Canadian Environmental Sustainability Indicators 2005

Freshwater Quality Indicator: Data Sources and Methods

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Environment Canada
Statistics Canada
Health Canada

Table of contents

1. Introduction

Canadians' health and their social and economic well-being are fundamentally linked to the quality of their environment. Recognizing this, in 2004, the Government of Canada committed to establishing national indicators of freshwater quality, air quality, and greenhouse gas emissions. The goal of these new indicators is to provide Canadians with information on the state of their environment and how it is linked with human activities. Environment Canada, Statistics Canada, and Health Canada are working together to develop and communicate these indicators. Reflecting the joint responsibility for environmental management in Canada, this effort has benefited from the cooperation and input of the provinces and territories.

This report is part of a suite of documents released under the Canadian Environmental Sustainability Indicators (CESI) initiative.[1] Each indicator reported in a given year under the CESI has an associated "data sources and methods" report to provide technical details and other background to facilitate interpretation of the indicator or allow others to build further analysis using the CESI data and methods as a starting point.

The information in this report should provide users with a better understanding of the basic concepts and methodology underlying the indicator, the strengths and limitations of the data, and how the data can be effectively used and analyzed. The information is of particular importance when making comparisons with data from other indicators and in drawing conclusions regarding change over time. This report deals with the underlying methods and data for the freshwater quality indicator as it was reported in 2005.

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2. Description of the indicator

The freshwater quality indicator provides an overall measure of the suitability of water bodies to support aquatic life at selected monitoring sites in Canada. The indicator is based on applications of the Water Quality Index (WQI) endorsed by the Canadian Council of Ministers of the Environment (CCME) in 2001 (CCME, 2001). Given that aquatic life can be influenced by the presence of hundreds of natural and anthropogenic substances in water, the WQI provides a useful tool that allows experts to translate vast amounts of water quality monitoring information into a simple overall rating.

At present, the freshwater quality indicator is presented as a national histogram of the WQI results from individual water quality monitoring sites across the country. The histogram groups WQI values into five categories: poor, marginal, fair, good, and excellent.

The indicator measures the frequency at which and the extent to which selected pollutants exceed water quality guidelines at individual monitoring sites. Water quality guidelines are maximum or minimum numerical values for physical, chemical, radiological, or biological characteristics of water, exceedance of which may result in adverse effects.[2] The water quality guidelines used for this indicator are those defined for the protection of aquatic life. They include national guidelines developed by the CCME, as well as provincial and site-specific guidelines

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1 http://www.environmentandresources.ca and http://www.statcan.ca.

2 Guidelines are specific to particular water uses, such as protection of aquatic life, crop irrigation, livestock watering, drinking water, and recreation.

developed by federal, provincial, and territorial partners. If a guideline value is exceeded at a given site, there is an increased probability of an adverse effect on aquatic life at that site.

The indicator reflects the potential for substances to impact aquatic life based on existing knowledge of toxicity and predicted fate and behaviour of the substances (i.e. it is based on guidelines). It is not a direct measure of changes to aquatic communities, such as changes in the composition or abundance of benthic invertebrates or fish.

In most aquatic ecosystems, water quality varies seasonally and annually due to fluctuations in weather (e.g. the timing and amount of precipitation, which affects the hydrological cycle). Thus, three years of monitoring data were combined to calculate WQI ratings, to dampen natural variability.

3. How the indicator is used

The CESI 2005 report uses the WQI to provide the first national picture of water quality for Canada.

On a regional level, the CCME WQI has been used by many types of organizations and jurisdictions, such as watershed conservation groups and provincial, territorial, and federal government agencies, to inform the public, decision-makers, and relevant stakeholders on the status and trends of the quality of local water bodies (BCMOE, 1996; Grand River Conservation Authority, 2004; Khan et al., 2004; CCME, 2005a; Environment Canada, 2005a; Lumb et al., 2006). It is also used to track the effectiveness of remedial measures on local water quality (Wright et al., 1999; Glozier et al., 2004) and to report on the effectiveness of government programs and policies (Alberta Environment, 2002).

Although the CCME provides general guidance on using the index (http://www.ccme.ca), practitioners are responsible for deciding which parameters, guidelines, time periods, and number of samples to include in a given application of the index. As a result of this flexibility, different approaches have been used to apply the index to achieve different objectives. For example, the British Columbia Ministry of Environment (BCMOE, 1996) used site-specific guidelines to evaluate the suitability of water quality to support different beneficial uses, using the most recent three years of data. Glozier et al. (2004) applied the index using background concentration[3] values from reference sites[4] to assess change in status and trends for downstream sites. In this work, trends were calculated as rolling values based on blocks of five years of samples (e.g. 1983–1987 and 1984–1988), while status was assessed for a 20-year period. In contrast, Wright et al. (1999) used background concentration values from a given time period (rather than reference sites) as benchmarks for the index to assess changes in water quality over time.

As a result of this flexibility in applying the index, a protocol for calculating the WQI ratings across Canada for this initiative was developed (Environment Canada, 2005b). For 2005, however, there remain some variations in the applications of the WQI across Canada (see section 6).

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3 The concentration of a naturally occurring water quality constituent, not influenced by human activity.
4 An area considered to be relatively unaffected by human activity.

4. Calculation of the indicator

The freshwater quality indicator is based on the application of the CCME WQI across Canada at 345 monitoring sites (streams, rivers, and lakes) using ambient water quality monitoring data for the 2001–2003 period and relevant water quality guidelines for the protection of aquatic life. The resulting ratings are presented in five categories (poor, marginal, fair, good, and excellent) in one national histogram.

4.1 Formulation of the CCME Water Quality Index

The CCME WQI relates water quality data to the various beneficial uses of water,[5] using relevant water quality guidelines as benchmarks. Each index is calculated for an individual monitoring site during a chosen reference period. During the reference period, water samples are collected. Each sample is analyzed for a suite of water quality parameters. Each parameter value is evaluated against a water quality guideline for that parameter. These are called tests. The percentage of parameters, samples, and tests that fail to meet the guidelines and the deviation (excursion) from the guidelines are captured in three factors (i.e. scope, frequency, and amplitude of excursions from the water quality guidelines) used to calculate the index (CCME, 2001). The index yields a number between 0 and 100. A higher number indicates better water quality.

CCME WQI formula

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

Scope (F_1)

The scope factor represents the percentage of the total number of parameters that fail to meet the water quality guidelines at any time during the reference period.

$$F_1 = \left(\frac{\text{number of failed parameters}}{\text{total number of parameters}} \right) \times 100$$

In 2005, the Province of Quebec used a variation of the F_1 formula, where F_{1q} is the scope factor:

$$F_{1q} = \frac{(F_{1a} + F_{1b})}{2}$$

where:

$$F_{1a} = \left(\frac{\text{number of failed parameters}}{\text{total number of parameters}} \right) \times 100$$

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5 These uses are protection of aquatic life, drinking water, livestock watering, crop irrigation, and recreational use (CCME, 1999).

$$F_{1b} = \left(\frac{\text{number of failed samples}}{\text{total number of samples}}\right) \times 100$$

A failed sample is a sample where at least one parameter has failed during the reference period.

Frequency (F_2)

The frequency factor represents the percentage of individual tests that fail to meet the water quality guidelines.

$$F_2 = \left(\frac{\text{number of failed tests}}{\text{total number of tests}}\right) \times 100$$

A failed test occurs when an individual parameter value within a sample exceeds the guideline. The total number of failed tests represents the total number of failed parameter values in every sample during the reference period. The total number of tests for an individual site is calculated by multiplying the average number of parameters per sample by the total number of samples during the reference period.

Amplitude (F_3)

The amplitude factor represents the average deviation of failed test values from their respective guidelines. The relative deviation of a failed test from the guideline is termed an excursion and is calculated as follows:

I. When the test value must not exceed the guideline:

$$\text{excursion}_i = \left(\frac{\text{failed test value}_i}{\text{guideline value}_i}\right) - 1$$

II. When the test value must not fall below the guideline:

$$\text{excursion}_i = \left(\frac{\text{guideline value}_i}{\text{failed test value}_i}\right) - 1$$

The collective amount by which individual tests are out of compliance is calculated as follows:

$$\text{nse} = \frac{\sum_i \text{excursion}_i}{\text{total number of tests}}$$

where nse is the ***n**ormalized **s**um of the **e**xcursions* from the guidelines. The F_3 factor is then calculated by a formula that scales the nse to yield a range between 0 and 100.

$$F_3 = \frac{\text{nse}}{(0.01\text{nse} + 0.01)}$$

The rating system of index values

The WQI yields a number between 0 and 100 that is indicative of the overall water quality for a particular use (Table 1).

Table 1 The rating system of the CCME WQI values

Interpretation
Water quality measurements never or rarely exceed water quality guidelines.
Water quality measurements rarely exceed water quality guidelines and, usually, by a narrow margin.
Water quality measurements sometimes exceed water quality guidelines and, possibly, by a wide margin.
Water quality measurements often exceed water quality guidelines and/or by a considerable margin.
Water quality measurements usually exceed water quality guidelines and/or by a considerable margin.

Notes: These interpretations are adapted from those endorsed by the CCME (2001), based on the initial assessment of over 100 sites by several experts in British Columbia (Rocchini and Swain, 1995).

4.2 Data preparation and presentation

The data used to calculate the freshwater quality indicator were derived from water samples collected at sites across the country during a three-year period from 2001 to 2003. Data were combined to calculate a single index value for each site using the equations described in section 4.1. The steps below, which are described in more detail in section 5, were followed in carrying out the calculations:

1. Selection step:
   a. Selection of sites
   b. Selection of parameters
   c. Selection of relevant national, regional, or site-specific guidelines
   d. Number of samples, timing, and collection period
2. Calculation step:
   a. Extraction of data
   b. Validation of data
   c. Calculation of index

The index values for each site were then classified into the five quality categories of the WQI and presented in a histogram as the national freshwater quality indicator. Subnational reporting of the indicator was not possible in the 2005 report due to the absence of methods to define minimum data requirements (i.e. number and location of stations) for regions, such as ecozones and water basins.

5. Data sources: review and selection

Water quality data used in the calculation of the freshwater quality indicator in the CESI 2005 report were obtained from a number of existing water quality monitoring programs across the country (Table 2). These programs are managed by federal and provincial departments and under federal–provincial agreements. They were originally established for many different reasons. Currently, there is no national network of water quality monitoring sites designed specifically for the purposes of reporting the state of Canada's water quality in a fully representative way at different geographic scales across Canada.

Each monitoring program follows standardized methods for sample collection in the field to ensure reliability of measurements. Chemical analyses are undertaken in Canadian laboratories accredited by the Canadian Association for Environmental Analytical Laboratories, ensuring that analytical methods are up to standard and proper quality assurance/quality control procedures are in place.

Table 2 Monitoring programs that provided data on ambient water quality from 2001 to 2003

Province/territory	Monitoring program
Alberta	Long-Term River Network Monitoring Program
Alberta	Prairie Provinces Water Board
British Columbia	Canada–British Columbia Water Quality Monitoring Agreement
British Columbia & Yukon	Federal Water Quality Monitoring Program
Manitoba	Canada–Manitoba Water Quality Agreement
Manitoba	International Red River Pollution Board
Manitoba	Provincial Water Quality Monitoring Network
New Brunswick	Canada–New Brunswick Water Quality Monitoring Agreement
New Brunswick	Kouchibouguac National Park
New Brunswick	New Brunswick Lakes Study
New Brunswick	New Brunswick Surface Water Monitoring Network
Newfoundland and Labrador	Canada–Newfoundland Water Quality Monitoring Agreement
Nova Scotia	Kejimkujik National Park
Nova Scotia	Pockwock Lakes Study
Nova Scotia	Pockwock/Clements Watersheds Study
Nova Scotia	Canadian Wildlife Service, Park Survey, Maritimes
Ontario	Provincial Water Quality Monitoring Network
Prince Edward Island	Canada–Prince Edward Island Water Quality Agreement
Quebec	Réseau-Rivières, Ministère du Développement durable, de l'Environnement et des Parcs du Québec
Quebec	The State of the St. Lawrence Monitoring Program, Environment Canada
Saskatchewan	Prairie Provinces Water Board
Saskatchewan	Souris River Bilateral Agreement, Federal Water Quality Monitoring Program

Each program monitors a specific array of parameters designed to suit the program's objectives and resource constraints. These monitoring programs track ambient concentrations[6] of major ions[7] (e.g. chloride and sulphate), nutrients (e.g. phosphorus and nitrogen), metals (e.g. mercury), organic compounds (including pesticides and industrial chemicals), and other parameters (e.g. dissolved oxygen, suspended solids, and pH). Sampling frequencies also differ among networks, with program needs, resource constraints, and ease of access to sites being important determinants.

5.1 Site selection

For the freshwater quality indicator in the CESI 2005 report, data from 345 sites across all provinces and the Yukon were selected (Table 3) from the available water quality monitoring sites that met the desired sampling frequency for the 2001–2003 period (see section 5.4).

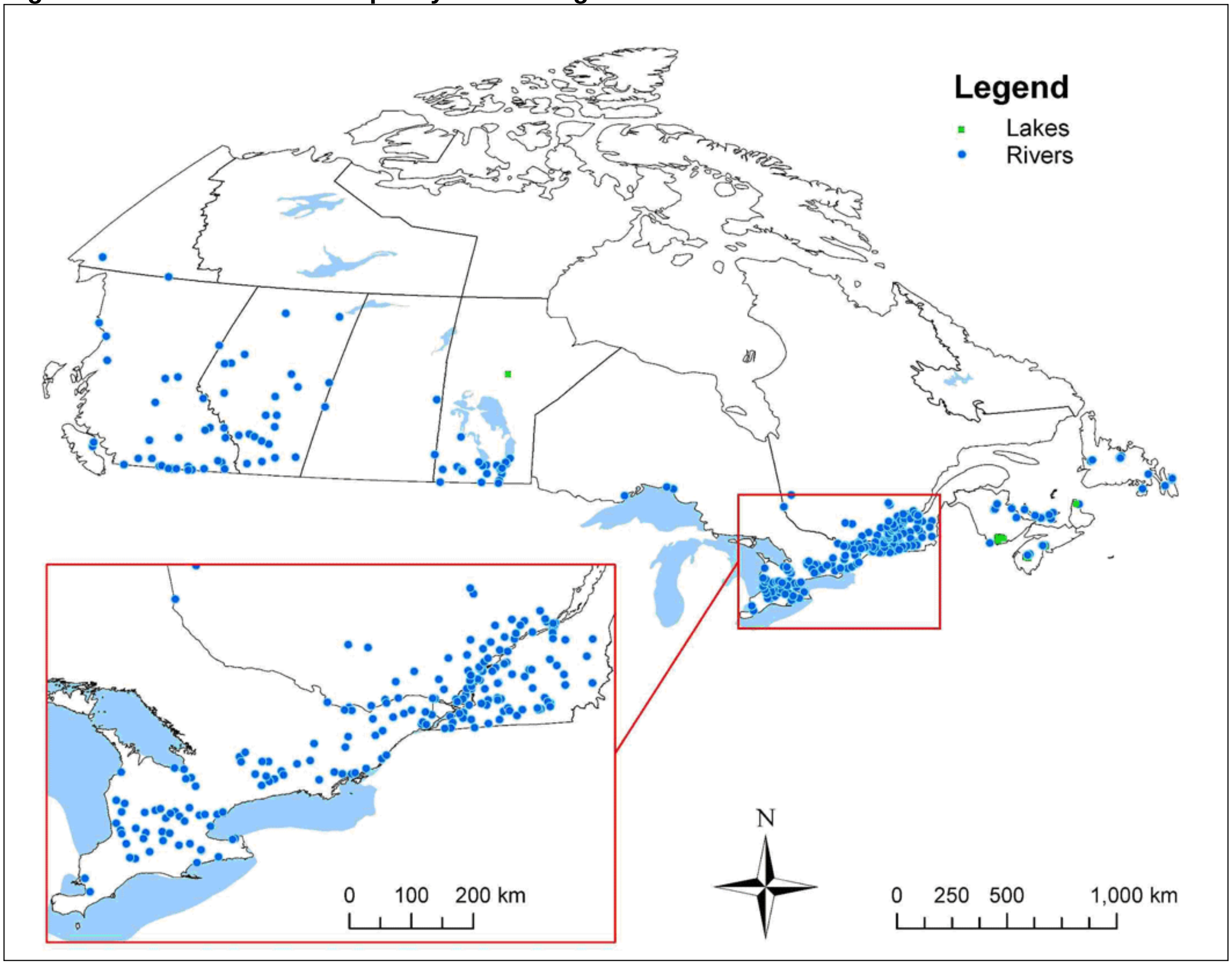
Table 3 Number of sites in each jurisdiction in the freshwater quality indicator

Province/territory	Number of stream/river sites	Number of lake sites
Alberta	22	0
British Columbia	32	0
Manitoba	20	1
New Brunswick	6	13
Newfoundland and Labrador	15	0
Nova Scotia	12	5
Ontario (excluding the Great Lakes)	90	0
Prince Edward Island	8	0
Quebec	115	0
Saskatchewan	4	0
Yukon	2	0
Canada total	**326**	**19**

6 Concentration of substances in the aquatic environment, as opposed to effluent discharges.

7 Positively or negatively charged molecules that occur naturally in water as a result of geochemical weathering of rocks, surface runoff, and atmospheric deposition. The eight major ions — calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, and chloride — account for most of the total dissolved solids in surface waters.

Figure 1 Locations of water quality monitoring sites across Canada



Sources: Data assembled by Environment Canada from federal, provincial and joint water quality monitoring programs.
Map developed by: Statistics Canada, Environment Accounts and Statistics Division.

The Great Lakes are treated separately in the freshwater quality indicator because of their disproportionate size and the unique nature of their surface water quality monitoring program. For the Great Lakes, the WQI was calculated using data collected through Environment Canada's Great Lakes Surveillance Program. Each lake is sampled at multiple sites once every two years. Conducted on a two-year rotation, this program measured Lake Erie, Lake Huron, and Georgian Bay in April 2004 and Lake Ontario and Lake Superior in April 2003. The measurements taken on the rotation were aggregated for each basin. Fifteen parameters were included in the calculation of the WQI, but not all of them were available for all lakes. For the indicator in the 2005 report, WQI ratings were calculated from 267 sites representing seven basins and two harbours in Canadian territory (Lake Superior, Lake Huron, Georgian Bay, Western, Central, and Eastern Lake Erie, Lake Ontario, Hamilton Harbour, and Toronto Harbour).

5.2 *Parameter selection*

The parameters used in the WQI calculations can be linked to the main stressors on water quality across Canada, including urban development, agriculture, forestry, mining, smelting, pulp and paper mills and other industrial facilities, deposition of atmospheric pollutants, and dams (Environment Canada, 2001).

Decisions regarding parameters to use for national reporting of the WQI were made by provincial, territorial, and federal water quality experts. The decisions were based on the local knowledge of issues potentially affecting water quality in the region, or at each site, using available monitoring data from the period 2001–2003. Only parameters relevant to the protection of aquatic life were included. This excludes bacterial counts, for example, which are primarily of concern for human health. For most jurisdictions, a common suite of parameters was applied to all sites within the jurisdiction or monitoring program. Site-specific selections of parameters were made in British Columbia, with four parameters (dissolved oxygen, phosphorus, pH, and water temperature) included at each site wherever available (refer to Table 4 for details regarding the parameters used in each jurisdiction).

Table 4 Parameters used in each jurisdiction or program for the WQI calculation

Parameter	AB[1]	BC and YT[2]	MB[1]	NB	NL	NS	ON (Great Lakes)	ON (rivers)	Prairie provinces[3]	PE	QC
Alkalinity		X									
Aluminum	X	X					X				
Ammonia	X		X					X	X	X	X
Antimony		X									
Arsenic	X	X	X		X		X		X		
Cadmium	X	X	X				X				
Chloride		X		X		X		X	X		
Chlorophyll											X
Chromium		X			X		X	X			
Copper	X	X	X	X	X	X	X		X		
Cyanide		X									
Dissolved oxygen	X	X	X						X		
Fluoride		X									
Iron		X	X	X	X	X	X				
Lead	X	X	X		X	X	X		X		
Manganese		X									
Mercury	X				X		X				
Molybdenum		X			X		X				
Nickel		X	X	X	X	X	X	X	X		
Nitrate[4]		X	X	X		X	X	X		X	X
Nitrite		X									
Nitrogen	X	X							X		
Pesticide – 2,4-D	X		X						X		
Pesticide –	X		X						X		

Parameter	AB[1]	BC and YT[2]	MB[1]	NB	NL	NS	ON (Great Lakes)	ON (rivers)	Prairie provinces[3]	PE	QC
MCPA											
pH		X	X	X	X	X			X	X	X
Phosphorus	X	X	X	X	X	X	X	X	X	X	X
Selenium	X	X			X		X				
Silver		X					X				
Sodium											
Sulphate		X									
Suspended solids			X							X	
Temperature		X									
Thallium		X									
Turbidity											X
Zinc	X	X	X	X	X	X	X	X	X		

Notes: (1) Includes only sites from provincial monitoring programs. (2) British Columbia and Yukon parameter selections were site-specific, with four common parameters at each site. (3) Includes only sites measured by federal monitoring programs and the Prairie Provinces Water Board. (4) Measured as nitrate/nitrite in the Great Lakes and Quebec.

5.3 Guideline selection

Nationally, guidelines are endorsed by the CCME and developed according to the methodology outlined by the CCME science-based protocols for guideline derivation (CCME, 1991). However, some provincial jurisdictions have developed provincial guidelines using similar protocols to that of the CCME, while other provinces and territories have directly adopted the CCME guidelines for their needs. Water quality guidelines are typically based on laboratory toxicity studies showing effects on various aquatic life (fish, invertebrates, plants) from different concentrations of a constituent in the water.

For the CESI 2005 report, calculation of the freshwater quality indicator relied largely on the use of existing water quality guidelines for the protection of aquatic life. Guidelines were selected on a site-specific or jurisdictional basis by teams of regional water quality experts from the suite of generic guidelines available from various sources[8] and from existing site-specific guidelines for the parameters of local interest (Appendix 1). The principle behind guideline selection is to choose those that are most “locally relevant,” meaning appropriate to local aquatic life, background levels of naturally occurring substances, and other characteristics of water, such as hardness and temperature, that can affect the toxicity of some of the substances of concern.

Most of the guidelines used in the freshwater quality indicator applications are based on chronic exposure. In a few instances, guidelines were applied for short-term exposure.[9] In addition, all recommended guidelines apply to a range of species and water chemistry conditions that occur in many regions of Canada. Generic guidelines (i.e. those not derived for a specific site) are often conservative to provide a high level of protection through the use of uncertainty factors,

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8 Sources include PPWB (1992), OMOE (1994), Alberta Environment (1999), CCME (1999), BCMOE (2001), Manitoba Conservation (2002), Williamson (2002), USEPA (2005), and MDDEP (2006).

9 Guidelines for short-term (acute) exposure were applied in the Pacific and Yukon Region for stations where extreme events (e.g. spills) were a possibility. In Quebec, the guideline used for turbidity is for short-term exposure.

depending on the quality and availability of toxicological information for the substance. Thus, background concentrations of naturally occurring substances may exceed these guidelines.

Analytical detection limits

The limit to which a monitoring instrument can measure a substance in water is related to its analytical precision. New, technologically advanced instruments are able to detect smaller amounts of substances than older instruments. Some monitoring programs are unable to afford new instruments, and problems arise when guidelines for substances fall near or below the detection limits of older instruments.[10] The protocol that was followed where the water quality guidelines for particular substances fell below the detection limits of analytical instruments was as follows:

- **If** the guideline value for a substance is below the detection limit **and** *more than half* of the observations are above the detection limit, **then** the detection limit is used instead of the guideline value. This approach is precautionary, because adverse effects can be influenced by minute quantities of toxic substances.

- **If** the guideline value for a substance or parameter is below the detection limit **and** *less than half* of the observations are above the detection limit, **then** the parameter is removed from the WQI calculation. The parameter is removed because of the analytical uncertainty associated with observations approaching the detection limit (i.e. they may be false positives). Seasonally applied pesticides were the only exception to this rule because of their toxicity and transient nature. All detectable values were used in this case.

5.4 Sample numbers, timing, and collection period

Annual fluctuations in meteorology and hydrology can have a considerable impact on water quality and, consequently, on the resulting index ratings when applied for individual years. Thus, index scores were based on three years of data in order to dampen natural variability and reflect a more general state of water quality. The years 2001–2003 were the most recent available years across all monitoring programs.

Minimum sample numbers for the three-year reporting period were established for lake and river sites (Table 5). Sites that did not meet these minima were excluded from the national reporting of the indicator in the CESI 2005 report.

Table 5 Sample frequency requirements for WQI application in the 2005 CESI report

Water body	Minimum requirements
Rivers	Four samples per year for the 2001–2003 period
Lakes	Two samples per year for the 2001–2003 period

In temperate lakes, the water column can become thermally stratified or layered by temperature during the summer and winter. Mixed conditions are typical during early spring and late fall. Chemical contaminants can also stratify in lakes, with their concentrations being determined in part by water density, which is in turn determined by water temperature. Lakes were sampled at

10 In the Pacific and Yukon Region, analytical uncertainty was accounted for by using only data with results that were more than 10 times higher than the analytical detection limit. In the Province of Quebec, the guidelines used were always above the detection limit.

least twice annually, once in the spring and once in the fall. If these spring and fall samples were not available, several samples were taken at various depths during another season. The results of these samples were weighted by the volume of water at the sampled depths and then averaged. Weighting by volume, however, was not always possible. As a final option, samples were taken at the surface of the lake.

In running water systems such as rivers and streams, surface sampling is generally considered to be representative of the water column, which is normally well mixed. However, sampling may need to be repeated more often throughout the year to better capture water quality variability. The CCME technical guidance document (CCME, 2001) recommended a minimum of four samples per year based on the original testing of the index.

5.5 Data management, calculation, and verification

Water quality data from each of the monitoring programs are stored in provincial or federal databases, managed by the respective environment departments. Basic site information (e.g. name and location) and water quality data were extracted from available databases by regional and provincial data providers and transferred to “WQI Calculators” (i.e. spreadsheets programmed to calculate WQI ratings). These calculators allow users to select parameters for inclusion, application periods, and guidelines (with options allowing guidelines to be modified by hardness, pH, or temperature, when appropriate).[11]

Suspected outliers in the data sets were identified and validated by verifying field forms and books to check for accuracy of data entry, by ensuring that reported units were correct, by consulting stream flow and meteorological records, and/or by comparing with the levels of other parameters in the data set (e.g. turbidity, major ions) that could explain the unusually high or low values of some parameters. Unless proven erroneous, “outliers” were left in the data set.
In most jurisdictions, calculations were undertaken twice after validation of the data set and then peer reviewed. Environment Canada experts then transferred site information, WQI ratings, and details on the application (i.e. data source, parameters, guidelines, sample numbers and dates, and contact information) onto templates for incorporation into a central database. This information was then used to generate the national histogram and map of monitoring site locations by experts at Statistics Canada, the National Water Quality Monitoring Office, and the Strategic Information Integration Directorate of Environment Canada.

The ratings and calculation methods (i.e. parameters included, guidelines used, site information) compiled in the national database were then verified for each site by each data provider to detect any errors introduced during the integration of this information.

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11 The CCME WQI calculator (v1.0) is available at http://www.ccme.ca/ourwork/water.html?category_id=102.

6. Caveats and limitations to the indicator and data

6.1 Location of monitoring sites

It is recognized that the current collection of monitoring networks was designed not to be representative of Canada and all its watersheds, but to respond to specific federal, provincial, or regional needs. Monitoring sites included in this analysis are almost all located in populated areas and other areas for which it is suspected that water quality is affected by surrounding land uses, such as agriculture, and other potential stressors, including acid rain deposition, dams, and industries (e.g. pulp and paper and mines). Even so, sites do not comprehensively cover all geographic areas with potential water quality issues or problems across Canada.

From a coverage standpoint, it is unknown what percentage of Canadian lakes and rivers, by geographic area or stream flow, is currently represented by the existing 345 monitoring sites. Additionally, each site was weighted equally and independently regardless of location.

6.2 Parameter selection

Type and number of parameters included in the WQI calculations varied among the water quality monitoring sites and/or jurisdictions. This flexibility allowed the specific local and regional water quality concerns and objectives of the monitoring programs to be reflected in the WQI scores. However, this variation in parameter selection among jurisdictions/sites makes comparability of sites for national aggregation uncertain. It was recommended that between 4 and 15 parameters be measured for the WQI calculation, and this guidance was followed (Environment Canada, 2005b). A recent sensitivity analysis, however, shows that the use of approximately 10 parameters may yield the most stable WQI results (Painter and Waltho, 2005).

In addition, not all relevant parameters were sampled everywhere, for several reasons: (1) the random nature of some releases (e.g. unknown or accidental spills); (2) some substances are tracked in other media, such as sediment or fish tissue, that provide more reliable measures; and (3) the high cost of measuring some parameters on a routine basis (e.g. organic substances).

For the Pacific and Yukon Region, metals were removed from the WQI calculation when conditions at a given site were highly turbid. The rationale behind this is the expectation that the high concentrations of metals measured during such events are due to the suspended sediments. These metals are not available for biological uptake and, as such, do not pose the same risk to aquatic life as dissolved metals.

6.3 Guidelines

In some areas of Canada, the background concentrations of some naturally occurring substances (e.g. metals) exceed the national or provincial guidelines. Thus, a portion of exceedances from all parts of Canada reflect naturally occurring conditions, rather than human influence only.

In most cases, metal guidelines are based on measuring total (extractable) rather than dissolved metals. This conservatively assumes that the full measured amount of the compound is available to be taken up by organisms. However, metals in unfiltered water may be bound to particulates, depending on the chemical species in question, organic contents, and particulate concentration, making them less bioavailable[12] than suggested by a measure of total metals.

6.4 Sample timing and frequency

Variation in timing and frequency of sampling exists among monitoring programs, with some being more intensive to capture the full range of variability/seasonality that is inherent to each site and other being less intensive, more opportunistic, and/or random, due to resource constraints and the remote nature of some sites. It is currently unknown to what extent this poses a problem or creates a bias for the overall indicator. The three-year time period selected as the basis for the indicator accounts for some of this variation and helps to reduce the potential for some sites to “misrepresent” water quality on an annual basis.

Owing to the hydrological variability of aquatic ecosystems across Canada, minimum sample numbers and timing of collection should, in future, be determined on a more regional or site-specific basis.

6.5 Formulation (F_1)

Further sensitivity testing related to F_1 modifications will be undertaken to compare how the WQI behaves using both the Province of Quebec F_1 (or F_{1q}) and the CCME F_1 and the extent to which these impact the national indicator.

6.6 Data quality

It is inevitable that errors will sometimes occur in water quality databases. The most common are field errors (sample contamination, mislabelling), laboratory errors (misidentified samples, miscalculations, analytical mistakes), and data entry errors. Quality assurance protocols are used to minimize errors and maximize data quality.

12 A chemical and physical form that allows a substance to affect organisms or be accumulated by them.

7. Future improvements

This first report provides information on the status of water quality in Canada as it relates to the protection of aquatic life. The indicator reported here will be broadened in future reports to include other water uses and improvements planned in relation to monitoring, analysis, and surveys, as described below.

7.1 Scope and monitoring

The need to protect aquatic life is relevant to every region of Canada, yet most systematic, long-term monitoring efforts are focused on developed or settled areas, largely located in the south. Over the next four years, Environment Canada, working with provincial and territorial counterparts, will enhance the current water quality monitoring network to more broadly represent the distribution of drainage areas throughout the country. The first step will be to identify the areas of Canada, usually remote and northern, that are clearly underrepresented in the national indicator; the second step will be to set clear priorities for increased monitoring effort.

Environment Canada and Statistics Canada, in consultation with the provinces and territories, will review the suite of water quality variables measured in different jurisdictions across Canada to ensure local and ecological relevance and to understand the implications of combining WQI values calculated using different variables. Investments may need to be made to increase the number of variables measured at some locations and standardize a subset that all networks should use (e.g. pH, temperature, and some others). Options will also be explored for measuring the health of aquatic organisms both to provide further context and to validate the WQI results.

An indicator of the quality of water used as a source for drinking water will be developed over the next four years. Health Canada will lead the development of a method and data needs assessment for calculating this indicator. Other major economic and social uses of water, including industry and agriculture (irrigation and livestock watering), will also be built into the indicator over time.

7.2 Guidelines

How well the WQI rates water quality depends directly on the use of appropriate water quality guidelines with which monitoring data can be compared. Guidelines used in the WQI computation should be *locally relevant*, meaning appropriate to the local organisms and local water characteristics. For example, hardness and temperature can affect the toxicity of some substances of concern. As well, the natural background levels for some substances (e.g. phosphorus, copper, and some other metals) can exceed existing national or provincial guidelines. The type of chemical analysis (e.g. total or extractable versus dissolved) used to measure certain parameters (e.g. phosphorus, aluminum) will also need to be revisited in the context of developing appropriate guidelines. In coming years, Environment Canada, in consultation with the provinces and territories, plans to assess the relevance of the water quality guidelines to local conditions and, where necessary, develop site-specific guidelines using nationally consistent methods and protocols for calculating the water quality indicator.

Further work is also planned on the methods for calculating the WQI, approaches to compensate for the unbalanced geographical distribution of monitoring sites, and methods for examining trends in the WQI over time.

Acronyms

BCMELP	British Columbia Ministry of Environment, Lands and Parks
BCMOE	British Columbia Ministry of Environment
CCME	Canadian Council of Ministers of the Environment
CESI	Canadian Environmental Sustainability Indicators
2,4-D	2,4-dichlorophenoxyacetic acid
MCPA	4-(2-methyl-4-chlorophenoxy)acetic acid
MDDEP	Ministère du Développement durable, de l'Environnement et des Parcs du Québec
n/a	not applicable
NTU	nephelometric turbidity units
OECD	Organisation for Economic Co-operation and Development
PPWB	Prairie Provinces Water Board
USEPA	United States Environmental Protection Agency
WQI	Water Quality Index

Appendix: The water quality guidelines used in each jurisdiction

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
Alberta	Aluminum	Dissolved	5 at pH <6.5; 100 at pH >6.5	µg/L	CCME, 2005b
	Ammonia	Un-ionized	0.019	mg/L	CCME, 2005b; Environment Canada, 2005
	Arsenic	Total	5	µg/L	CCME, 2005b
	Cadmium	Total	e^(1.0166*ln[hardness]−3.924)	µg/L	USEPA, 2005
	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada, 2005
	Copper[2]	Total	7	µg/L	Alberta Environment, 1999
	Copper[3]	Total	2, for hardness 0–90 mg/L; e^(0.8545*ln[hardness)]−1.465)* 0.2, for hardness >90 mg/L	µg/L	CCME, 2005b
	Dissolved Oxygen		6.5	mg/L	Alberta Environment, 1999
	Lead	Total	e^(1.273*ln[hardness]−4.705)	µg/L	CCME, 2005b; Environment Canada, 2005
	Mercury	(Total) inorganic	0.026	µg/L	CCME, 2005b
	Nickel	Total	e^(0.76[ln(hardness)]+1.06)	µg/L	CCME, 2005b
	Nitrogen	Total	1	mg/L	Alberta Environment, 1999
	Pesticides	2,4-D	4	µg/L	CCME, 2005b
	Pesticides	MCPA	2.6	µg/L	CCME, 2005b
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total	0.05	mg/L	Alberta Environment, 1999
	Selenium	Total	2	µg/L	BCMOE, 2001; Environment Canada, 2005
	Zinc	Total	7.5, for hardness ≤90 mg/L; 7.5 + 0.75*(hardness−90), for hardness >90 mg/L $CaCO_3$	µg/L	BCMOE, 2001; Environment Canada, 2005
British Columbia and Yukon[4]	Alkalinity		20	mg/L ($CaCO_3$)	BCMOE, 2001
	Aluminum	Total	<0.05 for pH >6.5; <e^[1.6−3.327(pH) + 0.402(pH)^2] for pH <6.5	mg/L	Butcher, 1988

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
	Antimony	Total	20	µg/L	BCMOE, 2001
	Arsenic	Total	SSG	µg/L	CCME, 2005b
	Cadmium	Total	SSG	µg/L	BCMOE, 2001; CCME, 2005b; Environment Canada, 2005c
	Chloride	Dissolved	15	mg/L	Levy et al., 1981
	Chromium	Total	SSG	µg/L	BCMOE, 2001; Environment Canada, 2005c
	Copper	Total	SSG	µg/L	Singleton, 1987
	Cyanide	Weak acid dissociable	SSG	µg/L	Singleton, 1986
	Dissolved Oxygen		SSG	mg/L	BCMELP, 1997
	Fluoride	Dissolved	0.37	mg/L	Warrington, 1995
	Iron	Total	300	µg/L	CCME, 2005
	Lead	Total	SSG	µg/L	Nagpal, 1987
	Manganese	Total	SSG	µg/L	Reimer, 1999
	Molybdenum	Total	73	µg/L	CCME, 2005b
	Nickel	Total	SSG	µg/L	BCMOE, 2001; CCME, 2005b; Environment Canada, 2005c
	Nitrate	Total as N	2.93	mg/L	CCME, 2005; Environment Canada, 2005c
	Nitrite	Not available	0.02	mg/L	Nordin and Pommen, 1986
	Nitrogen	Total and total dissolved	SSG	mg/L	BCMOE, 2001; Environment Canada, 2005c
	pH		SSG	n/a	McKean and Nagpal, 1991; BCMOE, 2001
	Phosphorus	Total	SSG	mg/L	Nordin, 2001
	Selenium	Total	SSG	µg/L	Howell and Nagpal, 2001
	Silver	Total	SSG	µg/L	Warrington, 1995; Environment Canada, 2005c
	Sulphate	Dissolved	SSG	mg/L	Singleton, 2000
	Temperature		SSG	°C	Fidler and Oliver, 2001

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
	Thallium	Total	0.8, when turbidity <797 NTU	µg/L	BCMOE, 2001; CCME, 2005; Environment Canada, 2005c
	Zinc	Total	SSG	µg/L	Nagpal, 1981
Manitoba	Ammonia[2]	Total as nitrogen	Calculation based on pH and temperature	mg/L	USEPA, 2005
	Ammonia[3]	Un-ionized	0.019	mg/L	CCME, 2005b
	Arsenic[2]	Total or extractable	0.15	mg/L	USEPA, 2005
	Arsenic[3]	Total	5	µg/L	CCME, 2005b
	Cadmium	Total or extractable	e^(0.7852*ln[hardness]−2.715) where hardness = mg/L as $CaCO_3$	mg/L	USEPA, 2005
	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada 2005c
	Copper[2]	Total or extractable	e^(0.8545*ln[hardness]−1.702) where hardness = mg/L as $CaCO_3$	mg/L	USEPA, 2005
	Copper[3]	Total	2, for hardness 0–90 mg/L; e^(0.8545*ln[hardness]−1.465)* 0.2, for hardness >90 mg/L	µg/L	CCME, 2005c; USEPA, 2005
	Dissolved Oxygen[2]		5	mg/L	USEPA, 2005
	Dissolved Oxygen[3]		6.5	mg/L	PPWB, 1992; Alberta Environment, 1999
	Iron	Total or extractable	0.3	mg/L	CCME, 2005c; Environment Canada 2005c
	Lead	Total (or extractable)	e^(1.273*ln[hardness]−4.705)	µg/L	CCME, 2005c; Environment Canada 2005c
	Nickel[3]	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005c; Environment Canada 2005c
	Nickel[2]	Total or extractable	e^(0.8460*ln[hardness]+0.0584), where hardness = mg/L $CaCO_3$	mg/L	USEPA, 2005
	Nitrate	Total (as N)	2.9	mg/L	CCME, 2005c; Environment Canada 2005c
	Nitrogen	Total	1	mg/L	Alberta Environment, 1999
	Pesticides	MCPA	2.6	µg/L	CCME, 2005b

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
	Pesticides	2,4-D	4	µg/L	CCME, 2005b
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total	0.05 (rivers); 0.025 (lakes)	mg/L	PPWB, 1992; Alberta Environment, 1999; Manitoba Conservation, 2002
	Total suspended solids		25	mg/L	Manitoba Conservation, 2002
	Zinc[3]	Total	7.5, for hardness ≤90 mg/L; 7.5 + 0.75*(hardness−90), for hardness >90 mg/L $CaCO_3$	µg/L	BCMOE, 2001; Environment Canada 2005c
	Zinc[2]	Total or extractable	e^(0.8473*ln[hardness]+0.884), where hardness = mg/L as $CaCO_3$	mg/L	USEPA, 2005
New Brunswick	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada 2005c
	Copper	Total	2, for hardness <60 mg/L $CaCO_3$; e^(0.8545*ln[hardness]−1.465)*0.2, for hardness >60 mg/L	µg/L	BCMOE, 2001
	Iron	Dissolved	300	µg/L	CCME, 2005b; Environment Canada 2005c
	Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005b; Environment Canada 2005c
	Nitrate	Total	2.9	mg/L	CCME, 2005b; Environment Canada 2005c
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total dissolved	0.03 (rivers); 0.02 (lakes)	mg/L	Dodds et al., 1998
	Zinc	Total	7.5 for hardness <90 mg/L; 7.5 + 0.75*(hardness−90) for hardness >90 mg/L	µg/L	BCMOE, 2001; Environment Canada 2005c
Newfoundland and Labrador	Arsenic	Total	5	µg/L	CCME, 2005b
	Chromium	Total	1	µg/L	CCME, 2005b
	Copper	Total	2, for hardness <60 mg/L $CaCO_3$; e^(0.8545*ln[hardness]−1.465)*0.2, for hardness >60 mg/L	µg/L	BCMOE, 2001
	Iron	Dissolved	300	µg/L	CCME, 2005b; Environment Canada 2005c

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
	Lead	Total	1	µg/L	CCME, 2005b; Environment Canada 2005c
	Mercury	Total	0.1	µg/L	CCME, 2005b
	Molybdenum	Total	0.073	mg/L	CCME, 2005b
	Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005b; Environment Canada 2005c
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total dissolved	0.03 (rivers)	mg/L	Dodds et al., 1998
	Selenium	Total	1	µg/L	BCMOE, 2001; Environment Canada 2005c
	Zinc	Total	0.03	mg/L	CCME, 2005b
Nova Scotia	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada 2005c
	Copper	Total	2, for hardness <60 mg/L $CaCO_3$; e^(0.8545*ln[hardness]−1.465)*0.2, for hardness >60 mg/L	µg/L	BCMOE, 2001
	Iron	Dissolved	300	µg/L	CCME, 2005b; Environment Canada 2005c
	Lead	Total	e^(1.273*ln[hardness]−4.705)	µg/L	CCME, 2005b; Environment Canada 2005c
	Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005b; Environment Canada 2005c
	Nitrate	Total (as N)	2.9	mg/L	CCME, 2005b
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total dissolved	0.03 (rivers); 0.02 (lakes)	mg/L	Dodds et al., 1998
	Zinc	Total	7.5 for hardness <90 mg/L; 7.5 + 0.75*(hardness−90) for hardness >90 mg/L	µg/L	BCMOE, 2001; Environment Canada 2005c
Ontario	Ammonia	Un-ionized	0.019	mg/L	CCME, 2005b; Environment Canada 2005c
	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada 2005c
	Chromium	Total	2	µg/L	CCME, 2005b (guideline for Cr(VI) adjusted to total chromium)

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
	Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005b; Environment Canada 2005c
	Nitrate	Total (as N)	2.93	mg/L	CCME, 2005b
	Phosphorous	Total	0.03	Mg/L	OMOE, 1994
	Zinc	Total	7.5, for hardness <90 mg/L; 7.5 + 0.75*(hardness−90), for hardness >90 mg/L $CaCO_3$	µg/L	BCMOE, 2001
Prince Edward Island	Ammonia	Un-ionized	0.019	mg/L	CCME, 2005b; Environment Canada 2005c
	Nitrate+nitrite	Total (as N)	2.93	mg/L	CCME, 2005b; Environment Canada 2005c
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total dissolved	0.03	mg/L	Dodds et al., 1998
	Suspended sediments	Total	29	mg/L	CCME, 2005b; Environment Canada 2005c
Quebec	Ammonia	Total (as N)	0.05, at pH 8.2 and 20 °C	mg/L	MDDEP, 2006
	Chlorophyll a		8	mg/m^3	OECD, 1982
	Nitrite+nitrate	Total (as N)	2.93	mg/L	CCME, 2005b; Environment Canada 2005c
	pH		>6.5; <9.0	n/a	MDDEP, 2006
	Phosphorus	Total	0.03	mg/L	MDDEP, 2006
	Turbidity		10	NTU	MDDEP, 2006
Saskatchewan	Ammonia	Un-ionized	0.019	mg/L	CCME, 2005b; Environment Canada 2005c
	Arsenic	Total	5	µg/L	CCME, 2005b
	Chloride	Dissolved	150	mg/L	BCMOE, 2001; Environment Canada 2005c
	Copper	Total	2, for hardness 0–90 mg/L; e^(0.8545*ln[hardness]−1.465)* 0.2, for hardness >90 mg/L	µg/L	CCME, 2005b; Environment Canada 2005c
	Dissolved Oxygen		6.5	mg/L	PPWB, 1992; Alberta Environment, 1999
	Lead	Total	e^(1.273*ln[hardness]−4.705)	µg/L	CCME, 2005b; Environment

Province/territory	Parameter	Form	Guideline description[1]	Unit	Source
					Canada 2005c
	Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L	CCME, 2005b; Environment Canada 2005c
	Nitrogen	Total	1	mg/L	Alberta Environment, 1999
	Pesticides	MCPA	2.6	µg/L	CCME, 2005b
	Pesticides	2,4-D	4	µg/L	CCME, 2005b
	pH		6.5–9.0	n/a	CCME, 2005b
	Phosphorus	Total	0.05	mg/L	PPWB, 1992; Alberta Environment, 1999
	Zinc	Total	7.5, for hardness ≤90 mg/L; 7.5 + 0.75*(hardness−90), for hardness >90 mg/L $CaCO_3$	µg/L	BCMOE, 2001; Environment Canada 2005c

Notes: (1) SSG means that different site-specific guidelines or formulas were used at different sites (specific site information available on request). (2) Applies to sites monitored by provincial monitoring programs. (3) Applies to sites monitored under federal monitoring programs and the Prairie Provinces Water Board. (4) British Columbia and Yukon parameter selections were site-specific.

References

Alberta Environment. 1999. *Surface water quality guidelines for use in Alberta*. Science and Standards Branch, Alberta Environment, Edmonton, Alberta (ISBN 0-7785-0897-8) (http://www3.gov.ab.ca/env/water/Legislation/Guidelines/index.cfm).

Alberta Environment. 2002. *Alberta Environment's performance measures and indicators — Levels 1 & 2 environmental indicators and behavioural indicators*. Alberta Environment, Edmonton, Alberta.

BCMELP. 1997. *Ambient water quality criteria for dissolved oxygen*. Water Management Branch, British Columbia Ministry of Environment, Lands and Parks.

BCMOE. 1996. *British Columbia water quality status report April 1996*. Environmental Protection Division, British Columbia Ministry of Environment (http://www.env.gov.bc.ca/wat/wq/public/bcwqsr/bcwqsr1.html).

BCMOE. 2001. *British Columbia approved water quality guidelines (criteria) 1998 edition*. Environmental Protection Division, British Columbia Ministry of Environment. Updated August 24, 2001 (http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html).

Butcher, G.A. 1988. *Water quality criteria for aluminum: Technical appendix*. Water Quality Unit, Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment and Parks.

CCME. 1991. Appendix IX — A protocol for the derivation of water quality guidelines for the protection of aquatic life (April 1991). In: *Canadian water quality guidelines*, Canadian Council of Resource and Environment Ministers, 1987. Prepared by the Task Force on Water Quality Guidelines (http://www.ccme.ca/assets/pdf/wqg_aql_protocol.pdf). [Updated and reprinted with minor revisions and editorial changes in *Canadian environmental quality guidelines*, Chapter 4, Canadian Council of Ministers of the Environment, 1999, Winnipeg, Manitoba.]

CCME. 1999. *Canadian environmental quality guidelines*. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

CCME. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, User's manual. In: *Canadian environmental quality guidelines*, 1999, Canadian Council of Ministers of the Environment, Winnipeg, Manitoba (http://www.ccme.ca/assets/pdf/wqi_usermanualfctsht_e.pdf).

CCME. 2005a. *Application and testing of the CCME Water Quality Index for selected water bodies in Atlantic Canada.* Prepared by Environment Canada, New Brunswick Department of Environment and Local Government, Nova Scotia Department of Environment and Labour, and Prince Edward Island Department of Fisheries, Aquaculture and Environment for Water Quality Task Group, Canadian Council of Ministers of the Environment, Winnipeg, Manitoba (http://www.ec.gc.ca/soer-ree/English/resource_network/status_report_e.cfm).

CCME. 2005b. *Canadian Environmental Quality Guidelines. Update 5.0.* Canadian Council of Ministers of the Environment, Winnipeg, Manitoba (http://www.ccme.ca/publications/ceqg_rcqe.html).

Dodds, W.K., J.R. Jones, and E. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. *Water Research*, 32: 1455–1462.

Environment Canada. 2001. *Threats to sources of drinking water and aquatic ecosystem health in Canada*. National Water Research Institute, Burlington, Ontario. 72 pp. (NWRI Scientific Assessment Report Series No. 1).

Environment Canada. 2005a. *Proceedings of the 2nd CCME National Workshop on the Water Quality Index — Towards a Nationally Consistent Water Quality Indicator for Canada, February 15–18, 2005*.

Environment Canada. 2005b. *Initial guidance for calculating the Water Quality Index (WQI) for the Environment and Sustainable Development Indicators [now the Canadian Environmental Sustainability Indicators or CESI] water quality indicator*. 17 pp.

Environment Canada. 2005c. *Recommended water quality guidelines for the protection of aquatic life for use in the 2005 national water quality indicators under the Canadian Environmental Sustainability Indicators (CESI) initiative* [draft]. National Guidelines and Standards Office, Environment Canada, Gatineau, Quebec. June 23, 2005.

Fidler, L.E. and G.G. Oliver. 2001. *Towards a water quality guideline for temperature in the Province of British Columbia*. Water Quality Section, Water Management Branch, British Columbia Ministry of Environment, Lands and Parks.

Glozier, N.E., R.W. Crosley, L.A. Mottle, and D.B. Donald. 2004. *Water quality characteristics and trends for Banff and Jasper National Parks: 1973–2002*. Ecological Science Division, Environmental Conservation Branch, Environment Canada, Saskatoon, Saskatchewan.

Grand River Conservation Authority. 2004. *Grand River Conservation Authority 2004 fall report*. Grand River Conservation Authority, Cambridge, Ontario.

Howell, K. and N.K. Nagpal. 2001. *Water quality guidelines for selenium: Technical appendix*. Water Protection Branch, British Columbia Ministry of Water, Land and Air Protection.

Khan, A.A., R. Paterson, and H. Khan. 2004. Modification and application of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for the communication of drinking water quality data in Newfoundland and Labrador. *Canadian Water Quality Research Journal*, 39(3): 285–293.

Levy, D.A., D.D. MacDonald, and N.K. Nagpal. 1981. *Ambient water quality guidelines for chloride*. Water, Air and Climate Change Branch, British Columbia Ministry of Water, Land and Air Protection.

Lumb, A., D. Halliwell, and T.C. Sharma. 2006. Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River basin, Canada. *Environmental Monitoring and Assessment*, 113: 411–429.

Manitoba Conservation. 2002. *Manitoba water quality standards, objectives and guidelines*. Water Quality Management Section, Water Branch, Manitoba Conservation, Winnipeg, Manitoba (http://www.gov.mb.ca/waterstewardship/water_quality/quality/website_notice_mwqsog_2002.html).

McKean, C. and N.K. Nagpal. 1991. *Ambient water quality criteria for pH: Technical appendix*. British Columbia Ministry of Environment.

MDDEP. 2006. *Critères de qualité de l'eau de surface au Québec.* Ministère du Développement durable, de l'Environnement et des Parcs du Québec (http://www.mddep.gouv.qc.ca/eau/criteres_eau/fondements.htm).

Nagpal, N.K. 1981. *Ambient water quality guidelines for zinc*. Environment and Resource Management Department, Water Management Branch, British Columbia Ministry of Environment, Lands and Parks.

Nagpal, N.K. 1987. *Water quality criteria for lead: Technical appendix*. British Columbia Ministry of Environment and Parks.

Nordin, R.N. 2001. *Water quality criteria for nutrients and algae. Overview report*. Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment.

Nordin, R.N. and L.W. Pommen. 1986. *Water quality criteria for nitrogen (nitrate, nitrite, and ammonia)*. Water Quality Unit, Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment and Parks.

OECD. 1982. *Eutrophication of waters: Monitoring, assessment and control*. Organisation for Economic Co-operation and Development, Paris. 154 pp.

OMOE. 1994. *Water management policies, guidelines, provincial water quality objectives of the Ministry of Environment and Energy* [reprinted February 1999]. Ontario Ministry of the Environment. 67 pp. (http://www.ene.gov.on.ca/envision/gp/3303e.pdf).

Painter, S. and J. Waltho. 2005. *Test driving the Canadian Water Quality Index*. Ecosystem Health Division, Environmental Conservation Branch, Ontario Region, Environment Canada.

PPWB. 1992. *Master agreement on apportionment "Schedule E Agreement on Water Quality."* Prairie Provinces Water Board, Regina, Saskatchewan.

Reimer, P.S. 1999. *Environmental effects of manganese and proposed freshwater guidelines to protect aquatic life in British Columbia*. Department of Chemical and Bio-Resource Engineering, University of British Columbia, Vancouver, B.C.

Rocchini, R. and L.G. Swain. 1995. *The British Columbia Water Quality Index*. Water Quality Branch, Environmental Protection Department, British Columbia Ministry of Environment, Land and Parks. 13 pp.

Singleton, H.J. 1986. *Water quality criteria for cyanide: Technical appendix*. Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment and Parks.

Singleton, H.J. 1987. *Water quality criteria for copper: Technical appendix*. British Columbia Ministry of Environment and Parks.

Singleton, H.J. 2000. *Ambient water quality guidelines for sulphate*. Water Quality Section, Water Management Branch, British Columbia Ministry of Environment, Lands and Parks.

USEPA. 2005. *Current national recommended water quality criteria*. United States Environmental Protection Agency (http://www.epa.gov/waterscience/criteria/wqcriteria.html).

Warrington, P.D. 1995. *Ambient water quality criteria for fluoride*. Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment, Lands and Parks.

Williamson, D.A. 2002. *Manitoba water quality standards, objectives and guidelines*. Manitoba Water Stewardship (Manitoba Conservation Report 2002-11).

Wright, C.R., K.A. Saffran, A.-M. Anderson, R.D. Neilson, N.D. MacAlpine, and S. E. Cooke. 1999. *A water quality index for agricultural streams in Alberta: The Alberta Agricultural Water Quality Index (AAWQI).* Prepared for the Alberta Environmentally Sustainable Agriculture Program. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta.

Further reading

Berger, T., J.R. Brown, S. Cross, S. Gwanikar, D. MacDonald, and D.Q. Tao. 1998. *Salmon River: water quality assessment and recommended objectives*. Environment Canada.

Brown, J., D. MacDonald, B. McNaughton, and S. Mitchell. 1997. *Lower Columbia River from Birchbank to international border: Water quality assessment and recommended objectives*. Environment Canada and British Columbia Ministry of Environment, Lands and Parks.

Butcher, G.A. 1987. *Peace River area: Peace River mainstream: water quality assessment and objectives: Technical appendix.* British Columbia Ministry of Environment and Parks.

Butcher, G.A. 1992. *Lower Columbia River Hugh Keenleyside Dam to Birchbank water quality assessment and objective: Technical appendix*. British Columbia Ministry of Environment, Lands and Parks.

Holmes, D.W. and R.N. Nordin. 1992. *Thompson River water quality assessment and objectives.* British Columbia Ministry of Environment, Lands and Parks.

Holms, G.B. and L.G. Swain. 1985. *Fraser–Delta area Fraser River sub-basin from Hope to Kanaka Creek quality assessment and objectives*. British Columbia Ministry of Environment.

Kangasniemi, B.J. 1989. *Campbell River area Middle Quinsam Lake sub-basin water quality assessment and objectives: Technical appendix*. Water Management Branch, British Columbia Ministry of Environment.

McKean, C. 1989. *Cowichan–Koksilah rivers water quality assessment and objectives: Technical appendix.* British Columbia Ministry of Environment.

Obedkof, W. 1981. *Water quality assessment and objectives for the Fraser River from Moose Lake to Hope.* British Columbia Ministry of Environment, Lands and Parks.

Swain, L.G. 1990. *Okanagan area Similkameen River sub-basin water quality assessment and objectives: Technical appendix first update*. British Columbia Ministry of Environment.

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