Canadian Water Quality Guidelines for the Protection of Aquatic Life

CCME WATER QUALITY INDEX USER'S MANUAL 2017 UPDATE

Summary

The CCME Water Quality Index (CCME WQI) provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience. The Index incorporates three elements: *scope* - the number of parameters not meeting water quality guidelines; *frequency* - the number of times these guidelines are not met; and *amplitude* - the amount by which the guidelines are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality). These numbers are divided into five descriptive categories to simplify presentation.

The specific parameters, guidelines, and time period used in the CCME WQI are not specified and indeed, could vary from region to region, depending on local conditions, purpose of the use of the index, and water quality issues. The original User's Manual (2001) recommended that at a minimum, four parameters sampled at least four times per year be used in the calculation of CCME WQI values. However, a recent review (Tri-Star Environmental Consulting 2012) found that more consistent and reliable CCME WQI scores are usually obtained when greater than that minimum number of parameters are used (preferably minimum of eight). In addition, the parameters and guidelines chosen should be based on relevant information about a particular site (e.g., upstream stressors and natural background concentrations). The CCME WQI can be used for both tracking changes at one site over time and comparisons among sites. If used for the latter purpose, care should be taken to ensure that there is a valid basis for comparison. Sites should be compared when the same parameters and guidelines, time periods and numbers of samples are used. Otherwise, each site should be measured against its ability to meet relevant guidelines.

Although calculation of CCME WQI values can be done by hand, this is not practical for even a moderate number of sites, guidelines, or samples. An application that automates the process is available athttp://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/calculators.html.

Preface

The CCME WQI was endorsed in 2001. Since 2001, the CCME WQI has been used extensively in Canada and throughout the world for reporting on the state of water quality. There has also been considerable testing and assessment of the CCME WQI by various researchers over the years. This User's Manual was prepared using the original development work on the CCME WQI along with supplemental knowledge developed since 2001. This User's Manual updates two CCME documents: the Technical Report (2001) and the User's Manual (2001).

Introduction

An integral part of any environmental monitoring program is the reporting of results to both managers and the general public. This poses a particular problem in the case of water quality monitoring because of the complexity associated with analyzing a large number of measured parameters. The traditional practice has been to produce reports describing trends and compliance with water quality guidelines on a parameter by parameter basis. The advantage of this approach is that it provides a wealth of data and information. However, in many cases, managers and the general public have neither the inclination nor the training to study these reports in detail. Rather, they require statements concerning the general health or status of the system of concern.

One possible solution to this problem is to reduce the multivariate nature of water quality data by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of water. In this way, the index can be used to assess water quality relative to its desirable state (as defined by water quality guidelines) and to provide insight into the degree to which water quality is affected by human activity. An index is a useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, and wildlife.

An index can be used to reflect the overall and ongoing condition of the water. As with most monitoring programs, an index will not usually show the effect of spills, and other such random and transient events, unless these are relatively frequent or long lasting.

The CCME WQI is based on the index developed by the British Columbia Ministry of Environment, Lands and Parks (Rocchini and Swain 1995) and incorporates modifications developed by the province of Alberta and closely resembles the Alberta Agricultural Water Quality Index (Wright *et al*. 1999). The major difference between the original index and the CCME WQI is the method for calculating one factor related to amplitude as discussed below.

The CCME WQI is based on a combination of three factors:

1. the number of parameters whose guidelines are not met (**Scope**)

2. the frequency with which the guidelines are not met (**Frequency**), and

3. the amount by which the guidelines are not met (**Amplitude**).

These are combined as the summation of the three vectors (scope, frequency and amplitude) to produce a single value between 0 and 100 that describes water quality (Figure 1).

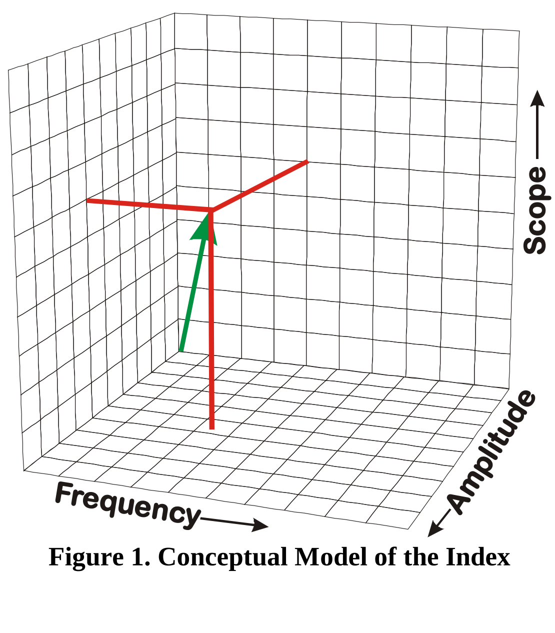

Figure 1. Conceptual Model of the Index

The CCME WQI is easily calculated and is sufficiently flexible that it can be applied in a variety of situations. The index can be very useful in tracking water quality changes at a given site over time or can be used to directly compare among sites. However, if the parameters and guidelines that feed into the index vary across sites, comparisons will be less reliable.

The intent of this manual is to provide users of the CCME WQI with sufficient background information to allow them to apply the CCME WQI to their own data. Since its development, the CCME WQI has been used extensively within Canada (most extensively through the Canadian Environmental Sustainability Indicators program - CESI) and in other parts of the world. In Canada, it has also formed the basis for the CCME Sediment Quality Index and has been applied for drinking water indices and agricultural water uses.

Internationally, the CCME WQI has been adopted for use under the United Nations Environment Programme in three forms: the Global Drinking Water Quality Index, a Health Water Quality Index, and its Acceptability Water Quality Index and has been used to rate water quality in Morocco, Argentina, Japan, Republic of Korea, Belgium, Poland, Switzerland, South Africa, India, Pakistan, and the Russian Federation. The CCME WQI has formed the basis for an Egyptian WQI (Khan *et al*. (2008). As well, a number of other authors have used the CCME WQI to rate water quality in other countries. These included marine water quality in New Zealand (Monitor Auckland 2010); to assess its use for shrimp culture in Brazil (Ferreira et al. 2011); to rate water quality in San Francisco Bay (Bay.org 2003) and Fall Creek in Indiana (IDNR, 2011); lake and river basins in India (Panduranga and Hosmani (Undated), Kerala State in India (2009) and Darapu *et al*. (2011), and surface water quality in Vietnam (Pham *et al*. 2011) and Iraq (Ali 2010).

General Description of the CCME WQI Index

The CCME WQI relies on measures of the scope; frequency and amplitude of excursions from guidelines (see next section). Once the CCME WQI value has been calculated, water quality is classified into one of the following categories:

Excellent: (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

Good: (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

The assignment of CCME WQI values to these categories is a critical, but somewhat subjective, process. The categorization is based on the best available information, expert judgment, and the general public's expectations of water quality.

Data for CCME WQI Calculation

The CCME WQI provides a mathematical framework for assessing ambient water quality conditions relative to water quality guidelines. It is flexible with respect to the type and number of water quality parameters to be tested, the period of application, and the type of water body (stream, river reach, lake, etc.) tested. These decisions are left to the user and therefore, need to be defined before calculating the index. For additional discussion on water quality parameters, see the Section titled *Applying the Index*.

The body of water to which the CCME WQI will apply can be defined by one station (e.g., a monitoring site on a particular river reach) or by a number of different stations (e.g., sites throughout a lake). Individual stations work well, but only if there are enough data available for them. The more stations that are combined, the more general the conclusions will be.

The time period chosen will depend on the amount of data available and the reporting requirements of the user. A minimum period of one year is often used because data are usually collected to reflect this period (e.g., monthly or quarterly monitoring data). Data from different years may be combined, especially when monitoring in certain years is incomplete, but as with combining stations some degree of variability will be lost.

Based on the recent review of the sensitivity and behaviour of the CCME WQI, it is recommended to use at least eight but not more than 20 parameters. The selection of appropriate water quality parameters for a particular region is necessary for the CCME WQI to yield meaningful results. Clearly, choosing a small number of parameters for which guidelines are not met will provide a different result than if a large number of parameters are considered of which only some do not meet guidelines. It is up to the professional judgement of the user to determine which and how many parameters should be included in the CCME WQI to most adequately summarize water quality in a particular region. For rivers and streams, it is recommended that about 10 samples per year be included in the calculation. However, flashier streams and rivers may require a higher number while more stable rivers or lakes may require fewer than 10 samples a year to capture natural variability.

Calculation of the CCME Index

After the body of water, the period of time, and the parameters and guidelines have been defined, each of the three factors that make up the CCME WQI must be calculated. The calculation of F_1 and F_2 is relatively straightforward while F_3 requires some additional steps. It has been determined that the contribution of the first term (F1) to the final CCME WQI score is greater than the contribution of the other two terms.

F_1 (**Scope**) *represents the percentage of parameters that do not meet their guidelines at least once* during the time period under consideration ("failed parameters"), relative to the total number of parameters measured:

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

*F2 (***Frequency***) represents the percentage of individual tests that do not meet guidelines ("failed tests"):*

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

*F3 (***Amplitude***) represents the amount by which failed test values do not meet their guidelines.* F3 is calculated in three steps.

i) The number of times by which an individual concentration is greater than (or less than, when the guideline is a minimum) the guideline is termed an "excursion" and is expressed as follows. When the test value must not exceed the guideline:

(3a) $$excursion_i = \left(\frac{FailedTestValue_i}{Objective_j}\right) - 1$$

For the cases in which the test value must not fall below the guideline:

(3b) $$excursion_i = \left(\frac{Objective_j}{FailedTestValue_i}\right) - 1$$

ii) The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their guidelines and dividing by the total number of tests (both those meeting guidelines and those not meeting guidelines). This parameter, referred to as the normalized sum of excursions, or *nse*, is calculated as:

(4) $$nse = \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ \ tests}$$

iii) F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from guidelines (*nse*) to yield a range between 0 and 100.

(5) $$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors (Figure 1) and using the Pythagoras theorem. The sum of the squares of each factor is therefore equal to the square of the CCME WQI. This approach treats the index as a three-dimensional space defined by each factor along one axis (Figure 1). With this model, the index changes in direct proportion to changes in all three factors.

(6) $$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^{\,2} + F_2^{\,2} + F_3^{\,2}}}{1.732}\right)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

Examples presented in Appendix 1 show the capability for the CCME WQI to identify differences among sites of varying water quality, and identify trends in water quality associated with improvement or degradation of a stretch of river.

How the CCME WQI is influenced by varying measurements scales and ranges of exceedances

Differing scales of measurement are characteristic of water quality analyses. Some substances, such as pesticides, may be environmentally significant at $ng \cdot L^{-1}$ ranges, while other substances are significant at the $mg \cdot L^{-1}$ range. Using a guideline-oriented approach allows these data to be assembled in the same multivariate index formulation, since the metric of interest is the comparison of the measured data relative to its guideline.

This approach also avoids the problem of weighting parameters. The relative toxicities of different chemicals are addressed during the development of water quality guidelines and further weighting is not warranted.

The asymptotic nature of the F3 function also attenuates the undue influence exerted by parameters having a very large range in values spanning orders of magnitude (e.g., bacteria counts) compared to those having very narrow ranges (e.g., pH).

A frequently encountered problem in reporting on water quality data is results that are below the analytical detection limit. Values less than detection can be used in the index as observations which are at the detection limit and compared to the guideline and all the statistical problems associated with how to deal with them are circumvented. If the detection limit happens to be higher than the guideline, as is often the case for cadmium for example, then the detection limit should be used as the guideline.

Example Calculation

Calculation of the CCME WQI by hand for a large amount of data is not recommended. An application has been developed for that purpose. To better understand how the CCME WQI works, however, it is useful to work through the following example which uses a simplified data set from the North Saskatchewan River at Devon, Alberta.

Ten parameters will be considered in the CCME WQI calculation (dissolved oxygen, pH, total phosphorus, total nitrogen, fecal coliform bacteria, arsenic, lead, mercury, 2,4-D, and lindane). The period to be examined is one year (1997). The sampling frequency at this site is monthly for most parameters (note one missing mercury sample) and quarterly for pesticides.

Table 1. North Saskatchewan River at Devon - 1997

	DO	**pH**	**TP**	**TN**	**FC**	**As**	**Pb**	**Hg**	**2,4-D**	**Lindane**
DATE	Mg/L		mg/L	mg/L	#/dL	mg/L	Mg/L	µg/L	µg/L	µg/L
7-Jan-97	11.4	8.0	0.006	0.160	4	0.0002	0.0004	L0.05	L0.005	L0.005
4-Feb-97	11.0	7.9	0.005	0.170	L4[2]	L0.0002	**0.0094**	L0.05		
4-Mar-97	11.5	7.9	0.006	0.132	4	L0.0002	L0.0003	L0.05		
8-Apr-97	12.5	7.9	**0.058**[1]	0.428	L4	L0.0002	0.0008	L0.05	0.004	L0.005
6-May-97	10.4	8.1	0.042	0.250	L4	0.0002	0.0008	L0.05		
3-Jun-97	8.9	8.2	**0.108**	0.707	26	0.0006	0.0013	L0.05		
8-Jul-97	8.5	8.3	0.017	0.153	9	0.0002	0.0004			
5-Aug-97	7.5	8.2	0.008	0.153	8	L0.0002	L0.0003	L0.05	L0.005	L0.005
2-Sep-97	9.2	8.2	0.006	0.130	12	0.0003	0.0018	L0.05		
7-Oct-97	11.0	8.1	0.008	0.093	12	L0.0002	0.0011	L0.05	L0.005	L0.005
4-Nov-97	12.1	8.0	0.006	0.296	8	L0.0002	**0.0051**	L0.05		
1-Dec-97	13.3	8.0	0.004	0.054	4	L0.0002	L0.0003	L0.05		
GUIDELINE:	*5*	*6.5 - 9.0*	*0.05*	*1*	*400*	*0.05*	*0.004*	*0.1*	*4*	*0.01*

[1] Bolded values do not meet the guideline
[2] L = less than

The number of parameters not meeting guidelines is 2 (TP, Pb). The total number of parameters is 10. Therefore:

$$F_1 = \left(\frac{2}{10}\right) \times 100 = \mathbf{20}$$

The number of tests not meeting guidelines is 4, and the total number of tests is 103. Note that there are missing data in the mercury and pesticide columns. In this case:

$$F_2 = \left(\frac{4}{103}\right) \times 100 = \mathbf{3.9}$$

The excursions, their normalized sum, and F_3 are calculated as follows:

$$excursion = \left(\frac{0.058}{0.05}\right) - 1$$ = 0.16, *(calculated for each value that exceeds its guideline)*

$$nse = \frac{(0.16 + 1.16 + 1.35 + 0.275)}{103}$$ = 0.029

$$F_3 = \left(\frac{0.029}{0.01(0.029) + 0.01}\right)$$ = **2.8**

With the three factors now obtained, the index value can be calculated:

$$CCMEWQI = 100 - \left(\frac{\sqrt{20^2 + 3.9^2 + 2.8^2}}{1.732}\right)$$ = **88**

According to the category ranges suggested earlier in this document, the water quality at this river reach would be rated as "Good" based on 1997 data.

For presentation purposes, it is important that a narrative statement explaining the result accompany the calculated CCME WQI value. In this example, the statement might read, "The CWQI indicates that water quality in the North Saskatchewan River at Devon was Good in 1997. Conditions at this site can be considered suitable for the protection of aquatic life. Measured total phosphorus and lead concentrations exceeded guidelines on two occasions each; however, these excursions were fairly small and likely reflect natural events."

Applying the CCME WQI

"More of a constraint than an intrinsic weakness, the efficiency and the accuracy of all indices bank on existing monitoring network, prevalent methods of physic-chemical analysis and guidelines." (Lumb *et al*. 2011). For this reason, one should not forget when using the CCME WQI that monitoring networks can be biased and that results have certain precision and associated accuracy for each parameter, depending on how far the value is from the analytical detection limit. Experience has shown that misuse of the CCME WQI can lead to erroneous conclusions. Therefore, the goal of the CCME WQI calculation should be clearly determined before proceeding further. Is that goal to rate water quality:

- in relation to just one or all water uses?
- at all times of year or only during certain periods, such as when flows are low in the summer?
- in relation to the effects from human stressors or all stressors, natural and human?

There are several rules for application that should be taken into consideration as shown in Figure 2:

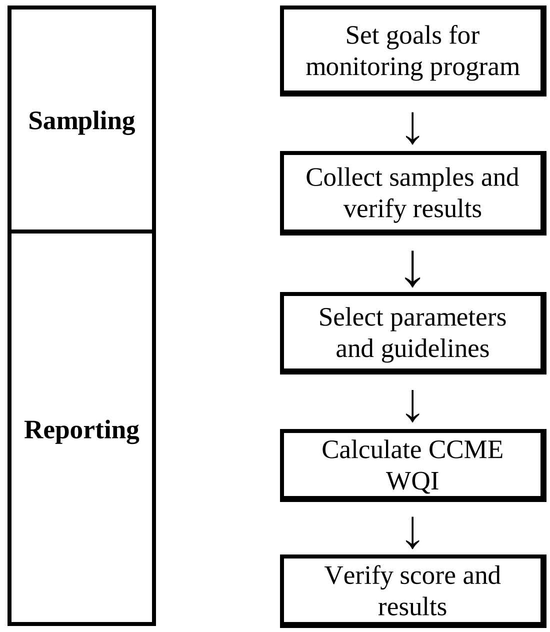

Figure 2. Process for using the CCME WQI

a) **Preparation, tools and approaches for validating data.** Data need to be reviewed prior to being used in the CCME WQI in order to ensure that they meet the data objectives of the water quality monitoring program. If this means that minimum data requirements for performing the calculation of the CCME WQI are not met, then it should not be calculated. Assuming that adequate quality-assured data are available, they should be used for each parameter to calculate the CCME WQI.

A number of questions should be addressed during the data review:

- Are values for each parameter and their guideline expressed in the same units and correct form (e.g., NO_3 as N mg/L)?
- Have high values been entered correctly into the spreadsheet?
- Are there a number of very high values on one date explained by a weather occurrence such as heavy rain that could result in very high suspended solids and associated nutrients and metals? And, if so, should these be excluded from the calculation? Kilgour and Associates (2009) have provided guidance for CCME on the exclusion of data associated with high flow events.

On the “Tested Data” page generated by the CCME WQI calculator, values that exceed the guidelines are highlighted in different colours depending on the extent that the guideline is exceeded. These highlighted data points can point to specific days of generally high values that can be investigated further. It can also illustrate whether the input guideline and data values are expressed in different units.

Colour coding from the Tested Data page of the CCME WQI **Calculator**

Supporting Information (green)
Failed values <10 times guideline (grey)
Failed values 10-25 times guideline (yellow)
Failed values >25 times guideline (red)

b) **Care should be taken with older data.** Analytical methods and detection limits have improved and become more refined. Older data sets go back to times when the sensitivity of analytical methodology was considerably less than with more modern methods. This is of particular concern in cases where there are older results that appear to be just above the detection limit. For example, metals data generated in the 1970s may have been obtained using colorimetric methods with detection limits significantly higher than current water quality guidelines. As well, all analytical methods can produce 'false positive' results and incorporation of these into the CCME WQI can provide misleading results. For example, if older cadmium data were derived from a method with a detection limit of 0.01 $mg \cdot L^{-1}$, there will be results at or slightly above the detection limit that may or may not be valid. If these data are run in the CCME WQI against a guideline of 0.0002 $mg \cdot L^{-1}$, false positives will represent very large excursions over the guideline and lower the score.

c) **The CCME WQI should be run on parameter sets relevant to the water body being tested.** Several jurisdictions have older data sets where large suites of parameters were tested. The CCME WQI should only include parameters in the calculation relevant to the human activities in the area and the water use being tested. The inclusion of many parameters, for example, all pesticides or metals in a scan, may artificially depress the CCME WQI score. This will be of particular concern in comparing index values through time or among sites when the number of tested parameters varies significantly.

The types of parameters selected for use in the CCME WQI should be water-use and human-stressor specific (Appendix 2). For water uses, such as drinking water (if untreated) and recreation, bacteriological parameters need to be included in the calculation of the CCME WQI. For aquatic life protection, bacteriological parameters need not be included. However, if the CCME WQI is used to look at multiple uses such as drinking water and aquatic life protection, then the use of bacteriological parameters in such situations is necessary and appropriate. This is particularly important if human stressors such as wastewater treatment plants or livestock grazing or feeding takes place near a water course, and potentially can impact water quality.

The number of parameters used in the calculation of the CWQI is also water-use and human stressor-dependent. Too many parameters used in the calculation will reduce the importance of any one parameter, while too few parameters will increase the importance of each parameter. The key is to obtain a good balance between these two extremes. It has been found that the larger the number of parameters, the lower the proportion of sites ranked in extreme categories ("poor" or "excellent") in comparison with the "marginal" and "fair" categories.

Based on all of these caveats, it is **recommended that a minimum of eight parameters and a maximum of 20 parameters** should be used in the calculation of the CCME WQI. In cases where it is appropriate to use more than 20 parameters, the subject area should be sub-divided into different water uses or sub-indices, such as metals and nutrients/organic enrichment if possible to reduce the number of stressors. Care must be taken to ensure that parameters selected are not highly correlated (e.g., pH and alkalinity, or turbidity and suspended solids,) to prevent the impact on the CCME WQI of counting the same impact twice.

d) **Minimal data sets should not be used.** The CCME WQI was not designed to replace proper evaluation of water quality conditions through thorough assessment of water quality chemicals of concern. **The WQI should not be run with less than four parameters and four sampling visits per year.** The timing of sampling is as important as the actual number of samples collected. Great care must be taken to ensure that a sufficient number of samples are collected so that events, such as seasonal peaks and troughs, are captured in the sampling. In most cases, this means that at least monthly samples need to be collected to ensure that events are captured. Safety concerns, such as ice conditions on many Canadian water bodies, may result in a reduction to ten monthly samples.

There are sampling locations where this ideal number of samples is not met but where CCME WQI scores can be verified with fewer than the ideal number of samples. In some situations, as few as one sample per season can be used assuming that human stressors and hydrological conditions at the station are well understood and are relatively unchanged through time.

e) **Time periods used in the calculation is important.** Water quality in a water body fluctuates both throughout the year and among years in response to precipitation events. This is particularly important in running waters but also in smaller lakes that respond to hydrologic events. To overcome this natural fluctuation, and in order not to confuse the public with naturally-occurring fluctuations, a longer time period is generally used for reporting on water quality. This has the benefit of flattening out the extremes from the CCME WQI score and categorization. As with other features of the CCME WQI, the key is to use a time period that is not so extreme that the CCME WQI output becomes meaningless.

Longer time periods can have other related concerns, such as changing analytical procedures and detection limits, as discussed earlier. These can cause confusion in the CCME WQI score. The balance between the two extremes of too short and too long a time period is about a **three-year period**. Three years is long enough to even out natural fluctuations, but short enough to see some changes over a short time period.

Keep in mind the time period used for reporting is a reflection of the purpose of the reporting event. In contrast to the long-term reporting scenario above, when reporting on improvements in water quality due to pollution abatement activities, a shorter time period, such as yearly, can be used so that the effect on the CCME WQI from the abatement activity can be seen quickly. In such a situation, using a three-year time period could delay seeing an improvement in the CCME WQI until all the pre-abatement data have been excluded from the CCME WQI calculation.

In the case of regular reporting of water quality information, it is important that any changes in CCME WQI scores or ranking that are reported are not due to the natural variability that exists in water quality parameters because of changes in hydrology, but are changes in the water quality itself. It is also important to remember that some water bodies will have CCME WQI scores that place them close to the boundaries for different categories. In such cases, professional judgment needs to be used in the reporting if the two different categories are due to a very small change in score that cause the category to change. This can be addressed in part by determining the confidence limits associated with a particular CCME WQI score. A method for estimating confidence limits on WQI scores is providing in Appendix 3. The method is based on a bootstrap procedure to sub-select samples, re-run multiple iterations and simulate the frequency distribution of the “score”. This function is available in version 2 of the CCME WQI calculator application.

When samples are collected during extreme events, such as a heavy rainfall, many parameters, such as metals or nutrients associated with suspended solids, can increase substantially for a short peak. As a result, the F1 factor can also rise. In such cases when short spikes in turbidity or suspended solids may not be a problem biologically, procedures outlined by Kilgour *et al*. (2013) for removal of extreme data can be considered.

f) **CCME WQI comparisons should only be made using the same sets of parameters**. Comparing a site where most of the measured parameters are pesticides to a site where most of the measured parameters are metals will yield information of limited value. It is possible to obtain CCME WQI scores, but comparison of these types of sites will only tell the user how each site is doing relative to those guidelines. There is no way the CCME WQI can replace a detailed site assessment of different types of pollutants. Similarly, if a trend-through-time index series is calculated for a specific site and the number and type of water quality parameters change significantly during the course of the time series, meaningless conclusions may be drawn.

g) **CCME WQI comparisons should only be made when the same sets of guidelines are being applied.** The CCME WQI allows the user to select the guideline set on which to compare the water quality. This is a design feature that increases the versatility of the CCME WQI considerably but allows for misuse. Different jurisdictions in Canada use different guidelines for water quality, and there are usually different guidelines for different water uses. Guidelines designed for the protection of water used for irrigation or livestock watering will be different from those designed to protect sensitive aquatic life. If an index value is calculated on one set of guidelines and compared to an index value based on a completely different set of guidelines, any conclusions drawn will be wrong.

h) **Relevant guidelines should be used.** A country as large as Canada has enormous differences in geography and geology through which our rivers and streams flow. Precambrian Shield waters are significantly different from waters that flow across the Prairies (e.g., high phosphorus), but may be similar to waters that flow across Newfoundland and Labrador (e.g., low pH and nutrients and high aluminum). As such, naturally occurring substances, such as metals, nutrients and major ions, will vary greatly from one area to another, and in some cases, often measured at higher concentrations than established guidelines – especially generic Canadian or provincial/territorial guidelines. In these cases, appropriate site-specific guidelines should be used to obtain the most reliable CCME WQI results (CCME 2003). Another key consideration when selecting guidelines is distinguishing between guidelines designed for acute or chronic toxicity. For most applications using monthly samples over a number of years, it is usually more relevant to use the more conservative chronic exposure guidelines as each sample provides a measurement at a specific time and place compared to continuous or frequent sampling (e.g., daily), which better capture the duration and intensity of the exposure.

i) **Validating the** CCME WQI **score is crucial**. Even when all of the preceding steps have been taken, there is a possibility that the CCME WQI score that is generated may not provide an accurate assessment of water quality conditions. In such cases, there are a number of questions that need to be addressed by the water quality professional. The following steps should be undertaken and questions addressed in order to validate the CCME WQI score:

1. Examine results relative to reference conditions or known impacts and ask the question: Are patterns logical?

2. Examine the influence of specific parameters, guidelines or samples on the ratings and ask the question: Do any apply an undue influence? To determine this, one can input new site-specific guidelines, remove the results associated with an outlier sample, or delete certain parameters from the CCME WQI calculation. Additionally:

    a. Are the guidelines used the best that can be used or should they be looked at to ensure that they are up-to-date and relevant to the situation being scored?
    b. Do certain samples point to the need to re-examine the actual monitoring design?

3. Review previous assessments and ask the question: Are findings consistent? Should the results be consistent? This goes back to:

    a. Were the same numbers of samples used in both cases?
    b. Were the same parameters tested in both cases?
    c. Were the analytical methodologies (and associated detection limits) for the parameters the same in both test periods?
    d. Were the samples collected in the same months or the same stage of the hydrograph?
    e. Were the same guidelines used in both cases for each parameter?

4. Assess potential pollution sources and ask the question: Are there any unexpected influences? Unexpected influences could arise from samples that were collected either too close to a source before it was fully mixed with ambient waters, or too far away from a source so as to not be able to differentiate the influence of one particular source. Both these cases relate to study design and the questions being posed that the monitoring program is supposed to answer.

5. Examine bio-monitoring or other habitat assessments and ask the question: In general do the findings concur? One should not expect 100% overlap because biological sampling often incorporates effects on biota over time, whereas individual surface water samples reflects the state of water quality at a particular instant. Water quality samples may miss short term events, such as spills or contaminated run-off, that have impacts on biota. In addition, factors other than water quality can also influence biota, such as sediment contamination, changes in

flow, and invasive species.

Allowing for the restrictions and cautions on its use, the CCME WQI has been successfully applied in several Canadian jurisdictions and has produced results that contain valuable information with regard to trends through time and spatial discrimination of impacted and non-impacted sites. It has been shown throughout the world that it has application as a management and communication tool if applied appropriately.

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Appendix 1 - CCME WQI Application

The CCME WQI as described above has been applied to several data sets from across Canada. This section provides some examples.

Newfoundland and Labrador

The CCME WQI was applied to three selected watersheds in Newfoundland and Labrador. Water quality data from 1986 to 1994, collected under Federal-Provincial Water Quality Agreement, for twelve stations located in the Humber Watershed, the Exploits Watershed and the Quidi Vidi Watershed were used in the analysis (see Figure 3). Parameters included in the index calculation were conductivity, turbidity, dissolved oxygen, pH, dissolved organic carbon, aluminum, arsenic, cadmium, chromium, copper, iron, manganese, lead, nickel, phosphorus and zinc.

The CCME WQI trend at eight of these sites is shown in Figure 4. An assessment of the application of the CCME WQI to these watersheds (Khan 1999) concluded that there was good discrimination between pristine sites (for example, Lloyds River - YN0001) compared to sites impacted by urbanization or past mining activities (YO0017, YO0001).

Index scores in the Quidi Vidi Watershed also reflect the high level of urbanization in the municipality of St. John’s compared to the more remote areas of the Exploits and Humber River Watersheds.

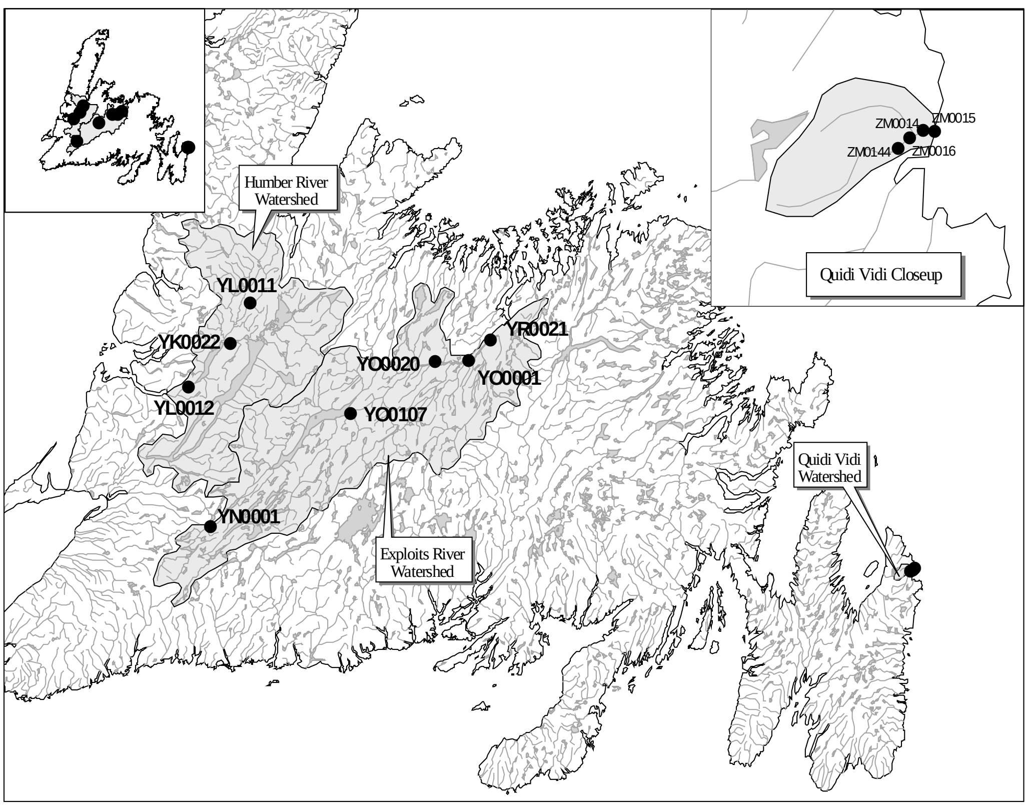


Figure 3. Water Quality Index Sites in Newfoundland and Labrador

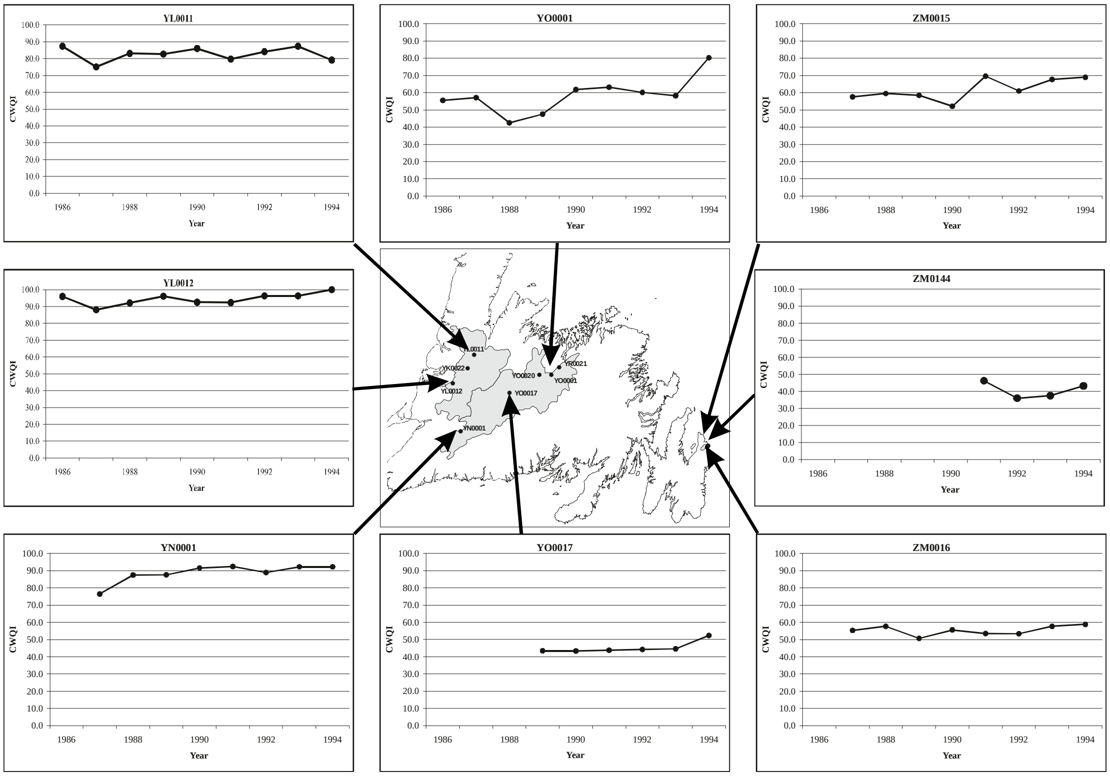


Figure 4. CCME WQI trends at selected sites in Newfoundland and Labrador

Saskatchewan

The data for the Saskatchewan application were obtained from the Prairie Provinces Water Board (PPWB). The PPWB was established in the 1930s and represents an agreement among the three Prairie Provinces and the Federal government. Originally, the PPWB was concerned only with water quantity (transfers across provincial boundaries) but the interests broadened over time and led to the inclusion of a water quality program starting in 1968. Currently the PPWB monitors water quality at twelve sites (six along the Alberta Saskatchewan boundary and six along the Saskatchewan-Manitoba boundary – see Figure 5).

Figure 6 shows the results when the CCME WQI is applied to eight of these reaches. Parameters included in this example are: chloride, copper, fecal coliform, iron, lead, manganese, NO_2 + NO_3, sodium, sulphate, zinc, phosphorus, dissolved oxygen, total dissolved solids and pH. Data were typically collected on a monthly basis.

As can be seen in Figure 6 overall water quality ranges from marginal to excellent depending on the river reach and sample year. As expected, the Churchill River, the least impacted in the sampling network, consistently shows the highest CCME WQI values. In contrast, the Carrot River, which is subject to both agricultural and forestry activity, has a water quality which is typically "fair", largely as a consequence of excursions to the phosphorus guideline. As with the PPWB analysis, the CCME WQI does not suggest a significant trend in water quality for any of these sites.

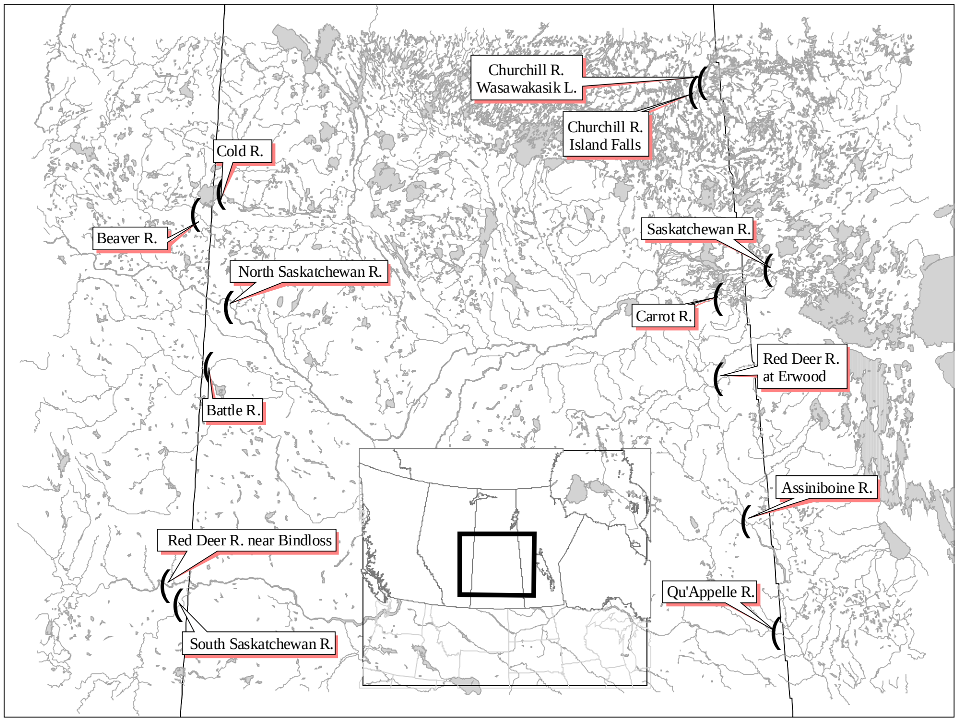


Figure 5. Prairie Provinces Water Board Sampling Sites

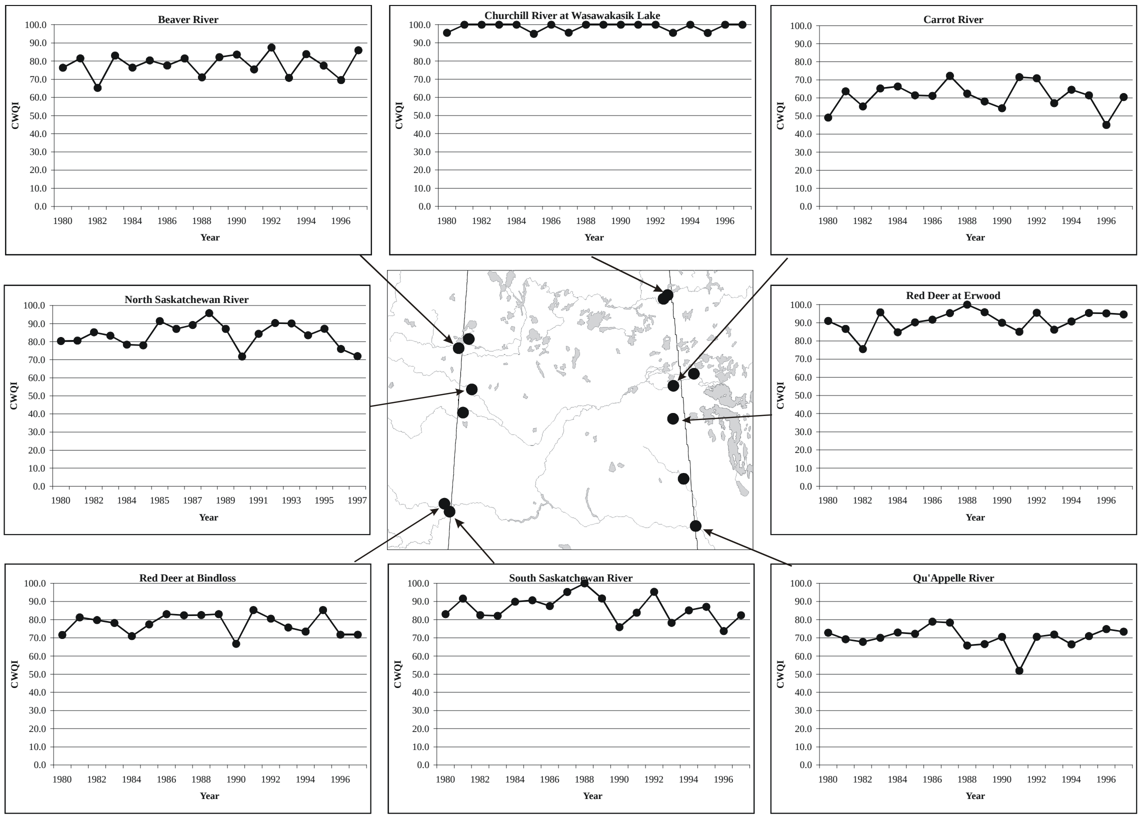


Figure 6. CCME WQI trends at Prairie Provinces Water Board Stations

Using the CCME WQI to assess upgrades to treatment facilities

Glozier *et al*. (2007) showed how activities such as improvements to a wastewater treatment facility can be delayed in the CCME WQI score when a longer time period is used (Figure 7). In this case, the CCME WQI score did not reflect the improvement in water quality until 1994, even though the improvement was made in April 1990. Glozier *et al*. (2007) used site-specific guidelines based on 90th percentile values for 15 parameters from an upstream station to calculate the index values.

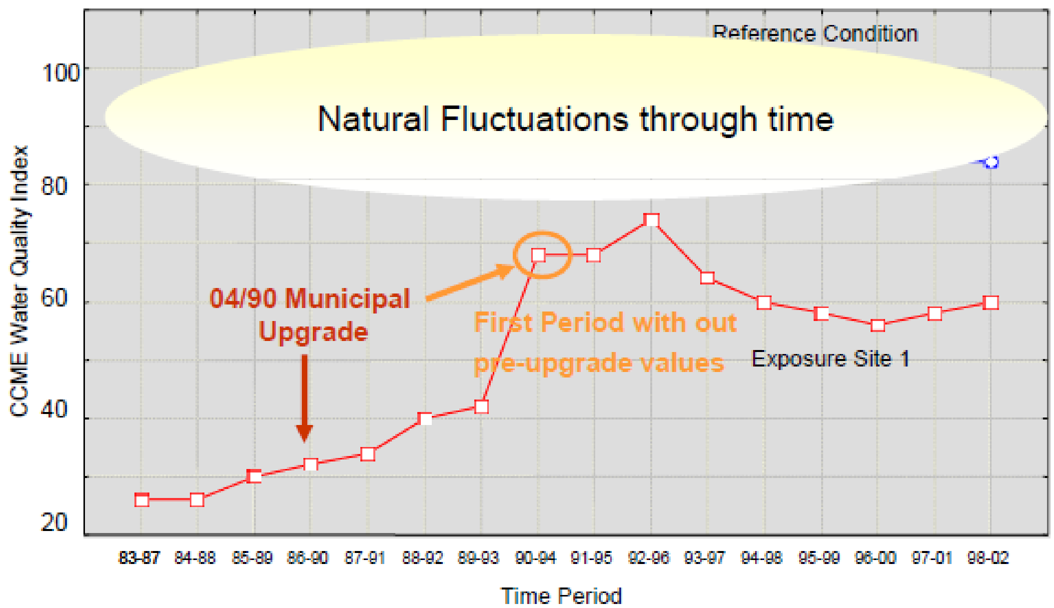


Figure 7. Delay in reporting of improved water quality following treatment plant upgrades when a five-year period is used to calculate the WQI (Source: Glozier *et al*. 2007)

In order to illustrate the difference in one-year CCME WQI scores compared to the three-year and five-year scores used by Glozier *et al*. (2007), data from 1985 to the end of 2010 for the exposure site were obtained from Environment Canada (Nancy Glozier personal communication), and the CCME WQI was calculated and plotted (see Figure 8). Figure 8 clearly shows that using the one-year time period provides clearer and more timely reporting of significant upgrades in a water body than does the five-year period. The three-year time period is somewhat between the two extremes and is likely a good compromise between responsiveness and timely reporting.

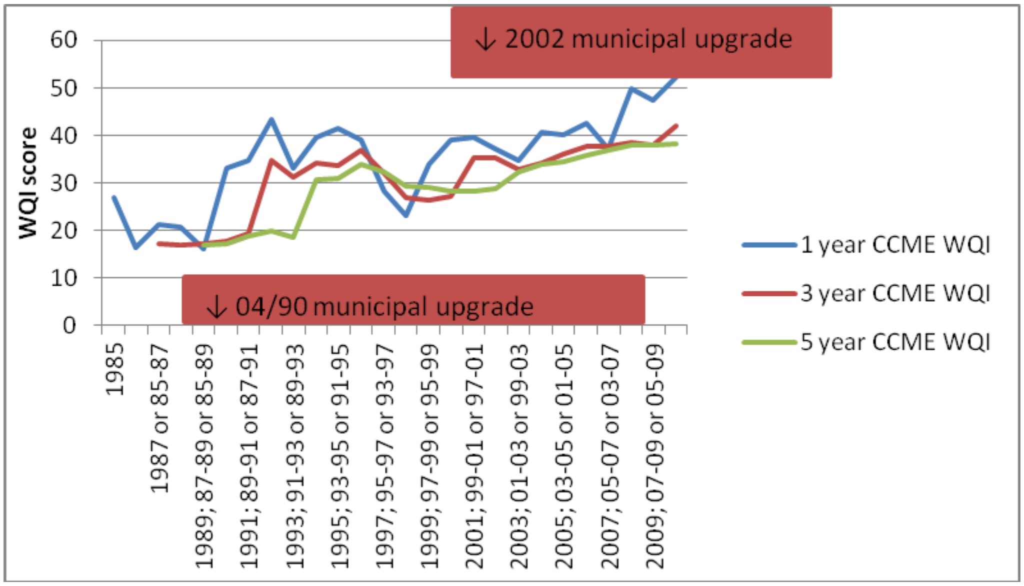


Figure 8. Reporting improved water quality following treatment plant upgrades with one-year compared to three- and five-year time periods (Data source: Nancy Glozier, Environment and Climate Change Canada)

Appendix 2 - Parameters to Consider for Water Uses and Discharge Types

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Agriculture – livestock	**Agriculture – crops**	**Fertilizer mfg.**	**Forestry – range**	**Forestry – road building**	**Forestry – Silviculture**	**Mining – base metal**	**Mining – coal**	**Mining – oil sands**	**Pulp and paper**	**Sewage (&CSO) Discharges**	**Smelters**	**Stormwater**	**Wood Preservation**	**Aquaculture**	**Oil and gas**	**Landfills – wood waste**	**Landfills – municipal**	**Landfills – industrial[6]**
Fecal coliforms	√	√[1]		√		√[3]					√		√					√[5]	
E. coli	√	√[1]		√		√[3]					√		√					√[5]	
T. Diss. Solids		√	√										√				√	√	√
pH	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
DO	√	√	√	√		√	√	√	√	√	√		√		√	√	√	√	√
TOC, DOC, BOD	√	√	√	√		√	√	√		√	√	√	√		√	√	√	√	√
Susp. Solids	√	√	√	√	√	√	√	√	√	√	√	√	√				√	√	√
Turbidity	√	√	√	√	√	√	√	√	√	√	√		√				√	√	√
Ammonia	√	√	√	√		√	√	√	√		√		√		√		√	√	√
Nitrate	√	√	√	√		√	√	√	√		√		√		√		√	√	√
Nitrite	√	√	√	√		√	√	√	√		√		√		√		√	√	√
Phosphorus	√	√	√	√		√	√	√	√		√		√		√		√	√	√
SO_4							√	√		√						√	√	√	√
Al							√[4]		√			√[4]	√						
Sb									√										
As							√[4]		√			√[4]							
Ba								√											
Be									√										
Cd							√[4]		√			√[4]	√						
Cu							√[4]		√		√	√[4]	√	√[4]					
Cr									√										
Fe					√		√[4]					√[4]							
Pb							√[4]		√		√	√[4]	√						
Hg									√										
Mn								√											
Ni									√										

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Agriculture - livestock	**Agriculture - crops**	**Fertilizer mfg.**	**Forestry - range**	**Forestry – road building**	**Forestry - Silvicture**	**Mining – base metal**	**Mining – coal**	**Mining – oil sands**	**Pulp and paper**	**Sewage (&CSO) Discharges**	**Smelters**	**Stormwater**	**Wood Preservation**	**Aquaculture**	**Oil and gas**	**Landfills-wood waste**	**Landfills - municipal**	**Landfills - industrial**
Se							√[4]	√	√			√[4]							
Ag									√										
Tl									√										
V								√	√							√			
Zn							√[4]		√		√	√[4]	√						
Cyanide							√[4]					√[4]							
PAHs								√	√		√	√	√			√		√	
Pthalates											√							√	
BTEX																√			
Hydrocarbons																√			
Pesticides		√[3]				√[2]								√[2]	√	√	√	√	

1 If fertilized with manure or similar animal-based product
2 If pesticides are applied and only for the pesticides used
3 If sheep are used as a control on vegetation growth
4 Metals appropriate to the operation – cyanide if gold leaching takes place
5 If sewage sludge disposed of at the site
6 Depends on industry

(Source: Tri-Star Environmental Consulting, 2012)

Appendix 3 – Confidence Intervals

Due to the nature of the water quality index calculation, it is impossible to define an analytical expression to calcuate the variance of the water quality index, and thus confidence intervals for its scores. Although there are several possibilities for estimating the variance, the simplest approach is to use a computational method such as the bootstrap procedures outlined below (Efron and Tibshirani, 1993). These bootstrap procedures estimate the frequency distribution of the index scores by resampling the data used to calculate the index and regenerating multiple index scores. The confidence limits are then determined from the resulting frequency distribution.

The first bootstrap procedure is parameter based and works as follows:

1. For the j^{th} parameter (j^{th} column of the data matrix) draw, with replacement, a bootstrap sample of the same size as the number of observations available for the parameter.
2. Repeat step 1 for each parameter creating a bootstrap replica of the original dataset.
3. Use the bootstrap data generated in step 2 and compute the WQI.
4. Repeat the above three steps B times (e.g., 10,000).
5. The confidence interval for the index score is determined by selecting the appropriate two percentiles based on the B samples. For example, to obtain 95% limits, use the 2.5% percentile and 97.5% percentile of the frequency distribution to determine the upper and lower confidence limits.

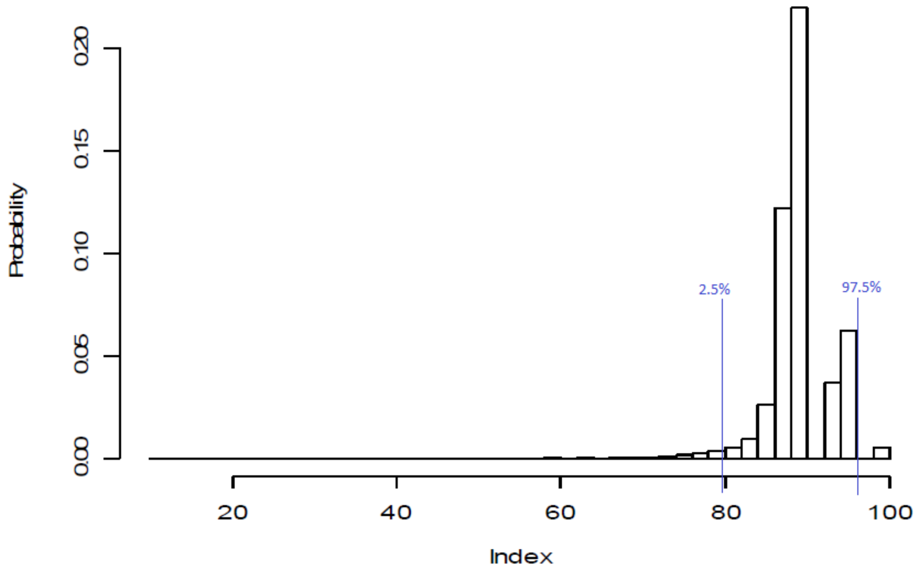
It should be noted that: a) the computation required to obtain the bootstrap distribution could be substantially reduced by restricting the resampling only to the parameters that exceed their guidelines; and b) this procedure ignores or assumes lack of correlation among parameters.

The second method is sample bootstrapping. It operates on the rows of the data matrix instead of its columns. This procedure maintains the correlation structure of the water quality parameters and works as follows:

1. For the i^{th} sample (i^{th} row of the data matrix) draw, with replacement, a bootstrap sample of the same size as the number of samples in the dataset creating a bootstrap replica of the original dataset.
2. Compute the index for each bootstrap dataset.
3. Repeat the above three steps B times (e.g., 10,000).
4. The confidence interval for the index score is determined by selecting the appropriate two percentiles based on the B samples. For example, to obtain 95% limits, use the 2.5% percentile and 97.5% percentile of the frequency distribution to determine the upper and lower confidence limits.

Example 1:
Using the data in Table 1 of this manual for the Saskatchewan River at Devon and following procedure 2 above, we can demonstrate the computation of confidence interval for WQI. For this dataset, the computed index score is 88. To obtain a confidence interval associated with this score, we calculated 10,000 bootstrap samples from the observed data by sampling the values of each sample separately. The bootstrap median is found to be 88.22. This score is slightly above the report value of 88 as a consequence of the left-skewed bootstrap distribution shown in the figure below. The confidence intervals are as follows: the 95% CI is 79.58 to 94.20.

Fig.1 The distribution of the bootstrapping index



At this time, it is recommended that option 2 (sampling rows or samples) be used to determine confidence intervals because it retains the correlation structure of the original dataset. This formula has been incorporated in the latest version of the CCME WQI Calculator application, available at:
http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/calculators.html.