Acknowledgements

Summary

A water quality index provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience. The CCME Water Quality Index (1.0) is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment. The Index incorporates three elements: *scope* - the number of variables not meeting water quality objectives; *frequency* - the number of times these objectives are not met; and *amplitude* - the amount by which the objectives are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality). These numbers are divided into 5 descriptive categories to simplify presentation.

The specific variables, objectives, and time period used in the index are not specified and indeed, could vary from region to region, depending on local conditions and issues. It is recommended that at a minimum, four variables sampled at least four times be used in the calculation of index values. It is also expected that the variables and objectives chosen will provide relevant information about a particular site. The index can be used both for tracking changes at one site over time, and for comparisons among sites. If used for the later purpose, care should be taken to ensure that there is a valid basis for comparison. Sites can be compared directly only if the same variables and objectives are used; otherwise, a comparison of the sites' ability to meet relevant objectives must be made in terms of the category obtained.

Although calculation of index values can be done by hand, this is not practical for even a moderate number of sites, objectives, or samples. An Excel macro that automates the process is available upon request.

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 variables. The traditional practice has been to produce reports describing trends and compliance with official guidelines or other objectives on a variable by variable 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 objectives) 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, wildlife, etc.

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.

Although there have been a variety of attempts to create such a water quality index, the most successful attempt to date appears to be the index developed by the British Columbia Ministry of Environment, Lands and Parks (Rocchini and Swain 1995). This index has been adopted for use by a number of provinces, including Manitoba (Manitoba Environment 1997).

The index is based on a combination of three factors:

1. the number of variables whose objectives are not met, (**Scope**)

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

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

These are combined to produce a single value (between 0 and 100) that describes water quality.

Unlike some earlier indices, the basic BC formulation captures all key components of water quality, 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 and can also be used to compare directly among sites that employ the same variables and objectives. However, if the variables and objectives that feed into the index vary across sites, comparing among sites can be complicated. In these cases, it is best to compare sites only as to their ability to meet relevant objectives. For example, in calculating the index for a mountain stream and a prairie river, one might employ different nutrient objectives but the sites could still be compared as to their rank (*e.g.*, both sites are ranked as "Good" under the index).

In January 1997, the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines Task Group, in cooperation with the CCME State of the Environment Task Group, formed a technical subcommittee. The task of the subcommittee was to examine and, if necessary, modify the BC index with a view to creating a CCME Water Quality Index (CCME WQI) that could be adopted by all provinces and territories. This subcommittee examined, modified and

tested the CCME WQI on artificial and "real world" data sets from a number of provinces. The final formulation of the CCME WQI, although based on the BC index, incorporates modifications developed by the province of Alberta; and closely resembles the Alberta Agricultural Water Quality Index, or AAWQI (Wright *et al.* 1999). A complete description of the development, testing and behaviour of the CCME WQI is available in CCME 2001.

The intent of this manual is to provide potential users of the CCME WQI with sufficient background information to allow them to apply the index to their own databases. Our ultimate goal is to combine the findings of the Water Quality Guidelines Task Group (CCME 2001) with those of individual jurisdictions to build a flexible, useful index that can be applied across all jurisdictions. This manual should thus be viewed as the first step in an iterative process and subject to modification as new information becomes available.

General Description of the Index

As with the BC and Alberta indices, the CCME WQI relies on measures of the scope, frequency and amplitude of excursions from objectives (see next section). However, the methods by which these measures are calculated differ somewhat in each index and will thus provide different results when applied to the same data set.

Another important difference between the BC index and the CCME WQI relates to the way in which the individual factors are combined to provide a final index value. In both cases the index value can range from 0-100. However, in the BC index increasing values are indicative of decreasing water quality while in the CCME WQI the opposite is true. Thus, in the CCME WQI a value of 100 is the best possible index score and a value of 0 is the worst possible.

Once the CCME WQI value has been determined, water quality is ranked by relating it to 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 termed "categorization" and represents 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. The categorization presented here is preliminary and will no doubt be modified as the index is tested further.

Data for Index Calculation

The CCME WQI provides a mathematical framework for assessing ambient water quality conditions relative to water quality objectives. It is flexible with respect to the type and number of water quality variables 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. Therefore, before the index is calculated, the water body, time period, variables, and appropriate objectives need to be defined.

The body of water to which the index 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 (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.

The calculation of the CCME WQI requires that at least four variables, sampled a minimum of four times, be used. However, a maximum number of variables or samples is not specified. The selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Clearly, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. It is up to the professional judgement of the user to determine which and how many variables should be included in the CCME WQI to most adequately summarize water quality in a particular region.

Calculation of the Index

After the body of water, the period of time, and the variables and objectives have been defined, each of the three factors that make up the index must be calculated. The calculation of F_1 and F_2 is relatively straightforward; F_3 requires some additional steps.

F_1 (**Scope**) represents the percentage of <u>variables</u> that do not meet their objectives at least once during the time period under consideration ("failed variables"), relative to the total number of variables measured:

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

F_2 (**Frequency**) represents the percentage of individual tests that do not meet objectives ("failed tests"):

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

F_3 (**Amplitude**) represents the <u>amount</u> by which failed test values do not meet their objectives. F_3 is calculated in three steps.

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

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

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

the objective:

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

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

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

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

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

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors. The sum of the squares of each factor is

therefore equal to the square of the index. This approach treats the index as a three-dimensional space defined by each factor along one axis. With this model, the index changes in direct proportion to changes in all three factors.

The CCME Water Quality Index (CCME WQI):

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

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

Example Calculation

Calculation of the index by hand for a large amount of data is not recommended. An Excel macro has been developed for that purpose. To better understand how the index 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 variables will be considered in the index 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 variables (note one missing mercury sample) and quarterly for pesticides.

North Saskatchewan River at Devon - 1997

DATE	DO Mg/L	pH	TP mg/L	TN mg/L	FC #/dL	As mg/L	Pb Mg/L	Hg g/L	2,4-D g/L	Lindane g/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		
OBJECTIVE:	*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 objective
[2] L = less than

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

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

The number of tests not meeting objectives 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:

$$excursion = \left(\frac{0.058}{0.05}\right) - 1 = 0.16, \text{ etc.}$$

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

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

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

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

Given the category ranges suggested in the 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 CCME WQI 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 objectives on two occasions each; however, these excursions were fairly small and likely reflect natural events."

References

Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, Technical Report. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Manitoba Environment. 1997. State of the Environment Report for Manitoba 1997. Winnipeg, MB. 174 pp.

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

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 (AESA). Published by Alberta Agriculture, Food and Rural Development. Edmonton, AB. 35 pp

Reference listing:

Canadian Council of Ministers of the Environment. 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.

For further scientific information, contact:

    Environment Canada
    Guidelines and Standards Division
    351 St. Joseph Blvd.
    Hull, QC K1A 0H3
    Phone: (819) 953-1550
    Facsimile: (819) 953-0461
    E-mail: ceqg-rcqe@ec.gc.ca
    Internet: http://www.ec.gc.ca

For additional copies, contact:

    CCME Documents
    c/o Manitoba Statutory Publications
    200 Vaughan St.
    Winnipeg, MB R3C 1T5
    Phone: 1-800-805-3025 (toll-free) or (204) 945-4664
    Facsimile: (204) 945-7172
    E-mail: spccme@gov.mb.ca

Aussi disponible en français.