



SYNTHESIS OF RESEARCH AND APPLICATION OF THE CCME WATER QUALITY INDEX

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ABSTRACT

The Canadian water quality index (CCME WQI) is a tool that originated in British Columbia in the mid-1990's and has been used to provide the public with information on water quality in an easy-to-understand format. Tri-Star Environmental Consulting was contracted by the CCME Water Quality Task Group, Reporting Methods Sub-group to summarize all previous work related to the understanding of the behaviour of the WQI. This was to focus on inputs to the WQI. This report provides a synthesis of previous work related specifically to:

- 1 The number and types of parameters selected;
- 2 The number and timing of samples;
- 3 Time periods that should be selected (e.g., one year, three years, etc.);
- 4 Preparing and validating data; and
- 5 Tools and approaches to use in order to validate the reliability of results.

Use of the CCME WQI

Since its development, the CCME WQI has been used extensively within Canada, and in other parts of the world. In Canada, it has been used widely for the reporting under the Canadian Environmental Sustainability Indicators (CESI) program and has formed the basis for the CCME sediment quality index and for drinking water indices and the agricultural indices.

The CCME WQI has been adopted for use under the United Nations Environment Programme in three forms: the Global drinking water quality index, its health water quality index, and its acceptability water quality index, each with specific parameters selected. In these forms, it 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.

Independently, a number of other authors have used the CCME WQI to rate water quality in other countries. These included marine water quality at 27 sites in New Zealand, to assess its use for shrimp culture in Brazil, to rate water quality in San Francisco Bay, Fall Creek in Indiana, a lake and three river basins in India, and surface water quality in Vietnam and in Iraq. In Egypt it has formed the basis for an Egyptian WQI.

The number and types of parameters selected

The number and types of parameters selected is a function of what is to be assessed using the CCME WQI. One "core set of parameters" can possibly be used when there is only one use to be assessed, and the nature of the human activities is limited to a few types of activities.

When water quality is to be assessed over a large geographical area with many diverse types of human stressors, it is likely not practical to dictate the actual parameters that should be used in the CCME WQI. Using groups of parameters such as metals, nutrients etc. may partially address this idea of core sets of parameters in such situations but the parameters still need to be relevant to the inputs or stressors on the system and need to have been collected at appropriate times of the year.

The second approach is to use varying numbers and types of parameters to calculate the CCME WQI, in response to the human stressors in the water body. The advantage of this approach is that the CCME WQI calculated will be relevant and accurate for that water body. However, it will make direct comparison of the CCME WQI from one water body to another virtually impossible.

The effect of the number of parameters is that too many parameters used in the calculation will reduce the importance of any one parameter, while too few parameters will increase the importance. Several researchers have shown that for a particular water body, the actual parameter chosen for use in the CCME WQI is of more importance than the absolute number of parameters used.

Based on all of these caveats, we recommend that a minimum of eight but less than 20 parameters should be used in the calculation of the CCME WQI. In cases where it is appropriate to use more than 20 parameters, we recommend that the subject area should be sub-divided if possible to reduce the number of stressors (and hence the numbers of parameters).

The number and timing of samples

The timing of sample collection is likely as important as or more important than the number of samples actually collected. Selective sampling at times when guidelines or objectives are not likely to be exceeded will yield CCME WQI scores that are better than the water quality actually is in a water body for an entire period. A sampling program that excludes a time period when water quality may be different or impacted is not truly collecting samples of the water quality throughout a year. In a similar vein, a program that focuses exclusively on a period of time when a guideline or objective may be exceeded may also not be appropriate. A time period of the year may be omitted when a guideline or use is not valid, and could focus on for example the recreation season. When samples are collected during extreme events, such as a heavy rainfall, many parameters will likely increase substantially for a short peak. In such cases, the F1 factor will increase significantly but in such cases, turbidity or suspended solids (and attached chemicals) during these events may not be a problem biologically.

The number of samples collected and used in the CCME WQI can have a significant effect on the CCME WQI. Too few samples can bias the results in general to a high CCME WQI because the fewer the samples collected; the less likely it will be to “catch” an event with poor water quality. Similarly, collecting too many samples can depress the CCME WQI. The key is to determine an adequate number of samples between these extremes.

Sampling should reflect seasonal variability and not episodic variability.

Time periods that should be selected

The time period needs to provide meaningful feedback to the intended audience. For the regular reporting of water quality it is important that any changes in CCME WQI scores or ranking are not due to the natural variability but are changes in the water quality itself.

Annual reporting of CCME WQI scores using a rolling three-year time period as has been done through CESI is likely a good way to remove a considerable amount of the natural variability in water quality data. It will also, to a degree, minimize the number of water bodies where there are swings in rankings and has the advantage of evening out natural fluctuations while still providing some feedback on changes in the water quality.

Synthesis of Research and Application of the CCME Water Quality Index

If the purpose of reporting is to provide information on the effectiveness of a pollution control activity or to show how water quality suffered due to a pollution event, then a shorter time period is likely warranted. For example, three-year periods have been shown to mask the impact of pollution control activities until the fourth year following the initiation of a project. This is not likely a satisfactory result for a public that may have spent millions of dollars to upgrade a wastewater treatment facility. In such cases immediate results are wanted, needed and yearly CCME WQI scores are warranted.

On the other hand, using time periods that are themselves long (e.g., decadal) really provides little meaningful information to the public. It is likely that analytical procedures and detection limits can change from one decade to another for the same parameters, and this will have inherent problems such as false positives near the detection limit that may be in excess of guidelines/objectives. If one is interested in making comparisons between two or more decades, it is likely better to provide graphs of CCME WQI scores over the long-term than to try to generate a meaningful score over any particular decade. Using this latter approach, if CCME WQI scores change suddenly at a particular time, one should investigate whether detection limits changed for some parameters at about the same time.

Preparing and tools and approaches to use for validating data

Data that are used in the CCME WQI should be reviewed to ensure that they meet certain standards. Data that have been rejected using quality assurance and quality control protocols should not be included in the index calculation. A similar process should take place with the CCME WQI scores that are generated. A series of questions should be answered when reviewing the outputs from the CCME WQI calculator but in essence, the key question to ask is “do the results make sense?”

SOMMAIRE

L'indice canadien de qualité des eaux (ci-après l'IQE du CCME), qui a vu le jour en Colombie-Britannique au milieu des années 1990, a pour but de fournir au public de l'information sur la qualité de l'eau sous une forme facile à comprendre. La firme Tri-Star Environmental Consulting a été engagée par le sous-groupe sur les méthodes de production de rapports du Groupe de travail sur la qualité des eaux du CCME pour produire une synthèse de tous les travaux antérieurs qui visaient à comprendre le fonctionnement de l'IQE, synthèse qui devait mettre l'accent sur les données d'entrée de l'IQE. Le présent rapport dresse donc une synthèse des travaux antérieurs qui portaient précisément sur les points suivants :

- 1 le nombre et les types de paramètres sélectionnés;
- 2 le nombre d'échantillons et le moment choisi pour les prélever;
- 3 la période à sélectionner (p. ex. un an ou trois ans);
- 4 la préparation et la validation des données;
- 5 les outils et méthodes à utiliser pour confirmer l'exactitude des résultats.

Utilisation de l'IQE du CCME

Depuis sa création, l'IQE du CCME a été abondamment utilisé au Canada et ailleurs dans le monde. Au Canada, on s'en est beaucoup servi pour produire des rapports dans le cadre du programme des Indicateurs canadiens de durabilité de l'environnement (ICDE), en plus de l'utiliser comme base pour la création de l'indice de qualité des sédiments du CCME, d'indices de qualité de l'eau potable et d'indices agricoles.

L'IQE du CCME a été adopté par le Programme des Nations Unies pour l'environnement sous trois formes : un indice global de qualité de l'eau potable, un indice de qualité de l'eau axé sur la santé et un indice de qualité de l'eau axé sur l'acceptabilité, chacun de ces indices étant assorti de paramètres précis. Sous ces formes, l'indice a servi à évaluer la qualité de l'eau dans de nombreux pays : le Maroc, l'Argentine, le Japon, la République de Corée, la Belgique, la Pologne, la Suisse, l'Afrique du Sud, l'Inde, le Pakistan et la Fédération de Russie.

D'autres auteurs ont utilisé de leur propre chef l'IQE du CCME pour évaluer la qualité de l'eau dans divers pays. Par exemple, on s'en est servi pour évaluer la qualité de l'eau à 27 endroits en Nouvelle-Zélande, pour déterminer s'il serait bon de l'utiliser pour l'élevage des crevettes au Brésil, pour évaluer la qualité de l'eau de surface au Vietnam et en Irak et pour évaluer la qualité de l'eau de la baie de San Francisco, d'un cours d'eau (Fall Creek) en Indiana ainsi que d'un lac et de trois bassins fluviaux en Inde. Il a également servi de base à la création d'un IQE égyptien.

Le nombre et les types de paramètres sélectionnés

Le nombre et les types de paramètres sélectionnés dépendent de ce que l'on veut évaluer avec l'IQE du CCME. Il est parfois possible d'utiliser un « ensemble de paramètres de base » lorsque l'évaluation porte sur un seul usage et que les types d'activités humaines en présence sont limitées.

Si la qualité de l'eau est évaluée sur un vaste territoire géographique qui abrite de nombreux types de facteurs de stress d'origine humaine, il est probablement préférable de ne pas dicter les paramètres à utiliser dans l'IQE du CCME. Dans ce genre de situations, l'emploi de groupes de paramètres comme les métaux ou les éléments nutritifs peut répondre en partie à la volonté

d'utiliser un ensemble de paramètres de base, mais les paramètres utilisés doivent tout de même s'appliquer aux données d'entrée ou aux facteurs de stress du système considéré et avoir été recueillis à des périodes appropriées de l'année.

La deuxième méthode possible pour calculer l'IQE du CCME est d'utiliser un nombre et des types de paramètres variables, déterminés en fonction des facteurs de stress d'origine humaine présents dans le cours d'eau. Cette méthode a l'avantage de calculer un IQE juste et adapté au cours d'eau à l'étude. Elle rend cependant pratiquement impossible toute comparaison directe entre les IQE du CCME de différents cours d'eau.

Le nombre de paramètres influence l'importance relative de chaque paramètre : en effet, le fait d'utiliser un trop grand nombre de paramètres dans le calcul réduira l'importance de chaque paramètre, tandis que l'utilisation d'un trop petit nombre aura l'effet contraire. Plusieurs chercheurs ont montré que les paramètres sélectionnés pour calculer l'IQE du CCME pour un cours d'eau donné ont plus d'importance que le nombre absolu de paramètres utilisés.

À la lumière de ces considérations, nous recommandons d'utiliser au minimum 8, mais moins de 20 paramètres dans le calcul de l'IQE du CCME. Lorsqu'il convient d'utiliser plus de 20 paramètres, nous recommandons de subdiviser si possible le champ d'étude pour réduire le nombre de facteurs de stress (et, par le fait même, le nombre de paramètres).

Le nombre d'échantillons et le moment choisi pour les prélever

Le moment choisi pour prélever les échantillons est probablement aussi voire plus important que le nombre d'échantillons prélevés. Un échantillonnage sélectif, effectué à des moments où les recommandations ou objectifs ont peu de risque d'être dépassés, conduira à des cotes d'IQE du CCME supérieures à la qualité réelle de l'eau dans le cours d'eau à l'étude pour l'ensemble de la période considérée. Un programme d'échantillonnage qui exclut une période où la qualité de l'eau est susceptible d'être différente ou perturbée ne recueille pas vraiment des échantillons représentatifs de la qualité de l'eau pour l'année entière. Dans le même ordre d'idées, un programme exclusivement axé sur une période où les recommandations ou objectifs sont susceptibles d'être dépassés risque de ne pas convenir non plus. Il est possible d'exclure une période de l'année pendant laquelle une recommandation ou un usage n'est pas valide ou encore de centrer l'échantillonnage sur une période particulière (la saison des vacances, par exemple). Lorsque des échantillons sont prélevés durant des événements extrêmes, comme de fortes précipitations, la valeur de nombreux paramètres risque d'augmenter pendant une courte période. Dans ces cas-là, le facteur F1 augmentera considérablement, mais la turbidité ou les solides en suspension (et les substances chimiques qui y sont fixées) observés pendant ces événements ne poseront pas nécessairement problème sur le plan biologique.

Le nombre d'échantillons prélevés et utilisés dans l'IQE du CCME peut influencer considérablement les résultats de l'IQE. Un nombre insuffisant d'échantillons peut fausser les résultats de façon générale, conduisant à un indice erronément élevé, car moins on prélève d'échantillons, moins on a de chances de « capter » un épisode de mauvaise qualité de l'eau. De la même façon, prélever trop d'échantillons risque de faire baisser la valeur de l'IQE du CCME. L'important est de déterminer le bon nombre d'échantillons entre ces deux extrêmes.

L'échantillonnage doit rendre compte de la variabilité saisonnière et non de la variabilité épisodique des données.

La période à sélectionner

La période choisie doit générer de l'information utile pour le public cible. Dans le cas des rapports périodiques sur la qualité de l'eau, il importe que tout changement à la cote ou au classement de l'IQE du CCME ne découle pas de la variabilité naturelle, mais qu'il représente un véritable changement à la qualité de l'eau proprement dite.

Produire une déclaration annuelle des cotes de l'IQE du CCME sur une période continue de trois ans à la manière du programme des ICDE est une bonne façon d'éliminer une part considérable de la variabilité naturelle des données sur la qualité de l'eau. De plus, cette façon de faire réduit dans une certaine mesure le nombre de cours d'eau qui présentent des changements de classements et a l'avantage de lisser les fluctuations naturelles, tout en générant de l'information sur les variations de la qualité de l'eau.

Si l'objectif d'un rapport est de produire de l'information sur l'efficacité d'une activité de réduction de la pollution ou de montrer la détérioration qu'a connue la qualité de l'eau à la suite d'un épisode de pollution, il est sans doute préférable d'utiliser une période plus courte. Par exemple, on a constaté que les périodes de trois ans masquaient l'effet des activités de réduction de la pollution jusqu'à la quatrième année suivant le démarrage d'un projet donné. Il ne s'agit sans doute pas d'un résultat satisfaisant pour une population qui a peut-être dépensé des millions de dollars pour moderniser une usine de traitement des eaux usées. Dans ces situations, des résultats immédiats sont désirés et nécessaires, et une déclaration annuelle des cotes de l'IQE du CCME est donc justifiée.

À l'opposé, l'utilisation de longues périodes (p. ex. dix ans) génère vraiment peu d'information utile pour le public. Il n'est pas rare que les procédures d'analyse et les limites de détection changent d'une décennie à l'autre pour les mêmes paramètres, ce qui entraîne divers problèmes, notamment de faux positifs proches de la limite de détection et susceptibles de dépasser les recommandations ou objectifs applicables. Une personne désireuse de faire des comparaisons entre deux décennies ou plus gagnerait probablement à produire des graphiques des cotes de l'IQE du CCME sur le long terme plutôt que d'essayer de générer une cote valable sur dix ans. Si on utilise cette dernière méthode et que les cotes de l'IQE du CCME changent subitement à un moment précis, on devrait vérifier si les limites de détection ont elles aussi changé pour certains paramètres à peu près à la même période.

La préparation des données ainsi que les outils et méthodes à utiliser pour valider les données

Les données utilisées dans l'IQE du CCME doivent faire l'objet d'un examen pour s'assurer qu'elles respectent certaines normes. Les données qui ont été rejetées par des protocoles d'assurance et de contrôle de la qualité ne doivent pas servir au calcul de l'indice. Les cotes de l'IQE du CCME générées doivent subir une procédure similaire. Pendant l'examen des données de sortie du calculateur de l'IQE du CCME, il convient de répondre à une série de questions, mais en substance, la première question à se poser est la suivante : « Les résultats obtenus ont-ils du sens? »

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To these people our thanks are given. We alone are responsible for errors and omissions in this guidance manual.

1.0 INTRODUCTION

The Canadian water quality index (CCME WQI but referred to by some authors as the CWQI) is a tool that originated in British Columbia in the mid-1990's (Rocchini and Swain, 1995). It is used to provide the public with information on water quality in an easy-to-understand format (B.C. MoE 1996). It was modified slightly by CCME (CCME 2001), and later updated in 2011 (CCME 2011) and has been used across Canada for reporting on water quality for many years (CESI 2009).

Tri-Star Environmental Consulting was contracted by the CCME Water Quality Task Group, Reporting Methods Sub-group to summarize all previous work related to the understanding of the behaviour of the WQI. This was to focus on inputs to the CCME WQI and was to provide conclusions and recommendations for revising the existing guidance manual. Upon acceptance of recommendations, the guidance manual was to be revised. This report provides a synthesis of previous work related specifically to:

- The number and types of parameters selected;
- The number and timing of samples;
- Time periods that should be selected (e.g., one year, three years, etc.);
- Preparing and validating data; and
- Tools and approaches to use in order to validate the reliability of results.

Tri-Star Environmental Consulting also undertook to provide a cursory overview of where the WQI has been used during the past decade.

Participants at the 2003 CCME National Water Quality Index Workshop, held in Halifax, Nova Scotia from November 24 to 25th, “felt that additional detailed guidance is needed to facilitate more consistent and effective use of the WQI.” (CCME 2004b). “As Risa Smith of Environment Canada commented in her opening remarks at the workshop: We need to take charge of how the Index will be used, because it will be used, and we need to make sure its use is credible.” To do this, the CCME (2004) workshop provided some recommendations that good guidance needed to be provided “on choosing the number and types of variables”.

This report is one step being taken by CCME to improve guidance on the use of the WQI and to ensure that its use is credible. It should be noted that the recommendations that flow from this report are meant as guidance based on the reviewed science, and not on inherent limitations in databases held by jurisdictions. It is recognized that such limitations may limit the practical application of all recommendations herein.

1.1 Background

As with any tool that simplifies data into an index, there are weaknesses and strengths associated with it. One of the main strengths of the WQI is that site-specific objectives, rather than universal guidelines, are used in the calculation process. This provides for the input of site-specific factors that can ameliorate the impacts of certain contaminants on the index score. As with any index,

the main weakness is the use of inappropriate and/or an insufficient number of data or data collected at different times of year or at a different frequency to calculate the index.

Davies (2006) discussed the importance of establishing appropriate objectives and the resulting monitoring programs. “A program with too few or mis-timed sampling periods will provide inaccurate data for water quality assessment. Because the CCME WQI is a reflection of the sampling data, pitfalls in the design of the sampling program will be reflected in the CCME WQI scores. Evaluating water quality with the CCME WQI requires consistent, sufficient, and appropriately timed samples to reduce random variation in the CCME WQI.” This emphasizes the importance of monitoring in the resulting CCME WQI scores. Monitoring is not separate from the index, but is an important factor in the resulting outputs from the index.

The WQI is described fully in CCME (2001). The WQI evaluates the number of parameters that exceed guidelines or site-specific objectives, as well as the frequency and magnitude by which this occurs. Index values range between 0 and 100, with higher values indicating water that is considered to be better water quality (i.e., tends to meet the guidelines more frequently) (Painter and Waltho, 2004).

The WQI is based on the concept of three vectors that form a resulting vector (Figure 1), based on the Pythagoras theorem. The three vectors, referred to in most papers as F1, F2, and F3, represent for a particular time period the number of parameters that fail as a percentage of the parameters tested (scope), the numbers of failed tests as a percentage of all tests made (frequency), and the amount by which the failed tests do not meet the objective (amplitude), respectively.

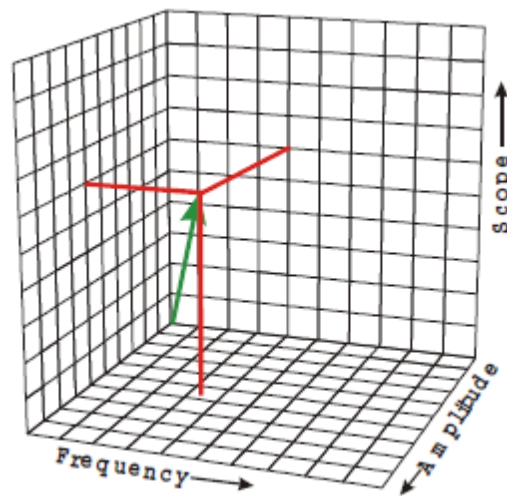


Figure 1. Conceptual model of the CCME WQI (Source: CCME 2001)

The rankings from the WQI are described as follows:

- Excellent (95–100) indicates that water quality measurements never or very rarely exceed water quality guidelines. Aquatic life is not threatened or impaired.

- Good (80–94) indicates that measurements rarely exceed water quality guidelines and, usually, by a narrow margin. Aquatic life is protected with only a minor degree of threat or impairment.
- Fair (65–79) indicates that measurements sometimes exceed water quality guidelines and, possibly, by a wide margin. Aquatic life is protected, but at times may be threatened or impaired.
- Marginal (45–64) indicates that measurements often exceed water quality guidelines by a considerable margin. Aquatic life frequently may be threatened or impaired.
- Poor (0–44) indicates the measurements usually exceed water quality guidelines by a considerable margin. Aquatic life is threatened, impaired or even lost.

1.2 Use of the CCME WQI since 2001

The original index tool, on which the CCME WQI is based, was used in 1996 (BC Ministry of Environment) to communicate the results of surface-water studies to lay audiences in British Columbia. The WQI subsequently also has been used across Canada (e.g., Khan *et al.*, 2003, 2004, 2005; Lumb *et al.*, 2006; de Rosemond *et al.*, 2008).

There have been many jurisdictions that have used the WQI since it was released by CCME (2001). Most jurisdictions have used the CCME WQI to report on the status of water quality. Through Environment Canada under the Canadian Environmental Sustainable Indicators (CESI) program, the index has been used as the basis for the water quality indicator. CESI reports deal specifically with water quality in relation to only one use: protection of aquatic life. The CCME WQI as used for CESI has been used to report on the status of chemistry of the water column, which in some cases ignores the partitioning into the bed sediments and biota that can occur for some organic contaminants. Whereas the original BC index on which the WQI is based (Rocchini and Swain 1995) was used just not for the evaluation of water column chemistry data, but in addition was used to calculate value that could include bed sediment data and aquatic life tissues data, as was appropriate. The BC index was based on protection of all water uses in a water body, which ensured the most restrictive guideline or objective for each parameter was used.

In addition to CESI, the CCME WQI has been used for a number of reporting programs under the United Nations Environment Programme (UNEP) Global Environmental Monitoring System (GEMS). The UNEP has many functions, but the most relevant to this review is assessing environmental conditions and trends. As such, it has adopted the WQI for its UNEP Global drinking water quality index, its health water quality index, and its acceptability water quality index, each with specific parameters selected. To perform the calculations, it uses the World Health Organization (WHO) guidelines. In these forms, it 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 (UNEP 2007).

Independently, a number of authors have used the CCME WQI to rate water quality in other countries. Marine water quality at 27 sites in New Zealand was assessed using the CCME WQI (Monitor Auckland 2010).

In the United States, the Bay Institute Ecological Scorecard (2003) used the CCME WQI to rate water quality in San Francisco Bay, while the Marion County (State of Indiana Undated) used the WQI to rate Fall Creek in Indiana.

Panduranga and Hosmani (Undated) used the CCME WQI to evaluate water quality in a lake in India, while the government of Kerala State in India (2009) used the CCME WQI for three river basins. Darapu *et al.* (2011) used the CCME WQI to look at water quality at seven stations in a river in India prior to and during monsoon conditions.

Surface water quality in Vietnam was rated using the CCME WQI (Pham *et al.* 2011) while that in a canal in Vietnam also was assessed (Lan and Long 2011). The CCME WQI was used directly to assess its use for shrimp culture (Ferreira *et al.* 2011) in Brazil. It has also been used in assessing the Greater Zab River in Iraq (Ali 2010).

Other researchers have used the CCME WQI as the basis for some minor modifications to make the outputs from the index more reasonable for their purpose. For example, work through CCME has resulted in the development of the (Canadian) Sediment Quality Index (SeQI). The SeQI is based on the formulae of the CCME WQI (CCME 2007). The SeQI provides a simple way of summarizing complex quality data, in this case sediment data. (Tri-Star Environmental Consulting, 2008).

The CCME WQI has been modified for specific uses such as reporting on the impact of agriculture on water quality (Wright *et al.* 1999, Guy *et al.* 2009), and for drinking water information (Khan *et al.* 2004, 2005b) and forestry (Tobin *et al.* 2007) in Newfoundland and Labrador. CESI and BC looked at evaluating the suitability of water for livestock watering and crop irrigation. It has also been modified for the Grand River watershed in Ontario to report on nutrient issues (Loomer and Cooke, 2011).

Khan *et al.* (Undated) refer to work undertaken in Egypt to develop an Egyptian WQI based on the CCME WQI but with categories potentially modified to reflect Egyptian expert opinion. Boyacioglu (2010) used the CCME WQI for five sites in Turkey but revised the five categories into only three.

2.0 PARAMETER SELECTION - NUMBER AND TYPE

Two approaches will be discussed and can be used in the calculation of the CCME WQI.

- Fixed parameter selection - which uses the same number and actual parameters (and associated guideline values) so that the WQI scores can be compared among water bodies. This approach is used in the drinking water index and the agricultural index.
- Variable numbers and types of parameters - this approach selects parameters for each site based on the specific human activities occurring upstream of the site.

2.1 Fixed parameter selection

Fixed parameter selection is a process whereby the same parameters are used for every water body where the CCME WQI is calculated. This type of selection process is beneficial because the water quality can be compared across a large number of water bodies without fear that any differences may be due to the use of different parameters in the formulation. Generally, this is a good process to use should only one water use such as drinking water be of concern to the public. It may not be suitable across a large area where there are numerous sources of different types of contaminants.

Wright *et al.* (1999) noted that comparable datasets are needed for calculation of the index, especially for the same water body or a series of stations which are to be compared. These authors used the case of dissolved phosphorus which had not been measured in 1995. In comparing the index score calculated for 1995 to those calculated for 1996 and 1997, “index values for this year are quite different from those for 1996 and 1997, and are not well correlated with agricultural intensity”. These authors went on to use this as confirmation that dissolved phosphorus is an important indicator of agricultural inputs and for that reason, excluded the 1995 data set.

One of the earliest attempts using a fixed number of parameters was on the Exploits River watershed in Newfoundland and Labrador (Newfoundland and Labrador Department of Environment, undated). Although this work used the initial British Columbia formulation of the index, the results are considered to be relevant to this discussion. The Department used the same variables in the formulation of the index scores along the length of the river. It was found that “water quality deteriorates progressively as the sampling stations move from the upper sub basin to the lower sub basin.” This type of conclusion is an important output that is possible only because the same number and parameters were used along the entire river.

Kahn *et al.* (2004) noted that the “CCME WQI, as any model, is also sensitive to inputs (i.e., number of variables and number of samples). The use of too few or too many variables and samples can change the results. To reduce the effect of variables and sample size, the same variables are being analyzed for all public water supply systems and the six most recent samples are being used for the computation of water quality indices. It is also important in using this tool to clearly define the specific set of variables used in the computation of the WQI.” For the purpose of this evaluation, the 24 variables for which there were drinking water guidelines were

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used for the calculations. In addition, the last six samples collected on each water body were used to calculate the CCME WQI. Thus one set of parameters proved useful for ranking the one use: drinking water quality.

Khan *et al.* (2005b) looked at using the CCME WQI to evaluate the impact of establishing best management practices (BMPs) in a protected water supply area in Lewisporte, Newfoundland and Labrador. Twenty-five samples were collected between 1993 and 2002, and the BMPs were established in 1997. Using the same 16 parameters, and looking at varying (rolling) pre- and post- BMP periods (starting in 1997), the authors found that “the effect of the BMPs was being reflected in water quality from 1998 onwards.” This is illustrated in dataset #2 in Table 1 where the CCME WQI score begins to increase in the post-BMP period, but is more pronounced in the following two periods.

Table 1. Pre-and Post- BMP CCME WQI scores for Stanhope Pond (Lewisporte) (Source: Khan *et al.* 2005a)

Datasets	Period	Time Frame	Number of parameters	Number of samples	CCME WQI value
1	Pre BMP Period	1993-1996	16	8	63
	Post BMP Period	1997-2002	16	17	59
2	Pre BMP Period	1993-1997	16	10	60
	Post BMP Period	1998-2002	16	15	61
3	Pre BMP Period	1993-1998	16	13	58
	Post BMP Period	1999-2002	16	12	64
4	Pre BMP Period	1993-1999	16	17	58
	Post BMP Period	2000-2002	16	8	64

Dubé *et al.* (2006) used the CCME WQI to look at cumulative effects in the Athabasca River ecosystem. These authors calculated a CCME WQI based on a five-year period (1998-2002) using one physical variable, two nutrients, four major ions and 14 trace metals. The CCME WQI was calculated using a consistent set of guidelines as opposed to site-specific objectives so that the index values could be compared among sites.

The calculations showed “water quality is classified as good along the length of the system with the exception of water quality in the river at Old Fort (fair classification). However these results require further examination before conclusions can be drawn. The parameters that were available to compare across sites do not include some of the most important parameters for assessment of northern river water quality (e.g., dissolved organic carbon, dissolved oxygen). In addition, it is not known if the implications of different sampling frequencies between sites to the validity of index results.” Dubé *et al.* (2006)

This case study illustrates the problem with using a consistent set of parameters at all sites: important variables can be omitted at some sites, likely leading to a misrepresentation of the actual water quality.

Therefore the use of the fixed parameter selection approach must use a consistent set of parameters for comparison among sites. Also, great care is required to ensure the most important

variables are included for comparison and that future activities and associated contaminants are tracked and considered.

2.2 Variable numbers and types of parameters

The variable numbers and types of parameters approach has been used more frequently to calculate the CCME WQI. It uses a varying number of parameters with perhaps different guidelines or objectives for the same parameter. The rationale for this approach is that only parameters that could be affected by human activities would be included in the calculation, while site-specific guidelines or objectives would take into account ameliorating factors for a specific water body, such as hardness or organic carbon content or high natural background concentrations. This in fact was the approach used in British Columbia (BC MoE 1996) for reporting on more than 100 water bodies, each with several different water uses designated for protection. In these types of situations, the parameters selected for inclusion may be based on consensus or may be based on the types of human activities in a watershed. One method to identify parameters to select based on human activities is shown in Appendix 1 (Tri-Star Environmental Consulting, 2011). In some cases generic guidelines may be used while for others, site-specific objectives can be used.

CCME (2004a) confirmed this in relation to the application of the CCME WQI to the Atlantic provinces. “The specific set of variables, time periods for which the index was applied, beneficial water uses assessed, and guidelines selected vary from one province to another. **Hence, comparisons among jurisdictions cannot truly be made given these differences, nor was this the objective of the study.**”

The CCME (2004b) workshop provided recommendations concerning the CCME WQI parameter selection. One recommendation was that a core set of variables should be established “that can be used to calculate the WQI for the purposes of reporting national, regional and local levels. The “core set” is a selection of variables intended to provide a “starting point” for calculating the WQI where little is known about the water quality and its natural and anthropogenic stresses. Site-specific customization of this “core set” is recommended whenever possible.” A further recommendation was that “consistent, detailed guidance should be provided to Index practitioners regarding the selection and use of additional variables. Overall, it is recommended including only relevant variables”.

Loomer and Cooke (2011) compared two formulations of the CCME WQI (traditional and revised with F1 removed) that also used CCME *Canadian Environmental Quality Guidelines* and site-specific guidelines, respectively, and with four and five parameters, respectively. These authors found that the results from the two formulations “were highly linearly correlated” and that the scores from the WQI were about ten points less than those from the revised formulation. It is not possible to determine whether the differences were due to the formulation, the number of parameters, or the use of site-specific objectives. It is suspected that the differences are due to all three, but mostly because of the use of different numbers of parameters and different guidelines.

A possible approach to take could be to look at the collective human activities occurring in an entire watershed. A consistent set of parameters for all the sites within that watershed could be selected that reflect the collective human activities. Such an approach would allow for better comparability while possibly minimally reducing some site-relevance.

2.3 Number of parameters

Painter and Waltho (2005) looked at the effect on the CCME WQI by using different number of parameters in the calculation. These authors looked at 50 water quality sites in Ontario and calculated the CCME WQI using six parameters (total phosphorus, ammonia, nitrate, nitrite, copper and zinc) and then sequentially eliminated one parameter to always maintain five parameters for the WQI calculation (Figure 2). “In total, ranking was affected in 72% of the sites. Thirty percent of individual site scores changed ranking when only 5 parameters were used.”

Painter and Waltho (2005) repeated this work using ten parameters, the original six as well as cadmium, nickel, lead and total chromium, which lead to more stable CCME WQI scores. “In total, ranking was affected in 48% of the sites. Only 14% percent of the sites changed ranking when only 9 parameters were used.” In any large number of results for different water bodies, the likelihood exists that there will be a few of those water bodies with scores close to ranking boundaries. For such cases, a minor change in score can lead to a change in ranking. In the case of Painter and Waltho (2005), the results and conclusions are still valid, even when this phenomenon is considered.

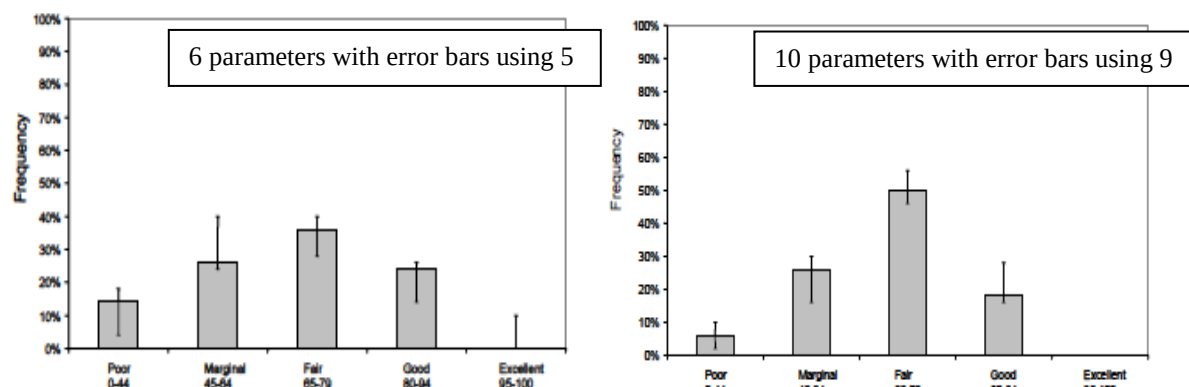


Figure 2. Distribution of CCME WQI scores using six and ten parameters (Source: Painter and Waltho 2005)

Figure 2 shows that the number of parameters should not fall below six since at that number, 30% of sites (15 of 50 sites) had different CCME WQI rankings. When nine parameters were used instead of ten, 14% of sites (7 of 50 sites) changed rankings. This implies that the more parameters used the more stable the index becomes. This is true but it is unlikely that there could never be a set number of parameters where there is no change in rankings.

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For two sites (Figure 3), as many as 32 parameters were available for testing. “The CWQI score steadily improved with the addition of more and more passing parameters. With 10 parameters, the two stations had an index of approximately 70 and ranked fair compared to an Index of approximately 85 with a ranking of good for all parameters.” Of most importance is the statement that “only small changes occurred once the Index was computed with 20 plus parameters.” (Painter and Waltho 2005)

Painter and Waltho (2005) did conclude however, that “the performance of the Index was reasonable when at least 10 or more variables were included and at least 30 observations over a period of at least 3 years were used in the calculation.”

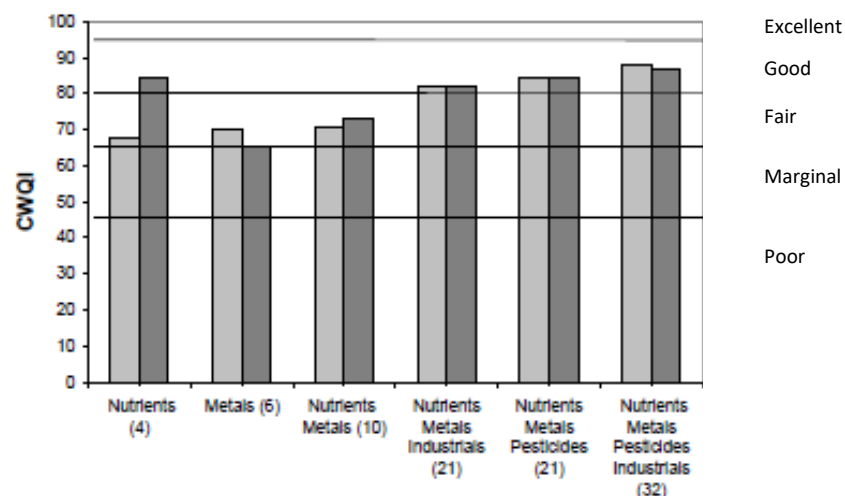


Figure 3. Sensitivity of the WQI for two sites with additional parameters included in the calculation (Source: Painter and Waltho 2005)

Lumb *et al.* (2006) also calculated the CCME WQI for several stations on the Mackenzie River, and looked at the impact on the index of different scenarios, including reducing the number of parameters used in the calculations. For the initial CCME WQI, the authors used up to 30 parameters to calculate the score, while for the second estimate, they eliminated up to six parameters: temperature, colour, turbidity, aluminum, copper, and iron. In both estimates, the CCME water quality guidelines were used as the threshold values. The scores were tabulated for a decadal time period.

Figure 4 is based on the data from Lumb *et al.* (2006) for the four decades. The CCME WQI score increased between 22 and 36 points when the number of samples are kept the same but the number of parameters tested is reduced, based on Mackenzie River data for the 1960's, 1970's and 1980's.

The Mackenzie River likely is a special case because the background levels for metals and nutrients are usually much higher than CCME water quality guidelines due to the high sediment load. Thus, the addition of parameters reduces the score rather than increases it (i.e., dilution effect).

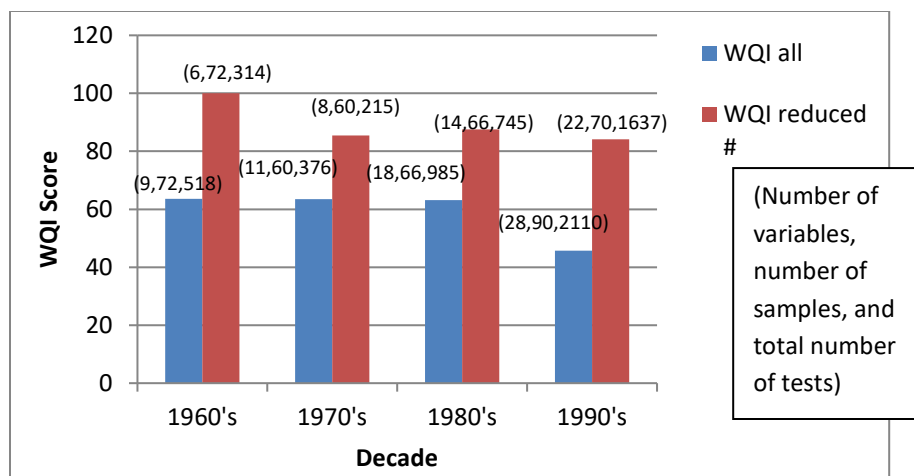
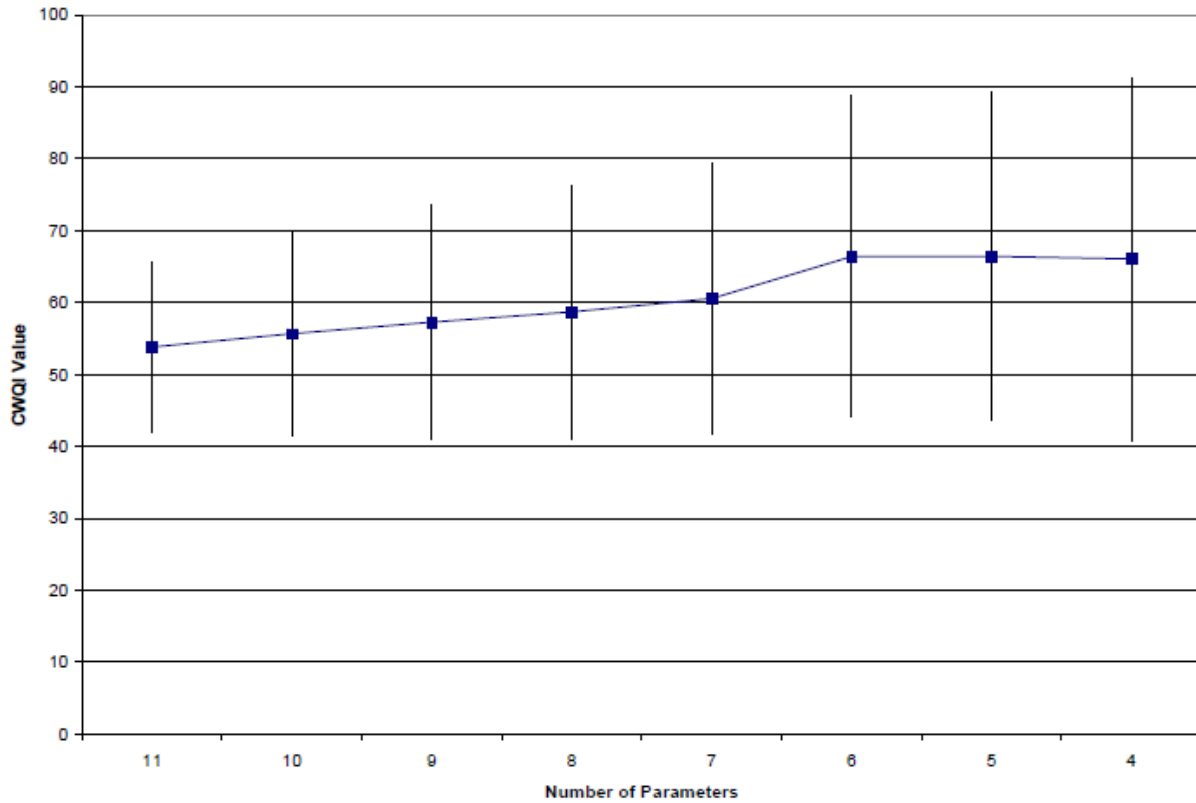


Figure 4. CCME WQI scores for the Mackenzie River at Norman Wells (based on data from Lumb *et al.*, 2006)

Gartner Lee (2006) looked at the sensitivity of the CCME WQI to the number of parameters used for the calculation. “The CWQI output stayed relatively stable (within 5 - 10% of the value calculated for all parameters) in both instances until the parameters dropped below 7. Based on this assessment, and an examination of the mean CWQI calculated on the twenty parameter removal trials, it would appear that 7 or more parameters are required in order to use the CWQI.” The authors also note that it is the selection of the parameters that has more of an effect on the CCME WQI score than the absolute number. They concluded that “Parameter selection should be based on measurements of water quality relevant to the site. There appears to be no simple “rule of thumb” for selecting an optimal parameter set.”

Gartner Lee (2006) also noted that “It is also difficult to formulate recommendations regarding the parameters to select, because they will be highly dependent on the site at which the CWQI will be calculated.” “If the index is to be used to assess the impact of mine drainage on a Boreal Shield site, then parameters associated with that water quality impact should be included. Adding a large number of parameters related to organochlorine pesticides and eutrophication related parameters will “dilute” the index and artificially increase the CWQI values.”

Gartner Lee (2006) showed the effect on the CCME WQI scores of 164 water bodies when one variable was serially removed at a time. The percentage of sites in each CCME WQI category with parameters removed is shown in Figure 6. In this case the removal of fecal coliforms had the most profound effect on the percentage of sites in each category, with the percentage of sites in the two lowest categories decreasing and with a corresponding increase in the percentage of sites in the fair, good, and excellent categories.



Note: * Summary of the Results of Twenty Random Parameter Removal Trials on Six Stations.

Figure 5. Influence of the number of parameters on the CCME WQI (from Gartner Lee 2006)

Figure 7 illustrates the importance that certain parameters have on the CCME WQI score for six stations when, in this particular case, cadmium was the parameter that was removed from the data set. The testing started with calculated CCME WQI scores using eleven parameters, then the index was recalculated with the orderly elimination of one variable at a time. As each variable was removed from the calculation, the CCME WQI scores generally decreased slightly at each of the six stations. When cadmium was removed, CCME WQI scores spiked up so that the highest CCME WQI scores for all scenarios at all six stations were recorded. This shows the importance of selecting the correct parameters on which to calculate the CCME WQI.

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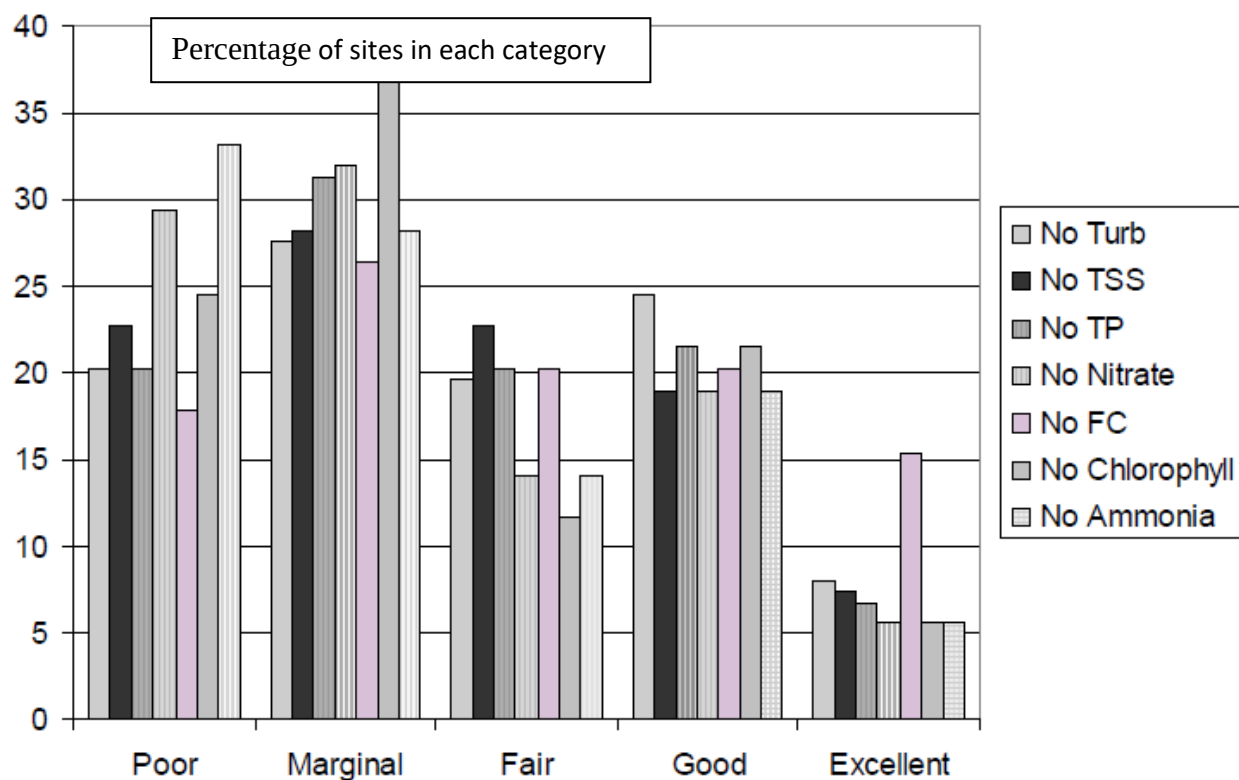


Figure 6. Influence of removal of different parameters on the percentage of sites (of 164) in each CCME WQI category (Source: Gartner Lee 2006)

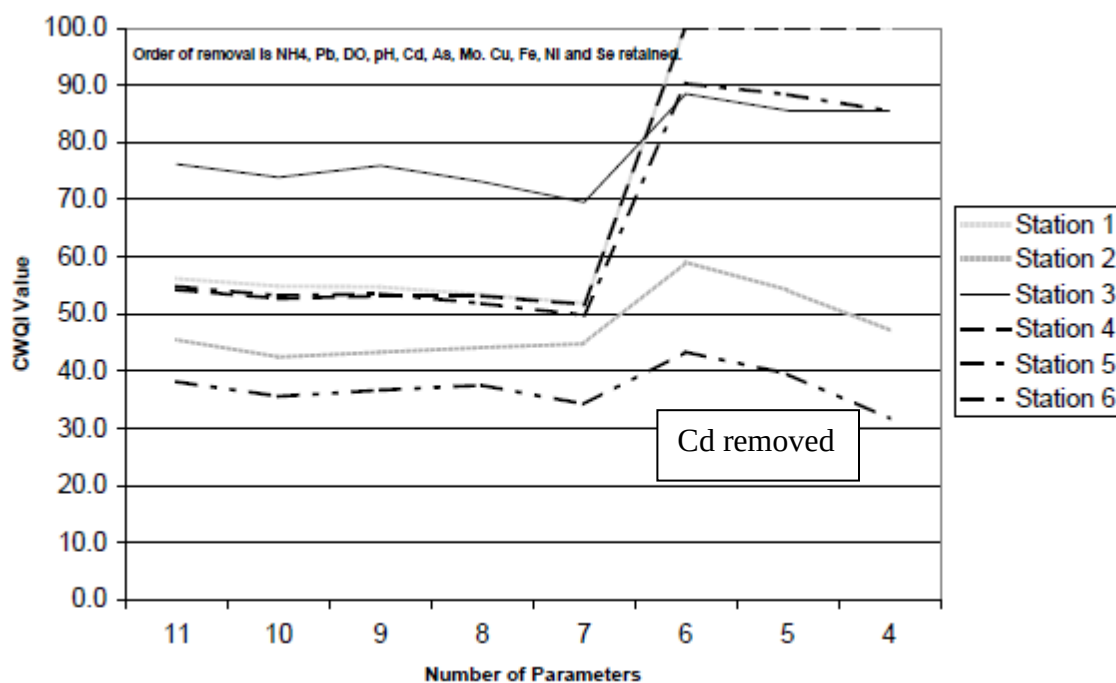


Figure 7. The effect on the CCME WQI scores of removing one parameter at a time from the calculation (Source: Gartner Lee 2006)

Davies (2006) examined the effect of different numbers of parameters on CCME WQI scores along the Qu'Appelle River. "Prior to 1978, fewer than 10 parameters were actually included in the CWQI calculation, whereas after 1978 up to 17 parameters were included. The additional parameters measured after 1978 often passed their objectives, thereby improving the F1, F2, and F3 scores. Re-analysis of the river sites using only the eight most commonly measured parameters produced the same general spatial and temporal pattern, but the improvement in water quality at Hwy #11 was lower, with no improvement at Edenwold and a slight decrease in water quality at Hwy#47." The eight parameters used by Davies (2006) were chloride, dissolved oxygen, pH, total phosphorus, ammonia, nitrate/nitrite, fecal coliforms and chlorophyll-a. In general, the 1978 CCME WQI scores were unchanged, whereas the larger effect of just using eight parameters was seen in the post-1978 CCME WQI scores (Figure 8).

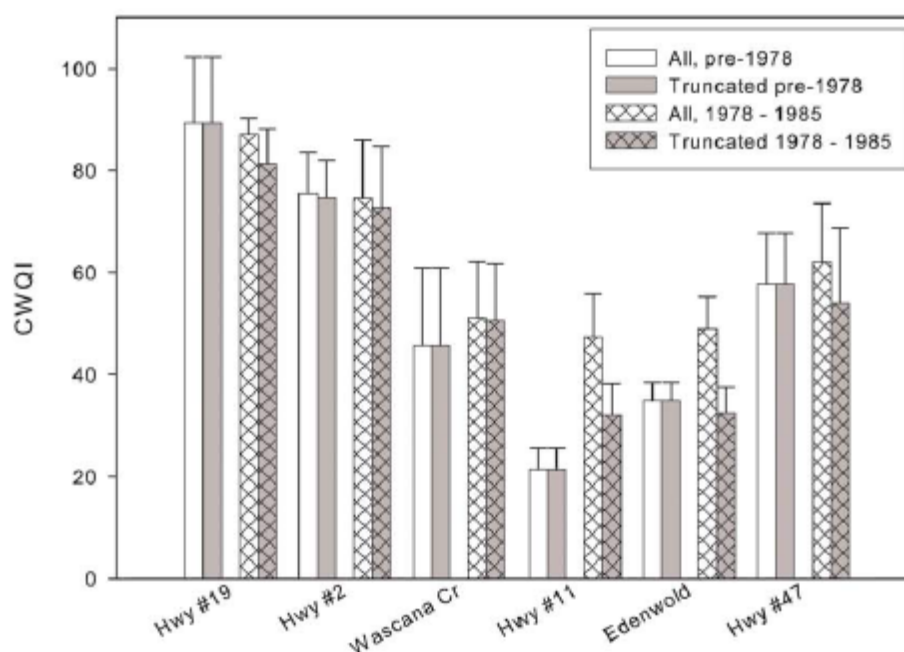


Figure 8. CCME WQI scores for sites along the Qu'Appelle River using only eight parameters for the truncated calculations (Source: Davies 2006)

UNEP (2007) performed sensitivity testing for two of their indices that are based on the CCME WQI, the difference between the two indices is the guidelines used as threshold values. For the acceptability water quality index (AWQI), it was found that "the removal of pH increased the number of stations designated as excellent from approximately 15% to 50%." For the health water quality index (HWQI), "the removal of lead and arsenic had the most impact on station designations." Parameters used in the sensitivity analyses were ammonia, chloride, iron, pH, sodium and sulphate for the AWQI and arsenic, boron, cadmium, chromium, fluoride, lead, manganese and mercury for the HWQI. The results for both the AWQI and HWQI are in Figure 9.

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UNEP (2007) used Pearson's correlation matrix with both the AWQI and HWQI and concluded that "both indices are not strongly driven by one particular parameter, but rather by a combination of all parameters."

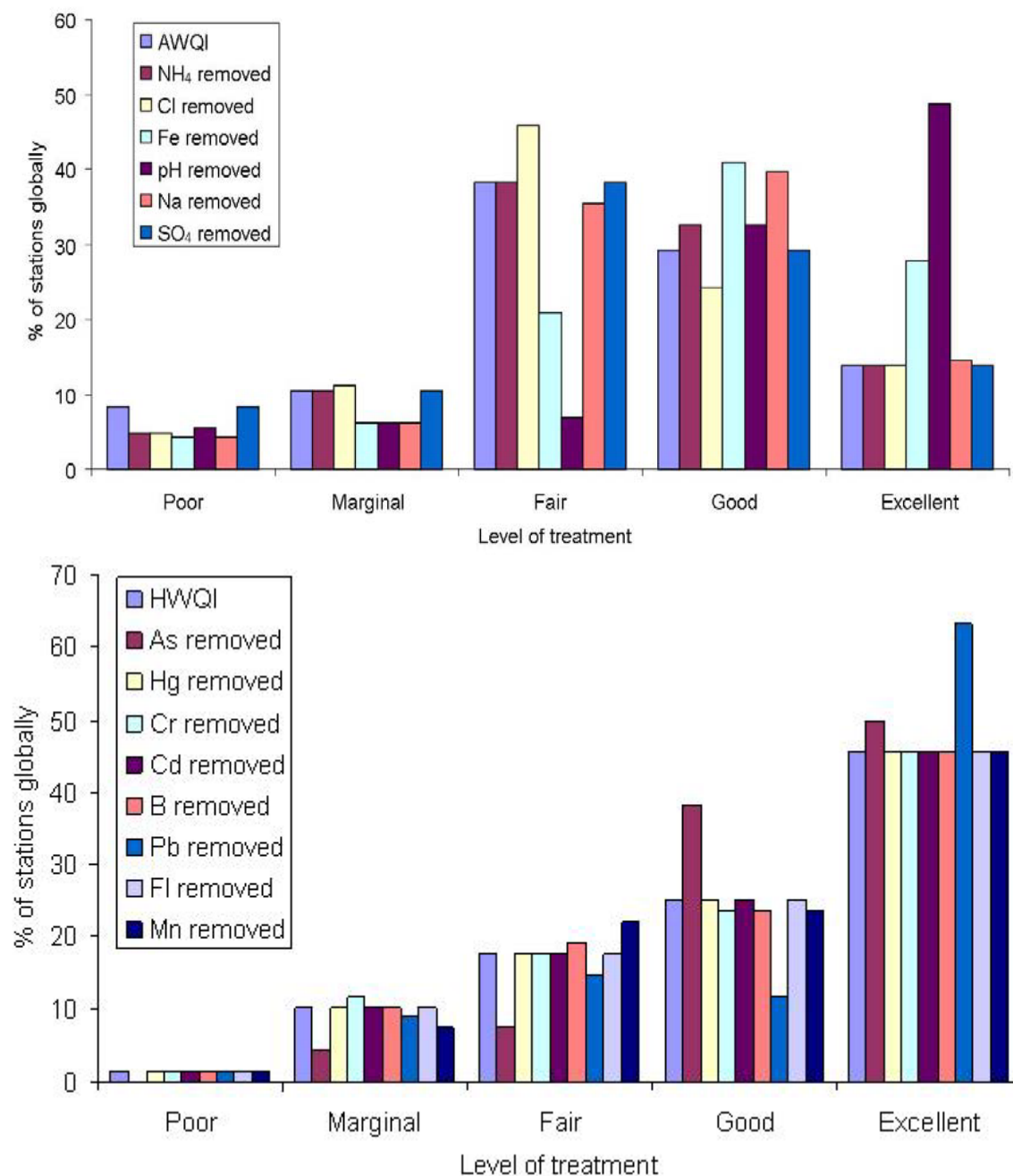


Figure 9. Contributions of each parameter to the AWQI and the HWQI for the 2002 stations (UNEP 2007)

Statistics Canada (2007) reported that based on a behavioural study that the "Index is sensitive to the number of parameters that enter in its calculation for a given number of samples. The larger the number of parameters, the lower the intensity of extreme categories ("poor" or "excellent")

in comparison with the “marginal” and “fair” categories, regardless of departure point.” Increases cited were from 51% to 83% in Newfoundland and Labrador in the marginal/fair categories when ten parameters were used instead of four; from 26.9% to 50% in Ontario when 14 parameters were used instead of four; and from 50% to 73.3% in British Columbia when eight parameters were used instead of four. These changes could be related to another of their findings related to the three factors that make up the Index: that the influence of F1 (number of failed parameters compared to the total number of parameters tested) was reduced slightly with the introduction of additional parameters. “The correlation is the highest between the last two terms of the index, and in general the correlation between the index terms depends on the number of parameters and samples.”

CESI (2008) recommended that between four and 15 parameters should be used for the CCME WQI calculation. The basis for this was that CESI reporting should be as inclusive as possible, to enable reporting of an indicator Canada-wide. CESI recognized this as a weakness and strove to improve consistency (i.e., 8 to 12 parameters) and to be more in line with the results of various sensitivity analyses (Environment Canada 2011). Parameters chosen for use with the CCME WQI should reflect the full range of expected disturbances and reflect ecologically-relevant conditions. They further recommend that if feasible and relevant to the site, that major parameter category such as metals, nutrients and pesticides should be included (Environment Canada 2011).

Lumb *et al.* (2011a) noted that the “majority of indices involve nine or more parameters with commonality of DO, BOD, pH, total dissolved solids, and fecal Coliforms or E.coli.” They compared the WQI to three other indices used in other jurisdictions by calculating WQI values for 30 Ontario rivers using both seven parameters and 10 parameters. The seven parameters were ammonia, chloride, chromium, nickel, nitrate, phosphate and zinc. The three parameters added for the 10 parameter set were pH, temperature and hardness. The authors determined that “the 7 parameter protocol seems reasonable as it mimics the scenario nearly similar to a higher number of parameters. Although a 10-parameter protocol is desirable from the consideration of stability and accuracy in the WQI score, it does warrant efforts and expenses in monitoring additional parameters”. Of course the actual parameters added or not used in the original formulation are a key consideration. The authors found that “the role of metals is insignificant in impairing water quality and major culprits are phosphates, nitrate, chloride and hardness.” Thus if phosphates, nitrate, and chloride had been used as the three additional parameters rather than pH, temperature and hardness, the conclusions would have been significantly different. This illustrates that the choice of the parameter, rather than the absolute number of parameters, is likely of more importance.

2.4 Importance of guideline selection

The guidelines that are used are the cornerstone for the CCME WQI calculation. Guideline values are used to determine the three components of the CCME WQI: the number of parameters that fail (F1), the number of samples that fail (F2), and the magnitude of such failures (F3). Guidelines that are higher than others for the same parameter will lead to higher scores and “better” water quality. It is crucial that appropriate guidelines are used for the CCME WQI calculation.

de Rosemond *et al.* (2009) looked at the effect of using generic CCME water quality guidelines in comparison to what were called region-specific objectives (RSO). The RSO values were calculated as the 90th percentile value for each parameter at the upstream reference site. These authors looked at outputs from the CCME WQI downstream from metal mines in comparison to upstream reference sites. The use of the CCME water quality guidelines “was found to be a good tool to assess absolute water quality as it relates to national water quality guidelines for the protection of aquatic life, but had more limited use when evaluating spatial changes in water quality downstream of point source discharges. The application of the RSO to the CCME WQI resulted in assessment of spatial changes in water quality downstream of point source discharges relative to upstream reference conditions.”

de Rosemond *et al.* (2009) conclude that the “RSO approach assesses water quality based on reference condition, which allows plasticity in the objectives based on reference conditions. As well, the RSO approach allows for the inclusion of variables currently without CWQGs. The application of the RSO to the CCME WQI allows the index to become a more effective communication tool to communicate if water quality has deviated from natural conditions, but is limited in its usefulness in rating absolute water quality relative to ideals for uses such as drinking water. The continued use of the CWQG or Canada-wide standards is warranted to assess the absolute condition of water quality as it relates to specific uses, but the RSO approach is more suited to evaluate spatial changes in water quality due to dominant man-made influences.” This illustrates the importance of the type of parameters used: whether the parameters actually provide information about the issue of concern in a specific body of water, or whether the purpose of reporting is to provide a broad-based approach on the state of water quality. If the latter, it has to be remembered that certain specific information will be “lost” in the reporting process.

Intrinsic (2010) provided the following advice on selection of parameters for developing site-specific objectives for use in the CCME WQI. “The selection should be based on knowledge of the characteristics of the water body (i.e., physical, chemical, and biological) and stressors that have influence on local water quality (e.g., urban development and agriculture). Parameters that have the potential to cause adverse environmental effects should be included.” See Appendix 1 for variables to consider for water uses and discharge types.

Parameters used in the calculating a CCME WQI must have a guideline or threshold that reflects the acceptability for that particular use and situation. Lumb *et al.* (2011a) note that “Depending upon the guidelines, conflicting interpretation and messages can emerge on the quality characteristics of the water. To reduce such a problem, efforts should be directed to develop site-

specific guidelines adapted to the prevailing ecological conditions (e.g., taking into consideration high background concentrations of phosphorus in the Prairies of Canada).” In addition, if there is a desire to report on individual water uses using the CCME WQI, then sufficient guidelines need to be available for the parameters of importance for that particular water use. “As the suitability of the water can vary greatly depending on its intended use, there is a need to provide use-specific assessments (e.g., for aquatic and recreational uses versus source water use for human consumption).” (Lumb *et al.* 2011a)

2.5 Summary on parameter selection

The concept of a “core set of parameters” has been discussed almost since the time of the formation of the WQI. In the context of Canada-wide or regional reporting (e.g., large drainage areas), it was suggested that a “core set of parameters” be supplemented by 2-3 site-specific parameters. The rationale was that this would help improve comparability among sites while allowing some flexibility for localized concerns that should be reflected in CCME WQI rankings. CCSI have considered the use of a core set of parameters but have considered this in terms of having representative parameters for each major area of concern, such as nutrients, metals, and pesticides.

A core set of parameters has also been used when only one use is considered, such as the agricultural index, and the drinking water index. These indexes have the advantage of being totally comparable from one water body to another, but have the disadvantage of not reflecting unique concerns that may exist at one site compared to another. Including or excluding relevant parameters will impact the WQI, by either providing false positive or poorer ratings.

Similarly, when the CCME WQI is used to assess water quality in relation to protection of aquatic life, it would be unreasonable to have one set of parameters to be used for every situation. Using groups of parameters such as metals, nutrients etc. may partially address this idea of core sets of parameters. However, the parameters still need to be relevant to the inputs or stressors on the system and need to be collected at appropriate times of the year. For example, if nutrients are to be examined, the question being asked (in collecting such data) is whether high levels are causing algal growths that are affecting aquatic life. Such growth normally takes place during the summer months, so if water samples have not been collected when such growths are likely to occur, will it matter whether the number of samples collected is four or 104.

The second approach is to use varying numbers and types of parameters to calculate the CCME WQI, in response to the human stressors in the water body. The advantage of this approach is that the CCME WQI calculated will be relevant and accurate for that water body. However, it will make direct comparison of the CCME WQI from one water body to another virtually impossible. The question that has to be asked is whether the comparison of CCME WQI scores is a realistic goal in a country as large as Canada, with diverse geography and geology that affects background water quality conditions. In an earlier section, we discussed this in terms of the fact that aquatic life have adapted to their natural environments in order to survive. We suggested that comparisons within drainage areas or ecoregions likely are more valid, and this is an approach frequently used to compare water quality between test and reference conditions.

Several researchers have shown that for a particular water body, the actual parameter chosen for use in the CCME WQI is of more importance than the absolute number of parameters used. Some researchers noted that pH, cadmium, phosphorus, nitrate and chloride could be having a larger influence on the CCME WQI than the number of parameters included.

In terms of the absolute number of parameters to use, most researchers have provided advice on the minimum number to use. Two researchers, Gartner Lee (2006) and Lumb *et al.* (2011b) recommended a minimum of seven parameters, while Davies (2006) recommended eight and Painter and Waltho (2005) recommended the use of ten parameters. The average number of parameters recommended by these four researchers is eight, which is a reasonable number of parameters. Care must be taken to ensure that parameters selected are not highly correlated to prevent “counting twice or more” frequently for the same impact (e.g., including pH and alkalinity, or turbidity and suspended solids).

3.0 SAMPLE SIZE – NUMBER AND TIMING

In reporting discussions from a 2006 CESI workshop, Intersol (2007) noted that one of the key challenges from a methodological perspective is “determining a sample size that accurately represents variability within a station.” This is a key input to the WQI, “because they impact the value”. Statistics Canada (2007) reported that for “certain parameters, the percentage of samples respecting the guidelines depends on the season. Therefore, the season would have an impact in the index categorization. Also, not including a certain season could introduce a bias to the index calculation and interpretation.” CESI (2008) confirmed this: “minimum sampling should increase for capturing seasonal variability” and that “the flashier the system, the more variable the water quality and the more frequent sampling is required.”

3.1 The relationship between monitoring and sample size used in index calculations

Before looking at the question of sample size, one needs to consider how most water quality monitoring programs are carried out. A program is designed to capture certain events, and a number of samples to do this are determined. Then, the sampling is scheduled on the basis of the normal hydrologic cycle associated with the water body, but usually using a calendar for scheduling. Scheduling usually occurs on a weekly, bi-weekly, monthly or quarterly basis in conjunction with several other programs so that flexibility in the actual sampling dates becomes limited. Bias also is introduced in scheduling, because most work is conducted between Monday and Friday due to work schedules, and likely between Monday and Thursday, or even a shorter “window” so that samples can be transported to the laboratory and time-sensitive analyses can be initiated without delay. This means that the actual sampling cannot be adjusted in response to the actual hydrology that occurs, and that when sampling coincides with an event it is as much the result of good luck rather than good management. Therefore to capture such events more samples may need to be collected.

Sample size has been shown to be a significant factor in calculating the WQI. If one steps back from the discussion and thinks in a logical fashion, it is obvious that the more frequently samples are collected, the more likely it will be to capture extreme events. At the same time, too few samples will mean that the odds of capturing extremes are reduced. The key is to be able to sample at a sufficient frequency to capture the normal range of values for each variable. The actual number of samples collected should be related to the parameters of concern. For example, some variables may better be sampled in low flow conditions, or alternately, others in high flow conditions. This relates to timing of samples, especially when certain concerns are seasonal in nature. An example of a seasonal concern would be bacteriological parameters for bathing beaches which would likely only be of concern during the recreation season.

3.2 Advice from the literature on sample size

The CCME (2004) workshop provided some recommendations concerning the frequency of sampling: a minimum of four samples per year with one sample per season. “A three-year rolling average of the data should be used as a basis for calculating the Index.” The rationale for this guidance was to provide a good representation of the general water quality.

In Section 2.2, Khan *et al.* (2005b) looked at using the CCME WQI to evaluate the impact of establishing best management practices (BMPs) in a protected water supply area in Lewisporte, Newfoundland and Labrador. The data in Table 1 are discussed below. For the purpose of this analysis, it was speculated that the effect of BMPs would be observed in 1997 (Table 1, in Section 2.2) had the number of samples used to calculate the pre-BMP period score been greater (i.e., more than 8 samples collected before BMP implemented as compared to the 17 samples collected after the BMPs were implemented). However, when the numbers of samples for each period were reversed in the last period (2000-2002), the trend in the scores was not changed from the previous year when 13 and 12 samples were collected, for the pre- and post-BMP CCME WQI scores, respectively. This case study indicates that a minimum of eight samples for WQI calculation may be required.

Painter and Waltho (2005) looked at ten sites and manipulated the data for the 1997-2002 periods into four scenarios: full year, using all available data; Seasonal (May to September) using all data; Seasonal (May to September) using first sample for the month data; and full year using the first sample collected for the month. “The average difference between the Index scores for the 10 sites and the various program designs was only 4 points. Eight of the 10 sites had similar scores regardless of the program design. The average difference between scores for those eight sites was less than 2 points. Two sites had scores that differed by 12 and 24 points depending on the program design.”

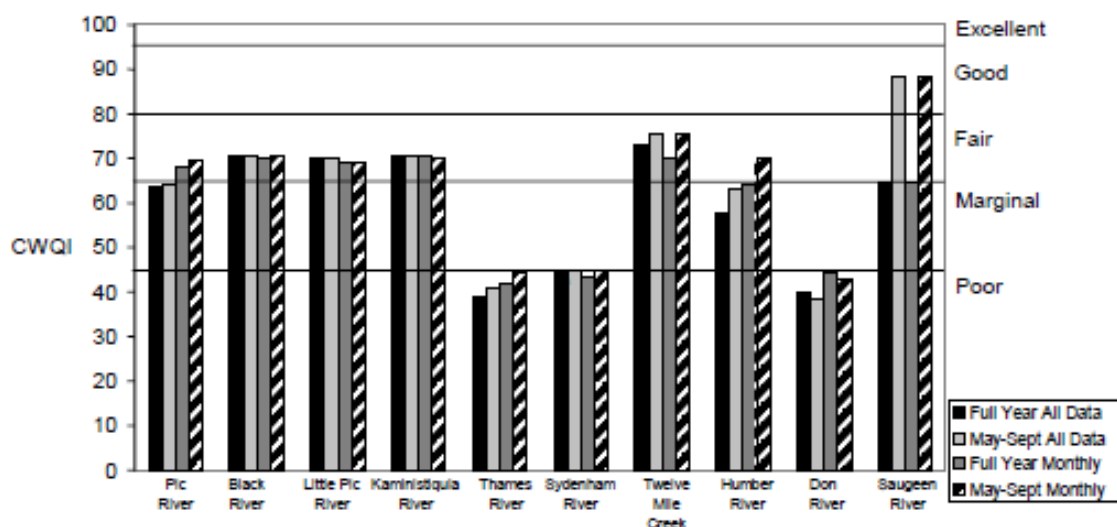


Figure 10. Effect of sampling frequency on the CCME WQI score at ten sites (Source: Scott and Waltho 2005)

The work of Painter and Waltho (2005) illustrate two important points. First, the number of samples collected for many sites possibly may not make a difference in the CCME WQI score. Secondly and more importantly, their work shows that for two of their sites (and therefore in 20% of the cases), a significant difference in score can be generated based on the number of samples. Of importance as well as illustrated in Figure 10, is that the lowest CCME WQI score was generated when all the data for the entire year were included in the calculation. The differences of 12 and 24 points cited by Painter and Waltho (2005) occurred when scores based on data for the entire year were compared to scores for data for a select period of time (monthly samples collected from May to September). This observation highlights the fact that taking fewer samples and/or covering a shorter period throughout the year increase the likelihood of missing hydrological events (e.g., spring freshet) that may result in peaks for some water quality parameters. As such, different conclusions or messages can result from the decisions taken in calculating the index. In this specific case, further investigation on the individual samples and parameters should be conducted to assess whether the observed peaks or spikes are biologically relevant (e.g., elevated nutrients when water is cold and biological activity is minimal).

In Section 2.1, Dubé *et al.* (2006) used the CCME WQI to look at cumulative effects in the Athabasca River ecosystem. The authors calculated a CCME WQI based on a five-year period (1998-2002) using one physical variable, two nutrients, four major ions and 14 trace metals. The CCME WQI was calculated using a consistent set of guidelines as opposed to site-specific objectives so that the CCME WQI values could be compared among other sites. Dubé *et al.* (2006) noted that “it is not known the implications of different sampling frequencies between sites to the validity of index results.” Water quality may also be misrepresented due to different sampling frequencies (i.e., number of samples) at some of the sites. One possible solution might be the elimination of samples at sites with extra sampling frequencies in order to make the frequency more consistent. In addition, the five-year time period used by Dubé *et al.* (2006) may be too long to provide meaningful information. These problems are likely more acute in larger river basins such as the Athabasca.

Gartner Lee (2006) discussed the sensitivity of the CCME WQI to different numbers of samples collected per year. They noted that “annual measurements can be expected to vary based on differences in hydrologic factors and pollutant inputs. Calculating the index based on longer-term data sets will dampen these effects.” “From a strictly computational standpoint, the index values were reasonably stable when calculated with 6 to 12 measurements. Since many provincial or federal water quality monitoring programs are designed with monthly samples taken, this appears to be adequate for CWQI calculation.”

Davies (2006) looked at the number of samples used for the CCME WQI calculation at two stations on the Qu’Appelle River (Figure 11). “A log relationship was found at both stations that were analysed, but the absolute change in the calculated CWQI from a single sample to 36 samples per index period was greater at Hwy#11 (22.8) than at Hwy#16 (16.7).” Data from 1969 to 2002 were used to randomly select, with replacement, 1000 index periods with a range in samples per index period from 1 to 36.

When the graphs were examined more closely, these data showed that for the Hwy#11 site at Lumsden, the change in the slope of the lines (breakpoint) for CCME WQI values took place

after eight samples were used for the calculation. For the Hwy#19 (Qu'Appelle dam) site, the breakpoint was at about eleven samples. This shows that depending on the water body, a sample size from 8 to 11 may be optimal.

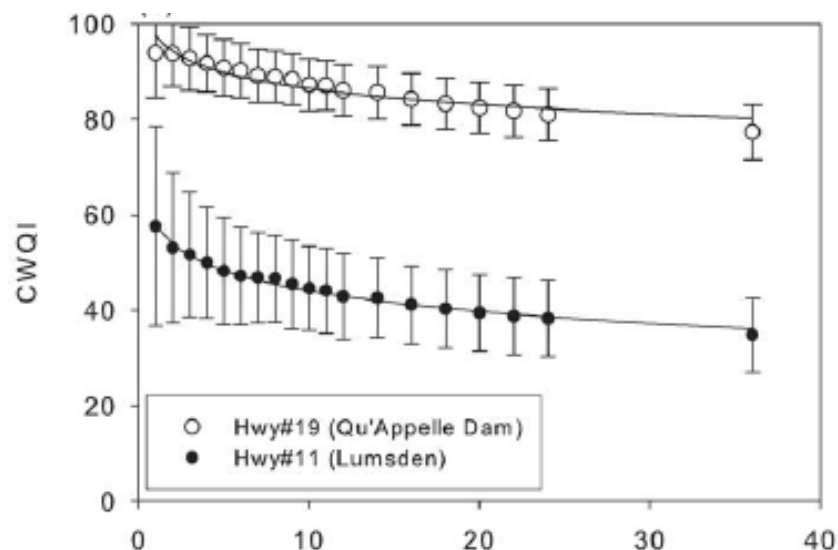


Figure 11. Sensitivity analysis of the CCME WQI for two sites on the Qu'Appelle River (Hwy#19 and Hwy#11) (Source Davies 2006)

Intersol (2007) reported at a water quality index workshop their finding regarding information presented on the effect of quarter frequencies on the calculation of the CCME WQI in Number of samples per index period the conclusions of the presentation were that when 12 samples per year were used they performed well in most cases, although there was appreciable increase from the original index ranking overall. 12 samples per year also provided better results than 4 samples per year. 4 samples per year introduced greater variability between scores, with a shift of the WQI rankings upward, and may not capture infrequent events related to effluent discharges, hydrological cycle, etc.” The graph from the presentation is shown as Figure 12. It clearly illustrates that the lowest CCME WQI score at each site is calculated using 26 samples per year, while the highest CCME WQI score is found using only four samples per year. As Intersol concluded in their presentation it may not be practical to collect 12 samples per year (presumably equally spaced), due to freeze-up and thawing of most waterways, 10 samples per year might be a more practical goal.

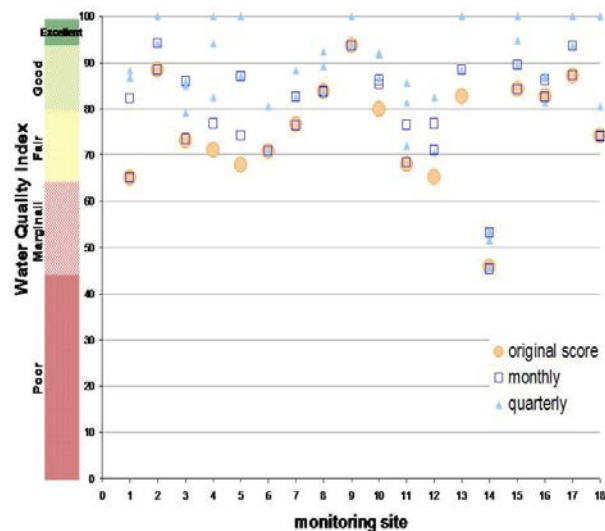


Figure 12. Effect on CCME WQI score of quarterly, monthly, and bi-weekly sampling (Source: Presentation to the 2006 CESI workshop by Lee-Ann Hamilton and Sheena Pappas, Environment Canada)

Statistics Canada (2007) reported that based on a behavioural study that “The larger the number of samples, the lower is the intensity of “good” and “excellent” categories in comparison with the “poor” and “marginal” categories, regardless of the departure point.” Increases cited were from 51.7% to 60.1% in Newfoundland and Labrador in the poor/marginal categories when ten samples were used instead of four samples based on four parameters; from 37.5% to 50.1% in Quebec in the poor/marginal categories when six samples were used instead of four samples, based on six parameters; from 25.6% to 57.5% in Ontario in the poor/marginal categories when 15 samples were used instead of four samples, based on ten parameters; and from 16.4% to 66.1% in British Columbia in the poor/marginal categories when 15 samples were used instead of four samples, based on seven parameters. Presumably, more samples represent the actual water quality conditions better than do fewer samples. Since Statistics Canada (2007) used different number of parameters in each jurisdiction, we have plotted the increases in the marginal/poor categories against the number of parameters used, and independently, against the number of samples used (Figure 13). This confirms that the increase is more strongly associated with the number of samples used.

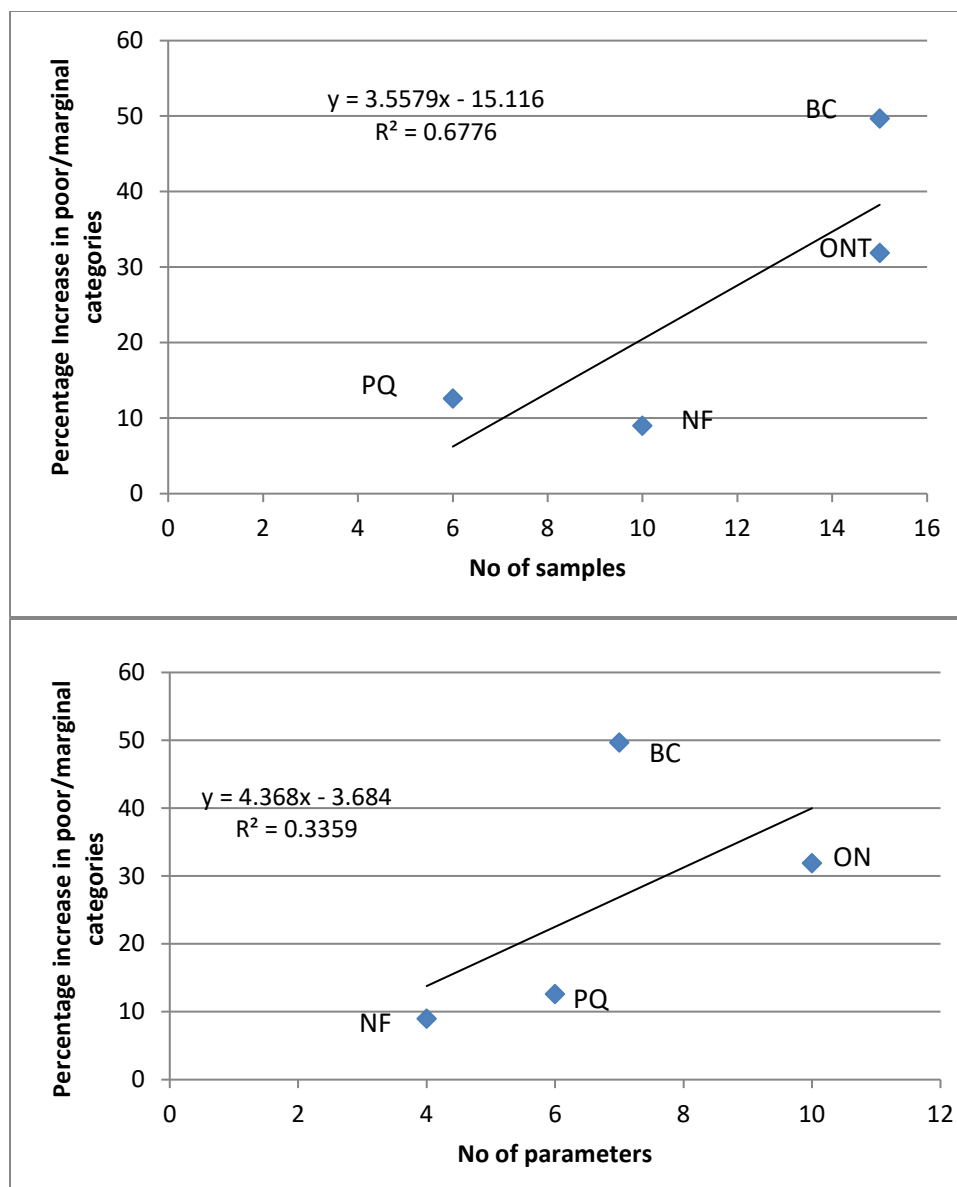


Figure 13. Increase in poor/marginal categories in relation to number of samples and number of parameters (based on data from Statistics Canada 2007)

Statistics Canada (2007) also discussed sampling costs for remote stations, and found that the “use of three samples per year instead of four does not influence index categorization results very much for all data made available to us. However, is this number satisfactory to represent water quality?” They further note that “there is considerable variability of the index within certain stations, regardless of the number of samples used in the calculation. This variability tends to diminish when we increase the number of samples. This reduction can be explained by the fact that when a higher number of samples are used, the data is more representative and more homogeneous.”

CESI (2008) noted that the “appropriate sampling frequency and timing needed to capture the natural variability in the parameters measured can vary from site to site and from one ecosystem

to another. This reflects the variety of climactic and hydrologic regimes across Canada.” Statistics Canada (2007) demonstrated that the range in the variability of confidence intervals among sites when a consistent number of samples are taken can be great due to this inherent variability (see Figure 14).

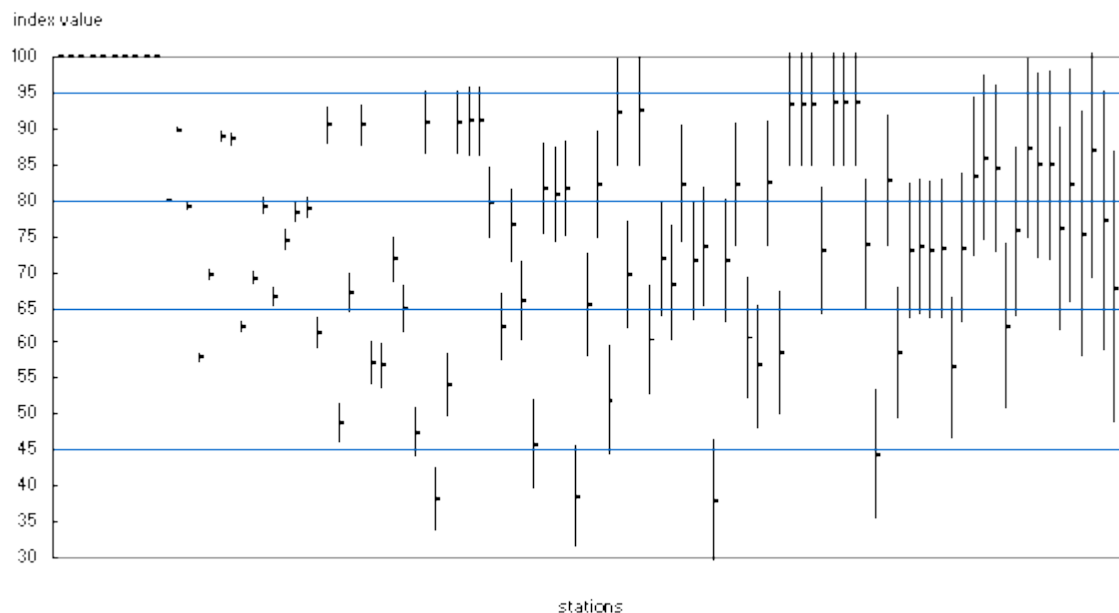


Figure 14. 95% confidence interval of the index value within stations when four samples per year are used for the Quebec dataset (Source: Statistics Canada 2007)

Note to Figure 14: The stations are ordered in ascending order of variability and the horizontal lines represent the index category change.

CESI (2008) recommend that at least four samples per year are collected at all sites, Exceptions to this would be for rivers in the north if the mid-winter sample is excluded, and on lakes if spring and fall overturn sampling is undertaken, in which case two samples per year could be satisfactory. This thinking shows the importance of capturing the “extreme” events associated with increased flows during spring runoff, and the less relative importance of the baseline flow period (under ice).

Increasing the number of samples collected can have the unfortunate effect of potentially increasing the likelihood that at least one sample will exceed a guideline for more parameters. In effect, this could increase the F1 score in the index, resulting in lower CCME WQI scores and a poorer rating of water quality. Kilgour and Associates (2009) provide options for dealing with more data in the WQI, especially for extreme events. “Trimming the water quality data for high-turbidity events increased the WQI values by as much as 30 points. There were modest but apparent increases in the strength of the association between the WQI and indices of benthic community composition when the water quality data records were trimmed of values that occurred during periods of high (extreme) turbidity.” (Kilgour and Associates 2009)

3.3 Summary of information on sample size

The timing of sample collection is likely as important as or more important than the number of samples actually collected. Selective sampling at times when guidelines or objectives are not likely to be exceeded will yield WQI scores that are better than the water quality actually is in a water body for an entire period. A sampling program that excludes a time period when water quality may be different or impacted is not truly collecting samples of the water quality throughout a year. In a similar vein, a program that focuses exclusively on a period of time when a guideline or objective may be exceeded may also not be appropriate. A time period of the year may be omitted when a guideline or use is not valid, and could focus on for example the recreation season. When samples are collected during extreme events, such as a heavy rainfall, many parameters will likely increase substantially for a short peak. In such cases, the F1 factor will increase significantly but in such cases, turbidity or suspended solids (and attached chemicals) during these events may not be a problem biologically. In such cases, processes outlined earlier for removal of such data need to be considered (Kilgour and Associates 2009).

We also noted in Section 3.0 that the practicality of sampling schedules for many agencies leads to sampling being biased between Monday and Wednesday or Thursdays for most weeks, and that the flexibility to modify sampling schedules to meet the actual hydrological situation in any one year may not exist. This means that more samples may need to be collected to capture certain events than in the ideal situation, simply because of limited flexibility of sampling programs.

Sampling should reflect seasonal variability and not episodic variability. Work undertaken by Gartner Lee (2006) recommended from 6 to 12 samples, while the work of Davies (2006) showed that eight samples were needed at one site and 11 samples at a second site. A presentation from the 2006 CESI workshop (Section 3.0) recommended 12 samples as evidenced by WQI calculations performing well at most stations with 12 samples, as opposed to using only four samples per year where greater variability in scores existed. Statistics Canada (2007) looked at the possibility of using three samples per year instead of four in remote areas of the country and found that such a reduction did not influence index categorization results significantly. However, Statistics Canada (2007) also pointed out that a larger number of samples would decrease the intensity of the highest categories in comparison with the lower two categories.

There are likely other situations where this goal of 10 to 12 samples per year may not have to be met and number of samples can be relaxed. For example, there are many long-standing networks with monitoring stations that have been sampled for 10, 20, or 30 or more years due to their importance (e.g., trans-boundary). In fact, it is likely applicable to stations that have a minimum of 60 samples during about a five year period. In such cases, a strong database exists to which CCME WQI scores can be compared. At such stations, as long as “events” (e.g., spring peaks or late season troughs) are captured, it is likely possible to calculate the CCME WQI from as few as four samples per year. This assumes that the status quo at the station in terms of human stressors and hydrology has not changed and that comparisons of scores to earlier periods can verify the accuracy of the CCME WQI calculation. This scenario places a great deal of decision-making power on to the water quality professional who will have to decide whether the data for such years are representative.

4.0 TIME PERIODS

The sampling period has important ramifications on the interpretation of CCME WQI results. Providing information on a one-year basis or shorter can lead to swings in the CCME WQI, while longer time periods (e.g., three years) have the effect of “evening out” the CCME WQI scores.

Environment Canada on their web site provides an example of the CCME WQI scores for the Fraser River at Hope for two different time periods: annual (Figure 15) and three-year rolling scores (see Figure 16) (arsenic, copper, lead, silver, thallium, zinc, total dissolved nitrogen, total dissolved phosphorus, dissolved oxygen, pH and temperature used to calculate the WQI scores).

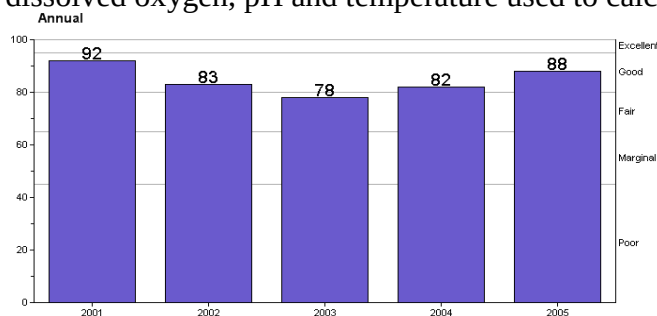


Figure 15: CCME WQI for the Fraser River at Hope on an annual basis (Source: Environment Canada 2011)

It is interesting to note the subtle differences. On an annual basis, the water quality at Hope can be either rated as “Good” or “Fair”. In contrast, when a three-year rolling mean is calculated, the water quality is consistently rated as “Good” (with identical scores each period). This illustrates an important feature about the CCME WQI when longer time intervals are considered: that extremes or fluctuations in water quality are “averaged out”. The one year CCME WQI shows the normal fluctuations that are inherent in water quality; however, the three-year rolling average is easier to explain to the public who do not readily accept that water quality can change between years naturally. This is especially important for scores near the boundary of rankings (see 2003 histogram – Figure 15) where a change of two points in 2003 would have resulted in a ranking of good and not fair.

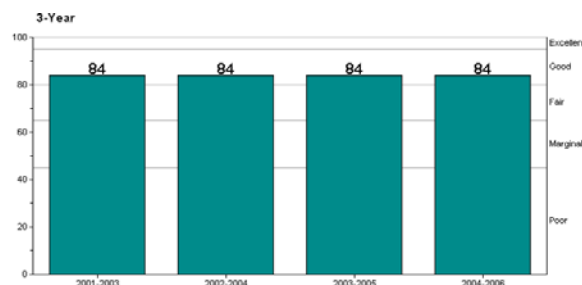


Figure 16: CCME WQI for the Fraser River at Hope on three-year periods (Source: Environment Canada 2011)

Painter and Waltho (2005) looked at the effect of using different time periods in calculating the CCME WQI for 50 Ontario water bodies (Figure 17). The CCME WQI was calculated using all the data for ten parameters (total phosphorus, ammonia, nitrate, nitrite, copper, zinc, lead, nickel, cadmium and total chromium) from the 1997-2002 period, and then for five subsequent time periods with one year removed from each (i.e., 1998-2002, 1999-2002, etc.). “There was a tendency of improvement as the time period was shortened.” “Increasing the number of years increased the number of observations thereby increasing the likelihood of having exceedances. Alternately, the more years of data included in the computation could also decrease the sensitivity of changes in water quality due to pollution prevention activities until the majority of the time period included in the computation reflected the prevention activity.” Unfortunately, this portion of their study does not lead us to know what time period produced the best estimate of the WQI.

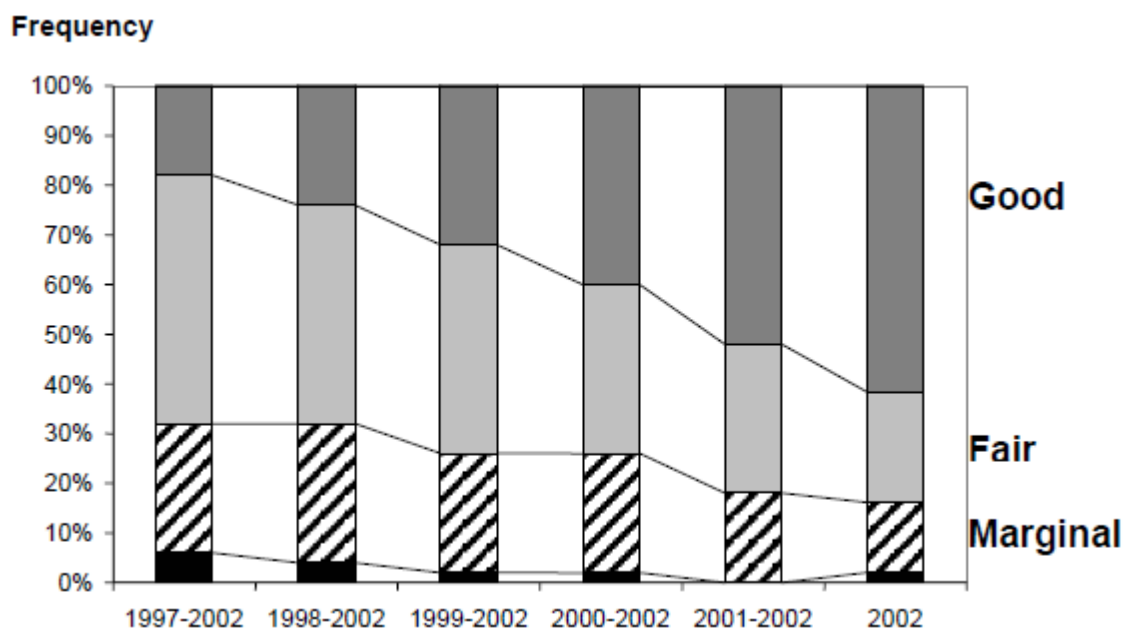


Figure 17. Frequency distribution chart for different time periods using all 50 sites (Source: Painter and Waltho 2005)

Synthesis of Research and Application of the CCME Water Quality Index

The authors also looked more intensively at 10 of the 50 sites that had adequate data to measure the CCME WQI annually (see Figure 18). There were approximately 14 to 20 samples per year used to calculate the CCME WQI and they concluded that “Significant variability occurred between years.” (Painter and Waltho 2005).

Painter and Waltho (2005) also concluded that “The stability of the Index improved when at least 3 years of data were included in the calculation.” This was based on the premise that use of fewer years increases the responsiveness of the index while too many years would dampen the representation of the environmental condition.

They also suggested that “The period used to calculate the Index is subjective and requires some knowledge of the variability in the environmental condition and the adequacy of the sampling program to represent that condition. Including several years’ data may ensure that the dataset has captured all the stressors occurring at a site. However, including too many years would render the Index insensitive to pollution prevention activities. A reasonable recommendation would be to include at least 3 years of information and at least 30 observations as the “Index period” (Painter and Waltho 2005).

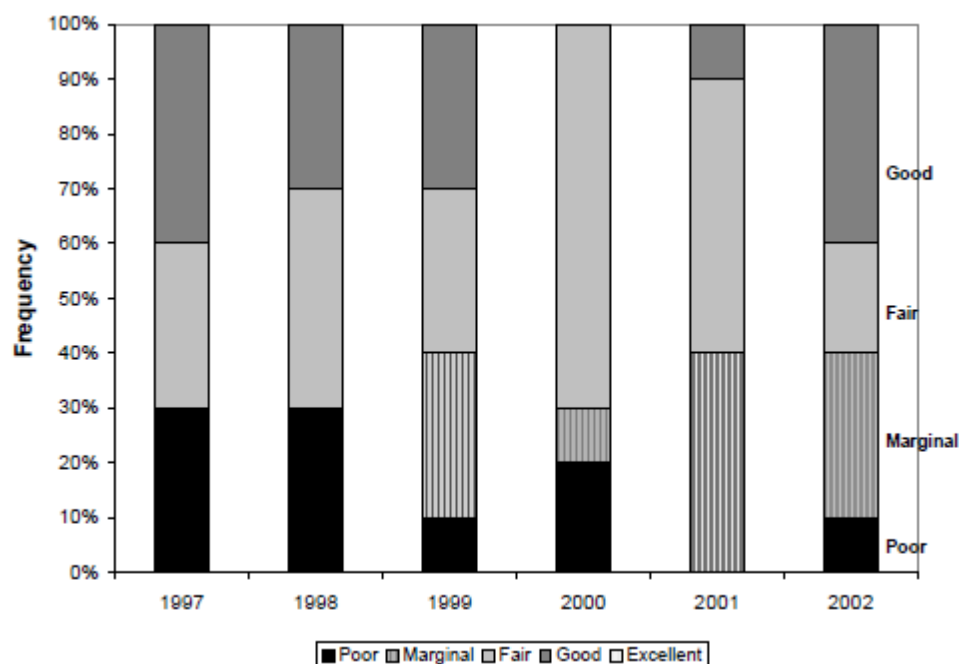


Figure 18. Frequency distribution for the ten sites with annual CCME WQI scores (Source: Painter and Waltho 2005)

Based on this observation, it may be a more reasonable approach to look at the purpose of the reporting to help determine the time period. When it is desired to look at how pollution prevention activities have impacted water quality, then shorter time periods such as yearly should be considered. If the purpose is to report on the state of water quality, and to minimize the natural variability inherent in water quality data, then perhaps the longer time period such as three years should be used.

Synthesis of Research and Application of the CCME Water Quality Index

Gartner Lee (2006) showed the effect of using a three-year period on the annual fluctuations of the CCME WQI at two sites (see Figure 19). Figure 19 shows that variability can be reduced by using a three year period to calculate the CCME WQI, similar to what was discussed for the Fraser River at Hope station (see Figure 15).

Gartner Lee (2006) concluded that “A minimum of six samples should be included for each index period. Larger sample sizes or longer index periods will produce a more stable index value, but may dampen yearly variation that is of interest.”

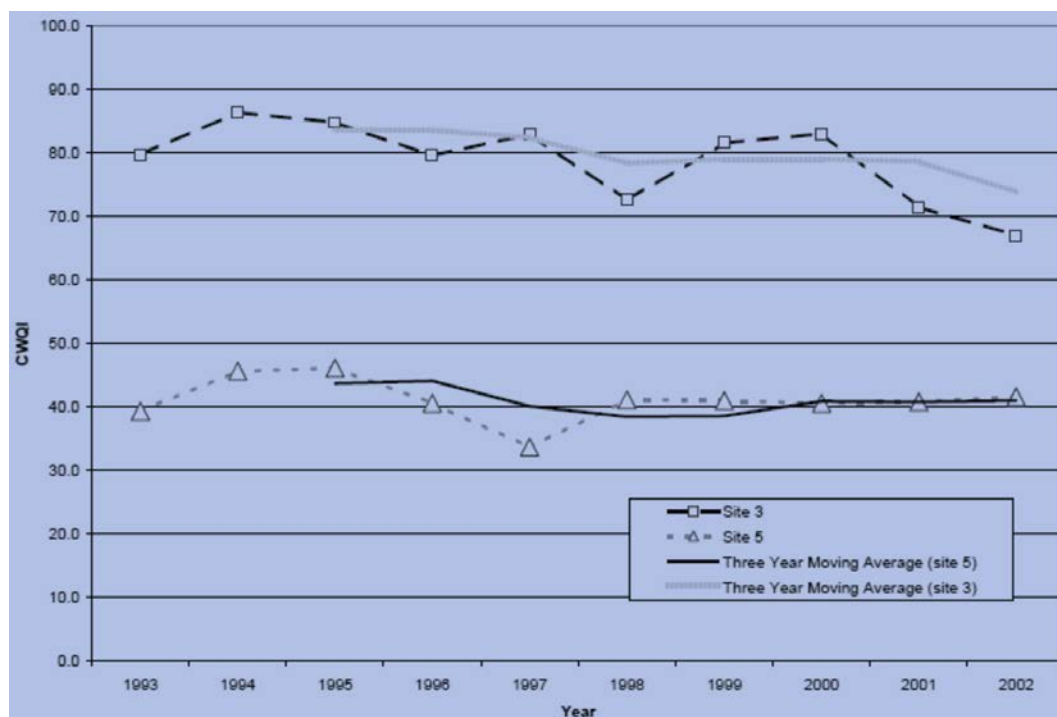


Figure 19. Effect of using a three-year time period for two sites (Source: Gartner Lee 2006)

Koning *et al.* (2006) reported CCME WQI scores on an annual basis based on fecal coliforms, *E. coli*, major ions, nutrients and dissolved oxygen. The resulting values are shown in Table 2. These illustrate the same variability as noted by Painter and Waltho (2005) when using shorter time periods such as yearly.

Synthesis of Research and Application of the CCME Water Quality Index

Table 2. CCME WQI scores for the Oldman River and tributaries, 1998 – 2002 (upstream to downstream sites) (Source: Koning *et al.* 2006)

	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	Average
OMR near Brocket	88	100	94	100	87	94
Beaver Cr at Hwy785	72	76	73	72	72	73
Sox Mile Coulee Spillway	64	65	54	61	49	59
OMR at Hwy 3 bridge	87	100	100	100	85	94
OMR SW of Diamond City	64	88	-	88	74	79
Piyami Drain	49	59	70	58	42	56
OMR at Hwy845	76	88	-	-	71	79
Battersea Drain	59	64	67	75	45	62
Little Bow R near mouth	88	81	81	81	58	78
OMR at Hwy 36 Bridge	75	82	100	100	74	86

OMR = Oldman River

*The number of samples per year per station was not identified in Koning *et al.* 2006

Glozier *et al.* (2007) showed how things such as improvements to a wastewater treatment facility can be delayed in the CCME WQI score when a longer time period is used (Figure 20). 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 objectives based on 90th percentile values for 15 parameters from an upstream station to calculate the index values.

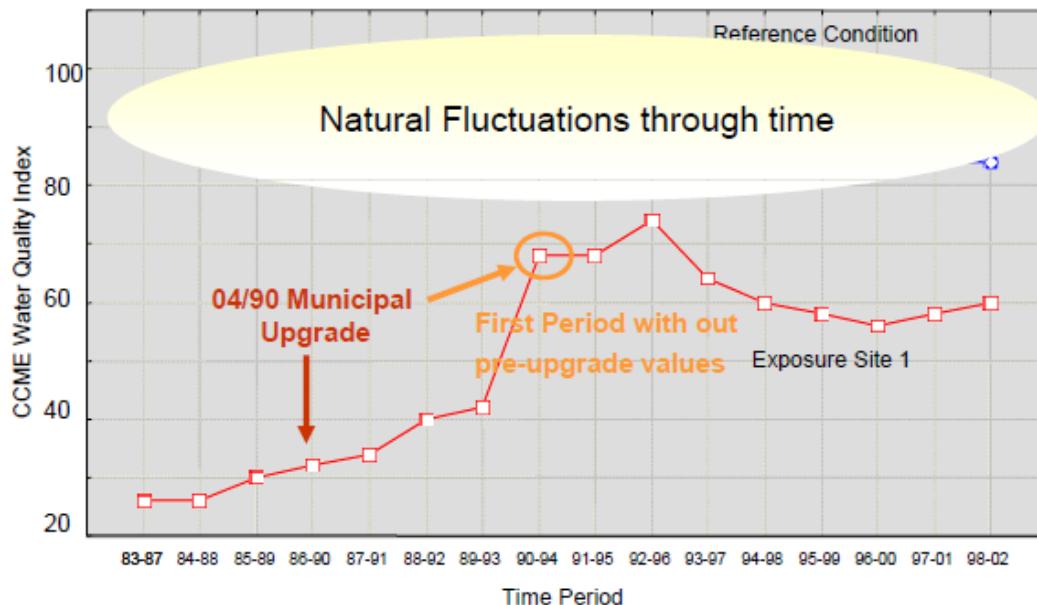


Figure 20. Delay in reporting of improved water quality following treatment plant upgrades when a five-year period is used to calculate the CCME WQI (Source: Glozier *et al.* 2007)

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 21). Figure 21 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.

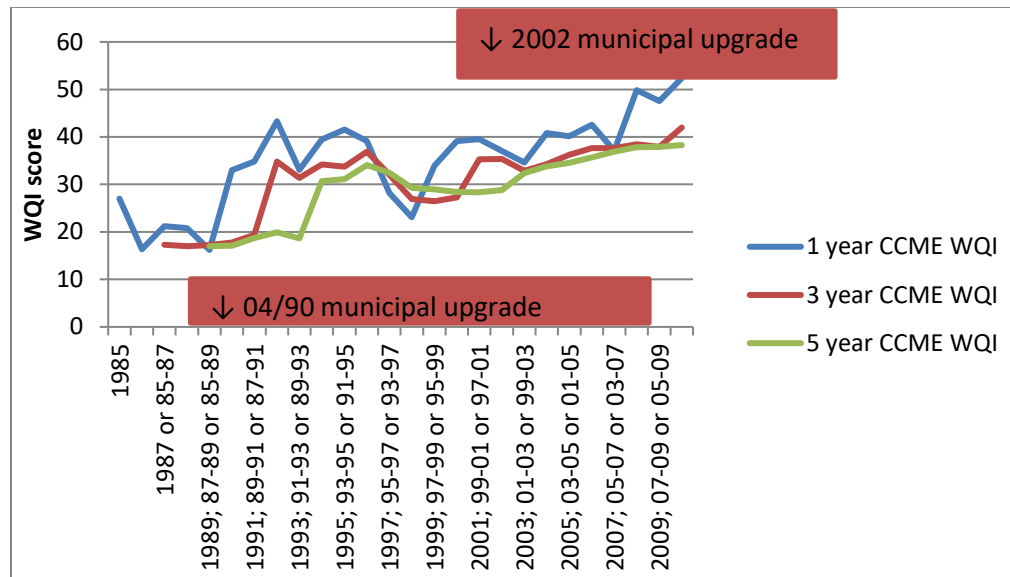


Figure 21. Reporting improved water quality following treatment plant upgrades with one-year compared to three- and five-year time periods (Data source: Nancy Glozier, Environment Canada)

CESI (2011) use a three-year time period for Canada-wide reporting purposes on the basis of:

- (1) Balancing natural hydrological fluctuations among years with capturing real changes in water quality,
- (2) Being inclusive of more monitoring programming or sites for Canada-wide reporting (especially those that sample as few as four times per year), and
- (3) Capturing more seasonal variation (using data over three year's increases chances of capturing peaks and troughs).

4.1 Summary of information related to time periods

The time period needs to provide meaningful feedback to the intended audience. For the regular reporting of water quality it is important that any changes in CCME WQI scores or ranking are not due to the natural variability but are changes in the water quality itself.

Annual reporting of CCME WQI scores using a rolling three-year time period as has been done by Environment Canada is likely a good way to remove a considerable amount of the natural variability in water quality data. It will also, to a degree, minimize the number of water bodies where there are swings in rankings due to having scores close to the boundary for one ranking. A three year time period was recommended by several researchers including Painter and Waltho (2005) and has the advantage of evening out natural fluctuations while still providing some feedback on changes in the water quality.

If the purpose of reporting is to provide information on the effectiveness of a pollution control activity or to show how water quality suffered due to a pollution event, then a shorter time period is likely warranted. We have seen examples in Section 4 where three-year periods masked the impact of pollution control activities until the fourth year following the initiation of a project. This is not likely a satisfactory result for a public that may have spent millions of dollars to upgrade a wastewater treatment facility. In such cases immediate results are wanted, needed and yearly CCME WQI scores are warranted.

On the other hand, using time periods that are themselves long (e.g., decadal) really provides little meaningful information to the public. In fact, it is likely that analytical procedures and detection limits can change from one decade to another for the same parameters, and this will have inherent problems such as false positives near the detection limit that may be in excess of guidelines/objectives. If one is interested in making comparisons between two or more decades, it is likely better to provide graphs of CCME WQI scores over the long-term than to try to generate a meaningful score over any particular decade. Using this latter approach, if CCME WQI scores change suddenly at a particular time, one should investigate whether detection limits changed for some parameters at about the same time.

5.0 DATA VALIDATION

The goal of data validation is to screen out human error and to ensure the data reflects the analytical detection limits. In general, outliers should not be removed unless measurement, sampling or data entry error is suspected (CCME 2005).

“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.* 2011a) For this reason, one should not forget when using the WQI that monitoring can have bias, and that results have certain precision and associated accuracy for each parameter, depending on how removed the value from the analytical detection limit.

In Section 2.2 of this report, we looked at the work of Khan *et al.* (2005b) who used the CCME WQI to evaluate the impact of establishing best management practices (BMPs) in a protected water supply area in Lewisporte, Newfoundland and Labrador. This work raised another important point in using the CCME WQI; how much change is truly a change of score and not just a fluctuation that might occur due to chance? When one considers that the WQI score is calculated from measurements which may, in the best of situations have a combined 10% accuracy and precision associated with them, then a change of score from 59 (dataset #1) to 61 (dataset #2) represents a 3% change (2/59) while increasing the score to 64 represents about an 8% change (5/59). Both these differences are less than what could be expected where there was good precision and accuracy in the dataset. In this particular case, however, the results are likely valid since the CCME WQI score increased but the scores also stayed high. There also was a management action that could be associated with the new higher CCME WQI scores. The concern related to precision and accuracy may be more of a consideration in other cases where the CCME WQI appears to fluctuate somewhat randomly between test periods.

CESI (2008) provides a summary of data validation process. It defines the validation steps to be undertaken from sampling to the database through to the CCME WQI calculation (Figure 22). This process provides check points to ensure the quality of the data that are used in CCME WQI reporting. It also provides for a check to be performed to ensure calculations were done properly and information was accurately transferred to the database and the final indicator. However, other than major outliers, it does not provide a mechanism to check/confirm that the values make sense (e.g., is a certain value for a parameter measured at a specific site correct?). For the path associated with the “sampling to database”, it was assumed for the purposes of this discussion that all agencies that collect water quality data will, as a minimum, perform checks for cross-contamination using blanks, and for precision use replicate samples. It also assumes that laboratories that analyze the samples will perform these checks as well as use standard reference materials or surrogate recoveries to ensure the accuracy of the results. For the purpose of this discussion, we will limit our review to the path from the “database to the CCME WQI calculation”.

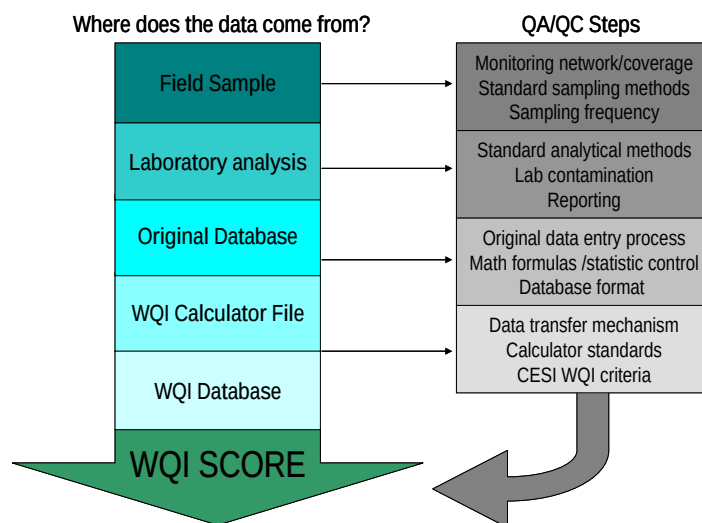


Figure 22. General steps to validate data for CCME WQI calculation (Source. CESI 2008)

Depoe *et al.* (2010) provide advice to ensure the overall CCME WQI score makes sense for the site and for a time period to do this. They stress the importance of understanding the data and the sites, so that the CCME WQI ratings can be validated by knowing what is driving the index score. The following steps and questions are suggested in order to confirm the CCME WQI rating for a site:

1. Examine results relative to reference conditions or known impacts and ask the question: Are trends logical?
2. Examine the influence of specific parameters, guidelines or samples on the ratings and ask the question: Does any apply an undue influence?

We would further suggest the questions:

- a. Are the guidelines used the best that can be used or should these be reviewed to ensure that they are up-to-date and relevant to the situation being scored? and
- b. Do certain samples point to the need to modify the monitoring program in terms of timing, parameters measured, or frequency?

3. Review previous assessments and ask the question: Are findings consistent?

We would further suggest the ancillary question: 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? and
- 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?

We would suggest that these 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.

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 incorporates in most cases, effects on biota over time, whereas surface water sampling reflects the state of water quality at a particular instant. The latter may not involve a situation that is long-lived or that has long-term impacts on biota. In addition, there is likely more natural variability in the biological community.

CCME (2004a) illustrate this in their discussion of the overall results from the Atlantic Provinces project. “In some water bodies, lower scores (i.e., fair and marginal) are indicative of human impacts and a need for conservation or remediation measures, while in others, lower scores reflect waters with high levels of some naturally occurring substances (e.g., coloured waters with low pH and high levels of metals). The latter situation points to a need for research in determining: (1) whether current levels of these substances are indeed considered to be having a negative impact, and if not, whether they should be included in the index; and (2) whether the resulting conditions are natural or rather reflect a wider environmental issue, such as acid range or climate change.” It is suspected that if wider issues are at play, then the impact of these issues on the CCME WQI should also be seen at other sites in the same relative geographic area that are evaluated for similar variables (e.g., number of samples, parameters tested, etc.).

Depoe *et al.* (2010) document an example at the Tusket River in Nova Scotia that illustrates the influence of a number of factors have on raising the CCME WQI score. This answered the question: How much influence does a particular guideline, sample or factor have on the outcome? The first change occurred when an outlier sample was removed, thereby increasing the score by over 8 points. When the guideline for pH was changed to a site-specific guideline, little change took place, less than one point. Removing lead from the parameters tested raised the score by about 2 points. This illustrates potential differences that can arise from changing or deleting certain parameters and/or data in the final CCME WQI score.

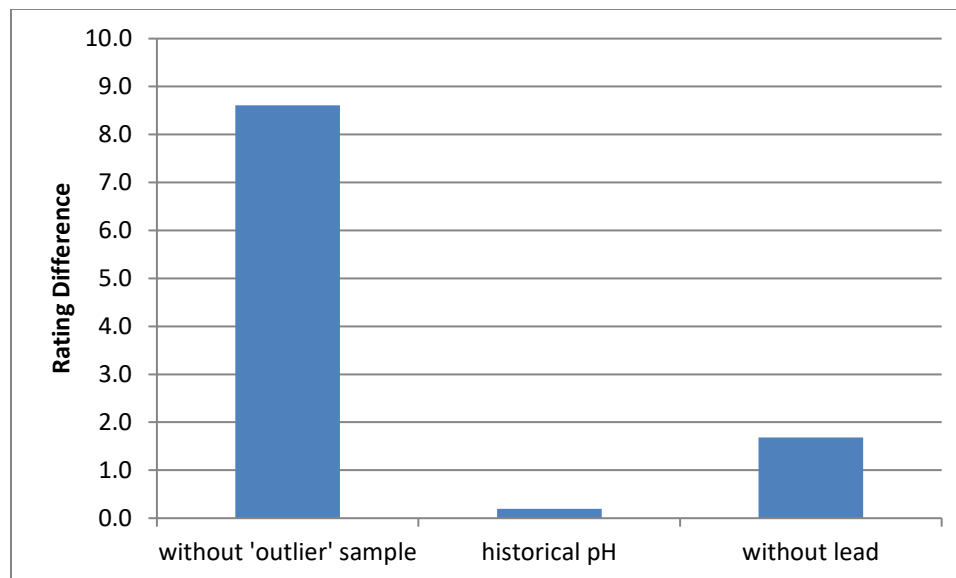


Figure 23. Example to illustrate the influence of removing different parameters or changing different objectives on the CCME WQI score (Source Modified from Depoe *et al.* 2010)

Astles and Hamel (2007) looked at the potential influence of one sample at one site on a running three-year CCME WQI score. The 2006 score was 52.5 while the 2007 score was 66.5. The biggest change between the two years was in the F1 factor that calculates the percentage of variables that are tested and have at least one failure. This factor decreased from 5 (71%) in 2006 to 3 (43%) in 2007. They attributed the difference to a single sample collected in January 2002 (used in the 2006 but not in the 2007 score) in which the chromium exceeded the guideline by 38% and the zinc by 28%. The authors raise the legitimate question: Is this an outlier sample? In this case, the data were not removed, likely because there were no other samples ever collected in January and one is not certain whether the sample accurately reflects the water quality or whether it is an outlier. Related to determining potential outliers, the reader is referred to Kilgour and Associates (2009) who provide some advice on dealing with extreme events associated with turbidity.

Another point raised by this example is: should the monitoring program be revised to ensure that samples are collected in January? Of course this is not a CCME WQI question, *per se*, but a question going back to the purpose of monitoring water quality at a site in the first place. The CCME WQI in fact brings to light this one sample that may in fact indicate that the parameters that are being tested should perhaps be reviewed.

In validating the CCME WQI results, one must ensure that appropriate guidelines for the jurisdiction have been used. Not all guidelines are created equally. Within the life of the CCME CWQG at least three different methods have been used to develop guidelines as per the following:

- (1) Aquatic life guidelines referenced to 1987 originate from the first compilation of guidelines from the predecessor of CCME, the Canadian Council of Resource and Environment Ministers. That set of guidelines, many of which have been included in the CCME CWQG,

were selected on a consensus-basis, having been chosen as much because an organization had a guideline for a particular substance as for any justification based on science.

- (2) Subsequent to this, guidelines were developed for nearly twenty years in Canada using the original CCME CWQG Protocol that used a safety factor and the most restrictive accepted toxicological study to produce a guideline for protection. Both of these factors provided a guideline that in most cases were expressed as maximum allowable concentrations, and were based on the results of chronic toxicity testing.
- (3) More recently, CCME have revised their Protocol to address substances with considerable toxicological data, by offering options for guideline development using a species-sensitive approach which yields both a short-term and long-term guideline.

At the same time, individual jurisdictions such as Alberta, British Columbia and Ontario have developed their own guidelines for use that often supersede the CCME CWQG. In British Columbia, Manitoba, and several other jurisdictions including the Prairie Provinces Water Board stations; site-specific water quality objectives have been established. This therefore makes it difficult, if not impossible, to compare water quality using the CCME WQI (that uses these different guidelines and objectives as threshold values) across Canada. More importantly, the question needs to be asked; should we try to make such comparisons? The reality is that the public will always have an appetite for such comparisons. Discussed in this report are a number of key components of the WQI that will make some comparisons meaningful when the CCME WQI is calculated using:

- a. the same parameters,
- b. the same guidelines or objectives,
- c. the same time periods and the same number of samples, preferably collected during the same months.

Only when these components are identical can comparisons truly be made; in all other cases there will always be uncertainty in any comparisons.

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, but may be similar to waters that flow across Newfoundland and Labrador. In all these jurisdictions, aquatic life have adapted to their natural environments in order to survive. So to anticipate that guidelines or objectives used in one jurisdiction should be the same as are used in another is not realistic. This is why the original guidance for use of the index was to use site-specific objectives. Using a similar logic, to suggest that water quality needs to look the same from one jurisdiction to another is also unrealistic. It is therefore not useful for validation purposes to compare the results from one jurisdiction to another. Comparisons within drainage areas or ecoregions likely are more valid, and this is an approach frequently used to compare water quality between test and reference conditions. In the case of more general broad comparisons across jurisdictions, one may report on how many sites are in different classifications. In this case, the need for consistency among the sites for the input data may not be as great.

5.1 Tools and approaches used to validate data and results

A valuable tool included in the CCME WQI can be used for verification of results is located on the “Tested Data” page. Values that exceed the objectives are highlighted in different colours; see Table 3, depending on the extent that the guideline/objective is exceeded. These highlighted data points indicate specific days of generally high values that can be investigated further. They may also indicate input guideline/objective expressed in one unit (e.g., µg/L) and the monitoring data expressed in another unit (e.g., mg/L), which can skew the final CCME WQI score.

Table 3. Colour coding from the Tested Data page of the CCME WQI Calculator

Supporting Information		Failed values <10 times objective	
Failed values 10-25 times objective		Failed values >25 times objective	

Another method for validating data is to perform CCME WQI calculations separately for sites using different sets of parameters (e.g., metals, solids, etc.). This is illustrated in UNEP (2007), where the AWQI and the HWQI are sub-sets for the aggregate drinking water quality index (DWQI). The Vistula River in Poland was used as a test case and the authors stated: “First, the significant correlations between the parameters in exceedance and the indices related well to previous studies conducted within the Vistula River, with high metal content reflected in the HWQI, and high chloride and ammonia content reflected in the AWQI.” “The DWQI, while corresponding well to the other two since it demonstrated similar temporal and spatial patterns, did not seem to be as sensitive or as descriptive as the HWQI or AWQI.” They further conclude that “This is not to say that the DWQI is not useful, but rather that the decision to use either index is dependent on the type of question or analysis that is being conducted.”

As well, Environment Canada has compared the CCME WQI score to the score generated for biological indicators using the Reference Condition Approach (RCA). An example of such a comparison is shown in Figure 24, which highlights two sites with extreme differences between the rankings. The Quinsam River was rated as fair using the CCME WQI and was consistently ranked as poor using the RCA, whereas the Fraser River at Marguerite (1994) was ranked as fair according to the CCME WQI but excellent according to the RCA. The Fraser River 1994 data should be checked to confirm their applicability or to determine if there was an outlier included in the calculation which caused both scores to deviate from the scores in the blue section. In the case of the Quinsam River which had fairly consistent results over the years, it is suggested that the input parameters used for calculating the CCME WQI needs to be checked to confirm whether an important parameter was missed.

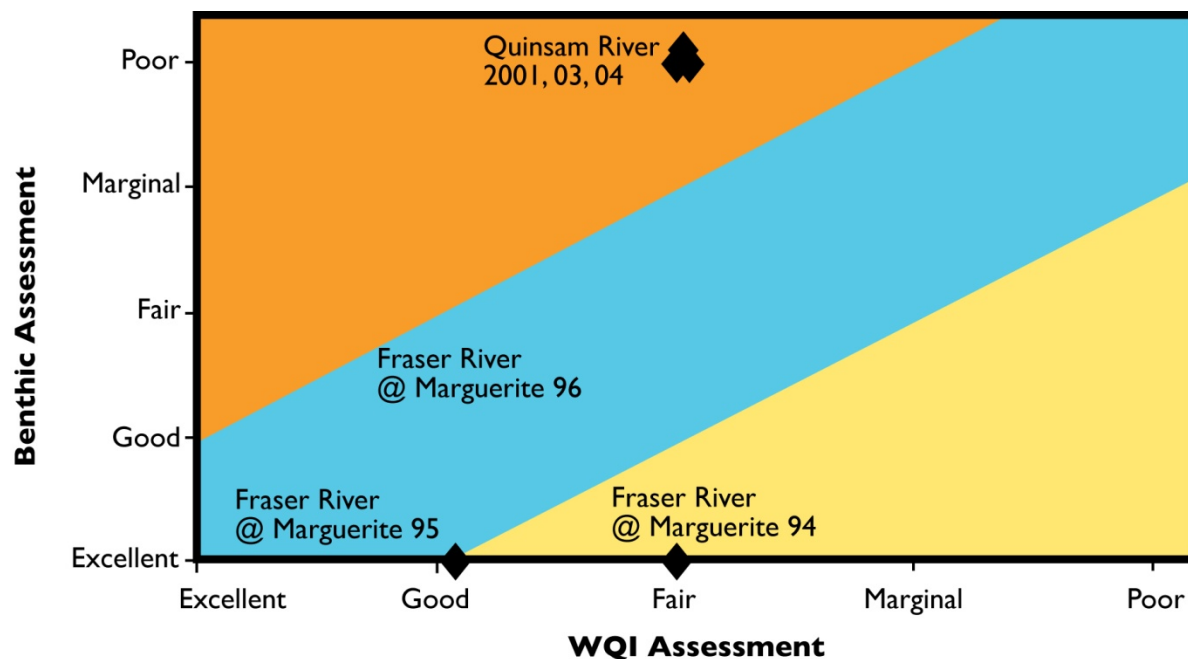


Figure 24: A comparison of water quality using the CCME WQI and the RCA methods in the Fraser and Quinsam rivers (Source: modified from Stephanie Strachan, Environment Canada, Pacific and Yukon)

The greatest degree of consistency between the indicators was achieved for the annual adjusted CCME WQI score (70% of the water quality indicators are similar). This shows that comparing the CCME WQI to other metrics is a good test for confirming the final result; however, there are times when the results will not necessarily coincide to each other. In these cases, the results for both metrics should be reviewed and the water quality professional should make an informed decision regarding the use of the CCME WQI.

5.2 Summary of tools and approaches for data validation

The quality of the water quality data and the interpretation of that data is a key component of how accurate the CCME WQI ranking will be. Questions to consider include:

- Were the data collected at sites appropriate to the question being asked of the CCME WQI, are the sampling sites located close to the sources of impact that are a concern or further away, if the interest is in the general state of water quality,
- Were the data collected at a frequency that meets the necessary level of confidence, and tailored to the hydrology of the water body and potentially to the discharge patterns from human activities and does the sampling frequency meet the sampling requirements for the guidelines used in the CCME WQI calculations (e.g., acute versus chronic guidelines),
- Are the parameters tested appropriate for the monitoring requirements in support of whether guidelines are being met (e.g., hardness) as well as monitoring parameters of concern, and

- Were the data collected at the appropriate time of year when the parameter is of most concern?

The CCME WQI is meant to “wrap-up” large amounts of data into a simple message. It has always been assumed in the development of indices that the data collected to help to answer a specific question or series of questions is appropriate. The monitoring program can be “fine-tuned” to include ancillary information that an index may require. There may also be other pressures driving the use or requirement for the index, such as performance reporting (success of treatment plant infrastructure) or general indicators of the state of the environment that require some consistency among stations or networks.

It is assumed in using the CCME WQI that the associated monitoring program will include a data handling mechanism that ensures the quality assurance and quality control data for each sample, and accepts or rejects the results based on such assessments. A similar process takes place with the CCME WQI scores once they are generated. A series of questions should be answered when reviewing the outputs from the CCME WQI calculator but in essence, the key question to ask is “do the results make sense”?

In reviewing both monitoring and CCME WQI results, one must always be cognizant of the inherent bias in monitoring data in terms of it being representative. The goal of data validation is to screen out human error and to ensure the data reflects the analytical detection limits. In general, outliers should not be removed unless measurement, sampling or data entry error is suspected (CCME 2005).

There are a number of checks that should be made once the CCME WQI scores have been calculated. These include comparing results where possible to reference conditions and to bio-monitoring or other assessments, or comparison to known impacts. The possible influence of different parameters, guidelines or samples should be examined to make sure that any of these do not carry an undue influence on the CCME WQI.

The general approach for reviewing the outputs from the CCME WQI calculator is to confirm that the output makes sense based on what is known about the water body. If it does not, then the objectives and parameters used should be verified, followed by a review of the “Tested Data” page to look for patterns of several parameters failing to meet an objective on the same day. This can point to possible problems related to one specific sample. As was mentioned earlier, it may also point to specific samples that have been collected at times when these samples are not normally collected.

Pappas *et al.* (2010 draft report) performed comparisons between CCME WQI and bio-monitoring (Canadian Aquatic Bio-monitoring network – CABIN) indicators for 12 streams in British Columbia. This study showed that in many cases water chemistry and biological response were giving consistent signals. However, in some cases there was divergence either because disturbances other than water quality were affecting biota or events occurring between water sample collections may have affected biota (Figure 25).

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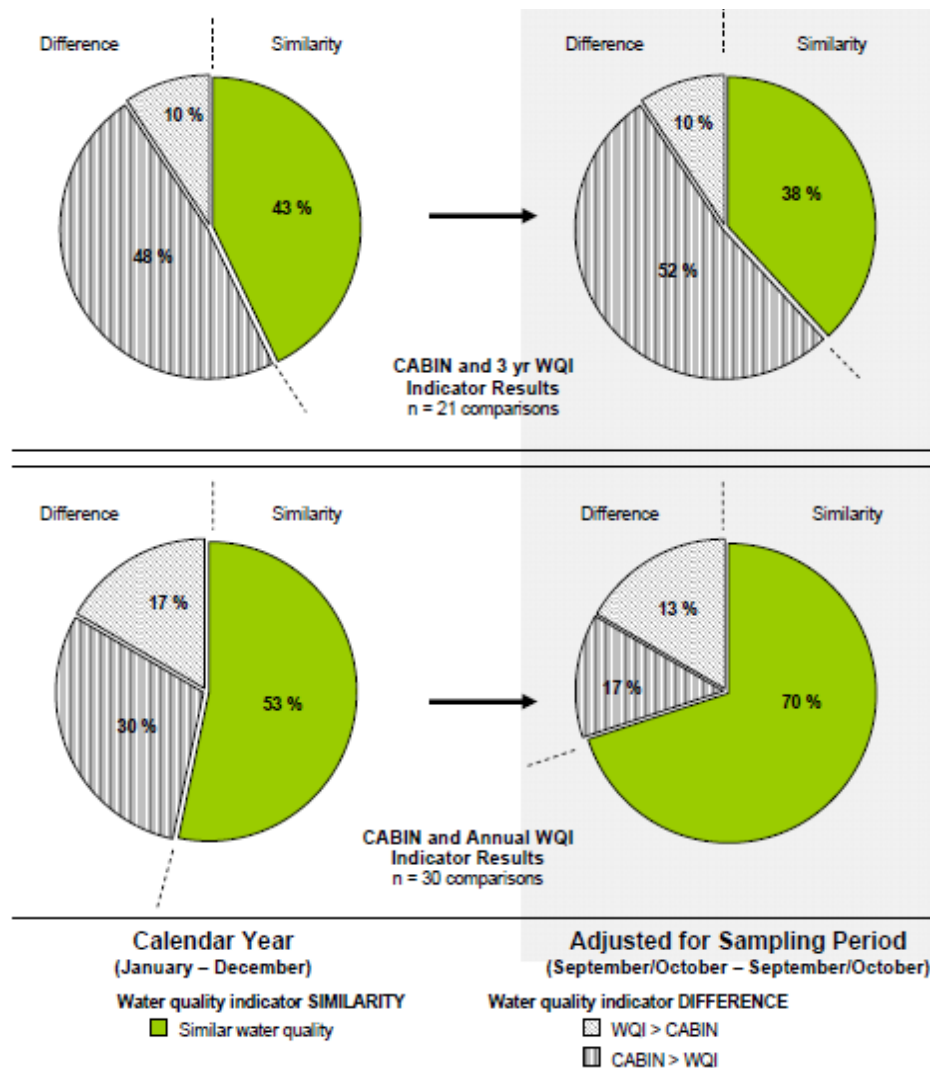


Figure 25. Summary of CABIN and CCME WQI comparisons at 12 BC water quality monitoring stations for the 1992 to 2006 period using different WQI formats (Source: Pappas *et al.* 2010 draft)

6.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

In developing this Synthesis document, we were asked to look at a number of key inputs to the use of the CCME WQI. These included the number and types of parameters selected, the number of samples and when these should be collected, the test period during which the CCME WQI should be calculated, preparation and tools and approaches to use to validate data. All of these questions hinge on the purpose of using the CCME WQI. What we mean by that is that different questions will need different approaches to be answered. **One must not lose focus of the purpose of using the CCME WQI.**

The CCME WQI is a communication tool. Overall water quality is a function of the interplay of many parameters. Reporting on one parameter is usually not enough so the CCME WQI was created as a tool that distils information about water quality stresses at a station into a ranking. It can't be used to diagnose problems, per se, but it might show the parameters that are causing problems. The parameters have been chosen for use in the WQI because it has been anticipated that they may fail to meet the objectives.

The performance of the CCME WQI is largely driven by the F1 factor, the number of parameters that fail to meet the objective during the test period. If parameters are selected that don't exceed their guideline, the CCME WQI output will indicate excellent water quality. If a guideline is below natural background concentrations of a substance, the CCME WQI score will be low. Choosing appropriate guidelines and parameters is about balancing the factor F1. Parameters should have the potential to fail.

Having too many samples usually lowers the CCME WQI score because there is a greater chance one or more will exceed the guideline. Conversely, if too few samples are used, the WQI score becomes higher because there is a lower chance a sample will fail to meet the guidelines.

The question to be answered when applying the CCME WQI should drive parameter and guideline choices. CESI has been designed to report on Canada-wide water quality status by using a core set of stations and core parameter lists to allow some comparability among stations. As noted earlier, de Rosemond *et al.* (2008) and Glozier *et al.* (2007) looked at reference and impacted stations to try to detect the impact of a wastewater treatment plant upgrade on water quality. Their choice of parameters and guidelines reflected that decision. Alternately, if the question to be answered relates to recreational water use, the use of bacteriological parameters and recreational use guidelines in the WQI are essential.

The CCME WQI provides a means to include more than one water use in the same calculation, and more importantly, to also include values and guidelines from other media (e.g., sediments, biota). This is an important aspect in relation to water quality, since some chemicals are hydrophobic in nature and are more appropriately measured in other media. To exclusively use only information available for the water column is itself misleading in a CCME WQI calculation. In fact if one looks at the use of the CCME WQI where it originated in British Columbia, scores were determined for both multiple water uses and in some cases for more than just the water column.

6.1 Use of the CCME WQI

It was noted that the CCME WQI has been used widely in Canada, but also in many other parts of the world. In Canada, it has formed the basis for the CCME sediment quality index and for drinking water indices and the agricultural indices.

In Egypt it has formed the basis for an Egyptian WQI. The CCME WQI has been adopted for use under the United Nations Environment Programme in three forms: the Global drinking water quality index, its health water quality index, and its acceptability water quality index, each with specific variables selected. In these forms, it 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. Independently, 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, to assess its use for shrimp culture in Brazil, to rate water quality in San Francisco Bay, Fall Creek in Indiana, a lake and river basins in India, and surface water quality in Vietnam and in Iraq.

6.2 The number and types of parameters selected

The number and types of parameters selected is a function of what is to be assessed using the CCME WQI. One “core set of parameters” can possibly be used when there is only one use to be assessed, and the nature of the human activities is limited to a few types of activities. Examples of this concept being used in practice are variants of the CCME WQI such as an agricultural index or a drinking water index.

When water quality is to be assessed over a large geographical area with many diverse types of human stressors, it is likely not practical to dictate the actual parameters that should be used in the CCME WQI. Using groups of parameters such as metals, nutrients etc. may partially address this idea of core sets of parameters in such situations but the parameters still need to be relevant to the inputs or stressors on the system and need to have been collected at appropriate times of the year. In addition, since metals are often measured as “packages” in laboratories, one must not include all 20 or 30 metals unless relevant to the situation being assessed. For example, if a metal mine extracts copper, lead and zinc, including other metals that are not being released in quantities to cause stress on the environment (e.g., titanium, strontium, etc.) is likely not realistic. In other cases, if nutrients are to be examined, the question being asked (in collecting such data) is whether high levels are causing algal growths that are affecting aquatic life. Such growth normally takes place during the summer months when some samples should have been collected.

It is **recommended that a minimum of eight variables and not more than 20 variables** should be used in the calculation of the CCME WQI. In cases where it is appropriate to use more than 20 variables, the subject area should be sub-divided (e.g., into different water uses) if possible to reduce the number of stressors (and hence the numbers of variables). Care must be taken to ensure that variables selected are not highly correlated in order to prevent the impact on the CCME WQI of “counting twice” or more frequently for the same impact (e.g., including pH and alkalinity, or turbidity and suspended solids, etc.).

6.3 The number and timing of samples

The number of samples collected and used in the CCME WQI can have a significant effect on the CCME WQI. For example, too few samples can bias the results in general to a high CCME WQI because the fewer the samples collected; the less likely it will be to “catch” an event with poor water quality. At the same time, collecting too many samples can bias the CCME WQI and “dilute” the results obtained that include samples with high concentrations. In addition, collecting (and using) too many samples will also lead to excessive monitoring costs, including performing adequate quality assurance/control steps. The key is to determine an adequate number of samples between these extremes.

The timing of the sampling can play a part in determining how many samples need to be collected. In general, timing of samples should be such to ensure that at least some extreme “events” are captured in the database. An extreme of this approach often is used in British Columbia, where the goal is to monitor at the time of year when it is anticipated that guidelines/objectives may not be met and to collect five weekly samples during that time period. The assumption is that if the guideline/objective is met during this “worst-case”, then they will likely always be met. Depending on the parameters of concern in a water body, this may result in two or more sampling periods when five weekly samples are collected since the “worst-case” may be at two entirely different times of year. Using this approach, based entirely on timing, five samples per year are collected.

But when this “worst-case” approach is not used, how many samples need to be collected. Assuming that sampling will be generally evenly spaced throughout the year, and that such sampling will ensure that “events” are captured, and then monthly sampling is likely the most practical approach. However, this does not mean that there will be twelve samples collected, because at certain times of year, such as ice-on and ice-off, sampling can be too dangerous, and so it is likely that only about ten samples per year will be collected.

There are likely other situations where this goal may not have to be met and these rules can be relaxed such as with many long-standing networks with monitoring stations that have been sampled for decades. If the CCME WQI scores can be compared to a strong database, and if “events” are captured, the CCME WQI can be calculated for as few as four samples per year, collected seasonally, assuming that the human stressors and hydrology has not been changed and that comparisons of scores to earlier periods can verify the accuracy of the CCME WQI calculation. Other situations could involve the release of water at dams on rivers, where the water behind the dam has a relatively steady flow for most of the year.

Based on safety concerns related to ice-on and ice-off events, 10 samples per year based on this study was a practical goal for use in the CCME WQI (i.e., monthly samples with provision that sampling may not be possible during two months due to conditions at a site). Site-specific assessment of sample counts should be considered when developing a monitoring program (see Statistics Canada 2007 which shows the range in confidence intervals among sites when using four random samples).

6.4 Time periods that should be selected (e.g., one year, three years, etc.)

The first step that needs to be taken by those using the CCME WQI for reporting is to determine the question that the use of the CCME WQI is to address. This will determine in large part the time period that should be used in the calculation. Water quality in a water body fluctuates both throughout the year in relation to flow and among years in response to precipitation events that vary among the years. To overcome this natural fluctuation, and in order not to confuse the public with naturally-occurring fluctuations, a longer time period is generally chosen for reporting on water quality. This has the benefit of generally “flattening out” these extremes from the CCME WQI score and ranking. Thus if the CCME WQI is being used for reporting on the state of water quality of a waterbody through time, then a longer period of time is appropriate. For example, a three-year period has been shown to reduce the fluctuations that can be inherent in reporting on a frequency that is too short.

At the same time, longer time periods such as three-years can be problematic in showing the impact to water quality of pollution events or pollution reduction steps. In such cases, the time period used for reporting should be as short as yearly so that the impact from the abatement activity can be highlighted quickly.

When samples are collected during extreme events, such as a heavy rainfall, many variables will likely increase substantially for a short peak. In such cases, the F1 factor will increase significantly but in such cases, turbidity or suspended solids (and attached chemicals) during these events may not be a problem biologically. The procedures outlined by Kilgour and Associates (2009) for removal of such data needs to be considered in such cases.

6.5 Preparation and tools and approaches to use for validating data

Data that are used in the CCME WQI should be reviewed to ensure that they meet certain standards. Data that have been rejected using quality assurance and quality control protocols should not be included in the index calculation. A similar process should take place with the CCME WQI scores that are generated. A series of questions should be answered when reviewing the outputs from the CCME WQI calculator but in essence, the key question to ask is “do the results make sense?”

REFERENCES CITED

- Ali, Luay A. 2010. Seasonal variation in physico-chemical properties and zooplankton biomass in Greater Zab River –Iraq. *Jordan Journal of Biological Sciences*. Volume 3, Number 3, June 2010. Pp. 115-120.
- Astles, Philip and Martin Hamel. 2007. Comparison of 2006 and 2007 water quality index reporting periods: implications for trend analysis. *Presentation made to the 2007 National workshop on the water quality index*. December 2007.
- Boyacioglu, H. 2010. Utilization of the water quality index method as a classification tool. *Environ Monit Assess*. 2010 Aug;167(1-4):115-24. Epub 2009 Jun 20.
- British Columbia Ministry of Environment. 1996. British Columbia water quality status report. (http://www.env.gov.bc.ca/wat/wq/public/bcwqsr/wq_status_report.pdf)
- Canadian Council of Ministers of the Environment (CCME). 2001. *CCME water quality index 1.0 technical report*. (http://www.ccme.ca/assets/pdf/wqi_techrptfctsh_e.pdf)
- CCME. 2004a. Application and testing of the water quality index in Atlantic Canada. *Summary Report*.
- CCME. 2004b. CCME national water quality index workshop, A path forward for consistent implementation and reporting. March 2004. *Workshop Proceedings*. November 24-25th, 2003.
- CCME. 2005. CCME 2nd national water quality index workshop, towards a nationally consistent water quality indicator for Canada. November 2005. *Workshop Proceedings*. February 15-18th, 2005.
- CCME (Canadian Council of Ministers of Environment). 2007. Sediment Index Quality Calculator (SeQI 1.0). (http://www.ccme.ca/ourwork/water.html?category_id=103)
- Canadian Environmental Sustainability Initiative (CESI) Water Team, Environment Canada. 2008. Freshwater quality indicator, internal program review 2005-2008, The WQI approach: science and program development challenges. *October 2008*
- Canadian Environmental Sustainability Initiative (CESI). 2009. *2008 Highlights*. March 2009. (<http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=68DE8F72-1>)
- Canadian Environmental Sustainability Initiative (CESI). 2011. Technical guidance document for water quality indicator practitioners reporting under the Canadian Environmental Sustainability Indicators (CESI) initiative 2008.
- Darapu, Er. Srikanth Satish Kumar, Er. B. Sudhakar, Dr. K. Siva Rama Krishna, Dr. P. Vasudeva Rao, and Dr. M. Chandra Sekhar. 2011. Determining water quality index for the evaluation of water quality of River Godavari. *International Journal of Engineering Research and Applications*, Volume 1, Issue 2, pp. 174-182, July-August 2011.
- Davies, John-Mark. 2006. Application and tests of the Canadian water quality index for assessing changes in water quality in lakes and rivers of central North America. *Lake and Reservoir Management*. 22(4) pp 308-320. 2006.
- Depoe, Sarah, Nancy Glozier, and Vincent Mercier. 2010. Interpretive guidance for applying the CCME WQI. *Presentation made to the 2010 National workshop on the water quality index*. February 2010.
- de Rosemond, Simone, Dennis C. Duro, and Monique Dubé. 2008. Comparative analysis of regional water quality in Canada using the Water Quality Index. *Environ Monit Assess* (2009) 156:223–240, DOI 10.1007/s10661-008-0480-6.

Synthesis of Research and Application of the CCME Water Quality Index

Dubé, Monique, Brian Johnson, Gary Dunn, Joseph Culp, Kevin Cash, Kelly Munkittrick, Isaac Wong, Kathlene Hedley, William Booty, Davis Lam, Oskar Resler, and Alex Storey. 2006. Development of a new approach to cumulative effects assessment: A northern river ecosystem example. *Environ Monit Assess* (2006) 113: 87-115.

Environment Canada. 2011. CCME WQI for the Fraser River at Hope on an annual basis. (<http://waterquality.ec.gc.ca/WaterQualityWeb/wqicalc.aspx?stationId=BC08MF0001>)

Ferreira, N.C., Bonetti, C. & Seiffert, W.Q., 2011. Hydrological and water quality indexes as management tools in marine shrimp culture. *Aquaculture. Article in Press*.

Gartner Lee Limited. 2006. A sensitivity analysis of the Canadian water quality index. *CCME PN 1355*.

Glozier, Nancy, and the Environment Canada national water quality team. 2007. Value and challenges of trend analyses with water quality monitoring data: some case studies. *Presentation made to the 2007 National workshop on the water quality index. December 2007*.

Government of Canada. 2008. Technical guidance document for water quality indicator practitioners reporting under the Canadian Environmental Sustainability Indicators (CESI) initiative 2008.

Guy, Martha, Julie Boyer, Vincent Mercier, Nadia Gagnon, and Jean-Francois Bibeault. 2009. Development of a WQI for agricultural water use. *CESI-WQI 2008 Technical series*. Draft Report March 2009.

Intersol. 2007. Canadian Environmental Sustainability Indicators (CESI): Water quality indicator national workshop, Summary report of key discussion issues. *March 2007*.

Intrinsik. 2010. Synthesis of research and methods for developing water quality guidelines for the Canadian Environmental Sustainability Indicators (CESI) freshwater quality indicator. February 2010.

Kerala State Council for Science, Technology and Environment. 2009. Environmental monitoring programme on water quality. Centre for Water Resources Development and Management. ISBN 81-86366-70-09

Khan, Amir Ali, Renée Paterson and Haseen 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. *Water Qual. Res. J. Canada, 2004 • Volume 39, No. 3, 285–29*.

Khan, Haseen, Amir Ali Khan, and Sarah Hall. 2005b. The Canadian water quality index: A tool for water resources management. *Abstract code No: MTERM_Ab025. MTERM International Conference, 06 – 10 June 2005 AIT, Thailand 1*.

Amir Ali Khan, Shaden Abdel-Gawad and Haseen Khan. (2008). A Real Time Water Quality Monitoring Network and Water Quality Indices for River Nile. *Proceedings of the XIIIth International Water Resources Association (IWRA) World Water Congress, Montpellier, France, September 1- 4, 2008*. (http://www.iwra.org/congress/2008/resource/authors/abs894_article.pdf)

Kilgour and Associates. 2009. Reducing the sensitivity of the Water Quality Index to episodic events. *CCME PN 1435*. April 2009.

Koning, C.W., K.A. Saffran, J.L. Little, and L. Fent. 2006. Water quality monitoring: the basis for watershed management in the Oldman River basin, Canada. *Water, Science and Technology. Vol 53 No 10 pp 153-161*.

Lan, Trinh Thi and Nguyen Phuoc Long. 2011. Assessment of surface water quality by water quality index (WQI) at the Cai Sao canal, An Giang province, Vietnam. *Livestock Research for Rural Development. Volume 23, Article #151*. (<http://www.lrrd.org/lrrd23/7/lan23151.htm>)

Synthesis of Research and Application of the CCME Water Quality Index

Loomer, H.A., and S. E. Cooke. 2011. Water quality in the Grand River Watershed: Current conditions and trends (2003 – 2008). Grand River Conservation Authority. October 2011.

Lumb, Ashok, Doug Halliwell, and Tribeni 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* (2006) 113: 411-429.

Lumb, Ashok, T. C. Sharma, and Jean-Francois Bibeault. 2011a. A review of genesis and evolution of water quality index (WQI) and some future directions. *Water Qual Expo Health* (2011) 3: 11-24

Lumb, Ashok, T. C. Sharma, J-F Bibeault and P. Klawunn. 2011b. A comparative study of US based and Canadian water quality index models. *Paper presented to the 64th Annual Conference of the Canadian Water Resources Association, held June 27-30, 2011 in St. John's, Newfoundland and Labrador.*

Marion County Health Department, State of Indiana. Undated. Water quality index as applied to Fall Creek. (http://www.mchd.com/wq/html/wq_index_fall_creek.pdf)

Monitor Auckland. 2010. Marine water quality. Last updated March 10, 2010. (<http://monitorauckland.arc.govt.nz/natural-environment-and-heritage/coastal-management-home/marine-water-quality.cfm>)

Newfoundland and Labrador Department of Environment. Undated. Water quality index applied to the Exploits River watershed.

Painter, Scott and Jasmine Waltho. 2005. Canadian water quality index: A sensitivity analysis. Ecosystem Health Division, *Environmental Conservation Branch – Ontario Region, Environment Canada.*

Panduranga Murthy, G 1 and Hosmani, S.P. Undated. Water Quality Index (WQI) to Evaluate Surface Water Quality for Protection of Aquatic Life: A Case Study: Bherya Lake, Mysore, Karnataka State, India.

Pappas, Sheena, Stephanie Strachan, and Andrea Ryan. 201 draft. Combining two national aquatic monitoring approaches for reporting: A preliminary examination of biological and physical-chemical freshwater quality indicator results from selected sites in British Columbia. Environment Canada. April 2010 draft report.

Rocchini, R. J. and L. G. Swain. The British Columbia Water Quality Index. November 1995.

Statistics Canada. 2007. Environment Accounts and Statistics Technical Paper Series, Volume 2007,number 3, Behavioural Study on the Water Quality Index of the Canadian Council of Ministers of the Environment, catalogue number 16-001-MWE.

The Bay Institute Ecological Scorecard. 2003. San Francisco Bay Water Quality Index Indicator analysis and evaluation. October 17, 2003. (http://www.bay.org/assets/Water_Quality.pdf)

Tobin, Annette, Amir Ali Khan, Len Moores, and Jim Taylor. 2007. Forestry water quality index – A planning tool for the assessment and communication of the impacts of forestry activities on water quality. *The Forestry Chronicle*. Vol 83 NO 2. March/April 2007.

Tri-Star Environmental Consulting. 2008. A review of recent advances in water quality reporting. *Prepared for CESI office of Environment Canada. October 2008*

Tri-Star Environmental Consulting. 2011. Variables to Consider for Water Uses and Discharge Types. *Updated from original that was presented by Les Swain to the CCME 2005 Victoria 2nd national water quality index workshop, and subsequently modified with input from Andrea Czarnecki, Water Resources Division, Aboriginal Affairs and Northern Development Canada.*

Synthesis of Research and Application of the CCME Water Quality Index

UNEP. 2007. Global drinking water quality index development and sensitivity analysis report. *United Nations Environment Programme Global Environmental Monitoring System (GEMS)/Water Programme*. ISBN 92-95039-14-9.

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). *Alberta Environmentally Sustainable Agriculture Program, Resource Monitoring, Water Quality Monitoring Component*. August 1999.

Pham Thi Minh Hanh, Suthipong Sthiannopkao, Dang The Ba, and Kyoung-Woong Kim. 2011. Development of water quality indexes to identify pollutants in Vietnam's surface water. *J. Environ. Eng.* 137, 273 (2011); doi:10.1061/(ASCE)EE.1943-7870.0000314 (11 pages)

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Appendix 1 - **Variables to Consider for Water Uses and Discharge Types** (Source: Tri-Star Environmental Consulting, updated from original that was presented by Les Swain to the CCME 2005 Victoria 2nd national water quality index workshop, and modified in 2011 with input from Andrea Czarnecki, Water Resources Division, Aboriginal Affairs and Northern Development Canada)

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 (&CCSO) Discharges s	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	√	√	√	√		√	√	√	√		√		√		√		√	√	√

Synthesis of Research and Application of the CCME Water Quality Index

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
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									√										

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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
Se							√ ⁴	√	√			√ ⁴							
Ag									√										
Tl									√										
V								√	√							√			
Zn							√ ⁴		√		√	√ ⁴	√						
Cyanide							√ ⁴					√ ⁴							
PAHs								√	√		√	√	√			√		√	
Phthalates											√							√	
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