A Framework for Identifying Indicators of Water Resource Conditions

Support of Ecological Health by Water Resources in the Grand River-Lake Erie Interface

Report from the Grand River - Lake Erie Working Group

July 2012

Table of Contents

Appendices:

List of Figures

List of Tables

Grand River – Lake Erie Working Group Members

Crystal Allan, Grand River Conservation Authority
Deborah Brooker, Ontario Ministry of Food and Rural Affairs
Luca Cargnelli, Environment Canada
Sandra Cooke, Grand River Conservation Authority, Chair
Claire Holeton, Grand River Conservation Authority
Tom MacDougall, Ontario Ministry of Natural Resources
Mary Ellen Scanlon, Ontario Ministry of the Environment

Acknowledgements

This report was greatly improved by the technical expertise and insight provided by Todd Howell (OMOE), Tony Zammit (GRCA), Shawn Staton (DFO). Additional assistance was provided by Mohammed Mohammed (OMOE) and Jose Bicudo (Region of Waterloo), whose reviews helped to improve the clarity and content in draft versions of this report.

Acronyms and Abbreviations

COA – the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem
COSSARO – Committee on the Status of Species at Risk in Ontario
COSEWIC – Committee on the Status of Endangered Wildlife in Canada
CWN – Canadian Water Network
FCGO – Fish Community Goals and Objectives
GLFC – Great Lakes Fishery Commission
GRCA – Grand River Conservation Authority
GRFMP – Grand River Fish Management Plan
GRFMPIC – Grand River Fish Management Plan Implementation Committee
LaMP – Lakewide Management Plan
SGRRWG – Southern Grand River Rehabilitation Working Group
SOLEC – State Of the Lakes Ecosystem Conferences

Preface

This report is the result of work undertaken to update the Grand River Water Management Plan, which was last documented in the 1982 Grand River Basin Water Management Study. The updated Water Management Plan represents a collective plan for sustainable water management agreed to by the Grand River Conservation Authority, municipalities, the federal and provincial governments, First Nations and others. It is a key component of the broader Integrated Watershed Plan for the Grand River Watershed. This plan for the management of water will complement other efforts, including plans for the management of fish (e.g., Grand River Fisheries Management Plan, Lake Erie Fisheries Objectives) and other wildlife (e.g., recovery strategies for rare or threatened species), natural heritage features in the Grand River Watershed (e.g., Dunnville Marsh Management Plan), and the Lake Erie ecosystem (e.g., Lake Erie Lakewide Management Plan). Goals of the updated Water Management Plan are to:

- Improve water quality to improve river health and reduce impact on the eastern basin of Lake Erie;
- Ensure sustained water supplies for communities, economies and ecosystems;
- Reduce flood damage potential; and
- Increase resiliency to deal with climate change

A small working group was formed by Grand River Conservation Authority staff and members from agencies including Environment Canada and Ontario Ministries of Environment, Natural Resources and Agriculture, Food and Rural Development, under an overarching goal of the Water Management Plan to "*Improve water quality to improve river health and reduce its impact on Lake Erie*". The working group was charged with:

- reviewing recent directives for both the Grand River and Lake Erie;
- aligning these directives with the Broad Water Objectives for the Grand River watershed; and
- recommending potential indicators with which to measure progress towards desired conditions as expressed by Broad Water Objectives of the Water Management Plan that support aquatic community health.

The scope of this exercise was focused on water resource conditions in the Lake Effect Zone which are required to meet the needs of aquatic communities. The Lake Effect Zone refers to the area within which there is the potential for the exchange of water between the Grand River and Lake Erie. Although some of the information in this report is specific to the Lake Effect Zone, the method by which it was used to derive potential indicators highlights a process or framework which can be applied in other settings.

The purpose of this report is to outline the indicators recommended by the Grand River – Lake Erie Working Group, as well as the methods and rationale for indicator selection. The information and recommendations contained in this report build on existing directives that are aligned with Broad Water Objectives for the improvement or conservation of ecological health. The process relies on the best available science and knowledge of current conditions. Conversely, the findings and recommendations in this report are also constrained by these sources of information. If knowledge and/or information is lacking, these gaps are highlighted so that they can be addressed in future efforts as part of an adaptive management framework. This is particularly relevant to the understanding of the Lake Erie ecosystem, for which knowledge is evolving due to shifts in ecological processes and rapidly changing conditions. Some of the current gaps in the understanding of ecosystem health in the Grand River watershed are expected to be addressed by an initiative supported by the Canadian Water Network to create a research consortium for cumulative effects assessment in the Grand River watershed. The associated research, over time, is anticipated to develop a framework for monitoring aquatic cumulative effects and identify biological indicators of ecosystem health appropriate for the Grand River watershed.

The Grand River - Lake Erie Working group contributed to the Water Management Plan update in a technical capacity, recommending science-based indicators of resource conditions that can be used to measure changes in water quality in the Grand River – Lake Erie region. Technical information compiled by the group will also serve to inform an integrated approach to determining targets and milestones for aquatic ecosystem health in the Lake Effect Zone and reduced impact of the river on the eastern basin of Lake Erie. Once targets and milestones are identified, partners to the Water Management Plan will commit to actions that will achieve milestones within a specified timeframe. If implemented, actions highlighted by the Plan are expected to improve ecosystem health by improving water quality in the Grand River. It is expected that measured improvements in water quality using indicators recommended here would be mirrored by biotic and ecosystem health metrics derived from parallel initiatives. It is important to recognize that actions identified by the Water Management Plan will be most effective at improving the health of the aquatic community if they take place in conjunction with other complementary efforts that evaluate the rehabilitation or restoration of aquatic ecosystems in the Grand River watershed.

Summary

The Grand River Conservation Authority is working with municipalities, the federal and provincial governments, First Nations and others to update the Grand River Water Management Plan. This update will reflect the considerable knowledge, tools and networks that have been developed since the last documentation of the Water Management Plan in 1982. The Water Management Plan is a key component of the broader Integrated Watershed Plan for the Grand River Watershed. It is anticipated that the process of updating the Water Management Plan will create a sense of collective ownership for sustainable water management across the watershed.

The goals of the Water Management Plan are underlain by Broad Water Objectives, which describe *qualitatively* the desired states or system conditions in the Grand River Watershed. Characteristics of these states or water resource conditions are measured *quantitatively* using Indicators. Desired endpoints are quantified by targets. Once identified, indicators and targets can be used to compare current water conditions with those that are required to meet the Broad Water Objectives of the Water

Management Plan Update. By allowing the health of the aquatic ecosystem and the Grand River's impact on Lake Erie to be tracked, indicators can aid in the identification of water quality issues and help to assess the effectiveness of management actions.

Under a goal of the Water Management Plan to "*Improve water quality to improve river health and reduce its impact on Lake Erie*", a small working group was formed by members from federal (Environment Canada) and provincial agencies (Ministry of Natural Resources; Ministry of Agriculture, Food and Rural Affairs; Ministry of the Environment) and Grand River Conservation Authority staff. The Grand River – Lake Erie Working Group was tasked with the identification of potential indicators of water quality in the interface of the Grand River and Lake Erie. The group developed a framework to identify potential indicators, which built on recent directives aligned with those Broad Water Objectives that are associated with the improvement or conservation of ecological health. Each of the directives was created from a science-based approach and developed with public input. Because the framework for indicator identification builds on these existing directives, it describes a process that is grounded in science and supports the values of local communities and other stakeholders.

The approach for identifying indicators of water resource condition was based on the collective knowledge and understanding of critical ecosystem functions within an Area of Focus. Areas of Focus delineate management units or 'zones'; they contain river reaches or areas with unique ecological characteristics and natural resources, and are potentially influenced by common impacts. Indicators, targets and milestones are identified within each Area of Focus. The framework specified in this report can be used to identify indicators appropriate for each of the Areas of Focus.

The framework for identifying indicators was applied to an Area of Focus described as the Lake Effect Zone: the area within which there is the potential for the exchange of water between the Grand River and Lake Erie. The approach identified potential indicators of the water resource conditions required by the aquatic community by examining the critical life cycle requirements of a subset of species for which ecological needs are relatively well-known. These species, termed "Aquatic Species of Interest", are those identified by recent directives or similar initiatives as having critical requirements limited directly or indirectly by water quality. To create the list of Aquatic Species of Interest, considerations included aquatic species which were ecologically important (e.g., keystone), underperforming or had the potential for rehabilitation or reintroduction and were highlighted as important in the Lake Effect Zone by scientific literature or recent directives. Aquatic Species of Interest were chosen according to sources of information relevant to the Lake Effect Zone ecosystem (e.g. Grand River Fisheries Management Plan, Species at Risk Recovery Strategy) and included: walleye, yellow perch, muskellunge, lake sturgeon, river redhorse, and three species of at risk freshwater mussels (mapleleaf, threehorned wartyback, fawnsfoot). These species were not chosen to function as indicators themselves, since their presence or abundance may be influenced other factors (e.g., predation, competition) in addition to water conditions. Rather, the Aquatic Species of Interest function as a tool to identify some of the critical water quality needs of the aquatic community. The synthesis of information about Aquatic Species of Interest works towards an ecosystem approach using a subset of the broader community. It is expected that actions that are beneficial to the selected species will likely have broader benefits for the entire aquatic community. Although the needs of these species may not be fully representative of the needs of the entire aquatic community, the process is undertaken within an adaptive management framework, so that new information and additional species can be considered in subsequent iterations.

Parameters that convey information specific to the processes by which water quality directly or indirectly affects aquatic community health were chosen as indicators. The working group recommends the following measures as indicators for the Lake Effect Zone:

- Phosphorus
- Turbidity (or TSS)
- Temperature
- Dissolved oxygen
- Flow regime
- Macrophyte community

These indicators quantify some of the most critical resource conditions required by Aquatic Species of Interest. Since the list was based on a portion of the aquatic community, there may be critical requirements for other species which are not included; however, it is expected that additional parameters may be added iteratively within the adaptive management framework of the Water Management Plan as more information about the aquatic community and ecological processes in the Lake Effect Zone becomes available.

The synthesis of current scientific knowledge supports the conclusion that improvements in the recommended indicators would help to achieve objectives under a goal of the Water Management Plan to "*improve water quality to improve river health and reduce its impact on Lake Erie*". Phosphorus has been highlighted by many recent directives as having an important influence on the ecological health of both the river and the lake. A detailed understanding of the nearshore nutrient dynamics and the processes currently influencing the nearshore ecology is limited, since the system may still be in a state of transition (Charlton et al. 2009). Regardless, the role of phosphorus as a key determinant of ecosystem health in the Lake Effect Zone as well as the offshore waters of Lake Erie's eastern basin has been clearly demonstrated (Ryan et al. 2003; Higgins et al. 2005; Charlton et al. 2009). Science compiled as part of the Nutrient Management Strategy for Lake Erie indicates that phosphorus from the Grand River contributes to negative impacts on the ecology of the eastern basin of Lake Erie. This was strong support for the recommendation of phosphorus as a candidate indicator in the context of the river's influence on the lake.

Information compiled as part of the systems approach for indicator identification points to the coastal wetlands of the Grand River as a sensitive and ecologically important area. Improvements to the ecological health of this area measured by the recommended indicators would also have ecological benefits for other areas. There is the potential for enhancing these benefits and improving the nutrient dynamics between the Grand River and Lake Erie with the restoration of the natural function of the adjacent floodplains. It is important to note, however, that the full realization of these benefits can only be achieved if other constraints, such as hydrology, geomorphology, connectivity and natural heritage of the surrounding landscape are considered as part of broader watershed management planning and through initiatives parallel to the Water Management Plan.

1. Background on the Water Management Plan Update

The Grand River Conservation Authority is working with municipalities, the federal and provincial governments, First Nations and others to update the Grand River Water Management Plan. This update will reflect the considerable knowledge, tools and networks that have been developed since 1982 when the Water Management Plan was last revisited. The Water Management Plan is a key component of the broader Integrated Watershed Plan for the Grand River Watershed. It is anticipated that the process of updating the Water Management Plan will create a sense of collective ownership for sustainable water management across the watershed. The process is based on the shared Vision[1] of a healthy Grand River watershed as distinguished by:

- Ecological integrity
- Clean, sufficient water
- Minimal flooding and erosion
- Economic prosperity and growth
- World class outdoor recreation
- Heritage appreciation and diversity
- A superior quality of life

The watershed Vision was derived from the review of *The Grand Strategy*, conducted as part of the designation of the Grand River as a Heritage River. The Grand Strategy was tabled with the Canadian Heritage Rivers Board in January 1994 as part of the process for designating the Grand as a Canadian Heritage River and was revisited in 2004. The Strategy indicates how long-term management will be carried out in order to ensure the conservation and interpretation of natural, cultural and recreational resources.

The Water Management Plan update is governed by a Steering Committee and supported by a Project Team and Working Groups. The Project Team is responsible for overall coordination, development and management of the project, and acts in an advisory capacity to the Steering Committee. Working Groups carry out specific tasks aligned on a topical basis and report directly to the Project Team.

The long term Goals[2] of the updated Water Management Plan are to:

- Improve water quality to improve river health and reduce impact on the eastern basin of Lake Erie;
- Ensure sustained water supplies for communities, economies and ecosystems;
- Reduce flood damage potential; and
- Build resiliency to deal with climate change

Support for these goals is developed through the process of identifying Broad Water Objectives, Indicators, Targets and Milestones (defined in Figure 1), which inform specific actions that can be implemented by partner agencies. The objectives (listed in Appendix A) build on and reaffirm existing community values and aspirations in plans that have been developed for the Grand River watershed through public input (e.g., Fisheries Management Plan for the Grand River, Grand River Corridor Conservation Plan, and Centre Wellington's Official Plan).

[1] A vision is defined as a broad aspirational description of the future state of the watershed, which is supported by all partners to the Plan.

[2] Goals are defined as broad statements of the water quality and quantity conditions in the watershed, which are aspired to in the long term.

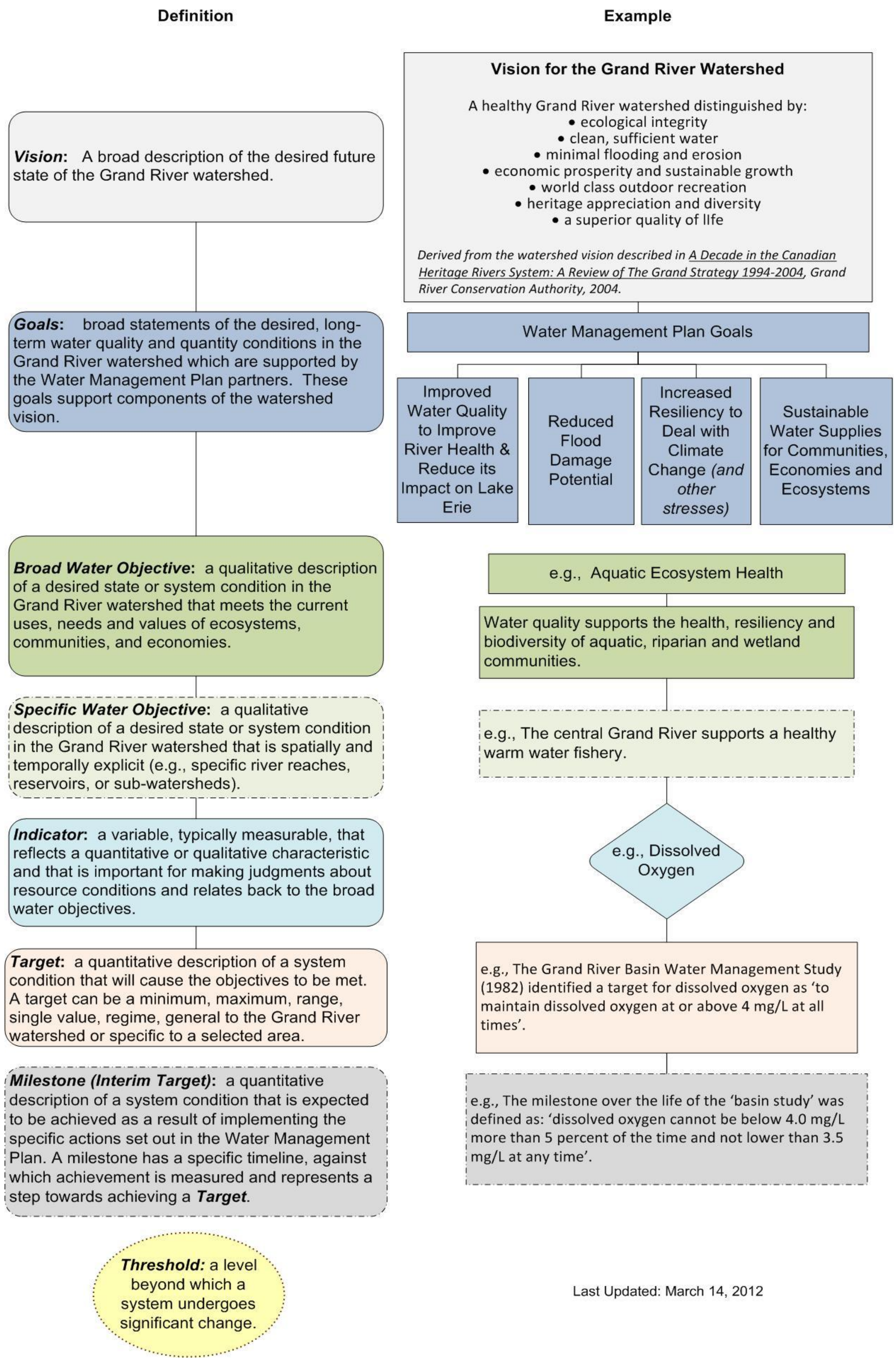

Figure 1. Schematic showing the hierarchy of components within the Water Management Plan Update

1.1. Indicators, Targets and Milestones for Aquatic Ecosystem Health

In the Water Management Plan, indicators and targets will provide a means to quantitatively assess current conditions relative to desired conditions as described qualitatively by Broad Water Objectives. A subset of the objectives focus on aquatic ecosystem health; this report describes a framework by which indicators of the aquatic resource conditions necessary for aquatic ecosystem health can be identified through a science-based process. In this context, indicators provide a *qualitative* measure of resource conditions, which is further refined by *quantitative* targets and milestones.

The aquatic resource conditions described by targets represent the state necessary for a healthy aquatic ecosystem and are based on ecological needs. Milestones (interim targets) specify a system condition that is expected to be achieved as a result of implementing the specific actions set out in the Water Management Plan. A milestone has a specific timeline and represents a step towards achieving a target. An assessment of progress towards the Broad Water Objectives can be made by collecting data on the indicators (e.g., through monitoring) to compare current conditions with targets or milestones using indicators.

The process of developing relevant indicators and quantifying targets and milestones is the role several integrated working groups, each established in an adaptive way based on the evolving needs and understanding of issues relative to the Grand River watershed. Recommendations made by the working groups are approved by the Project Team and Steering Committee.

1.2. Areas of Focus

A description of ecosystem or resource conditions is typically bounded by a spatial extent, which can be a river reach, a subwatershed, or another area. These river zones or 'Areas of Focus' should comprise areas or reaches with similar characteristics (e.g., physiography, hydrology). The delineation of rivers into zones is an arbitrary process that reflects the interests and concerns of water managers (Heathcote, 2002). Areas of Focus provide a framework for the management of watershed or river units and are typically delineated using best professional judgement. Some of the considerations for identifying the spatial extent of Areas of Focus for the development of indicators and the application of targets and milestones include:

- Key hydrologic processes and ecological functions (e.g., groundwater discharge, nutrient assimilation)
- Presence of significant aquatic resources (e.g., cool water fish community, riparian wetlands)
- Anthropogenic impacts (e.g., point and non-point sources)

Areas of Focus delineate unique management units within which ecosystem processes and resource conditions are examined in order to develop and subsequently apply indicators, targets and milestones. Several Areas of Focus have been identified by the Water Management Plan, including the interface between the Grand River and the eastern basin of Lake Erie.

2. The Grand River-Lake Erie Working Group

This update to the Water Management Plan for the Grand River recognizes the inherent link and interactions with Lake Erie. In doing so, it acknowledges that actions in the watershed have the potential to support goals and objectives developed for Lake Erie (e.g. Lake Erie Lakewide Management Plan). Consequently, there is a need to align the goals and objectives for both Lake Erie and the Grand River watershed.

Under an overarching goal of the Water Management Plan to "*Improve water quality to improve river health and reduce its impact on Lake Erie*", a small working group was formed by Grand River Conservation Authority staff and members from agencies including Environment Canada, Ontario Ministries of Environment, Natural Resources and Agriculture, Food and Rural Affairs. Membership in the Grand River – Lake Erie Working group consisted of representatives from agencies whose mandates recognize the directives set out in the Great Lakes Water Quality Agreement (GLWQA) and the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA). The purpose of the Agreements is to maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem.

The Grand River - Lake Erie Working group contributed to the Water Management Plan update in a technical capacity, drawing on science-based linkages between the Grand River and Lake Erie. The working group was charged with reviewing recent directives for Lake Erie (e.g., Nutrient Management Strategy; Fisheries Objectives etc.) and the Grand River (e.g., Grand River Fisheries Management Plan; Species at Risk Recovery Strategies) ecosystems; aligning these directives with the stated Broad Water Objectives for the Grand River watershed; and recommending potential science-based indicators of resource conditions that can be used to measure changes in water quality in the Grand River – Lake Erie region. Consideration was given to the influence of water quality on ecosystem health in the Lake Effect Zone and on the ecology of the eastern basin of Lake Erie. The Grand River – Lake Erie Working Group met monthly from November 2011 to March 2012.

This report details the recommendations by working group tasked with the identification of indicators relevant to the interface of the Grand River and Lake Erie. Technical information compiled by the group will also serve to inform an integrated approach to determining targets and milestones for aquatic ecosystem health in the Lake Effect Zone and reduced impact of the river on the eastern basin of Lake Erie. To identify potential indicators, the working group completed a synthesis of information about the conditions and ecological processes that occur or could potentially occur at the interface between the Grand River and Lake Erie. This exercise was focused on the Lake Effect Zone, which refers to an Area of Focus within which there is the potential for the exchange of water between the Grand River and Lake Erie.

3. The Grand River Lake Erie Interface – An Introduction

3.1. Geography of the Grand River watershed and the Lake Effect Zone

The Area of Focus called the Lake Effect Zone includes portions of the Grand River closest to the mouth, as well as portions of the Lake Erie nearshore that are influenced by the plume of the Grand River. The Lake Effect Zone contains two areas with unique characteristics: the portion of the river dominated by coastal wetlands and the area at the mouth of the river together with portions of the Lake Erie nearshore that are influenced by the plume of the Grand River. The physical, chemical and biological processes which make these two areas distinct occur along a gradient, but make a marked transition near the narrowing of the drowned river mouth from estuarine to nearshore conditions. The coastal wetlands (Figure 2) contains an area referred to as the Dunnville Marsh complex that contains five individual wetlands. The wetland complex represents one of the few remaining large river mouth marshes in Southern Ontario and is designated as provincially significant wetlands (NHIC 2012).

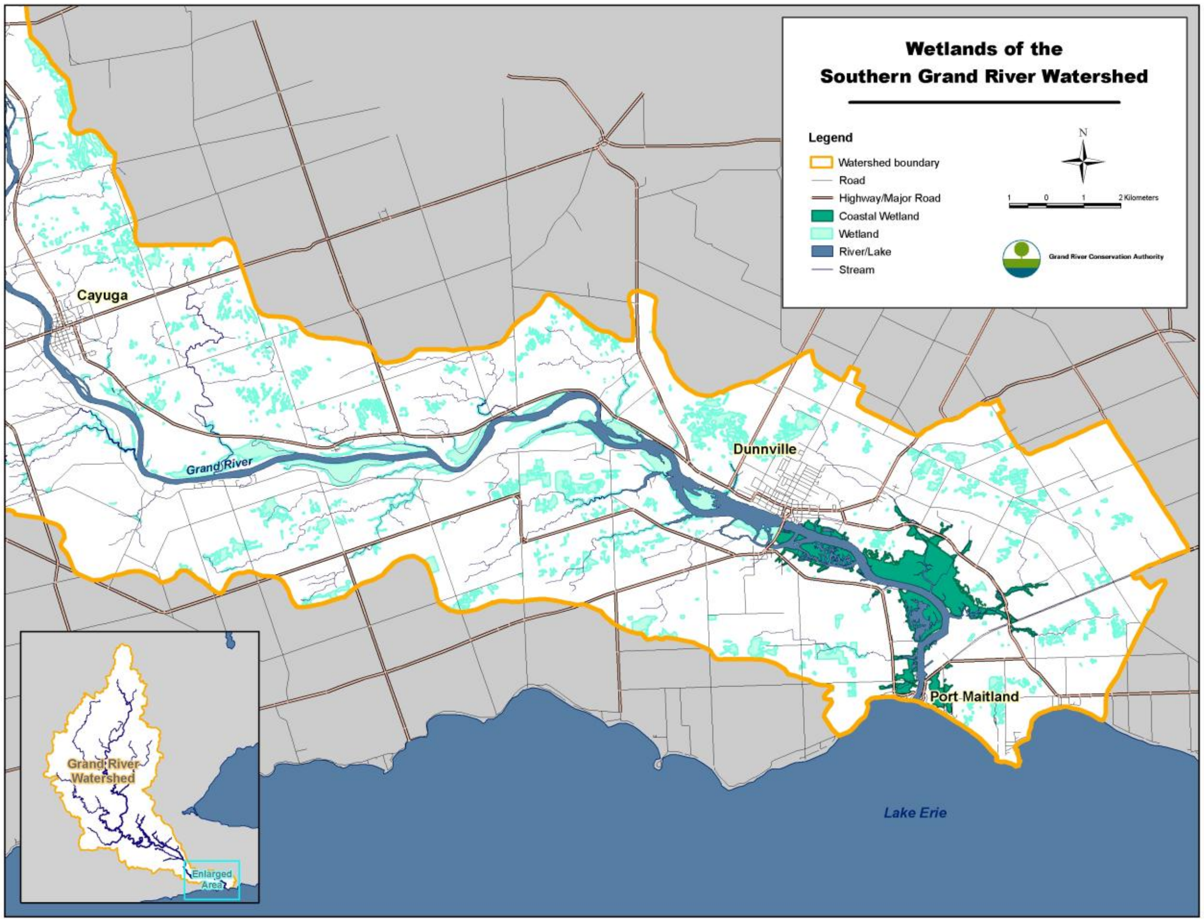

Figure 2. Interface of the Grand River watershed in Ontario, Canada with Lake Erie, showing the extent of coastal wetlands.

The Grand River watershed upstream of the Lake Effect Zone is the largest in southern Ontario (6,800 km^2). The river stretches from headwaters near Dundalk at the northern end to Port Maitland in the south, where it flows through unique coastal wetlands and merges with the waters of the eastern basin of Lake Erie. The main tributaries of the Grand River are the Conestogo, Eramosa, Speed, and Nith Rivers. The surficial geology varies throughout the watershed with till plains in the north, silty till plains interspersed by moraines and sandy tills in the central region, and clay plains in the south.

There is a high proportion of agricultural land in the watershed, some of it underlain by tile drains (particularly in the northern and western portions). The watershed is home to a rapidly growing urban population, concentrated in cities near the centre of the drainage area. In 2011, the urban population in the five largest cities (Kitchener, Waterloo, Cambridge, Guelph and Brantford) was approximately 660,000 people; the combined urban/rural population in the watershed is close to 1 million people (Statistics Canada 2012). There are 28 municipal and 2 first nations wastewater treatment plants within the watershed, all of which discharge treated effluent into rivers and streams.

3.2. Significant features and functions of the Grand River – Lake Erie interface

The interface between the Grand River and Lake Erie is a valued economic and cultural resource as well as an integral link between the ecology of both natural systems. The area is appreciated for the recreational activities it supports (e.g., sport fishing, boating) and as an amenity in the community.

Human uses of the aquatic areas have economic benefits, supporting cottaging and increasing property values. Economic benefits are also derived from tourism and from eastern basin commercial and sport fisheries. The unique stock of walleye produced in the lower reach of river can contribute to up to 1/3 of the lake's eastern basin commercial walleye fishery (Jackson et al 2003), the economic impact of which is valued at just over $2,000,000 annually (derived from OMNR 2006 and OMNR 2011). The river provides essential spawning, nursery, and juvenile habitat for this stock (MacDougall et al. 2008) which serves as a keystone predator, structuring the fish community of both the river and the lake.

From an ecological perspective, there is a significant exchange of energy, nutrients and aquatic life at the interface between the Grand River and the eastern basin of Lake Erie that has benefits for both the river and the lake. Water flowing from the river brings nutrients to the lake, which supports biological production in both the offshore and nearshore areas of Lake Erie. Nutrients are the fundamental 'building blocks' of the aquatic food web; too little will limit productivity and too much can cause noxious growth of aquatic plants or algae. The ecosystem of the eastern basin and nearshore is sensitive to the timing of delivery and form of nutrients that originate in the Grand River (Higgins et al. 2005, Charlton et al. 2009). Similarly, the timing and intensity of riverine water chemistry and temperature signals to the nearshore of Lake Erie have the potential to inform the migration patterns of a variety of lake-resident fish species which spawn in the river (Johnsen and Hasler 1980, Binder et al 2011, and Goniea et al 2006). For fish that elicit natal homing (the tendency for individuals to reproduce at the sites where they were born), these signals can be very important for creating and maintaining stock structure and genetic distinctiveness (Jennings et al. 1996). This is particularly significant for the Grand River stock of walleye (Stepien and Faber 1998).

The Grand River watershed receives water from an area of approximately 6,800 km^2 before it flows into Lake Erie; it is the largest Canadian tributary of Lake Erie, draining into the eastern basin. As a consequence, the Grand River likely has a large effect on nutrients in the eastern basin of the lake. There have been no recent or comprehensive assessments of tributary loads; however, estimates based on data from 2004 suggest the Grand River accounts for 40% of the phosphorus load from tributaries to the eastern basin of Lake Erie (unpublished data D. Dolan, U. Wisconsin). The plume from the Grand River (Figure 3) can be detected along the Lake Erie shoreline for a distance of 12 km and up to 3 km offshore, dependant on weather (Charlton et al. 2009). The concentration of total phosphorus in the plume can be as much as 10 times higher than in the offshore water of the eastern Lake Erie basin (Charlton et al. 2009). As a result of the plume, there are large spatial variations in phosphorus concentration within the Lake Effect Zone where the mouth of the Grand River opens out into the nearshore of Lake Erie.

Figure 3. Plume of water from the Grand River as it flows into the eastern basin of Lake Erie.

Conversely, Lake Erie has the potential to affect the water quality and hydrologic conditions within the Lake Effect Zone. The intrusion of lake water into the lower portion of the river and onto the floodplains can benefit habitat in the coastal wetlands, improving ecosystem health and promoting biological diversity (Lougheed et al 2001; Gilbert and Ryan 2007). The influence of Lake Erie water levels on the frequency and amplitude of changes in wetland water levels can increase complexity of habitat in the wetlands and help to structure the plant community, which in turn can affect water quality within the wetland (Chow-Fraser 1998). Other ecological benefits of a healthy marsh ecosystem include nutrient processing and production of high quality energy sources to downstream aquatic food webs and also to the terrestrial food web in adjacent areas (Maynard and Wilcox 1997).

The physical connection between the Grand River and Lake Erie is important for meeting the life cycle requirements of many aquatic species in both the river and the lake. For instance, numerous fish species which reside in the lake have historically had spawning sites in the Lake Effect Zone or in tributaries of the Grand River (Goodyear et al 1982). Connectivity between the river and the lake ensures migratory species can use the Lake Effect Zone during their migration between habitat types. The connection also allows the transfer of physical energy (in the form of seiches or storm surges) in the lake into the lower portion of the river; such occurrences can result in a large influx of water within the portion of the river where water movement in an upstream direction is unobstructed.

Modifications to the river in the form of physical barriers (e.g., construction of a dam at Dunnville in the 1800's) have restricted the transfer of energy between Lake Erie and the Grand River. Prior to these modifications, there was an exchange of water throughout the ~30 km reach between Cayuga (where the riverbed is level with the surface of Lake Erie) and the river mouth at Lake Erie (Figure 4). The current extent of the Lake Effect Zone in the Grand River is limited to the sections downstream from the dam at Dunnville. Many of the chemical, physical and biological processes that occur in these areas are dependent on the interconnection between the Grand River and Lake Erie.

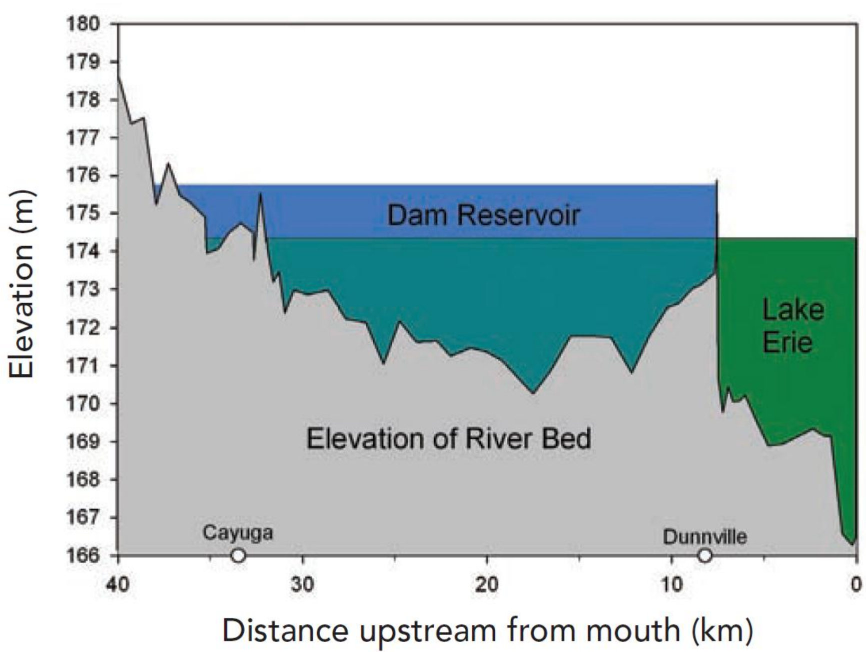

Figure 4. Historic extent of the Lake Effect Zone, as shown by locations in the Grand River where the river bed lies below the elevation of water levels in Lake Erie (from MacDougall and Ryan 2012).

3.3. Historical context and recent trends

Grand River watershed and coastal wetlands

Many of the alterations to Lake Erie and the Grand River watershed over the past two centuries have affected the physical and chemical processes at the interface between the two. These changes have been coincident with shifts in the aquatic community. For example, water quality in the lower reaches of the watershed is impacted by the culmination of multiple stressors throughout the watershed, such as nutrient input from point and non-point sources. Population growth and changes to land cover in the watershed have resulted in an increase in the load of nutrients and suspended sediment carried by the river, some of which is transferred to the eastern basin of Lake Erie. The turbid, high nutrient water of the southern Grand River is the cumulative result of anthropogenic stressors which add to the load of sediment from natural processes. Turbidity or suspended solids can be particularly high in the Boston-McKenzie and Fairchild Creeks, which drain agricultural lands and empty into the southern Grand River (Chang-Kue 1972; Cooke 2006; MacDougall and Ryan 2012). The erodible soils of the clay plains underlying the southern Grand River cause the water to be naturally turbid, but the additional inputs of nutrients and suspended sediments have likely pushed the system above the natural range of conditions. Turbidity can be beneficial to some species (e.g., walleye); however, excessive concentrations of suspended sediment can be physiologically harmful to aquatic organisms or cause indirect harmful effects (e.g., smothering of spawning habitat, augmentation of biochemical oxygen demand or eutrophication) (Waters, 1995; Henley et al. 2000). Increased sediment and nutrient loadings have been identified as key threats to several species of “at risk” fresh water mussels currently present in the southern Grand River (Bouvier and Morris 2010).

The sediment load in the southern Grand River has likely increased historically as the result of a number of changes in the Grand River watershed, such as the loss of riparian vegetation and urbanization, which cause erosion and slumping of stream banks and increased sediment in surface runoff. Modifications to the landscape have altered the flow regime in the River, increasing peak flows and lowering base flows. Other modifications to the hydrologic regime such as the creation of dams have also likely contributed to alterations in sediment transport processes in the river. The cumulative effect of these changes can cause changes to in-stream processes that have the potential to affect water quality. For instance, the ability of organisms in the stream to act as natural “filters” by taking up nutrients is impaired by stream bank armouring, a process caused by the accumulation of fine sediments in the streambed. A change in size structure of sediment loads has also impacted the coastal wetlands; there has been an increase in fine silts and clays and a loss of the supply of coarser sediment to the marsh areas adjacent to the Grand River (Corbett et al. 1997). The fine sediments that now dominate in the wetlands are easily re-suspended by carp that have become abundant in the area and by human activity, maintaining the water in a turbid state with high levels of suspended solids (Corbett et al. 1997). The growth and nutrient uptake of submerged aquatic plants are reduced in highly turbid waters, since reduced water clarity limits light penetration. This mechanism is thought to be responsible for the absence of submerged aquatic plants in many of the wetland areas bordering the lower reaches of the Grand River (Gilbert and Ryan 2007).

Many processes have led to altered nutrient dynamics in the lower reaches of the Grand River. For instance, phosphorus has become elevated where the water slows down behind barriers causing fine sediments and associated nutrients to settle out. The results of a monitoring program in 2003-04 to characterize the southern Grand River show total phosphorus concentrations were elevated behind the on-line dams during summer low flows (MacDougall and Ryan 2012). This phenomenon has also been confirmed by Kuntz (2008), who demonstrated the gradual increase in total phosphorus concentrations in the Grand River between Cayuga and Lake Erie, with the highest concentrations detected at the monitoring site above the dam at Dunnville.

Eutrophication is associated with episodic periods of anoxia, observed to last as long as 12 days, in the slow moving deep reaches of the Grand River below Cayuga where the riverine system transitions to marshes and lake-like conditions (Figure 5) (MacDougall and Ryan 2012). During these periods of anoxia, phosphorus stored in the accumulated sediments can be released in a soluble form through the process of “internal loading” (Søndergaard et al. 2003). This release of phosphorus into the water column is then available for primary production given suitable conditions such as light availability and temperature, or transferred downstream in river flows.

Figure 5. View of the Grand River and coastal wetlands, looking downstream from Dunnville. with Lake Erie on the horizon.

Data from the Grand River between Cayuga and Lake Erie suggest that there is seasonal variation in the proportion of biologically available phosphorus (estimated using soluble reactive phosphorus), with lower concentrations during the summer relative to the spring and fall (Kuntz 2008). The study suggests that the variation may be driven by phosphorus uptake by phytoplankton that occurs during the summer growing season, but not in the spring and fall (Kuntz 2008). This seasonal pattern was also observed during monthly monitoring of the Grand River at Dunnville as part of the Provincial Water Quality Monitoring Program; the proportion of soluble reactive phosphorus in the fall, winter, and early spring was much higher (~50%) than during the summer months (<10%) (Loomer and Cooke 2011). This suggests that phytoplankton growth can significantly modify the concentration and form of nutrients delivered by Grand River to the eastern basin of Lake Erie during the growing season.

Eastern basin of Lake Erie

The supply of nutrients from tributaries is essential for biological production in the eastern basin of Lake Erie, which is currently oligotrophic (< 10 µg/L total phosphorus; Charlton et al. 2009). The 1960s and 1970s marked the appearance of algal blooms, notably in the open waters of the western basin, as well as an increase in the growth of the attached filamentous algae, *Cladophora* in the eastern basin (Figure 6). The nuisance growth and subsequent die-off of *Cladophora* decreases aesthetic value of the nearshore waters (e.g., beach fouling) and causes degradation of nearshore habitat. This loss of habitat can be significant for the nearshore fish community, particularly those species which utilize hard substrate for spawning (e.g., walleye, lake trout). These changes in the Lake Erie ecosystem were a vivid demonstration that nutrient (specifically, phosphorus) loading to Lake Erie had become excessive. The highly enriched inputs of phosphorus from the tributaries and point sources to the lake (e.g., wastewater treatment facilities) were impacting the ecology of the lake and nearshore. The eutrophic conditions also resulted in a deterioration of the resources used by humans (e.g., drinking water supply, beach areas and fisheries). During the following decades, improved management of point sources resulted in reduced phosphorus concentrations, and conditions in the lake ecosystem showed progress (Charlton et al. 2009).

Despite these promising results, the ecosystem did not continue to respond as expected. The late 1990's saw the resurgence of large blooms of *Cladophora* that fouled extensive areas of the northern shoreline in Lake Erie's eastern basin (Higgins et al. 2005). Earlier that decade, a shift had been initiated in the ecosystem of Lake Erie, caused by changes to nutrient cycling and food web dynamics, coincident with the invasion of non-native invasive species (e.g., zebra mussels, round gobies) (Ryan et al. 2003; Hecky 2004).

Figure 6. Growth of *Cladophora* in the Lake Erie nearshore

The "nearshore phosphorus shunt" (Hecky et al. 2004) resulting from the establishment of invasive Dreissenid mussels is hypothesized to have modified the nutrient cycling in the nearshore as well as the nutrient exchange with offshore waters. The concentration of nutrients in the nearshore waters by the mussels is thought to have heightened the *Cladophora* problem. With the exception of the area at mouth of the Grand River, the widespread blooms of *Cladophora* in the nearshore waters of eastern Lake Erie become phosphorus-limited early in the growing season (Higgins et al. 2005). Excretion of wastes by the mussels increase the availability of dissolved phosphorus in the nearshore, fueling growth of *Cladophora*. Although the growth of *Cladophora* may also be influenced by other factors such as light limitation, the availability of dissolved phosphorus is thought to be the main determinant of *Cladophora* biomass in the Lake Erie nearshore (Higgins et al. 2005). The growth of the nuisance algae is highly sensitive to availability of dissolved phosphorus, particularly in the spring, with variations of only a few µg/L causing large (350%) increases in *Cladophora* biomass (Charlton et al. 2009). The establishment of Dreissenids has also altered water clarity in the nearshore such that increased water clarity has contributed to an expansion of *Cladophora* in deeper waters of the nearshore, where previously the lack of light had limited growth (Higgins et al. 2005).

The processes by which tributaries such as the Grand River can affect the trophic status and nutrient dynamics of the Lake Erie ecosystem (which may still be in transition) are currently not well understood (Charlton et al. 2009). Research and long-term monitoring of tributaries in Ohio suggest that, although the load of phosphorus to western basin of Lake Erie may not have increased since the mid 1990's, there may have been a shift in the predominant form of phosphorus delivered by the tributaries (OLEPTF 2010). Data from the Maumee and Sandusky Rivers suggest that there has been an increase in the fraction of the dissolved form of phosphorus, which is more bioavailable. It is unclear if similar trends have occurred in Ontario tributaries of Lake Erie, since data are sparse for this period. Data and knowledge about the lower trophic levels of the ecosystem and delivery of nutrients from tributaries such as the Grand River are currently inadequate to form an understanding of how bottom-up forces are driving changes within the lake.

4. Recent Directives for the Grand River and Lake Erie

Lake Erie has been the focus of a number of recent directives, including some which outline objectives or recommendations of significance to the Grand River watershed. These directives identify the environmental conditions necessary to achieve binational Lake Erie objectives. A synthesis of the information relevant to the Grand River watershed will help to align the Broad Water Objectives of the Water Management Plan with those for Lake Erie. The consideration of information at a scale appropriate to water management can initiate a dialogue on how to act at the watershed level to meet objectives for both Lake Erie and the Grand River watershed. The following section describes the recent directives that were considered in determining appropriate objectives, indicators and targets for the updated Grand River Water Management Plan . A summary is provided in Appendix B of this report.

Documents that were considered in detail included:

- *Directives and associated technical report for the Lake Erie Lakewide Management Plan (LaMP) (i.e., Binational Nutrient Management Strategy; Status of Nutrients in the Lake Erie Basin)*
- *Information compiled by the Lake Erie LaMP Southern Grand River Ecosystem Working Group)*
- *The Grand River Fisheries Management Plan*
- *Great Lakes Fishery Commission directives for Lake Erie (i.e., Fish Community Goals and Objectives; Environmental Objectives)*
- *Information and strategies about Species at Risk associated with the Grand River watershed*

In addition to these key documents, the process for identifying indicators to assess the **Broad Water Objectives** of the Water Management Plan that support aquatic community health also considered other frameworks or assessment tools. One example is the suite of indicators developed for the State of the Lakes Ecosystem Conferences (SOLEC). The SOLEC indicators function as tools for science-based reporting on the state of the Great Lakes ecosystem (e.g., State of the Great Lakes series). The SOLEC indicators are informative about the current *ecosystem* conditions in Lake Erie, but were not found to be consistent in purpose and scope to the indicators for *water quality* conditions as defined by this update of the Water Management Plan[3] (Endnote i). As a consequence, they were considered but not adopted as potential indicators by the framework for indicator selection.

Lake Erie Lakewide Management Plan

The Binational Great Lakes Water Quality Agreement (GLWQA) aims to maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem. The GLWQA supported the creation of Lake Ecosystem Objectives and Lakewide Management Plans (LaMPs). The Lake Erie LaMP provides the overall direction and scientific support for the restoration, protection and maintenance of the Lake Erie ecosystem, including tributaries and coastal wetlands. The GLWQA and the Lake Erie LaMP highlight the need for coordinated and strategic actions for nutrient management, or more specifically, reductions in sources of phosphorus leading to the effects of eutrophication. The **Binational Nutrient Management Strategy** (Lake Erie LaMP 2011) was created for Lake Erie as the result of research undertaken in collaboration with the Lake Erie LaMP. The Strategy was informed by the best available science and identifies the necessary actions to reduce the eutrophication of Lake Erie. A report, **Status of Nutrients in the Lake Erie Basin** (Charlton et al. 2009), put together by the Lake Erie Nutrient Science Task Group synthesised the best available science as of November 2008 to provide a weight of evidence rationale for the nutrient management actions in the Strategy. The Strategy outlines goals, objectives, quantitative targets and management actions needed to improve current conditions in Lake Erie and prevent further eutrophication. Objectives of the Strategy include:

- *Prevention of further degradation resulting from human-induced eutrophication by ensuring nutrient concentrations do not rise above current levels.*

---

[3] Goals are defined as broad statements of the water quality and quantity conditions in the watershed, which are aspired to in the long term.

- *Where waters already meet nutrient targets, maintain concentrations and prevent potential increases that may result from future land use practices.*
- *Reduce phosphorus loading and concentrations in waters that do not meet nutrient targets using a focused nutrient management approach that considers both current and future land uses.*
- *Monitor and report regularly on nutrient status in the tributary, coastal wetlands, nearshore, and offshore area waters of Lake Erie.*
- *Continue research into nutrient cycling and the effect of human activities to improve management decisions.*

(p. 5, Lake Erie LaMP 2011)

In addition to the information synthesis in the Nutrient Management Strategy, the Grand River-Lake Erie working group extended consideration to knowledge and information contained in scientific reports and publications. For instance, detailed information about the role of nearshore nutrient dynamics in the growth patterns of *Cladophora* was synthesized from a key scientific publication (Higgins et al. 2005).

Southern Grand River Ecosystem Working Group

Additional information about the key issues and priorities for improving the state of the Grand River-Lake Erie interface was compiled by a Lake Erie LaMP working group (Southern Grand River Ecosystem Working Group). This included a summary of COA-funded habitat assessments (Gilbert and Ryan 2007; MacDougall and Ryan 2012) and the proceedings of an associated LaMP / COA workshop (Doyle 2008).

Grand River Fisheries Management Plan

The **Grand River Fisheries Management Plan** (GRFMP; OMNR and GRCA 1998) used a community-based approach to fisheries management involving collaboration of the Ontario Ministry of Natural Resources (OMNR), the Grand River Conservation Authority (GRCA), and twelve partners representing organized stakeholder groups, other agencies, and one university (University of Waterloo). The process for developing the GRFMP began with a science-based framework which was then taken to the public in a series of public meetings to obtain local input, recommendations, and observations (e.g., species distributions). This consultation helped to refine and improve the understanding of the ecology and the state of fish communities in the Grand River system, and allowed the public to make informed and scientifically defensible recommendations and decisions. The GRFMP was divided into seven standalone components, separated by sub-basins with distinct regional physiography since this has a strong influence on the likely distribution of opportunities and constraints for various fish communities and species to survive in various locations in the river. Within each component, fish community objectives were made for each water type (e.g., mainstem, cold water tributary, reservoir). The GRFMP also included an assessment of issues affecting fish as well as the management strategies for each water type. In the “Lower Grand River Reach” (Brantford to Lake Erie) the Fish Community Objectives for the main stem of the Grand River included the following:

- *“Diverse warmwater fish community dominated by top predators (e.g., walleye, muskellunge, pike, channel catfish)”*
- *“Recognition that main stem is a migratory route for trout and salmon”*

(p. 38, OMNR and GRCA 1998)

The GRFMP highlighted water quality and quantity issues in the "Lower Grand River Reach" including (but not limited to) nutrient enrichment and sediment inputs resulting from land use activities, increased temperatures, discharge of stormwater and wastewater treatment plant effluents, and effects of land drainage and irrigation on summer baseflows.

Great Lakes Fishery Commission

The Great Lakes Fishery Commission (GLFC) endorsed the Lake Erie LaMP on the principle that healthy fish communities are indicative of a healthy ecosystem. The **Fish Community Goals and Objectives for Lake Erie** (FCGO; Ryan et al. 2003) were part of the Joint Strategic Plan for Management of Great Lakes Fisheries which was developed by the GLFC using an inter-jurisdictional, ecosystem-based approach. The process for establishing FCGO demonstrated some progress towards the recovery of ecological integrity in Lake Erie that is supported by the GLWQA. The process did not identify quantifiable fish community objectives since there continued to be dramatic and rapid changes in the ecosystem (Ryan et al. 2003). For the eastern basin of Lake Erie, the FCGO endorsed a fish community consistent with mesotrophic conditions in the nearshore: "*cool-water community of organisms dominated by a balanced and harmonic percid community in which the walleye is the dominant predator*" (p. 36, Ryan et al. 2003), where harmonic is defined as "*well integrated, resilient, or resistant to invasion by exotic species*" (p. 32, Ryan et al. 2003). The fish community objectives applicable to the "Lake Effect Zone" as defined by our framework include the following:

- "*<u>Ecosystem conditions</u> – maintain mesotrophic conditions (10-20 µg/L)*" *and* "*summer water transparencies ranging from 3-5 m in mesotrophic areas*" *of the eastern basin nearshore*
- *"<u>Nearshore habitat</u> – maintain nearshore habitats that can support high quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye*"
- "*<u>Riverine and estuarine habitat</u> – protect and restore self-sustaining, stream-spawning stocks of walleye, white bass, lake sturgeon, and rainbow trout*"
- "*<u>Genetic diversity</u> – maintain and promote genetic diversity by identifying, rehabilitating, conserving, and/or protecting locally adapted stocks*"
- *"<u>Rare, threatened, and endangered species</u> – prevent extinction by protecting rare, threatened, and endangered fish species . . . and their habitats*"

(p. 40-41, Ryan et al. 2003)

The Joint Strategic Plan also directed the development of **Lake Erie Environmental Objectives** (Davies et al. 2005) for the lake ecosystem and the associated rivers and estuaries. The creation of the Environmental Objectives included a critical examination of the physical, chemical and/or biological conditions or processes that help or hinder the achievement of the Fish Community Objectives. The Environmental Objectives serve to make the link between fishery objectives and habitat conditions (including water quality and quantity) more explicit. Documentation of both the Environmental Objectives and the Fish Community Goals and Objectives make specific reference to the Grand River. The Environmental Objectives highlight the Grand River as a priority management area with respect to several objectives including the following:

- *"Restore natural hydrological functions in Lake Erie rivers and estuaries*. " (p. 23, Davies et al. 2005)
- *"Maintain dissolved oxygen conditions necessary to complete all life history stages of fishes and aquatic invertebrates.*" (p. 25, Davies et al. 2005)
- *"Restore submerged macrophyte communities in estuaries and embayments and protected nearshore areas.*" (p. 27, Davies et al. 2005)

Priority management areas were selected in recognition that specific locations may have importance to sub-units of depressed or extirpated fish stocks, since their life history is adapted to the use of those places.

Species at Risk Recovery Strategy

The Grand River watershed contains areas of potential habitat for many aquatic species which are considered to be at risk and in need of special protection or rehabilitation. Some of these species (e.g., lake sturgeon) have been extirpated from the Grand River watershed and others have extant populations within the watershed (e.g., mapleleaf mussel). The **Recovery Strategy for Fish Species at Risk in the Grand River, Canada** was created in support of the recovery of 5 fish species in the Grand River (Portt et al. 2007). The long-term goal of the Recovery Strategy is "*to conserve and recover species at risk in the Grand River, and to enhance the native fish community…*" (VI, Portt et al 2007). The short-term objective of the Recovery Strategy is to "*investigate unknown aspects of ecosystem function and species at risk life history and ecology*..." the Recovery Strategy provides an important synthesis of the scientific understanding of aquatic ecosystems in the Grand River. Since the Recovery Strategy used an ecosystem approach, it provided information supplemental to the Assessment and Update Status Reports for each of the five fish species (eastern sand darter, black redhorse, river redhorse, redside dace, and the silver shiner). Not all of these five species have a natural range which extends into the Lake Effect Zone; however, some of the information has relevance for other species whose range does include the Lake Effect Zone. In addition to the Recovery Strategy, we considered information about other species at risk (including organisms other than fish) in other reports and also in the scientific literature.

Broad Water Objectives of the Grand River Water Management Plan update

The Water Management Plan 2012 update identified Broad Water Objectives that describe the state or system conditions in the Grand River watershed that meet the needs and values of ecosystems, communities and economies. As a first step in the determination of objectives, the process identified agreed upon statements that acknowledge the human uses, ecological needs and the social and cultural value of water. A subset of the documented uses, needs and values of water are particularly relevant in the context of aquatic community health in the Lake Effect Zone:

- *Aquatic, riparian, wetland and associated Lake Erie habitat is dependent on the quantity, quality and flow of surface and ground water.*
- *Aquatic species in the river system and portions of Lake Erie are dependent on the quantity, quality and flow of water.*
- *Wildlife use surface water for foraging and drinking.*
- *Grand River – Lake Erie commercial fisheries are supported by water quality and quantity.*

The uses, needs and values (detailed in Appendix A) are statements that underpin the Broad Water Objectives of the Water Management Plan 2012 update.

Several of the Broad Water Objectives are of heightened importance to water quality and quantity in the context of aquatic communities in the Lake Effect Zone:

- *Water quality supports the health, resiliency and biodiversity of aquatic, riparian and wetland communities.*

- *The flow regime supports the lifecycle requirements of aquatic and riparian species.*
- *Water quality does not promote excessive growth of aquatic vegetation or harmful algal blooms in rivers, reservoirs and lakes.*
- *Interactions between the Grand River and Lake Erie support the chemical, biological and physical integrity of both systems.*
- *Water quantity and quality are sufficient for optimal production of Grand River-specific stocks for commercial fisheries*
- *Water quantity and quality needs of sport fish populations are met, such that angling opportunities and community benefits are optimized.*

Other objectives in the complete list of Broad Water Objectives in the Water Management Plan (Appendix A) may also have relevance to aquatic community health, but have not been shown above. The Broad Water Objectives are consistent with and inclusive of the objectives stated within the directives outlined above. Collectively, they help to identify the importance of the link between the river and the lake ecosystems.

5. Framework for the development of indicators

The Grand River – Lake Erie Working Group was tasked with the identifying potential indicators of resource conditions required for ecological health in the context of water quality in the Grand River. Used in this context, an indicator reflects a quantitative characteristic that can be used to make a judgement about the condition of a resource (i.e., water quality). Once identified, indicators and targets can be used to compare current conditions with those that are required to meet the Broad Water Objectives. The work of the Grand River – Lake Erie Working Group focused on the Broad Water Objectives related to ecosystem health. By allowing the health of the aquatic ecosystem to be tracked, the indicators can aid in the identification of water quality issues and help to assess the effects of management actions. Potential indicators were identified through a synthesis of current scientific knowledge and information, and (if available) information from recent directives about resource conditions limiting aquatic community health in the Lake Effect Zone.

To compile a list of potential indicators, the working group considered information about the water conditions in the Area of Interest (i.e., the Lake Effect Zone) required for a healthy aquatic community. Rationale for the choice of indicators was based on a systems approach to identify the dependencies of aquatic communities on the resource conditions that are influenced by water conditions. The approach built on an understanding of the key processes by which water quality directly or indirectly limits aquatic community health. Information about the current state of the ecosystem was also used to inform the process. Indicators were chosen to reflect critical requirements of the aquatic community that are currently limited by water quality conditions in the Area of Interest.

The scope of this exercise was focused on the Lake Effect Zone, which refers to the area within which there is the potential for the exchange of water between the Grand River and Lake Erie. Although much of the information in this report is specific to the Lake Effect Zone, the method by which it was used to derive potential indicators highlights a process or framework which can be applied in other areas. It is expected that many of the processes by which resource conditions are limited in the Lake Effect Zone are also common to other parts of the Grand River watershed.

5.1. Selection of Aquatic Species of Interest

A subset of aquatic species was selected to represent some of the ecological needs of the broader aquatic community. In our framework for indicator identification, these species were not chosen to function as indicators themselves, since their presence or abundance may be influenced not only by water quality, but also by other factors (e.g., inter-specific competition, physical barriers). Rather, the Aquatic Species of Interest were used as a tool to identify some of the critical water quality needs of the aquatic community.
A comprehensive assessment of all species in the area would likely have revealed additional insight, but such an approach was unfeasible in the allotted time frame (3 months). Our process was also constrained by the extent of available information. The choice of species considered:

1. *Species which occupy a key position in the community (e.g., keystone species)*
2. *species that are currently present but are underperforming*
3. *species that are known to be extirpated but are recognized as important*
4. *species which are not known to be present but have the potential to occur (based on occurrence in similar habitat or on historic distribution)*

The list of species was further refined based on the importance of the species as highlighted by recent directives (identified in Section 4 of this report) or scientific literature relevant to the Lake Effect Zone.

For this iteration of the approach, the list was restricted to those species for which information was available. It is important to note that the resulting list is not considered to be a comprehensive representation of the needs of all species which potentially occur in the area; however, actions that are beneficial to these species will likely have broader benefits for the entire aquatic community. Since this process takes place within an adaptive management framework, additional species can be considered in subsequent iterations.

It is expected that a research consortia developed as part a Canadian Water Network initiative on aquatic cumulative effect assessment will yield information specific to the Grand River watershed. Since the research will focus on biological indicators of cumulative impacts related to water quality, is anticipated to be particularly relevant to subsequent iterations of this exercise.

5.2. A systems approach to identifying indicators for limiting resource conditions

Information about each of the Aquatic Species of Interest was synthesized using a method comparable to a systems approach, in that it outlines the current understanding of the mechanisms by which water quality directly or indirectly influences key limiting resource conditions in the Area of Interest. The process focused on the ecological needs of the Aquatic Species of Interest, particularly the needs that are influenced directly or indirectly by water quality and quantity. This process is illustrated in Figure 7.

A first step in this process was the compilation of information about the habitat requirements for each of the Species of Interest. Since habitat needs change throughout an organism's life cycle, habitat needs had to be considered for each life stage. This step was necessary for the determination of whether the Lake Effect Zone currently meets (or could potentially meet) the requirements for a particular life stage. Additionally, the information about the spatial and temporal scales of the habitat helped in some instances to highlight the mechanisms by which water quality can influence resource conditions. Particular attention was given to life stages or habitat types known to have a large influence on the health of local populations. Potential indicators were identified as the recurring factors impacting the resource conditions in the Lake Effect Zone that are currently limiting aquatic species.

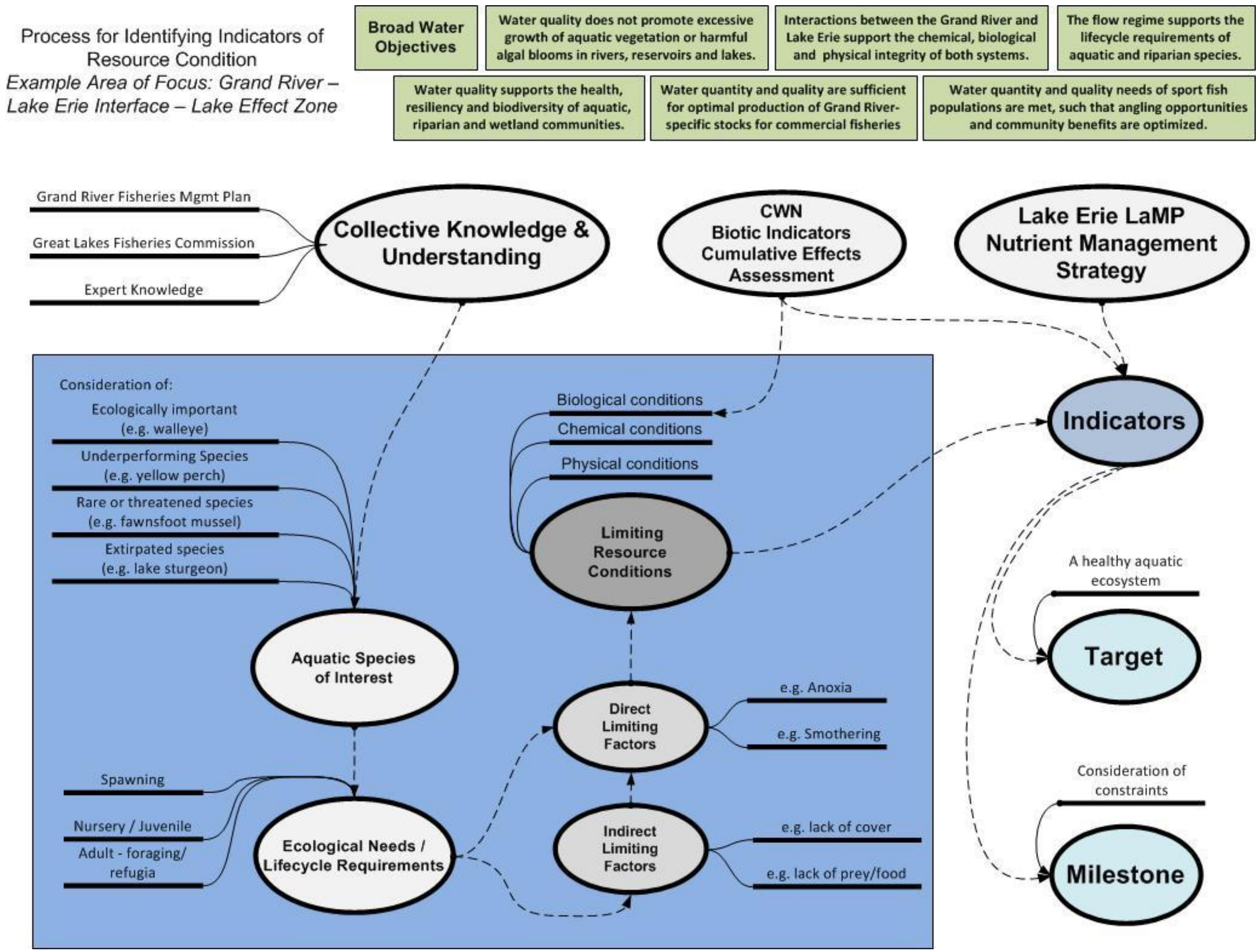

Figure 7. Schematic showing how potential indicators of limiting water resource conditions were identified.

6. Limitation of aquatic community health in the Lake Effect Zone

6.1. Aquatic Species of Interest for the Lake Effect Zone

The Aquatic Species of Interest selected by the Grand River-Lake Erie working group to identify some of the needs of the broader aquatic community include:

- fish species which exert top-down control on the food web, but are underperforming or rare (walleye, muskellunge);
- a species which is considered to be a key component of a resilient Lake Effect Zone fish community (yellow perch);
- fish species at risk (river redhorse, lake sturgeon); and
- freshwater mussels which are considered to be at risk or rare (mapleleaf, fawnsfoot, threehorn wartyback).

Although not a criterion for selection, populations of the Aquatic Species of Interest which inhabit or rely on the Lake Effect zone have special significance in the context of local culture, economics, ecology and/or biodiversity (Table 1). It is acknowledged that the list is not a comprehensive representation of the needs of all species in the aquatic community of the Lake Effect Zone; however, the list includes species for which water quality is known to be an important limitation. Recent directives outlined in Section 4 of this report and scientific literature have highlighted water quality in the Lake Effect Zone as having an important role in the success of these species.

Since there is an existing plan for fish management in the Grand River watershed with detailed information for specific reaches, fish species dominate the list of Aquatic Species of Interest (Table 1). Information about other species potentially present in the Lake Effect Zone is currently scarce. Regardless, the needs of fish likely represent a wide range of environmental conditions; since many fish occupy top trophic position, they have the potential to be influenced indirectly by factors that alter other parts of the food web (e.g., producers), and therefore represent the needs of a broader range of aquatic organisms.

Each of the Aquatic Species of Interest listed in Table 1 have been specifically mentioned in recent directives or scientific literature in the context of the Lake Effect Zone. Both walleye and muskellunge were given special consideration by the GRFMP (OMNR and GRCA 1998) for the lower reach of the Grand River. Yellow perch were highlighted by the GLFC FCGO as an important component of the "harmonic percid community"[4] that should dominate in the nearshore, tributaries and embayments of eastern Lake Erie (Ryan et al. 2003). The FCGO for Lake Erie also target walleye as a key member of the fish community in the nearshore waters (Ryan et al. 2003). One of the GLFC objectives addresses the maintenance of nearshore habitat; walleye, muskellunge and yellow perch are among the species which are specifically mentioned by this objective. Each of these fish species is also recognized by the GLFC Environmental Objectives (Davies et al. 2005) with specific reference to the Grand River coastal marshes.

Walleye was chosen as a Species of Interest not only because of its important ecosystem role in the Lake Effect Zone (OMNR and GRCA 2001) but because it is the focus of active rehabilitation efforts directed at

[4] i.e. a community featuring fish in the taxonomic family Percidae (perches and darters) that is resilient, predictable and productive

Table 1. List of Aquatic Species of Interest used by the Grand River-Lake Erie working group to identify aquatic community needs that are affected by water quality in the Lake Effect Zone.

Aquatic Species of Interest	Status in Lake Effect Zone	Significance			Directive with specific mention
		Cultural, economic	**Ecological**	**Biodiversity**	
Fish					
Walleye (*Sander vitreus*)	under-performing	sport and commercial fisheries	top predator	Grand River stocks re-cognized as genetically important to Lake Erie	Ryan et al. 2003; OMNR and GRCA 1998
Yellow perch (*Perca flavescens*)	poorly characterized; likely rare, no recruitment	other stocks support sport and commercial fisheries	key component of percid community (historically)		Ryan et al. 2003
Muskellunge (*Esox masquinongy*)	unknown	highly prized sport fish	top predator		Ryan et al. 2003; OMNR and GRCA 1998
River redhorse (*Moxostoma carinatum*)	extant but poorly characterized	food source for indigenous cultures		special concern (COSSARO, COSEWIC) [1]	Portt et al. 2007
Lake sturgeon[2] (*Acipenser fulvescens*)	Extirpated[3]; possible L. Erie recruitment	cultural significance for First Nations		threatened (COSSARO, COSEWIC) [1]	Ryan et al. 2003
Mussels					
Mapleleaf (*Quadrula quadrula*)	poorly characterized; likely present but rare		key food item	threated (COSSARO, COSEWIC) [1]	Bouvier and Morris 2010[3]
Fawnsfoot (*Truncilla donaciformis*)	poorly characterized; likely present but rare		key food item; sensitive component of benthic community	endangered (COSSARO, COSEWIC) [1]	Bouvier and Morris 2010[3]
Threehorn wartyback (*Obliquaria reflexa*)	poorly characterized; likely present but rare		key food item; sensitive component of benthic community	candidate species (COSEWIC)	Metcalfe-Smith et al. 1998

1. Designation by COSSARO based on elaws consolidation from 12 January, 2012 to 9 March, 2012; COSEWIC status based on NHIC database, last updated 2010. 2. Great Lakes - Upper St. Lawrence River population. 3. Population spawning in the Grand River. 4. Information compiled in support of possible future directives.

habitat quality and quantity (MacDougall et al. 2007). As a genetically distinct stock within the larger population of Lake Erie, it is important not only to the stability of the eastern lake walleye fishery (Einehouse and MacDougall 2010) and nearshore fish community, but to overall intra-species biodiversity on a landscape scale as recognized by the Ontario Biodiversity Council (Ontario Biodiversity Council 2011). Outside of the Lake Effect Zone, the structure and stability of the eastern basin fish community would likewise be enhanced by recovery of lake sturgeon and muskellunge populations (Ryan et al. 2003; Davies et al. 2005), all historically linked to Grand River habitat.

These species are an example of fish with lifecycle-specific requirements of the Lake Effect Zone. Although not year-round resident, environmental conditions need to be adequate for migratory staging, migratory passage, larval passage/retention and, particularly for sturgeon, juvenile maintenance. As water quality and quantity issues have played a role in the disappearance of both sturgeon and muskellunge from the Grand River watershed, achieving a satisfactory reversal is likely critical to a natural expansion back into the Lake Effect Zone from extant Lake Erie populations.

Mapleleaf, fawnsfoot and threehorn wartyback are species of rare or at-risk freshwater mussels that have a very limited range in Canada but are known to occur in the Lake Effect Zone (Metcalfe-Smith et al. 1998; Staton 2008; Bouvier and Morris 2010). Field observations, including some in the Grand River have linked poor water quality to decreased abundance of freshwater mussels (Metcalfe Smith et al. 2000). Although their physiological tolerances are poorly known, high loads of suspended sediment have harmful effects on most mussels (Henley et al. 2000). Water quality has been implicated as an important factor in the conservation of freshwater mussels in the southern Grand River (COSEWIC 2008; Bouvier and Morris 2010). The inclusion of freshwater mussels in the list of Aquatic Species of Interest is important since they provide important ecological functions such as stabilization of substrates and provision of habitat and they occupy a key position in the food web between producers and consumers. In addition, since these mussels can occupy areas not utilized as critical habitat by the selected fish species, their inclusion expands the range of ecological requirements represented by the Aquatic Species of Interest.

6.2. Ecological needs: a life-cycle approach

The needs of the Aquatic Species of Interest were identified using the framework outlined in Figure 7Figure 7 and are detailed in Appendix C. The approach focused on limiting factors related to water quality in the Lake Effect Zone, but also described the processes by which water quality can indirectly cause constraints on the Aquatic Species of Interest by affecting other resource conditions. The relevant habitat types that potentially occur in the Lake Effect Zone are shown in Table 2. Habitat requirements of some species could not be met within the Lake Effect Zone throughout their entire life cycle because of the area's natural physical characteristics. For instance, appropriate substrate or geomorphology for spawning habitat of some species (e.g., river redhorse, lake sturgeon) may not occur within the current functional extent of the Lake Effect Zone (i.e., downstream of the dam at Dunnville).

Table 2. Ecological needs of Species of Interest with habitat that occurs or could potentially occur in the Lake Effect Zone. For each habitat type, the ecological needs that respond to environmental conditions are shown, as well as associated pressures acting as stressors.

Aquatic Species of Interest	Stage / habitat type	Requirement (resource condition)	Process/ response	Pressure / stressor
Percids (e.g., yellow perch, walleye), muskellunge	Eggs, larvae/ spawning	Oxygen supply to eggs	*Episodic anoxia resulting from increased BOD (eutrophication)*	• **Nutrients**
			Suffocation/smothering of eggs and habitat by siltation	• **Suspended sediment**
			Reduction in dissolved oxygen caused by warming of water	• **Temperature**
			Reduced circulation/supply of oxygenated water	• **Flow regime** • **Water depth**
		Water movement between eggs	*Buildup of wastes from reduced water circulation*	• **Flow regime**
			Drop in water level causing desiccation of eggs	• **Water depth**
	Young / nursery	Cover (submergent macrophytes); attachment sites (submergent and emergent macrophytes);	*High turbidity causing shading of benthos and reduction in light available for growth of submergent macrophytes*	• **Suspended sediments** • **Nutrients**
Percids (e.g., yellow perch, walleye), muskellunge	Young / nursery	Prey items (zooplankton, benthic invertebrates)	*Eutrophication causing oxygen depletion in sediments, shift to pollution tolerant species*	• **Nutrients**
		Optimal thermal regime	*Reduced circulation of water causing warming*	• **Temperature** • **Flow regime** • **Water depth**
		Tolerable range of dissolved oxygen	*(direct physiological effect)*	• **Temperature** • **Flow regime**
	Adult / foraging	Optimal thermal regime (foraging?)	*Reduced circulation of water causing warming*	• **Temperature** • **Flow regime** • **Water depth**
		Tolerable range of dissolved oxygen	*Reduction in dissolved oxygen caused by reduced circulation and warming of water*	• **Temperature** • **Flow regime**
		Tolerable range of suspended sediment	*(direct physiological effect)*	• **Suspended sediment**

Aquatic Species of Interest	Stage / habitat type	Requirement (resource condition)	Process/ response	Pressure / stressor
Migratory fish (e.g., lake sturgeon, river redhorse)	Young/ nursery (sturgeon only)	Prey items (larger zooplankton)	*Eutrophication causing oxygen depletion in sediments, shift to pollution tolerant species*	• **Nutrients**
	Adult / migratory route, foraging	Tolerable range of suspended sediment	*(direct physiological effect)*	• **Suspended sediment**
		Prey items (benthic macroinvertebrates)	*Smothering of benthic habitat by sedimentation, reduction in diversity and abundance of prey*	• **Suspended sediment**
			Eutrophication causing oxygen depletion in sediments, shift to pollution tolerant species	• **Nutrients**
		Cues for migration	*Temperature in Grand River plume not appropriate for eliciting migratory response from lake-resident fish to spawn in the river*	• **Temperature**
Freshwater mussels (e.g., fawnsfoot mapleleaf)	Adult	Tolerable range of dissolved oxygen in benthos	*Episodic anoxia*	• **Nutrients** • **Dissolved oxygen**
			Suffocation/smothering	• **Suspended sediment**
		Attraction of host fish using visual stimulus	*High turbidity causing decreased water clarity*	• **Suspended sediment** • **Nutrients**
	Glochidia	Dispersal to appropriate adult habitat by host fish	Restrictions on movement of fish limit the mussel recruitment range	• **Flow (connectivity)**

Direct and indirect impacts of water quality

The following paragraphs describe the known mechanisms by which Lake Effect Zone habitat required by Aquatic Species of Interest is impacted directly or indirectly by water quality (Table 2). In the subsequent sections, these concepts are applied to an examination of current conditions in the Lake Effect Zone to identify the critical factors limiting Aquatic Species of Interest.

Temperature, dissolved oxygen

Ecological needs common to all species and life stages include optimal ranges of temperature and dissolved oxygen. These requirements have direct physiological effects on an organism or can indirectly limit their populations by reducing prey availability (Table 2). The physiology of each species and life stage dictates the range of tolerance, but few aquatic organisms can survive extremes (i.e., highs or lows) of temperature and oxygen. The ecological requirements can be more critical during particular life stages (e.g., oxygenation of fish eggs). The requirement for oxygen is particularly sensitive, in part because it can be impacted by multiple stressors; increased temperature and limited water circulation can aggravate the effects of low dissolved oxygen concentrations. Thresholds for lethal concentrations may vary between species, but oxygen is a critical requirement of most fish species. The requirement for movement of water around fish eggs to ensure delivery of oxygen and dilution of metabolic wastes from the eggs is a common requirement during the early life stage of many fish species. Correspondingly, fish spawning habitat is typically characterized by an optimal range of flow that varies between species. Stressors causing environmental conditions that impact dissolved oxygen, temperature and the flow regime can have a large impact on the survival of many fish species which could spawn in the Lake Effect Zone, including walleye, yellow perch and muskellunge.

Freshwater mussels are members of the benthic community that are sensitive to water quality conditions (Table 2). For example, periods of anoxia (i.e., oxygen depletion) in the water overlying the mussel beds can cause declines in mussel populations. The lack of mobility of mussels increases their sensitivity to localized sources of pollutants or impacts associated with episodic events such as diurnal sags in dissolved oxygen that result from respiration of aquatic plants. The role of nutrients and sediment loadings in the development of low dissolved oxygen conditions in tributary lake effect zones and coastal wetlands are highlighted by the GLFC environmental objective for dissolved oxygen. They propose that the objective for dissolved oxygen be met by controlling tributary loadings of sediment and nutrients (Davies et al. 2005).

Nutrients, suspended sediments/turbidity, macrophyte community

Elevated concentrations of nutrients or suspended sediments can cause environmental conditions that limit populations of the Aquatic Species of Interest by indirectly impacting their ecological needs (Table 2). For instance, nutrient enrichment (i.e., eutrophication) can result in a reduction of dissolved oxygen by causing the proliferation and subsequent decay of aquatic plants. Excessive growth of plants can also result in extreme highs and lows in dissolved oxygen as the diel cycle of light shifts the balance between oxygen production (i.e., through photosynthesis) and consumption (i.e., respiration) in plants (Wetzel 2001). The role of nutrients and sediment loadings in the development of low dissolved oxygen conditions in tributary lake effect zones and coastal wetlands are highlighted by the GLFC environmental objective for dissolved oxygen. They propose that the objective for dissolved oxygen be met by controlling tributary loadings of sediment and nutrients (Davies et al. 2005).

Sustained high levels of sediment may cause permanent detrimental alterations in community structure, diversity, density, biomass, and growth of organisms. High concentrations of suspended sediment can negatively impact respiration directly, by causing physiological harm to breathing structures (e.g., clogging siphons, gills), or indirectly, by smothering immobile life stages (e.g., fish eggs, adult mussels) (Henley et al. 2000). High concentrations of nutrients and suspended sediments can also reduce the availability of appropriate habitat through the accumulation of fine particles or buildup of organic matter, thus altering the chemical and physical composition of the substrate.

Other indirect effects of high suspended sediment and nutrients include a reduction in water clarity as a result of high turbidity. Nutrient enrichment can contribute to increased turbidity by stimulating the growth of planktonic algae. The resulting reduction in water clarity may limit light penetration such that there is insufficient light available for the growth of submerged aquatic plants (i.e., macrophytes). A healthy macrophyte community is a critical ecological requirement during one or all life stages of many aquatic species. For instance, fish species may require submerged macrophytes for protection from predators (e.g., juvenile yellow perch) shelter from light (e.g., adult walleye), ambush predation (e.g., muskellunge), or as attachment sites for eggs (e.g., muskellunge). In addition, macrophytes provide important ecological functions that improve water quality, such as uptake and storage of nutrients, sheltering of areas from suspended sediments and reducing erosion and suspension of bed sediments (Madsen et al. 2001). The macrophyte community can also have indirect benefits for some species, by creating or improving habitat for prey species.

Additional impacts associated with excessive turbidity include disruption of visually-mediated behaviours such as the attraction of fish hosts by mussels (Bouvier and Morris 2010) or foraging activities of sighted predators (Trebitz et al 2007). Prey availability for planktivorous life stages may also be reduced by elevated turbidity as a result of light limitations on phytoplankton (and therefore zooplankton) production (Henley et al., 2000). Consequent reductions in abundance of planktivores may lead to shifts in the aquatic food web. If the shift in species composition of the fish community includes an increase in the common carp (*Cyprinus carpio*), water quality can become further degraded (Chow-Fraser 1998). This species can maintain marsh areas in a turbid state through feeding and spawning activities that cause re-suspension of sediments and destruction of submerged macrophyte beds.

Hydrologic regime

The hydrologic regime can have a strong influence on water quality. Both flow and water levels have the potential to enhance poor water quality conditions: increased temperature and lack of circulation in nutrient rich waters allow the development of unfavourable dissolved oxygen conditions. With reduced flow or low water levels, habitat quality often decreases since both factors can lead to fluctuating or extreme temperatures that can be lethal to many species.

Limiting resource conditions for Aquatic Species of Interest

The Lake Effect Zone contains two areas with unique characteristics that are influenced by different physical, chemical and biological processes: the estuary where the river and lake waters mix (i.e., the “lacustuary”), and the portion of the Lake Erie nearshore that is influenced by the plume of the Grand River. As mentioned in section 3.3, there remains a large amount of uncertainty in the understanding of the nearshore ecosystem of the Lake Erie eastern basin. The processes currently influencing the ecology of the nearshore are poorly understood and the ecosystem may still be in a state of transition (Charlton et al. 2009). While it is clear that water quality in tributaries such as the Grand River have the potential to have a large influence on both the nearshore and offshore ecosystem, the mechanisms or processes and sources of variability are poorly understood. These gaps hamper a systems approach to identifying the linkages between water quality and limiting resource conditions in the nearshore portion of the Lake

Effect Zone. As a consequence, the information for indicator selection is focused primarily on the conditions and the mechanisms by which they are affected in the lacustuarine environment of the Lake Effect Zone. New information about the nearshore environment of the Lake Effect Zone will be incorporated into subsequent iterations of the Water Management Plan as part of an adaptive management framework.

The coastal wetlands of the Grand River

Figure 8. Marshes near Dunnville, part of the lacustuarine ecosystem at the interface between the Grand River and Lake Erie.

Coastal wetlands are the dominant ecological feature of the lacustuarine environment in the Lake Effect Zone of the Grand River (Figure 8). The Dunnville Marsh complex has been designated as a provincially significant coastal wetland complex (NHIC 2012). The ecological health of coastal wetlands, such as the Dunnville Marshes, is sensitive to the conditions of the water that flows into it from upstream (Maynard and Wilcox 1997). For instance, high turbidity cuts off the transmission of light through the water column, a mechanism which is thought to limit the growth of submerged macrophytes in this area (Gilbert and Ryan 2007). As a result, there is currently little vegetative cover by submerged macrophytes (Gilbert and Ryan 2007; Aseel 2009). The lack of submerged macrophytes worsens already turbid conditions; if present, the macrophytes could contribute to a decrease in turbidity by preventing re-suspension of fine sediments and promoting settling of sediments at the marsh fringes. In addition, nutrient uptake by the submerged macrophytes could decrease the potential for planktonic algal growth to contribute to turbidity. The establishment of macrophytes could also improve oxygen conditions in the sediments, which in turn could also benefit water quality in the marshes (Madsen et al 2001).

A diverse community of plants including submerged macrophytes can be a good indication of a healthy marsh (Chow-Fraser 1998) and is a critical ecosystem feature that would be desirable to re-establish. Efforts to restore submerged aquatic macrophytes in other marshes have demonstrated the importance not only of improvements in water quality, but also of hydrologic processes and the harmful effects of invasive species such as the common carp (Chow-Fraser 1998). This highlights the importance of an integrated approach. The restoration of submerged macrophyte communities in “embayments and protected nearshore areas” is specifically mentioned as an Ecosystem Objective for the mouth of the Grand River by the GLFC (Davies et al. 2005). The GLFC suggest that improvements in water transparency (i.e. reductions in turbidity) would be an appropriate measure for progress towards the conditions described by the Ecosystem Objective and would be achieved through reductions in sediment and nutrient loadings (Davies et al. 2005). It is worth noting that optimal turbidity should be considered as a range rather than an upper threshold. For example, walleye are known to occur in high turbidity wetlands, but abundance in these types of habitats is thought to be restricted as a result of reduced feeding success due to visual impairment as well as degradation of spawning and nursery habitat caused by the shading of submerged vegetation and smothering effects of fine sediments (Trebitz et al 2007). A review by Ryan of water quality requirements for Grand River stocks of walleye (unpubl.) examines the physiological effects of turbidity (e.g., larval mortality) in addition to the effects on walleye habitat quality (e.g., growth of submerged macrophytes versus nuisance algae) and the food web (e.g., bottom-up effects).

Natural hydrological functions play a significant role in determining water quality and by correlation, habitat quality in the coastal wetlands of the Grand River. As mentioned in Section 3 of this report, the hydrologic regime influences riverine processes and has the potential to improve water quality and structure the diversity of plant communities. For instance, the variation in water levels in wetland systems helps to increase ecological resiliency by maintaining habitat complexity, which supports diverse communities of plants and animals (Chow-Fraser 1998).

Figure 9. Water covers the floodplain adjacent to the marshes below Dunnville. Natural flooding events can provide a range of ecological benefits.

Since settlement, alterations to the landscape and geomorphology of the river have disrupted some of the ecological benefits of the hydrologic processes, such as a linkage of nutrient dynamics between the river and the floodplain (Corbett et al. 1997). Prior to these modifications , complex floodplain pool systems in the lower portion of the Grand River had the potential to be inundated for an extended period during the spring and early summer (OMNR and GRCA 2001; Figure 9). Water also spills into the floodplain during seiche events when there is an influx of water into the lower river and coastal wetlands as a direct result of wind-driven increases in Lake Erie water levels. Restoration of natural processes in the coastal wetlands and associated floodplain may increase processing and storage of nutrients in these areas (Maynard and Wilcox 1997), which could potentially decrease nutrient levels in the river and in the plume of the Grand River. Other ecological benefits of the hydrologic linkage with the floodplain include the promotion of biological diversity (Lougheed et al 2001; Gilbert and Ryan 2007) and the creation of spawning and nursery habitat for fish, including yellow perch, muskellunge and lake sturgeon (OMNR and GRCA 2001). These benefits underscore the importance of the restoration of natural hydrological functions in improving water quality and ecological health in the Lake Effect Zone.

The restoration of natural hydrological functions in areas such as the Lake Effect Zone was noted as one of the GLFC Ecosystem Objectives to sustain critical fish habitats (Davies et al. 2005) and was also highlighted in the proceedings of a LaMP/ COA workshop on restoration of the Southern Grand River (Doyle 2008). Strategies identified by these documents stress the need for a more natural flow regime and connectivity between river reaches, wetlands and floodplains in the Grand River. Such changes could yield important benefits in terms of improved water quality and aquatic community health in the Lake Effect Zone. For instance, changes to the flow regime can improve sediment dynamics (Nelson et al. 1987), which could improve conditions in the lower reaches of the Grand River. The importance of the flow regime and connectivity to the ecology of Lake Effect Zone are well-known, but additional work is needed to determine specific information about current conditions and ecological flow needs in this area (Davies et al. 2005).

Mussels

The main factors limiting populations of at-risk mussels in the Lake Effect Zone have been identified as increased sediment and nutrient loading (Portt et al. 2007; Bouvier and Morris 2010). Some of the threats present in previous decades, such as the fragmentation of habitat, have been reduced as a result of improvements to the management of the river (e.g., the creation of fish ladders to allow dispersal of hosts) (Metcalfe-Smith et al. 2000). Increases in abundance of many freshwater mussels have also been observed in the Grand River during previous decades with improved control on point sources such as poorly treated wastewater (Metcalfe-Smith et al. 2000). Although the species occurring in the Lake Effect Zone are less sensitive than other mussels to conditions such as silt/muck substrate and sluggish currents, water quality is still an important factor in their ability to thrive. Turbidity is cited as an important threat to populations of mapleleaf in the Grand River (COSEWIC 2006a). The turbid conditions currently impacting the lacustuarine habitat of the mapleleaf are likely caused by high concentrations of suspended sediment from upstream sources combined with inherent geology and flow regime in the southern reaches of the Grand River. The contribution by phytoplankton to turbidity is likely relatively minor; it has been suggested that the growth of phytoplankton is limited by light, not nutrients, due to the reduction in water clarity by the suspended sediment (MacDougall and Ryan 2012). In addition to sources of sediments from areas upstream, disruption of sediments by recreational activities (e.g., boating) can have negative impacts on nearby mussel beds. Improvements in the populations of mussels in response to decreased nutrient and sediment loading would be indicative of broader improvements in aquatic health, such as recovery of predator species (e.g., river redhorse and lake sturgeon) and greater diversity of the benthic invertebrate community. These changes would return the aquatic community to a more diverse and resilient state by supporting positive effects on the food web.

Fish

Both water quality and quantity have been identified as significant threats to at-risk fish species in the southern Grand River (Portt et al. 2007). The GLFC environmental objectives stress the importance of improving the low dissolved oxygen conditions that occur in many of the coastal wetlands and tributary lake effect zones, including the Grand River (Davies et al. 2005). The GLFC also highlight the role that sediment and nutrients play in creating these conditions, and propose that the objective for dissolved oxygen be met by controlling tributary loadings of sediment and nutrients. In addition, the GLFC note the restoration of a more natural flow regime as a mechanism to achieve the objective for dissolved oxygen conditions (Davies et al. 2005).

Some of the most critical limitations caused directly or indirectly by water quality conditions in the Lake Effect Zone are those that affect fish species during the first year of life. The lack of suitable spawning and nursery habitat is an important constraint on a number of the Aquatic Species of Interest (i.e., walleye, yellow perch, and muskellunge) in the Lake Effect Zone (Ryan et al. 2003; OMNR and GRCA 1998). In its current degraded state, portions of the Lake Erie nearshore (closest to the Grand River mouth) and the coastal wetlands, including the Dunnville Marsh complex, offer poor quality nursery and/or spawning habitat for these species. A healthy plant community in the marsh, including submerged aquatic macrophytes, would help to restore some of the critical habitat features and ecological functions that are currently limiting fish Species of Interest (Table 2). Improvements to water quality and the hydrologic regime in the lacustuarine environment of the Lake Effect Zone could help to restore a healthy aquatic plant community in the coastal wetlands and lead to improved use of the area as habitat for juveniles and/or adult fish Species of Interest (OMNR and GRCA 2001; Corbett et al. 1997).

Summary of Indicators

The synthesis of knowledge compiled about critical requirements of the Aquatic Species of Interest in the Lake Effect Zone highlighted a number of processes by which water quality has the potential to negatively impact aquatic community health (Table 2). Parameters that convey information specific to the processes by which water quality directly or indirectly affects aquatic community health were chosen as indicators. The following variables describe measures of resource conditions that limit Aquatic Species of Interest as a direct or indirect result of water quality in the Lake Effect Zone:

- Phosphorus
- Turbidity/suspended solids
- Temperature
- Dissolved oxygen
- Flow regime
- Macrophyte community

These indicators quantify some of the most critical resource conditions required by the Aquatic Species of Interest. Since the list was based on a portion of the aquatic community, there may be critical requirements for other species which are not included; however, it is expected that additional parameters may be added in an adaptive management framework as more information about the aquatic community and ecological processes in the Lake Effect Zone becomes available.

7. Influence of the Grand River on the eastern basin of Lake Erie

From an ecological perspective, exchange between the Grand River and the eastern basin of Lake Erie has significant benefits for both the river and the lake. Conditions in the Grand River watershed have important implications for the ecology of the lake. For instance, many lake-dwelling species rely on habitat in the Grand River for a portion of their lifecycle. Water quality conditions in the river are important in the context of the environmental conditions in the eastern basin of the lake. Particular attention has been focused recently on the supply of nutrients flowing from the tributaries, which support biological production in both the offshore and nearshore areas of the eastern Lake Erie basin. Conditions in the nearshore at the mouth of the Grand River suggest eutrophication is contributing to the degradation of habitat and disruption of beneficial uses in the immediate vicinity of the river plume by fueling nuisance growth of *Cladophora* (Higgins et al. 2005). However, the interplay of the tributary nutrient load with other factors that are driving recent changes in the nearshore and offshore ecosystems of the eastern basin of Lake Erie is not well understood; details of the mechanisms by which lower trophic levels are impacted are unclear (Davies et al. 2005).

Even with this uncertainty, there is consensus among Lake Erie resource managers that phosphorus enrichment (eutrophication) is largely responsible for the current poor state of water quality in the lake that impairs many of the lake's beneficial uses (Lake Erie LaMP 2011). For instance, research into the supply of nutrients to *Cladophora* indicates that basin-wide phosphorus availability is a key determinant of *Cladophora* blooms in Lake Erie (Charlton et al. 2009). Scientific research supports the assertion that reducing the input of total phosphorus is the primary mechanism to restore the health of the Lake Erie ecosystem (Charlton et al. 2009). Accordingly, there is consensus that basin loads of phosphorus should, at a minimum, not be allowed to increase (Ryan et al. 2003; Hecky et al. 2004; Charlton et al. 2009). In spite of previous success with attempts to reduce loading of phosphorus to the lake in past decades, these controls are now insufficient due to the changes resulting from exotic invasive species and potentially the future effects of lake warming.

Reduced loads of phosphorus to Lake Erie are the focus of the Binational Nutrient Management Strategy, a multi-jurisdictional, multi-partner and multi-year commitment to management actions to reduce excessive phosphorus loadings and eutrophication of Lake Erie (Lake Erie LaMP 2011). The

Strategy is based on the synthesis of scientific research undertaken in collaboration with the Lake Erie LaMP. The findings about the influence of nutrients on the state of the Lake Erie ecosystem were used to form a "weight of evidence" rationale for the Strategy. Since the approach taken in the development of the Strategy is consistent with the guiding principles of the Grand River Water Management Plan update (included in Appendix A), it provided an appropriate source to inform the selection of an indicator for the Grand River's impact on the eastern basin of Lake Erie.

The Nutrient Management Strategy identifies the Grand River as a priority watershed which is in urgent need of action since it currently far exceeds nutrient targets (>32 µg/L; Lake Erie LaMP 2011). Estimates from data compiled in 2004 suggest that the supply of nutrients from the Grand River to Lake Erie is likely significant in the context of the tributary nutrient load to the eastern basin of the lake (unpublished data 2004, D. Dolan, U. Wisconsin). Studies are currently underway as a partnership between Environment Canada and the Grand River Conservation Authority to collect data on flows and concentrations to obtain more current and detailed information about loads of phosphorus from the Grand River. The concentration of phosphorus in the southern Grand River has previously been identified as excessive since it is responsible for impacting the ecosystem of the southern Grand River itself: the GRFMP (Ontario Ministry of Natural Resources and Grand River Conservation Authority 1998), the Southern Grand River Ecosystem Working Group (Doyle 2008; MacDougall and Ryan 2012) and the GLFC Environmental Objectives (as it relates to dissolved oxygen; Davies et al. 2005) all associate excessive phosphorous concentrations with ecological degradation of the southern Grand River.

A weight of evidence approach based on information compiled as part of the Lake Erie LaMP suggests that phosphorus is a useful indicator for quantifying the impact of the Grand River on the eastern basin of Lake Erie. Current conditions suggest that the influence of nitrogen on ecological health in the Lake Effect Zone is minor in comparison to phosphorus, so lake management efforts have not previously focused on reductions of nitrogen loads to the lake (Lake Erie LaMP 2011). The Lake Erie LaMP has recommended, however, that monitoring of nitrogen continues, since loads (and thus ecological significance) appear to be increasing.

8. Recommendations of the Grand River - Lake Erie Working Group

8.1. Framework for indicator identification

An approach for indicator identification was developed by the Grand River – Lake Erie Working Group as part of the update to the Water Management Plan for the Grand River watershed. This approach was applied to the Lake Effect Zone and can also be used as a framework for the determination of appropriate indicators in other Areas of Focus. The process, similar to a systems approach, uses a select number of species (Species of Interest) to identify some of the critical limiting resource conditions that are impacted directly or indirectly by water quality in the Area of Focus. The application of the approach relies on information and recent directives relevant to the Area of Focus.

The primary limitations or shortfalls of the approach are driven by gaps in knowledge and information about the ecological processes or current conditions in the Area of Focus. In the context the Lake Effect Zone, steps to address these gaps include:

- Improved information about current water quality conditions and flow regimes in the Lake Effect Zone (increased spatial and temporal monitoring)
- Collection of information about the distribution and critical requirements of a more diverse range of species

- Monitoring of nutrient loading from Grand River to Lake Erie (the timing and mode/form of delivery)
- Continued research on the influence of nutrients from the Grand River on the growth of *Cladophora* in the nearshore of eastern Lake Erie

8.2. Indicators recommended for the Lake Effect Zone as part of an integrated approach for aquatic ecosystem health

A set of potential indicators was derived by the Grand River – Lake Erie Working Group using the framework described above. The development of indicators using this framework focussed mainly on the lacustuarine environment of the Lake Effect Zone since gaps in information about the mechanisms or processes and sources of variability driving ecosystem changes in the nearshore hampered a comprehensive systems-approach for all areas of the Lake Effect Zone. Through this process, the coastal wetland was highlighted as being particularly important to the health and resiliency of the Lake Effect Zone ecosystem.

The synthesis of knowledge about critical requirements of the Aquatic Species of Interest highlighted a number of processes by which water quality in the lacustuarine environment of the Grand River has the potential to negatively impact aquatic community health. These processes, described in Table 2, illustrate the means by which water quality directly or indirectly affects the lacustuarine ecosystem in the Lake Effect Zone. The following measures are recommended by the working group as indicators of resource conditions impacted directly or indirectly by water quality:

- Phosphorus
- Turbidity/suspended solids
- Temperature
- Dissolved oxygen
- Flow regime
- Macrophyte community

The synthesis of current scientific knowledge supports the conclusion that improvements in these indicators would help to achieve objectives under a goal of the Water Management Plan to "*improve water quality to improve river health and reduce its impact on Lake Erie*". Based on the information in recent directives, elevated phosphorus and turbidity are likely to be particularly effective indicators for critical resource conditions impacted by water quality in the Lake Effect Zone. Since most aquatic organisms have temperature and dissolved oxygen requirements, these parameters represent indicators of direct water quality needs that should be ubiquitous (i.e., applicable to many other areas). Similarly, since water quality is strongly influenced by hydrologic processes, the flow regime is a useful measure of the indirect mechanisms by which ecological health is impacted by water quality. The macrophyte community represents another important indicator of resource conditions for the lacustuarine environment of the Lake Effect Zone. A healthy macrophyte community is an ecological requirement for many of the Aquatic Species of Interest during at least one stage in their life cycle and an integral component of a resilient coastal wetland ecosystem (Table 2; Maynard and Wilcox 1997).

The mechanisms affecting some of these indicators may be inter-related; nevertheless, the use of multiple complementary indicators is likely to provide a more complete picture of the ecosystem. These indicators quantify some of the most critical resource conditions required by the Aquatic Species of Interest. Since the list was based on a portion of the aquatic community, there may be critical requirements for other species which are not included. It is expected that additional parameters may be added iteratively within the adaptive management framework of the Water Management Plan as more information about the aquatic community and ecological processes in the Lake Effect Zone becomes available.

Information compiled as part of the systems approach for indicator identification points to the coastal wetlands in the Lake Effect Zone as sensitive and ecologically important areas. The wetland features associated with the Dunnville Marsh complex are the dominant features of the Grand River's coastal wetlands. Improvements to the ecological health of the Dunnville Marsh complex would have ecological benefits for other areas. For instance, water quality improvements in the Grand River may enable some fish species to use the marshes as much needed spawning or nursery habitat. Reductions in turbidity would enable submerged macrophytes to grow in the marsh areas. The growth of submerged macrophytes would have broad benefits including the provision of new spawning habitat. Submerged macrophytes could also lead to improvements in water quality within the marsh by slowing the flow of sediment-laden water from the river, causing sedimentation at the fringe of the marsh. There is the potential for enhancing these benefits and improving the nutrient dynamics between the Grand River and Lake Erie with the restoration of the natural function of the adjacent floodplains. In a healthy state, the floodplain can have a positive influence on water quality, by providing nutrient storage and dampening the inflow of water from Lake Erie. A shift towards more natural flow regimes, including and improved connectivity between river reaches, wetlands and floodplains could yield important benefits in terms of improved water quality and aquatic community health in the Lake Effect Zone. The importance of the flow regime and connectivity to the ecology of Lake Effect Zone are well-known, but additional work is needed to determine specific information about current conditions and ecological flow needs in this area (Davies et al. 2005). This example demonstrates the need for addressing water quality concurrently with other limiting resource conditions. The full realization of these benefits can only be achieved if other constraints, such as hydrology, geomorphology, connectivity and natural heritage of the surrounding landscape are considered as part of broader watershed management planning and through initiatives parallel to the Water Management Plan, such as the Dunnville Marsh Management Plan and the Fisheries Management Plan.

The processes currently influencing the ecology of the nearshore are poorly understood and the ecosystem may still be in a state of transition (Charlton et al. 2009). While it is clear that water quality in tributaries such as the Grand River has the potential to have a large influence on both the nearshore and offshore ecosystem, the mechanisms or processes and sources of variability are poorly understood. These gaps hamper a systems approach to identifying the linkages between water quality and limiting resource conditions in the nearshore portion of the Lake Effect Zone. Regardless, the role of phosphorus as a key determinant of ecosystem health in the Lake Effect Zone as well as the offshore waters of Lake Erie's eastern basin has been clearly demonstrated (Ryan et al. 2003; Higgins et al. 2005; Charlton et al. 2009). Current conditions suggest that the influence of nitrogen on ecological health in the Lake Effect Zone is minor in comparison to phosphorus, so it may not currently be an important indicator of the Grand River's effect on Lake Erie. It is recommended, however, that there continue to be monitoring of nitrogen since loads (and thus ecological significance) appear to be increasing.

References

Aseel, K. 2009. Dissolved Oxygen Dynamics in the Dunnville Marsh on the Grand River, Ontario, Canada. Thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Master of Science in Biology. Waterloo, ON. xii + 81 p.

Binder T. R., Cooke S. J., and Hinch S. G. 2011. The Biology of Fish Migration. In: Farrell A.P., (ed.), Encyclopedia of Fish Physiology: From Genome to Environment, volume 3, pp. 1921–1927. San Diego: Academic Press.

Bouvier, L. D., and T .J. Morris. 2010. Information in support of a Recovery Potential Assessment of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadula*), and Rainbow (*Villosa iris*) in Canada. Research Document 2010/120. Fisheries and Oceans Canada, Burlington, ON. 57 pp. Accessed 02/13/12 from http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-5-2010-120.pdf

Canadian Council of Ministers of the Environment (CCME). 2004. Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems. In: Canadian environmental quality guidelines, 2004, Canadian Council of Ministers of the Environment, Winnipeg, MB.

Charlton, M. 2009. Status of Nutrients in the Lake Erie Basin. Prepared by the Lake Erie Nutrient Science Task Group for the Lake Erie Lakewide Management Plan. Presented at the Lake Erie Millennium Network 5th Biennial Conference, April 29 – May 1, 2008, University of Windsor, ON. vi + 34 p.

Chang-Kue, K. T. J. 1972. Physical and Chemical Limnology of the Lower Grand River. Master's thesis presented to the Faculty of Graduate Studies of the University of Guelph, ON. December 1972. vii + 151p.

Chow-Fraser, P. 1998. A conceptual ecological model to aid restoration of Cootes Paradise Marsh, a degraded coastal wetland of Lake Ontario, Canada. *Wetlands Ecology and Management*, 6(1): 43-57.

Cooke, S. 2006. Water quality in the Grand River: A Summary of Current Conditions (2000-2004) and Long Term Trends. Grand River Conservation Authority, Cambridge, ON. 98p.

Corbett, B., D. Crumb, P. General, S. George, L. Halyk, P. Mason, J. Robinson, T. Silver, O. Steel, and A. Yagi. 1997. Dunnville Marsh Management Plan. Dunnville Marsh Management Committee. Grand River Conservation Authority, Cambridge, ON. 17 pp.

COSEWIC [Committee on the Status of Endangered Wildlife in Canada]. 2006a. COSEWIC assessment and status report on the Mapleleaf mussel *Quadrula quadrula* (Saskatchewan-Nelson population and Great Lakes-Western St. Lawrence population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. Vii +58 pp. Accessed 02/13/12 from http://publications.gc.ca/collections/Collection/CW69-14-487-2006E.pdf

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2006b. COSEWIC assessment and status report on the river redhorse *Moxostoma carinatum* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 31 p.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2008. COSEWIC assessment and status report on the Fawnsfoot *Truncilla donaciformis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 39 pp. Accessed 03/07/2012 from http://publications.gc.ca/collections/collection_2008/ec/CW69-14-551-2008E.pdf

Davies, D., B. Haas, L. Halyk, R. Kenyon, S. Mackey, J. Markham, E. Roseman, P. Ryan., J. Tyson, and E. Wright. 2005. Lake Erie Environmental Objectives. Report of the Environmental Objectives Sub-Committee of the Lake Erie Committee Great Lakes Fishery Commission. 57 p.

Doyle, M., editor. 2008. Southern Grand River Ecosystem: Current Conditions and Rehabilitation Strategies, Lake Erie Lamp Workshop, Cambridge Ontario, March 4–5, Proceedings. Environment Canada, Burlington, ON.

Einhouse, D.W. and MacDougall, T.M. 2010. An Emerging View of the Mixed-Stock Structure of Lake Erie's Eastern-Basin Walleye Population. In Status of walleye in the Great Lakes: proceedings of the 2006 Symposium. Great Lakes Fisheries Commission Technical Report. 69. pp. 1-14.

General, P. and G. Warrick. 2009. *The Grand River Sturgeon Fishery*. Paper presented at the 2009 Symposium of the Ontario Archaeological Society, University of Waterloo, Waterloo, ON. Oct 17, 2009.

Gilbert, J. M., and P. A. Ryan. 2007. Southern Grand River Wetland Report. Ontario Ministry of Natural Resources, Lake Erie Management Unit, Port Dover, ON. vii + 107 p.

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L.C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. *Transactions of the American Fisheries Society*, 135: 408–419.

Goodyear, C. S., T. A. Edsall, D. M. Ormsby Dempsey, G. D. Moss, and P. E. Polanski. 1982. Atlas of the spawning and nursery areas of Great Lakes fishes. Vol. 9: Lake Erie. U. S. Fish and Wildlife Service, Washington, DC. FWS/OBS-82/52.

Hecky, R. E., R. E. Smith, D. R. Barton, S. J. Guildford, W. D. Taylor, M. N. Charlton, and T. Howell. 2004. The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 61(7): 1285-1293.

Heathcoate, I. W. 2002. River Zonation and Parameters of Concern in the Credit River Basin. Report prepared for Credit Valley Conservation. Wyndham Research Inc., Guelph, ON. 24 pp.

Higgins, S. N., T. E. Howell, R. E. Hecky, S. J. Guildford, and R. E. Smith. 2005. Wall of Green: The Status of *Cladophora glomerata* on the northern shores of Lake Erie's eastern basin, 1995-2002. *Journal of Great Lakes Research*, 31: 547-563.

Holm, E., N. E. Mandrak, and M. E. Burridge. 2010. The ROM Field Guide to Freshwater Fishes of Ontario. Royal Ontario Museum, Toronto, ON. 462 pp.

Henley W. F., M. A. Patterson, R. J. Neves, and D. A. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resources managers. *Reviews in Fisheries Science*, 8(2): 125-139.

Jackson, D. A.,T. Howell, B. Shuter, and C. C. Wilson. 2003. Environmental issues and the restoration of river and nearshore habitats and dependent fish stocks in eastern Lake Erie. Project completion report to Lake Erie Standing Technical Committee, Great Lakes Fish. Comm., Ann Arbor, MI.

Jennings, M. J., J. E. Claussen, and D. P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two walleye groups. *Transactions of the American Fisheries Society*, 125: 978-982.

Johnsen, P. B., and A. D. Hasler. 1980. The use of chemical cues in the upstream migration of coho salmon, *Oncorhynchus kisutch* Walbaum. *Journal of Fish Biology*, 17: 67-73.

Kaiser, A. S. 2009. Dissolved oxygen dynamics in the Dunnville Marsh on the Grand River, Ontario, Canada. A thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Master of Science in Biology. Waterloo, ON. .

Kerr, S. J., B.W. Corbett, N.J. Hutchinson, D. Kinsman, J.H. Leach, D. Puddister, L. Stanfield and N. Ward. 1997. Walleye habitat: A synthesis of current knowledge with guidelines for conservation. Percid Community Synthesis, Walleye Habitat Working Group, Ontario Ministry of Natural Resources, Peterborough, ON. 98 p.

Kerr, S.J., M.J. Davidson, and E. Funnell. 2011. A review of Lake sturgeon habitat requirements and strategies to protect and enhance Sturgeon habitat. MNR report 52581.Fisheries Policy Section, Biodiversity Branch. Ontario Ministry of Resources. Peterborough, ON. 58 p. + appendices. Accessed 02/14/12 from http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@letsfish/documents/document/stdprod_085836.pdf

Kuntz, T. 2008. System and plankton metabolism in the lower Grand River, Ontario. Masters of Science, Department of Biology, University of Waterloo, Waterloo, ON. 84p.

Lake Erie LaMP. 2011. Lake Erie Binational Nutrient Management Strategy: Protecting Lake Erie by Managing Phosphorus. Prepared by the Lake Erie LaMP Nutrient Management Task Group.

Loomer, H, and S. Cooke. 2011. (Draft) Water Quality in the Grand River Watershed: Current Conditions & Trends (2003 – 2008). Grand River Conservation Authority, Cambridge, ON. 175p.

Lougheed, V. L., B. Crosbie, and P. Chow-Fraser. 2001. Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: latitude, land use, and water quality effects. *Canadian Journal of Fisheries and Aquatic Science*, 58: 1603-1612.

Madsen, J. D., P. A. Chambers, W. F. James, E. W. Koch and D. F. Westlake. 2001. The interaction between water movement, sediment dynamics and macrophytes. *Hydrobiologia*, 444(1-3): 71-84.

MacDougall, T. M. and P. A. Ryan. 2012. An Assessment of Aquatic Habitat in the Southern Grand River, Ontario: Water Quality, Lower Trophic Levels and Fish Communities. Lake Erie Management Unit, Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Port Dover, Ontario. 140p. + appendices

MacDougall, T. M., C. C. Wilson, L. M. Richardson, M. Lavender and P. A. Ryan. 2007. Walleye in the Grand River, Ontario: an Overview of Rehabilitation Efforts, Their Effectiveness, and Implications for. Eastern Lake Erie Fisheries. *Journal of Great Lakes Research*, 33 (Supplement 1): 103–117.

Maynard, L. and Wilcox, D. 1997. Coastal Wetlands of the Great Lakes. State of the Lakes Ecosystem Conference Background Paper. Environment Canada. Cat. No. En40-11/35-2-1997E. Accessed 05/28/2012 from http://publications.gc.ca/site/eng/286015/publication.html

Metcalfe-Smith, J. L., G. L. Mackie, J. Di Maio, and S. K. Staton. 2000. Changes over time in the diversity and distribution of freshwater mussels (Unionidae) in the Grand River, Southwestern Ontario. *Journal of Great lakes Research*, 26(4): 445-459.

Natural Heritage Information Centre (NHIC). 2012. Natural Areas Summary Report for Ontario Ministry of Natural Resources, Peterborough, Ontario. Queen's Printer for Ontario. Accessed June 7, 2012 from http://www.biodiversityexplorer.mnr.gov.on.ca/nhicWEB/nhicIndex.jsp

Natural Resources Research Institute. 2004. Eastern Sand Darter Status Assessment. NRRI Technical Report No. NRRI/TR-2003/40. 44 p.

NatureServe. 2011. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1 NatureServe, Arlington, Virginia. Accessed March 9, 2012 from http://www.natureserve.org/explorer.

Nelson, R. W., J. R. Dwyer, and W. E. Greenberg. 1987. Regulated flushing in a gravel-bed river for channel habitat maintenance: a Trinity River fisheries case study. *Environmental Management*, 11(4): 479-493.

New, J. G., L. A. Fewkes, and A. N. Khan. 2001. Strike feeding behaviour in the Muskellunge, *Ezox Masquinongy*: Contributions of the lateral line and visual sensory systems. *Journal of Experimental Biology*, 204: 1207-1221.

Ohio Lake Erie Phosphorus Task Force (OLEPTF). 2010. Ohio Lake Erie Phosphorus Task Force Final Report. http://www.epa.ohio.gov/dsw/lakeerie/ptaskforce/index.aspx

Ontario Biodiversity Council. 2011. Ontario's Biodiversity Strategy, 2011: Renewing Our Commitment to Protecting What Sustains Us. Ontario Biodiversity Council, Peterborough, ON. ISBN 978-1-4435-6955-2 (Print). 69 pp.

Ontario Ministry of Natural Resources (OMNR). 2006. Status of the Fish Community and Fisheries in Eastern Lake Erie; Results from the 2000-2004 East Basin Rehabilitation Plan. Lake Erie Management Unit, ISBN 1-4249-0960-0. 113 pp. + appendices.

Ontario Ministry of Natural Resources. 2010. Biodiversity Explorer. Natural Heritage Information Centre database (NHIC, 1.2 General User). Website content last updated from NHIC on 07/30/2010. Accessed from March 9, 2012 from http://www.biodiversityexplorer.mnr.gov.on.ca/nhicWEB/main.jsp

Ontario Ministry of Natural Resources (OMNR). 2011. 2010 Status of Major Stocks. Lake Erie Management Unit, ISSN 1718-4924 (Print), ISBN 978-1-4435-6432-8 (Print, 2010 ed.), ISSN 1925-5454 (Online), ISBN 978-1-4435-6433-5 (PDF, 2010 ed.). 69 pp.

Ontario Ministry of Natural Resources and Grand River Conservation Authority (OMNR and GRCA). 1998. Grand River Fisheries Management Plan. 105 p.

Ontario Ministry of Natural Resources and Grand River Conservation Authority (OMNR and GRCA). 2001. Technical Background Report the Grand River Fisheries Management Plan.

Parker, B. J. 1988. Updated status of the river redhorse, *Moxostoma carinatum*, in Canada. *Canadian Field-Naturalist* 102:140-146.

Portt, C., G. Coker, and K. Barrett. 2007. Recovery Strategy for Fish Species at Risk in the Grand River in Canada [Proposed]. In Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. 104 pp.

Ryan, P.A. 2004 (draft). Habitat Objectives for TSS, Temperature and Dissolved Oxygen and Strategy to Support Rehabilitation of Yellow Perch and Walleye Stocks in Lake Effect Zones of Tributaries and Coastal Wetlands, of the Lake Erie and the St. Clair Corridor. Lake Erie Management Unit, OMNR File Report. 12p. + tables.

Ryan, P. A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. Fish-community goals and objectives for Lake Erie. *Great Lakes Fishery Commission Special Publication* 03-02. 56 p.

Scott, W. B. and E. J. Crossman. 1998. Freshwater Fishes of Canada. Galt House Publications Ltd. Oakville, ON. xx + 966 p.

State of the Lakes Ecosystem Conferences (SOLEC). 2011. Great Lakes Indicator Review: Findings and Future Direction. Accessed 4/20/2012 from http://solecregistration.ca/en/indicator_review.asp

Statistics Canada. 2012. GeoSearch. 2011 Census. Statistics Canada Catalogue no. 92-142-XWE. Ottawa, Ontario. Last updated February 8, 2012. Accessed 02/21/2012 from http://geodepot.statcan.gc.ca/GeoSearch2011-GeoRecherche2011/GeoSearch2011-GeoRecherche2011.jsp?lang=E&otherLang=F

Staton, S. 2008. Aquatic Species at Risk in the Southern Grand River. Page 17 in: *Southern Grand River Ecosystem: Current Conditions and Rehabilitation Strategies, Lake Erie Lamp Workshop, Cambridge Ontario, March 4-5, Proceedings*, M. Doyle, editor. Environment Canada.

Staton, S. K. 2012 (draft). Southern Grand River Species at Risk: Fishes and Freshwater Mussels.

Stepien, C. A. and J. E. Faber. 1998. Population genetic structure, phylogeography and spawning philopatry in walleye (*Stizostedion vitreum*) from mitochondrial DNA control region sequences. *Molecular Ecology*, 7: 1757-1769.

Søndergaard, M., J. Peder Jensen, and E. Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia*, 506-509: 135-145.

Trebitz, A. S., J. C. Brazner, V. J. Brady, R. Axler, and D. K. Tanner. 2007. Turbidity tolerances of Great Lakes coastal wetland fishes. *North American Journal of Fisheries Management*, 27(2):619-633.

Waters, T. F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7.

Wetzel, R. G. 2001. Variations in Oxygen Distributions. Pages 158-164 in: *Limnology: Lake and River Ecosystems*. Third Edition. Academic Press, San Diego.

Young, J. A. M., and M. A. Koops. 2010. Recovery potential modelling of Eastern Pondmussel (*Ligumia nasuta*), Fawnsfoot (*Truncilla donaciformis*), Mapleleaf (*Quadrula quadula*), and Rainbow (*Villosa iris*) in

Canada. Research Document 2010/119. Fisheries and Oceans Canada, Burlington, ON. 14 pp. Accessed 02/13/12 from http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-5-2010-119.pdf

---

Endnotes

[i] The purpose of the SOLEC indicators was to enable reporting on conditions at a particular point in time and trends over time. The suite of indicators identified by the SOLEC was intended to be used to produce a "big picture perspective" for the Great Lakes basin that built a common decision making tool for federal, state, provincial, and local management organizations (SOLEC 2011). The suite of indicators covered a very broad range of variables and was divided among categories defined by a DPSIR (Driving forces, Pressures; State of environment; Impacts; Response) framework. The SOLEC 'State' indicators are illustrative of "how the Great Lakes are doing" and most similar to the concept of indicators used by the Water Management Plan update. SOLEC State indicators span three sub-categories: Chemical, Biological and Physical Integrity. To some extent, these three subcategories mirror the definition of indicators in the Water Management Plan update; however, there is a large difference in scope between the SOLEC and Water Management Plan update. The ecosystem approach used by the SOLEC indicators includes the management of natural heritage features and wildlife, which are outside the scope of the *Water* Management Plan update. In addition, many of the SOLEC State indicators are not relevant or specific to the resource conditions at the scale of the management unit used by the Water Management Plan update (i.e. Area of Focus). Despite this, the range of indicators was informative of the gaps in information or understanding about the ecosystem within Areas of Focus . For instance, very little is known about some types of aquatic dependant wildlife in the Grand River (e.g., invertebrates and amphibians). Consequently, once these gaps are addressed, additional indicators may be apparent and should be incorporated into the next update of the Water Management Plan.