GRAND RIVER WATERSHED
Water Management Plan

Grand River Water Management Plan 2013 Update

Water Quality Targets to Support Healthy and Resilient Aquatic Ecosystems in the Grand River Watershed

Report from the Water Quality Working Group

February 2013

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Members of the Water Quality Working Group

Crystal Allan (GRCA)
Mark Anderson (GRCA)
Jose Bicudo (Region of Waterloo)
Dave Bray (OMAFRA)
Luca Cargnelli (EC)
Sandra Cooke (GRCA)
Craig Fowler (OMOE)
Natalie Feisthauer (AAFC)
Sandra George (EC)
Claire Holeton* (GRCA)
Todd Howell (OMOE)
Pamela Joosse (AAFC)
Selvi Kongara (City of Brantford)
Anne Loeffler (GRCA)
Tom MacDougall (OMNR)
Kevin McKague (OMAFRA)
Mohamed Mohamed (OMOE)
Tracey Ryan (GRCA)
Mary Ellen Scanlon (OMOE)

* *research and writing, with input from the group*

Suggested Citation

Grand River Water Management Plan. 2013. *Water Quality Targets to Support Healthy and Resilient Aquatic Ecosystems in the Grand River Watershed*. Prepared by the Water Quality Working Group. Grand River Conservation Authority, Cambridge, ON.

Acknowledgements

This report was greatly improved by the technical expertise and insight provided by members of the Water Quality Working Group, members of the Science Advisory Committee to the Water Management Plan, and other experts including Jack Imhof (Trout Unlimited Canada) and Tim Fletcher (OMOE), whose reviews helped to improve the clarity and content in draft versions of this report.

Abbreviations

AAFC	Agriculture and Agri-Food Canada
CCME	Canadian Council of Ministers of the Environment
CEQG	Canadian Environmental Quality Guidelines
DO	Dissolved oxygen
EC	Environment Canada
GRCA	Grand River Conservation Authority
NTU	Nephelometric Turbidity Units
OMNR	Ontario Ministry of Natural Resources
OMOE	Ontario Ministry of the Environment
PWQO	Provincial Water Quality Objectives
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency

Executive summary

As part of the 2013 update to the Water Management Plan for the Grand River watershed, a set of recommendations was assembled by the Water Quality Working Group including targets for conditions that support healthy aquatic ecosystems. This report details the targets recommended for a set of aquatic resource condition indicators for the Grand River watershed. It reflects previous work to identify indicators of resource conditions related to water quality that support healthy, resilient ecosystems (GRWMP 2012) and a synthesis of scientific information in the context of water resource management. The targets are informed by science and reference the ecological requirements of aquatic communities. The targets recommended in this report complement the existing set of water management tools; they are not intended to replace existing policies, legislation, and regulations. The targets enable Water Management Plan partners to use a coordinated approach for the quantitative assessment of conditions in a manner that is specific and appropriate to the Grand River watershed.

A target was defined as *"a quantitative description of a system condition that will cause the broad water objectives to be met*". The broad water objectives of the plan describe many aspects of aquatic ecosystems that are desired, such as resilient and biodiverse aquatic, riparian and wetland communities; quantities of aquatic vegetation and algae growth that are beneficial for aquatic foodwebs but not excessive such that harmful effects occur; chemical, physical and biological integrity of the river and lake ecosystems; water quality and quantity that meet the requirements of aquatic species, including sport fish and commercial fisheries. The targets can be used to gauge whether aquatic resource conditions are able to support these desired features of healthy and resilient ecosystems now and into the future.

A necessary first step preceding the establishment of targets was the selection of appropriate indicators. In this context, an indicator is defined as "*a variable, typically measurable, that reflects a quantitative or qualitative characteristic that is important for making judgments about resource conditions and relates back to the broad water objectives of the Water Management Plan*". Indicators for resource conditions that limit aquatic communities in the Lake Effect Zone were identified by the Grand River – Lake Erie Working Group (GRWMP 2012). The exercise focused on the mechanisms by which poor water quality currently impairs the structure and function of ecosystems. It considered a broad range of factors including those that influence water quality, such as the flow regime and water levels. Subsequent assessment of information available for other key areas of the watershed, such as the central Grand River region and the headwater regions, demonstrated that the initial list of indicators covered some of the basic resource condition requirements for a broad range of ecosystems. The assessment of other key areas also highlighted toxic forms of nitrogen (ammonia and nitrate) and chloride as important additions to the list of indicators for resource conditions that support healthy aquatic ecosystems in the Grand River watershed.

To develop targets for each of the resource condition indicators, information was sought on the desired ecological endpoints and potential sources of variability (e.g., seasonality, flow regime). Existing guidance and supporting scientific information were reviewed from various jurisdictions (e.g., Canadian, provincial and United States etc.) and evaluated in the context of the Grand River watershed. The synthesis of information and recommended targets for the following prioritized indicators are described in this report: dissolved oxygen, suspended particulate matter (turbidity, suspended solids), toxic forms of nitrogen (nitrate and ammonia), temperature, and nutrients. Targets for other resource condition indicators (e.g., macrophyte community, flow, chloride) will continue to be developed within an adaptive management framework.

Some of targets take the form of a single threshold value separating a desired range of conditions (i.e. that support healthy ecosystems) from an undesirable range. Other targets include multiple criteria, to

account for a broader range of conditions; this was necessary since variability is a natural (and in some cases desirable) feature of an ecosystem (Landres *et al.* 1999). Since water quality is influenced by dynamic natural processes (e.g., weather) and location-specific characteristics (e.g. physiography), it is inherently variable with time and space. Where feasible, targets were specified to bracket the *range* of values (e.g., upper or lower thresholds) that quantify conditions required for healthy, resilient ecosystems. Where it was not feasible to specify numeric criteria, a narrative description of indicator conditions was given.

Numeric criteria specified by targets represent a threshold of resource conditions that separate the desired state from one in which there are adverse effects on valued ecosystem features or processes. For the target to be met, conditions should *at least* attain the threshold of desired conditions, if not surpass it. Where conditions do not meet the target, actions that decrease the likelihood of falling outside the desirable range of conditions will contribute to a shift towards a healthy state. Such actions may also help to increase ecosystem resiliency, but do not necessarily guarantee the transition to a healthy ecosystem, since ecosystem state is affected by many factors (e.g. inter- and intra-species competition) as well as natural variability. Regardless, an increase in frequency, duration and extent to which conditions are within the desired state is a good indication of a shift towards a healthy, resilient ecosystem.

Although this process was not comprehensive in the review of all ecological requirements for all aquatic species in the Grand River watershed, it is a starting point. More work is needed. A more detailed review of information from other areas of the watershed may provide further insight into the ecological needs of the broader aquatic community. When new information becomes available, it should be incorporated into the indicators and targets framework for the watershed's Water Management Plan.

Preface on ecosystem health in the Grand River watershed

The term "ecosystem health" is commonly used in the context of resource management and although it is infrequently defined, can take on a variety of interpretations. To aid the reader, we offer the following description of ecosystem health in the context of the Water Management Plan for the Grand River watershed.

Conceptually, ecosystem health incorporates the status of individual components, such as the plants and animals or state of abiotic factors (e.g., nutrients) as well as the processes by which they interact. Although rooted in ecological concepts, the state described as 'healthy' is chosen on the basis of human values. An ecosystem can be said to be healthy when the interaction of the components produces a system with preferred attributes and functions (Lackey 2001). Consequently, the frame of reference for what defines a healthy ecosystem (i.e. the desired ecological endpoints) may vary, depending on the context. Ecosystems in a less-modified state are usually considered to be more healthy, but an ecosystem need not necessarily be pristine to be healthy. Given the widespread alteration of landscapes, transplantation of species and the global nature of climate change, few ecosystems could now be considered truly pristine (i.e., free from anthropogenic influence) (Hobbs *et al.* 2009).

In the Grand River watershed, hundreds of years of anthropogenic alterations have resulted in changes in the composition of aquatic communities, and in some places, fundamental or irreversible changes in the structure and function of the aquatic system. It is likely that aquatic ecosystems in the Grand River watershed will never return to pre-settlement conditions. That said, the Water Management Plan partners can strive for healthy aquatic ecosystems which maintain, enhance or restore critical watershed functions which in turn, help to sustain aquatic communities.

1. Introduction

1.1. The Water Management Plan

The Water Management Plan focuses on water resources in the Grand River watershed; it is a key component of integrated watershed planning work that will support the development of a broader integrated watershed plan. This update to the plan will reflect the considerable knowledge, tools and networks that have been developed since the last substantial revision in 1982. The updated Water Management Plan will align the efforts of all partners: GRCA, watershed municipalities, provincial and federal representatives, key stakeholders, industry and business, the agricultural community and watershed residents. It will document actions to which the partners commit and galvanize all participants to achieve mutually supported targets for sustainable water management, flood control and water quality improvements.

The updated Water Management Plan aspires to the following goals:

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

Support for these goals is developed through the process of identifying broad water objectives, indicators and targets (Table 1), which inform specific actions that can be implemented by partner agencies. The broad water objectives were created through a collaborative process that gathered the collective viewpoints of the partners to the plan and other stakeholders. The process of identifying indicators and targets for achieving the broad water objectives was informed by science and interpreted in the context of water management.

Table 1. Definitions of common terms used in the Water Management Plan

Broad water objective:	a qualitative description of a desired state or system condition in the Grand River watershed that meets the current uses, needs and values of ecosystems, communities, and economies.
Indicator:	a variable, typically measurable, that reflects a quantitative or qualitative characteristic and that is important for making judgments about resource conditions and relates back to the broad water objectives.
Target:	a quantitative description of a system condition that will cause the objectives to be met. A target can be a minimum, maximum, range, single value, or regime, general to the Grand River watershed or specific to a selected area.
Milestone (Interim Target):	a quantitative description of 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, against which achievement is measured and represents a step towards achieving a Target.

This report outlines recommendations and rationale for targets associated with the following broad water objectives that describe some of the desired conditions that support of ecosystem health:

- Water quality supports the health and biodiversity of aquatic, riparian and wetland communities
- 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 quality and quantity needs of sport fish populations are met, such that angling opportunities and community benefits are realized.
- Water quantity and quality are sufficient for optimal production of Grand River specific stocks for commercial fisheries.

Additional broad water objectives related to water quantity and environmental flows were also stated as part of the update to the Water Management Plan, but are considered as part of parallel, but separate processes within the plan update:

- The flow regime supports healthy river processes.
- The flow regime supports the lifecycle requirements of aquatic and riparian species.
- Groundwater recharge and discharge function is maintained, such that water quality, water availability and habitat are supported.

1.2. Quantifying the requirements for healthy aquatic ecosystems

As part of the 2013 update to the Water Management Plan, targets will be established for indicators of the resource conditions that support healthy, resilient aquatic ecosystems in the Grand River. Whereas indicators provide a variable with which to measure the status of resource conditions required for healthy ecosystems, targets identify a frame of reference to quantitatively assess the status of those conditions.

Indicators

In the Water Management Plan, indicators are variables that are useful for making judgments about the resource conditions that can be improved by water management (Table 1). Indicators are used to describe conditions that can be impacted by human-related disturbance, but if improved, will support needs of the aquatic community and contribute to a healthy ecosystem state. Indicators provide information about the way in which aquatic resource conditions affect the desired ecological state. A change in a resource condition indicator will contribute to an ecological change, but may not produce a measureable change in the biotic condition of the ecosystem since the aquatic community is influenced by multiple environmental factors as well as interactions with other biological elements (e.g. inter or intra-specific competition).

To identify resource condition indicators, a framework was developed by the Grand River – Lake Erie Working Group that focused on the region that connects the Grand River to Lake Erie (GRWMP 2012). The area was later refined to the “Lake Effect Zone”. The framework identified the resource condition requirements of aquatic species (e.g. fish, invertebrates) in order to highlight the conditions which are currently limiting ecosystem health in the Lake Effect Zone. Indicators of water resource conditions impacting the Lake Effect Zone included dissolved oxygen, turbidity, suspended solids, temperature, nutrients (e.g. phosphorus), flow regime and macrophyte communities. Subsequent assessment of the information available for the other key areas of the watershed such as the central Grand River region and the headwater regions highlighted similar resource condition needs for some of the aquatic species in those areas. In addition to the indicators selected for the Lake Effect Zone, toxic forms of nitrogen (ammonia and nitrate) and chloride were considered to be important indicators of resource conditions for other areas. The process of identifying indicators was neither comprehensive nor complete, but it helped to characterize the linkages between aquatic species and resource conditions that can be improved by water management.

To date, the identified indicators focus on stressors, rather than on the response of the biological community. While these indicators will provide useful information about how management actions are changing environmental stressors, it is anticipated that a complementary approach will be used to gage whether the changes are having the desired result on aquatic communities.

Targets

In the Water Management Plan, a target is defined as a quantitative description of a system condition that will cause the broad water objectives of the plan to be met (Table 1). Targets are useful to water managers as a tool for comparison of resource conditions with those that support healthy aquatic ecosystems; the information this comparison yields will help the plan partners gauge the conditions in the Grand River watershed that could be improved to increase support for healthy, resilient aquatic ecosystems. The identification of a target includes a description of the desired ecosystem attributes, features or processes that define the frame of reference for healthy aquatic ecosystems. The quantification of targets is informed by science and information about the ecological conditions that support the needs of aquatic communities.

The identification of the frame of reference that defines a healthy ecological state is an important step in the determination of targets. This process involves interest or value-based judgements, since it is focused on the selection of desired ecological attributes or functions. Once the frame of reference is identified, science can inform the process by which a quantitative expression of the target is determined. Information about the relationship between the desired biological elements and an indicator of resource conditions can guide the identification of a target that quantitatively describes the environmental conditions required to achieve healthy ecosystems.

To identify targets, it is useful to consider the expected response of biological elements of an ecosystem (e.g. biodiversity, vitality) to the type of changes in ecosystem conditions that are known to occur with anthropogenic disturbance. This response typically describes a relationship in which biological quality worsens with increasing anthropogenic disturbance. Science can provide an estimate of these relationships (e.g. through analysis of monitoring data or physiological studies), but estimates are often imprecise due to natural sources of variability (e.g. influence of season or hydrologic state) and uncertainty in the data. A precise quantification of the state can also be difficult since there may not be a sharply defined boundary marking the transition from a healthy state to a degraded one. One type of relationship (i.e., a sigmoidal curve) is illustrated as an example in Figure 1, but other types of relationships are also possible. Although only a portion of the variation in the biological condition is driven by the state of the resource condition indicator, it is this portion that offers an opportunity for the management of water such that it supports the health and resilience of aquatic ecosystems.

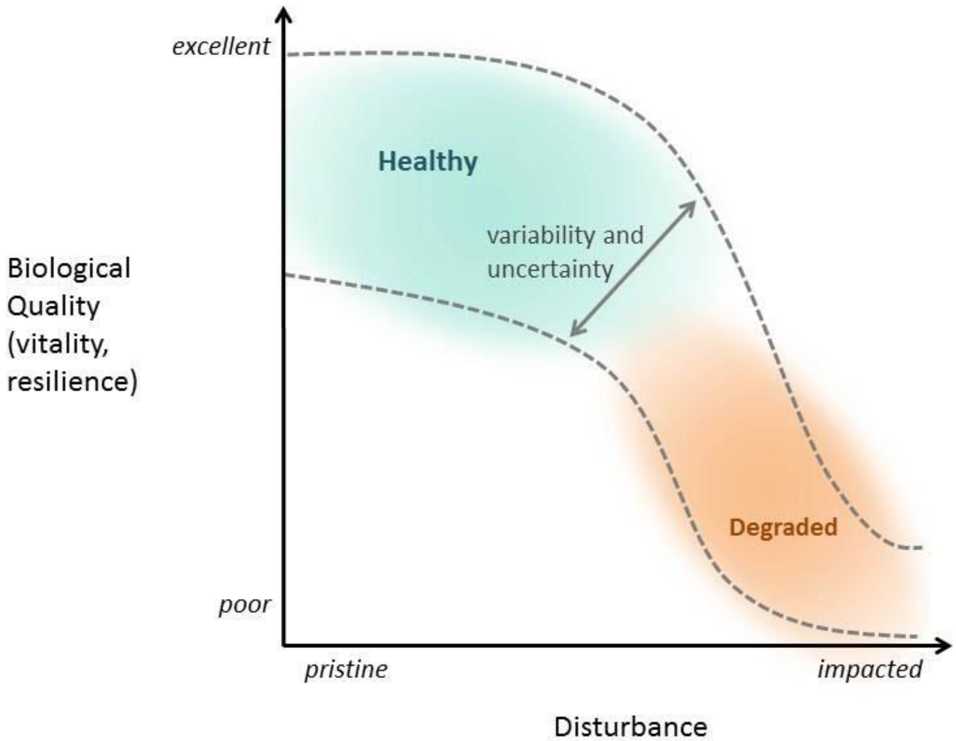


Figure 1. Schematic illustrating the shift from a healthy to a degraded ecosystem as biological quality worsens in response to a disturbance that alters environmental conditions.

The resource conditions required to achieve the desired biotic state may vary with the context in which the target is used. For instance, natural characteristics such as stream order or geology may moderate or change the response of the desired biological elements to environmental conditions (Figure 2). These factors need to be taken into account in the identification of targets that are specific and appropriate for the context of aquatic ecosystems in the Grand River watershed; however, in cases where specific information is not available, it may be necessary to use a generic target.

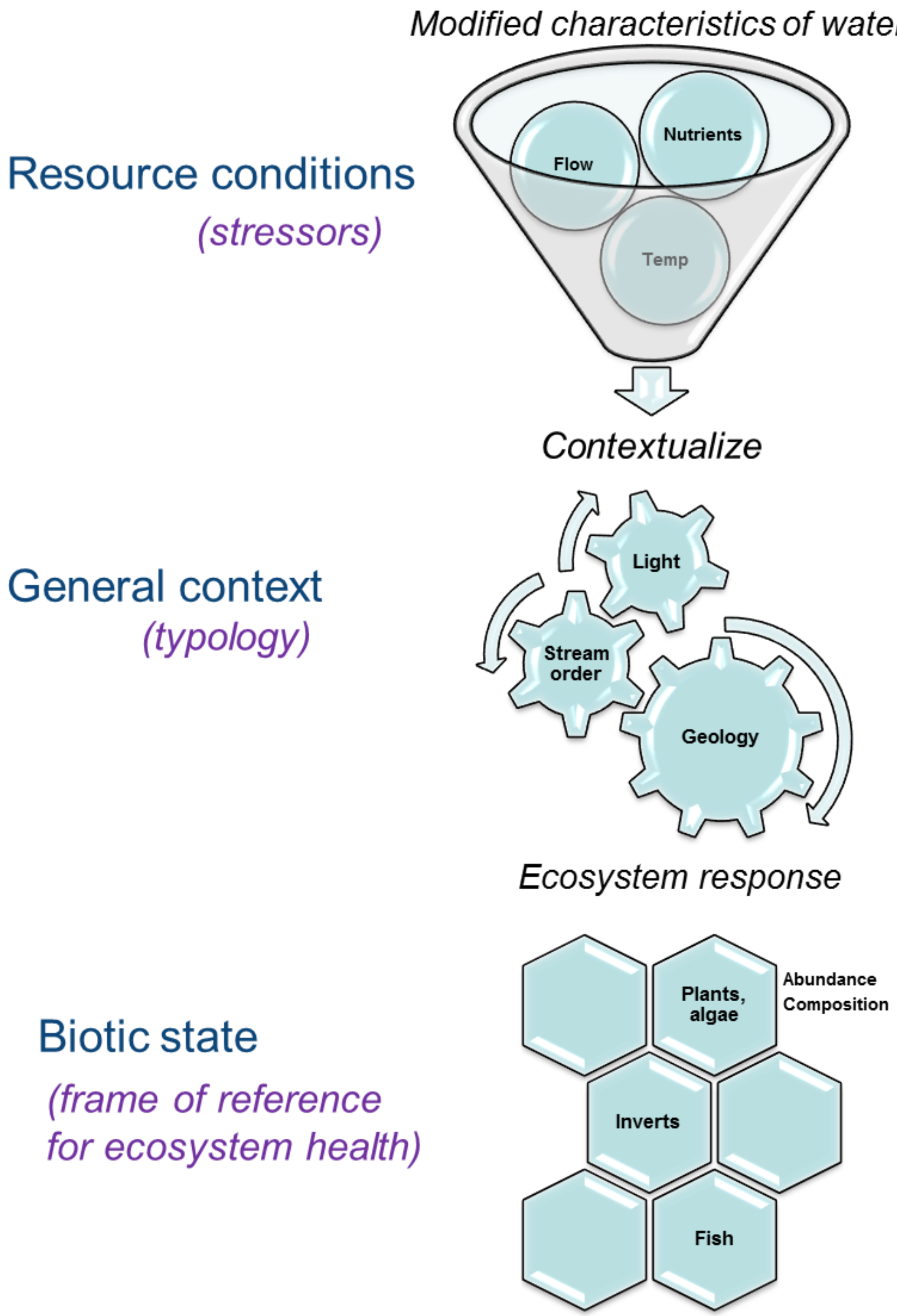
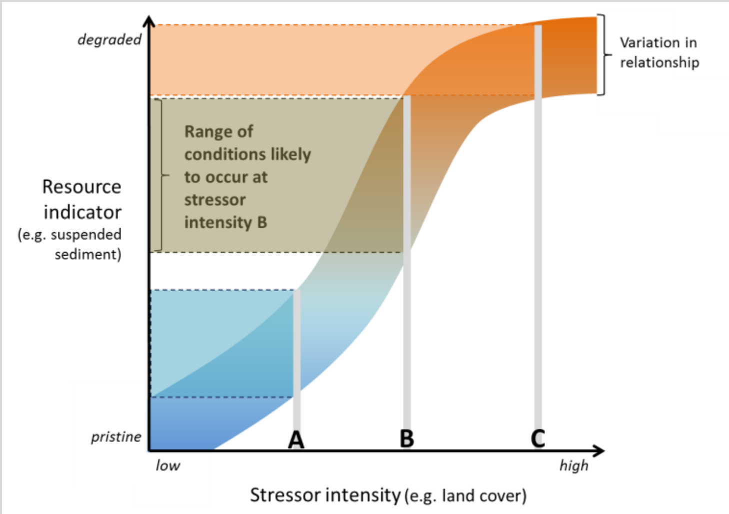


Figure 2. Conceptual diagram illustrating the influence of site -specific characteristics (often generalized into categories or classified by typology) on the ecosystem response to characteristics of water that can function as stressors.

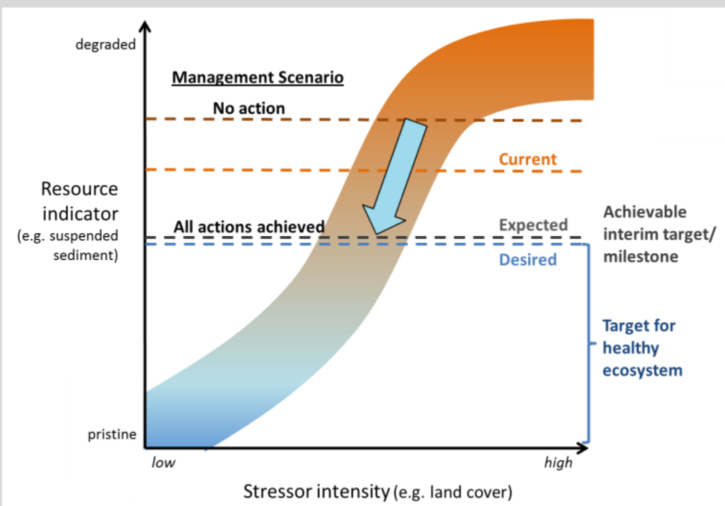
Interim Targets

To progress towards targets, the Water Management Plan will also set interim targets (also termed milestones) once management actions have been identified. An interim target is a quantitative description of the system condition that is expected to be achieved as a result of implementing the specific actions set out in the plan (Table 1). Whereas target identification is informed by science, interim targets are informed by management actions that are agreed to by partners of the Grand River Water Management Plan. Interim targets benchmark the *expected* resource conditions that would result from actions, such as wastewater treatment plant upgrades, that are achievable in the current planning horizon. In Box A., an hypothetical example illustrates how interim targets quantify the progress expected to be achieved by actions that aim to minimize or mitigate the impact of a stressor, such as land use. The example also demonstrates that in some cases the target may not be achieved, even with the adoption of currently available and recommended best available processes and technologies. It is important to recognize that the expected improvements resulting from actions agreed to in the plan are constrained by the scope of water management. Achievement of the target of a healthy aquatic ecosystem can also be supported by an holistic approach that includes other components of the broader Integrated Watershed Plan for the Grand River watershed.

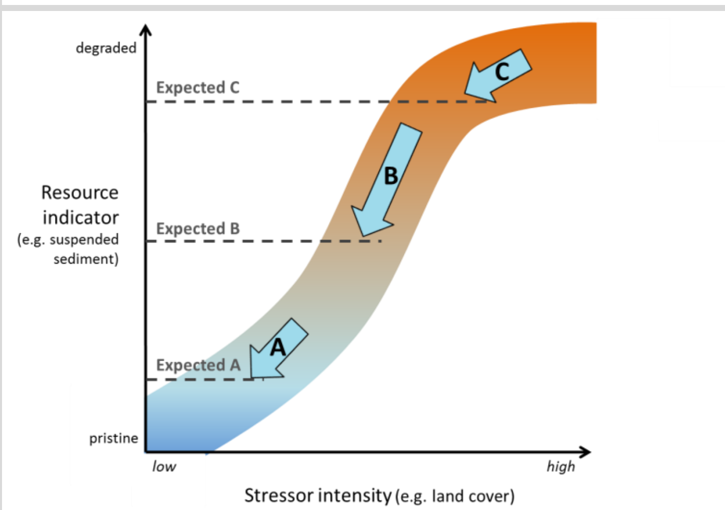
Box A. Schematic illustrating how interim targets quantify the expected level of progress toward the target of aquatic ecosystem health that is achievable through management actions.



Resource condition indicators are influenced by the intensity of stressors. For instance, resource conditions at A and B are less degraded than C due to a lower stressor intensity. The range of conditions at A will be most likely to support a healthy ecosystem. At B and C, **management actions are required to shift the range of conditions towards a healthy ecosystem.**



Degraded conditions may currently exist where stressor intensity in high, but can be improved by management actions that reduce the stressor or mitigate its effects. Dashed lines indicate average conditions under different management scenarios. **Progress towards the target of a healthy aquatic ecosystem is benchmarked by interim targets that are achievable by management actions.** The interim targets are determined from the conditions expected to result from the actions that are agreed to as part of the Water Management Plan.



Improvements in response to management actions may not achieve the healthy ecosystem target in all cases. The range of achievable conditions may be limited by irreversible changes to the landscape or aquatic community. As shown in the case of C, use of all currently available and feasible best available processes and technologies may be insufficient to achieve target conditions without other means (e.g. change in land use) that are achievable in the current planning horizon. In the future, advances in the effectiveness or scope of management actions may help shift the range of achievable conditions further towards the healthy ecosystem target.

2. Tools and considerations for target setting

2.1. Considerations for information synthesis

To guide the creation of targets which describe the conditions necessary for ecosystem health, a number of considerations can be used to identify information about each indicator that is ecologically relevant to the Grand River watershed. This series of considerations were used to aid in the formulation of targets:

Step 1: *Is there a guideline / target for this parameter?*

- *Is it appropriate for the area of interest? (if yes, then adopt it)*

Step 2: *Are there comparable ecosystems?*

- *Is this an appropriate frame of reference for the desired state? (if yes, then quantify target from reference conditions)*
- *Is there a guideline/ target for this system? (if yes, then adopt it)*

Step 3: *Weight of evidence from literature and observations*

- *What is relationship between biota and indicator parameter? (Set target based on the desired condition of biota)*

If followed in order, the steps place an emphasis on the use of existing assessments that have been used to develop guidance (e.g. standards, targets, objectives, criteria etc.) for the protection of aquatic life.

2.2. Sources of guidance - background

As a first step in the description of targets for aquatic ecosystem health, it is helpful to draw on existing assessments that quantify the conditions that support a healthy aquatic community. Such assessments are often done by governmental agencies to create a source of guidance for a regulatory framework that seeks to protect ecosystem health. Although assessments for different jurisdictions (e.g. provincial, Canadian) have a common aim at a broad level, the definition of what is considered 'acceptable' may vary (e.g., low risk vs. no adverse effects). Consequently, it is important to consider the purpose for which each source of guidance was created and the scope of application for which it was intended.

Provincial Water Quality Objectives

Ontario Provincial Water Quality Objectives (PWQOs) represent a level of water quality that is *desirable* to maintain in all surface waters throughout the province. They describe conditions that are "protective of all forms of aquatic life and all aspects of the aquatic life cycle during indefinite exposure to the water" (OMOE 1994). Additional PWQOs have been set to protect recreational water uses; these objectives were derived using public health and aesthetic considerations.

PWQOs established for the protection of aquatic life are based on data compiled by a review of global aquatic toxicological information (OMOE 1979). For a PWQO to be established, compiled data must meet the minimum criteria of information in each of three categories: aquatic toxicity, bioaccumulation and mutagenicity. The PWQO value corresponds to the lowest effect concentration for any of these effects plus a uncertainty factor (related to the quantity and quality of data available).

Some considerations must be taken into account in the use of PWQOs for the protection of aquatic community health. The individual PWQOs do not account for joint toxicity (additive, antagonistic, or synergistic effects of substances present as a mixture) (OMOE 1994). As a result, conditions in which several parameters are at or near PWQOs may not be fully protective of aquatic life. It is also acknowledged that in some situations PWQO values may not adequately describe the full range of natural variability and the application of site-specific information and/or biomonitoring studies are recommended (OMOE 1994).

Canadian Environmental Quality Guidelines

Canadian Environmental Quality Guidelines (CEQG) for the Protection of Aquatic Life are established by the Canadian Council of Ministers of the Environment (CCME). The protocol for deriving guidelines was recently updated in response to advances in the field of toxicology and better understanding of the environmental impact of toxic substances (CCME 2007). Consistent with the original approach, the Guidelines are derived using the most recent scientific information as a science-only benchmark with no regulatory component. The CEQG are numerical concentrations or narrative statements that describe conditions that should result in "*negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support*" (CCME 1999a). As with PWQO's for Ontario, the approach to determining EQGs for the protection of aquatic life considers all aspects of life-cycles (CCME 2007). To derive the CEQG, the CCME follow the guiding principle to protect all aquatic life, including all aspects of the aquatic life cycles of the most sensitive species and life stage over the long term, from the negative effects of exposure to anthropogenic inputs or alterations to environmental parameters (e.g. temperature, dissolved oxygen).

In correspondence with the updated guiding principles for the CEQG, many of the recently revised CEQG for the protection aquatic life specify values for both long and short term exposures. The CEQG for long and short term exposures are intended to be used in consort. Since the benchmarks identified by guidelines for short term exposures only infer protection for a specified fraction of individuals from acute effects during transient conditions, they do not fulfill the guiding principle of full protection for aquatic life. Consequently, in the context of the Water Management Plan, the long-term CEQG may be more relevant to the identifying the requirements for a resilient, healthy ecosystem. Where a single value is specified as a CEQG, it is based on a long-term no-effect concentration (CCME 1999a). The CEQG are intended to provide the basis for the derivation of site-specific guidelines and objectives that account for different conditions and/or requirements.

National Agri-Environmental Standards Initiative

National Agri-Environmental Standards Initiative (NAESI) was a partnership between Environment Canada and Agriculture and Agri-Food Canada, to develop a set of national non-regulatory environmental performance standards (Bowerman *et al.* 2009). The standards included Ideal Performance Standards (IPS), science-based measures of the environmental condition needed to maintain ecosystem health. The information was intended to inform the relationship between agriculture and the environment, so the desired measure of environmental condition was identified with data from agricultural watersheds using a regional approach. Although the approach captured data from locations with a range of characteristics, data from the Ontario Mixedwood Plain region (that contains the Grand River watershed) included only wadable streams with catchment areas ranging from 0.04 to 75.7 km^2 and <10% urban land cover upstream.

To derive the IPS, water quality data (physical/chemical parameters) from agricultural watersheds was analysed using a variety of statistical methods with the aim of determining unimpacted conditions. To ensure the resulting values represented a healthy ecosystem, the IPS were then cross-referenced to measures of biological endpoints (e.g., diversity of benthic macroinvertebrates) that have functional associations with the indicator.

U.S. Water Quality Criteria

The United States Environmental Protection Agency (USEPA) developed water quality criteria to assist in the development of water quality standards. The criteria are based on a non-regulatory, scientific assessment of the scope and extent of all identifiable effects from pollutants in any water body, including groundwater (USEPA 1986). Criteria for the protection of aquatic life are based solely on data and scientific judgements about the relationship between pollutant and environmental effects. They do not consider economic impacts or the feasibility of meeting the criteria values. There is an allowance for site-specific modifications of the criteria, based on local environmental conditions. The type of considerations that should be made for local conditions are outlined in technical guidance reports that accompany each set of criteria.

3. Dissolved oxygen

3.1. Ecological context

A balanced and diverse aquatic ecosystem depends on the availability of a minimum level of dissolved oxygen (DO) at any given time. It is well established that low DO levels can have lethal and chronic (e.g. behavioural or physiological changes) impacts on aquatic organisms, especially fish, with early life stages usually being the most sensitive.

Oxygen requirements are particularly important at increased temperature, since biological processes such as respiration increase and ambient concentrations of DO decrease. Due to the relationship between oxygen saturation and water temperature (Figure 2), the availability of oxygen can become reduced by the warming of water.

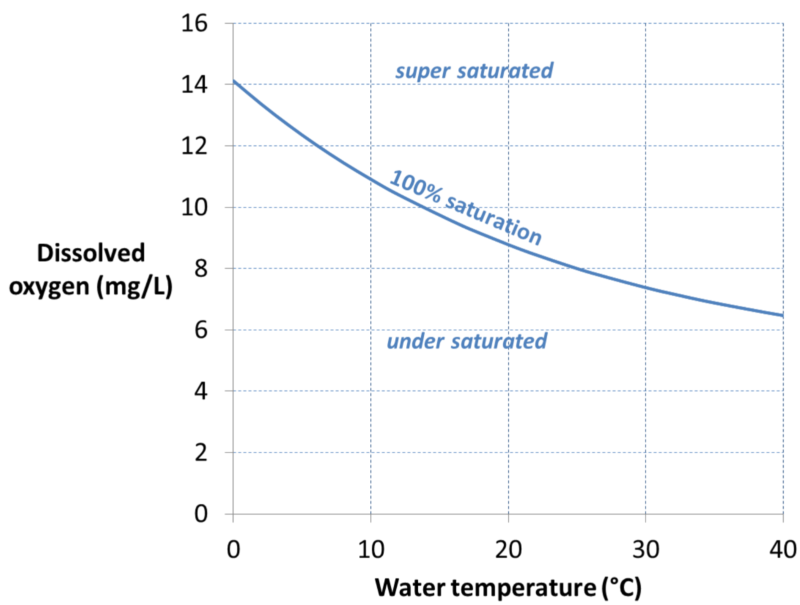


Figure 3 Oxygen solubility decreases with increasing water temperature; the line indicates the point where fresh water is fully saturated with dissolved oxygen (at an altitude of 270 m above sea level).

In river systems, the amount of oxygen dissolved in the water column also often changes in response to the relative rate of re-aeration (i.e. oxygen gas exchange with the atmosphere at the water surface), photosynthesis during daylight hours and respiration (i.e. all biochemical processes that consume oxygen) (Figure 3). A diurnal cycle in oxygen concentration is often observed during the growing season with peak oxygen levels occurring in the late afternoon and a minimum concentration in the early morning just before sunrise. Waters receiving point sources with a high concentration of oxygen-consuming substances (e.g., ammonia) can experience significant reductions in DO within a localized area. The consumption of oxygen in the decomposition of organic material derived from plants and animals (e.g. decaying plant matter) may also lead to decreased DO, particularly in areas where productivity is high and physical processes supplying oxygen to the water (e.g. mixing of the water column) are slow.

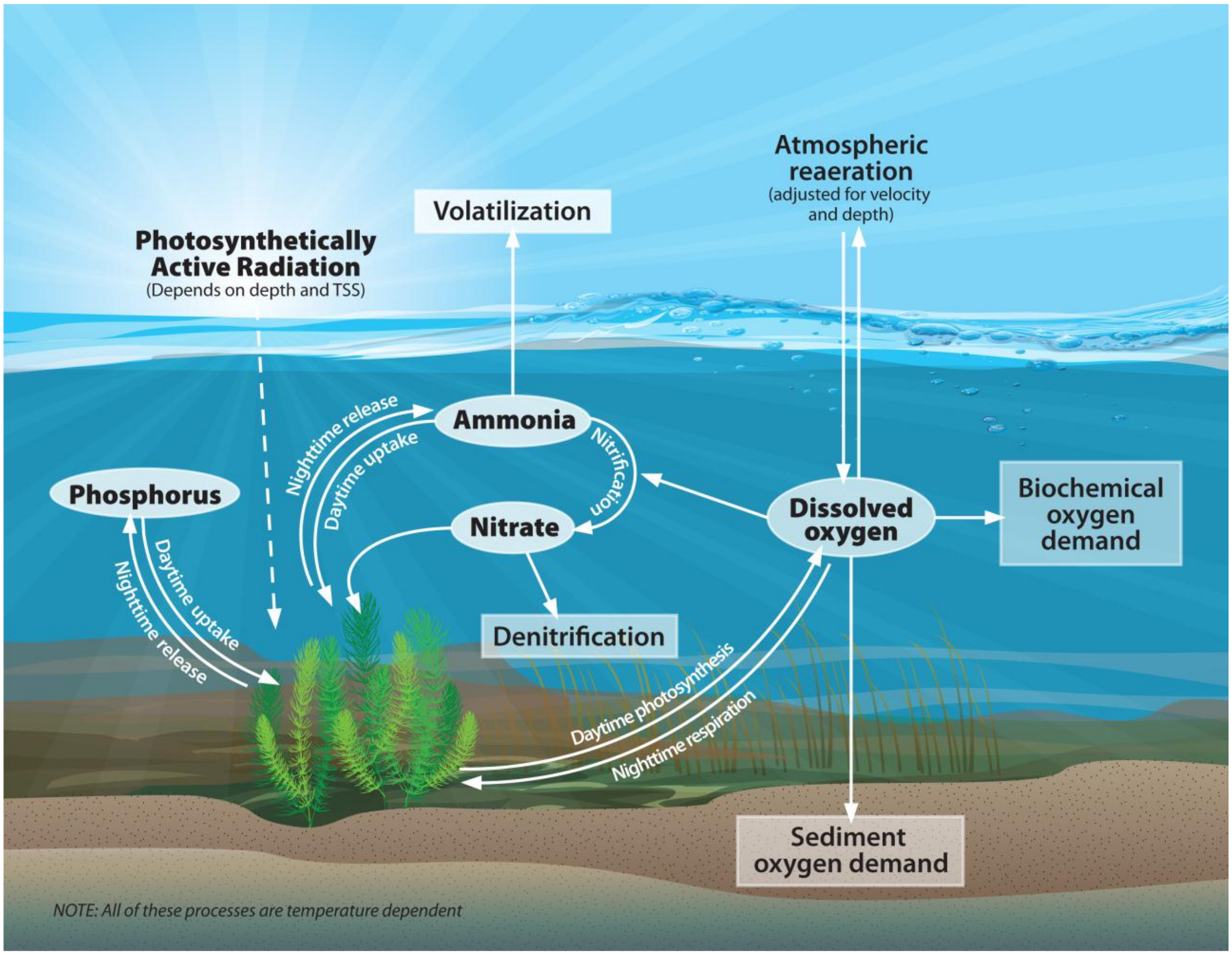


Figure 4. Conceptual diagram of the major biological and chemical processes that contribute to the dynamics of dissolved oxygen in aquatic systems.

Diurnal fluctuations in DO can increase in response to eutrophication, which can occur in aquatic systems affected by anthropogenic inputs of nitrogen and phosphorus. Eutrophication often results in substantial growth of aquatic plant and algae. The photosynthetic and respiratory activity of this biomass can result in rapid changes in DO concentrations with a large spread between the maximum and minimum values within a 24 hour period. In order to adequately characterize DO concentrations under these conditions, continuous monitoring of DO (e.g. measuring and recording DO concentrations every 10 or 15 minutes) is often suggested. A minimum of two days of monitoring to properly assess the daily minimum DO is recommended by the US EPA (USEPA 1986).

Ecological requirements: Most organisms have a physiological requirement for oxygen. Organisms such as fish (eggs, juvenile, and adults), and benthic invertebrates are sensitive to the effects of hypoxia, or low DO. Targets for direct ecological requirements can be based on physiological tolerance ranges; however, it is important to note that the equilibrium of many other biochemical processes, such as those which control nutrient cycling, is also dependent on the availability of DO.

Critical period: Periods of decreased availability of DO usually occur during summer months when water temperature and biological activity are at their peak (i.e. during the growing season).

3.2. Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g. provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Provincial objective

The value of the Ontario PWQO for oxygen varies with the water temperature and the type of fish community that is expected to be present (Table 2). Although these values should be protective of the majority of aquatic biota, guidance associated with the PWQO for DO suggests that more stringent criteria may be required "in waters inhabited by sensitive biological communities, or in situations where additional physical or chemical stressors are operating" (OMOE 1994).

Table 2. Minimum acceptable concentrations of dissolved oxygen to support aquatic life, specified by the Ontario Provincial Water Quality Objectives (OMOE 1994).

Temperature °C	Cold Water Biota[1]		Warm Water Biota[2]	
	% saturation	mg/L (approximate)	% saturation	mg/L (approximate)
0	54	8	47	7
5	54	7	47	6
10	54	6	47	5
15	54	6	47	5
20	57	5	47	4
25	63	5	48	4

Notes: [1] *e.g. salmonid fish communities such as brook trout or brown trout*
[2] *e.g. centrarchid fish communities such as largemouth bass and sunfish*

Canadian Environmental Quality Guidelines

The CCME established CEQG for DO for the protection of aquatic life in freshwater systems (CCME 1999b). The derivation of the guidelines was based on data on species of fish and invertebrates at different life history stages. Consideration was also given to sub-lethal effects (e.g. behavioural and physiological) which can be detrimental to long-term survival as a result of chronic exposure. CEQGs are categorized on the basis of physiological sensitivity, with separate guidelines established for warm water and cold water ecosystems and more stringent guidelines for sensitive early life stages (Table 3). The guidelines for early life stages are applicable to times and places where salmonid spawning and invertebrate emergence are known to occur, or are likely to occur. The guideline values were based on US EPA's "slight production impairment" estimates (1986 USEPA) with an added 0.5 mg/L margin of safety.

Table 3. Minimum acceptable concentrations of dissolved oxygen to support aquatic life, specified by the Canadian Environmental Quality Guidelines (CCME 1999b).

CEQG for Dissolved Oxygen (mg/L)		
Ecosystem	Early life stages	Other life stages
Warm water	6	5.5
Cold water	9.5	6.5

US EPA Water Quality Criteria

The US EPA recommends the use of a two-number criterion for average and minimum DO (Table 4). Although it was noted that percent saturation is a more ecologically appropriate measure, the criteria were expressed as mg/L for ease of use (USEPA 1986). The specification of two threshold values is intended to be inclusive of the influence of the duration of exposure: minimum values are intended to protect against lethal effects of hypoxia in the short term; average values demark the threshold between no- and low-risk from long-term persistence (for days or weeks) of low DO concentrations. For full protection of aquatic life, DO should meet both minimum concentrations and average values assessed over the long-term.

Table 4. USEPA Water Quality Criteria for minimum ambient dissolved oxygen concentration (mg/L) (USEPA 1986)

	Coldwater ecosystem		Warmwater ecosystem	
Criterion	Early life stages*	Other life stages	Early life stages	Other life stages
30 day mean	NA	6.5	NA	5.5
7 day mean ▼	9.5 (6.5)	NA	6.0	NA
7 day mean min ◊	NA	5.0	NA	4.0
1 day minimum	8.0 (5.0)	4.0	5.0	3.0

** water column concentrations required to achieve the intergravel DO concentrations shown in parenthesis; NA (not applicable); ▼ mean of the daily average over 7 days; ◊ mean of the daily minimum over 7 days*

The criterion is split for coolwater and warmwater species, with the rationale for the dichotomy based primarily differences between known requirements for "coldwater" salmonid communities and "warmwater" non-salmonid communities, which are often dominated by centrarchids. An additional criterion is specified for early life stages, which are generally more sensitive to low DO concentration. The US EPA recommended that the applicability of the less stringent criterion be based on site-specific presence-absence data.

The data on which the DO threshold values were based was biased towards the physiological requirements of fish, however the assumption was made that DO criterion representing a low level of risk to fish would be adequate for other aquatic organisms such as invertebrates (USEPA 1986). Although the scope was limited, toxicological data of several groups of aquatic invertebrates (e.g. stonefly, mayfly, caddisfly) were also included. The derivation of the DO threshold considered effects on fish at the adult and early life stages, on and invertebrates that resulted in "production impairment";

the range of observed effects included lethality as well as effects detrimental to growth, reproduction and normal behaviour.

The criteria specified are not considered to be assured no-effect levels, but instead characterize represent "annual worst case" conditions that should be a rare occurrence (USEPA 1986). The values represent some risk of effect to sensitive species only if conditions are maintained near this threshold for considerable periods. These values were derived from DO concentrations at which the risk of production impairment is between slight to none (Table 5).

Table 5. DO concentrations (mg/L) below which a qualitative level of effect occurs on fish and invertebrates (reproduced from USEPA 1986).

	Salmonid waters		Non-salmonid waters		Invertebrates
Production impairment	Embryo and larval stages*	Other life stages	Embryo and larval stages	Other life stages	
None	11 (8)	8	6.5	6	8
Slight	9 (6)	6	5.5	5	5
Moderate	8 (5)	5	5	4	
Severe	7 (4)	4	4.5	3.5	
AML**	6 (3)	3	4	3	4

** water column concentrations required to achieve the intergravel DO concentrations shown in parenthesis for all stages to 30d following hatching; ** AML: limit to avoid acute mortality*

Slight production impairment is defined as "representing a high level of protection of important fishery resources, risking only slight impairment of production in most cases", whereas the limit to avoid acute mortality is the "minimum DO concentration deemed not to risk direct mortality of sensitive organisms" (USEPA 1986). In the use of the physiological studies to derive the US EPA criteria, it was noted that even in pristine conditions, the combination of natural processes influencing DO (e.g. low flow, high temperature, decay of organic matter) can result in some production impairment resulting from low DO concentrations. For this reason, the US EPA selected the DO values at which there is a "slight" risk of production impairment rather than a no-effect level.

To account for the variability in oxygen which occurs due to natural (i.e. unaltered) conditions, additional guidance was given by the US EPA for situations where natural conditions create depressions in DO close to the threshold values. Where natural conditions alone result in DO concentrations <110 % of threshold values, the USEPA suggest that the minimum acceptable concentration is 90% of the natural conditions (USEPA 1986).

3.3.Target formulation

Synthesis of information

All sources of guidance detailed above (e.g. PWQO, CEQG, US EPA criteria) are grounded in the physiological requirements of aquatic species (i.e. cold/warm water fish communities, benthic invertebrates) that are an important component of aquatic communities in the Grand River watershed. Since fish and benthic invertebrates are particularly susceptible to the harmful effects of low oxygen, their requirements for oxygen are likely a good representation of the conditions that support the broader aquatic community.

Differences between values specified as thresholds between acceptable and unacceptable conditions (Table 6) arise from varying measures of the degree of risk of effects from low DO. Since, even in pristine conditions, there are natural conditions which contribute to the occurrence of fluctuations in DO, it is difficult to determine a precise level at which impacts are at a minimum. Numerically, the most conservative value is the minimum acceptable DO concentration specified by the CEQG. The US EPA uses the same concentrations of DO as criteria for acceptable values of DO, calculated as a 30 day mean. The approach employed by the US EPA criteria (i.e. different thresholds specified for periods of different duration) has the advantage that it allows for greater accommodation of the dynamic nature of DO by accounting for both acute and chronic effects; however, the multiple thresholds of the US EPA criteria are somewhat less simple to measure and assess.

Table 6. Comparison of thresholds for minimum acceptable dissolved oxygen concentration (mg/L) according to guidance intended for the Province of Ontario (PWQO), Canadian rivers and streams (CEQG), and rivers and streams in the United States (US EPA).

	Coldwater community	Warmwater community
PWQO (10-15°C)	6	5
PWQO (20-25°C)	5	4
CEQG	6.5 (9.5)	5.5 (6)
US EPA (30 day mean)*	6.5	5.5
US EPA (7 day mean)*	5.0 (9.5)	4.0 (6.0)
US EPA (1 day min)	4.0 (8.0)	3.0 (5.0)

*Values in parenthesis are specified for early life stages; *value is calculated as the mean of the daily average (early life stages) or daily minimum (adults) over 7 or 30 days.*

An approach similar to the multiple criteria of the US EPA has been adopted in Canada by the province of Alberta using a simplified two-tiered set of criteria: water quality guidelines to protect aquatic life are specified for acute (daily minimum >5.0 mg/L) and chronic exposure to low DO (7-day mean >6.5 mg/L) (Alberta Environment 1999). Alberta does not have separate guidelines for coldwater and warmwater communities; however, following the recommendation of the CEQG, a water quality guideline for DO is specified to support early life stages. To account for increased DO requirements during an ecologically significant period, an additional DO threshold (>8.3 mg/L DO as a 7-day mean) is specified for mid-May to the end of June to protect emerging mayfly (Alberta Environment 1999).

Interstitial requirements for oxygenation (e.g. in redds) are addressed by each of the CEQG, US EPA criteria, and Alberta WQG, but are not referenced by the Ontario PWQO for DO in surface water. The common principle behind the derivation of these thresholds is that DO values in the water column >3 mg/L above the interstitial requirements should ensure sufficient supply of oxygen.

Target description and considerations:

The Grand River Water Management Plan has previously used the Ontario PWQO for DO as a frame of reference for the desired ecosystem state. In the 1982 Grand River Water Management Basin Study, the primary focus for assessment of DO was primarily on the protection of warm-water biota (which occupy most reaches in the Grand River basin) during the summer months when risk of hypoxia is highest (1982 GRCA). The Study used the threshold of 4 mg/L DO as a frame of reference for minimum threshold of desired DO concentrations, based on the PWQO for warm water biota at water temperatures similar to summer water temperatures (20-25 °C).

Based on the review of sources of guidance for comparable aquatic systems (Table 6), 4 mg/L is recommended as a lower threshold for the daily minimum DO concentration. This target should protect most sensitive organisms from adverse effects of hypoxia. This value is consistent with (and in some cases more conservative than) a threshold above which adverse effects of short term exposure are unlikely to include lethality. In circumstances where early life stages (e.g. fish eggs), sensitive infauna (e.g. mayfly), or cold water fish communities (e.g. including brook trout) are present, however, it may not be sufficient protection.

Even in pristine aquatic systems, a high degree of spatial and temporal variability in DO can result from natural factors (e.g. temperature, water depth). Healthy aquatic ecosystems are resilient to occasional periods of hypoxia; some organisms are able to recolonize rapidly (e.g. benthic invertebrates) while others are able to cope by seeking nearby thermal refugia (e.g. fish). Despite this, populations of aquatic organisms are susceptible to sublethal effects of long-term exposure to low DO. Ecosystems with DO concentrations that are chronically low may be unsuitable habitat for populations of many species. A chronic worsening of DO conditions can result in increased morbidity and in existing communities and a decrease in ecological resilience. To account for these adverse effects, it may be advantageous to supplement the use of a daily minimum target with an approach similar to that taken by the US EPA and the province Alberta, which take into account chronic conditions. The merit of these approaches is that they recognize that the effects of low DO can accumulate with frequent exposure by setting targets with two criteria: 1) a threshold for the effects of hypoxia in the short term, and 2) a threshold for sublethal effects over the long term. The US EPA Water Quality Criteria for long term conditions (mean of the daily minima for 30d should be >5.5 mg/L) is likely appropriate as the lower threshold for acceptable DO conditions in the Grand River watershed since it is based on the needs of species similar to those found in the Grand River watershed.

Target:

The recommended target for DO has two criteria: one to account for short term effects of hypoxia and a second related to the adverse effects of chronic DO concentrations. In most circumstances, the recommended target for low risk of effects of hypoxia can be met with daily minimum concentrations of DO above a threshold of 4 mg/L (Table 7). This threshold is consistent with both the PWQO for normal summer water temperatures (approximately 20-25°C) and the US EPA criterion for the average daily minimum of a 7 day period for a warmwater community. According to these sources of guidance, DO concentrations above 4 mg/L pose a very low risk of hypoxia to organisms in a resilient warmwater community during the warm temperatures that prevail during the growing season. The corresponding threshold for low risk of effects of chronically low DO is a 30 d average DO concentration above 5.5 mg/L (calculated as the mean of 30 daily minima). Actions that elevate DO concentrations above this threshold will help to support aquatic communities in the Grand River watershed and increase ecosystem resilience.

Table 7. Summary of the DO targets to support aquatic community health in the Grand River watershed, expressed as the lower threshold for desired concentrations (mg/L) in reaches where cold or warmwater communities are expected to occur.

	Coldwater community	Warmwater community
Daily minimum	>5 (6)	>4 (6)
30d mean (of daily minimum)	>6.5	>5.5

Value in parenthesis is specified for early life stages or organisms which have low resiliency to hypoxic conditions.

Where and when more sensitive species or early life stages are present (e.g. larval fish, emerging mayfly), daily minimum DO that exceeds a threshold of 6 mg/L is more suitable since these organisms often have heightened physiological requirements for DO and reduced resiliency to recover from the effects of hypoxia. The 6 mg/L threshold for sensitive organisms is derived from the US EPA criterion and the CWQG for early life stages in a warmwater community. Similarly, where a cold water fish community is expected to be present, a target for the daily minimum concentration of DO to exceed 5 mg/L and the 30 d mean to exceed 6.5 mg/L account for the increased DO requirements.

The DO concentrations summarized in (Table 7) represent the lower threshold of the desired state; the target is for concentrations that exceed these values. Actions that decrease the likelihood of DO falling below these thresholds will be supportive of aquatic community health. Such actions can improve ecosystem resiliency, but do not necessarily guarantee that there is no risk of adverse effects from low DO, since variations in DO resulting in slight impairment of organisms are a natural feature of aquatic systems, even in pristine ecosystems. Regardless, an increase in frequency and extent to which the daily minimum DO concentrations exceed the thresholds in Table 7 are generally indicative of a shift towards a healthy, resilient ecosystem.

Recommendations:

It is recommended that the set of thresholds in (Table 7) be accepted as a target for DO that meets the needs of aquatic life in the Grand River watershed. It is important to characterize the communities which are expected to occur in each area so that the target is appropriate for the most sensitive needs. The Grand River Fisheries Management Plan is recommended as a starting point for this characterization.

To improve the characterization of the needs in different areas, it is recommended that the following types of information be collected and considered:

- habitat suitability for cold water fish community (e.g. temperature range, substrate);
- ability of populations to use thermal refugia (e.g. presence of sensitive sessile organisms, availability of refugia);
- thermal characteristics (e.g., potential for high temperature to decrease DO);
- resiliency of local populations (i.e. potential to recover or recolonize following population decline)

In areas with unique characteristics contributing to low or very dynamic DO as a natural feature (e.g. in wetlands), comparable site specific thresholds are recommended that take into account:

I. the sensitivity of the community expected in a healthy state and

II. the potential for severe impacts of hypoxia during transient events as well as the potential for chronically low DO to have adverse effects at the population or community-level.

Improved understanding of ecosystem function is required to identify areas with unique characteristics and to help inform the determination of appropriate site specific target conditions. Recent discussions have highlighted the Lake Effect Zone as an area with a number of factors potentially contributing to chronically low DO conditions. This area has good potential as a case study for the creation of site specific target conditions since a number of studies exist which could inform the determination of specific ecological needs.

4. Turbidity / suspended solids

4.1. Ecological context

Turbidity provides a measure of the penetration of light through the water column, which is decreased by elevated concentrations of particulate matter (e.g. suspended solids, phytoplankton). Turbidity is sensitive to the size spectrum and composition of particles. Silt and clay particles (<0.063 mm) remain in suspension in flowing waters and are largely the cause of turbidity.

Turbidity can be highly variable, even in unimpacted systems, since suspended solids are correlated to stream flow and velocity. Processes such as erosion or re-suspension of bed sediments can contribute to turbidity in unaltered ecosystems by increasing the load of suspended of sediments. The dynamics of these processes can be altered by human activity, often leading to increased fluctuations and magnitude of suspended sediment concentrations. Human activity can also contribute indirectly to elevated turbidity by increasing the nutrients available for the growth of phytoplankton. A reduction in sediment supply is a less common result of human activities, but can cause significant habitat degradation in some circumstances (e.g. alteration of substrate or channel form).

Impacts to aquatic life from excessive suspended sediment can be divided into two types: effects resulting from sedimentation; and effects which occur in the water column. The effects of excessive suspended sediment on sensitive aquatic organisms, such as fish and aquatic invertebrates can be summarized by the following types of modes of action:

- direct effects to the physiology or behaviour (e.g. damage to gill tissue, escape/avoidance);
- prevention of successful growth or reproduction (e.g. egg smothering);
- modification of movement or migration; and
- habitat degradation

(EIFAC 1965).

The type and severity of effects depend on a number of factors such as the particle size and composition, hydrology, and duration of exposure (Kerr 1995). The likelihood and severity of effects increases with the length of exposure (Figure 5). Effects range in severity from behavioural (drift response by invertebrates, avoidance/alarm response by fish) to sub-lethal (e.g. temporary physiological stress, reduction in feeding), up to lethal (e.g. population-level reductions by predation and/or physiological stress) (Newcombe 1998). The impacts occur along a gradient of concentrations, with no sharply defined boundary or threshold for the onset of each type of effect. On the basis of a dose-response model (dose = concentration x exposure) a stress index was developed (Newcombe and MacDonald 1991) and was later modified to become a severity-of-ill-effects model (Newcombe and Jensen 1996). The basis of the model is a ranking of the effects on aquatic organisms (benthic invertebrates and fish), based on their severity. The model provides a common measure (severity of effect, or SEV) to quantify a wide range of adverse effects on aquatic biota. Although the impacts of sediments can vary with the size of particle, for utility sake, the model is based on a common unit measure, total suspended solids (TSS).

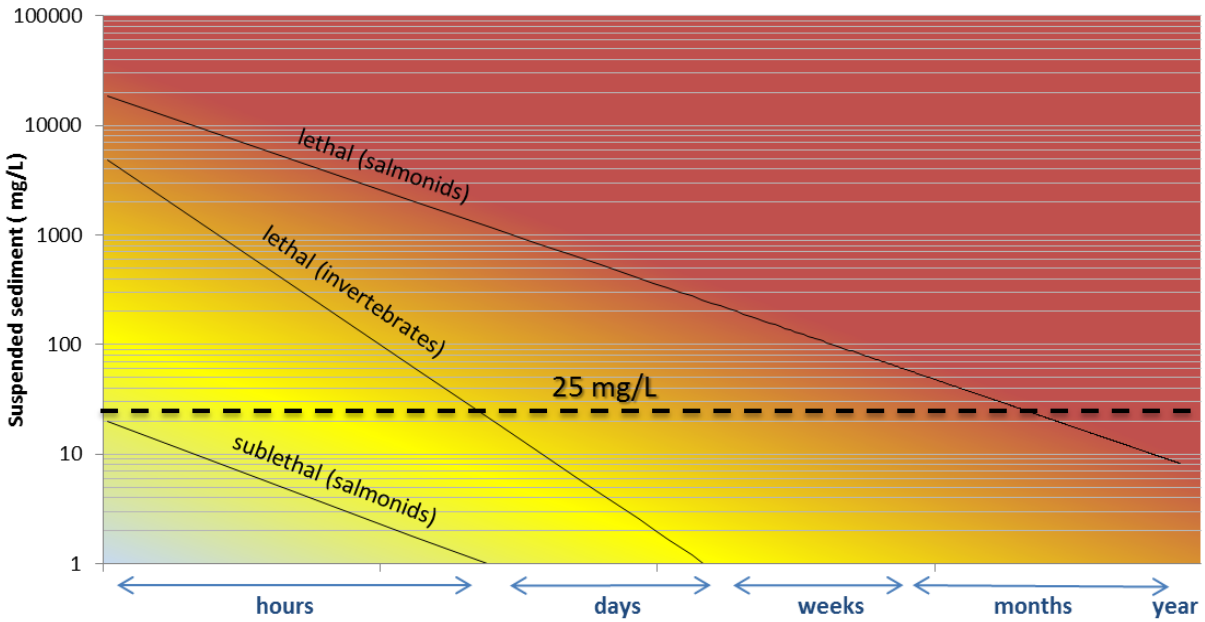


Figure 5. Effects of suspended sediments on aquatic biota, increasing as a gradient of severity in response to increasing concentration and duration of exposure. Solid lines indicate approximate concentrations and duration at which effects on fish and invertebrates increase in severity, based on data compiled by Newcombe (1998). A dashed line has been shown as a frame of reference to compare the effect of short and long exposures.

In addition to the direct effects of suspended sediments, increased turbidity can be detrimental to ecosystem as a result of indirect effects (Kerr 1995). For instance, turbidity increases the absorption of sunlight and can cause increased water temperature. Visually-mediated behaviours associated with feeding or reproduction, can be impaired at turbidity as low as 25 NTUs (Nephelometric Turbidity Units) (CCME 2002). The reduction in water clarity resulting from increased turbidity can also limit the growth of aquatic plants. A study of 19 Great Lakes wetlands indicated that the diversity of submergent macrophytes was decreased above a threshold of 20 NTUs (Lougheed *et al.* 1998). Such alterations in plant diversity can indirectly limit the use of the area by other organisms, for which plants serve critical functions (e.g. cover, forage) (Cvetkovic *et al.* 2010; Trebitz *et al.* 2007). Reduced water clarity can also impact visually mediated behaviours. For instance, the foraging ability of small mouth bass is reduced in turbid water: below 20 NTU, small improvements in water clarity result in relatively large increases in the ability to detect prey, which may lead to higher prey consumption and subsequent growth (Sweka and Hartman 2003).

The timing of acute effects caused by short term exposure to very high suspended sediment loads (e.g. disruption of feeding; gill clogging) is largely driven by episodic high flow events. The high load of suspended sediment during these events may also account for a large proportion of the particle-associated nutrients, which may impact downstream areas. The ability of organisms to tolerate extended periods of exposure to elevated suspended sediment may be reduced during early or sensitive life stages (e.g. larval drift of walleye) which most often occur during the spring. Warm water temperature may also lower an organism's ability to tolerate elevated suspended sediment (CCME 2002).

Impacts resulting from siltation can occur during low or high flow but are most likely to cause impacts when organisms are in a sensitive, less motile state (e.g. pre-hatch). Impacts on fish eggs, which are highly susceptible to negative effects of siltation, can occur following spawning events in the early spring. The negative effects associated with chronically elevated turbidity are most critical during the growing season, when growth of submerged aquatic plants can be limited by light as a result of low water clarity.

In addition to the effects due to the physical properties described above, particulate matter including suspended sediment can have impacts on aquatic life as a result of co-occurring nutrients or contaminants. The following section will focus only on the effects resulting from the physical properties of particulate matter. Due to the complexity of nutrient dynamics, targets for nutrients are discussed separately.

Ecological requirements: Most aquatic communities function optimally at a relatively low range of turbidity. Excessive sedimentation or the presence of excess suspended sediments in the water column can result in reduced growth or reproduction in sensitive aquatic organisms such as fish and benthic invertebrates. Excessive turbidity can cause alterations to the species composition of the aquatic plant community, which indirectly, can have negative consequences for many other organisms.

Critical period: Peaks in suspended sediment causing acute effects are most likely during high flow events. Negative effects can also occur at lower concentrations during low flow as a result of long-term exposure or the presence of sensitive organisms or life stages, which typically occur during the spring. Sensitivity to effects may also worsen during periods of warm water temperature. Long-term effects of elevated turbidity causing poor water clarity are most critical during the growing season.

4.2. Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g., provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Provincial Objective:

Ontario does not have a PWQO for suspended sediment in support of aquatic life. Instead, a PWQO for turbidity which relates to the addition of "suspended matter" to surface waters: additions should not change the natural Secchi disk reading by more than 10% (OMOE 1994). The value of 10% was chosen somewhat arbitrarily, but is considered to reflect quantifiable alterations in light transmission, representative of a level at which changes in algal production are likely to occur (OMOE 1979). Although the documentation supporting the objective makes note of the direct impacts of suspended sediment on fish and invertebrates, no objective is set to prevent the direct effects of suspended sediments on such organisms (OMOE 1979).

Canadian Water Quality Guideline for the Protection of Aquatic Life:

CEQG for induced increases in total particulate matter were developed by the CCME for suspended sediments, turbidity, deposited bedload sediments and streambed substrate (CCME 2002; Table 8). The guidelines were based on technical guidance compiled for the development of British Columbia water quality criteria to protect freshwater, estuarine and marine waters (Caux *et al.* 1997). The approach used to develop the guidelines takes into account the gradient in severity of effects which follows a dose-dependent response (where dose is equal to the combined effect of concentration and duration of exposure). The effect thresholds were based on a large database of toxicological and physiological studies (Newcombe 1994; Newcombe and Jensen 1996). The resulting guidelines, shown in Table 8, specify a level of protection that prevents changes in suspended sediment causing an increase of one severity of ill-effect (SEV) score in the most sensitive group of organisms. In the case of the short term guideline for suspended sediment, adult salmonids had the greatest change in SEV with increasing suspended sediment dose. The long-term guideline for clear stream systems was derived from an extrapolation of the model for SEV scores, and toxicological data for mortality of rainbow trout eggs. The guidelines for high flows and in turbid waters were based on the guideline for short term exposures during clear flows.

Table 8. CEQG for suspended sediments and turbidity for clear or turbid flowing waters.

	Suspended sediments guideline	Turbidity guideline
Clear flow		
Longer inputs (lasting 24h – 30d)	Average increase: < 5 mg/L above background	Average increase: < 2 NTU above background
Short term (exposures <24h)	Maximum: 25 mg/L above background	Maximum: 8 NTUs above background
High flow*		
	(*During high flow periods when background is 25 - 250 mg/L*) Maximum: 25 mg/L above background	(*During high flow periods and in turbid water when background is 8 - 80 NTUs*) Maximum: 8 NTUs above background
	(*During high flow periods when background is > 250 mg/L*) Maximum: 10% above background	(*During high flow periods and in turbid water when background is > 80 NTUs*) Maximum: 10% above background

**turbidity guidelines also apply to naturally turbid waters which do not have periods of clear flow*

The guidelines for turbidity were extrapolated from suspended sediment guidelines using a general suspended sediment to turbidity correlation of 3:1, developed from watercourses in the Kootenay Region of BC (CCME 2002; Caux *et al.* 1997). It was acknowledged that this relationship can vary (e.g. with particle size), but it was considered to be sufficiently robust to develop guidelines for the general case. The rationale and values separating hydrologic states (i.e., separation of clear and turbid/high flow at 25 mg/L) was also based on data from watercourses in BC (Caux *et al.* 1997).

The long-term guideline for clear streams is intended to protect against all harm to aquatic life; the increase represents the threshold at which sensitive fish exhibit minor physiological stress and increased rates of coughing and respiration. If small induced inputs increase the concentration of suspended sediments above the guideline for short term exposures, it will result in effects on fish that may be reversible (e.g., behavioural or low sublethal effects); however if the mechanism causing the inputs is not rectified and the pulsed exposures continue, more severe adverse effects can ensue.

For most lotic systems, background values are to be assessed during periods of clear flow, which may be a broader range of conditions than low flow. The timing and determination of conditions during clear flow periods is suggested to be assessed on a site-specific basis. Guidelines for waters which are naturally turbid and may not have a clear flowing period are the same as the guidelines short term exposures in clear flowing systems. To adequately assess the potential effects of short term exposures, the CCME recommends hourly sampling over a 24h period during flow events.

Although not described here, the effects of particulate matter on the benthic environment are covered by separate guidelines (i.e. for streambed substrate and deposited sediment) for the protection of spawning and juvenile salmonids as well as benthic invertebrates (CCME 2002).

BC Provincial Water Quality Guidelines

The BC provincial water quality criteria (guidelines) differ from the CEQG, although based on the same database of physiological and toxicological studies (BC MOE 2001). The BC criteria for high flow or turbid waters are separated at a lower threshold than the CEQG: the division occurs at 50 NTUs or 100 mg/L, rather than 80 NTUs or 250 mg/L (Table 9). The criteria for background levels at the lower end of this division are correspondingly lower: the BC guidelines indicates increases above background should be less than 5 NTU or 10 mg/L, rather than 8 NTUs or 25 mg/L as in the CEQG.

Table 9. British Columbia water quality criteria for suspended sediments and turbidity during high flow or in turbid waters aquatic life (fresh, marine and estuarine) (BC MOE 2001). Criteria for clear flow not shown.

	Suspended sediments guideline	Turbidity guideline
High flow or turbid waters		
	(*When background is 25 - 100 mg/L*) Maximum: 10 mg/L above background	(*When background is 8 - 50 NTUs*) Maximum: 5 NTUs above background
	(*When background is > 100 mg/L*) Maximum: 10% above background	(*When background is > 50 NTUs*) Maximum: 10% above background

**turbidity guidelines also apply to naturally turbid waters which do not have periods of clear flow*

As with the Canadian guideline, the guidance for the BC criteria specify that background conditions do not include periods of high flow. Measures of sediment during spring freshets and storms are to be excluded from assessments of background conditions.

National Agri-Environmental Standards Initiative

The set of NAESI environmental performance standards included an assessment of suspended particulate matter (suspended sediments and turbidity) (Culp *et al.* 2009). Analysis of data from agricultural watersheds indicated that there was significant variation among study sites in the natural characteristics that influence the amount and type of particulate matter. This made generalization at the national level difficult. They suggested that since there was significant variation among regions in the relationship between the stressor and the landscape, a national IPS was not appropriate.

For the Ontario Mixedwood Plains region that contains the Grand River watershed, analysis of physical data (TSS and turbidity) yielded IPS values of 4.1 mg/L TSS and turbidity of 2.2 NTU. Analysis of stressor-biota relationships suggested that these values were more protective than required to protect against *measurable* impacts to aquatic life. Data used to derive biotic IPS value for the Mixedwood Plains region of Ontario included a suite of 16 benthic macroinvertebrate metrics. Depending on the metric, the threshold at which an increase in concentration produced a significant decline in biotic condition ranged from 3.2 to 5.5 mg/L for TSS and 3.78 to 16.7 NTU for turbidity. The average of these values was used to produce a final biotic IPS for the Mixedwood Plains region of Ontario of 3.6 mg/L for TSS and 6.1 NTU for turbidity.

Since the data used to derive the IPS values was predominantly from small agricultural streams, it may not characterize the communities expected to be present in larger rivers such as the lower reaches of the Grand River. It is also important to note that these quantified long-term conditions, and were not intended to represent concentrations maintained at all times. The frequency of occasions on which the conditions are to be assessed was not determined, but it was suggested that a seasonal or annual average period be considered.

US State/Federal water quality standards for suspended solids and turbidity

The US EPA has published an extensive review on suspended and bedded sediments (SABS), including the effects as well as approaches for setting criteria to protect aquatic life from adverse effects of SABS (USEPA 2003). The information was incorporated into a framework that describes a scientific process which is recommended for the development of criteria for SABS (USEPA 2006). The framework was preceded by an existing water quality criteria similar to Ontario's PWQO, which recommended that changes in settleable or suspended solids should not alter the compensation point for photosynthesis by more than 10% (USEPA 1986). The newly recommended framework uses a synthesised approach that takes into account natural conditions and the variability of the water and protects designated uses including aquatic life. A site-specific approach, or one built on case studies using available data, is recommended by the US EPA since natural features such as physiography, stream gradient, vegetative land over, and climate can cause significant differences among watercourses in sediment supply and transport (USEPA 2006).

The framework described by the US EPA is focused on the effects of sediment imbalance (USEPA 2006); emphasis is put on the *balance* of sediment transport processes rather than gauging impacts only from peaks in sediment concentration. This departure from standard approaches is unique because it takes into account circumstances in which there is a beneficial function of sediment supply. One step highlighted as important by the framework is the use of scientifically defensible information to establish links between causal factors and ecological endpoints (e.g., exposure-response relationships; Figure 6). The identification of the mechanistic connection in this step ensures that measures of exposure reflect the aspect of the process (e.g., intensity, frequency or duration) that can lead to an imbalance. The framework offers guidance for the creation of a classification system so that the approach creates targets that can be generalized for a set of waterbody types and regions.

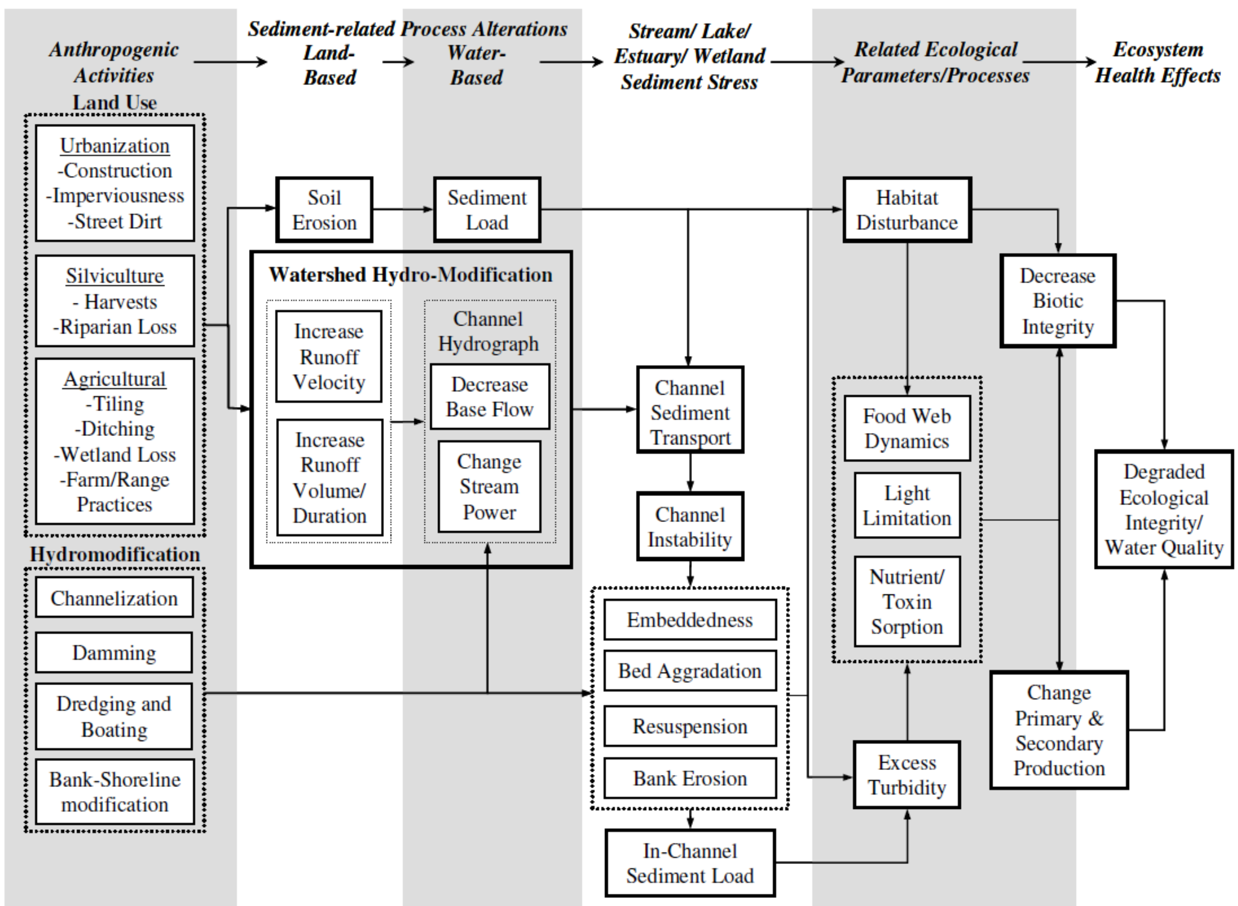


Figure 6. Conceptual diagram of sources of sediment stress in rivers and streams (from USEPA 2006)

4.3.Target formulation

Synthesis of information

The traditional approach to water quality criteria is to identify a single threshold, beyond which the risk of adverse effect increases. Historically, 25 mg/L TSS was commonly accepted as a threshold for adverse biological effects of suspended sediment, regardless of duration of exposure (e.g., US EPA 1972).

However since there is no sharply defined concentration below which organisms are unharmed (Figure 3; EIFAC 1965), guidance that uses this approach will yield a poor measure of the nature and extent of harmful effects of excess sediment, primarily because it fails to incorporate duration of exposure into the determination of effect severity. In contrast, the flexible approach to deriving threshold values according to the Canadian guideline is based on a dose-response model for sensitive organisms. The approach aims to limit increases in severity of effects that are above background (i.e., existing) levels.

Most sources of guidance regarding turbidity or suspended sediments refer to the effects of increases in concentration which are induced by causes of human origin above a background value. In this context, the term "background" is not necessarily equated with an undisturbed (i.e., pristine) state, but is typically considered to be a frame of reference for the desired state. The guidance for the CEQG for particulate matter acknowledges that where large scale alteration of the landscape has occurred, conditions characteristic of the altered state (i.e., the new norm) may be the most appropriate reference for the purposes of protection from additional inputs of sediment (CCME 2002). In some circumstances, this interpretation of "background" may not achieve ecosystem health, since the range of conditions possible in an unrehabilitated state may not support desired ecosystem attributes. This highlights the fundamental difference between guidance aimed at protection versus guidance that seeks to restore an ecosystem. While protection is focused on the support of an existing healthy aquatic community, restoration aims to improve conditions so that they are more appropriate for species that used to be, but are not currently present.

In the context of the Water Management Plan, targets characterize conditions which support a healthy aquatic community. In keeping with this interpretation, *background refers to a frame of reference in which habitat conditions support the type of community expected to be present in a healthy aquatic system*. It is important to reiterate that a healthy system need not necessarily be in a pristine state. For instance, where the upstream landscape is highly altered or new species have become established, irreversible changes may have occurred such that it would not be feasible to expect the same community as was present in a pristine state. In this case, background can be referenced from conditions in a comparable ecosystem which is in a healthy state.

Regardless of whether the intent of the target is protection or restoration, many sources of guidance acknowledge natural variability in suspended sediment by specifying different targets for sites or circumstances classified on the basis of characteristics such as hydrologic state or heighten ecological sensitivity (e.g., when the fish community includes salmonids). For instance, the Canadian guidelines distinguish between states of clear and turbid flow to account for hydrologically-driven variations in suspended sediments; a concentration of 25 mg/L suspended sediments is applied as the transition between these states, but since it was based on hydrologic data from BC watercourses, it is unclear if it would also be representative of watercourses in the Grand River watershed.

Target description and considerations:

The synthesis of scientific information and existing guidance demonstrates the complexity of setting targets for particulate matter due to high natural variability in conditions within and among locations as well as the broad range of ecological endpoints. The recommended approach to identify targets appropriate for the Grand River watershed is to identify thresholds for effects associated with chronically turbid conditions separately from acute exposure effects associated with episodic increases in suspended sediment. This distinction mirrors the Canadian guidelines which are separated based on hydrologic state and also acknowledges that the mechanisms causing ecological impacts may be different in the short term versus the long term.

Quantification of the impacts of extreme values during peak flows is largely focused on the result of lethal effects of sediments on fish and invertebrates (e.g., gill clogging, abrasion). Sublethal or indirect effects such as those mediated by a reduction in water clarity mostly occur over longer time scales and can be caused not only by suspended sediment, but also by the contribution of other particulate matter to turbidity. Consequently, it may be advantageous to use suspended sediment as a measure of the potential for adverse effects during high flow events, and turbidity as a measure of the potential for impacts occurring as the result of chronic turbidity.

The adverse effects associated with chronic reductions in water clarity are known to have a large impact on ecosystem health in parts of the Grand River watershed, particularly in the south-most reaches closest to Lake Erie. These effects were described for the Lake Effect Zone in the report by the Grand River – Lake Erie working group (GRWMP 2012) and also highlighted in a study investigating conditions in the Dunville Marshes within the Lake Effect Zone (Cvetkovic and Chow-Fraser 2012). This underscores the need to identify a target for turbidity which describes background conditions that would support improvements in these areas. As noted previously, this usage of background is interpreted as describing conditions support the type of community expected to be present in a healthy aquatic system. A turbidity value of 20 NTU was identified by several studies as a threshold above which reductions in water clarity associated with negative effects on the plant community and with disruption of visually-mediated behaviours (Lougheed *et al.* 1998; Sweka and Hartman 2003). Based on the relevance of this scientific research to aquatic communities in the Grand River watershed, the recommended target for turbidity is to maintain background conditions below a threshold of 20 NTU over the long term (Table 10). The target conditions become particularly important to ecological health during the growing season when the risk of impacts is highest.

The recommended turbidity target of 20 NTU is based on the functional response of communities that are known to be impacted by chronic high levels of turbidity, such those documented for the lower reaches of the Grand River (GRWMP 2012). While this level may protect many of the reaches in the Grand River watershed that are known to be impacted, measures of the biota-stressor relationship in the NAESI study suggest some communities (e.g. in smaller order streams) may require a lower range of values.

Table 10. Rationale and targets recommended for particulate matter in the Grand River watershed.

Resource conditions	Frame of reference	Target
Chronic reduction in water clarity	Absence of key aquatic plants; sub-lethal and behavioural effects on fish and invertebrates	Background <20 NTU during the growing season
Peaks in suspended sediment from hydrologic events or discrete inputs	Lethal effects on fish and invertebrates (gill clogging, smothering)	Tiered framework, based on background* and dose-response for the most sensitive type of organism expected to be present

**Background should be classified on the basis of hydrologic state (e.g. clear flow or turbid flow)*

For most of the Grand River watershed, there is little or no information about the current conditions and impacts associated with acute effects of peaks in suspended sediment of short duration. The identification of a target threshold for peaks in suspended sediments driven by hydrologic events or from discrete inputs should take into account 1) lethal effects of extremely high concentrations and 2) conditions that can cause reductions in populations of sensitive biota by persisting at sublethal levels for several days or weeks (e.g. during the spring freshet), disrupting important ecological functions. Because of the lack of a distinct threshold for the onset of these effects and the degree of variability in the natural characteristics throughout the Grand River watershed, it is recommended that a target threshold for peaks in suspended sediment of short duration not take the form of a single numeric value.

The set of criteria in the CEQG for particulate matter offer promise as potential targets to adopt, based on the rationale that it yields an approach that is both flexible to natural variations and representative of a wide range of potential effects; however, the numeric values (i.e., separating hydrologic states and effect levels) may not be representative of the characteristics and species in the Grand River watershed. It is therefore recommended that a more appropriate set of targets for episodic increases in suspended sediment be developed, based on current conditions and scientific research into potential effects that are specific to the Grand River watershed. Such an exercise should take into account available data for the watershed and reference recommendations for flow (including associated sediment transport processes) in reaches of the watershed where flow is regulated that have been made in the Water Management Plan as part of a parallel process. The process for identifying suspended sediment targets may also want to consider the framework developed by the US EPA (USEPA 2006) as a potential source of guidance.

It is recommended that the target for harmful effects occurring from peaks of short duration (i.e. driven by hydrologic events or discrete inputs) be based on measurements of suspended sediment (rather than turbidity) until a suspended sediment:turbidity conversion ratio appropriate for the Grand River watershed is developed. Based on a limited dataset, the 3:1 ratio for TSS:turbidity used to derive CEQG for turbidity is not representative of conditions in the Grand River watershed. Preliminary analysis of data from the central region of the watershed suggests the ratio is much closer to equity, although it varies greatly under high flow conditions. A more thorough analysis of the relationship between measurements of TSS and turbidity would also be beneficial to the characterization of conditions through the collection of environmental data; such a relationship would allow turbidity to serve as a surrogate TSS, improving the potential spatial and temporal scale of data collection and allowing conditions to be measured remotely at much lower expense. Since this relationship varies with the type of particle, it is characteristic of upstream sources, it may be necessary to establish it on a site specific basis, or for reaches with similar upstream characteristics.

Recommendations

The recommended generic target for turbidity in the Grand River watershed is for background conditions below a threshold of 20 NTU, assessed over the long term. Actions that contribute to decreasing the frequency, magnitude and duration of exceedances over the 20 NTU threshold will help to support ecological health in the Grand River watershed. In areas with characteristics contributing to naturally turbid conditions (e.g. the Lake Effect Zone), site specific targets may better reflect the inherent limitations on water quality. Similarly, other areas (e.g. small headwater streams) may require a site specific target with a lower threshold that better reflects the needs of sensitive species adapted to unique conditions. **To identify where site specific targets may be more appropriate, an investigation is recommended to improve the understanding of the natural factors that have the potential to contribute to turbid conditions**. Such a process should also consider the role of shifts in ecosystem structure and processes that may be difficult to reverse (e.g. sediment resuspension caused by a larger carp population). In such cases, identification of appropriate background concentrations can be informed by knowledge about comparable ecosystems.

It is not currently feasible to determine a generic target for suspended sediment that appropriately characterizes the needs of healthy ecosystems in the Grand River watershed. It is recommended that a **target be developed that brackets the range of variability in suspended sediment using a tiered set of criteria**; this includes short term increases in concentrations associated with hydrologic events. This approach requires a range of information about:

1. ecological sensitivity (i.e., the type of community expected to occur in each area)
2. a measure of background condition appropriate for the characteristics specific to the site or area

An investigation is recommended into the effectiveness of methods for determining ecological sensitivity other than by direct observation of community composition (e.g. estimation based on hydrology, geomorphology and other constraints). The framework developed by the US EPA may serve as useful guidance in this process (USEPA 2006). In addition, improvements in methods to use turbidity as a surrogate for measurements of suspended sediment could help to increase the understanding of variation in suspended sediment concentrations with hydrologic state and season in reaches with different characteristics in the Grand River watershed.

5. Nitrate

5.1. Ecological context

Although the mode of nitrate toxicity to aquatic life is unclear, toxicological studies have confirmed that nitrate can have wide-ranging effects in aquatic organisms such as fish and invertebrates (CCME 2012). Observations of these adverse effects include: mortality, growth reduction, reduced feeding rates, reduced fecundity, reduced hatching success, lethargy, behavioural signs of stress, and physical deformities. The risk of more severe effects is greater with long-term exposures, since nitrate can accumulate in the blood, impairing oxygen transport and leaving organisms in a weakened state and making them more susceptible to additional impacts (Camargo and Alonso, 2006).

Nitrate toxicity can vary with other water quality parameters, but not always in a predictable way. Studies of fish and aquatic life stages of invertebrates have suggested that toxicity of nitrate to some aquatic organisms decreases with increasing hardness; however, the reverse pattern has been observed for some species (CCME 2012).

In addition to the toxic effects of nitrate, it can also have adverse effects on ecosystems because of its role as a nutrient. Enriched concentrations of nitrate may contribute to eutrophication under some conditions. The adverse effects of eutrophication can represent a substantial impact on some ecosystems and will be covered in a separate section for nutrient targets.

Ecological requirements: maintenance of toxic forms of dissolved nitrogen below levels that are likely to cause reduced growth or reproduction in sensitive aquatic organisms including fish (eggs, juvenile, adults), mussels and other benthic invertebrates.

Critical period: The greatest risk of severe effects from nitrate toxicity is with long-term exposure, usually occurring during the winter when there is reduced dilution potential and reduced uptake by plants.

5.2. Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g., provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Provincial objective

Ontario does not have a PWQO for nitrate to protect aquatic life.

Canadian Environmental Quality Guideline for the Protection of Aquatic Life (freshwater)

The CEQG guidelines for nitrate consider only the toxic effects of nitrate, not the contribution of nitrate to eutrophication; they are not intended to provide guidance for effects of eutrophication. An interim environmental quality guideline for the protection of aquatic life from the toxic effects of nitrate was specified in 2003 and recently updated. A review of information about nitrate toxicity was recently completed and the guideline was updated (CCME 2012) in accordance with the guiding principles for the derivation of CEQG (CCME 2007). The methods used to derive the nitrate CEQG follow the protocol used by the CCME to formulate guidelines for Canada that are generic in scope using toxicological data from a limited number of species. The methodology includes minimum data requirements (e.g. includes at least one species of salmonid) to ensure adequately represents the range of sensitivity of aquatic life in Canadian ecosystems.

The review found that acute effects occurred at some of the lowest levels in species of freshwater invertebrates; fish were able to tolerate much higher levels of nitrate. The same pattern was not observed with sub-lethal effects: different types of organisms (i.e. fish, amphibians, invertebrates) seemed to be similarly impacted by chronic exposure to nitrate. Early life stages of coldwater fish were among the most sensitive species and life stages.

The CEQG with the aim of protecting against all harmful effects of long-term exposure in freshwater ecosystems is 3.0 mg/L as N (13 mg/L nitrate ion). The guideline for long term exposures was derived by applying statistical methods to long-term no- and low-effect endpoint toxicity data (i.e. using the Species

Sensitivity Distribution method) (CCME 2012). A benchmark for short term exposures was also specified (124 mg/L as N) as a concentration at which effects can be severe or lethal to sensitive species or life stages over short time periods (24 - 96h).

British Columbia Provincial Guideline

The province of British Columbia updated the Provincial Guidelines for nitrogen in 2009. The Guidelines represent safe conditions for province-wide application and are intended to protect the most sensitive species and sensitive life stage, indefinitely (BCMOE 2009). They are science-based and only used in a regulatory context if they are adopted or modified to become ambient water quality objectives. For full protection of freshwater aquatic life, the average concentration over 30 days should not exceed 3.0 mg/L as N over a 30-d average or 32.8 mg/L as N at any time.

US EPA Water Quality Criteria

The review of studies by the US EPA for the Water Quality Criterion for nitrate suggests that although salmonids appear to be are more sensitive than other fish to the harmful effects from nitrate concentrations, these only occur concentrations which are unlikely to occur in natural surface waters (USEPA 1986). Consequently, the US EPA has not specified restrictive criteria for nitrate for the protection of aquatic life.

5.3. Target formulation

Synthesis of information

Of the available sources of guidance, the CEQG reflects the most current scientific information about the potential for harmful effects of nitrate on aquatic organisms occurring in Canadian freshwater ecosystems. Since it considers both lethal and sublethal effects, intent of the guideline for long-term exposures is more consistent with the frame of reference for targets that support healthy ecosystems than the short term benchmark. The short term benchmark for nitrate allows for lethal effects in a small proportion of species (CCME 2012), so does not infer a level of protection adequate to meet the broad water objectives of the plan.

The most sensitive species in the derivation of the guidelines, were salmonid fish (lake trout) and net-spinning caddisfly (*Hydropsyche*). Lake trout, the species with the lowest LC50 values, do not occur in the Grand River watershed; however, other sensitive salmonids, such as brook trout do occur in some coldwater reaches in the watershed. Nitrate toxicity data are scarce for brook trout, however, one study of brook trout embryo and fry from Wisconsin streams reported observable effects (including mortality) after short term exposure to a nitrate concentration of 6.25 mg/L as N, with no apparent effect of water hardness on toxicity (Johnson 2002). Although the study suggested brook trout are less sensitive than other fish species to short term exposures, it is unclear if brook trout embryos may be more susceptible to effects of long term exposure since their eggs have a relatively long incubation time (Scott and Crossman 1998). The amphipod, *Hyalella azteca*, does inhabit streams in the Grand River watershed and was one of the more sensitive species which was used to derive the guideline for long term exposures to nitrate.

The threshold set by the CEQG for increased effects from long term exposure to nitrate (3.0 mg/L as N) is well above the range of concentrations typical of undisturbed lakes and streams within Canada. Where concentrations of nitrate exceed 0.9 mg/L as N, they are considered to have been affected by human activities (CCME 2012).

Target description and considerations:

Nitrate has physiological effects on aquatic species, so targets that aim to protect against these effects can be quantitatively estimated using toxicological studies. A conservative target should be protective of the most sensitive species likely to occur in the reach under consideration. Toxicological information is currently limited to a small number of species, some of which occur in the Grand River watershed. As a result, the identification of targets that protect the aquatic community in the Grand River watershed may need to use a more general interpretation of available data. It is therefore recommended that the species used to derive the CEQG for nitrate be considered representative of the nitrate sensitivity of species the Grand River watershed in the broad case. This is a precautionary approach and is consistent with the methods used by the CCME to derive CEQGs from toxicity data for a limited number of species.

The nitrate guideline for Canada, based on the assemblage of species for which toxicological data is available, indicates that long term exposure to nitrate concentrations above a threshold of 3.0 mg/L as N can have adverse effects life in freshwater ecosystems. Consequently, **it is recommended that a target to protect against the effects of long term exposure to nitrate** be adopted for the Grand River watershed such that the desired range of concentrations (assessed over the long term) is **less the threshold of 3.0 mg/L as N**.

The target for long term exposure to nitrate is considered to be protective in the broad case, based on a precautionary approach. The concentration specified in the target represents the upper threshold of the desired state; concentrations that fall below this value meet the target conditions. Actions that decrease the likelihood of exceeding this threshold will be supportive of aquatic community health and increased ecosystem resiliency. An increase in frequency and extent to which the concentration of nitrate is below this threshold for toxic effects is generally indicative of a shift towards conditions that support healthy, resilient ecosystems.

As information that is more specific to the species assemblage and water chemistry in the Grand River watershed becomes available, it is recommended that it be considered in the context of re-evaluating the targets for nitrate so that they better reflect the stressor-response relationship. Similarly, although nitrate toxicity can be moderated by certain aspects of water chemistry (e.g. hardness, chloride concentration), the data is currently inadequate to develop targets that reflect these relationships. It is recommended that as the understanding about these relationships becomes available, it be incorporated into nitrate targets for the Grand River watershed as part of an adaptive management framework.

6. Ammonia

6.1. Ecological context

Ammonia nitrogen is present in aquatic environments in equilibrium between two forms: ammonium ion (NH_4^+) and un-ionized ammonia (NH_3). Although both forms can naturally occur in aquatic environments, elevated concentrations typically result from human activity (CCME 2010). Ammonia is usually measured as total ammonia, which refers to the sum of all forms of ammonia (NH_4^+ + NH_3). The proportion of ammonia that is in the un-ionized (and more toxic) form increases with increasing temperature and pH. The pH of the water is thought to have a larger influence than temperature on the equilibrium between ionized and un-ionized forms of ammonia (CCME 2010). Ammonia concentrations can decrease through the conversion of ammonia to nitrate (nitrification), which occurs naturally in surface water. Although this process reduces the risk of toxicity from un-ionized ammonia, it increases nitrate concentrations and removes oxygen from the water, potentially creating low oxygen conditions that can adversely affect aquatic organisms.

Observations of adverse effects of ammonia as a result of toxicity on aquatic life include: mortality, growth reduction, reduced feeding rates, reduced fecundity, reduced hatching success, lethargy, behavioural signs of stress, and physical deformities. Toxicological studies of aquatic species suggests sensitivity to ammonia toxicity is highest among adult fish and early life stages of fish and mussels (CCME 2010).

Ecological requirements: maintenance of ammonia below levels that are likely to cause reduced growth or reproduction in sensitive aquatic organisms including fish (eggs, juvenile, adults), mussels and other benthic invertebrates.

Critical period: The greatest risk of toxic effects of ammonia is with long-term exposure. Ammonia concentrations can become elevated near sources during periods of low flows, since there is reduced potential for dilution. Concentrations can also remain elevated in the winter due to reduced uptake by plants. In the summer, risk of ammonia toxicity increases, due to the effects of warm temperatures and extremes in pH caused by high rates of photosynthesis.

6.2.Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g., provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Provincial Objective:

The Ontario PWQO for the toxic form of ammonia (un-ionized ammonia) is a maximum concentration of 20 µg/L. The derivation of the objective was based on toxicological studies on nine species of fish, including rainbow trout, Atlantic salmon, perch, carp, and stickleback (OMOE 1979). Salmon were the most sensitive of the organisms studied. Most of the studies only reported levels at which lethal effects were observed (1 – 4d LC_{50} values), but a few studies also included other effects such as reduced growth or impaired development.

Canadian Water Quality Guideline for the Protection of Aquatic Life:

The CEQG to protects aquatic life from the toxic effects of ammonia was developed using a community ecological risk criteria by Environment Canada in addition to a CCME protocol (CCME 2001). The guideline for un-ionized ammonia is 19 µg/L. A separate narrative CEQG was specified for total ammonia, since the proportion of un-ionized ammonia (and corresponding toxicity) is temperature and pH dependent (Table 11). Toxicological studies used to derive the guideline included fish and invertebrates. Effects on the growth of a species of freshwater alga were also included.

Table 11. CEQG thresholds for maximal acceptable total ammonia N (mg/L) at specified water temperature and pH (CCME 2001).

pH:	6	6.5	7	7.5	8	8.5	9	10
0°C	190	60.0	19.0	6.02	1.92	0.616	0.206	0.035
5°C	126	39.7	12.6	3.98	1.27	0.413	0.141	0.028
10°C	83.9	26.6	8.47	2.68	0.855	0.282	0.100	0.024
15°C	57.3	18.1	5.74	1.83	0.588	0.197	0.073	0.021
20°C	39.5	12.5	3.96	1.27	0.410	0.141	0.055	0.020
25°C	27.6	8.72	2.77	0.888	0.291	0.103	0.044	0.018
30°C	19.5	6.17	1.97	0.631	0.211	0.077	0.035	0.017

Values are expressed as mg/L of total ammonia as N.

US EPA Water Quality Criteria

The USEPA are in the process of updating the water quality criteria for ammonia. Draft criteria, documented in 2009, include additional toxicity data and improve the methods by which numeric criteria are derived from the data (USEPA 2009). The review of ammonia toxicity data for the re-evaluation of the water quality criteria indicated that early life stages of mussels were among the organisms most sensitive to chronic exposure. Since many freshwater mussels are threatened or endangered species, it was considered important that the new criteria were reflective of the most complete data available for these species. Among the most sensitive species in the newly added toxicity data were the wavy-rayed lamp mussel (*Lampsilis fasciola)*, and the rainbow mussel (*Villosa iris*), both of which are known to occur the Grand River watershed.

Two sets of draft criteria were specified by the US EPA for freshwater ecosystems with or without mussels present (Table 12). Each set of criteria included pH and temperature-dependent thresholds of total ammonia for both acute or chronic exposure.

Table 12. Draft criteria proposed by the US EPA to protect freshwater communities with or without mussels from ammonia toxicity (US EPA 2009). Values of the draft criteria are maximal acceptable concentrations of total ammonia (mg/L as N at pH 8 and 25°C).

exposure:	acute	chronic
Community includes mussels	2.9	0.26
Community without mussels	5.0	1.8

6.3. Target formulation

Synthesis of information

A comparison of the Canadian and US sources of guidance indicates that even the most conservative set of water quality criteria specified by the US EPA for total ammonia is less conservative than the thresholds for Canada and Ontario. The CEQG for ammonia are nearly equivalent to the Ontario provincial guidance for un-ionized ammonia; the difference can be attributed to rounding of comparable concentrations. In addition to a threshold for unionized ammonia, CEQG for also include a lookup table for equivalent concentrations of total ammonia which may provide additional utility since measures are often expressed as total ammonia. Since field measurements are usually made as total ammonia, and collected in consort with measurements of water temperature and pH, the CEQG offers an approach which does not require an additional calculation step.

Target description and considerations:

The recommended target to protect against the toxic effects of ammonia on aquatic organisms in the Grand River watershed takes the form of a maximal threshold for the unionized ammonia of 20 µg/L which can also be expressed as a threshold of total ammonia that varies with temperature and pH, as shown in Table 13. **The ammonia targets recommended for the watershed is consistent with guidance for both Ontario and Canada.** Derivation of the target was based on the physiological requirements of cold and warm water fish species, invertebrates and a species of freshwater alga, which are considered representative of requirements that support the health of broader aquatic communities in the Grand River watershed. Considerations for the target take into account lethal effects in sensitive species and sublethal effects such as reduction of growth or exposure causing a weakened state. Comparison of the threshold in the target recommended for the Grand River watershed (Table 13) with the draft water quality criteria proposed by the US EPA (Table 12) suggests the recommended targets represent a low risk of toxic effects due to ammonia exposure for communities that include sensitive freshwater mussels.

Table 13. Summary of the generic target for ammonia in the Grand River watershed, expressed as the upper threshold of the desired total ammonia concentration (mg/L as N). Concentrations below these values pose a low risk to aquatic organism of the toxic effects of unionized ammonia.

pH:	6	6.5	7	7.5	8	8.5	9	10
0°C	190	60	19	6.02	1.92	0.616	0.206	0.035
5°C	126	39.7	12.6	3.98	1.27	0.413	0.141	0.028
10°C	83.9	26.6	8.47	2.68	0.855	0.282	0.1	0.024
15°C	57.3	18.1	5.74	1.83	0.588	0.197	0.073	0.021
20°C	39.5	12.5	3.96	1.27	0.41	0.141	0.055	0.02
25°C	27.6	8.72	2.77	0.888	0.291	0.103	0.044	0.018
30°C	19.5	6.17	1.97	0.631	0.211	0.077	0.035	0.017

The concentrations in Table 13 represent the upper threshold of the desired state; the target is for concentrations that fall below these values. Actions that decrease the likelihood of exceeding these thresholds will be supportive of aquatic community health and increased ecosystem resiliency. An increase in frequency and extent to which the concentration of ammonia is below the threshold for toxicity is generally indicative of a shift towards conditions that support healthy, resilient ecosystems.

7. Water temperature

7.1. Ecological context

Since water temperature is highly dynamic, conditions are often described for a given location as a characteristic of the range of temperatures over a period of time (e.g. daily range or maximum). The thermal regime of a reach characterizes the variations in water temperature that have the greatest consequence for aquatic organisms. Natural geomorphic characteristics and inputs from groundwater and overland flow have a strong influence on the potential for a reach to attain a particular thermal regime. The realized thermal regime is also affected by a combination of factors such as ambient air temperature, riparian shading, flow depth and velocity.

The influence of temperature on the health of an aquatic ecosystem can be as a result of physiological effects, or ranges of tolerance by organisms, but also as a result of the chemical and biological processes that are a function of temperature. For instance, increased temperature decreases the capacity of the water to hold oxygen, increasing the risk of harmful effects associated with hypoxia. The ability of organisms to tolerate extremes of temperature is related to their genetic ability to adapt to thermal changes, the temperature to which they are acclimated and the duration of exposure.

The thermal regime has a strong influence on the fish community since fish are among the types of organisms most sensitive to temperature. If fish experience temperature near their physiological limits in locations of refuge, and exposures are longer than a few hours, mortality can result. Less severe departures from temperature near the preferred range of fish can result in alteration of the community structure if it becomes a frequent occurrence. Fish are also likely to avoid locations where increases in temperature impact the ability of the water to hold oxygen. If appropriate refugia are not available nearby, it will decrease the habitat quality for these species. Species diversity and ecosystem health is impaired if the range of temperature persists above the temperature that is preferred by the more sensitive members of the aquatic community. For instance, persistently high temperatures (e.g. >25 °C) may favour the dominance of more thermally-tolerant species such as carp (Hasnain *et al.* 2010), a species which can negatively impact habitat structure and water quality in some ecosystems (Lougheed *et al.* 1998).

Ecological requirements: The influence of temperature on the health of an aquatic ecosystem can be as a result of physiological requirements, or ranges of tolerance by organisms, and also as a result of the chemical and biological processes that are influenced by temperature. For instance, increased temperature decreases the capacity of the water to hold oxygen, increasing the risk for harmful effects associated with hypoxia.

Critical period: temperatures may climb close to upper limits of physiological tolerance in summer months; potential for indirect impacts of increased temperature (as a result of reduced DO concentrations) is worst during warm summer months when biological activity is high (growing season)

7.2. Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g., provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Ontario Provincial Water Quality Objective:

The Ontario PWQO for temperature recommends that there be no alterations to the natural thermal regime. The rationale for the objective is focused on temperature changes resulting from inputs of human origin (OMOE 1979). The aim of the objective is to protect against adverse effects including loss of diversity and decreased distribution and abundance of plant and animal life.

Canadian Water Quality Guideline for the Protection of Aquatic Life:

The CEQG include guidelines for the protection of aquatic life from the effects of thermal additions. The CEQG for temperature take the form of a complex set of narrative guidelines, based on site specific information (CCME 2008). Thresholds in the guidelines are based on the physiological needs (e.g. optimum growth temperatures, upper incipient lethal limits) of species that are considered important in the area in question. The guidelines take into account ambient temperatures to which the existing community is acclimated, in addition to the sensitivity of different life stages during various parts of the year. There are guidelines for maximum average weekly temperatures as well as for short term exposures to temperature extremes.

BC Provincial Objective

In the province of BC, temperature is a particularly important aspect of water quality due to the prevalence of temperature-sensitive salmonids. The province has an objective for temperature to support aquatic life that uses a simplified set of criteria based on the CEQG for thermal alterations (BC 2001). A two tiered approach is used that separates the broad case from waters frequented by species with heightened temperature sensitivity (Bull Trout and/or Dolly Varden). In each case, the objective sets numeric thresholds for maximal temperatures based on the species present. Where there is an unknown fish distribution, a generic set of numeric thresholds are set for daily and weekly average maximal temperatures.

7.3. Target formulation

Synthesis of information

Water temperature can be highly dynamic, even in pristine systems, since it is influenced by environmental drivers that change rapidly such as ambient air temperatures and heat energy from sunlight. In addition, natural characteristics that vary spatially (e.g. groundwater inputs) contribute to inherent differences in the ranges of temperature among ecosystems. The range in conditions have resulted in different types of aquatic communities that physiologically adapted to a particular range in water temperature. As a consequence, it is difficult to characterize all situations with a single numerical target for temperature, so a narrative statement is often used describe the desired condition with respect to water temperature. Few directives have been specified for water temperature, but those that exist (e.g. the Ontario PWQO, Canadian Environmental Quality Guideline) use an approach that focuses on the maintenance of maximal temperatures within the existing thermal regime.

The thermal regime of an aquatic ecosystem describes the characteristic behaviour and pattern of water temperature and is related to the ability to buffer or resist changes in water temperature (i.e. thermal stability). From a resource management perspective, thermal regime is commonly divided into categories based on the temperature preferences of fish communities, since they have sensitive temperature requirements. Commonly, classifications include (at least) warm, cool and coldwater systems. Coldwater systems are most thermally stable and warmwater systems typically experience a greater range of temperatures, with higher temperatures in the summer and lower temperatures in the winter.

Many methods exist to assess and categorize thermal regimes; one example of a classification system was created using data from headwater streams in Ontario (Stoneman and Jones 1996). This method is focused on the thermal suitability of streams for cold, cool and warmwater fish communities on the basis of resiliency to increases in air temperature. By assessing the difference between the temperature in the water and the air over a range of temperatures, the method can provide information about thermal stability (i.e., how temperature ranges within a thermal regime) (Figure 7). This approach yields a flexible, more ecologically appropriate target than some of the other methods for categorizing thermal regimes, which may only specify a single value as an upper threshold (e.g. Coker *et al.* 2001). The main advantage of this approach is that it takes into account the *functional response* of the ecosystem to daily or seasonal variations in climatic pressures.

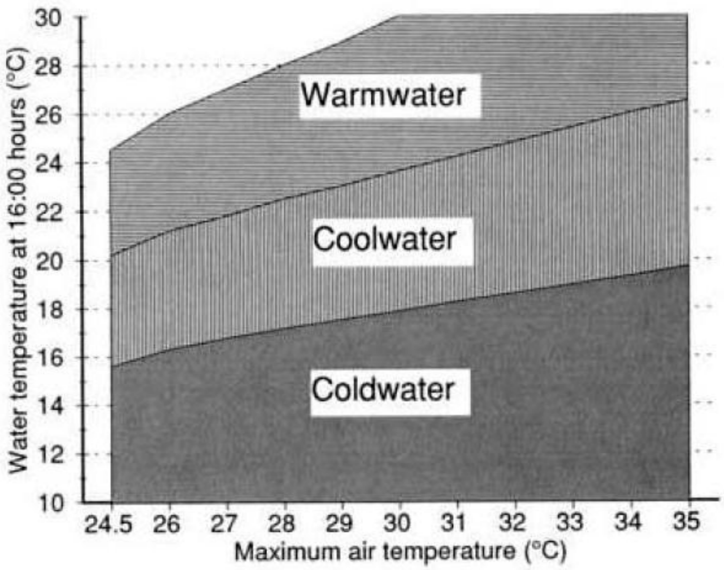


Figure 7. Nomogram of thermal stability, based on daily measurements of air and water temperature (as illustrated in Stoneman and Jones 1996)

Target description and considerations:

Existing guidance for temperature is largely aimed at preventing impacts that result from alteration of the existing thermal characteristics rather than restoration where alteration of the thermal regime has already impacted aquatic communities. Since targets in this report have been defined as a measure of the conditions that support healthy aquatic ecosystems, a target for water temperature should reference the physiological requirements or critical ecosystem functions required to sustain aquatic communities. Therefore, it is important to recognize that in some cases, it may not be possible to meet water temperature targets by maintenance of existing conditions and that actions to restorative actions may be necessary to attain the desired result.

A narrative target is recommended for temperature that, parallel to the approach of the PWQO and CEQG, describes the maintenance of maximal temperatures within a range defined by the appropriate thermal regime. The interpretation of the narrative relies on knowledge of the type of aquatic community that is expected to occur. In this context, three categories are commonly recognized: thermal regimes that support fish with preferences for cold, cool or warm water. This classification system is particularly useful since fish are among the organisms most sensitive to temperature, and the fish community information exists for most of the Grand River watershed. As part of the Grand River Fisheries Management Plan, most reaches in the watershed have been characterized according to the expected type of fish community (OMNR and GRCA 1998). This characterization draws on knowledge and information about the natural characteristics of the Grand River watershed that have the potential to influence natural variations in water temperature, such as hydrology and physiography.

The **recommended temperature targets for the broad case in the Grand River watershed are described using narrative statements** (Table 14). Since the upper threshold of a thermal regime is equated with the boundary to the next regime, descriptions of a warmwater regime generally do not include an upper bound. Consequently, in order to provide a simple, consistent approach, the recommended narrative target for warmwater systems is based on the requirements of most sensitive organism expected to be present. In the application of these targets it is important to recognize that temperature requirements change seasonally and as organisms go through different life stages. Therefore it is recommended that more conservative targets be considered where sensitive life stages are expected to be present.

Table 14. Recommended narrative targets for the water temperatures required for ecosystem health of rivers and streams in the Grand River watershed

Type of aquatic community	Target for water temperature
Coldwater or coolwater	Temperature fluctuations are within a range corresponding to the thermal regime that supports the type of community expected to occur.
Warmwater	Temperature meets the physiological requirements of the most sensitive organism expected to be present, as determined on a site specific basis.

To translate the narrative target into a numeric one, it is necessary to provide a numeric interpretation of thermal regime. The classification scheme of Stoneman and Jones (1996) provides an example of a method to assess the characteristics of water temperature as belonging to cold, cool or warmwater thermal regimes (Figure 7). Using their scheme, a series of thresholds for water temperature that separate each regime can be identified, which take into account the influence of ambient air temperature (Table 15). This scheme provides a coarse-level assessment of thermal regime which would not capture variations within a regime category, although they may be of large significance to aquatic life. Consequently, it would be beneficial to supplement with such an approach with a more detailed analysis (e.g. examining daily rate of change, consistent trends) where possible.

Table 15. Upper thresholds for streams with cold or cool water thermal regimes, as determined by paired daily maximums of water and air temperatures. Adapted from a classification scheme for Ontario streams by Stoneman and Jones (1996).

		WATER TEMPERATURE (daily max, °C)	
	Regime:	**Coldwater**	**Coolwater**
Air temp. (°C)	**24**	15.8	20.2
	26	16.5	21.3
	28	17.2	22.3
	30	17.9	23.4
	32	18.6	24.4
	34	19.3	25.5
	36	20.0	26.5

The categorization of thermal regimes as shown above can provide useful information about thresholds for water temperature that are appropriate for most streams in the Grand River watershed; however, this method may have limited utility in larger systems, such as the mainstem of the Grand River, since the values are derived from observations in relatively small streams (Stoneman and Jones 1996). However, most of the larger reaches in the Grand River watershed are characterized as warmwater systems (OMNR and GRCA 1998), so this may not pose a problem since the target for warmwater systems references a threshold determined from physiological data (Table 14). To meet target conditions in in warmwater systems, the range of temperature should stay below a threshold set by preferred or tolerable temperatures such that growth and reproduction are not adversely affected. The upper incipient lethal limit may provide a frame of reference for which data is readily available; however, it is important to recognize that sublethal effects are likely to occur as temperatures approach this threshold.

Another point to note, particularly in the case of warmwater systems, is the connection between temperature and DO; the adverse effects of increased temperature often manifest as low DO due to decreased solubility of oxygen and increased metabolism. As a result, in warmer water it may become difficult to maintain the concentration of DO above the target. Strategies to improve DO conditions should also consider the influence of temperature.

8. Nutrients

8.1. Ecological context

Nutrients are fundamental to the health of all ecosystems since they form the building blocks of organic matter. In aquatic systems, phosphorus (P) and nitrogen (N) are the primary nutrients fueling the growth of plants and algae, but in most freshwater environments, P is the growth-limiting nutrient (Wetzel 1983; Schindler 2012).

In natural waters, P exists in a variety of forms (Table 16): dissolved or particulate phases in organic or inorganic molecules. The sum of all forms is referred to as total P (TP). The largest pool of P in water is in the organic form, attached to particles and incorporated into organisms. In most environments, a small portion of TP is present as orthophosphorus, the most biologically available form. Since biochemical processes cause very rapid cycling between the different forms of P, TP typically provides the most meaningful measure of P (Wetzel 1983).

Table 16. Forms of phosphorus in aquatic environments

Particulate		**Dissolved**	
Organic	Inorganic	Organic	Inorganic
Cellular constituents; adsorbed to organic particles	Complexed with rock or soil particles	Adsorbed to colloids; phosphate esters	Orthophosphate; polyphosphates

Nitrogen can exist in aquatic systems within a wide variety of organic compounds (e.g. amino acids), or a an inorganic form of nitrogen such as ammonia, nitrite or nitrate. The proportion of each form of inorganic nitrogen is affected by a variety of environmental parameters including pH, temperature and ionic strength. In well-oxygenated waters, nitrate is the principle form of nitrogen used by plants and algae. Some of the inorganic forms of nitrogen can be toxic to aquatic life (nitrate, nitrite, un-ionized ammonia) at elevated concentrations (as discussed in previous chapters), however, adverse effects of inorganic nitrogen can also occur at much lower concentrations as a result of their use in biological production.

Nutrients are required for a healthy aquatic ecosystem, but changes to the nutrient dynamics to which an aquatic ecosystem is adapted can be detrimental to ecosystem health. Alteration of the nutrient supply to plants and algae can impact the structure, function and composition of the aquatic community through a number of mechanisms. For instance, elevated nutrient concentrations can favor the dominance of opportunistic species (such as cyanobacteria), allowing them to outcompete slower growing species for other resources such as light (Caputo *et al.* 2008). Changes in the community of producers can also result from alteration to the ratio of available nutrients. For instance, an elevated concentration of P concurrent with relatively low N availability is sometimes linked to the proliferation of cyanobacteria, which have the potential to form toxic blooms in lakes and reservoirs (Orihel *et al.* 2012). These shifts in species composition may have negative implications for food web structure, changing the flow of energy to consumers. Increased supply of nutrients can also fuel blooms or excessive growth of plants or algae that cause harmful effects through the subsequent decay of organic matter which consumes oxygen, or by altering the suitability of the habitat for other organisms. The environmental impacts resulting from the enrichment of nutrients have long been known and continue to be among the most important threats to freshwater ecosystems (Smith *et al.* 1999; Stendera *et al.* 2012).

Unlike most other indicators which have a toxic endpoint, the adverse effects of a change in the nutrient regime are often the result of secondary processes. The mechanistic link between nutrients and ecological health is the use of nutrients by plants or algae for production of organic matter. The negative consequences of changes to the nutrient regime can occur at the ecosystem level as the result of secondary effects of alterations to plant and algal productivity. It follows then, that the most appropriate measure of ecological health corresponding to nutrients is biological productivity. Since levels of productivity occur along a broad gradient in natural systems, classifying a level of productivity that is 'healthy' poses a particular challenge to the identification of an appropriate target for nutrients.

Historically, the mechanisms linking nutrients to algal production and the resulting biological structure of the ecosystem were incorporated into the concept of trophic status. The concept has been widely used in the context of lake ecosystems to provide a classification system for the functional relationship between water resources/characteristics (i.e. nutrients) and biological production (Carlson 1977; Vollenweider and Kerekes 1980). In broad terms, trophic state categorizes a production continuum. A shift along the continuum in the direction of more plant biomass is termed "eutrophication". The idea that eutrophic means "well-fed" and oligotrophic means "poorly-fed" originated from the nutrient condition of bogs, but the terms have typically been used to distinguish clear, unproductive lakes from turbid high-biomass lakes (Hutchinson 1969). In recent decades, the concept of trophic state has also been applied lotic ecosystems (reviewed by Dodds 2007), although some of the challenges arising from differences to lentic ecosystems will be discussed below.

Since the relationship between nutrients and production may change in different circumstances, the nutrient conditions supporting ecosystem health can also vary. This is especially the case for rivers and streams. The characteristics of river ecosystems change along a longitudinal gradient, so it is expected that the relationship between nutrients and biological production can change with increasing stream order. This continuum of structure and function is the result of a gradient in the physical environment between the headwaters and mouth of lotic systems (Vannote *et al.* 1980). In addition to the variation in nutrient dynamics caused by natural features, fluvial geomorphic processes influence the form and flow of organic matter. Nutrient cycling in flowing waters involves not only the transformation but also the translocation of nutrients, hence it is termed nutrient 'spiraling'. As a consequence of these inherent differences, some assessments of nutrient status or production exclude or consider large river systems separately (e.g. Porter *et al.* 2008).

Ecological requirements: A supply of nutrients is necessary to support biological production in aquatic ecosystems, however, enrichment of nutrients (eutrophication) can cause alterations to ecosystem structure and function by releasing constraints on biological production. Effects of eutrophication include the proliferation of opportunistic or nuisance species and increased plant and algal growth potentially leading to large fluctuations in oxygen availability and habitat degradation.

Critical period: The period during which the effects of nutrients are most critical is during the growing season (late spring and summer months). Ecological sensitivity to the effects of eutrophication may worsen during periods of low flow or warm temperatures.

8.2. Existing guidance

The following paragraphs detail the rationale on which guidance for various jurisdictions (e.g., provincial objectives, Canadian guidelines) was based, and outline any considerations which have been specified for their applicability. With each source of guidance it is important to consider:

1) whether the principle (i.e. intent) is aligned with the meaning of a target as defined in the Water Management Plan and
2) if it is broadly appropriate for the Grand River Watershed or should be altered by situational context (e.g. species assemblage, regional physiography, seasonal cycles).

Ontario Provincial Water Quality Objective:

The development of an interim Ontario PWQO for phosphorus in rivers and streams was based on the guideline that a total phosphorus (TP) concentration of <0.030 mg/L should eliminate excessive plant growth in rivers and streams (OMOE 1979; Table 17). However, it was acknowledged that since there was insufficient scientific evidence at that time to quantify a "firm" objective, these values were intended as general guidelines which should be supplemented by site-specific studies, such as monitoring of daily oxygen fluctuations. Ontario has not specified an objective for nitrogen in the context of the nutritional status of aquatic ecosystems.

Table 17. Ontario Provincial Water Quality Objectives for nutrients during the ice-free period (OMOE 1979).

Ecosystem	Biological endpoint	Scientific rationale	Threshold/ objective*
Lakes	Algal concentrations (aesthetics)	Threshold for surface algal scums	<0.02▼ mg/L TP
Lakes	Dissolved oxygen	Prediction of trophic status	<0.01▼ mg/L TP
Rivers, streams	Macrophyte growth	Threshold for proliferation of nuisance species	<0.03 mg/L TP

**interim values* ; ▼*measured in the spring*

The PWQO for rivers and streams was derived from studies of the growth of a macrophyte (*Potamogeton pectinatus*) and attached filamentous alga (*Cladophora glomerata*). These species are commonly responsible for "nuisance" growth in nutrient enriched rivers and streams of SW Ontario, including some reaches of the Grand River and its tributaries. Studies included observations from the Grand River watershed (in headwater reaches of the Conestogo, Grand, Nith, and Speed Rivers) (Painter *et al.* 1976). Measurements of the relationship between nutrients and photosynthesis in *C. glomerata* indicated that optimal growth was reached at ambient TP concentrations of approximately 0.060 mg/L, suggesting nutrient constraints are lifted above this concentration (Wong and Clark 1976; Painter et al. 1976). Studies of *P. pectinatus* showed that it was absent where the ambient TP concentration was

<0.030 mg/L (Painter *et al.* 1976). Lowest tissue stores of phosphorus in *P. pectinatus* were found below an ambient concentration of 0.034 mg/L; however, a critical concentration limiting daily relative photosynthesis was not observed. It was hypothesised that light, rather than nutrients limited growth of *P. pectinatus* in the study areas and that interspecific competition may have been responsible for its absence from some reaches. Notably, the authors of the study observed that even at average ambient TP concentrations of 0.039 mg/L, DO frequently dipped to low concentrations (<5mg/L). They indicated that ambient TP concentrations near 0.030 mg/L should not necessarily be interpreted as nutrient conditions that result in desirable biomass or DO concentration. Although the rationale for the PWQO for TP also noted this point, the value of 0.030 mg/L was recommended as an objective for aesthetic conditions which was also likely to provide protection against excessive daily oxygen fluctuations (an assumption to be confirmed with site specific data; OMOE 1979).

Canadian Water Quality Guideline for the Protection of Aquatic Life:

As part of the Environmental Quality Guidelines (EQGs), a framework was proposed for developing site-specific recommendations for management of freshwater ecosystems in the context of phosphorus (CCME 2004). The rationale for not recommending a single guideline value for phosphorus was based on the lack of feasibility for using a 'one-size-fits all' approach to characterize the ambient conditions to which the broad range of aquatic communities are adapted. Instead, the framework guides the creation of step-wise criteria that form the basis of decisions for management of phosphorus (e.g. "Do concentrations impinge on site-specific goals and objectives?"). It is recommended that particular attention be given to sites that receive variable phosphorus loads or exhibit marked morphological and hydrological differences (CCME 2004).

The framework is based on a comparison of current conditions to baseline conditions or natural levels at similar, high quality "reference" sites. The choice of reference conditions is guided by the site-specific goals and objectives, such as the enhancement, protection, or restoration of the ecosystem. According to the framework, if TP concentrations in the most sensitive part of the reach/lake under consideration exceed the trigger range (Table 18) determined from reference sites, or increase > 50% above the baseline conditions at the site, there is risk that impacts due to eutrophication have occurred or are occurring and further investigation is warranted. Although a detailed assessment to determine appropriate management strategies is not considered to be necessary where risk is low (i.e. where the trigger range is not exceeded and increases are <50% above baseline conditions), the framework recommends that ongoing monitoring of phosphorus concentrations should continue, to guard against future increases.

Table 18. Trigger ranges of TP concentrations that define the reference trophic condition for Canadian lakes and rivers as specified by the CCME (2004) framework for the management of freshwater ecosystems.

Trophic status:	Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic
TP trigger range (mg/L)	<0.004	0.004 – 0.010	0.010 – 0.020	0.020 – 0.035	0.035 – 0.100	>0.100

Unlike other methods, the approach does not necessarily require measurements from a pristine reach. Instead, it uses the best conditions from reaches with similar characteristics (e.g. climate, geology) as a frame of reference to determine the trophic status and appropriate TP range. The framework suggests that an ecoregion is a useful unit for this comparison, since natural factors contributing to nutrient enrichment (e.g. soil, vegetation, climate) will be similar within an ecoregion.

The concentrations for each trigger range defining the reference trophic status (Table 18) were derived from ranges specified by the OECD (Organisation for Economic Co-operation and Development) with one exception: the OECD "meso-eutrophic" category was further subdivided to include an additional category ("mesotrophic"). The rationale for this division was to reflect the considerable variation in community composition and biomass that occurs within the original range in Canadian rivers and lakes (CCME 2004).

The framework can assist in the determination of the risk of adverse effects, but it may not necessarily trigger further investigation in all situations where adverse effects are possible. For instance, in lakes with high baseline concentrations of phosphorus (e.g. 0.012 mg/L TP), an increase of less than 50% is considered a low risk, but may result in decreases in DO. While it is recognized that in such situations the framework may be inadequate as a single means to identify and prevent adverse effects, it is considered to be the best method for determining risk where other empirical data (e.g. on biotic condition) is not available.

Ontario Ecoregion Phosphorus Guidelines

Ecoregion-based phosphorus guidelines were synthesized for the CCME by Gartner Lee Ltd. (2006). The ecoregions within Ontario were used as a case study to determine the feasibility of applying the Phosphorus framework developed by the CCME (2004) to other Canadian ecoregions. Ecoregions are areas with distinctive natural characteristics such as geology, soils, climate, vegetation and fauna; they are contained within larger ecozones, which are representative of very generalized ecological units (i.e., sub-continental scale). The Grand River watershed sits within the Mixed Wood Plains ecozone and straddles two ecoregions: Manitoulin-Lake Simcoe to the north and the Lake Erie Lowland ecoregion to the south, just below the confluence between the Nith and the Grand River (Figure 8).

An ecoregion is a useful unit for developing nutrient guidelines since it is determined from ecologically relevant characteristics; the classification system allows a more appropriate generalization than at a province-wide level. The development of the ecoregion guidelines considered similar approaches for regional classification such as those used in British Columbia and the United States, which delineated units at the sub-basin and ecoregion scale, respectively (Gartner Lee Ltd. 2006).

To determine reference phosphorus concentrations within each ecoregion, available datasets for Ontario (e.g. from Ontario Ministry of the Environment's Lake Partner Program and Provincial Water Quality Monitoring Network), were pooled by ecosystem type (i.e. river or lake). Sites immediately downstream of point sources such as sewage treatment plants and industrial operations were excluded. Other influence of human activity was removed from the data using statistical approaches. For instance, where human sources of nutrients were expected, the baseline was considered to be equivalent to the lower of the range of concentrations. Since the data from southwestern Ontario included a relatively low proportion of undeveloped areas, sites with the 25% lowest average TP concentrations (25^{th} percentile) were used as an indication of baseline conditions within each ecozone or ecoregion.

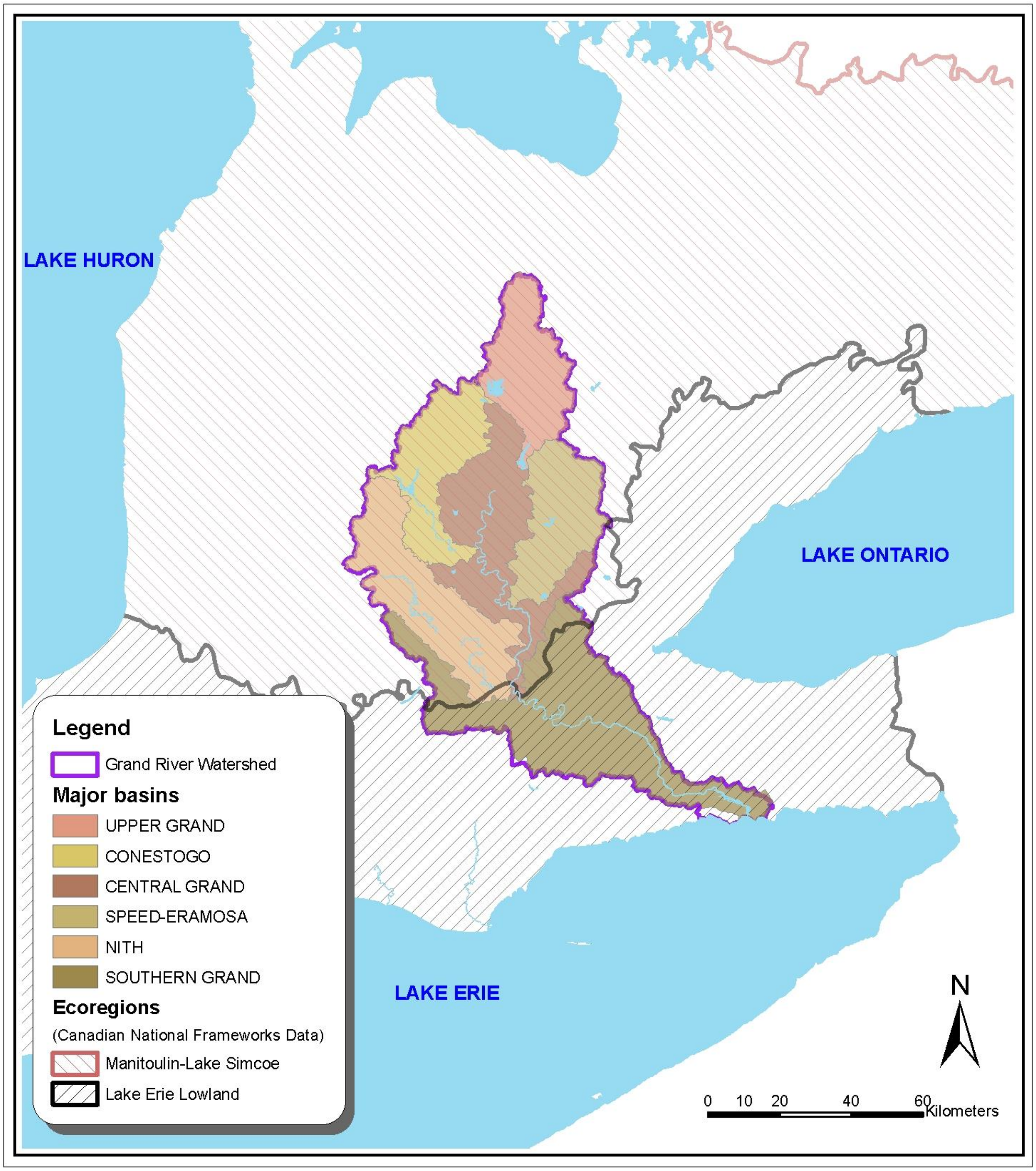


Figure 8. Location of major drainage basins of the Grand River watershed with respect to ecoregions delineated by the National Ecological Framework for Canada.

Statistical methods were used to determine if unique clusters of phosphorus concentrations could be explained by ecological characteristics. Ecozones were found to be a better predictor of TP concentrations than other water chemistry characteristics such as calcium and chloride concentrations. The 25th percentile of average TP concentrations were significantly different among Ontario's ecozones and ecoregions. Estimates of natural TP concentrations (i.e. 25th percentile) in rivers in the Mixedwood Plains ecozone (0.027 mg/L) were significantly higher than the Boreal Shield ecozone to the north (0.01 mg/L), respectively. Average concentrations in most rivers in the Mixedwood Plains ecozone were in a range commonly considered to indicate mesotrophic to eutrophic conditions in lotic ecosystems (0.025 – 0.075 mg/L and >0.75 mg/L TP, respectively; Dodds *et al.* 1998); only a small number are classified as oligotrophic (<0.025 mg/L TP). For lakes, there was a similar trend between these ecozones, however, differences in sample sizes may have skewed the results.

Estimates of natural TP concentrations increase gradually with the transition from igneous to sedimentary geology and thin to thick soils, as reflected by the higher values of the 25th percentile in Lake Erie Lowland rivers and lakes (Table 19). Similarly, the legacy of human activity concentrated in the Lake Erie Lowland ecoregion is likely responsible for the high value of the upper range of TP concentrations, relative to the other ecoregions.

Table 19. Statistical analysis of average TP concentrations at sites in the two ecoregions that contain the Grand River watershed. The 25th percentile is an estimate of natural TP concentrations within an ecoregion and is used to determine reference trophic status within the phosphorus framework for Canada (CCME 2004).

	Ecoregion	25th percentile	75th percentile	N
Rivers	Manitoulin-Lake Simcoe	**0.024**	0.061	309
	Lake Erie Lowland	**0.032**	0.139	315
Lakes	Manitoulin-Lake Simcoe	**0.010**	0.020	83
	Lake Erie Lowland	**0.014**	0.038	10

The analysis also indicated that there was spatial variance in concentrations *within* ecoregions. The report discussed the effect of potential sources of variation including surficial geology, terrain and wetland and lake dynamics. It was recommended that the influence of such factors be taken into account in the prediction of natural TP concentrations within an ecoregion. Further consideration was also recommended for longer river systems, since concentrations will increase with distance through natural processes, independently of human activity. The report warned that in the absence of such considerations, this approach may yield “false positive” indications of enrichment in downstream reaches of large rivers. It was suggested that this approach be used as an initial screening step to determine reference trophic status, supplemented by more detailed assessments and regional monitoring programs.

National Agri-Environmental Standards Initiative

Under the Nutrient Subgroup of the Water Theme in the National Agri-Environmental Standards Initiative (NAESI), Chambers *et al.* (2008) developed and tested approaches for setting environmental quality targets for N and P concentrations for small (2-4th order) streams, as well as medium and large rivers (watershed area 100 – 1000 or 1000 – 10 000 km^2, respectively) in agricultural landscapes. The goal was to produce non-regulatory performance standards for nutrient concentrations that were protective and supportive of conditions for a diverse community of aquatic and riparian organisms.

The Ideal Performance Standards (IPS) define the threshold of a chemical or biological condition below which no adverse ecological effects are known or expected to occur. IPS for total P (TP) and total N (TN) were produced for streams and for agricultural watersheds in 6 Canadian ecozones including the

Mixedwood Plains ecozone in Ontario, which contains the Grand River watershed. IPS for streams were developed from analysis of nitrogen (N) and phosphorus (P) concentrations from more than 200 water quality stations across Canada as well as detailed ecological study at approximately 70 sites. Recommendations for IPS for agricultural watersheds at the ecozone scale were produced using data from approximately 200 medium and large rivers across Canada. In Ontario, data was compiled from sites located in streams in the Grand, Maitland, Thames and Saugeen watersheds. The Mixedwood plains ecozone contained data for 113 medium and 18 large rivers.

The NAESI IPS (Table 20) were based on the derivation of a reference condition (i.e. undisturbed). The approach relied on a variety of numerical calculations of all available data rather than measurements at reference sites. The analysis used existing long-term datasets of chemical parameters (collected by watershed and provincial authorities) and additional monitoring of physical, chemical and biological (e.g., benthic macroinvertebrates, periphyton, sestonic algae) parameters. Using the long-term data (1985- 2005), a reference condition was derived using a variety of methods (e.g., pre-set percentile, hindcasting from land use relationships). The median reference condition from these methods was used as a draft IPS, which was then cross-calibrated with biological condition using relationships between nutrients and biological metrics from the newly collected dataset. Since the relationship between nutrient concentration in rivers and biological condition (chlorophyll-*a* concentration) was relatively poor, there is a low level of certainty that IPS values would yield the desired ecological condition (sestonic and periphyton biomass). As a consequence, the recommended IPS for rivers (Table 20) were derived solely from the 25^{th} percentile.

Table 20. Recommended IPS for concentrations of total phosphorus (TP) or total nitrogen (TN) to protect the ecological condition in agricultural rivers and streams within the Ontario Mixedwood Plains ecozone.

	TP (mg/L)	TN (mg/L)
Small streams (2-4th order)	0.024	1.07
Medium rivers (watershed area 100 – 1000 km^2)	0.024	1.02
Large rivers (watershed area 1000 – 10 000 km^2)	0.019	0.63

It was recommended that IPS for TP and TN in medium and large rivers would be improved by a more targeted study of the relationship between nutrients and aquatic plant biomass, including the effect of other factors such as light limitation and flow.

Nutrient Management Strategy for Lake Erie

Tributary target of an annual mean concentration of TP <0.032 mg/L applies to tributary waters immediately above the lake effect zone of the tributary that contains a mix of Lake Erie water and tributary water (Lake Erie LaMP 2011). Based on targets developed by research by Environment Canada as part of NAESI (Chambers *et al.* 2008). The Strategy also specified a target TP concentration for coastal wetlands although it recommended that additional studies be conducted to elucidate the relationship between ecological state and nutrient loading in these environments. The coastal wetlands target of at least one instance per year of less than 0.03 mg/L is based on the State of the Lakes Ecosystem Conference indicator “Nitrate and Total Phosphorus for Coastal Wetlands (Indicator ID: 4860)”.

US EPA Water Quality Criteria

Under the Clean Water Act, States and Tribes must establish criteria to protect designated uses, but have discretion as to the method they can use. To assist States and Tribes, technical guidance was documented by the USEPA for developing nutrient criteria for rivers and streams in the US to protect aquatic life from acute and chronic effects of nutrient over-enrichment (USEPA 2000). Guidance from the US EPA in the determination of nutrient criteria spans a range of methods, including statistical methods to derive reference conditions, mechanistic modelling and more recently, an approach to derive numeric criteria based on stressor-response relationships (USEPA 2010).

The approach for developing criteria recommended by the US EPA involves a series of iterative steps, beginning with the identification of the goals and needs for water quality (i.e., recreation, cold water fishery). This step acknowledges that the frame of reference for the desired state may vary between locations. The following steps classify the rivers and streams on the basis of natural characteristics (e.g. biological, physical, ecological features) so that criteria can be applied on a broad- rather than site-specific scale. This grouping includes two steps: first, a stream classification based primarily on physical parameters and regional characteristics (e.g., fluvial geomorphology, nutrient ecoregion); and second, a classification based on nutrient gradient (i.e., trophic status). The recommended approach takes into account an understanding of dose-response relationships between algae and nutrients.

There is wide variation in the development of criteria, both in the methods and in the resulting values. Some states have developed statewide criteria for nutrients (e.g. Wisconsin, Virginia, Vermont). Where statewide criteria have been proposed, most have categorized lakes and reservoirs; rivers and streams; or wetlands separately. Categories also include a separation based on fisheries resources or thermal regime, morphometric or hydrologic characteristics, or fluvial geomorphology (e.g. substrate, depth, steam order). In most cases (particularly for lotic systems), criteria are set for P but not N.

8.3. Target formulation

Synthesis of information

The range of approaches to developing guidance for nutrients in aquatic ecosystems reflects both the diversity of ecosystems and also the variation in the desired outcome or ecological endpoint (Table 21). The measures used to assess a healthy productivity regime or trophic state depend on the use or value of the natural system (e.g. ‘nuisance growth’/aesthetics; community structure/biodiversity). Similarly, different measures of nutrients are also possible. Although the form of the nutrient is important to the ecological processes, TN and TP are generally considered the most meaningful measures for control of primary production by nutrients (USEPA 2000; CCME 2004). Both N and P are considered to play a role in the control of primary production (Dodds 2007); however, most guidance focuses on the role of P since it is considered the limiting nutrient in most cases. In most jurisdictions, there is no guidance for N to prevent the effects of nutrient enrichment.

Table 21. Approaches for the development of guidance for phosphorus in Canadian rivers and streams.

Source (jurisdiction)	**TP Threshold**	**Frame of reference**	**Approach**	**Desired outcome/ ecological endpoint**
Interim PWQO (Ontario)	0.030 mg/L for all streams in Ontario	Absence of nuisance macrophytes	Limit set at threshold for absence of *P. pectinatus* in headwater streams	Aesthetic conditions (lack of proliferation of nuisance macrophyte species)
CCME CWQG (Canada; site-specific)	Variable value based on site-specific goals and objectives	Desired trophic status	Framework to determine risk; acceptable ranges defined by reference trophic status	Trophic status; desired state set by site-specific goals and objectives
Ecoregion Guidelines (Canada)	Meso-eutrophic trophic trigger range*: 0.020 – 0.035 mg/L	Undisturbed conditions	Reference trophic status derived from 25th percentile of TP averages at all available sites (20 year span)	Trophic status, supported by TP concentrations
NAESI (Agricultural landscapes; ecozone-specific)	(Mixedwood Plains) small streams, medium rivers: 0.024 mg/L large rivers: 0.019 mg/L	Undisturbed conditions	Reference condition determined by modeling, statistical analysis; cross-calibration with multiple biological indicators	Algal biomass, community structure of algae and benthic invertebrates typical of undisturbed conditions

* *trigger ranges specified by CCME (2004) framework*

Most approaches to developing nutrient guidance acknowledge that differences in the characteristics of aquatic ecosystems can lead to variation in background concentrations. Approaches differ in the methods with which to deal with this variation, but most propose a classification system to group ecosystems with a similar expected level of production or natural background concentration of nutrients, based on common characteristics or natural features. For instance, the guidance based on ecoregion or ecozone (Gartner Lee Ltd. 2006; Chambers *et al.* 2008) indicates that characteristics such as the naturally rich productive soils in southwestern Ontario likely lead to higher background concentrations of TP in the Grand River watershed relative to other regions of Ontario. Despite the usefulness of these units for generalization, the technical background and considerations for the use of the guidance suggest that they may still be too broad to generalize appropriate TP concentrations. Most sources of guidance recommend the proposed approaches be supplemented with more detailed assessment, which takes into consideration additional factors such as the position in the landscape or in-steam processing; or the potential for flow or light to influence primary production.

Target description and considerations:

Harmful effects of nutrient enrichment include the degradation of habitat (e.g. nuisance growth of plants and algae; oxygen depletion) and changes in the composition of producers, which can alter the food web, potentially impacting many other organisms. Stress resulting from alteration to the nutrient regime can also impact ecosystems far from the source, in downstream reaches. Nutrients have an important role in supporting the broad water objective: "Water quality does not promote excessive growth of aquatic vegetation or harmful algal blooms in rivers, reservoirs and lakes".

Guidance for nutrients in freshwater ecosystems commonly take the form of recommendations for the concentration of TP. It is therefore recommended that a target for TP be used in the broad case for the Grand River watershed to characterize the conditions that are protective of the negative effects of nutrient enrichment.

In the Water Management Plan, targets characterize the conditions that would result in the outcome of a healthy ecosystem with desired attributes or characteristics. Consequently, some of the existing guidance may not be appropriate to adopt as a target since they do not have a comparable frame of reference (Table 21). For instance, the frame of reference for the interim PWQO for TP is the absence of nuisance species in unshaded clear-flowing headwater reaches (OMOE 1979). Since it does not take into account other desired ecological characteristics such as the biomass of primary producers or DO concentration, the PWQO TP value does not represent conditions supporting the full range of conditions in a comprehensive interpretation of ecosystem health. In addition, the rationale for the PWQO may not be applicable to areas of the watershed with different characteristics (e.g. larger reaches). Similarly, the guidelines proposed for ecozones or ecoregions (Chambers et al. 2008; Gartner Lee Ltd. 2006) are not comparable with the frame of reference for Water Management Plan targets since the guidelines represent undisturbed conditions and the Water Management Plan targets are intended to represent a broader range of conditions than those that are pristine. Despite these differences, the existing guidance may be helpful as source of possible methods for the development of more appropriate targets, or as an indication of conditions that bracket the desired conditions of the Water Management Plan target.

The concept of trophic status is a useful means to classify the desired ecological condition likely resulting from nutrient concentrations. Boundaries and number of categories for trophic state categorization can vary between methods for classification (e.g., USEPA 2000; CCME 2004; Dodds 2007). The variation in the details of classification methods is not unexpected, since trophic state categorized a continuum of production, which lacks sharp boundaries or “break points”. Regardless, the original categories, “oligotrophic” and “eutrophic” are common across most classification systems and are used to separate conditions which are nutrient-starved from those which are nutrient-saturated. The term “mesotrophic” is commonly associated with an intermediate level, which characterizes a system in which a moderate amount of production is influenced by the ambient nutrient concentrations.

Broadly, most sources of guidance indicate that concentrations of TP in a range intermediate between oligotrophic and eutrophic represent a productivity regime to which species in rivers and streams in the Grand River watershed are adapted (Table 21). Consequently, a level of production in the intermediate or mesotrophic range is consistent with the broad water objectives of the Water Management Plan that support a healthy ecosystem. In the absence of a determination of the conditions supporting the ecological endpoint appropriate for the goals and objectives of the Water Management Plan, the desired status of “mesotrophic” is currently the best representation of the target condition for nutrients in reaches in the Grand River watershed.

Recommendations:

Information is currently incomplete to determine numeric targets for nutrient conditions that support of healthy aquatic ecosystems in the Grand River watershed. Due to the diverse range of natural characteristics in the watershed, it is difficult to identify a single ecological endpoint that defines the frame of reference for a healthy state in all aquatic ecosystems. Since a single numeric target for the broad case is likely not appropriate, **it is recommended that a productivity regime supporting mesotrophy is accepted as the frame of reference for a generic nutrient target in the Grand River watershed until more definitive targets can be determined**. In this context, mesotrophy refers to a level of productivity such that it is neither nutrient-saturated nor nutrient-starved. Attributes of such a state include:

- growth of plants or other organisms that does not cause oxygen dynamics that are harmful to aquatic life; or
- desirable community composition (e.g. diversity of aquatic plants, absence of nuisance species).

It is recommended that **further work be completed to develop numeric targets that recognize the diversity of conditions to which aquatic communities in the Grand River are adapted**. To develop numeric targets, it may be necessary to first identify a more specific frame of reference for healthy conditions. Such an approach would benefit from the utilization of information specific to conditions in the Grand River watershed and take into consideration the role of regional characteristics and ecology. Collection of data to support the quantification of a targets should be at a spatial and temporal scale that would best characterize the role of nutrients in shaping both the structure and function of the ecosystem. Targets should be generalized for categories that take into account the typology, such as assemblages of species expected to be present or variations in other natural characteristics relevant to productivity.

The Water Quality Working Group recommends that a Science Dialogue be held to address gaps in the knowledge and information needed to develop nutrient targets that quantify the desired productivity regime and are appropriate for the diverse aquatic ecosystems in the watershed. The Science Dialogue would bring together scientific experts to discuss the quantification of nutrient targets based on the frame of reference that has been chosen to define a healthy state.

9. Summary of targets and recommendations

The Water Quality Working Group built on the work previously undertaken in this update of the Water Management Plan to identify indicators of resource conditions that can be improved by water management. An initial list of indicators was identified by the Grand River – Lake Erie Working Group by developing a framework that focused on the resource condition requirements of aquatic communities in the Lake Effect Zone (GRWMP 2012). These indicators of resource condition describe conditions that can be impacted by human-related disturbance, but if improved, will support needs of the aquatic community and contribute to a healthy ecosystem state. Subsequent consideration of ecosystems in other key areas of the watershed identified additional indicators and confirmed that the previously identified indicators are relevant to fundamental resource condition requirements in a broad spectrum of aquatic communities.

The scope of assessment completed by the Water Quality Working Group included narrative or numeric targets for the following indicators:

- Dissolved oxygen
- Particulate matter (turbidity and suspended solids)
- Toxic forms of nitrogen (nitrate and ammonia)
- Temperature
- Nutrients

Work will continue through an iterative process to refine these targets and to develop targets for additional indicators. The Water Quality Working Group did not identify targets for all of the indicators that were identified as important for healthy aquatic ecosystems in the Grand River watershed (e.g. flow and the macrophyte community); however, targets for some of the indicators not addressed in this report will be incorporated into the Water Management Plan through parallel processes and by other working groups.

The current list of indicators focus on stressors, rather than on the response of the biological community. While these indicators will provide useful information about how management actions are changing environmental stressors, it is anticipated that a complementary approach will be used to gauge whether the changes are having the desired result and contributing to healthy, resilient ecosystems. Collaboration between plan partners and researchers is ongoing and will help to identify tools to fill in this gap and build a framework that provides a more integrated approach

9.1. Summary of recommended targets

The targets recommended by the Water Quality Working Group to support healthy, resilient aquatic ecosystems in the Grand River watershed are summarized in Table 22. These generic targets for the watershed were derived from knowledge of the conditions the Grand River watershed and existing assessments that quantified the contribution of water quality to conditions supporting ecosystem health. The intent of the targets is to provide the plan partners with common tools to measure the resource conditions that support the desired features and functions of healthy aquatic ecosystems. Comparison of the targets with monitored conditions can aid in tracking the progress towards achieving the broad water objectives for healthy aquatic ecosystems.

Table 22. Targets for resource conditions that support healthy aquatic ecosystems in the Grand River watershed

Indicator	Frame of reference for target	Target
Dissolved oxygen (daily fluctuation)	Sufficient to support **physiological requirements** of aquatic organisms (Low risk of hypoxia or lethal effects in sensitive species)	*Daily minimum above a threshold of:* 4 mg/L; or 5 mg/L where a coldwater fish community is expected to be present; or 6 mg/L where sensitive species or early life stages are expected to be present
Dissolved oxygen (chronic reduction)	Sufficient to support **physiological requirements** of aquatic organisms (Low risk of sub-lethal effects from long term exposure, e.g. reduced growth or reproduction)	*Average of daily minima over 30d above a threshold of:* 5.5 mg/L; or 6.5 mg/L where a coldwater fish community is expected to be present
Suspended sediment (event-driven peaks)	**Low risk of harmful effects** of suspended sediment (e.g. harm to of fish and invertebrates from smothering, gill clogging)	Tiered framework, based on background* and dose-response for the most sensitive type of organism expected to be present Further work needed to develop site-specific numeric targets
Turbidity (chronic reduction in water clarity)	**Water clarity** that supports processes leading to healthy plant and animal communities (e.g. visual cues to behaviour, underwater plant growth)	Background *belowe* a threshold of 20 NTU during the growing season
Nitrate (toxicity)	**Low risk of toxicity causing harmful effects** including sub-lethal effects from long term exposure	Concentrations of nitrate *below* a threshold of 3.0 mg/L as N (as representing chronic conditions)
Ammonia (toxicity)	**Low risk of toxicity causing harmful effects** including sub-lethal effects from long term exposure	Concentrations of unionized ammonia *below* a threshold of 20 µg/L (or expressed as total ammonia concentrations, varying with temperature and pH)†
Water temperature (shift in thermal regime)	**Thermal regime** consistent with physiological requirements of natural communities (range of preferred or tolerable temperatures)	Tiered framework, based on the most sensitive members of the aquatic community expected to be present
Phosphorus and nitrogen (nutrient enrichment)	**Productivity regime** supporting mesotrophy in rivers and streams (as defined by desired ecosystem features and functions)	Further work needed to develop numeric targets for all types of rivers and streams in the watershed

**Background does not include high flow events; ** background should be assessed on the basis of hydrologic state (e.g. clear flow or turbid flow)*

The numeric targets represent a threshold between the desired state and one with adverse effects on ecosystem health. To meet such a target, measures should *at least* attain a desirable condition expressed by the target, if not surpass it. Where conditions do not meet targets, actions that decrease the likelihood of falling outside the desirable range of conditions will contribute to improved aquatic community health. Such actions can improve ecosystem resiliency, but do not necessarily guarantee the transition to a healthy ecosystem, since ecosystem health is affected by many factors in addition to natural variability. Regardless, an increase in frequency, duration and extent to which conditions are in the desired state (as expressed by the targets) is a good indication of a shift towards a healthy, resilient ecosystem.

9.2. Considerations for the interpretation of target conditions

Targets for a healthy aquatic ecosystem are informed by science and provide a generic frame of reference for the desired condition in the Grand River watershed. Ecosystem "health" is described in the context of desirable attributes or functions by the broad water objectives of the Water Management Plan. It is important to recognize that although the frame of reference for the targets typically refers to a less disturbed state, the support of these attributes or functions does not necessarily require pristine conditions. It is also important to recognize that alteration of ecosystem state resulting from human disturbance is superimposed onto natural sources of variation. As a consequence, comparison of conditions with targets requires professional judgement about the role of natural of anthropogenic factors.

The targets are generic for the Grand River watershed: they are intended to reflect conditions that are supportive of ecosystem health in most cases. There may be circumstances where more specific targets are needed to account for unique conditions. Correspondingly, the conditions characterized by the recommended targets are not intended to represent no-effect levels under all scenarios. The calculation of the recommended numeric targets does not take into account the increase in sensitivity that can occur when other indicators are at non-ideal levels (i.e. cumulative effects). For instance, sensitivity to nitrate toxicity is likely to be much higher if an organism is already in a weakened state due to low DO conditions. This limitation highlights the utility of a more holistic approach that takes into account groups of indictors, including biological conditions, which allows a more robust understanding of the factors affecting ecosystem health (Bunn *et al.* 2010). Such an approach was difficult to use in the determination of targets for the Water Management Plan, however, on-going research will play a critical role in identifying and filling gaps in science that can inform future strategies for the collection and interpretation of data.

The recommended indicators and targets are based on information about current conditions and the best available knowledge about natural variability in the watershed and in comparable ecosystems. The need for iterative re-evaluation of conditions as part of an adaptive management approach is underscored by the potential for current constraints to be replaced by others as new pressures emerge or existing pressures are mitigated. Improvements in some indicators may heighten the role of other factors (e.g. a reduction in turbidity may increase the role of nutrients in reaches where production is currently light-limited). As a result, it is possible that if target conditions are met through water quality improvements, the biological state may not respond as expected since other constraints may become more important (e.g., Thomasen and Chow-Fraser 2012). Response of the aquatic community to restoration efforts is often complicated and difficult to predict. For instance, under some circumstances the is a 'tipping point' in ecosystem degradation, beyond which it is difficult or impossible to restore ecosystem health even if a 'normal' range of concentrations are achieved. Since it is difficult to predict the outcome in such scenarios (e.g. due the establishment of nonindigenous species), it is important to collect data and iteratively re-evaluate the relationship between the indicators and the desired conditions to ensure targets are ecologically appropriate in the context of the current conditions.

9.3. Adaptation of target to generalized or site-specific considerations

As information that is more specific to the characteristics of the Grand River watershed (e.g., species assemblages, geology and water chemistry) becomes available, it is recommended that it be considered in the context of re-evaluating the targets so that they better reflect the stressor-response relationship. In some cases, site-specific targets may be more appropriate than targets for the broad case. Such instances may include areas with unique water quality characteristics (e.g., natural background concentrations above target values), species assemblages or when multiple stressors are likely (e.g., low DO and high temperatures). For example, the natural characteristics of the slow-moving warmwater reaches of the southern Grand River result in a species assemblage adapted to a different set of conditions than headwater streams.

A determination of the appropriateness of local or site-specific targets may want to consider:

- the resident species (including different life stages) and their sensitivities;
- the influence of hydrologic and fluvial geomorphic processes on water quality;
- factors affecting the choice of desired ecological state (frame of reference)

The adaptation of targets to the full range of characteristics in the watershed would benefit from a consideration of existing guidance that is documented in this report for the creation of site-specific or tiered targets. Where possible, site-specific information should be used to derive more generalized targets for other sites or circumstances with similar stressor-response relationships. To develop appropriate units for generalization, it may be most effective to build on pre-existing categories, such as ecoregions or similar units based on natural characteristics. Ecoregions are generalized ecological units that contain areas with distinctive natural characteristics such as geology, soils, climate, vegetation and fauna. It may also be useful to utilize units which are already used in the context of watershed management. For instance, the Grand River Fisheries Management Plan divides the watershed into three physiographic regions as a coarse scale, and into warm, cool and coldwater reaches at a finer scale.

9.4. Recommendations and next steps

The Water Quality Working Group recommends to the Project Team and Steering Committee that the targets detailed in this report be a starting point for evaluating the resource conditions that support aquatic ecosystem health in the Grand River watershed. It is anticipated that the targets and the list of indicators will be updated iteratively as new data and information becomes available.

Further, the Water Quality Working Group also recommends that these targets, where appropriate, be adapted to account for local or site specific conditions or ecological requirements.

To improve the recommended targets and provide more specific guidance (where necessary), a number of actions are suggested to address the gaps in knowledge or understanding:

- detailed discussion, including water managers and scientific experts, to determine the frame of reference for nutrient targets that is appropriate for the diverse characteristics of aquatic ecosystems in the Grand River watershed;
- continued collection of data on the condition of resources (e.g., water quality) and corresponding biological state; and
- revision and amendment of the list of targets and indicators by incorporation of new data and information.

The Water Quality Working Group recommends that continued work to develop targets for nutrients include a Science Dialogue that will address the gaps in knowledge and information. These gaps currently hamper the development of a more specific (i.e. measurable) target for nutrient conditions that support healthy ecosystems in the Grand River watershed.

To improve or refine the targets as detailed in this report, continued collection of data on the condition of resources (e.g., water quality) and corresponding biological state is recommended. The collection of these measurements should be concurrent where possible, in order to validate the relationships between resource condition (e.g., water chemistry) and biological state (e.g., producer biomass) on which the targets are based. There is also the need for improved understanding about the interplay between factors (e.g., flow, light, temperature).

The list of identified indicators focus on stressors, rather than on the response of the biological community. While these indicators will provide useful information about how management actions are changing environmental stressors, it is anticipated that a complementary approach will be used to gauge whether the changes are having the desired result on aquatic communities.

To measure the progress towards targets, the Water Management Plan will also set interim targets that describe the condition that is expected to be achieved as a result of implementing the specific actions set out in the Water Management Plan. Since interim targets are based on the expected result of achievable management actions, such as wastewater treatment plant upgrades, a necessary first step is the identification of actions that will be agreed to as part of the Water Management Plan. Once actions have been identified, the expected conditions, or interim targets, can be determined.

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Appendices

Appendix A. Context of targets: key components of the 2013 update to the Water Management Plan for the Grand River watershed.