSWA 2015)	Drone	Vegetation cover, signs of human activity and alteration	Assessment of level of impairment to riparian zone	~$1350 to purchase drone

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3.1.11 Monitoring of Tributary Effects on the Nearshore

One of the most common objectives of nearshore monitoring is to understand the effect of watersheds on nearshore water quality. Tributaries deliver nutrients, contaminants and sediment loads (and possibly aquatic invasive species, AIS) to the nearshore and activities in the watershed (e.g., agricultural practices, urban development, reservoirs, water pollution control plant discharges) can have a direct influence on the nearshore environment. Ginn (2011) found, for example, that macrophyte growth in the nearshore of Lake Simcoe was strongly influenced by phosphorus loading from the nearest tributary. The wide variety of tools we have documented for monitoring the nearshore can also be used for monitoring the influence of tributaries on the nearshore. The unique nature of tributary/nearshore interactions, however, requires some modifications to monitoring design, as detailed below.

Monitoring of the plume at the river mouth is complicated by the volume of the river plume which can vary in response to seasonal flows (e.g., spring melt vs. low flows) or storm events within the watershed. The dispersion of the plume in the nearshore is further influenced by wind driven currents and other physical conditions. For example, depending on the temperature and thus density of the receiving water, as well as the plume and the physical mixing conditions induced by waves and currents, a riverine plume may:

- spread out on the surface of the receiving water (lighter than the receiving water and with limited physical mixing);

- sink to the bottom of the receiving water and diffuse at depth (more dense with limited exchange due to mixing); or,

- if the two waters are of similar density and turbulent mixing is occurring in the nearshore due to wind induced waves and currents, the plume will diffuse throughout the water column;

- be entrained in the longshore drift and move parallel to the shore; or

- move in a radial pattern away from the river mouth in the absence of lake currents.

A monitoring program must try to appropriately consider the broad range of possibilities and effectively address these. Sampling should be designed to incorporate environmental gradients that exist from the river mouth out toward the offshore and longshore sections of the lake to effectively monitor nearshore responses to tributaries. A radial or geometric sampling design is recommended to detect the zone of influence away from the river mouth (Fig. 3.4). This design should be used for every sampling event and results related to ambient currents and wave action. Water, sediment and biota should be sampled in the tributary just upstream of the mouth and in the nearshore at the mouth. Subsequent sampling should proceed at increasing geometric distances in and out from the river mouth (e.g., 100, 300, 1000, 3000 m for a larger tributary; 10, 30, 100, 300 m for a smaller tributary), moving along both directions of the nearshore to accommodate changes in nearshore currents. Water quality should be monitored on a seasonal basis to capture the influences of different flows on the nearshore and during stable flow, storm flow, low and high flow of the tributary. Sediments could be sampled every three to five years (if appropriate – see discussion in Section 3.1.9 above), always following a long period of stable or declining flow (e.g., late autumn, well after spring freshet). Fish sampling would need to consider the difference between resident species and those moving into the tributaries for spawning or feeding.

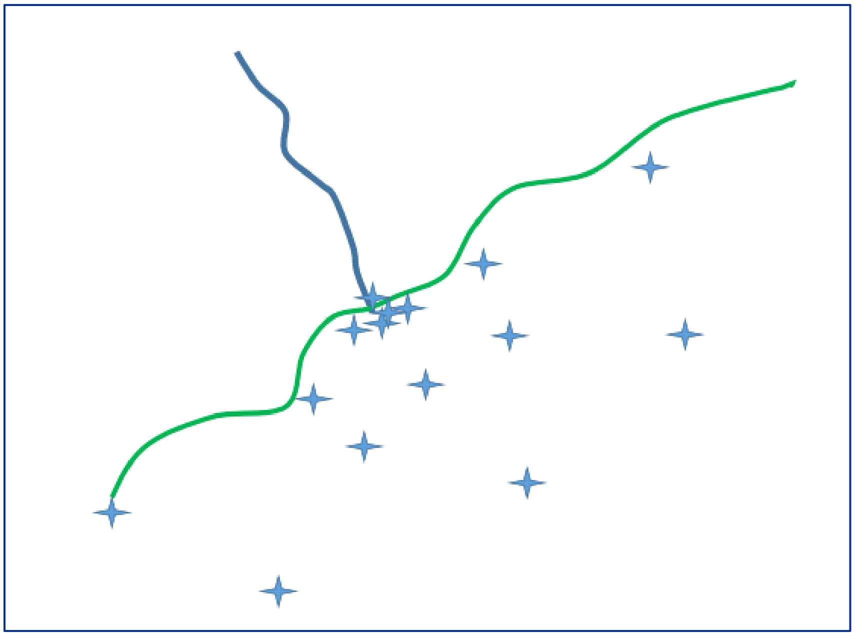

Figure 3.4. Schematic of nearshore monitoring design to capture the zone of impact gradient.

3.1.11.1 Lake Ontario Nearshore Monitoring around Duffins Creek

TRCA has undertaken nearshore water quality monitoring since 2006 in the vicinity of the mouth of Duffins Creek and the Duffin Creek Water Pollution Control Plant which discharges offshore (TRCA 2016). The monitoring program has evolved over time as a result of expert review and knowledge gained from experience (Figs. 3.5 and 3.6). Evolution of a monitoring program demonstrates that the water quality data collected is being evaluated and the program adjusted accordingly.

Initially, eight transects extended from shore to 3 km offshore, with surface water samples taken at 0 m, 100 m, 400 m, 1 km, 2 km, and 3 km out. Additional samples were also taken at middle and bottom depths (approximately 1 m off bottom) via discrete water samplers along one of these transects. In 2010, the transect length was extended to 5 km so that shoreline water chemistry could be compared with 'background' nutrient levels, and sampling was added at middle and bottom depths along all transects. The number of transects was reduced from eight to four, with sampling stops at 100 m, 1 km, 3 km and 5 km from shore to offshore. More transects were added close to shore in 2014, and only surface samples were taken in water less than 1 km from shore (TRCA 2016).

Effective nearshore monitoring for the characterization of nearshore water quality in the presence of tributary discharges and different water masses and movements is complex and requires extensive effort and resources to undertake effectively. In 2015, TRCA commenced the use of a conductivity-temperature depth profiler at stations 400 m and farther from shore to better understand the dynamics of water masses in the lake. Samples are now taken along 10 transects: at the surface only close to shore (i.e., at 0 m, 100 m and 400 m) since the entire water column is well mixed at these depths and at both the surface and bottom of the lake at 1 km, 3 km and 5 km offshore (TRCA 2016). Over time, TRCA has also worked with ECCC to refine detection limits for key parameters such as total phosphorus and SRP. Monitoring designs must constantly improve detection limits in response to findings and improvements in technology.

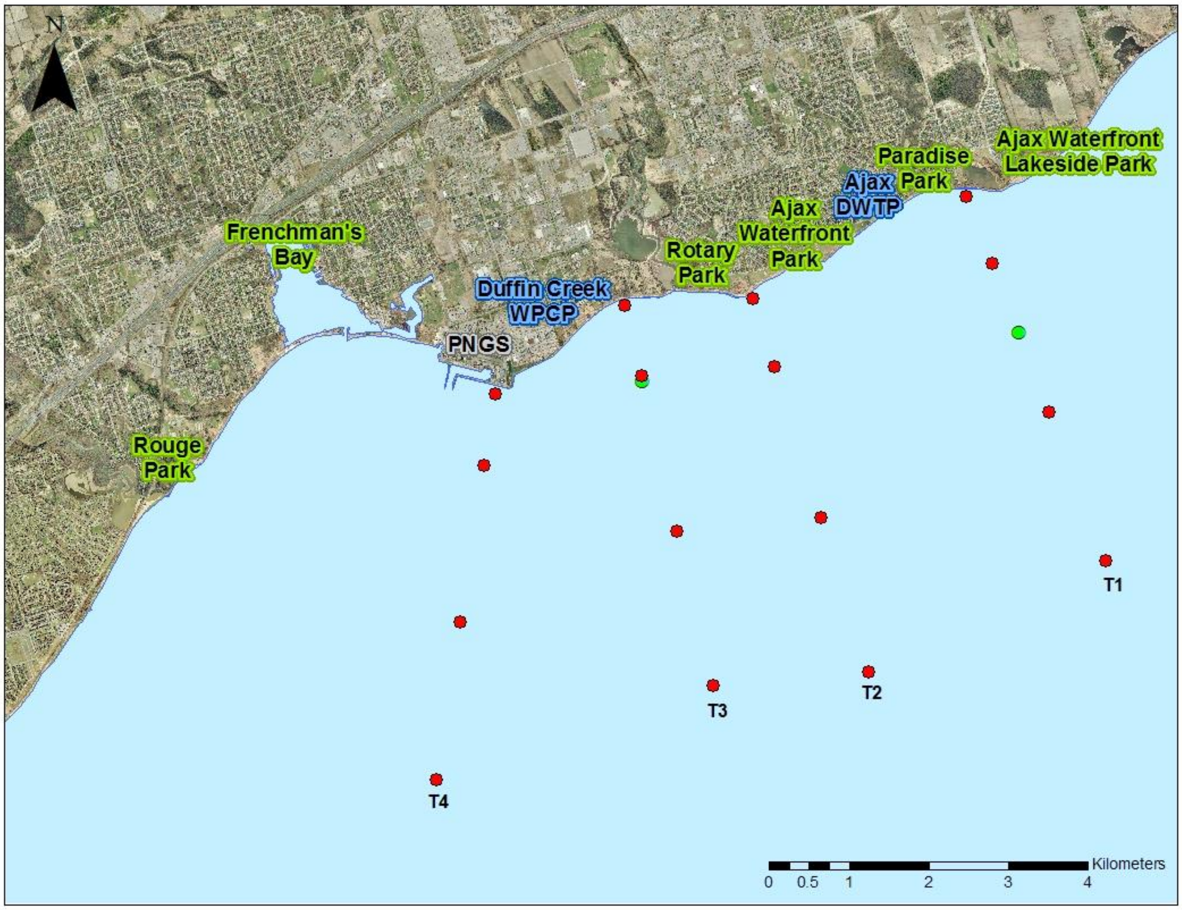

Figure 3.5. TRCA transect locations from 2011-2012.

Note: Transect numbers are identified by T1-T4 labels. Sampling distances from shore extend from 100 m, 1 km, 3 km, and 5 km. The Duffin Creek Water Pollution Control Plant Outfall and the Drinking Water Intake are the green circles in Transects 3 and 1, respectively. (TRCA 2016; http://trca.on.ca/the-living-city/watersheds/lake-ontario-waterfront/western-durham/sampling-design.dot).

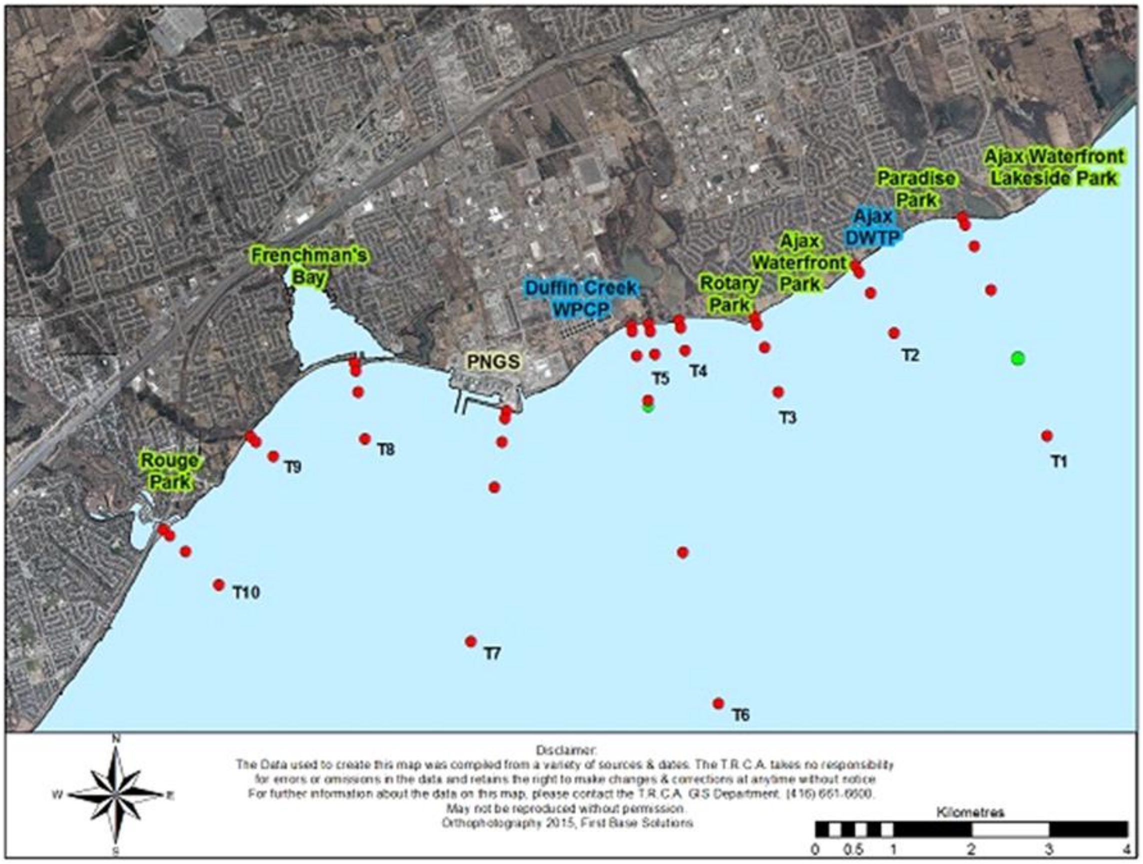

Figure 3.6. TRCA sampling transects and locations of sampling and conductivity profiles in 2015.

Note: Transect numbers are identified by T1-T10 labels. Sampling distances from shore extend from 0 m, 100 m, 400 m, 1 km, 3 km, and 5 km. The Duffin Creek Water Pollution Control Plant Outfall and the Drinking Water Intake are the green circles in Transects 1 and 6, respectively (TRCA 2016; http://trca.on.ca/the-living-city/watersheds/lake-ontario-waterfront/western-durham/sampling-design.dot).

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3.1.12 Monitoring of Coastal Processes

Coastal processes can have a significant influence on the nearshore environment and must be considered when designing a monitoring program. A number of physical factors in the nearshore can contribute to high variability in biological, physical and chemical monitoring variables, including wind-induced resuspension of sediments, shoreline erosion or deposition, and shoreline hardening (Makarewicz and Howell 2006). Information on these processes is often critical for interpreting nearshore monitoring results and for understanding the stressors that impact the nearshore environment. For example, the nearshore is typically characterized by shore-parallel flow, which can transport watershed discharges (e.g., tributary inputs) along and even onto the shoreline. This process can result in discrepancies between shoreside monitoring in very shallow water and monitoring by boat further out in the nearshore zone. Small volumes of discharge may not disperse into deeper water to be detected by boat, but may be very apparent along the shoreline. Thus, environmentally significant information may be lost under these circumstances if monitoring is restricted only to boats in the deeper nearshore (Rao and Murthy 2001).

Changes in lake water levels can result in periods of high erosion of bluffs and even loss of beach materials. These erosion rates will decrease during times of lower lake levels so lake level information should be assessed to understand any cycles in lake levels that may be occurring.

The construction of beach or shoreline protection structures can reduce shoreline erosion rates, thereby protecting the shoreline, but the loss of the sediment supply can result in a change in the nature of the sediment in the nearshore. Sand may be replaced by cobbles or even boulder pavement if the fine grained material is winnowed out of the till that often forms the shoreline and the original sediments. This process is referred to as beach starvation and shoreline protection in one area can result in increased erosion leeward of the structure. Knowledge of historical sediments and shoreline erosion rates are thus important. Historical information on Great Lakes sediments is available from ECCC (see below) and summarized in Section 3.1.10 Shoreline Monitoring.

3.1.12.1 Lake Ontario Shoreline Recession Monitoring Program

Shoreline recession was evaluated along part of Lake Ontario (in Mississauga) to provide background information for establishing a long-term recession monitoring program within the entire CVC watershed (Geomorphic Solutions 2012). At each of 12 locations, a cross shore profile was conducted, and complemented by alongshore and cross shore photographs, offshore bathymetric sounding and underwater observations of the composition of the lakebed (through underwater video). Cross shore profiles included written descriptions of the composition of the bluff, beach and nearshore, and lakebed, and topographic line graphs of the nearshore. Aerial interpretation was also carried out to enlarge the study area. Long-term monitoring of these sites will provide information on shoreline recession rates, impacts due to climate change, lake level regime, and condition and maintenance requirements of shore protection structures such as piers, sea walls, groynes, boulders or armoured headlands. Monitoring will also highlight opportunities for restoration and informed shoreline management and planning (Geomorphic Solutions 2012).

3.1.12.2 Elgin County Shoreline Management Plan

Baird & Associates (2015) developed a shoreline management plan for Elgin County to quantify coastal hazards and identify management objectives. The Elgin County shoreline was traversed from the west to east boundary. A total of 51 sites were visited and at each location GPS coordinates were collected, along with digital photographs and video, field notes on site observations, plus records of discussions with stakeholders. A conceptual littoral cell model was used to characterize the shoreline compartment, boundary or zone defined by the supply, transport, and deposition of sand and gravel. Within a littoral cell, there is an updrift supply area, a net direction of longshore sediment transport (LST), a downdrift depositional area, and no (or only minimal) leakage of sediment at the cell boundaries. The littoral cell approach is considered a useful way to address coastline management (Baird & Associates 2015).

A key consideration when evaluating nearshore sediment cover and the shoreline is the mobility of the material over various temporal scales (e.g., single storm events to several decades of fluctuating water levels). Long-term water level trends or cycles on the Great Lakes provide insight to the mechanism for bar migration and erosion rates.

The shoreline was sub-divided into different reach types based on geological and geomorphic features, land use patterns and exposure to coastal hazards as follows (i.e., high bluff, large beaches, port lands and navigation channel, and residential development).

Historical aerial photographs were available for the majority of the study coastline from flights completed in 1977 and 1978. In locations with sufficient ground control along the coast in both photo series (i.e., 1977/78 and 2010), such as local road networks, the historical imagery was geo-referenced to the 2010 county wide orthophotographs. A total of nine bluff areas were investigated covering 12.8 km of shoreline. Once geo-referenced, the top of bank was digitized for the eroding bluffs in both the 1977/78 and 2010 imagery. A custom software application, Baird ShoreTools, was used to generate shore perpendicular erosion transects between the historical and 2010 bluff crest position. The transects were spaced at 10 m increments to calculate recession measurements. This information was used to map the shoreline and identify hazards and to assist the partners in managing the regional shoreline in a consistent manner.

Direct monitoring of nearshore physical processes can be complicated and expensive (see for example USACE 1995), but there are a number of surrogate indicators that can be used to characterize conditions in a general manner, including:

- Average energy conditions of the shoreline can be approximated by the grain size of shoreline substrate. For example, fine grained silts and clays indicate a sheltered low energy environment, sand generally indicates a medium to high energy environment if there is a continuous source of sediment (e.g., Wasaga Beach), and boulders or bedrock indicate medium to high energy environment in the absence of a steady supply of sediment from shoreline erosion; and

- Longshore currents and be qualitatively estimated with respect to predominant direction and energy based on the accumulation of sediment on structures on the shoreline and the size of material accumulated.

Information on historical, current and forecast conditions for the Great Lakes that may help characterize physical coastal processes for nearshore monitoring are available from the National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory (http://www.glerl.noaa.gov/res/glcfs/), including:

- Wind speed
- Wave height
- Surface temperatures
- Surface currents
- Temperature transects
- Temperature profiles
- Water levels
- Ice cover.

An example of the kind of information available at this site is illustrated for currents in Lake Huron and Georgian Bay on January 28, 2016 (18:00 GMT; Fig. 3.7; NOAA undated).

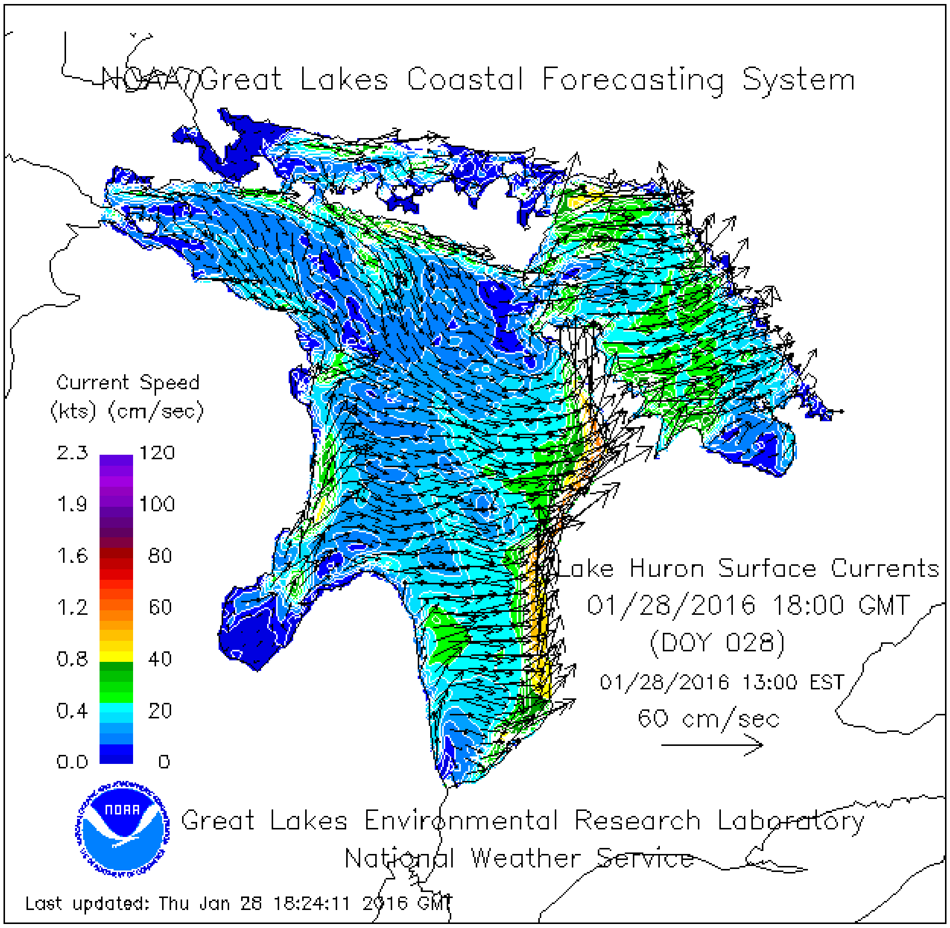

Figure 3.7. Sample of Lake Huron and Georgian Bay surface currents for January 28, 2016 (NOAA undated).

3.1.12.3 Historical Great Lakes Nearshore Sediment Survey

A comparison of current sediment characteristics with historical information for a specific location is helpful in understanding coastal processes. A change, for example coarsening of the sediments over time, likely indicates a loss of replenishment sources and a winnowing of the fine grained material from the nearshore. This commonly results from a hardening of the shoreline to protect facilities or structures on the shore. The structures may be small in scale such as often documented in the shoreline management reports completed by the conservation authorities (see for example discussion on Elgin County Shoreline Management Plans (Baird & Associates 2015) in Section 3.1.10) or major shoreline protection works, such as the > 1 km long breakwall and associated piers constructed in Pickering on Lake Ontario to protect the Pickering Nuclear Generating Station. Cumulative effects of both small and large scale projects can significantly alter the nearshore sediments.

The current sediment characteristics can be compared to historical nearshore sediment characteristics data, which are available from ECCC (2013). Samples were generally collected between 1969 and 1975 with grab samplers from boats along the shoreline in various depths of water up to 30 m. The purpose of the sampling was to describe the physical nature of the sediments in the nearshore including descriptions of sediment and core properties, grain-size statistics, sediment patterns and x-radiographs of sediment cores. Underwater photographs are also available for Lake Huron and Georgian Bay.

Miscellaneous data, including sediment, acoustic and underwater-television surveys for a number of sites and supporting a variety of objectives, are also available. Samples, cores and, in some cases, acoustic-bottom-classification and bathymetric data were collected at Darlington, Oshawa, Toronto, Port Dalhousie, eastern Lake Erie, northern Lake Michigan, Lake St. Clair, the nearshore zones of eastern and western Lake Ontario, and Lac St-Louis and Lac St-Pierre in the St. Lawrence River.

The Great Lakes Sediment Database (also known as the National Water Research Institute Sediment Archive) is an archive of data on the sediments of the Great Lakes, their connecting channels, and the St. Lawrence River which was collected by the National Water Research Institute in cooperation with other agencies between 1968 and 2001. It is housed in ECCC's National Water Research Institute in the Canada Centre for Inland Waters in Burlington, Ontario (additional information on the Archive can be found at http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=9890771E-1).

3.1.12.4 Historical Great Lakes Water Levels

Water levels can have a major impact on shoreline characteristics, particularly erosion rates and flood hazards during high water levels. Lake water levels in the Great Lakes fluctuate both seasonally and through longer cycles (except for Lake Ontario which since 1958 has been controlled within a relatively narrow range at the Moses – Saunders Power Dam at the outlet of Lake Ontario to the St. Lawrence River). Water levels are documented in Canada by the Canadian Hydrographic Service (Fisheries and Oceans Canada 2014; http://www.waterlevels.gc.ca/C&A/netgraphs_e.html) and in the US by the USACE (USACE undated; http://www.lre.usace.army.mil/Missions/GreatLakesInformation/GreatLakesWaterLevels/CurrentConditions.aspx). Data are generally available since 1918.

3.1.12.5 Meteorological Data

Wind speed and direction data can be used to qualitatively or quantitatively assess prevailing or specific event conditions. Commonly, ECCC's meteorological data are used and are available for current and historical conditions from selected weather stations at http://climate.weather.gc.ca/index_e.html (Government of Canada 2015). These data can be used to characterize wind conditions and calculate nearshore currents and wave conditions (wave hindcasting) but this type of work is generally undertaken by specialists in this field.

Table 3.11. Summary of Coastal Processes Monitoring Approaches

Method Name	Type of Gear	Parameters Measured	Type of Use	Cost
Field Monitoring				
Lake Ontario Shoreline Recession Monitoring Program (Geomorphic Solutions 2012)	Aerial photography, topographic maps, bathymetric sounder, underwater video	Shoreline recession rates, climate change impacts, lake level regime, condition of shore protection structures	Documentation of climate change impacts, monitor condition and maintenance requirements of shore protection structures, identify restoration, management and planning options	First 2-3 years: $12,000-14,000/yr; Ongoing: $4000-6000/yr; Offshore bathymetry and underwater video once every 15-20 years: $8000-10,000 per sounding
Elgin County Shoreline Management Plan (Baird & Associates 2015)	GPS, digital photography, video, interviews, orthophotography, digitizer, computer model	Shoreline hazards	Development of management objectives	
Desktop Monitoring				
Great Lakes Coastal Forecasting System		Historical, current and forecast physical conditions (e.g., wind speed, surface temperature, water level etc.)	Characterize nearshore coastal processes	
ECCC's Sediment Database		Historical nearshore sediment characteristics for 0-30 m depth		
Canadian Hydrographic Service/ USACE		Historical water levels		
ECCC's Meteorological Database		Historical and current wind speed and direction		

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3.2 Guidance Manuals for Protocol Development

We identified several monitoring manuals that provided useful guidance for the design of the Nearshore Monitoring Protocol. The focus of these guides ranged in scale (from national to regional to watershed levels), and aquatic ecosystem targeted (e.g., lakes, rivers and streams, wetlands, estuaries), and a wide variety of biotic and abiotic monitoring variables were reviewed and discussed. We reviewed these documents and used their information to inform our recommendations on monitoring design and selection and ranking of monitoring variables in Section 5. We briefly summarize each of the monitoring guidance manuals below.

3.2.1 GLWQA Habitat and Species Annex (7)

The updated GLWQA has established a Habitat and Species Annex (Annex 7) to conduct an inventory of existing nearshore habitat and develop an integrated nearshore framework. This initiative is currently underway throughout the Great Lakes and has the potential for application to nearshore monitoring. The habitat assessment is comprised of two stages, the first to delineate and classify nearshore areas based on habitat type, and the second to assess the ecological condition of these habitat types. The process will involve identifying areas of high ecological value, as well as current or potential areas threatened by stressors. The overall goal of the initiative is to use the baseline information to establish a target of net habitat gain for the entire Great Lakes Basin, which can be used to measure changes in habitat condition and functionality, ecosystem resilience and representativeness of protected areas in nearshore waters (Annex 7 Task Team 2015).

The Annex 7 Task Team identified key environmental variables for use in each stage of the assessment. Static or slow-changing variables, such as vertical temperature gradients, surface water temperature, lake substrate type, bathymetry, tributary inflows (e.g., watershed size, flow range), and water circulation were recommended for the classification stage. Dynamic variables such as benthic invertebrates, fish, macrophytes, chlorophyll a, physical water quality (e.g., dissolved oxygen, pH, conductivity), nutrients, sediment quality, and tributary inflows (e.g., pollutant load) were recommended for the assessment stage (Heathcote 2015).

3.2.2 Studies under Alberta's Water for Life – Healthy Aquatic Ecosystems Program

The Province of Alberta released its Water for Life Strategy for Sustainability in 2003, which aims, in part, to achieve and maintain healthy aquatic ecosystems. Research was conducted to determine the best techniques for monitoring and assessing aquatic ecosystem health in support of this goal. We reviewed two of the resulting studies: (i) Stantec 2005 and (ii) North/South *et al*. 2007. These studies evaluated what components of the aquatic ecosystem were best suited for monitoring aquatic ecosystem health, based on factors such as ecological significance, predictable response to stressors, ease of use, cost, and applicability to a range of aquatic habitats. The studies reviewed numerous biotic and abiotic components of the aquatic ecosystem, such as benthic invertebrates, zooplankton, macrophytes, phytoplankton, water quality, and sediment quality.

3.2.3 US Environmental Protection Agency's National Lakes Assessment

The National Lakes Assessment program surveys lakes, ponds and reservoirs across the lower 48 states to document lake condition and to evaluate the relative impact of different stressors on these aquatic ecosystems. The program began in 2007 and monitoring occurs every five years in randomly selected lakes representing different ecological regions (note that the Great Lakes are not part of the program). Surveys cover both offshore and nearshore zones of lakes. A suite of chemical, physical and biological variables were chosen for monitoring, based on their ability to effectively and reliably assess ecological integrity, trophic status, the ability to support recreational uses and key stressors in lakes. These variables include benthic invertebrates, zooplankton, macrophytes, phytoplankton, water chemistry, nutrients, and physical habitat characterization (US EPA 2012).

3.2.4 CCME's Guidance Manual for Optimizing Water Quality Monitoring Program Design

CCME has developed a guide for evaluating and optimizing existing water quality monitoring programs across Canada. The document focuses on monitoring design for rivers, lakes, estuarine waters and coastal waters. Existing approaches to optimizing program design are evaluated for their strengths and weaknesses, and recommendations are made for the most appropriate approaches. The guide examines five main steps in developing an effective monitoring program: (i) optimizing goals and objectives; (ii) optimizing monitoring design; (iii) optimizing data collection and data quality; (iv) optimizing data analysis, interpretation and evaluation; and (v) optimizing communication and interpretation. Decision-making flowcharts and optimization tools are presented to assist with the design of field sampling and data analysis, and the selection of monitoring variables.

Common monitoring variables used in lakes are identified in three categories: biological (e.g., benthic invertebrates, fish, phytoplankton, macrophytes), physiochemical (e.g., transparency, temperature, oxygenation, salinity, acidification, nutrients, metals) and hydro-morphological (e.g., flow characteristics, residence time, lake morphometry). The guide discusses how to prioritize variables to use based on significance (i.e., address objective and most sensitive to stressor), ease of sampling, equipment requirements, cost and logistical considerations of sampling design (i.e., spatial coverage and temporal frequency). Additional technical guidance is provided on recommended sampling frequency, duration and intervals based on monitoring objectives (CCME 2015).

3.2.5 CVC Draft Integrated Watershed Monitoring Program Framework

CVC has been running an Integrated Watershed Monitoring Program since 1999 to help protect and improve water quality and quantity, protect biological diversity and productivity, and support a healthy environment for people in the watershed. In 2015, CVC produced a draft framework document detailing the nature of its monitoring program and providing guidance on the general design of an environmental monitoring program to measure ecological integrity and identify key stressors. CVC uses a suite of biotic and abiotic monitoring variables to track conditions in groundwater, stream, wetland and forest environments (e.g., benthic invertebrates, fish and water quality are monitored in streams). The framework includes useful information to be considered when developing a monitoring program, including adaptive management, development of goals and objectives, stressor identification, selection of monitoring variables, as well as sampling design, data collection, analysis and management, and communication and reporting of results.

4. Considerations for Protocol Development

4.1 Background

Monitoring is a key component of environmental management and decision-making. A well-designed and executed monitoring program can provide valuable information on the current ecological condition of an area, the impacts of stressors on it, as well as changes over space and time. Knowledge of the ecological health of an area, and the threats it faces, is necessary before policy and management can be developed to effectively address the issues. A successful monitoring program, therefore, needs to be reliable and consistent, collecting appropriate data for the identified goals and objectives in a systematic, standardized and repeatable manner and using scientifically sound tools to analyze and interpret monitoring results. Furthermore, a well-designed monitoring program should include a process for regular communication of results to resource managers, decision-makers and the public, to ensure that monitoring data actually inform management and policy decisions (CCME 2015; CVC 2015).

4.1.1 Monitoring Purpose

The program design must begin with a clear understanding of its purpose. Environmental monitoring is generally conducted either for the purpose of early warning or early control (CVC 2015). Early warning programs are designed to detect ecosystem changes and identify possible causes so that decisions can be made on whether action is necessary. In comparison, early control programs assess whether remedial action has been successful and can indicate where changes may be necessary to improve management. Within these broad categories, monitoring may be classified further based on more specific functions as follows:

Early Warning

- Baseline monitoring: to establish the current state of the system and characterize the status and trends of ecosystem components and stressors;

- Investigative monitoring: to determine the cause and effect of an observed state or change in the ecosystem;

Early Control

- Baseline monitoring: to establish the state of the degraded system prior to implementing management activities;
- Effectiveness and restoration monitoring: to measure the success of a management approach in meeting its objectives (i.e., to test whether management is working);
- Compliance monitoring: to evaluate whether action directed under guidelines, standards, policy or legislation is being properly implemented to meet standards or targets (CCME 2015; CVC 2015).

4.1.2 Monitoring Goals and Objectives

Once the overall purpose of the monitoring program has been determined, it is crucial to identify the specific goals and objectives. Both goals and objectives should be clear, concise and measurable (CVC 2015). Goals articulate the overarching reason for monitoring and provide the framework for program design. For example, goals for a nearshore monitoring program might include:

- Protect the ecological integrity of the nearshore;
- Support recreational uses in the nearshore;
- Protect surface water sources for drinking;
- Identify the impacts of shoreline development on the nearshore;
- Identify the impacts of climate change on the nearshore;
- Restore degraded nearshore water quality or habitat.

Objectives provide more detail on the specific intent of goals and can be quantified through monitoring variables and associated metrics and targets (CCME 2015). For example, under the goal of protecting the ecological integrity of the nearshore, the following objectives, variables, metrics and targets might be identified:

Table 4.1. How monitoring goals and objectives translate into variables, metrics and targets measured in monitoring.

Monitoring Goal	Protect ecological integrity
Monitoring Objective	Ensure that biological communities are similar to those found under reference conditions (e.g., either reference sites or past conditions at the study site before observed stressor)
Monitoring Variable	Fish community
Metric	Diversity and abundance of fish
Target	Statistical difference is significant at $p<0.05$ for comparison with reference conditions

(adapted from CCME 2015)

Goals and objectives may focus on addressing particular stressors of concern in the nearshore (e.g., dredging, flooding, sedimentation, contaminated runoff), protecting human uses in the nearshore (e.g., swimming, boating, drinking water, First Nations values), or a combination of the two. First Nations values refer to the spiritual, cultural and sustenance aspects of a lake environment that are important to First Nations. For example, in the Kawarthas, wild rice harvesting has been practiced by the First Nation community for thousands of years, and nearshore monitoring could be used to monitor environmental conditions affecting the crop.

Once the objectives are established the program design can address questions such as: how long the program needs to last, what variables are to be measured and the intensity and frequency of sampling. Performance criteria can also be identified at this stage, which will track the progress of the monitoring program in meeting its stated goals and objectives. For example, if the goal is protect the fish community from shoreline development, then a performance criterion might be for the fish community at the affected site to be 80% similar to the fish community at a reference site. If this criterion is not met within a given timeline (e.g., two years of monitoring) then this should trigger a management response (Thom *et al.* 2007).

Examples of typical monitoring objectives for freshwater ecosystems, and the timescales required to address them, are summarized in Table 4.2. In all cases, statistical considerations such as reducing Type I and Type II errors and improving power are critical to the program objectives and should be integral components of the design of the monitoring program.

Table 4.2. Timescales for addressing common monitoring objectives.

Monitoring Objective	Timescale	Number of Variables	Temporal Frequency	Duration	Lag (time between surveys)
Preliminary survey	Short-term	High	Low to medium	Short (< 1 year)	Short (month)
Baseline monitoring	Long-term	Medium to high	Very high	Several years	Medium
Track spatial and temporal trends	Short and long-term	Low for single objective, high for multiple objectives	Very high	> 10 years	> 1 year
Answer research questions	Short-term	Specific to questions	Medium	1 year to several years	Short to medium
Characterize water quality for human use	Short-term	Specific to objective	Medium	Variable	Short (monthly or weekly)
Assess compliance with water quality standards	Short and long-term	Specific to objective	Medium	Variable	Medium

Monitoring Objective	Timescale	Number of Variables	Temporal Frequency	Duration	Lag (time between surveys)
Assess ecological status	Long-term	Low for single objective, high for multiple objectives	Medium	Several years	Medium
Conduct impact assessment	Short-term	Specific to objectives	Medium	Variable	Short to medium
Early warning	Long-term	Very limited	Continuous	Unlimited	None

(adapted from CCME 2015)

4.1.3 Selection of Monitoring Variables

The identification of monitoring goals and objectives will help to define what variables should be measured in the field. Once goals and objectives are known, the following questions can help guide the development of the monitoring program:

- What do we want to measure in the nearshore environment?
- What are the environmental variables best suited for this task?
- What is the appropriate statistical analysis for obtaining the information we need? (CCME 2015).

Variables are components of the environment (biological, physical and chemical) that respond to stressors and thus provide quantitative or qualitative information on ecological condition, and the presence and impact of stressors (Stantec 2005). Since it is not possible to measure all components of the environment, it is critical that the best variables be selected to address the goals and objectives of the monitoring program. Numerous criteria can be used to narrow down the choices to a manageable and effective toolbox. Several key factors, however, should be considered to optimize variable selection.

The first requirement is that variables have significance (i.e., they reflect environmental condition and address monitoring objectives) and respond in a predictable way to environmental stressors. Furthermore, the more sensitive a variable is to a particular stressor (or stressors) the more useful it will be to monitor. Ideally, variables should be chosen whose response to environmental change is relatively easy to interpret and understand, and cost-effective to monitor (Stantec 2005). Biological components of the aquatic environment can be useful in monitoring because they provide an ecosystem perspective to environmental change (CCME 2015). Consequently, it is recommended that at least one biological variable be included in a monitoring program (Heathcote 2015). Since no single variable can reflect response at all spatial and temporal scales and because many variables are inter-related, the best approach is to select a suite of variables representing biological, physical and chemical components. This may not be possible, however, if there are budgetary or resource constraints.

In this case, a successful monitoring program can still be developed based on a tiered or scaled down approach, in which only the absolutely essential monitoring variables are included, with the option of adding in other useful variables in future as money and capacity allow.

A number of technical criteria may be useful for further refining variable selection. These include consideration of type of habitat and substrate in which variables can be monitored, ease of measurement and analysis, whether standardized methods and QA/QC protocols exist, the level of training required, health and safety concerns and overall cost-effectiveness. We present summary tables ranking each of the monitoring variables reviewed for the Nearshore Monitoring Protocol based on the scientific and technical criteria we have outlined in this section (see Tables 5.1-5.3).

4.1.4 Field Sampling Design

4.1.4.1 Temporal Frequency and Spatial Coverage

A number of factors need to be considered when designing the field sampling component of monitoring. The temporal frequency and spatial coverage of field sampling will need to be determined, based on both the inherent variability of the selected monitoring variables and logistical constraints (CCME 2015). Ideally, field sampling design will incorporate the appropriate monitoring variables needed to adequately detect response to stressors, combined with the appropriate spatial coverage and temporal frequency needed to adequately document those variables' response to stressors. However, optimizing all three aspects of sampling design can be logistically challenging (CCME 2015). For example, increasing the number of monitoring variables may necessitate a reduction in spatial extent or the number of times samples are collected. Similarly, if it is decided that many sampling events are needed to overcome temporal variability, the spatial extent of the monitoring program may have to be restricted. A priori power analysis is a useful statistical tool to determine sampling frequency, based on the magnitude of change one wishes to detect at a given statistical level of confidence (CCME 2006). Ultimately, a cost-benefit analysis may needed to determine the best sampling design given budgetary and/or resource constraints.

The design of long-term monitoring programs (e.g., baseline monitoring for trend assessment) requires a solid understanding of short-term variability of conditions. The interval between sampling events should be long enough to minimize costs, but short enough to adequately sample important variability (MacDonald *et al.* 2009). While historical water quality data may provide insight into background conditions, it may also be necessary to carry out a short-term pilot project to determine appropriate sampling frequency and spatial extent of a longer term monitoring program. Alternatively, a long-term monitoring program could be designed to sample intensively in its first year, and then be scaled back after an evaluation of the level of temporal and spatial redundancy in the data collected (MacDonald *et al.* 2009). For water quality variables, sampling in less than 10 day intervals tends to yield redundant data. Nonetheless, if transient events, such as floods or isolated discharges, are of interest, continuous monitoring may be necessary to properly characterize conditions (MacDonald *et al*. 2009).

Variables with high temporal variability will need to be sampled more often than variables with lower temporal variability, which will affect monitoring costs. CCME (2015) recommends timing sampling in such cases to coincide with periods of low natural variability but this comes with trade-offs in resolution. For example measuring nutrient levels during the spring turnover when conditions are uniform with depth in the lake reduces overall sampling effort and will be sufficient to detect long term changes (Clark *et al.* 2010) but may miss important changes later in the summer that drive ecological phenomena such as algal blooms). CCME (2015) describes two statistical approaches for calculating the appropriate sampling frequency (one using the confidence interval of the mean and the other using trend analysis). Both have the advantage of optimizing the number of sampling events required, but both are limited by their need for historical data and by the fact that they do not apply to multiple monitoring variables. Monitoring activities will also need to be coordinated to coincide with seasonal fluctuations of interest, such as periods of low or high flow, timing of pesticide application, or discharge of sewage from lagoons (CCME 2015).

The spatial extent and location of monitoring sites are also important considerations in field sampling design. The area covered by the monitoring program should adequately reflect the entire area of interest, with sites strategically placed throughout to provide full geographic representation. To overcome the potential variability of nearshore biological, physical and chemical variables caused by coastal processes (see Section 3.1.12), it is recommended that a mix of sampling strategies be employed that encompass shoreside and transect approaches throughout the nearshore zone (Makarewicz and Howell 2008). The accessibility of sites will need to be considered, as well as site-specific features (such as sensitive habitat, areas of discharge, or mixing zones etc.). It is also recommended that Intake Protection Zones (IPZs) be considered when determining monitoring locations. IPZs are vulnerable areas delineated around surface water intakes for the protection of sources of drinking water under the Clean Water Act, 2006. These areas include intakes in the Great Lakes, connecting channels, and inland lakes and tributaries. Related local Source Protection Plans may contain policies governing monitoring programs, which can be tied to a nearshore monitoring program to avoid duplication in monitoring efforts.

Reference sites are required for status and trend monitoring because they help distinguish between natural background variability and changes caused by stressors (CCME 2015). It may be difficult, however, to find sites that represent true reference conditions in areas of intense human activity. The program design will need to carefully consider what stressors are of interest and choose the appropriate reference sites. For example, a reach of shoreline may be subject to numerous stressors but if the program is intended to assess the impact of a tributary or wastewater treatment plant discharge then the reference sites become those areas outside of the influence of those two stressors. Alternatively, it may be possible in some cases to perform monitoring before and after a known stressor is introduced to assess its impact on the nearshore environment, although the required prior warning to plan this type of monitoring is often not available.

Physical and chemical water quality variables typically exhibit marked temporal and spatial variability. Disentangling signals from this background noise can be a challenge (MacDonald *et al*. 2009). We summarize potential sources of variability and recommended ways to address them in Table 4-3.

Table 4.3. Sources of spatial and temporal variability in the field and strategies to address them in sampling design.

Source of variability	Recommended strategy
Spatial	
Small scale (over metres)	Replicate sampling to determine level of homogeneity over small distances
Large scale (over kilometres)	Intensive sampling at numerous locations within a watershed
Temporal	
Diurnal	Intensive sampling at multiple times over a 24-hour period
Seasonal	Frequent sampling at fixed locations throughout the year
Interannual	Long-term sampling at regular intervals at fixed locations

(adapted from Macdonald et al. 2009)

4.1.4.2 QA/QC

QA/QC should be an essential component of any monitoring program because improper sample collection, handling, processing, storage and analysis can lead to incorrect conclusions that ultimately misinform management action and policy decisions (CCME 2011). The first step in creating a strong QA/QC framework is to ensure staff are properly trained in all aspects of the monitoring program. A second important element is establishing clear instructions on sampling design and methods, so that monitoring is carried out in a systematic and consistent way regardless of who is involved. These instructions should include details on when and where samples are to be collected, types of sampling and collection equipment to be used, what types of samples to collect, which methods to use, what measurements to take in the field, what procedures to follow for handling, processing, storage and analysis, and which laboratory to ship samples to (if applicable). A number of standard practices should be adopted to ensure QA/QC at all stages of the monitoring program, including keeping sample bottles clean at all times, keeping samples cool, having clean hands for collection, properly washing and rinsing sampling equipment after use, and maintaining and calibrating all field equipment (Alberta Environment 2006; CCME 2011). When monitoring multiple variables, it is important to sample in the proper order to minimize environmental disturbance. Thus, sampling should begin with water column variables (e.g., water chemistry, plankton) and proceed to sampling associated with the substrate (e.g., periphyton, macrophytes) or sediment (benthic invertebrates, sediment quality) so that substrate or sediment do not contaminate water column samples (Becker Nevers and Whitman undated).

Several specific protocols are commonly followed in freshwater monitoring to minimize the risk of, and increase the detection of, sample contamination or degradation. Blank samples are used to test for contamination of water samples during transport (trip blank) or over the entire sampling process (field blank). Replicate samples are used to measure the precision of samples taken from the same location with the same equipment and are useful for indicating field, laboratory and environmental variation. They can be multiple samples (e.g., benthic invertebrate grabs or sediment cores) to examine how representative a single sample is of the entire community or to determine necessary sample size based on assigned level of sampling confidence. Alternatively, replicates can be portions of a single sample (e.g., sectioned grabs) to examine more localized variation (CCME 2011). CCME (2011) recommends that one duplicate sample should be collected per sample set, or for every 10 regular samples. Overall, the total number of QA/QC samples (including, for example, blanks) should comprise at least 10% of the total number of samples. Relative percent differences (RPD) between parameter concentrations in the duplicate samples should be considered significant if they differ by more than 20% or are greater than 5 times the detection limit (US EPA 2012). If samples are subsequently shipped to a commercial laboratory for analysis, the laboratory will have its own additional QA/QC protocols which should be available to review. For biological samples involving taxonomic identification, it is recommended that voucher specimens be collected for verification from an external expert. To further increase taxonomic QA/QC, a subset of samples should be re-counted and re-identified by an external taxonomist to determine error associated with numeration and identification. More details on QA/QC samples (including additional types such as reference samples, spikes and splits) is provided in CCME (2011).

4.1.4.3 Field Equipment

The type of sampling equipment required for nearshore monitoring can vary from very simple to very complex, depending on the monitoring variables selected and the degree of resolution desired. For example, flow-through systems mounted on a boat enable recording of continuous real-time information on lake water quality, compared with monthly or seasonal information provided by manual sampling in the wadeable nearshore. Expensive field equipment such as SCUBA gear or motor boats may not be available to some organizations and design of the monitoring program will need to proceed with a clear idea of what equipment is required and feasible for each of the different monitoring variables considered.

Several data collection technologies may be useful to include in monitoring programs. Passive *in-situ* sampling allows long-term monitoring for a wide variety of contaminants and is particularly effective under highly variable conditions or in areas experiencing seasonal impacts from human activities (CCME 2015). Automated sampling with data loggers provides continuous and long-term collection of water quality and hydrometric data. Data loggers are commonly used during high flow events to measure nutrient loading and turbidity (CCME 2015) or to record diurnal profiles of temperature or dissolved oxygen. Remote sensing, meanwhile, contributes large-scale spatial and temporal data on biological, physical and chemical components of aquatic ecosystems, which can help to identify stressor origins and impacts over time and space (Grieg 2015). The Annex 7 Task Team working to develop a baseline survey assessment of the Great Lakes (under the GLWQA) has identified nearshore monitoring variables that could be remotely sensed, such as chlorophyll a, water clarity, water surface temperature, vertical temperature gradients, lake substrate types, and bathymetry. Using remote sensing data for these variables would extend spatial coverage while reducing monitoring costs (Annex 7 Task Team 2015).

4.1.4.4 Health and Safety

Health and safety concerns should be paramount when designing a monitoring program. Basic precautions should be taken for all types of monitoring, including having first aid equipment and training, life jackets or personal flotation devices, proper footwear and clothing, and communication equipment. Additional training will be required for working from boats or on ice. It is recommended that a safety plan be formulated as part of the monitoring program, which details required training, lines of communication in safety and emergency situations, environmental safety considerations (e.g., risks of hypothermia, heat exhaustion, drowning, insect bites/stings etc. and how to minimize) and equipment safety considerations (e.g., hazards involved in operating equipment and how to minimize) (Clark *et al*. 2010). Potential dangers associated with the monitoring work need to be identified and understood, and a plan to avoid and deal with them developed, well before monitoring begins (Alberta Environment 2006). Health and safety considerations may influence what activities are possible in a monitoring program. For instance, sampling by boat more than 3.2 km from shore requires a Small Vessel Operator License. Scuba diving, meanwhile carries large liability risks, which are likely to restrict its use in most monitoring programs.

4.1.4.5 Aquatic Invasive Species Hygiene

Aquatic invasive species (AIS), which include invertebrates, fish, amphibians, reptiles, algae and plant species, can be spread inadvertently from lake to lake through monitoring activities. A few basic precautions, however, can easily be incorporated into monitoring protocols to ensure the risk of AIS transfer is minimized. AIS can be transported undetected in a variety of ways, including in residual water associated with sampling equipment, and on watercraft, nets and waders. As a result, thorough cleaning, drying and inspection of all monitoring equipment and gear is recommended following each sampling event (or after each lake is sampled if multiple lakes are monitored concurrently). All visible plants, animals and mud should be removed with a high pressure rinse, preferably with very hot water (50°C) (CCME 2011). Water should be drained from all sampling equipment and watercraft (including motor, live well and bilge) either at the source or on land. If rinsing is not possible, watercraft should be left to dry for a minimum of five days in the sun. Equipment and gear can be frozen for at least two days instead of rinsing, or soaked in a saline, vinegar or bleach solution (see CCME 2011 for details). Avoid transporting and releasing animals, plants, mud or water to different lakes.

4.1.4.6 Groundwater

Groundwater can enter the nearshore directly through the lakebed through shallow or deep flow paths, or indirectly via tributary inputs (Grannemann and Stempvoort 2015). Groundwater/surface water exchanges are complex and show significant spatial and temporal variability in the nearshore because of variability in geologic material, sediments on the lake-bottom and coastal processes such as wave action and evapotranspiration and it is difficult to assess groundwater input volumes or chemistry in the nearshore environment as a result. Direct groundwater discharge to the lake bottom has been evaluated through field measurements, water balance calculations and modelling but all approaches are associated with considerable uncertainty. Groundwater volume also tends to make up a small percentage of the inflow to the Great Lakes (e.g., 0.1 - 2.7% of the total inflows to Lake Superior, Lake Huron, Lake Ontario and Lake Erie; Neff and Nicholas 2005).

Groundwater chemistry is determined by the characteristics of the water-bearing sediments and rocks and the time that groundwater has been stored. Groundwater inputs typically affect nearshore water chemistry through a moderation of surface temperatures and pH, lowered dissolved oxygen concentrations and altered calcium and magnesium concentrations in areas with carbonate parent material (Grannemann and Stempvoort 2015). The majority of groundwater inputs, however, are sourced from shallow systems (e.g., sand and gravel aquifers) which typically contain similar chemistry as lake water. Groundwater inputs to the nearshore are not a substantial driver of water quality in Georgian Bay because of dilution, water chemistry that is often similar, and the importance of other factors such as tributary influence, climate and thermal inertia.

Groundwater monitoring should be considered if the stressor under investigation causes pollution of groundwater or if monitoring programs are focused on tributaries but nearshore water quality and aquatic habitat is not greatly affected by direct groundwater inputs. It is also recommended that groundwater-related vulnerable areas (delineated under the *Clean Water Act*, 2006) be considered. Related local Source Protection Plans may contain policies governing monitoring programs, which can be tied to a nearshore monitoring program to avoid duplication in monitoring efforts.

4.1.4.7 Tributary Influence

Tributary inputs can have profound effects on biological, physical and chemical components of the nearshore environment. Tributaries deliver nutrients, contaminants, sediment loads and AIS to nearshore waters, providing a direct link between activities in the watershed (e.g., agricultural practices, urban development) and the lake. The wide variety of variables reviewed for monitoring the nearshore can be applied to monitoring the influence of tributaries. The unique nature of tributary/nearshore interactions, however, requires special consideration when incorporating monitoring of tributary effects into monitoring design. We recommend that Section 3.1.11 be referred to for guidance on sampling design in the vicinity of tributaries. Effective characterization of tributary effects can be complex and requires extensive effort and resources to undertake successfully.

4.1.5 Minimum Detection Limits

Minimum detection limits (MDLs) are the analytical precision that laboratories are capable of achieving for a given parameter. MDLs vary substantially among laboratories and parameters. The selection of appropriate MDLs is a critical step in the successful design of water and sediment quality monitoring programs because they represent the sensitivity of discrimination for measuring parameters of interest. The lower the MDLs, the greater confidence that results are accurately depicting any spatial or temporal change in parameters that may exist. Selection of appropriate MDLs, however, will depend on a number of factors, including financial resources (lower MDLs are generally more expensive), laboratory expertise, study objectives and study area.

In terms of study objectives, MDLs must be sensitive enough to test a given hypothesis and characterize the level of change of interest. The hypothesis will depend on the intent of the monitoring program, but the level of change is often related to established water or sediment quality objectives. Mitchell (2006) recommends MDLs that are 10 times lower than the water or sediment guideline for the variable of interest, while CCME (2011) recommends MDLs which are 5-10 times lower.

The study area must be considered during selection of MDLs to find the appropriate balance between costs and receiving data that can be used successfully. Water and sediment quality in southeastern Georgian Bay are spatially variable, but generally conditions are relatively pristine, with low concentrations of nutrients and suspended solids. Consequently, low MDLs will often be required to effectively characterize these conditions and detect change.

The other major consideration related to MDLs is how to handle data that are reported as below detection limits. Values equal to the detection limit, one-half of the detection limit, or zero are often substituted for these values prior to analysis, while more complex methods, such as Maximum Likelihood Estimation and Imputation can also be employed (Mitchell 2006). The appropriate data substitution or transformation is dependent on the percentage of data that are below the detection limit and sample sizes. The handling of values less than the MDLs must be carefully considered because there are major implications during subsequent data comparison. If most of the data are below detection limits, data comparison and testing will be restricted, highlighting the importance of selecting appropriate MDLs (and a laboratory equipped to measure low levels) during study design so that the proportion of these non-detects is minimized.

Adaptive monitoring aims to inform decision-making on an ongoing basis. It is thus important that monitoring efforts strive to constantly improve MDLs in response to findings and improvements in technology.

4.1.6 Data Analysis and Interpretation

There are several main approaches to analyzing monitoring data, depending on the type of monitoring undertaken:

- Evaluating status and trends over time or space (e.g., baseline monitoring);
- Comparing values between different sites or time periods (e.g., investigative monitoring, effectiveness and restoration monitoring); and
- Assessing extent to which values meet regulatory limits, guidelines, criteria or objectives (e.g., effectiveness and restoration monitoring, compliance monitoring) (CCME 2006).

Ideally, the appropriate analyses for the monitoring data should be determined during the design of the monitoring program, as these analyses will influence data collection in the field (e.g., what measurements are taken and how often). Statistical considerations such as reducing Type I and Type II errors and improving power should be integral components of the design of the monitoring program and must be carried through to the analysis.

Data may be analyzed in raw form (e.g., number of fish species) or converted into indices (e.g., index of biological integrity for benthic invertebrates, CCME water quality index). Appropriate statistical tests should be chosen based on the nature of the data (i.e., qualitative or quantitative), data distribution (i.e., parametric or non-parametric) and the question being addressed, and may include univariate and/or multivariate approaches. Some common statistical analyses applied to monitoring data include:

- analysis of variance (ANOVA) and linear regression to test for spatial or temporal differences in status:
- ordination and multiple regression to test for relationships between environmental and biological variables (CVC 2015).

Results from the data analysis should then be interpreted in the context of the original monitoring goals and objectives. For example, referring back to Table 4-1, the study results should indicate whether fish diversity and abundance differ significantly at the monitored sites from reference conditions (either at other unaffected sites or the same sites prior to the environmental change).

Correct interpretation of results is a crucial step in the adaptive monitoring process. If findings are misinterpreted this will have cascading repercussions during the reporting and decision-making stages, leading to "flawed conclusions, misguided recommendations, and potentially damaging actions" (CVC 2015 p. 95). Furthermore, incorrect interpretation can hinder evaluation of the effectiveness of the monitoring program and the subsequent identification of modifications needed to improve program performance. The risk of subjective interpretation can be minimized through the identification of clear statistical objectives, the selection of appropriate statistical analyses, and proper study design (CVC 2015). In addition, the analyst should make good use of peer review and consultation with other practitioners to ensure interpretation is valid and transparent.

4.1.7 Reporting and Communication

Reporting monitoring results and interpretation is essential for building and maintaining support for the monitoring program and for ensuring information is integrated into the decision-making process (CCME 2015). Communication needs to occur on multiple levels to reach different audiences, including the general public, stakeholders, partners, resource managers, scientists and policy-makers. As such, the type of messaging should be tailored to the audience being targeted. For example, detailed technical reporting of scientific results will be more appropriate for resource managers and scientists, while higher level summaries of key trends is generally better suited for non-scientific audiences such as the general public and policy-makers. A variety of formats can be used to communicate monitoring results, including interactive websites, watershed report cards and peer-reviewed scientific publications. The range of communication products can include:

- raw data for scientific audiences interested in conducting their own analyses;
- technical reports with analysis and synthesis of findings, including detailed statistical analyses, for resource managers and scientists;
- summary reports which summarize status and trends (e.g., through descriptive statistics) for the general public; and
- strategic messaging at a high-level to emphasize key messages such as emerging threats and issues, as well as recommendations for action, geared toward policy-makers, resource managers and the general public (CVC 2015).

Communication of results needs to be regular and consistent so that audiences remain informed and understand the value of the monitoring program. Reporting must include a process to amend the monitoring program in response to review of the results (Fig. 1) and to communicate the rationale for any changes to interested parties. Furthermore, ongoing strategic reporting to decision-makers can promote the development of robust and effective management action and policy based on sound scientific information. Publication of results in peer-reviewed scientific journals is also important for contributing to scientific knowledge (CVC 2015).

Documentation of the mechanics of the monitoring program (i.e., details on design and implementation) is equally important as communication of actual results. Recording information on how monitoring was conducted during each field season, as well as modifications that were made to improve the program, can be invaluable for ongoing assessment and evolution of a monitoring program, and can provide a useful resource for other organizations planning similar projects. For example, TRCA's documentation of its nearshore monitoring program has changed over time, from notes, emails, maps and powerpoint presentations in the early years to an annual workplan and field season overview today. The workplan is prepared in the winter in consultation with field crew and project partners and sets the agenda for the summer field season. The plan is then revisited at the end of the sampling period to document what was actually achieved given constraints related to weather, staff availability, or equipment problems (Bowen pers. comm. 2016).

5. Protocol Toolbox

We have evaluated existing monitoring programs, protocols and research studies to identify the most appropriate approaches for monitoring in the nearshore. We provide guidance on recommended monitoring variables, methods and equipment to use in particular nearshore habitats and to address specific stressors in the following sections. A key lesson learned from our review and the November 2015 workshop was the need for any program to be adaptable and evolve in response to findings. One can adopt methods or designs that turn out to be impractical or unsuitable, or one can add or delete variables as resources permit or in response to program findings. Nevertheless, any changes in the program must not jeopardize the utility of data already collected or invalidate former results through methodological changes. The protocol must therefore be carefully reviewed before any changes are made. The integrity of the long-term dataset is of paramount importance to the monitoring program.

The following recommendations are based on thorough review and assessment of best monitoring practices for the nearshore environment. The protocol cannot anticipate every potential circumstance and eventuality that may be encountered in a particular monitoring program and hence was approached as an "adaptive" protocol. It is ultimately the responsibility of those using the Nearshore Monitoring Protocol to assess whether the recommendations made herein are suitable for each site-specific situation and to use the material provided to develop their program. Furthermore, each user of the Protocol must ensure that a safety plan is integrated into monitoring and that all involved have received proper training in its procedures.

We developed the Adaptive Process for Nearshore Monitoring (Fig. 1.1) to demonstrate how the Nearshore Monitoring Protocol project fits within a broader adaptive management process. We have modified Fig. 1.1 to provide a conceptual model of how to use the Nearshore Monitoring Protocol as part of a nearshore monitoring program (Fig. 5.1). In Appendix A, we create an example scenario to illustrate how to apply the Protocol to real world situations.

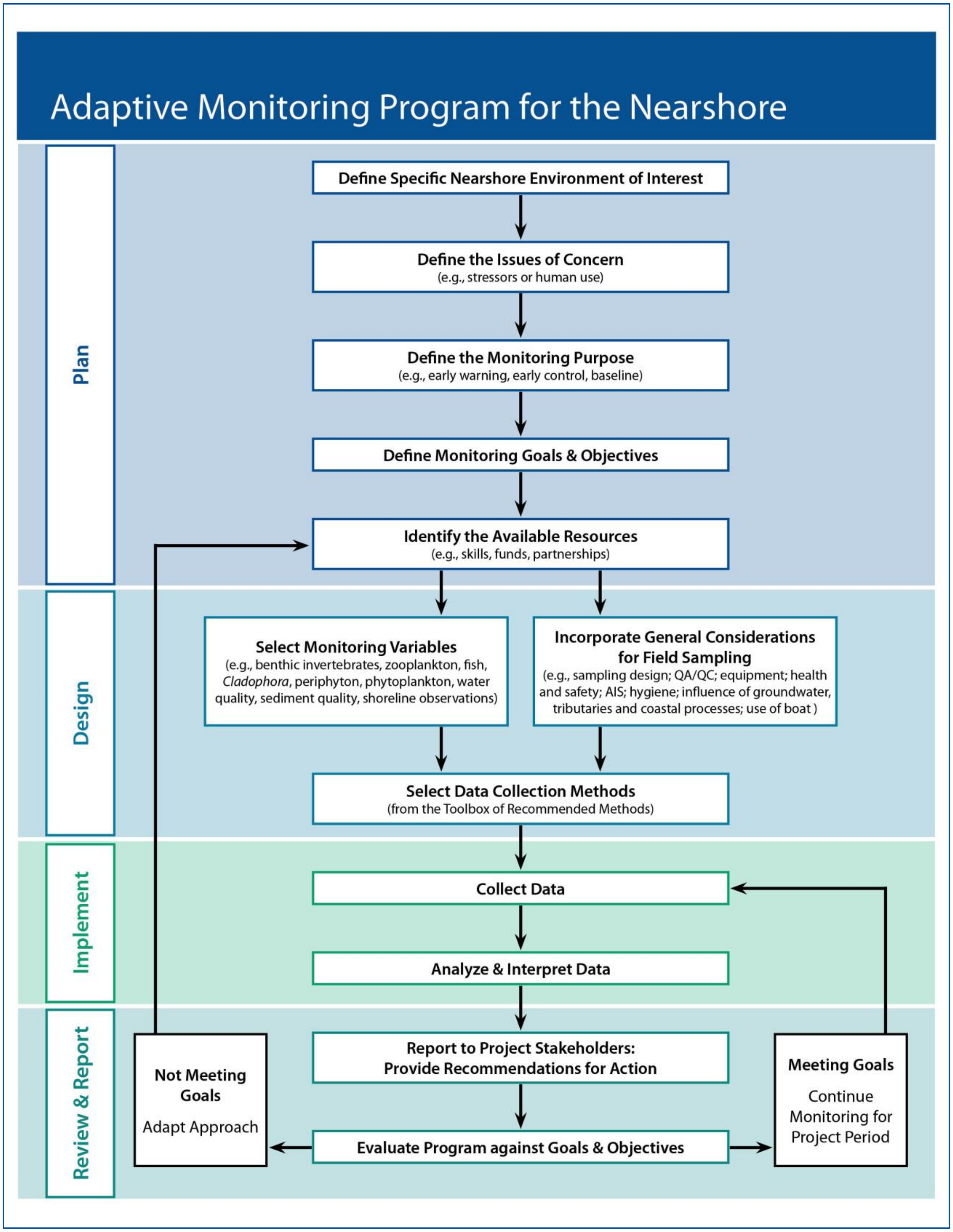

Figure 5.1 Conceptual model of the application of the Nearshore Monitoring Protocol.

5.1 Guidance for Protocol Selection

We developed a decision-making framework to guide users through the necessary steps for identifying the appropriate monitoring variables and methods to use for nearshore monitoring. Once the Considerations for Protocol Development (Section 4) have been reviewed and incorporated into the monitoring design, the choice of monitoring variables can be narrowed down through a two-step process addressing (i) applicability to particular stressors or human uses; and (ii) feasibility based on available capacity and resources.

Step 1

We provide two reference tables to identify the best variables for monitoring different stressors (Table 5.1) or for monitoring environmental condition relevant to human uses (i.e., recreational, drinking water, aesthetics, First Nations values; Table 5.2) in the nearshore. In most cases, several variables will be identified as appropriate for addressing the stressor or use of interest.

Table 5.1. Applicability of biotic and abiotic monitoring variables for addressing various primary and secondary stressors.

Primary Stressor	Land Use Activities Directly Impacting the Nearshore								Land Use Activities in the Watershed of Tributary Discharging to the Nearshore							Land Use Change		Harvesting of Biological Resources				Invasive Species			Climate Change										
Secondary Stressor	Contaminated Surface Water Runoff	Direct Discharge from Wastewater Treatment Plant	Vegetation Removal	Erosion	Sedimentation	Flooding	Shoreline Hardening	Dredging	Nutrient Enrichment	Vegetation Removal	Erosion	Sedimentation	Flooding	Pesticide Runoff	Increased Tile Drainage	Low or Fluctuating Water Levels	Altered Circulation Patterns	Vegetation Removal	Erosion	Sedimentation	Overfishing	Habitat Alteration	Competition/Predation of Native Species	Water Pollution	Temperature Fluctuations	Extreme Winds	Changes in Precipitation	Changes in Storm Magnitude, Frequency, Direction of Storms	Increased Surface Water Temperature	Low or Fluctuating Water Levels	Altered Circulation Patterns	Erosion	Habitat Alteration	Coarsening or Removal of Shoreline Materials	Reduced Ice Cover
Benthic Invertebrates	✓	✓			✓	✓		✓	✓			✓	✓	✓	✓							Dependent on Invasive Species		✓	✓								✓		
Zooplankton	✓	✓							✓					✓	✓						✓			✓	✓								✓		
Fish	✓	✓												✓	✓						✓			✓	✓								✓		
Cladophora																																			
Macrophytes			✓							✓								✓																	
Periphyton	✓	✓			✓	✓		✓	✓			✓	✓	✓	✓					✓				✓	✓								✓		
Phytoplankton	✓	✓							✓					✓	✓						✓			✓	✓								✓		
Water Quality - Physical	✓		✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓				✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
Water Quality - Chemical		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓				✓	✓		✓	✓	✓			✓		✓	✓
Sediment Quality		✓			✓	✓		✓	✓			✓	✓							✓				✓											
Shoreline Observations				✓			✓									✓														✓				✓	

Table 5.2. Applicability of biotic and abiotic monitoring variables for addressing human use in the nearshore environment.

Use	Recreational			Drinking Water	Aesthetics	First Nations Values
	Swimming	Fishing	Boating			
Benthic Invertebrates	✓	✓				✓
Zooplankton	✓	✓				✓
Fish	✓	✓				✓
Cladophora	Dependent on *Cladophora* Presence/Absence					
Macrophytes	✓	✓	✓		✓	✓
Periphyton	✓	✓			✓	✓
Phytoplankton	✓	✓		✓	✓	✓
Water Quality - Physical	✓		✓	✓	✓	✓
Water Quality - Chemical	✓	✓	✓	✓	✓	✓
Sediment Quality		✓				✓
Shoreline Observations					✓	✓

Step 2

The next step is to determine which of the variables selected in Step 1 are feasible based on their performance and the capacity and resources of the user. We provide guidance in Table 5.3, evaluating variables according to a number of scientific and technical criteria. The first four criteria in Table 5.3 evaluate variables based on their scientific usefulness for monitoring ecological condition and tracking environmental change. Specifically, the criteria address whether variables show predictable response to stressors, are applicable to multiple stressors, are diagnostic of a particular stressor, and integrate the effects of multiple stressors.

Biotic variables generally respond to multiple stressors and are integrative because they reflect and react to overall environmental conditions over both short and longer timescales. As a result, biotic variables, on their own, tend not to be diagnostic of the source of environmental change to which they are responding. In comparison, variables such as water quality and sediment quality can be used to identify particular stressors that may be causing the observed environmental change and associated biological response. By combining biotic variables that respond to multiple stressors and are integrative, with abiotic variables that are diagnostic of particular stressors, a more complete indication of cause and effect can be ascertained. For example, monitoring the fish community might reveal that fish diversity has declined, but would not indicate potential reasons for that decline. Adding water quality monitoring could provide additional useful information (e.g., that pesticide levels are elevated), pointing to a possible reason for the observed decline in fish diversity.

The remainder of the criteria evaluate variables based on technical aspects related to their feasibility of use, such as in what habitats and substrates they can be monitored, effort require for measurement and analysis, whether standardized protocols exist, level of training required, health and safety considerations, and cost-effectiveness. For each variable, our evaluation is based on monitoring the variable according to our recommended methods for the Protocol (Section 5.2). Thus, if alternative methods not recommended in the Protocol are adopted to monitor variables, the ranking of variables could change.

We ranked variables in Table 5.3 on whether they met or did not meet certain criteria ("yes" or "no") in the following categories: predictable response to stress, applicable to multiple stressors, diagnostic of a particular stressor, integrative, and existence of standard protocols (i.e., whether well-established and well-tested approaches to monitor the variable exist that are commonly and widely used).

We adopted a qualitative ranking system for several other criteria, scoring variables as "low" "medium" or "high" in the following categories: measurement effort, analysis effort, level of training required, health and safety concerns, and cost-effectiveness. Ranking in these qualitative categories was relative to all other variables, and based on the recommended method(s) we present in Section 5.2. We used a combination of our professional experience and critiques of variables and associated methods documented in the literature review to guide this evaluation. Table 5.3 presents a summary of this evaluation for each variable, however, the literature review and recommended methods in the Protocol should be referred to for more detailed information on this evaluation.

Measurement effort refers to how easy it is to collect data on the variable according to our recommended methods, either in the field (most variables) or through desktop exercises (e.g., in the case of coastal processes). For example, benthic invertebrates were scored as high in the ease of measurement category because benthos are widespread and stationary, and because the recommended sampling methods (kick and sweep, grab sample) are relatively straightforward to undertake. In contrast, zooplankton were scored as low in the ease of measurement category because they exhibit high spatio-temporal variability, which necessitates a more complex and intensive sampling design, and because a boat is required. Analysis effort refers to how easy it is to analyze and interpret monitoring data, and includes consideration of factors such as taxonomic identification for biotic variables, chemical analyses for water quality and sediment quality, and interpretation of wave and wind data to characterize coastal processes. Level of training refers to the skill required to carry out collection, analysis and interpretation of monitoring data according to the methods we recommend in the Protocol. Thus, if measurement effort and analysis effort are low for our recommended approach, then level of training will be low. Similarly, if measurement effort and analysis effort are high, then level of training will likewise be high.

Health and safety concerns were evaluated for each variable based on the relative risks involved with data collection and analysis. For example, monitoring benthic invertebrates was ranked as having a low health and safety concern, since monitoring can be done in shallow waters without a boat and analysis consists of taxonomic identification which does not involve hazardous chemicals or procedures. In contrast, phytoplankton monitoring was ranked as having a medium health and safety concern because monitoring requires sampling in deeper waters with a boat, but like benthic invertebrates, analysis is relatively free of safety concerns. Cost-effectiveness was evaluated based on the overall estimated cost of data collection and analysis, including training and equipment considerations, for each variable. In this case, periphyton are ranked as being highly cost-effective (i.e., low cost) because they are relatively easy and inexpensive to collect, and no boat is required. In contrast, phytoplankton has low cost-effectiveness (i.e., high cost) because of the intensive sampling frequency required, combined with the need for a boat.

As with Step 1, several variables may be identified as appropriate options for use. Ideally, a suite of appropriate variables should be chosen to maximize coverage of environmental responses and increase confidence in monitoring results (including a combination of response and diagnostic variables as discussed above). If use of multiple variables is not possible, however, we provide guidance on how to further prioritize which variable(s) are best to focus on through an overall ranking in Table 5.3. It is important to recognize, however, that this overall ranking is not meant to be an absolute prescription of which variable(s) to use in all situations, but instead should be only one component of the decision-making process outlined in Table 5.3, that is shaped by a diverse array of factors including scientific usefulness, applicability to different habitats and substrates, and technical considerations. We therefore emphasize that interpretation of Table 5.3 requires professional knowledge of monitoring conditions and requirements for the particular nearshore area and issue of interest.

The variable with the lowest overall ranking represents the best overall score. The overall ranking, however, does not take into consideration habitat and substrate of the study area, which the user will also have to incorporate into the final decision. To determine the overall ranking, we took a subset of the entire ranking criteria and scored them numerically. All yes/no rankings were assigned a binary scoring, with yes = 0 and no = 1. Similarly, the qualitative rankings were assigned overall ranking with high = 2, medium = 1, and low = 0.

Variables having a ranking range for a particular criterion (e.g., low to medium for measurement effort) were assigned the average numerical ranking for the range (e.g., 0.5).

Scores were then summed across criteria to produce an overall ranking for each variable. The lower the overall score the better the variable fared in individual criteria, indicating the best overall performance.

Table 5.3. Ranking of monitoring variables based on various performance criteria.

Potential Variable	Parameters Commonly Assessed	Predictable Response to Stress	Applicable to Multiple Stressors	Diagnostic of a Particular Stressor	Integrative	Applicable to Multiple Habitats	Applicable to Multiple Substrates	Measurement Effort	Analysis Effort	Standard Protocols	Level of Training	Health and Safety Concerns	Cost	Overall Ranking
Benthic invertebrates	richness, % Ephemeroptera, Plecoptera, Trichoptera, abundance, diversity and evenness indices, composition (% different taxonomic groups, % tolerant and intolerant groups), tolerance indices	Y	Y	N	Y	bays, river mouths, sheltered areas	mixed substrates preferred	L	M	Y	M	L	L	3
Zooplankton	biomass, composition, abundance, dominance	Y	Y	N	Y	all nearshore	all	H	H	N	H	M	H	11
Fish	species richness, species identification, abundance, age class distribution, total fish biomass, trophic composition, % diseased or malformed fish	Y	Y	N	Y	all nearshore	all	L-M	L	Y	M	M	M	5.5
Cladophora		Y	N	N	N	shallow nearshore, sand beaches	in-situ: cobble/ boulders, exposed bedrock; onshore: beaches	*in-situ*: H; onshore: L	L	Y	*in-situ*: M; onshore: L	L	*in-situ*: H; onshore: L	*in-situ*: 8; onshore: 3
Macrophytes	species identification, total area covered, % cover	N	N	N	N	bays, wetlands, sheltered areas	cobble/ boulders, organics, sand, mixed	M	L	N	M	L	L	7

Potential Variable	Parameters Commonly Assessed	Predictable Response to Stress	Applicable to Multiple Stressors	Diagnostic of a Particular Stressor	Integrative	Applicable to Multiple Habitats	Applicable to Multiple Substrates	Measurement Effort	Analysis Effort	Standard Protocols	Level of Training	Health and Safety Concerns	Cost	Overall Ranking
Periphyton	species richness, total number of genera, diversity indices for diatoms, chlorophyll a, autotrophic index (ratio of total organic matter/ chlorophyll a)	Y	Y	N	Y	all nearshore	all, rocky substrates preferred	L	H	N	M	L	L	5
Phytoplankton	biomass, chlorophyll a, species diversity, abundance, community composition, dominance, photosynthetic rate	Y	Y	N	Y	all nearshore, sheltered embayments preferable	all	M	H	Y	M	M	H	8
Physical and Chemical Water Quality	temperature, pH, dissolved oxygen, biochemical oxygen demand, conductivity, turbidity, alkalinity, nutrients (phosphorus and nitrogen), total and suspended solids, also hydrocarbons, metals, pesticides and other organic pollutants	Y	Y	Y	Y	all nearshore	all	L	M	N	M	L	M	4
Physical and Chemical Sediment Quality	nutrients, metals, pesticides, trace organics	Y	Y	Y	Y	all nearshore	organics, sand, mixed	L	M	Y	M	M	M	4
Shoreline Observations	alteration, degradation and development of shoreline	Y	N	Y	N	all nearshore	all	L-M	L	N	L	L	L	3.5

Once the two-step process has been completed, the user should have selected one or more variables most appropriate for addressing the issues of concern given the nearshore habitat of interest and the resources and capacity of the monitoring organization.

5.2 Nearshore Monitoring Toolbox

The next step is to follow recommended methods for the selected variables. Detailed information on specific methods and equipment to use for each variable is presented in the following section. At the end of this section we present a summary of which recommended methods can be done with and without a boat (Table 5.18).

5.2.1 Benthic Invertebrates

Benthic invertebrates are the most commonly used organisms in the biological assessment of freshwater ecosystems and their tolerance levels are well known (Bailey *et al.* 2004). Benthic invertebrate monitoring is widely used throughout Ontario and many methods provide standardized approaches that ensure consistent and comparable monitoring results across different projects and geographic areas. Biological metrics such as richness, diversity, Hilsenhoff's Biotic Index and % Ephemeroptera, Plecoptera and Trichoptera, have been used extensively to characterize the benthic invertebrate assemblage and to assess the impact of stressors, leading to an increased understanding of how metrics relate to water quality conditions. Consequently, it is possible to gain insight into the benthic invertebrate community and the habitat of interest based on relatively few samples. Identification, especially to the OBBN defined group level, is much easier to learn than for other biotic monitoring variables (e.g., phytoplankton).

Habitat conditions (e.g., sediments, cover, flow, food resources) influence the benthic invertebrate assemblage and it is vitally important to control for the impact of habitat through proper study design and interpretation so that habitat differences do not cloud any impacts caused by the stressors under study. If the Reference Condition Approach is used, habitat at reference and test sites needs to be similar, which may be difficult in some environments.

Much of the nearshore habitat in Georgian Bay is comprised of exposed bedrock, boulders, sand and organic substrates, none of which support a diverse benthic community because of lack of suitable substrate, food sources and dissolved oxygen. Mixed substrates provide more suitable habitat for development of a diverse benthic invertebrate assemblage. Artificial substrates can be used to provide habitat for benthic invertebrate colonization when sampling natural habitat is difficult or habitat limits invertebrate colonization, but other monitoring tools are often preferred in such situations.

5.2.1.1 *Method Selection*

Advantages and disadvantages of the various benthic invertebrate monitoring methods are included in Table 5.4. The Ontario Benthic Biomonitoring Network (OBBN) (Jones *et al.* 2007) includes a comprehensive benthic invertebrate monitoring methodology which is used throughout much of Ontario, allowing for spatial comparison. The common taxonomic resolution in OBBN studies is a 27-group level which is relatively coarse but which reduces processing time and cost. Taxonomic identification can be adjusted to a finer resolution if required using the same methodology. Many aspects of the OBBN approach are recommended but its methods are limited to wadeable water. Sampling in the littoral zone is often preferred to deeper waters because benthic invertebrate communities tend to be more diverse here (due to increased availability of suitable habitat), thereby increasing the potential sensitivity of the bioassessment. We recommend that users check whether OBBN reference sites exist within their study area and, if they do, that they be incorporated into the monitoring program. For deeper waters, sampling via a grab sampler is recommended (e.g., following LSRCA's Standard Operating Procedures, OMOECC's Great Lakes Index Station Network and US Geological Survey's Lake Monitoring Guidelines).

Table 5.4. Summary of benthic invertebrate sampling methods.

Method	Advantages	Disadvantages
OBBN (kick and sweep)	Widely used, adaptable, standardized field, lab and data analysis methods	Coarse taxonomic level
Great Lakes Coastal Wetlands Monitoring Plan (kick and sweep)	Adaptable, standardized field and data analysis methods	Designed for wetlands
CABIN (kick and sweep)	Widely used, standardized field, lab and data analysis methods	Designed for wadeable streams
LSRCA SOPs (petite Ponar grab, kick and sweep)	Shoreline monitoring follows OBBN, littoral and profundal zones	Sampling limited in hard substrate areas
OMOECC Great Lakes Index Station Network (Ponar grab)	Large-scale and long-term (well-tested)	Limited diversity of benthic assemblage
US Geological Survey Lake Monitoring Guidelines (Ekman and Ponar grab)	Adaptable to different substrates	General guidance, not prescriptive

Sampling Equipment / Depth of Water

Two main collection methods are used in benthic invertebrate monitoring: kick-and-sweep collection with a D-net for a specific duration and Ponar grab sampling, which requires a boat. Kick-and-sweep techniques are often completed in shallow water (<1 m) along transects by kicking substrate to dislodge benthic invertebrates and collecting the animals by sweeping a net through the water.

Grab samples are generally collected in deeper water from a boat with a Ponar type sampler that "bites' into the sediment after a messenger initiates the closing mechanism. A greater variety of benthic invertebrates tend to be collected during kick-and-sweep collection because a larger area is sampled but some quantitative analyses (e.g., individuals/m^2) are not possible with this method because the amount of sampled habitat is unknown. We recommend sampling for 10 minutes with a 500µm D-net in water depths < 1m per OBBN instruction and a Ponar or Ekman grab sampler in water depths > 1m.

Habitat

Predominant benthic habitats in Georgian Bay include sandy beaches, bedrock, mixed substrates and wetlands. Sandy beaches and bedrock do not provide sufficient prey for most benthic invertebrate species and therefore monitoring in these areas will likely result in limited diversity and low power during analysis. Wetland environments generally contain depository, organic, unconsolidated substrates and low oxygen concentrations because of the decomposition of macrophytes and algae, resulting in low abundance and diversity, both which limit the effectiveness of a benthic invertebrate monitoring program. Benthic invertebrate assemblages are more diverse in mixed substrates where water quality conditions (such as dissolved oxygen concentrations) are favourable at the water/sediment interface, and food sources are more abundant. Consequently, monitoring programs should be focused in these areas.

Time of Year

Sampling should be conducted during the ice-free season, any time from spring through fall, as long as samples are collected at the same time every year to enable statistical comparisons among sites or over time. Winter sampling is not recommended because of health and safety considerations related to working on ice and in frigid water conditions. The OBBN includes a discussion of advantages and disadvantages associated with sampling in different seasons.

Effort

Three replicates should be collected via kick-and-sweep or grab sampling per site to ensure the representativeness of the sample. If this is not possible, fewer replicates can be collected as some information is better than none, but this may limit statistical analysis, especially where habitat and invertebrate diversity is high. Each replicate should contain at least 100 benthic invertebrates (it may be necessary to adjust sampling time or area to achieve this number). If abundance is too low to permit the collection of 100 benthic invertebrates a timed picking limit should be implemented or a different monitoring tool should be utilized depending on the study objectives.

Taxa should be identified to a minimum of the OBBN 27-group level which includes phylum, class, order and family, while additional sensitivity and better characterization of response will be afforded at lower taxonomic resolutions such as family, genus or species.

Assessment

A variety of habitat variables should be recorded during sampling, including: water temperature, substrate and vegetation, so that the influences of habitat can be differentiated from the stressor under investigation. A variety of picking methods are described for the OBBN that minimize equipment cost and processing time. The preferred method is in-lab with preserved samples, using a Marchant Box to randomly sub-sample and a microscope for assistance. Benthic invertebrate results should be analyzed through biological metrics such as richness, diversity and compositional indices. Further evaluation through a multi-metric or multivariate approach is dependent on study objectives.

QA/QC

The OBBN offers regular training and certification programs in its sampling methods and invertebrate identification, promoting QA/QC of the protocol. It also provides an equipment checklist and field data summary sheets to further assist with consistency and standardization of technique and data collection (Jones *et al.* 2007).

Adaptability

The benthic invertebrate monitoring protocol can be varied depending on available resources and expertise. Adaptable components are noted in Table 5.5.

Table 5.5. Adaptable components of the benthic invertebrate sampling.

Component of Method	Range	Minimum
Identification	27-group level to species level	27-group level
Replicates	1 – 3/sample	1/sample
Sampling Events	1 – 3/yr	1/yr

A summary of recommended methods for benthic invertebrate sampling is provided in Table 5.6.

Table 5.6. Recommended methods for sampling benthic invertebrates.

Method	Equipment	Depth	Effort	Frequency
Kick and sweep	500 μm D-net	< 1 m	3 replicates per site, at least 100 individuals per sample	1-3 times per year during the ice-free season
Grab sample	Ponar grab, boat	> 1 m		

5.2.2 Zooplankton

Zooplankton respond rapidly to stressors, making them a sensitive indicator of environmental change, including nutrient enrichment and acidification. Sampling is relatively easy and inexpensive but there are many disadvantages associated with zooplankton monitoring compared with other monitoring variables, especially considering that most anticipated users of this protocol will have financial constraints and limited expertise. Zooplankton monitoring has not been as widely used as other biotic monitoring variables, such as benthic invertebrates. As a result, few people have training in zooplankton sampling, sorting, identification and assessment. While zooplankton are easier to sort and identify than phytoplankton, they still require specialized taxonomic knowledge and experience. Furthermore, an overall framework for interpreting zooplankton data is lacking, making it difficult to draw firm conclusions on the response of zooplankton communities to stressors. The greatest disadvantage with zooplankton monitoring, however, is that it requires a high sampling frequency to accurately characterize the zooplankton community because it is highly variable both spatially and temporally.

Zooplankton monitoring is not recommended unless the resources are available to complete a rigorous monitoring program that includes sufficient sampling events, sample sites and expertise. If the resources are available, we recommend following methods similar to LSRCA's Nearshore Monitoring Program to characterize the zooplankton assemblage. Alternative methods, such as those for monitoring AIS zooplankton (e.g., the spiny water flea) are not discussed.

5.2.2.1 Method Selection

Sampling Equipment

A variety of collection methods exist and selection of the most appropriate technique is often undertaken based on the type of zooplankton being monitored or the depth of water that is being sampled. If a specific type of zooplankton is not being targeted, plankton nets are most commonly used, namely vertical tows at specified depths. LSRCA methodology is a simple and effective approach that uses vertical 64 µm "Wisconsin"-style plankton nets for net hauls from boats. We recommend that the plankton net is a closing style net so that specific water depths can be sampled.

Water Depth

Vertical net tows are generally conducted from near the bottom to the water surface. LSRCA recommends sampling from 0.5 m off bottom to the water surface. Zooplankton composition is often homogeneous within specific thermal layers in the lake (i.e., hypolimnion and epilimnion) so vertical net hauls should be completed through each of these water depths to sufficiently describe the zooplankton and allow for accurate comparison between sites. A water temperature profile should be completed at the same time as zooplankton sampling, epilimnion and hypolimnion boundaries should be determined based on water temperatures recorded at 1-m depth intervals, and a closing net should be used to sample both water depths for zooplankton (Yan pers. comm. 2016). Sampling within specific water depths will generally result in lower error per effort extended and result in an increased ability to compare species assemblages between sites.

Time of Year

Sampling should be completed at the same time each day to account for vertical migration. Sampling programs should span most of the ice free season to ensure the greatest range of species are monitored (Paterson 2002). At a minimum, we recommend that monthly samples are collected from June to September to provide a representative sample of the ice-free zooplankton assemblage.

Spatial variability in zooplankton is often determined by wind. Samplers should take note of consistent (~1-2 day) unidirectional wind events, because zooplankton can exhibit spatial patchiness. Sampling should be avoided during these conditions.

Effort

The LSRCA recommends two net hauls per site and 300 individuals collected per sample. We recommend two net hauls per site but one within the epilimnion and one within the hypolimion as discussed previously. Zooplankton should be identified to species level and counted.

Assessment

Data is commonly analyzed through biomass, abundance and community composition measures.

QA/QC

QA/QC protocols are focused on ensuring identification is accurate through the use of voucher specimens, and standardizing plankton net retrieval speeds.

Adaptability

The inherent spatial and temporal variability associated with zooplankton assemblages, combined with the lack of information for interpreting trends makes them a less than ideal choice for nearshore monitoring. Many monitoring organizations will not have the capacity to fulfill the intense sampling requirements, nor the taxonomic expertise needed for assessment. The LSRCA methodology represents the minimum effort required to provide lake managers with interpretable data. Sampling events must be completed monthly between June and September to provide sufficiently detailed information for monitoring the impact of stressors and developing practical lake management options for lake managers.

A summary of the recommended method for sampling zooplankton is provided in Table 5.7.

Table 5.7. Recommended zooplankton sampling method.

Method	Equipment	Depth	Effort	Frequency
Vertical plankton net	64 µm Wisconsin-style closing net, boat	0.5 m off bottom to surface; discrete sampling in hypolimnion and epilimnion	2 net hauls per site, 300 individuals per sample	Monthly June-September

5.2.3 Fish

Fish populations are often monitored because of recreational considerations such as setting catch limits, assessing stocking opportunities or evaluating heavy metal content in fish for consumption purposes. Fisheries monitoring is also completed to provide an indication of ecosystem health because fish assimilate environmental conditions in their surrounding habitat and from lower trophic levels. Sampling objectives are often focused on determining presence/absence, species richness, relative abundance and/or density (Portt *et al*. 2006).

It is not possible to prescribe sampling methods focused on individual resident fish species in Georgian Bay because of the variability associated with different species. Instead, we recommend methods to assess the overall fish assemblage and environmental conditions in Georgian Bay.

Fish monitoring has a number of advantages, including the fact that:

- fish are good indicators of long-term effects and habitat conditions;
- monitoring methods are adaptable to different habitats and purposes;
- less time is needed for identification and sample processing than monitoring other biotic variables(such as benthic invertebrates, zooplankton, periphyton, or phytoplankton); and
- results are easily interpreted by the public.

Fish monitoring has a number of disadvantages, however, which include the fact that:

- fish, including piscivorous, planktivorous and benthivorous species, are at higher trophic levels than other aquatic organisms so they generally are less sensitive and therefore do not respond as early to stressors as other biotic variables;

- many fish migrate extensively in Georgian Bay and the Great Lakes making it difficult to use results as indicators of local conditions;

- fish are often killed during collection, especially through gill and trawl netting.

- fish collection is often time consuming.

5.2.3.1 Method Selection

It is difficult to recommend a single method to best assess fish communities because the sampling approach is dependent on water depth, habitat and resources, including the types of gear available. The most appropriate techniques to characterize fish populations in the nearshore of Georgian Bay, however, are gill nets, trap (i.e., fyke) nets, electrofishing by boat and beach seining. The majority of collection methods require a boat but seine nets, hoop nets and backpack electrofishing can be completed without a boat in wadeable waters.

Water depth is a primary consideration during evaluation of collection techniques. Seine netting can be carried out in shallow water but due to the large size of Georgian Bay and the migratory nature of fish, seine netting would not provide a large enough dataset to allow lake managers to make informed management decisions unless the stressor under investigation was a point source and/or the study area proved suitable (i.e., being a small size and having relatively consistent presence of fish species under investigation). The large fetch and potential for large wave formation in Georgian Bay also limits seine netting in many areas due to health and safety concerns.

The Nearshore Community Index Netting (NSCIN) Program provides a standardized method to evaluate fish abundance and community composition in shallow waters (1.7 – 3.5 m) with trap nets. Trap nets are also used as part of the Great Lakes Wetlands Monitoring Plan (Burton *et al.* 2008) to assess fish assemblage in relation to an established index of biological integrity; a scoring system which allows for a greater interpretation of results with reduced sampling effort. Trap nets are relatively inexpensive, fish can be live released, nets can be set to catch fish passively over an extended period of time and they are well suited to capturing fish moving along known migration routes, such as during spawning migrations (Portt *et al.* 2006). They should not be used in deep water but provide a sensible option in relatively shallow water (>4m).

Gill nets are also relatively inexpensive and can be used to passively fish, but fish are often killed in the process, depending on the size of the mesh and duration of net set and are highly selective. The Spring Littoral Index Netting (SLIN) Program contains a standardized methodology using gill nets for inland lakes that could be successfully implemented in the nearshore environment of Georgian Bay when water is too deep for the use of trap nets.

Boat electrofishing sampling is utilized in the Great Lakes Areas of Concern Surveys (Brosseau *et al*. 2005) and Great Lakes Coastal Wetlands Monitoring Plan (Burton *et al*. 2008). The method is limited by high start-up costs associated with purchasing an electrofishing boat, and sampling is limited to the upper portion of the water column (depending on the depth of the anodes, strength of the electrical current and conductivity of the water), but sampling is efficient and can be completed in any habitat, although macrophytes can clog propellers. We recommend traversing specified electrofishing transects and standardizing effort through the recording of electrofishing seconds.

Beach seines can be used by wading or deployed from a boat. Net hauls are completed by forming a U-shape in the seine, pulling the net through the water while keeping the lead line on the bottom to prevent fish from escaping, and bringing the two ends together to encircle fish. Beach seines can be hauled through shallow waters (<1.3 m) but capture efficiency is impacted by avoidance, especially by benthic fishes (Alberta Environment and Parks 2013: Portt *et al*. 2006). It is a simple method of sampling a large area in a short time where small-bodied fishes are targeted.

The OMNRF requires electrofishing certification to ensure safe use of electrofishing monitoring equipment. Certification includes completion of an Electrofishing Certification Course which is offered by various organizations, and up- to-date CPR certification. Sampling should include the completion of field operational safety procedures, use of personal safety equipment such as personal flotation devices, ear plugs and rubber gloves, and ancillary equipment, and proper maintenance of electrofishing equipment maintenance (Trent University 2009).

Habitat

Most sampling methods can be conducted in a variety of nearshore habitat types. Wetlands, however, pose some potential difficulties, as unconsolidated sediments limit the ability to walk around on the lake bottom, and abundant macrophytes can get tangled in nets or provide refuge for fish, limiting collection efficiency. Trap nets and boat electrofishing are thus recommended in wetland environments to overcome these challenges.

Beach seines can become snagged on rocks and logs so smooth lake bottoms with no debris or obstructions are preferred to improve capture efficiency and reduce snags (Portt *et al*. 2006).

Time of Year

Sampling is often completed in the summer (e.g., the NSCIN is completed in late summer when water temperatures are greater than 13 °C while boat electrofishing is completed in July or August as part of the Great Lakes Coastal Wetlands Monitoring Plan). SLIN is completed in the spring because the target species, Lake Trout, are active and are found in shallower depths than in later seasons, but gill netting can be completed in other open water seasons depending on study objectives and seasonal movement patterns of targeted fish species. Seine netting is also recommended during the summer months when water temperatures are greater than 15 °C (Alberta Environment and Parks 2013). The federal Department of Fisheries and Oceans has timing windows to conduct projects in or around water to protect fish during spawning periods which should be consulted to ensure that sampling is completed outside of sensitive periods for resident nearshore fish species (see http://www.dfo-mpo.gc.ca/pnw-ppe/timing-periodes/on-eng.html).

Effort

The amount of effort ranges considerably among methods and will depend in part on study objectives and the size of the monitoring area. The NSCIN prescribed 16 trap nets set per lake over at least two consecutive years. Gill nets are set six times per day for 90 minute intervals at 30-60 locations per lake by OMNRF area offices and OMNRF Fisheries Assessment Units in accordance with the SLIN protocol. The NSCIN and SLIN methods have been extensively tested and documented to determine the effort needed to produce a robust dataset but the methods have been developed for inland lakes much smaller than Georgian Bay. Boat electrofishing transects 100 m long are sampled through the Great Lakes Areas of Concern Surveys while seven transects are fished per wetland as part of the Great Lakes Coastal Monitoring Plan. Alberta Environment and Parks (2013) recommends eight beach seine net hauls per lake, while Allen *et al.* (1992) determined that maximum species richness in estuarine habitats was reached after 6 to 12 seine hauls depending on year and season. It is not possible to prescribe sampling effort for fish monitoring in Georgian Bay because of the migratory nature of fish and the size of the water body, but study areas and study objectives should be compared to lakes monitored through the NSCIN, SLIN, boat electrofishing or beach seining methods to provide a starting point for study design.

Assessment

Fish should always be measured for length and weight. Additional information can be collected on age and sex, supplemental information that is important when describing community composition. Data can then be assessed through abundance, species richness, biomass, trophic composition and other metrics.

QA/QC

QA/QC procedures used in fish monitoring include collecting reference specimens for future identification and flagging data that fall outside the normal range of variation (OMNR 1999; Brosseau *et al.* 2005).

Adaptability

A variety of factors can be adjusted in fish monitoring programs, including collection methodology and number of sample sites but it is not possible to determine acceptable minimum standards because of the migratory nature of fish species and the size of Georgian Bay. NSCIN and SLIN protocols provide good collection options for collecting fish in the nearshore environment both at shallow depths (NSCIN - 0-4 m) and deeper depths (4+ m).

A summary of the recommended methods for fish monitoring are provided in Table 5.8.

Table 5.8. Recommended fish monitoring methods.

Method	Equipment	Depth	Effort	Timing
Trap net	Trap net	< 4 m	Depends on objectives and study area	Seasonal movement patterns and spawning of fish need to be considered
Gill net	Gill net	Shallow and deep waters		
Boat electrofishing	Electrofishing boat	epilimnion	100 m transects in open waters; 7 transects per wetland	July or August
Beach seining	Seine net	<1.3 m	Depends on objectives and study area	Summer when water temperatures are greater than 15°C

5.2.4 Cladophora

Monitoring of *Cladophora in-situ* (i.e., where it grows in the nearshore) can be labour-intensive and potentially expensive. It generally is only recommended when there is a demonstrated problem and mitigation or management options are being considered that justify the cost (areas in the Great Lakes where it is currently undertaken include Presqu'ile Park at the west end of Lake Ontario, the Ajax and Halton Region waterfronts and certain areas in western Lake Erie where accumulation of sloughed *Cladophora* causes beach fouling and odour problems). As noted, the socio-economic issue associated with *Cladophora* in the Great Lakes is not that it exists, but that its growth can be prolific, and following storm events or senescence in the early fall, it detaches from the bottom and floats on the surface rotting, or fouls beaches and decays, resulting in high bacterial counts and obnoxious smells (Higgins *et al.*, 2008; Bootsma 2009; Depew *et al.* 2011; Auer 2014; University of Waterloo *Cladophora* Study Team undated). Consequently, a *Cladophora* monitoring program should adopt a phased approach, with a comprehensive *in-situ* assessment only occurring if a severe problem has been identified. A detailed standardized approach to *Cladophora* monitoring does not seem to exist. As a result, we recommend the following protocol:

1. Determine if the substrate is appropriate for *Cladophora* growth. This can be based on local knowledge and understanding, as well as historic documentation, of the nature of the shoreline and bottom within the nearshore zone (i.e., hard substrate consisting of cobbles, boulders and/or bedrock). Note that hard substrates will also support Dreissenid mussels,

which have been linked to the nearshore phosphorus shunt and *Cladophora* growth (Depew,*et al*. 2011);

2. Determine the density and surface area extent of man-made structures (break walls, docks etc.) within your study area and within a given distance of the study area that could support *Cladophora*. As sloughed *Cladophora* can be transported long distances we recommend considering at least a 5 km distance either side of the study area, or if a single direction is predominant for the littoral current, it may be appropriate to extend this documentation in a single direction;

3. If the answers to 1 and 2 are yes, then the monitoring program should determine if *Cladophora* growth and subsequent decay are sufficient to cause a significant socio-economic problem (e.g., the vegetation decays on the shoreline), by implementing a monitoring program to assess the frequency and significance of *Cladophora* decay on beaches and in sheltered embayments (this could possibly involve trained volunteers). We recommended that monitoring follow the approach outlined in Riley *et al*. (2015). This consists of trained individuals walking along beach transects periodically during the growing season and characterizing the *Cladophora* accumulation as: "none [0]; scattered clumps [1]; isolated mats [2]; scattered continuous coverage [3]; continuous mats [4], or thick continuous mats [5]" (Riley *et al*. 2015). Numerical scores are used rather than estimates of the area covered by *Cladophora* for consistency due to the difficulty of accurately measuring the area or biomass of many small clumps of algae; and,

4. If the shoreline monitoring program demonstrates that quantities of sloughed *Cladophora* are accumulating in nuisance quantities that result in beach closures, beach cleaning, or annoying odours for extensive periods of time, advanced more intensive nearshore monitoring program may be required.. Advanced monitoring should follow procedures developed by ECCC and OMOECC (i.e., using sonar and/or video surveys, remote sensing techniques, divers or quadrat sampling), or be undertaken jointly with these agencies to avoid duplication and maximize comparability and efficiencies (e.g., see Howell 2012 for an *in-situ* monitoring protocol developed by OMOECC for the nearshore of Lake Huron). We restrict our *Cladophora* protocol discussion to the simplified shoreline monitoring program required to determine the scope of the problem, if any.

The simplified monitoring protocol based upon the US Geological Service's AMBLE program can be implemented consistently and at very low cost using volunteer monitors with limited training. The monitoring has to be undertaken only during the spring, summer and early fall months (May or June through October or November) and requires a relatively small commitment of time on the order of once or twice per week. The whole beach does not need to be monitored but the same approximately 1 km length section (between the water's edge and the high water line) must be monitored each time. This 1 km section should be selected based on a general assessment or anecdotal reports of where the greatest concerns with respect to *Cladophora* accumulation occur along the full length of the beach. If possible, small inlets or areas where decaying vegetation may collect (e.g., on the upstream and lee side of rock outcrops and artificial structures that intersect the shoreline) should be incorporated into the shoreline section.

No special equipment is required once the program is set up. Importantly, the observations can be fairly uniform among different observers while their frequency will provide an indication of seasonal and yearly trends. As noted by Riley *et al.* (2015) the numeric scores provide consistency that is often difficult to achieve when estimating areal mass of numerous small clumps. Consistent data over a number of years will document annual variability and should indicate if a trend is occurring that requires more intensive investigations including *in situ* monitoring to identify production areas and potential causes and mitigation options.

5.2.4.1 Method Selection

Sampling Equipment

Gear is limited to a note pad and staking of the beach or shoreline transect to ensure that the same section is monitored during each sampling event. Digital photographs noting location on the beach transect, direction of view and date and time of photograph are desirable to substantiate observations. Weather conditions can also be recorded (or obtained after the fact from nearby weather station data).

Time of Year

Monitoring is only required during the main growing season which at a maximum likely extends from late May or early June through to late October or early November.

Effort

The effort is small, of the order of one hour per site visit, once or twice per week for 6 months or a total of 24 to 48 hours annually plus training and downloading, reviewing and reporting the results.

Assessment

A qualitative assessment of *Cladophora* accumulation on beaches or along shorelines is used for monitoring. Training of how to take measurements is relatively simple and consists of documenting the accumulation of *Cladophora* based on numerical scoring (Riley *et al*. 2015). If the section of shoreline monitored includes small inlets and natural rock outcrops or artificial structures that intersect the shoreline, it may be necessary to segment the shoreline into sections since accumulation may be concentrated near these features. The numerical scores can be analysed to investigate the timing of *Cladophora* accumulation within a year and the inter-year variability can be determined using annual frequency distribution histograms of each measurement category.

QA/QC

This consists of trained individuals walking a beach transect on a periodic basis during the growing season and characterizing the *Cladophora* accumulation, as noted by Riley *et al.* (2015) as "none [0]; scattered clumps [1]; isolated mats [2]; scattered continuous coverage [3]; continuous mats [4], or thick continuous mats [5]." Numerical scores are used rather than estimates of the area covered by *Cladophora* since it is difficult to accurately measure the area or biomass of many small clumps of algae. As long as the work is done consistently and at the determined frequency, the quality of the data should be acceptable. The key in achieving quality here will be consistent training to have a standard approach to characterizing the *Cladophora* accumulation and periodic review by the trainer to ensure consistency. Training will also need to include distinguishing *Cladophora* from other algae and weeds which may also accumulate on the shoreline.

Adaptability

This protocol is highly adaptable to different locations, but does require accessible beach habitat. The same protocols (visual inspection and documentation) can be used to assess the abundance of floating *Cladophora* mats in quiescent nearshore water as nuisance accumulations can occur offshore as well as on the beach area. The turbulence of the Great Lakes nearshore, however, means that any floating mats will be short-lived in open water but may accumulate in sheltered embayments or where protected by docks, piers or groynes. Coordination and an understanding of the factors that control *Cladophora* growth are necessary to select appropriate locations and or beach sections to monitor.

A summary of the recommended approach to monitoring *Cladophora* is provided in table 5.9.

Table 5.9. Summary of recommended Cladophora approach.

Method	Equipment	Depth	Effort	Frequency
Shoreline monitoring	Stakes for transects	On shore (e.g., beach)	~1 hour to survey 1 km stretch per visit	1-2 times/week during the growing season (approximately June-November)

5.2.5 Macrophytes

Macrophyte monitoring does not appear to be an effective indicator of anthropogenic impacts on the nearshore because of their sensitivity to a variety of often unrelated drivers (e.g., light, substrate). Other monitoring variables are thus generally a more appropriate choice for overall assessment of ecological condition. Macrophytes are useful to monitor, however, when macrophyte growth is a concern due to nutrient enrichment or spread of invasive (e.g., Eurasian Milfoil) or problematic species (e.g., Coontail). If factors driving the growth are being monitored (such as nutrients in the water column), it is important to monitor the density, species and extent of macrophytes in the area of concern so that management options can be developed and the success of management can be evaluated. LSRCA conducts annual localized macrophyte surveys and lakewide surveys every five years in Lake Simcoe, mainly because of public concern about macrophyte growth. Direct management of nuisance macrophytes is often required through mechanical harvesting, hand pulling, herbicide application or biological control (e.g., introduction of an aquatic weevil predator).

5.2.5.1 Method Selection

LSRCA has completed focused macrophyte inventories in areas where macrophyte growth was problematic (i.e., Cook's Bay, Lake Simcoe) and monitor abundance, wet and dry biomass for each species and total biomass as part of their Nearshore Monitoring Program. LSRCA's methodology should be adopted for focused studies in areas of concern or as part of routine monitoring where macrophyte monitoring is required. Study design should include a review of aerial photographs to identify areas of concern and for preliminary mapping of major vegetation zones such as wet meadow, emergent or submergent.

Sampling Equipment

Macrophytes should be collected with a grab sampler (petite Ponar Grab) in deep (i.e., >2m) water from boats and with a lake rake at shallow wadeable sites.

Time of Year

Sampling should be completed between July and September, depending on the timing of macrophyte emergence and maturation in the study area, with a focus on the timing of emergence and maturation of species (e.g., Eurasian Milfoil) under investigation. The number of sampling events is dependent on the spread of the macrophytes under investigation. If routine monitoring is completed, sites could be sampled once every five years but if specific areas have been identified through interpretation of aerial photography or through public complaint, annual monitoring should be completed.

Effort

It is difficult to determine the number of sample sites required to document conditions within an area of unknown size. If, however, monitoring is being completed as part of a routine program, three transects should be established in each major vegetation zone which was identified through a review of aerial photography within the study area. Fifteen 1m^2 quadrats should be placed 25 m apart along the three transects in accordance with sampling effort utilized in the

Great Lakes Coastal Wetlands Monitoring Plan (Burton *et al.* 2008). Macrophytes should be collected from each quadrat at least every five years to provide an indication of temporal trends. In water deeper than 2 m, a grab sampler should be used to collect plants from a location marked with GPS coordinates.

Assessment

Plants should be identified to species and wet and dry weighed. Abundance (number per sample, scaled to unit area), wet and dry weight biomass (by species for each sample, scaled to unit area), and total biomass (wet or dry weight of all species per sample, scaled to unit area) should be measured (LSRCA 2013).

QA/QC

The main QA/QC consideration in macrophyte monitoring is accurate identification of species. Representative specimens of all macrophytes surveyed should be collected and stored for later reference (e.g., if there are identification problems, or for future study; LSRCA archives representative specimens in its herbarium; Stantec Consulting Ltd. 2007; Ginn 2011; LSRCA 2013).

Adaptability

Macrophyte monitoring is not recommended to provide an indication of lake condition but monitoring programs can be successfully implemented to provide direct evidence of macrophyte coverage as part of routine monitoring programs or within targeted areas. Sampling interval can range from one to five years, due to the anticipated timeframe for nutrient inputs to cause major shifts in macrophyte communities. If monitoring is being completed because of the spread of invasive species, the number and frequency of sampling events should be based on the characteristics of the species under investigation.

A summary of recommended approaches for sampling macrophytes is provided in Table 5.10.

Table 5.10. Recommended methods for macrophyte sampling.

Method	Equipment	Depth	Effort	Frequency
Lake rake	Lake rake, quadrats	< 2 m	3 transects per vegetation zone, 15 1 m^2 quadrats per transect	July-September, at least every 5 years
Grab sample	Petite Ponar grab, quadrats	> 2m		

5.2.6 Periphyton

Periphyton monitoring is a good option for assessing water quality conditions at the water and sediment interface in the nearshore. Periphyton respond quickly to a variety of short-term and localized stressors, they are stationary so impacts can be analyzed spatially, tolerances of different taxa are well documented and sampling can be completed within the wadeable portion of the nearshore environment. They are also relatively easy and inexpensive to sample. Although there are no standardized protocols for monitoring periphyton in lakes, they can be a useful component of a broader monitoring program that includes other biological variables. Nonetheless, fine resolution taxonomic identification may be required to detect signals in the data, and thus advanced taxonomic expertise may be needed.

Sunlight and coastal processes, such as nearshore currents, wave action and bottom scouring, all directly influence the colonization of substrates by periphyton. The impacts of these factors should be considered during study design and controlled during assessment through proper sample site selection and comparison, and timing of sample collection.

5.2.6.1 Method Selection

The Ontario Algal Bioassessment Protocol (OABP), which was developed for river or stream systems, is designed to complement the OBBN and Provincial Water Quality Monitoring Network and its methodologies could be easily transferred to lake environments. If data were collected following the OABP, comparison between monitoring of periphyton in tributaries and the nearshore environments would be enhanced. The methodology also includes a tiered assessment which provides adaptability for monitoring with varying levels of resources. The OABP includes modules for collection of diatoms and a visual assessment of algae.

Sampling *Equipment*

Sample collection depends on the substrate under investigation but we recommend sampling cobble whenever possible. Rocky substrates are easily sampled, ubiquitous in Georgian Bay and results will be more easily compared if periphyton samples are uniformly collected from the same substrate type. Hard, removable rocky substrates should be scraped with a knife or stiff spatula, or brushed with a toothbrush, from an area at least the size of a loonie; if other substrates are sampled (such as surface sediments), samples should be siphoned with a turkey baster and shaken in a sample jar. We do not recommend sampling other substrates (e.g., plants or woody debris) because periphyton growth is often more inconsistent on these surfaces, leading to difficulties comparing periphyton results across sample sites.

Samples should be preserved with alcohol after collection. Lugol’s solution can be used as a preservative as well, but it poses health and safety concerns and breaks down silica over time.

Time of *Year*

Periphyton should be sampled at the height of summer (i.e., July or August) when growth is at its peak and maximum levels of abundance and diversity can be measured. Sampling under such conditions will increase the sensitivity of the monitoring program to detect changes among sites. Sampling should be completed at the same time each year so that annual results are comparable. The OABP recommends that sampling be avoided for two to three weeks after a bottom-scouring storm event, but this is based on river or stream conditions and it is unlikely that such an occurrence would cause the same level of disturbance (e.g., uprooting) to periphyton in the nearshore region of Georgian Bay. Nonetheless, the impacts of extreme wave activity should be considered when determining appropriate sampling times.

Effort

Effort depends on the module undertaken: 10-15 minutes for diatom sampling and 30-45 minutes for visual assessment.

We recommend following the OABP protocol but have adapted sample depths for lake environments. Thomas *et al.* (2011) collected diatoms and completed visual assessments within transects running parallel to shore in water 0.4-0.6 m deep, depths which are suitable for lake monitoring. Diatoms should be scraped and a visual assessment should be completed at sampling stations along each transect. The number of sampling stations and sites will depend on the study area and study objectives. The visual assessment surveys both sediment and algal characteristics, by estimating the percentage of the lakebed that is covered by different substrate types, identifying categories of periphyton based on thickness and colour, and estimating periphyton coverage. The OABP recommends three transects for both diatoms and visual assessments, with five sample sites per transect The number of sites chosen for monitoring in the nearshore environment will depend in part on the study area and stressors under investigation, but OABP guidelines are a useful starting point.

Assessment

Goncalves *et al.* (2011) recommend identifying 400 diatoms/sample to the species level as part of the OABP. Diatom assemblage should be assessed through a variety of biological metrics such as richness and diversity.

Multiple studies report that species-level identification of diatoms provides the best data to interpret the impacts of stressors so this tier of assessment should be completed if resources permit. Coarser taxonomic resolution (e.g., identification into major taxonomic classes) or assessment of biomass could prove useful in Georgian Bay if the range in conditions is sufficiently large between sites -a determination that will need to be made by personnel designing the monitoring program. Chlorophyll a and ash free dry mass are often measured during periphyton assessment to calculate biomass and can be used successfully to characterize periphyton assemblage as part of a more tightly scoped study. Ash free dry mass is preferred in this situation because it is a measure of actual biomass while chlorophyll a is dependent on lake conditions (e.g., light intensity), which increases the chance of statistical error because of inherent differences in physical conditions among sample sites.

Adaptability

Periphyton sampling programs can include a visual assessment and/or assessment of the diatom community. Diatom counts at high taxonomic resolution are recommended because they have the strongest link to water quality (Gonclaves *et al.* 2011) and shoreline development (Thomas *et al.* 2011) but coarser identification to major algae classes and determination of biomass can provide a sufficient level of detail to assess some stressors of interest which result in a relatively large gradient in environmental conditions.

A summary of recommended methods for periphyton monitoring are provided in Table 5.11.

Table 5.11. Recommended methods for monitoring periphyton.

Method	Equipment	Depth	Effort	Frequency
Diatom sampling and visual assessment (OABP)	Knife, spatula or toothbrush for hard substrate; turkey baster for soft substrate	0.4-0.6 m	3 transects, 5 sampling stations per transect, 10-15 minutes for diatom sampling, 30-45 minutes for visual assessment, 400 diatoms/sample	July or August

5.2.7 Phytoplankton

Phytoplankton are useful indicators of short and long-term environmental change and shifts in assemblages can indicate underlying environmental drivers, but high spatial and temporal variability require proper study design and at least monthly sample collections. Spatio-temporal variability in phytoplankton assemblages is often influenced by factors such as water movement and amount of sunlight, which can confound interpretation of response to stressors if these factors are not adequately considered in monitoring design. Sheltered embayments are often more appropriate for phytoplankton monitoring because the exchange of water masses is not as pronounced, allowing for greater control of spatial variability and subsequently, easier comparison between sites and sampling dates. Specialized skills and training are also required for enumeration and identification, which may not exist in house. Laboratories and taxonomists do, however, offer enumeration and identification services but costs can be prohibitive.

Cyanobacteria (i.e., blue-green algae) receive a lot of public attention because they produce toxins that can be harmful to human and animal life and taste-and-odour concerns. Cyanobacteria can migrate vertically throughout the water column to access optimal levels of light and nutrients and can fix molecular nitrogen from atmospheric sources, two characteristics that provide a competitive advantage over other algal species. Monitoring programs can focus on evaluating occurrence, distribution and concentration of toxins and taste-and-odour compounds or evaluation of causal factors (Graham *et al.* 2008) but monitoring often occurs following observation of a bloom formation. Sampling equipment and depth of sampling will depend on the characteristics of the bloom under investigation. Assessment should include identification of taxa and evaluation of life history characteristics as well as analysis of microcystin concentrations, which are commonly measured because they are the most common group of cyanobacterial toxins (Graham *et al.* 2008). Additional toxin analysis, such as bioassays or mass spectrometry, will depend on study objectives. Water chemistry monitoring with an emphasis on nutrients is often completed when evaluating causal factors.

The OMOECC responds to blue-green algae bloom reports and tests for the predominant algal species and microcystin toxin concentrations. Blue-green algal blooms should be reported to the Spills Action Centre at 1-800-268-6060.

5.2.7.1 Method Selection

Sampling Equipment

LSRCA utilized a vertical tow, horizontal tow and discrete sampler to collect phytoplankton samples from a boat through their Nearshore Monitoring Program and components of our recommended methodology are based on that protocol. A vertical 64 µm net should be deployed by a sampler from a boat and hauled through the epilimnion. Discrete depth sampling is not recommended because phytoplankton are either mixed throughout the euphotic zone or epilimnion or can accumulate at high densities in specific areas where light, nutrients or water density are optimum. LSRCA sampled with a discrete sampler from 0.5 m off bottom to assess phytoplankton composition in anoxic or hypoxic conditions, a focused approach that is not being described here. We do not recommend sampling via a horizontal tow, because a smaller sampled depth would result in less control of phytoplankton's noted spatio-temporal variability at a depth where phytoplankton presence and absence is greatly controlled by sunlight.

Time of Year

Phytoplankton samples should be sampled at least once per month between approximately July and October or throughout the stratified period. Sampling needs to be completed monthly to account for fluctuations in nutrients, sunlight and predation pressure (Becker Nevers and Whitman undated). Sampling should be conducted at mid-day to maximize the number of phytoplankton collected, since they congregate in the upper water column (i.e., epilimnion) when light transparency is at its highest

Effort

Three or four net hauls should be completed through the epilimnion and combined into a sample container to represent a single composite sample (Findlay and King 2001). Samples should be counted with a counting chamber until 400-600 cells are enumerated.

Assessment

Taxa should be identified to species and wet-weight biomass should be calculated based on cell volume. Data should be assessed through a variety of biological metrics including species richness, diversity and a similarity index. Biomass can be used to determine seasonal, annual and long-term trends (Findlay and King 2001).

QA/QC

We recommend a number of QA/QC measures during collection and processing, including:

- double checking identification in 10-15% of the samples to ensure accuracy;
- double checking counts by comparing independent counts of the same sample and ensuring that counts are within ±20%;
- retention of voucher specimens.

Adaptability

There are few component of the recommended phytoplankton monitoring approach that can be adapted. The number of sampling events and net hauls represent a minimum effort required to accurately characterize phytoplankton assemblages. Biomass can be used in place of fine resolution species-level identification to assess population trends but interpretative abilities will be diminished and other monitoring tools would likely provide a better understanding of lake condition in many cases.

A summary of the recommended approach to monitoring phytoplankton is provided in Table 5.12.

Table 5.12. Recommended method for monitoring phytoplankton.

Method	Equipment	Depth	Effort	Frequency
Vertical plankton net	64 µm net, boat	epilimnion	304 net hauls for a single composite sample, 400-600 cells per sample	Monthly July-October

5.2.8 Physical and Chemical Water Quality

Water quality sampling provides a snapshot of environmental conditions while biological monitoring provides a longer-term indication of conditions because aquatic biota assimilate water quality conditions over a longer period of time. Water quality data tend to be more straightforward to interpret than biological data because they are often directly linked to stressors under investigation, and unlike biological variables, not as dependent on factors such as habitat, food web interactions, or light, that may confound monitoring results. Water quality, however, can still be highly variable both spatially and temporally, and monitoring programs require careful planning to accurately characterize this variability. Water quality in the nearshore of eastern Georgian Bay, for example, exhibits marked variability due to watershed characteristics, and the timing, magnitude, transport and fate of materials from the watershed to the bay (Diep *et al*. 2007). Factors that contribute to the dynamic nature of water quality in these nearshore waters include mixing of water from different biogeochemical sources (i.e., water from the Precambrian shield watershed, which is generally soft acidic to circumneutral, with high levels of dissolved organic matter, combined with offshore clear alkaline water) and the heterogeneous nearshore landscape, which can be affected by degree of shelter and connectivity with open waters (Diep *et al*. 2007) and climate. Careful planning should include:

- a thorough assessment of adjacent land uses and tributary influences through a review of aerial photography prior to design of the monitoring program to help determine appropriate sampling locations;

- recording of broad habitat features such as distance from land, degree of shelter and connectivity to open water of Georgian Bay to address mixing of water from different biogeochemical sources during data interpretation.

Schiefer and Schiefer (2005) found that conductivity can provide a good indication water circulation and mixing patterns within the Georgian Bay archipelago. Open water typically contained higher conductivity concentrations while lower conductivity concentrations were typically found around interior channels, islands and river mouths because of the runoff from adjacent granite bedrock. They used conductivity to distinguish the predominant influence of off Shield runoff in Severn Sound (high conductivity) from low conductivity runoff from the Precambrian Shield.

Water quality monitoring programs are often focused on determining if conditions allow for swimming in recreational areas. District Health Units are responsible for monitoring and reporting recreational water quality conditions but agreements are in place with various agencies, including Conservation Authorities, to complete the monitoring programs in some areas. All monitoring groups utilize the same sampling protocol, analyses and decision tree to determine when swimming advisories or beach closures are required (see Ministry of Health and Long-Term Care 2014). The number of sample sites is dependent on the length of the beach under investigation, with the goal of collecting samples that represent conditions for the majority of the bathing area. Analysis is focused on *E. coli* which is a subgroup of fecal coliforms found in the intestines of warm-blooded animals and which is an indicator of faecal contamination of freshwaters. The most common sources of *E. coli* in the Great Lakes are birds, septic systems, sewage treatment plants, urban runoff and agriculture.

The geometric mean of *E. coli* concentrations from five sampling events is compared to the Ministry of Health Guideline of 100 *E.coli*/100 mL in Ontario (or 200 *E.coli*/100 mL in other parts of Canada) to determine management actions. The geometric mean is calculated because *E. coli* often exhibits a clumped distribution causing extremely high and low values. Extremely high values can lead to public concern, which may be unfounded if the overall geometric mean is below provincial guidelines so education is an important component of recreational water quality monitoring and reporting.

The Muskoka Lakes Association has completed a water quality monitoring program since 2001. Total coliform and E.coli samples are analyzed by volunteers using ColiPlates (Beacon Environmental 2013), manufactured by Bluewater Bioscience Inc. Water samples are poured into the commercially available bacteria testing kit, which has 96 wells. Blue reactions indicate the presence of coliform bacteria. *E.coli* are then analyzed by exposing the plate to ultraviolet light and recording wells that appear blue/green and fluorescent. Any bacterial sampling program must be conducted with QA/QC procedures such as distilled water blanks, a good selection of reference sites, the ability to distinguish higher counts of bacteria that originate naturally from wetlands and inflowing tributaries from any that are related to potential stressors such as failing septic systems, and a knowledge that bacteria tend to occur in clumped distributions as they are not dissolved in the water column. All of these factors need to be considered when interpreting bacterial data.

5.2.8.1 Method Selection

A number of water quality monitoring programs have been completed in Georgian Bay but there are no standardized protocols that are consistently applied. We have therefore developed a methodology based on findings from the literature review (including the LSRCA Standard Operating Procedure for monitoring lake health, and Georgian Bay monitoring programs), and professional experience. As with all of the monitoring methods, there are components that can be modified based on the study objectives and resources available but the methodology described below represents a solid starting point for lake managers when designing monitoring programs.

Sampling Equipment/Water Depth

Water quality sampling will often be completed from a boat but can be completed in the wadeable portion of the nearshore environment if sampling locations are justified, coastal processes are accounted for, and agitation of the lake bottom during walking is controlled. Water quality parameters are measured in the field and through laboratory analysis. Parameters are generally measured in the field using a YSI Multi-Probe Water Quality Meter (or similar device) and should include measurements of temperature, dissolved oxygen, conductivity and pH at 1-m depth intervals. Water clarity should also be collected using a Secchi disk on the shady side of the boat. The Secchi disk is lowered and the depth at which it is no longer visible recorded, then pulled up until it is visible and that depth is recorded as well. The mean Secchi depth is then calculated.

A composite sampler should be used to collect water samples through the epilimnion for analysis of water chemistry. A composite sample from the epilimnion is not as sensitive to the mixing of waters from different biogeochemical sources as a grab sample and provides a more robust indication of water quality.

If a dissolved oxygen sag is noted in the bottom waters indicating hypoxic or anoxic conditions, a discrete sampler (e.g., van Dorn sampler) should be used to collect a water sample 0.5-1.0 m off bottom to gain insight into any internal loading of nutrients. It is important that the bottom water sample does not disturb the lake bottom and entrain a heightened concentration of suspended solids because nutrient concentrations will be artificially inflated in such cases.

Time of Year

LSRCA completes monthly physical monitoring (i.e., dissolved oxygen and temperature profiles) beginning with the spring (~June or July) turnover and ending with the fall (~October) turnover, and we recommend the same approach, resulting in four to five physical sampling events per year. We also recommend sampling for water chemistry during each of these sampling events.

Effort

Recording of physical parameters at 1-m depth intervals can be time-consuming if the water is deep at sample sites. Collection of water samples from the epilimnion for water chemistry and 1-m off bottom (if required) is not as time consuming. The location and number of sample sites will depend on study objectives and resources.

Assessment

Selection of water quality parameters will be dependent on study objectives and available finances as analysis can be quite expensive. A standard suite of physical and chemical water quality parameters to provide a solid depiction of water quality condition and assessment of common stressors (e.g., nutrient enrichment, stormwater) includes: total phosphorus (low level), ammonia, nitrate, nitrite, TKN, chloride, calcium, colour, alkalinity, hardness, dissolved organic carbon, turbidity and total suspended solids. The results of many parameters can be compared to Provincial Water Quality Objectives (PWQOs) or Canadian Environmental Quality Guidelines for interpretative purposes (e.g., to see whether measured values meet guidelines for protection of aquatic life or recreational use). In the case of ammonia, it is important to convert raw measures of total ammonia to un-ionized ammonia based on pH and water temperature measurements for comparison with a PWQO. Spatial and temporal trends should also be assessed in relation to study objectives.

An assessment of land uses, tributary influences and mixing of water from different biogeochemical sources should be completed during interpretation of results.

QA/QC

A number of QA/QC procedures should be included in a water quality monitoring program, including:

- collect replicates;
- submit field blanks to laboratory;
- compare data with other monitoring programs in the same area if possible;
- pay attention to laboratory analytical methodologies (a laboratory changed analytical methods while maintaining the same minimum detection limit during LSRCA's Nearshore Monitoring Program and reported results changed substantially due to the change in analytical procedure);
- assess minimum detection limits in accordance with study objectives. Historical water quality data should be reviewed to determine background concentrations of water quality parameters under investigation and allow for an educated determination of required minimum detection limits needed to characterize water quality conditions and assess any stressors under investigation. For example, total phosphorus concentrations in many parts of Georgian Bay are very low and total phosphorus would have to be analyzed at a lower level of detection (0.03 mg/L) than the standard analysis to provide meaningful results.

Adaptability

A few components of a water quality monitoring program can be adapted based on study objectives and resources:

- number of sites is dependent on study objectives and can vary considerably;
- sampling of bottom waters is contingent on study objectives and determination of hypoxic or anoxic conditions in the bottom waters through measurement of dissolved oxygen concentrations;
- parameters analyzed at a laboratory are contingent on study objectives and available finances. Standard suites of parameters (such as that noted

above) should be used for routine monitoring. Additional parameters should be utilized when monitoring is being completed to assess impacts of a known stressor;

- monthly sampling events between spring and fall turnover are recommended for physical and chemical water quality measurements, but the number of events could be reduced if water quality conditions do not exhibit much temporal fluctuation in the study area under investigation.

A summary of recommended approaches to monitoring water quality is provided in Table 5.13.

Table 5.13. Recommended methods for monitoring water quality.

Method	Equipment	Depth	Effort	Frequency
Epilimnion composite sampling	Water quality meter, Secchi disk, composite sampler, van Dorn sampler, possibly a boat	Epilimnion (unless bottom waters are anoxic, in which case 0.5 – 1.0 m off bottom as well)	1 m depth intervals for physical parameters, epilimnion sampling for chemistry parameters	Monthly June-October

5.2.9 Physical and Chemical Sediment Quality

There are two basic reasons to undertake surficial sediment monitoring in the nearshore:

1. To characterize the averaged historical physical and chemical conditions of the overlying water column; and,

2. To characterize the long term changes occurring in the nearshore based upon changes to the physical nature of the sediment.

In the first case, since sediments accumulate solids from the overlying water column (including inorganic and organic matter), sampling and analysis of the sediments can provide a record of how the lake water quality has changed over time. Historical records from the sediments for example, can demonstrate the impacts of anthropogenic activities such as eutrophication on a lake, based on the nutrient concentrations and the changes in the preserved biological record. Industrial contamination can be documented from the record of organic (e.g., hydrocarbons, chlorinated compounds, flame retardants) and inorganic contaminants (e.g. metals) found in the sedimentary record.

In the second case, the nature of the sediments (grain size, thickness) can illustrate that changes are occurring in the sediment composition of the nearshore due to, for example, changes to the shoreline. This is discussed in the shoreline section.

The characterization of bottom sediments for physical and chemical attributes is an important aspect of monitoring in the nearshore because accumulating sediments provide a time integrated "long term" record of the chemical and biological attributes of the water column. Nearshore zones where sediments are not accumulating (e.g. rocky headlands and eroding or areas "starved" of fine grained sediments) are not considered here. Beach accumulations are dynamic and, while frequently the area of the shoreline most associated with human contact, are also typically not monitored as the sands on beaches are more typical of their source area (e.g., eroding shorelines) rather than the lake. Thus sediment monitoring in the nearshore is limited to zones of accumulating fine grained sediments consisting of fine sands, silts and clays because this material provides the historical perspective that is of interest.

The main advantages of sampling sediment are that:

1. it characterizes average conditions and does not have to be sampled frequently like water;

2. requires a reduced sampling frequency, on the scale of once every 5 to 10 years, greatly reduces cost;

3. as sediment provides a historical record, new techniques or issues can be evaluated by collecting deeper sediments or by accessing archived surficial sediments from previous sampling events;

4. sampling can be done consistently using established methods;

5. analytical methods are well developed for low level detection of compounds or elements of concern; and,

6. guidelines and criteria have been established for concentrations of pollutants in the sediment that indicate the potential hazard of the sediments to the aquatic system (sediment quality guidelines for exposure limits – see for example CCME Sediment Quality Guidelines, Province of Ontario, Soil Groundwater and sediment standards for use under Part XV.1 of the Environmental Protection Act, Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (1993)).

Due to the integrated temporal record of sediments, the detection of changes occurring in the nearshore environment may not be observed for many years and even decades after they are first observed in other media. Sediment often accumulates slowly, and physical mixing of sediment may also occur, making it difficult to know precisely the time period represented in the sample (unless sediment dating is conducted). The integrated nature of the conditions monitored may also tend to mask impacts such that differentiating an effect from the normal observed variability can be challenging. Shoreline conditions, such as hardening of the shoreline due to urbanization or industrial activities, may result in major shifts and even losses of sediment accumulation zones resulting in a loss of long-term record in extreme situations. The sediment grain size must be taken into account when deciding if sampling is feasible in a given location. If analysis of chemical composition is required, then sampling will need to be restricted to fine material, such as fine sand and silt. Medium to coarse grained sand or larger indicates dynamic sediment that is transitory in the area. Furthermore, coarser particles have less surface area than fine particles and thus less capacity to adsorb contaminants. Sampling does require the use of specialized equipment (which is generally available for purchase or rental) and appropriately sized watercraft or floating platform to conduct the work safely. Sampling by foot in the wadeable nearshore is impractical because of the risk of disturbing sediment and potential difficulties carrying a full dredge back to shore for processing. As with most monitoring programs, there is no substitute for experience in the design and use of equipment, the collection of representative samples and the interpretation of the resultant information.

5.2.9.1 Method Selection

Surficial Grab Samplers vs. Core Samplers

There are two types of samplers generally used for collecting bottom sediments: (1) grab samplers for collecting surface sediments (which sample the horizontal distribution of variables); and (2) core samplers (which sample the vertical distribution of variables). Grab samplers, which are relatively easy to use and can collect a large quantity of sediment, are often used for measuring pollutants. Core samplers, in comparison, are typically used for assessing long-term historical (of the order of 50 to 100 years) inputs.

It is important to distinguish the differences in resolution available with the two techniques. Grab samplers will sample sediment to depths of up to ~10 cm and combine all sediments into one sample. This could combine a temporal record of decades to a century or more into one sample and are therefore better suited to sampling reference areas where there have been little changes and particle sizes and chemical composition are uniform with depth. Core samplers, on the other hand, will preserve a vertical record of temporal changes in the water body or watershed. Extruding samples of 0.5 cm depth from a core will provide enough sample for most chemical analyses and allow temporal resolution of changes in chemistry as low as 3-5 years. Sampling sediments in a clear Plexiglas tube may also allow visual determination of changes in sediment colour or texture that may relate to watershed processes. Repeated sampling of surficial sediments at 3-5 year intervals is recommended as the preferred method of tracking temporal changes in sediment quality.

The type of sampler used will depend on the study purpose, the nature of the sediments (e.g., some samplers work better in soft sediments such as the Ekman and Ponar, whereas the Shipek may be more appropriate for harder sediments) and the project design.

Grab samplers are designed with jaws that close once the sampler is lowered into the sediment. Ekman and Ponar grabs use vented or hinged tops that allow water to flow through the device as it is lowered through the water column to minimize the risk of sediment disturbance. Other designs include the mini-Ponar, Shipek and Van Veen samplers. These samplers come in various sizes and they should be selected based upon the nature of the sediments being sampled. Samplers should be relatively light and lowered slowly into soft sediments so as not to disturb the fresh, light sediment (floc) on the surface. Ponars, Ekmans and Van Veens can be used in these situations, whereas the Shipek is better for harder, coarser grained sediments due to its spring loaded rotating bucket. Woody debris, vegetation and stones, however, can all interfere with the collection of a sediment sample by keeping the jaws from closing, allowing sediment to escape when the sample is recovered.

Core samplers penetrate deeper into the sediment than grab samplers, enabling a longer time period of sediment accumulation to be sampled. Cores can be inspected inside the clear acrylic core barrel and then sliced vertically to provide information on sediment accumulation or can be extruded from the barrel in thin horizontal layers (0.5 or 1.0 cm. thick) and analysed to provide a detailed record of the chemical or ecological history of the lake. In both cases, analysis should be carried out by a trained geoscientist with expertise in sedimentology.

The corer is allowed to penetrate the sediment by free falling from an appropriate height based upon knowledge of the sediments and experience in collecting cores. Inadequate penetration of the sediment may result in the corer falling over or the recovery of insufficient sediment. Weights can be added to a corer to increase the penetration but this may result in the entire apparatus being buried beneath the surface (which should be avoided) and loss of the surface sediment. A valve or a piston at the top of the sampler closes by messenger, creating a vacuum seal that prevents the sediments from washing out. The most common core sampler is the Kajak-Brinkhurst sampler, although many variations on this design are available from commercial suppliers.

Collecting Sediment Samples

Sediment samples are collected for analysis of chemical and physical properties of the sediment. A number of basic requirements must be met to obtain representative sediment samples:

- the sampling device must penetrate the sediment to a sufficient depth to measure the variables of concern accurately;
- the sampling device should penetrate to the same depth and thus enclose the same quantity of sediment each time;
- the sampling device must close completely each time; and, care should be taken not to disturb the sediments prior to deployment of the sampling device.

It is important to know the water depth at each sampling station to ensure that adequate rope or cable is attached to equipment, and to properly control the speed at which the sampler enters the sediment. Water depth should be confirmed each time you sample even if you have sampled at the location before or have good bathymetric data for the site. Water depth can be measured either with a weighted rope or with an electronic depth sounder.

The speed at which the sampler is deployed strongly influences the success of sampling. If the sampler is deployed too quickly it can create a shock wave which displaces soft unconsolidated surface sediments. Furthermore, rapid deployment can lead to equipment malfunction, such as the trigger mechanism activating prior to the sampler reaching the sediment. Conversely, if the speed of deployment is too slow, not enough sediment will be collected. Site–specific conditions will affect deployment speed and should be recorded in field notes (e.g., height from which the corer dropped).

Time of Year

Sampling for sediment chemistry and physical properties may be conducted from the open water any time of year or from the ice surface when it is safe to do so (i.e., ice should be at least 8 cm thick). Collecting cores from the ice is a common practice as it gives a solid platform to work from and core devices are circular and thus easily deployed and recovered through holes drilled through the ice. These holes are often too small or too confined for grab samplers, which are usually used in calm open water conditions. Winter sampling must take into account the health and safety considerations related to working on ice and in frigid water conditions. In the Great Lakes only sheltered areas will provide stable and thick ice cover suitable for winter sampling.

Effort

Sediment sampling should generally be done every five to ten years depending upon the issue or the site being addressed. Thus, while the planning and execution effort is large, it is infrequent. Determining the number of sites to be sampled depends on the known or anticipated homogeneity of the site. An important thing to remember is that if you think that the site is homogeneous and take one sample per square kilometre initially and your data indicate inhomogeneity, you can always go back next month or next year and collect more samples based upon your expanding knowledge of the site.

The volume of sediment required for each site to fill all of the sample containers provided by the laboratory for the planned analytical suite should be determined in advance. Sampling may be limited to the top several centimetres of the grab sample using specialized, pre-cleaned sub-samplers if you are only interested in recent conditions (e.g., last decade). If the entire mass collected by the sampler is to be used because you are interested in a longer period of time or the sedimentation rate is known to be high, the sample should be homogenized in a separate pre-cleaned container appropriate to the objectives of the sampling/analytical program. For example, if you are focusing on metals, then to the extent possible, sediment should be collected from a part of the sample that is not in contact with the metal sampler, metal sub-sampling equipment should be avoided and plastic type materials should be used. If the focus is industrial contaminants then clean stainless steel tools are preferred. If the sampling is targeting multiple contaminants then replicate samples should be taken and handled according to the analytes being targeted.

In many cases, taking the full depth of sediment from the sampler will result in a sample that characterizes a very long time period (perhaps even to early or pre-European settlement) resulting in a sample that does not appropriately characterize current conditions. This has to be considered in planning the sampling program. Ideally the laboratory should be involved in the planning phase to ensure that sample containers are available, to provide appropriate solvents for field cleaning equipment and to ensure that sufficient sample volume is collected for the analysis required. Replicate samples should be collected and preserved frozen in the event that additional sediment is required for follow up analysis or loss of sample. Sample containers should be obtained from the laboratory in accordance with the analytical plan including sufficient sample containers for the duplicate samples.

Assessment

Photographs of each sample (grab or core) should be taken at the time of collection and labeled to link the photograph to the sample location. A photographic record of each sample is recommended so there is visual documentation of the characteristics of the sample sediment prior to being subsampled or homogenized. A general description of the sample (colour, water content, approximate grain size) should be documented in the field notes, along with information on location and water depth. The analytical information received from the lab should be checked and validated and the data can be mapped if the emphasis is spatial distribution or plotted with time or depth if trends are being evaluated. Cores collected for trend assessment should also have samples collected for dating. Further evaluation through a multi-metric or multivariate statistical analysis is dependent on study objectives.

QA/QC

A number of precautions should be adopted to minimize the risk of sample contamination. These include:

- cleaning all sampling equipment following procedures recommended by the laboratory for the analytical suite selected, with the laboratory providing appropriate solvents or soaps and purified water as appropriate;
- acquiring clean sample containers (new), certified by the issuing laboratory as 'contamination free' if pre-cleaned by the laboratory;

- using the recommended type of sample container for each analysis (review with the laboratory in advance);
- ensuring nothing touches the inner portion of sample containers and caps (e.g., bare hands, gloves, etc.) other than the sample itself;
- ensuring sample containers are capped at all times and stored in clean shipping containers (coolers) both before and after the collection of the sample;
- if sampling for hydrocarbons, avoiding contamination from other external sources of petroleum (e.g., gasoline, oil, exhaust fumes);
- storing samples in a cool place (e.g., coolers packed with ice packs are recommended);
- avoiding freezing of samples unless it is part of the preservation protocol;
- wearing clean latex or nitrile gloves while working with samples. If mercury is one of the variables to be analysed, special precautions are required including wearing masks while handling the samples.

Additional field quality control is achieved through the use of replicate and reference samples. Replicate samples are used to capture variability within the environment, to estimate measurement precision and to ensure the sample is reproducible. Replicates could comprise multiple samples from different sites within the study area (to measure overall heterogeneity of the area) and/or multiple sub-samples taken from a single sample (i.e., to measure site-specific heterogeneity). Reference samples, meanwhile, are mainly used to detect bias in the laboratory analysis, but can also reveal contamination during field collection, handling or analysis stages. Reference samples are supplied by the laboratory and should be acquired prior to sampling, then submitted to the laboratory along with field samples.

Adaptability

Sediment sampling is adaptable and well developed and provides time integrated information on the sediment quality which in turn is determined by conditions in the water column. However, the usefulness of sediments are limited to zones of accumulating fine grained sediments and consequently large parts of the nearshore zone may not be appropriate. While sampling is relatively straightforward, trained professionals are required for collection and interpretation of sediment quality data. Furthermore, sampling by foot is generally impractical so a boat or floating platform is recommended.

A summary of recommended approaches to monitoring sediment quality is provided in Table 5.14.

Table 5.14. Recommended methods for monitoring sediment quality.

Method	Equipment	Depth	Effort	Frequency
Grab sample	Ekman, Ponar, Shipek, or Van Veen sampler depending on sediment, boat or floating platform	Depends on study objectives	Number of sites depends on spatial variability, volume of sediment depends on objectives	Every 5-10 years
Core sample	Kajak-Brinkhurst sampler, boat or floating platform			

5.2.10 Shoreline Observations

Shoreline characterization can provide useful background information for the design of nearshore monitoring programs because it can help to identify stressors, describe baseline conditions and document change over space and time. Shoreline development and alteration can be monitored through a combination of analysis of aerial photography and site investigations in the field, providing a broad-scale quantitative assessment of conditions. Data collected may include shoreline habitat types and vegetation cover, patterns of shoreline development and recession, and bathymetry and composition of the lakebed. Aerial photography can provide substantial spatial information, and, if available on demand, can be a powerful tool for capturing real-time conditions that would otherwise not be measureable (e.g., after storm events in the winter). Aerial photography can be obtained through a variety of sources, including manned and unmanned aircraft (i.e., drones) and through reference to existing photographic records kept by different levels of government (e.g., municipal, provincial, federal). Photographs should be geometrically corrected (orthorectified) to remove distortion and to produce a uniform scale with GIS software for analysis. Aerial information often needs to be corroborated with more detailed information to identify or characterize land-based stressors, so access to site-specific data or supplemental field investigations are often required.

A detailed large-scale study of the shoreline can be expensive, and beyond the scope of many monitoring organizations. A long-term shoreline recession monitoring program for the Lake Ontario shoreline within CVC's jurisdiction, for example, is estimated to cost $12,000-14,000 annually for the first few years, $4000-6000 annually thereafter to maintain, and $8000-10,000 for bathymetric sounding every 15-20 years as required (Geomorphic Solutions 2012). A more general and short-term assessment of shoreline characteristics may be preferred if financial resources are tight, such as one that relies on existing photographs and focused surveys in the field to document conditions (costs will be further reduced if GIS capabilities are available). Drones can be a useful and cost-effective tool for shoreline characterization. As drone technology evolves and costs diminish, they become an increasingly feasible option. Shoreline investigations should be completed in some capacity by any organization designing monitoring programs in Georgian Bay.

5.2.10.1 Method Selection

The NVCA examined shoreline alteration along south-eastern Georgian Bay to determine the amount of degradation between 2002 and 2012 through a combination of aerial imagery data cross-referenced with information on habitat, biodiversity and natural heritage features. A Shoreline Habitat Zone Framework was developed based on aquatic habitat, natural heritage and biodiversity features to allow for categorization of shoreline areas but challenges were encountered when trying to compare two sets of aerial imagery to assess temporal change. The mapping protocol was developed to assess a point in time and was not intended to compare different imagery sets from various years. We recommend that future shoreline characterization studies in southeastern Georgian Bay use this framework, but with altered GIS protocols to allow for temporal comparisons. We also recommend that use of aerial photography be incorporated into the design stage of monitoring programs, to help refine study objectives (e.g., through the identification of stressors, such as different types of shoreline alterations) and to help identify suitable locations for sampling (e.g., by assessment of shoreline habitat).

A summary of the recommended approach to monitoring shoreline observations is provided in Table 5.15.

Table 5.15. Recommended method for monitoring shoreline observations.

Method	Equipment	Effort	Frequency
Shoreline Habitat Zone Framework	Aerial photography, GIS	Depends on study objectives (e.g., for use in study design vs. long-term monitoring of change)	

5.2.11 Coastal Processes

Physical processes should be considered in monitoring design as they play a fundamental role in shaping nearshore conditions. Wind, waves, longshore currents, thermal and density currents and upwelling, for example, can all contribute to variability in biological, physical and chemical monitoring variables. While it is impractical (if not impossible) to adequately characterize all physical processes underway in the nearshore, their effects can be minimized by sampling during low energy periods, such as spring, summer and fall seasons (Rao and Murthy 2001), and field monitoring of selected aspects of coastal processes can provide valuable information. In addition, while direct monitoring of nearshore physical processes can be complicated and expensive, a number of surrogates can be used to characterize conditions, such as grain size of shoreline substrate and accumulation patterns of sediment.

Field monitoring of coastal process should include the following components:

- Shoreline erosion: through erosion monitoring stations where stable structures (such as surveying pins, benchmarks, buildings or piers) are surveyed annually and after major storms;

- Nearshore bathymetry: through echo sounding/LIDAR every 5-7 years (ideally coordinated with neighbouring conservation authorities to reduce costs);

- Shoreline protection structures (including stormwater outlets): through an inventory of protected structures (e.g., walls, revetments, groynes, breakwaters) and natural shoreline every 5-7 years;

- Substrate survey: which could be completed concurrently with the bathymetry or shoreline protection survey every 5-7 years.

- For the substrate survey, we recommend the approach used by OMOECC to characterize the nearshore lakebed of southeastern Lake Huron (Howell 2012). The composition of the surficial substrate was qualitatively documented by determining the percentage that is silt, clay, sand, gravel, cobble, rock, bedrock, boulder, shale etc.). The underlying substrate type was also described using a sturdy probe with a measuring scale to document the type and depth of substrates below the surficial layer (Howell 2012).

Field monitoring data can be supplemented with additional information from online resources or from existing coastal engineering reports prepared for the study area (contact the local conservation authority for more information)..

The NOAA Great Lakes Environmental Research Laboratory runs the Great Lakes Coastal Forecasting System, that provides data on historical, current and forecast physical conditions for all of the Great Lakes. Data are available online (http://www.glerl.noaa.gov/res/glcfs/) on a wide range of features, including wind speed, wave height, surface temperature, surface currents, temperature transects, temperature profiles, water levels and ice cover. Information can be accessed for a given location and time period from 2006 to present, and up to 120 hour (5 days) in the future. We recommend using this resource as a useful tool for planning nearshore monitoring in the Great Lakes.

Current sediment characteristics can be compared to historical nearshore sediment characteristics data, which are available from ECCC (2013). Samples were generally collected between 1969 and 1975 with grab samplers from boats along the shoreline in various depths of water up to 30 m. The purpose of the sampling was to describe the physical nature of the sediments in the nearshore including descriptions of sediment and core properties, grain-size statistics, sediment patterns and x-radiographs of sediment cores. Underwater photographs are also available for Lake Huron and Georgian Bay.

Miscellaneous data, including sediment, acoustic and underwater-television surveys for a number of sites and supporting a variety of objectives, are also available. Samples, cores and, in some cases, acoustic-bottom-classification and bathymetric data were collected at Darlington, Oshawa, Toronto, Port Dalhousie, eastern Lake Erie, northern Lake Michigan, Lake St. Clair, the nearshore zones of eastern and western Lake Ontario, and Lac St-Louis and Lac St-Pierre in the St. Lawrence River.

The Great Lakes Sediment Database (also known as the NWRI Sediment Archive) is an archive of data on the sediments of the Great Lakes, their connecting channels, and the St. Lawrence River which was collected by the NWRI in cooperation with other agencies between 1968 and 2001. It is housed in ECCC's NWRI in the Canada Centre for Inland Waters in Burlington, Ontario (additional information on the Archive can be found at http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=9890771E-1).

Water levels can have a major impact on shoreline characteristics, particularly erosion rates and flood hazards during high water levels. Water levels are documented in Canada by the Canadian Hydrographic Service (Fisheries and Oceans Canada 2014; http://www.waterlevels.gc.ca/C&A/netgraphs_e.html) and in the US by the USACE(USACE undated; http://www.lre.usace.army.mil/Missions/GreatLakesInformation/GreatLakesWaterLevels/CurrentConditions.aspx). Data are generally available since 1918.

Wind speed and direction data can be used to qualitatively or quantitatively assess prevailing or specific event conditions. Commonly, ECCC's meteorological data are used and are available for current and historical conditions from selected weather stations at http://climate.weather.gc.ca/index_e.html (Government of Canada 2015). These data can be used to characterize wind conditions and calculate nearshore currents and wave conditions (wave hindcasting) but this type of work is generally undertaken by specialists in this field.

A summary of recommended methods to use for coastal processes is provided in Table 5.16.

Table 5.16. Summary of approaches for monitoring coastal processes

Method	Equipment / Data Available	Frequency
Field Monitoring		
Shoreline erosion survey		Annually and after major storms
Nearshore bathymetry survey	Echosounding/LIDAR, boat	Every 5-7 years
Shoreline protection structures survey	Camera or video-recorder, boat	Every 5-7 years
Substrate survey		Every 5-7 years

Method	Equipment / Data Available	Frequency
Desktop Monitoring		
Great Lakes Coastal Forecasting System	Historical, current and forecast physical conditions (e.g., wind speed, surface temperature, water level etc.)	As required
ECCC's Sediment Database	Historical nearshore sediment characteristics for 0-30 m depth	
Canadian Hydrographic Service/ USACE	Historical water levels	
ECCC's Meteorological Database	Historical and current wind speed and direction	

5.2.12 Options for Monitoring with and without a Boat

Access to a boat is generally required for nearshore monitoring in the Great Lakes due to access issues and health and safety concerns. We recognize, however, that not all monitoring organizations own or can easily acquire a boat for sampling purposes. As a result, we summarize which recommended methods of the Protocol are feasible with and without a boat in Table 5.18.

Table 5.17. Summary of recommended methods and boat requirements for monitoring the nearshore.

Monitoring Variable	Boat	Boat Method Summary	Boat Sampling Limitations	Wadeable	Wadeable Method Summary	Wadeable Sampling Limitations
Benthic invertebrates	✓	Grab sampler	Deep benthic habitat often supports low diversity, reducing the sensitivity of the bioassessment.	✓	Travelling kick-and-sweep	Kick-and-sweep often preferred because of greater diversity of benthic invertebrate assemblage in littoral environment but influence of habitat must be controlled during assessment.
Zooplankton	✓	Vertical net tow	None, boat sampling required.	x	None	Zooplankton assemblage in the littoral environment is too variable to control for monitoring purposes.
Fish	✓	Boat electrofishing, gill nets, hoop net	None, boat sampling preferred.	✓	Hoop net, seine net	Seine nets limit the sampling area and considering the size and connectivity of Georgian Bay to other waterbodies, and migratory nature of fish, so study objectives and area must be appropriate to allow for the collection of meaningful data.
Cladophora	✓	Visual assessment	Limitations dependent on study area.	✓	Visual assessment	Limitations dependent on study area.
Macrophytes	✓	Grab Sampler	Boat sampling more difficult because of standardization of sampling areas and logistics.	✓	Lake rake	None, wadeable sampling preferred.
Periphyton	x	None	Wadeable sampling required to access substrates with periphyton growth.	✓	Scraping, siphoning or shaking	None, wadeable sampling required.
Phytoplankton	✓	Vertical net hauls	None, boat sampling required.	x	None	Phytoplankton assemblage in the littoral environment is too variable to control for monitoring purposes.
Physical and Chemical Water Quality	✓	Physical profiles and epilimnetic composite sampling	None, boat sampling preferred.	✓	Physical measurements and grab sample	Water quality conditions in the littoral environment are more variable than as characterized through an epilimnetic composite.
Physical and Chemical Sediment Quality	✓	Grab or core sampler	None	✓	Grab or core sampler	None
Shoreline Observations	Not applicable because methods are focused on GIS investigations.					

6. Summary & Conclusions

The intent of this project was to develop a toolbox of standardized approaches to nearshore monitoring for application to southeastern Georgian Bay, with ultimate expansion to the Great Lakes. The aim was to document standard methods for characterizing the nearshore environment through an evaluation of field collection and data analysis techniques and through an identification of stressors and habitats of interest for monitoring. The Protocol was designed following an adaptive and tiered approach, allowing it to be flexible to address local and site-specific issues and varying levels of capacity and resources, while responding to changing needs, conditions, and problems, as well as growing experience over time.

We synthesized information on nearshore monitoring gained through review of published and grey literature and consultations with the Advisory Team to develop the Protocol. We reviewed over 100 documents in our research on local, provincial, national and international approaches to monitoring the nearshore environment.

Relatively few examples of standardized methods (defined as being well-tested and widely and commonly used) for monitoring were identified, and none that were specifically designed for monitoring in the complex and dynamic nearshore environment. Standardized methods were described for monitoring benthic invertebrates, fish, *Cladophora*, phytoplankton and sediment quality, which were developed for a range of habitats, including river/stream systems, wetlands, and beaches. No standardized methods were found for monitoring zooplankton, macrophytes, periphyton, water quality or shoreline observations. Consequently, we provided guidance on adapting existing monitoring approaches to the nearshore environment.

While no monitoring variable is perfect for addressing the goals and objectives of any particular monitoring program, we supplied decision-making tools for narrowing down the suitable choices and prioritizing the most appropriate variables given specific concerns, habitats of interest and capacity and resources. Ultimately, a suite of the best monitoring variables, representing both biotic and abiotic components of the environment, are recommended to create as detailed and accurate a picture of environmental conditions and response to stressors as possible.

Our findings begin the process of filling in a major gap in research focusing on the nearshore environment, which reinforces the need for initiatives like the GLWQA's integrated nearshore framework and Conservation Ontario's interest in improving environmental information on the nearshore to strengthen decision-making.

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Appendix A.

Example scenario illustrating how to use the Nearshore Monitoring Protocol

We have created an example scenario to demonstrate how a monitoring organization could use the Nearshore Monitoring Protocol to address an issue of concern affecting the nearshore environment. A summary of the steps followed in our example scenario is provided in the accompanying flowchart (Fig. A1).

1. Define specific nearshore environment of interest.

The area of interest is Collingwood, a community of approximately 20,000 on the shores of Nottawasaga Bay in southeastern Georgian Bay.

2. Define the stressors.

A subdivision development is proposed along a section of the Collingwood shoreline that is currently undeveloped. The urban development would both directly and indirectly impact the nearshore (through drainage into tributaries discharging to the nearshore). Potential secondary stressors associated with this development could include:

- increase in impervious surfaces;
- contaminated surface water runoff;
- direct discharge from municipal wastewater treatment plants;
- vegetation removal;
- erosion;
- sedimentation;
- flooding;
- shoreline hardening.

3. Define the monitoring purpose.

The organization decides that monitoring should be conducted to determine if the development has any adverse effects on the nearshore environment. The type of monitoring will thus be 'Early Warning', to detect ecosystem changes. More specifically, baseline monitoring will be undertaken, to establish background conditions, which can then be compared with conditions during and after the construction of the subdivision.

4. Define monitoring goals and objectives

The organization identifies two main goals of the monitoring program:

- to protect the nearshore aquatic ecosystem; and
- to protect recreational uses in the nearshore (e.g., swimming, fishing, boating).

The objectives of the program are:

- to assess whether the development changes the nearshore biotic community; and
- to assess whether the development changes the nearshore water quality conditions supporting recreational uses.

5. Define available resources.

The monitoring organization reviews what resources are available for conducting the monitoring program. It has four biologists on staff to carry out field work, two of whom are summer students who will need to receive preliminary training in aquatic sampling. One biologist will be assigned to conduct the data analysis and reporting. The organization has a budget of $25,000 per year for data collection, data analysis and reporting stages of the program. Since the organization lacks its own boat, it forms a partnership with a local environmental group which will lend its boat during the summer field season. In return, the organization will share its findings with the environmental group through a data-sharing agreement. The organization has also spoken with the developer, who will conduct terrestrial monitoring at the site of the subdivision project, and who has agreed to share those data with the organization.

6. Select monitoring variables.

The monitoring organization consults Tables 5.1 and 5.2 of the Monitoring Protocol to begin selection of appropriate monitoring variables. Based on the identified stressors and human uses of interest, all variables except *Cladophora* are highlighted as possible for inclusion in the monitoring program.

The monitoring organization next consults Table 5.3 to further narrow down options for variables. The nearshore environment to be monitored is open shallow water characterized by cobble boulders and a gradual slope to deeper waters. Based on these habitat and substrate criteria, zooplankton, fish, periphyton, and phytoplankton emerge as response variables, and water quality and shoreline observations emerge as diagnostic variables. The organization is able to immediately rule out using zooplankton or phytoplankton in the monitoring program, since it has no one on staff with the required taxonomic expertise, and because these two biotic variables do not rank as well overall as the other two biotic variables (fish and periphyton). Fish are not selected because the area does not provide specialized habitat (e.g., spawning) for resident fish species and fish species in the area are too mobile to allow for a direct evaluation of the proposed development. The organization weighs the remaining criteria in Table 5.3 against its existing resources, capacity and budget, and decides that it is feasible for it to monitor periphyton, water quality and shoreline observations.

7. General considerations

The monitoring organization reviews additional background considerations for the design of a monitoring program at this stage. This includes designing a health and safety plan for monitoring and ensuring all staff are properly trained in its policies and procedures, and establishing an aquatic invasive species (AIS) hygiene plan that is strictly followed to prevent the introduction and spread of AIS in the field. In addition, the organization carries out some background research to document the potential role of tributaries, groundwater and coastal processes in the nearshore. It learns that groundwater is not a significant influence on water quality in Georgian Bay from published studies. The organization also learns that a tributary will drain from part of the subdivision to the nearshore, which will require a radial or geometric sampling design in the vicinity of the tributary to track the environmental gradients. Finally, the organization reviews several engineering reports to gain an understanding of the influence of coastal processes on the nearshore. .

8. Open Toolbox of Recommended Methods and Data Collection

The monitoring organization plans to initially monitor for five years, based on secured funding for this time period. The monitoring organization hopes to extend monitoring over a longer term if additional funding can be found. Monitoring begins one year before construction for the development is initiated, and continues throughout the construction phase of the project (e.g., three years), as well as one year post-construction, for a total of five years of monitoring data.

Periphyton

Periphyton are sampled annually at the height of the summer from rocky substrates with either a knife to scrape or toothbrush to collect samples. Samples are collected along longitudinal transects in front of the area proposed for development in water that ranges from 0.4 – 0.6 m in depth and visual assessments are also completed along the same transects. Diatoms are identified to the species level and analyzed through simple biological metrics, such as abundance (the number of individuals of each taxa), species richness, number of genera, proportion of individuals of each taxa, and diversity indices, to assess any potential changes to the nearshore as the development proceeds. Sampling locations are located within the perceived zone of influence prior to the initiation of construction activities to provide a temporal indication of reference conditions. The zone of influence is identified through characterization of stormwater runoff from the proposed construction site and consideration of coastal processes.

Physical and Chemical Water Quality

Water quality is monitored on a monthly basis during the ice-free season, when construction activities tend to cause erosion and sedimentation. Sampling should occur prior to the initiation of construction activities to characterize nearshore water quality conditions under low and high flow conditions. The majority of sampling events during the construction phase should correspond with rain storm events, when the usefulness of erosion and sediment control measures will be determined. Sampling should occur when the waters are still so that waves and nearshore currents do not confound any changes in water quality. Sample locations range from the mouth of any inflowing tributaries to offshore locations that will depend on the predominant nearshore currents. Shallow nearshore sites are sampled via grab samplers, while epilimnetic composite samples are collected further offshore. The following parameters are analyzed to evaluate the impacts of the development on nearshore water quality: total suspended solids, turbidity, nutrients (ammonia, total phosphorus, nitrate), and dissolved organic carbon, while water temperature, dissolved oxygen, conductivity and pH are monitored in the field with a multimeter. The following aspects of water chemistry are interpreted to gain a greater understanding of nearshore conditions and impacts of development:

- an evaluation of conductivity to help determine source waters;
- an analysis of the impact of total suspended solids in determining phosphorus concentrations; and
- a characterization of low/high flow trends.

Water chemistry results collected during the construction phase are compared with conditions prior to construction; results are also compared to relevant water quality guidelines to infer the presence and amplitude of any impacts.

Shoreline Observations

Shoreline observations are completed through an evaluation of aerial photography. Monitoring should include an evaluation of the study area prior to and post-construction. Observations are used to help with study design and sample site selection through identification of existing stressors in the immediate area, and to characterize alteration to the nearshore post-development. The NVCA is contacted for assistance with gathering the necessary aerial photography and habitat mapping for the area, as well as to access the Shoreline Habitat Zone Framework used to assess shoreline alteration (NVCA 2014).

9. Data Analysis and Interpretation

The monitoring organization wishes to compare monitoring data prior to and post-construction to determine if there are any impacts of development on the nearshore area. As it plans to report on monitoring efforts to stakeholders on an annual basis, it decides to carry out annual analysis of data, as well as an overall analysis at the end of the five-year monitoring period.

Preliminary work is conducted to differentiate any water masses in the nearshore by examining spatial patterns in conductivity levels. Conductivity concentrations are then mapped on the nearshore study area to determine the distribution of waters from offshore sources for each event vs. waters from watershed sources. If water quality data clearly distinguishes offshore water masses from nearshore runoff then the offshore data subsequently omitted from further analysis.

Data are tested for normality and found to have normal distributions. The following analyses are then performed:

- multi-factorial analysis of variance (ANOVA) to test for differences in periphyton abundance, species richness, total number of genera, proportion of individuals of different taxa and diversity between replicated sites and pre- and post- construction to determine if changes reflect a change over time or spatial differences between sites and any interactions;

- ANOVA to test for differences in water quality parameters (i.e., total suspended solids, turbidity, nutrients, dissolved organic carbon, water temperature, dissolved oxygen, conductivity, pH, low and high flow trends) between replicated sites and pre- and post-construction to determine if changes reflect a change over time or spatial differences between sites and any interactions;

- Total suspended solids (independent variable) and phosphorus (dependent variable) regression to determine the strength of the causative relationship between any nutrient enrichment and runoff from the development;

- characterization of low/high flow impacts on water quality through a comparison of water quality results during low flow periods and following storm events;

- linear regression to test for relationships between periphyton community composition and water quality conditions (e.g., total suspended solids vs. diversity).

Water quality parameters pre- and post-construction are also compared with Provincial Water Quality Objectives (Ontario Ministry of Environment and Energy 1994) and federal Water Quality Guidelines for Protection of Aquatic Life and Guidelines for Canadian Recreational Water Quality (Health Canada 2012).

The monitoring organization also has access to ongoing terrestrial monitoring data on the subdivision site, which is collected annually by the developer. The monitoring organization can use these data to assist in interpreting trends and patterns it finds in its aquatic monitoring data.

The analysis of monitoring data indicates that periphyton species richness declines over the course of the monitoring period. Total suspended solids, turbidity and phosphorus also increase, and the magnitude and frequency of high flow events also increases. None of the provincial or federal water quality objectives or guidelines are exceeded.

10. Reporting and Communication

The monitoring organization establishes several lines of reporting and communication on its monitoring program. It provides:

- ongoing access to its partner environmental group to raw data according to their data-sharing agreement;
- annual technical reports summarizing monitoring initiatives and results to its staff, other environmental organizations in the area (e.g., conservation authorities, environmental groups), the Town of Collingwood, and the developer;
- annual summary reports to the general public summarizing conditions and trends;

  a high-level report at the end of the five-year monitoring period highlighting the observed differences in nearshore conditions pre- and post-construction, including recommendations for action, for the Town and the developer;
- a public presentation for the community at the end of the five-year monitoring period summarizing the observed differences in nearshore conditions and recommendations for action.

The monitoring organization believes, based on its own data and the data provided by the developer, that the subdivision's erosion and sediment control measures are insufficient for protecting aquatic life and recreational uses in the nearshore environment. It therefore recommends to the developer and the Town improvements must be made to limit impacts in the nearshore environment. The monitoring organization makes the following specific recommendations:

- that the developer erect silt fences to prevent sedimentation of the nearshore after storm events;
- that the developer create temporary sediment ponds to capture runoff from the site; and
- that the developer implement a phased construction schedule so that a smaller portion of the development site is under construction at any one time.

11. Review of Monitoring Program

The monitoring organization conducts annual reviews of the effectiveness of its monitoring program. Once construction begins in year 2, it discovers that the initial sampling area does not adequately cover the zone of influence for the development in the nearshore, so additional sampling locations are added. At the end of the five-year program, a second development is proposed one kilometre further east along the shoreline from the initial monitoring program, where the nearshore is characterized by a mixed substrate. The monitoring organization secures additional funding and extends its monitoring program to include this new area. It also adds benthic invertebrate sampling to the suite of variables monitored at the second site. After discussions with the Town and the developer, it is agreed that the monitoring organization's recommendations will be implemented. The monitoring organization receives funding to carry out an additional five year early control monitoring at the first site to evaluate the success of the remedial measures on nearshore conditions.

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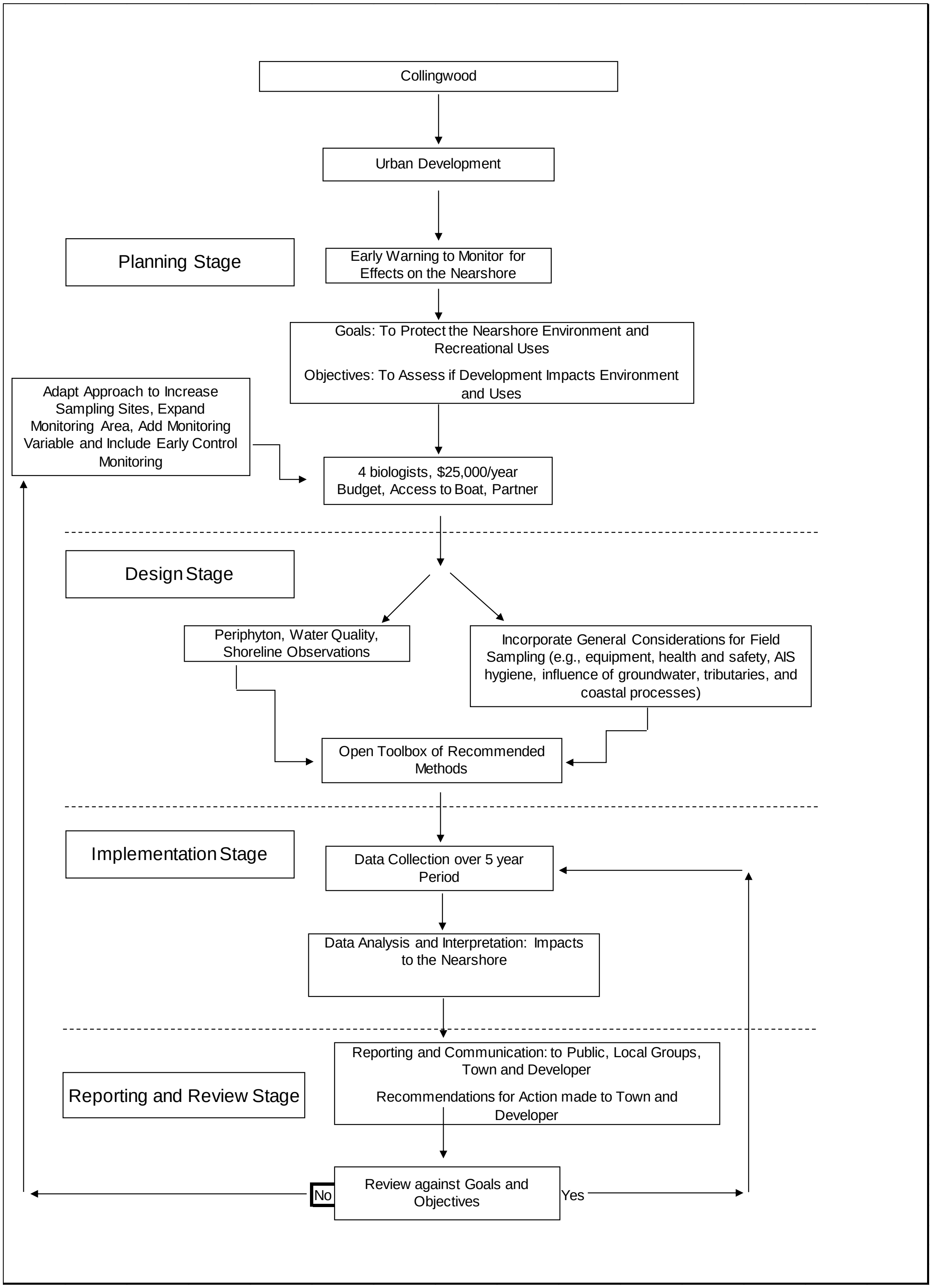

Figure A.1 Conceptual model illustrating application of the Protocol to the example scenario.