*Water Qual. Res. J. Canada, 1998*
*Volume 33, No. 4, 519-549*


# Analysis of the British Columbia Water Quality Index for Watershed Managers: a Case Study of Two Small Watersheds

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**The use of indices in ecosystem management is attractive because it allows for the representation of a complex set of information on ecosystem variables in a simple fashion. Recently the British Columbia Ministry of Environment, Lands and Parks developed the British Columbia Water Quality Index (BCWQI). As this index is currently being considered as the basis for other provincial indices and a national water quality index, the character of the BCWQI needs to be carefully considered. This study evaluates the performance of the BCWQI and assesses how useful and appropriate it is as a management tool at the watershed level. For this purpose the index is used to express the results of two sampling programs, one by the British Columbia Ministry of Environment, Lands and Parks, and the other by the Westwater Research Centre, of two relatively small watersheds in the Greater Vancouver area: the Brunette River watershed, heavily impacted by urbanization, and the Salmon River watershed on the urban-rural fringe. For both watersheds the intended use is the protection of aquatic life and only those water quality objectives are considered. The results indicate that the BCWQI is extremely sensitive to sampling design and highly dependent on the specific application of water quality objectives. A comparison is made with another type of index in widespread use in North America: the National Sanitation Foundation Water Quality Index (NSFWQI). This index appears promising for stream stewardship groups because of its simplicity and ease of use. For watershed managers, an alternative to the BCWQI is suggested, based on exceedance factors for individual objectives. This Simple Water Quality Index (SWQI) recognizes the importance of objectives that are specific to a particular water body, but overcomes some of the limitations of the BCWQI. A presentation format is suggested for objective exceedance factors, with a clear indication of exactly which objectives were included — without this, the final numerical index value is meaningless. This study suggests that the BCWQI in its current form has serious limitations for comparing water bodies and for establishing management priorities. If local watershed managers use the BCWQI in guiding efforts to protect aquatic resources, they should consider these limitations carefully.**

*Key words:* **water quality index, water quality objectives, water quality monitoring, watershed assessment, stormwater runoff**

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## Introduction

Recently the British Columbia Ministry of Environment, Lands and Parks (the Ministry) developed a water quality index and used it to evaluate the status of water quality for many water bodies in the province for which water quality objectives have been established (BCMOELP 1995a). These objectives are specific to the intended uses of the respective water bodies. The index was developed primarily to consistently reduce large volumes of technical information into something the public could understand. The initial application of the index was published in the Water Quality Status Report (BCMOELP 1996). This report was criticized by many water quality experts in the region. For example, in the case of the Brunette River watershed, a relatively small urban watershed in the Vancouver region, the index was in the "good" range for the protection of aquatic life even though there were long-standing water quality concerns in the watershed. In addition, while the index was not developed to be used by professionals to evaluate water quality conditions, local watershed managers perceive the index to be a useful tool in determining their progress in meeting water quality objectives. Given that aspects of the British Columbia Water Quality Index (BCWQI) are being evaluated by the Canadian Council of Ministers of the Environment for application in all provinces, a critical look is required at the limitations of this approach to using an index.

This study attempts to evaluate the performance of the BCWQI to gain insight into its usefulness as a tool for evaluating water quality conditions. Ideally, such a tool would accurately describe the environmental conditions (is there a problem?), identify spatial and temporal patterns (are things getting better or worse and what are the areas of highest concern?), and provide direction for future management efforts (what can we do about it?).

In theory the most rigorous testing of the index would be achieved by using a computational procedure for a number of hypothetical scenarios for sampling design, natural variability in water quality parameters, spatial and temporal patterns, and various sets of water quality objectives. While useful, this approach would only illustrate the qualities of the inherent design of the index. The focus of this study is the usefulness of the index in a practical setting and its relevance to the evaluation of water quality management efforts. Accordingly, the performance of the index is illustrated using two case studies: the Brunette and Salmon River watersheds. Both theoretical and practical considerations will be highlighted in this real-world application. These two watersheds are representative of small watersheds in British Columbia that are affected by urban and agricultural development, but do not represent all types of water bodies the Ministry has to deal with (which include both fresh and salt waters, lakes, rivers and water bodies of very different sizes).

Since water quality indices are used in other jurisdictions, one other popular index, the National Sanitation Foundation Water Quality Index, is evaluated using the Brunette River data. Finally, a simple alternative for the BCWQI is proposed which overcomes some of its shortcomings.

## Water Quality Management

### Water Quality Guidelines and Objectives

Water quality management efforts make use of criteria, guidelines, objectives and standards. For the purpose of this study, the definitions used by Strachan (1987) are used. Criteria are the scientific data evaluated to derive recommended (guidelines and objectives) limits for water uses. Guidelines are the numerical concentration limits or narrative statements recommended to support and maintain a designated water use. Objectives are the numerical concentrations or narrative statements that had been negotiated to support and protect the designated use of water at a specific site. Standards are objectives that are recognized in enforceable environmental control laws of a level of government.

A key component of these definitions is that criteria, guidelines and objectives are specific for particular designated uses: these can include drinking water, recreation, protection of aquatic life, agricultural uses and industrial water supplies. The most widely used guidelines in Canada are the Canadian Water Quality Guidelines (CCME 1995). In theory, these guidelines for specific uses are used to develop site-specific water quality objectives based on local considerations. Factors to be considered in this process are described in detail in Appendix V of the Canadian Water Quality Guidelines, and include the characteristics of the type of water body, local environmental conditions, processes affecting the concentration of parameters in water and factors that modify toxicity to aquatic organisms (CCME 1995). In practice, much of this information is not available for the many water bodies to be considered and the objectives for a particular water body are equal to the Canadian Water Quality Guidelines.

In theory, water quality objectives are more appropriate and useful than water quality guidelines because they are much better at taking local conditions into account. However, this requires a fairly good understanding of what those conditions are and how they might affect ecological functions. Another difficulty is that in practice the objectives established for a water body are often based on current designated uses, which in turn may already be based on the existing water quality conditions. Objectives, therefore, may not be a good reflection of (potential) water quality conditions in the absence of human disturbances.

An alternative to using a single numeric value in the form of a guideline or objective for specific water quality parameters is the use of probability distributions for environmental exposure concentrations and species response data. The overlap of these two distributions is a measure of the risk to aquatic life. This approach is far more rigorous than only determining whether or not guidelines or objectives are exceeded (for a good recent example of this approach, see Hall et al. [1997]). However, this ecological risk assessment approach to water quality evaluation requires very large and complete data sets and substantial analysis efforts. The use of single numerical water quality objectives for the protection of aquatic life is therefore still considered to be a useful approach to evaluate water quality conditions.

### Water quality indices

Water quality is an integrative measure of the impact of many stresses in a watershed. For the purpose of this study, water quality includes sediment quality and biota, because these media are considered in the water quality objectives of British Columbia. Typically water quality is assessed by measuring a wide range of parameters, including pH, dissolved oxygen, temperature, turbidity, alkalinity, conductivity, total and suspended solids, and the concentration of a variety of pollutants, including nutrients, pathogens, metals and organics, in addition to the concentration of pollutants in sediments and biota. No single parameter or medium is sufficient to adequately express water quality. On the other hand, the enormous amount of data generated by monitoring require some integration if the results are to be presented meaningfully to local watershed managers, decision makers and the general public.

For this reason, water quality indices have been developed, which try to integrate measurements of a variety of parameters into one single index, usually a dimensionless number between 0 and 100. Such indices can be used to compare different water bodies, or compare over time data for one water body. Several North American jurisdictions have used water quality indices (Ott 1978). More recently water quality indices have become popular in the United Kingdom (House et al. 1989; Newman 1992; Saeger 1994) and the Netherlands (RIVM 1997).

The use of indices is not unique to the area of water quality. For example, indices are very commonly used to express the integrity of invertebrate communities (e.g., Kerans et al. 1994; Kluada et al. 1998) and fish communities (e.g., Karr et al. 1987; Steedman 1998; Roth et al. 1998). Indices are also increasingly being used for habitat quality (e.g., Yoder et al. 1998; Wang et al. 1997) and the condition or entire ecosystems (Brooks et al. 1998). Considering the popularity of indices to express biological and physical attributes of aquatic resources, the limited number of attempts to develop water quality indices is in fact surprising. Table 1 highlights some of the major advantages and disadvantages of the use of indices, as well as some indication of their most appropriate uses.

## Case Study

### Description of the Brunette and Salmon River Watersheds

The BCWQI was tested using case studies of the Brunette and Salmon River watersheds, both in the Greater Vancouver region in British Columbia, Canada (Fig. 1). The Brunette is a small urban watershed of 70 km$^2$, while the Salmon is a small watershed of 80 km$^2$ on the urban-rural fringe. Both are lowland watersheds, dominated by heavy rainfall

**Table 1.** Considerations for the use of indices

| Advantages of indices | Disadvantages of indices |
|---|---|
| • Represents measurements of a variety of parameters as a single index, thereby reducing complexity.<br>• Allows for the combination of various parameters with different units into a single metric.<br>•Facilitates the communication of results by using a single metric unit or dimensionless score. | • Makes trends in single parameters invisible.<br>• Results are highly sensitive to how the index is derived or calculated.<br>• Interpretation of the results is specific to the particular index and cannot be extrapolated to similar indices.<br>• Many indices are developed for specific types of ecosystems and regions and cannot simply be transferred to other areas.<br>• Interactions between parameters are not considered. |
| **What can be done with indices** | **What cannot be done with indices** |
| •Illustrate general spatial and temporal trends in overall conditions.<br>•Explore relationships with other variables by using graphical representations and correlations.<br>• Compare index values to values of reference sites established as part of the development of the index. | • Carry out calculations, such a averaging over time, calculating means, etc., beyond what the index was designed for.<br>• Run (multiple) regression analysis.<br>• Attribute meaning to the index values without reference to how the index was developed originally. |

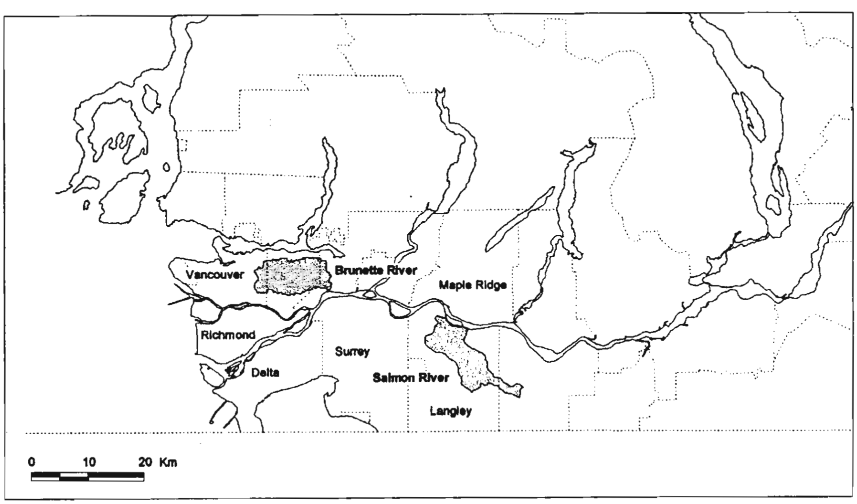


**Fig. 1.** Location of case study watersheds in the Greater Vancouver region.

from November to March and long dry periods in the summer. In the Brunette River watershed, urbanization has had a significant impact on the aquatic biota in the watershed and its use for recreational activities. The watershed has been studied extensively to determine the cumulative effects of urbanization; for example, the extent of hydrocarbon pollution in the watershed was recently documented by Larkin et al. (1998). In the Salmon River watershed, agricultural and residential development have transformed the landscape dramatically, but overall conditions of the aquatic biota in the watershed is considered good (Westwater Research Centre 1993). The watershed has been studied extensively to determine the cumulative effects of urbanization; for example, nitrate-N dynamics in the watershed were recently documented by Wernick et al. (1998)

### Sampling Design: Ministry of Environment versus Westwater

Water quality information was obtained from two sources: the Ministry of Environment and the Westwater Research Unit of the University of British Columbia. The two sampling programs are described in Table 2. The location of the sampling stations for both programs in the two watersheds are shown in Fig. 2 and 3. The Ministry's monitoring is typical of the water quality sampling carried out by a regulatory agency as part of a much larger program for monitoring a wide variety of water bodies under its jurisdiction; the Westwater program is typical of a research project and represents a comprehensive and focused sampling program. No information is provided in Table 2 on the timing of sampling in relation to the hydrograph, which is of crucial importance. While the Ministry has monitored baseflow conditions, no information is provided on the exact timing of the sampling. Westwater's sampling included both stormwater events and baseflow conditions, typically at least several days after the last rainfall. The implications of the possible differences in timing for baseflow monitoring are not explored in this study.

The Ministry's data used in this study are taken from SEAM (BCMOELP 1995b), the database used by the Ministry for the Status of Water Quality Report. No complete data could be obtained for the Salmon River, so the comparison for this watershed is not complete. The Westwater data used in this study only represent the most recent sampling efforts (Macdonald et al. 1997; McCallum 1995; Wernick 1996) and not all available data. The two contrasting sampling designs allow for a comparison of the effect of sampling design on the water quality index.

### Water Quality Objectives for the Case Study Watersheds

Objectives have been established by the Ministry for 21 water quality parameters in the Brunette River watershed and 6 in the Salmon River watershed (Tables 3 and 4). These objectives are based on the "approved and working criteria for water quality" in British Columbia (Nagpal et al. 1994), which in turn are based on the Canadian Water Quality Guidelines (CCME 1995). The objectives for the Brunette River watershed apply to

**Table 2.** Characteristics of the sampling programs in the case study watersheds

| | Ministry of Environment | Westwater |
|---|---|---|
| **Brunette River watershed — water** | | |
| | 1990–93 | 1994–95 |
| Water bodies sampled and number of stations (baseflow conditions) | Brunette River (2)<br>Still Creek (1)<br>Deer Lake (1)<br>Burnaby Lake (1)<br>4 in total | Brunette River(2)<br>Still Creek (5)<br>Eagle Creek (2)<br>Stoney Creek(2)<br>Creeks around Deer Lake (2)<br>5 in total |
| Total number of stations | 5 (baseflow only) | 13 (baseflow); 3 (storm events); 4 (street runoff) |
| Frequency of sampling | 20 times in 4 years (baseflow only) | 10 times in 2 years (baseflow); 12 times (storm events); 8 times (street runoff) |
| Number of parameters typically measured | 14 | 34 |
| Total number of measurements | 750 | 2500 (baseflow)<br>2800 (storm events)<br>1500 (street runoff) |
| **Brunette River watershed — metals in streambed sediments** | | |
| | 1990–93 | 1994 |
| Total number of stations | 4 | 36 |
| Frequency of sampling | 4 times in 4 years | Once |
| Number of parameters | 15 | 10 |
| Total number of measurements | 450 | 360 |
| **Salmon River watershed — water** | | |
| | 1986–1993 | 1994–1995 |
| Water bodies and number of stations | Middle (2) and lower (2) Salmon River | Upper (3), middle (3) and lower (2) Salmon river; Coghlan Creek (2), Davidson Creek (1) |
| Total number of stations | 4 (baseflow only) | 11 (baseflow only) |
| Sampling frequency | Varies | 8 times in 1 year (baseflow) |
| Number of parameters | Varies | 10 |
| Total number of measurements | Not determined | 400 (baseflow) |

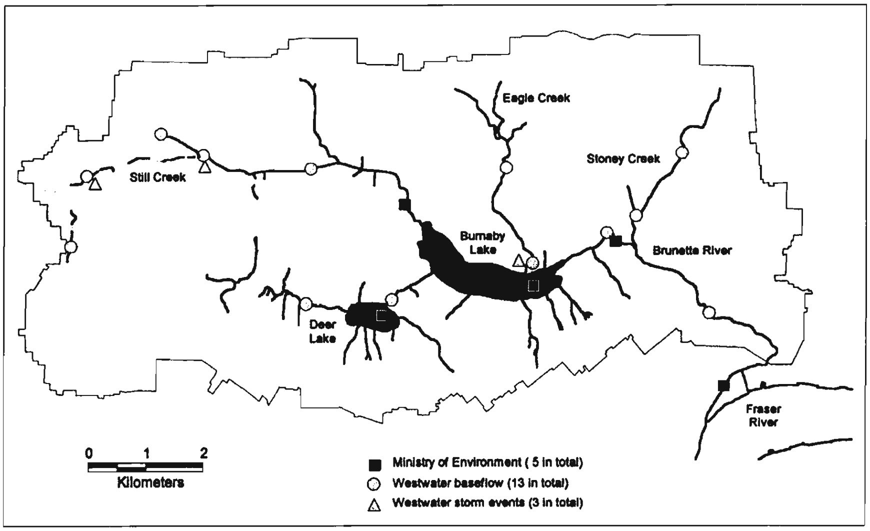


Fig. 2. Location of sampling stations and water bodies in the Brunette River watershed.

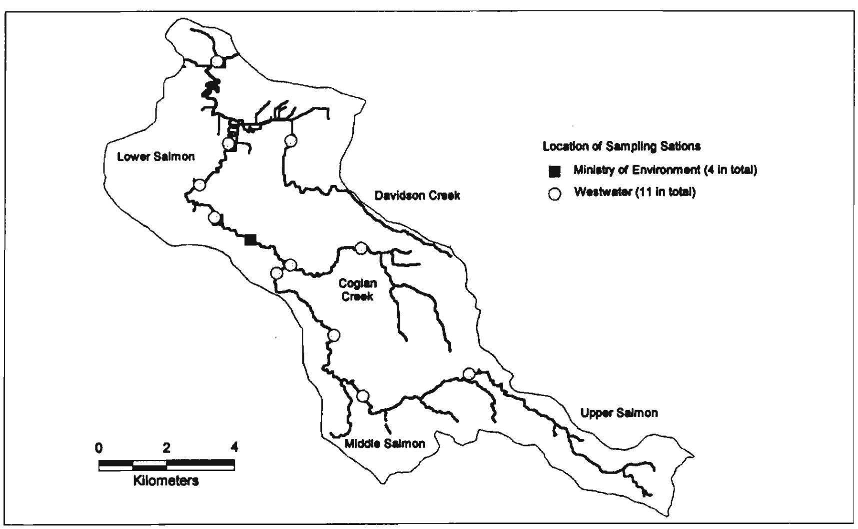


Fig. 3. Location of sampling stations and water bodies in the Salmon River watershed.

**Table 3.** Water quality objectives for the Brunette River watershed[1]

| Parameter | Objective | Notes |
|---|---|---|
| pH | 6.5 to 8.5 | |
| Dissolved oxygen | 6 mg/L<br>8 mg/L<br><br>11 mg/L | Still Creek and lakes April–Oct (short term)<br>Still Creek and lakes April–Oct (long term<br>Brunette River April–Oct<br>All waters Nov–March (long term) |
| Suspended solids | Increase of 10 mg/L or 10% | Greater of the two criteria applies |
| Turbidity | Increase of 5 NTU or 10% | Greater of the two criteria applies |
| Fecal coliforms[2] | 200 /100 mL<br>400 /100 mL | Geometric mean<br>90th percentile |
| E.coli[2] | 77 /100 mL | Geometric mean (long term) |
| Enterococci[2] | 20 /100 mL | Geometric mean (long term) |
| Ammonia-N[3] | 1.84 mg/L<br>0.762 mg/L<br>9.31 mg/L | Average @ pH=7; T=10°C<br>Average @pH=8; T=20°C<br>Average @pH=8; T=20°C |
| Nitrite-N | 0.02 mg/L<br>0.06 mg/L | Average<br>Maximum |
| Total P[4] | 0.015 mg/L | Average long-term objective April–October |
| Chlorophyll *a*[5] | 100 mg/m$^2$ | |
| Total copper | 2 µg/L<br>5 g/L | Long-term average<br>Long-term maximum value |
| Total lead | 4 µg/L<br>12 µg/L<br>18 µg/L | 30-day average<br>Maximum value for lakes<br>Maximum value for streams |
| Total zinc | 30 µg/L | Maximum value |
| Total chromium | 20 µg/L | Maximum value |
| Total copper in sediments | 30 mg/kg | Long-term average |
| Total lead in sediments | 5 mg/kg | Long-term average |
| Total mercury in sediments | 0.07 mg/kg | Long-term average |
| Total zinc | 70 mg/kg | Long-term average |
| Total lead in fish muscle[5] | 0.8 µg/g wet weight | |
| Total mercury in fish tissue[5] | 0.05 µg/g wet weight | |

[1] Based on Swain (1989); objectives include sediment and fish tissue concentrations. All objectives are for the protection of aquatic life, except the presence of pathogens (fecal coliforms, E. coli and Enterococci), which are for recreation.

[2] Objectives for pathogens are only for lakes, not for streams, since only the lakes are designated for secondary contact recreation.

[3] Ammonia objective varies with temperature and pH (Nagpal et al. 1995); only two values are shown here for illustration.

[4] Total phosphorous objective is only for lakes.

[5] Not so commonly measured.

**Table 4.** Water quality objectives for the Salmon River watershed[1]

| Parameter | Objective | Notes |
|---|---|---|
| Ph | 6.5 to 8.5 | |
| Dissolved oxygen | 11.2 mg/L<br>8 mg/L<br>6 mg/L | During embryo and larval stages of salmonids.<br>During other life-stages of fishat all times. |
| Ammonia[2] | 0.03 mg/L<br>0.007 mg/L | Unionized, maximum per sample.<br>Unionized, mean value for five weekly samples during 30-day period. |
| Nitrite | 0.02 mg/L as N | Continuous exposure of salmonids. |
| Nitrate + nitrite | 40 mg/L as N | |
| Fecal coliforms[3] | 4000/100 mL<br>1000/100 mL<br>100/100 mL[3] | Maximum for irrigation and livestock watering.<br>Geometric mean over 30-day period for irrigation.<br>90th percentile for domestic water withdrawal. |

[1] Based on Swain (1989). All objectives are for the protection of aquatic life, except the fecal coliform objectives which are for agricultural uses.

[2] The objective for ammonia is set for the unionized form ($NH_3$), which is different from total ammonia.

[3] The 100 per 100 mL objective for fecal coliforms is a proposed objective only and not considered in the calculations.

the Brunette River, Still Creek, Burnaby Lake and Deer Lake (differences among the water bodies are highlighted in the table where applicable), but not to the smaller tributaries. The designated use for the streams in the Brunette River watersheds is the protection of aquatic life. For the two lakes in the Brunette River watershed, the designated use includes the protection of aquatic life and recreation. As a result, the objectives for fecal coliforms, E. coli and Enterococci only apply to the lakes. It should be noted, however, that the streams in the Brunette are in fact being used for recreation (e.g., wading through the stream, recreating on the banks).

The objectives for the Salmon River watershed apply only to the main stem of the Salmon River itself and not to the tributaries. The designated uses for the Salmon River watershed are the protection of aquatic life and agricultural use (livestock watering and irrigation). The only objectives which apply to the agricultural uses are fecal coliforms — all others apply to the protection of aquatic life.

Some objectives are set relative to a reference condition: for example, the objective for suspended solids is 10 mg/L or 10% over an upstream control site, whichever of the two is greater. The Ministry, however, typically does not establish a control site for the Brunette River watershed, so the measurements for turbidity and suspended solids are not considered in the objectives evaluation by the Ministry.

## British Columbia Water Quality Index

### Description of the Index

The BCWQI was developed in 1995 by the Ministry. The index is based on the attainment of water quality objectives which have been developed for more than 100 water bodies in British Columbia. A complete description of the index can be found in a technical document from the Ministry (BCMOELP 1995a). Only a brief description is provided here. The BCWQ is defined as:

$$BCWQI = \sqrt{(F_1)^2 + (F_2)^2 + (\frac{F_3}{3})^2} / 1.453 \qquad (1)$$

where $F_1$ is the number of objectives not met as percent of all objectives checked; $F_2$ is the frequency with which objectives not met as percent of all instances of objectives being checked; and $F_3$ is the amount by which objectives not met as the maximum deviation for any one objective.

All three factors are percent values between 0 and 100. The deviation in factor $F_3$ is calculated as [(measured value — objective] / measured value *100%] for objectives defined as a maximum value; for objectives defined as a minimum value (e.g., dissolved oxygen) the deviation is calculated as [(objective — measured value] / objective * 100%). The factor $F_3$ was divided by three since testing of the formula indicated that this factor was very dominant in certain data sets (BCMOELP 1995a). The factor 1.453 assures the maximum value of the formula is 100. To illustrate how the BCWQI is calculated, Table 5 shows the calculation of the index for one station in the Brunette River watershed using Westwater data. The BCWQI values range from 0 to 100: the lower the value, the better the water quality. A qualitative description of the water quality conditions associated with the index values is given in Table 6.

### Calculating the British Columbia Water Quality Index Using Ministry Data

Since limited information is provided in the Status of Water Quality Report (BCMOELP 1996) with respect to the data and objectives included in the calculations of the BCWQI, the index was recalculated using the Ministry's own data to determine if the Ministry's results could be replicated. Earlier water quality reports had indicated that the Ministry often omits results for lack of reference conditions (upstream sampling location in the case of suspended sediments and turbidity) and high detection limits (for some metals in the water column). To explore the impact of these

**Table 5.** Example calculation of the BCWI at one station (Atlin station) in Still Creek using Westwater data

| | | Sampling results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Objective** | 5/25/94 | 6/29/94 | 7/26/94 | 8/24/94 | 10/3/94 | 11/24/94 | 2/1/95 | 5/25/95 | 7/31/95 | 8/22/95 |
| DO (mg/L) | 6.0 (summer); 11.0 (winter) | 6.4 | 7.4 | 6.5 | 6.6 | 7.8 | 10.9 | 11.8 | 9.4 | 7.9 | 7.3 |
| Objective exceeded? | | no | no | no | no | no | yes | no | no | no | no |
| Deviation (%) | | — | — | — | — | — | 0.91 | — | — | — | — |
| pH | 6.5 to 8.5 | 7.15 | 7.26 | 7.57 | 7.04 | 7.42 | 7.69 | 7.40 | 7.12 | 7.53 | 7.60 |
| Objective exceeded? | | no | no | no | no | no | no | no | no | no | no |
| Deviation (%) | | — | — | — | — | — | — | — | — | — | — |
| Turbidity (NTU) | 13 (summer); 17 (winter) | — | 16 | 11 | 11 | 4 | — | 20 | 7 | 8 | 5 |
| Objective exceeded? | | — | yes | no | no | no | — | yes | no | no | no |
| Deviation (%) | | — | 18.8 | — | — | — | — | 15.0 | — | — | — |
| TSS (mg/L) | 19 (summer); 28 (winter) | — | — | — | — | — | — | 28 | 0.8 | 9 | 14 |
| Objective exceeded? | | — | — | — | — | — | — | no | no | no | no |
| Deviation (%) | | — | — | — | — | — | — | — | — | — | — |
| $NH_3$-N (mg/L as N) | >1.50 | 1.12 | 0.72 | 0.49 | 0.43 | 0.37 | 0.13 | 0.14 | 0.52 | 0.36 | 0.30 |
| Objective exceeded? | | no | no | no | no | no | no | no | no | no | no |
| Deviation (%) | | — | — | — | — | — | — | — | — | — | — |

*(continued)*

**Table 5.** *(concluded)*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Cu (µg/L) | 5 | | | 18 | 27 | 35 | 21 | 12 | 18 | 31 | 16 |
| Objective exceeded? | | — | — | yes | yes | yes | yes | yes | yes | yes | yes |
| Deviation (%) | | — | — | 71.4 | 81.5 | 85.7 | 76.2 | 58.3 | 72.2 | 83.9 | 68.8 |
| Total Pb (µ/L) | 18 | | | | | | 0.9 | 1.9 | 1.1 | 0.9 | 0.2 |
| Objective exceeded? | | — | — | — | — | — | no | no | no | no | no |
| Deviation (%) | | — | — | — | — | — | — | — | — | — | — |
| Total Zn (µ/L) | 30 | | 67 | 35 | 87 | 33 | 34 | 18 | 24 | 48 | 29 |
| Objective exceeded? | | — | yes | yes | yes | yes | yes | no | no | yes | no |
| Deviation (%) | | — | 55.3 | 14.3 | 65.5 | 9.1 | 11.8 | — | — | 37.5 | — |

$F_1$ = number of objectives not met ÷ number of objectives checked x 100% = 4 ÷ 8 x 100% = 50.0%. $F_2$ = frequency of objectives not met ÷ all instances of objectives being checked x 100% = 17 ÷ 64 x 100% = 26.6%. $F_3$ = maximum deviation for any one objective = 85.7%.
BCWQI = 44 (borderline conditions).

**Table 6.** Interpretation of BCWQI values

| Index value | Description of water quality |
|---|---|
| 0–3 | Excellent |
| 4–17 | Good |
| 18–43 | Fair |
| 44–59 | Borderline |
| 60–100 | Poor |

types of omissions, four basic scenarios were used: (1) only the basic parameters not requiring a reference site — these basic parameters include pH, dissolved oxygen, nitrite, ammonia and chlorophyll *a*; (2) the basic parameters with a reference condition for suspended solids and turbidity; (3) use of the basic parameters including metals in the water column; and (4) the basic parameters with a reference condition for suspended solids and turbidity and including metals in the water column. Calculations were carried out for Still Creek and the Brunette River only, since the Westwater monitoring did not include samples from Deer Lake and Burnaby Lake. Since the designated water uses for the streams do not include recreation, fecal coliform objectives have not been established for the streams and these data were not used in calculating the index for the streams. Objectives for metals in sediments were not used in these calculations.

The reference condition for suspended sediments and turbidity was based on the Westwater data set and was set to the average value for that water body over the whole course of the monitoring program, differentiating between summer and winter conditions. This effectively sets the objective for suspended sediment at 10 mg/L above the baseflow average, and for turbidity at 5 NTU above the baseflow average. Given the high turbidity and sedimentation in the system during non-baseflow conditions, this is a fairly conservative approach. Based on Westwater's baseflow monitoring, the objective for suspended sediment for the different water bodies in the Brunette River watershed varies from 15 to 19 mg/L in summer and from 19 to 28 mg/L in winter. The objective for turbidity varies from 8 to 13 NTU in summer and from 10 to 17 NTU in summer.

Figure 4 compares the original assessment by the Ministry with the four recalculated scenarios using the Ministry's data. According to the Status of Water Quality Report (BCMOELP 1996) the objectives included in the analysis are suspended sediment, turbidity, ammonia, nitrite, chlorophyll *a*, dissolved oxygen, metals and pH. No information is provided on which objectives were actually included in the calculations, but suspended sediment and turbidity were most likely not included as the Ministry does not regularly sample at an upstream location, which is required to check these objectives. Whether metals are included is doubtful since metals data for the Brunette River watershed have typically been

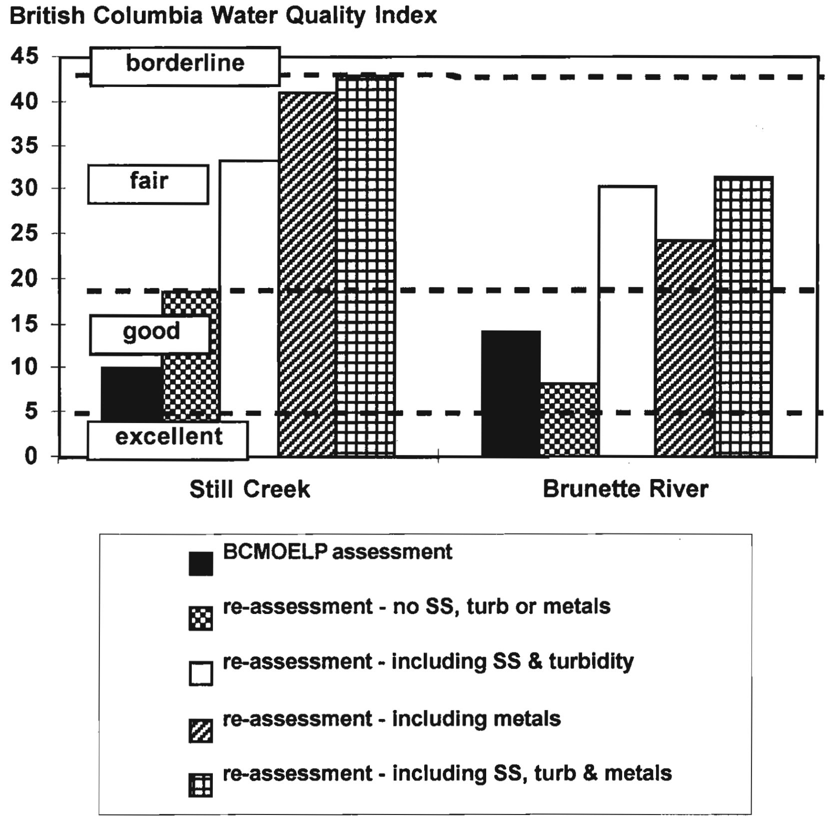


**Fig. 4.** British Columbia Water Quality Index values based on Ministry data for different assumptions. The Ministry monitoring was carried out at one station in Still Creek and two stations in the Brunette River for the period 1990–93, for a total of 20 sampling dates. The results show the sensitivity of the index values to the set of objectives included in the analysis.

disregarded in interim water quality objectives attainment reports (e.g., BCMOELP 1991). The reporting format of the Ministry does not allow for an exact replication of the index calculation, but only excluding the data on metals, suspended sediments and turbidity gives results similar to those published in the Water Quality Status Report. The inclusion of the data on suspended solids and turbidity or on metals in the analysis results in much higher index values; the inclusion of all variables together gives the highest score. Not only are the index values much higher, indicating water quality is "fair" instead of "good", the analysis also shows higher values for Still Creek than for the Brunette River — the reverse of the original assessment by the Ministry. It should be noted here that suspended solids and total metals are often closely associated in stormwater, so the small differences between including either one of them or both are not surprising.

While the selection of the reference conditions for suspended solids and turbidity and the use of some of the metal data (Cu in particular) are somewhat arbitrary, the analysis clearly suggests that the index values are highly sensitive to the parameters included in the calculation and the interpretation of the objectives related to reference conditions. It also illustrates that without proper documentation of this interpretation and without a discussion of which objectives and which data were considered, the index values cannot easily be verified by other parties. It should be pointed out that the recalculations presented here are not necessarily better: they are only presented here to demonstrate how the final assessment is influenced by the interpretation of the objectives.

No reassessment of the BCWQI for the Salmon River was conducted as no complete data set could be obtained. The Ministry's report resulted in an index value of 14, indicating "good" conditions.

### Calculating the British Columbia Water Quality Index Using Westwater Data

There were two reasons for using data from Westwater when calculating the BCWQI: (1) to determine the extent to which a different monitoring program leads to different results and (2) to determine the performance of the index when dealing with spatial and temporal variability.

When using the Westwater data for the Brunette River watershed, the maximum number of objectives was included, corresponding to scenario 4 under the previous section (reference conditions for suspended sediments, turbidity and metals). The set of objectives considered consists of pH, dissolved oxygen, ammonia, suspended solids, turbidity, and copper, lead and zinc in the water column. Since no objectives exist for the other streams for which data were available, the objectives established for the Brunette River were used for the Eagle Creek, Stoney Creek and the streams around Deer Lake. Again, no data on fecal coliforms and metals in sediments were included.

The BCWQI values using the Westwater data are presented in Fig. 5 and compared to the original assessment by the Ministry and the reassessment using Ministry data with the maximum number of parameters. The results show that the reassessed Ministry data reveals index values relatively similar to the baseflow monitoring data from Westwater, albeit a little lower. This suggests that the much more intense monitoring does not necessarily lead to different results. However, Fig. 5 also illustrates two major benefits from the more intense monitoring. First, a better understanding of the spatial variation in water quality conditions is indicated: index values for baseflow conditions using Westwater data for Stoney and Eagle Creek, for example, are very different than for Still Creek and the Brunette River. This illustrates that a water quality monitoring design that excludes streams only because no objectives have been set for them can be misleading. Second, a better reflection of the dynamic nature of water quality is indicated: index values during storm events are higher than during baseflow, with summer storms being more polluted

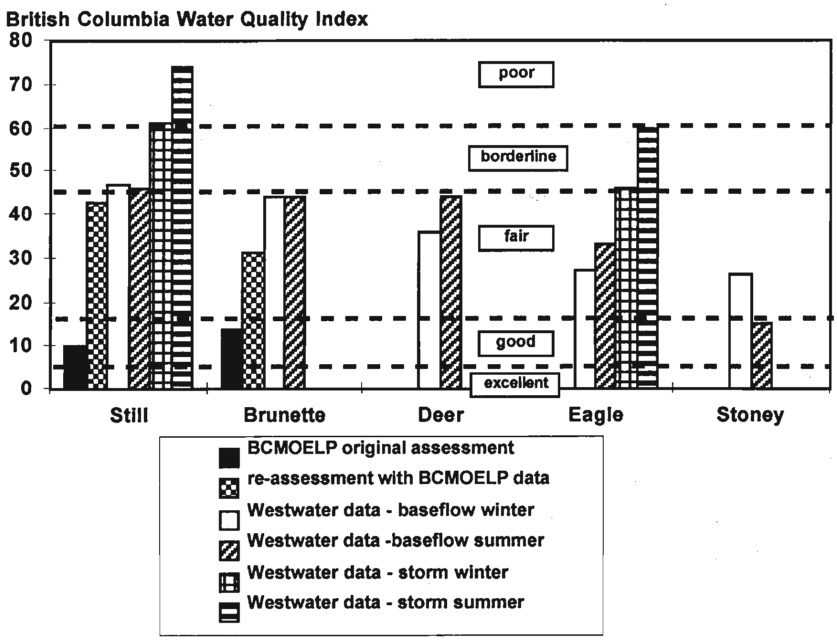


Fig. 5. British Columbia Water Quality Index values based on Ministry and Westwater data for different conditions. Ministry monitoring was carried out at one station in Still Creek and two stations in the Brunette River for the period 1990–93, for a total of 20 sampling dates. Westwater baseflow monitoring was carried out at five stations in Still Creek and two stations in each of the other streams for the period 1994–95 for a total of 10 sampling dates. Storm event monitoring by Westwater was carried out at two stations in Still Creek and one in Eagle Creek for the period 1994–95 for a total of 12 sampling dates. Objectives have been established only for Still Creek and the Brunette River. The objectives for the Brunette River were used for the tributaries around Deer Lake and Eagle Creek and Stoney Creek. The re-assessment with Ministry data includes the use of a reference condition for suspended sediments and turbidity, and the use of metal data, similar to the procedure used for the Westwater data. All water bodies are located within the Brunette River watershed. The results show the sensitivity of the index values to sampling design and to flow conditions.

than winter storms, while differences between summer and winter baseflow conditions are small. This corresponds well with the findings from the detailed stormwater loading calculations based on the water quality monitoring (Macdonald et al. 1997), which indicate that summer storms are higher in loadings as a result of the longer dry periods between storms. This illustrates that monitoring only during baseflow conditions can be very misleading. The index itself, however, performs sufficiently to reveal these dynamics.

Despite the use in Fig. 5 of the index to illustrate differences between water bodies and between summer and winter conditions, in general the

BCWQI is not a good indicator for demonstrating spatial or temporal trends. To illustrate this, Fig. 6 shows the index for five stations in Still Creek and compares it to the recalculated index value for Still Creek if data from all five stations were combined. The combined index value is not simply the average of the five values, but is recalculated by pooling all sampling results. In the case of baseflow conditions, the index for the combined data (47 in winter, 46 in summer) is higher than the average of the index values for the five stations (44 in winter, 33 in summer). In fact, the combined index value for summer baseflow is much higher than any of the values for the individual stations. This is not a coincidence, but a direct result of the calculation procedure of the index: for almost all data sets, factors F1 and F3 will increase as the monitoring intensity in a single water body increases (more stations and/or more frequent monitoring), while F2 will remain about the same, even when exactly the same parameters are measured. This increase in F1 and F3 is related to the increased probability of exceeding objectives with large sample size. Basically, the more intense the monitoring, the worse water quality will appear to be. This is especially true when going from a very low intensity (several samples at one station) to a medium intensity (many samples at several stations): further intensity increases will only lead to minor changes in the index.

In the case of the Salmon River watershed, the objectives considered are pH, dissolved oxygen, nitrate + nitrite nitrogen and fecal coliforms. Ammonia was not considered because the objectives are set for ammonia ($NH_3$) while ammonia + ammonium ($NH_4^+$) was determined in the Westwater study (ammonia could be calculated using pH and tempera-

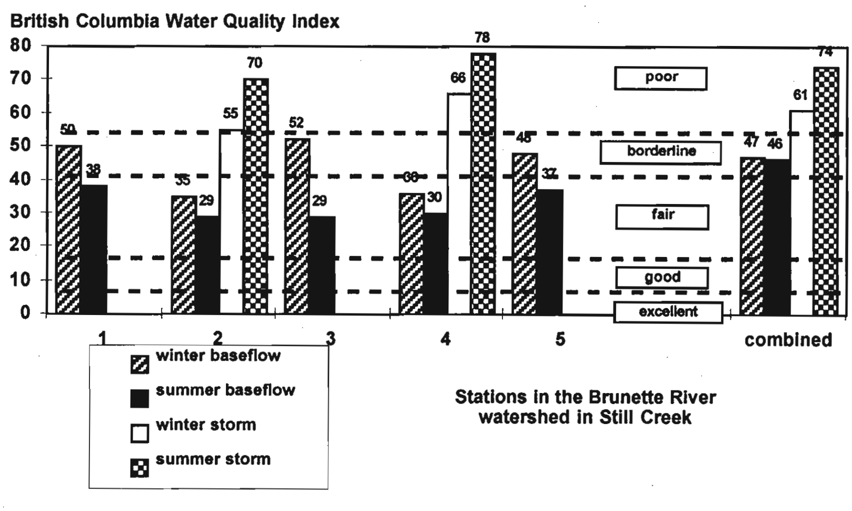


**Fig. 6.** British Columbia Water Quality Index values for Still Creek at the five monitoring stations compared to the index values for the whole water body, using Westwater monitoring data. These combined index values represent a recalculation of the index after pooling the water quality measurements from the individual stations.

ture, but this is not pursued here) For fecal coliforms, the objective for domestic water use (100/100mL) was not considered as it is only a proposed objective; the irrigation and livestock watering objectives were used instead.

Figure 7 shows the BCWQI values for three sections of the Salmon river and two tributaries in addition to the value for the whole watershed after pooling all the data (all using Westwater data) and the result of the assessment by the Ministry (using its own data). The differences are evident, with the Ministry's result indicating "good" conditions and the results from this study indicating "good" to "fair" conditions. The Ministry's sampling locations included both the lower (2 stations) and the middle (2 stations) Salmon River, so the difference is not due to differences in the spatial distribution of sampling. Again, aggregation of the data from all stations for an assessment of the whole watershed results in a higher index value (if the domestic water intake objective for fecal coliforms were used, the index value would be 56, suggesting "borderline" conditions). A closer examination of the factors which cause these relatively high index values indicates that objective exceedances only occurred for pH and dissolved oxygen (objectives for nitrate + nitrite nitrogen and fecal coliforms were never exceeded). In addition, the exceedances were fairly minor. Because so few objectives (four in this case) are established, these minor exceedances result in high index values. The requirement of having at least three independent objectives for using the BCWQI (BCMOELP 1995a) appears insufficient. In addition, one of the key water quality concerns in the watershed (nitrate pollution resulting from agriculture and septic system) does not affect the index because objectives are only set for aquatic life and not the lower drinking water objective. The nitrate problems are addressed for the Hoppington aquifer which provides summer base flow for the river, but the index for the aquifer has little meaning because only one objective is considered (in this case the drinking water objective for nitrate-nitrogen).

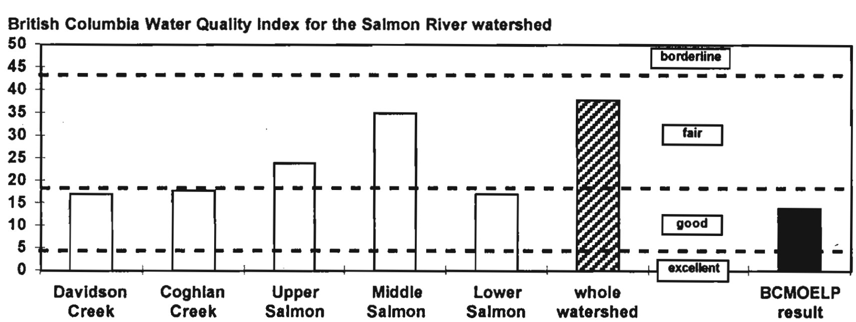


**Fig. 7.** British Columbia Water Quality Index values for the Salmon River based on Westwater monitoring, compared to the results for the watershed as determined by the Ministry. All water bodies are located within the Salmon River watershed.

The case study results indicate that the usefulness of the index values is very dependent on the quality and consistency of the monitoring design. This dependence makes the index inappropriate for the analysis of spatial and temporal trends, either within one water body or among water bodies. Comparing the index values for different water bodies, such as done in the water quality status report, can therefore be very misleading since each index value is based on a different monitoring program and a different set of objectives.

It should be recognized that the fairly low intensity and irregular nature of the sampling carried out by the Ministry in most water bodies is typical of most monitoring at the provincial/regional level. As a result, the BCWQI values should be considered very unreliable and should not be used as the basis for any sort of comparative analysis among water bodies or decisions on the allocation of resources for water quality management among different water bodies. Furthermore, while the BCWQI might serve a purpose at the provincial/federal level for developing a report card on water quality management, the use of the BCWQI by watershed managers for evaluating water quality conditions should be discouraged.

## National Sanitation Foundation Water Quality Index

### Description of the Index

The National Sanitation Foundation Water Quality Index (NSFWQI) was developed in the 1970s with an extensive expert consultation process using the Delphi technique. The consultation process consisted of sending out questionnaires to experts, integrating the responses and sending the results out again for further refinement. The result was a set of nine key water quality indicators (DO %, FC, pH, $BOD_5$, temperature, $PO_4$-P, $NO_3$-N, turbidity and total solids), complete with rating curves and an additive, weighted integration mechanism. The NSFWQI is very widely used in water quality sampling manuals for community groups and has been used in modified form by many jurisdictions in North America (Ott 1978).

A rating curve exists for each of the nine parameters. Each curve was constructed by finding an "average" curve among a set of curves drawn by experts. As a result, some curves (pH, temperature and total solids) do not have a maximum value of 100. All curves, except for temperature, are absolute, that is, the field measurements are used directly in the rating curve, without consideration of objectives or reference conditions. In the case of temperature, the parameter to be considered is a temperature increase compared to a reference condition, which could be upstream or in another water body. The final score is derived by multiplying the score for each of the nine parameters with a set of weight factors and summing up these results, as shown in the equation below.

$$\text{NSFWQI} = \sum_{i=1}^{9} (\text{weightfactor})_n * (\text{parameter score})_n \qquad (2)$$

The weights were the result of the expert consultation process, but can be modified to suit regional needs (which was not pursued for this study). If certain parameters were not measured, a comparable final score can be derived by adjusting the weights to reflect the new total maximum score. The final score (between 0 and 100) is than compared to a predefined scale to come up with a qualitative description of the water quality. A score is derived for each individual sample, but the simple additive formula makes it possible to combine data from multiple samples at one site or from multiple sites. It is important to note that the scoring for the NSFWQI is the opposite of the BCWQI: in the case of the NSFWQI higher index values indicate better conditions.

A more elaborate description of how the index was developed can be found in Ott (1978). Rating curves for all nine parameters and more elaborate descriptions on how to use the index can be found in many water quality monitoring manuals, such as Mitchell et al. (1991). A description of a simplified version of the index, using only dissolved oxygen, temperature, pH and turbidity, is part of the popular Streamkeepers handbook (Tacogna et al. 1995), used by many local stream stewardship groups in British Columbia.

Since the NSFWQI and the BCWQI are very different in their approach to assessing water quality, no attempt is made to rigorously compare the performance of both indices. However, the Westwater data were used to demonstrate the use of the index.

## Calculation of the NSFWQI

To illustrate the use of the index, the Westwater data were used to calculate index values for the Brunette River watershed for baseflow conditions. Not all nine parameters in the index were measured directly, so the following considerations are in place: total solids was calculated as 0.6 x specific conductivity + total suspended solids (Clesceri et al. 1989); and BOD was not measured for all samples, so 30% of the COD value was used, based on the relationship between COD and BOD for those samples where BOD was measured.

The use of only seven directly measured parameters limits the interpretation of the results, but no attempts are made here to calculate the final index values or compare them to other water bodies.

Figure 8 illustrates the NSFWQI for three streams in the Brunette River watershed. The results immediately illustrate that fecal coliforms are a concern in all streams (streams with scores below 50 are considered "poor"), but particularly in Still Creek, while dissolved oxygen and BOD are also a concern in some streams.

## Advantages of the NSFWQI

The NSFWQI describes water quality based on nine water quality parameters. While it lacks the ability of directly determining whether water quality objectives are met, it does not depend on how comprehensive the objectives setting process is. This allows for a much wider use of the index for water bodies for which no objectives have been established.

Since the NSFWQI is calculated using a strictly additive, weighted formula of one-dimensional scores, the index for multiple samples (from different times or locations) is simply the average of the index values of the individual samples. The results across different water bodies with different monitoring program will therefore be more comparable.

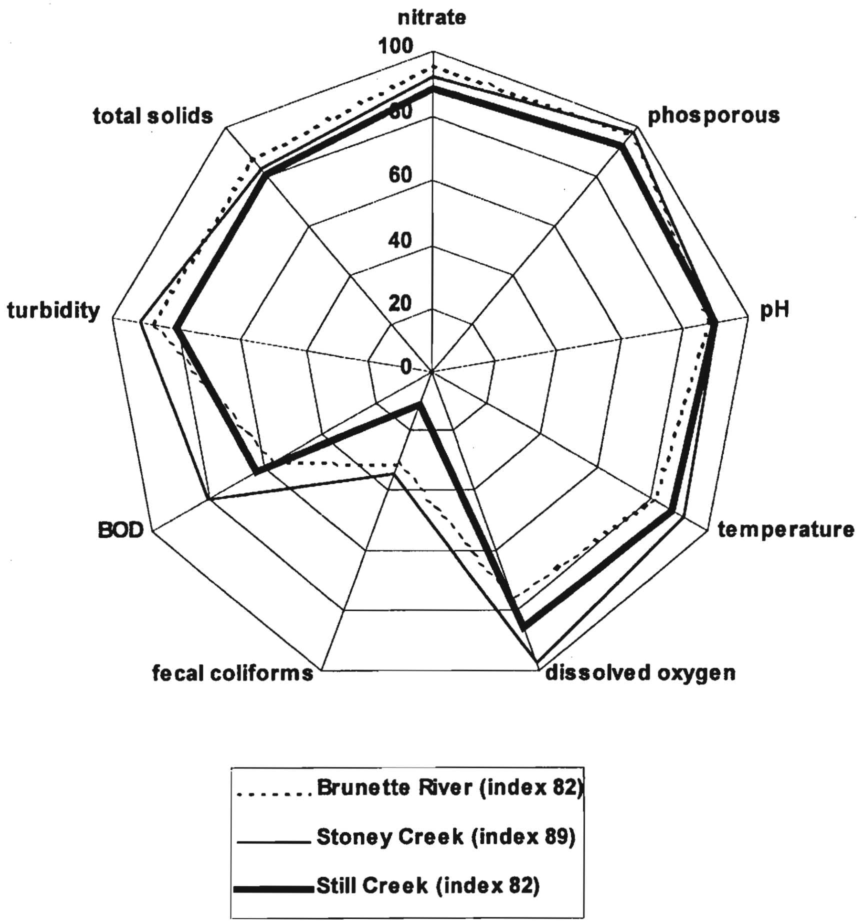


**Fig. 8.** Radar plot of the National Sanitation Foundation Index values for nine water quality parameters for baseflow conditions in three streams in the Brunette River watershed. Westwater monitoring data was used. The number of stations per stream is five for Still Creek and two for the other streams. Scores for individual streams were calculated by averaging the scores for all samples in those streams. Higher scores indicate better water quality conditions.

### Limitations of the National Sanitation Foundation Water Quality Index

It is important to point to some of the limitations of the NSFWQI. First, it was developed in the 1970s and the curves do not necessarily reflect current concerns — the NSFWQI typically rates water quality as being better than what today's experts would say. Secondly, some critical water quality parameters are missing, such as metals and persistent organic contaminants — when the index was developed water quality experts felt uncomfortable including these parameters due to a lack of knowledge. Thirdly, being an absolute index, the calculation procedure does not take local uses and local conditions into account. Finally, and perhaps most importantly, the index is not developed with one particular water use in mind — most of the parameters and scoring diagrams are based on the protection of aquatic life, and no consistent protocol for considering different water uses was followed in the development of the index.

Given these limitations it is not suggested here that the BCWQI be replaced by the NSFWQI. However, the NSFWQI is definitely a very good approach for stream stewardship groups, since the parameters can be measured with relatively little effort, limited training and at low cost, while still giving a reasonable insight into the overall conditions of a water body, particularly when documented over time. However, the NSFWQI is unlikely to meet the needs of local watershed managers.

## An Alternative: the Simple Water Quality Index

This study suggests the use of an alternative index and a different format for presenting the results. The starting point for this index is the acceptance of the existing water quality objectives as a management tool, and the index uses the same water quality objectives as the BCWQI. Implicit in this assumption is that for the watersheds considered in this analysis, the designated use is only the protection of aquatic life and that the existing water quality objectives are appropriate and sufficient. The development of the index is further guided by the requirement that it should not be very sensitive to monitoring design and is able to identify spatial and temporal patterns.

The index is determined as follows: in each water body and for every objective the percentage of samples exceeding this objective is calculated, referred to as the objective exceedance factor; the overall index value for that water body is simply the average of these exceedance factors. This index is not equal to factor F1 nor F2 in the BCWQI, but a different expression of objective exceedances. The index is labeled the Simple Water Quality Index (SWQI) since it uses a very simple and transparent calculation procedure.

The key weakness in the SWQI is that it does not count for the magnitude of the exceedances in any way (which factor F3 in the BCWQI does). It should be recognized, however, that the factor F3 is very sensitive to sampling frequency and can be influenced strongly by large but infrequent exceedances of one or few objectives. Some of the advantages of the SWQI suggested here include the fact that it weighs all objectives equally. The BCWQI is very sensitive to differences in the frequency of measuring different parameters (e.g., measuring pH 20 times over the period considered and total zinc only 5 times). The SWQI accounts for these differences by determining exceedance factors for each objective separately. It is also less sensitive to spatial scales of integration and sampling frequency. The BCWQI is sensitive to the degree of spatial aggregation and the overall frequency of sampling. The procedure suggested here is not sensitive to these factors if the sampling frequency and types of parameters measured are fairly similar across all sampling locations in the water body. Transparency is also a factor: the SWQI allows for a simple and quantitative analysis of how each parameter contributes to the overall result, in the form of a breakdown of exceedance factors for individual objectives. A similar analysis using the BCWQI is very complex, if not impossible, because of the non-linearity of the calculation formula.

One key limitation of the SWQI as presented here is the lack of a rating scheme, which would indicate what percent exceedance would constitute excellent, good, fair or poor conditions (see Table 6 for the BCWQI). The development of such a rating scheme, however, is beyond the scope of this study. The process of developing a rating scheme for the SWQI would require the consideration of many more different water bodies and objectives for different water uses as well as consultations with local water quality experts.

A second limitation of the SWQI is the fact that the index would not give any warning of ominous trends in water quality deterioration until objectives are exceeded. This could forestall any preventative action on the part of water quality managers. This limitation is inherent in any index using the exceedance of water quality objectives as a measure of water quality.

The SWQI presented here is very simple, but overcomes some of the difficulties associated with the BCWQI, while incorporating the importance of water quality objectives. To illustrate the index, Fig. 9a and b show the objective exceedances for Still Creek, based on Ministry and Westwater data, respectively. Sediment quality data is included here, but should be considered with caution considering the importance of particle size distribution that is not properly accounted for in this comparison. The number of samples considered in the assessment is indicated for each objective, providing a measure of confidence in the results (assuming sampling followed some elementary considerations in terms of considering temporal and spatial variability). The results reveal that for many objectives the two data sets point in the same direction, re-affirming that the indicator is not very sensitive to sampling design (considering only baseflow conditions in this case).

The final water quality index values are simply the average of the factors shown in Fig. 9a and b. As indicated earlier, however, the decision as to which parameters to include can strongly influence the result. Table 7

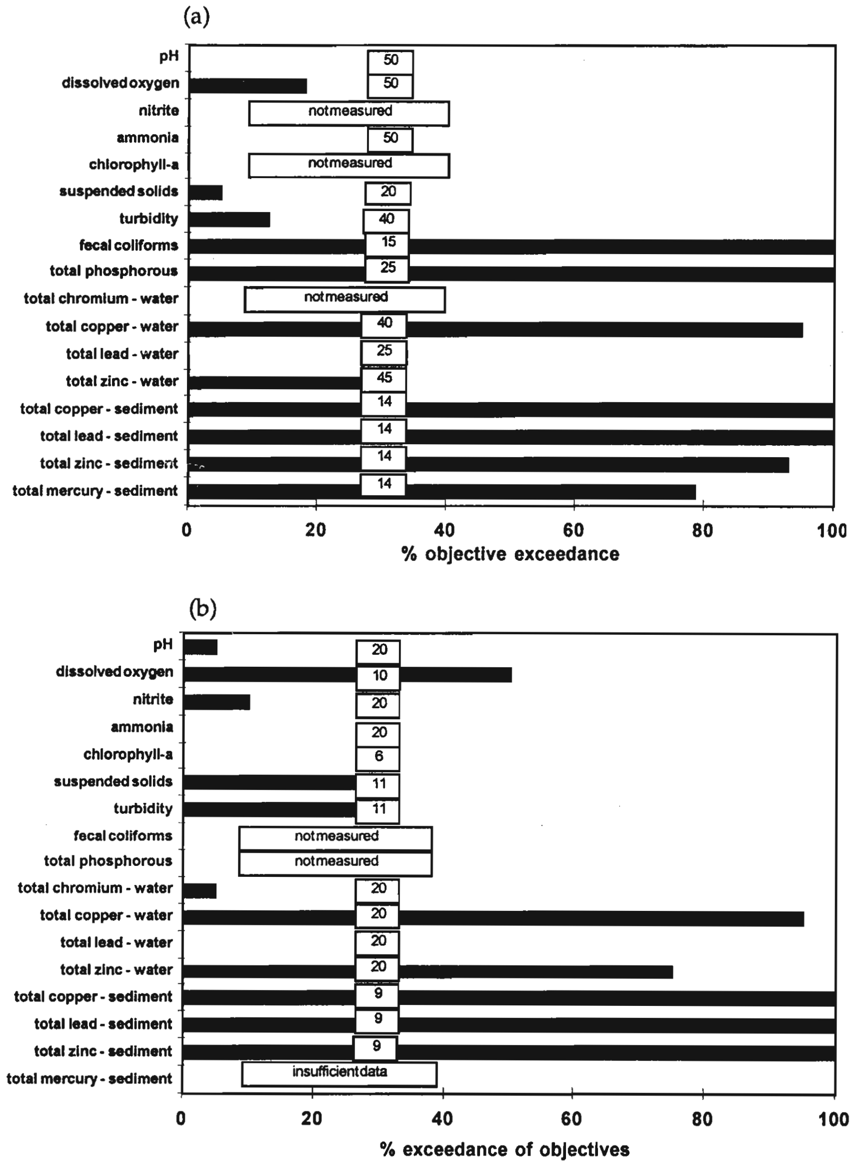


**Fig. 9.** (a) Exceedances of water quality objectives for Still Creek in the Brunette River watershed using Westwater monitoring data. Boxed numbers indicate the number of samples analyzed. (b) Exceedances of water quality objectives for Still Creek in the Brunette River watershed using Ministry monitoring data. Boxed numbers indicate the number of samples analyzed.

**Table 7.** Exceedance factors for different sets of objectives

| | Scenario[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Monitoring data source** | **Ministry of Environment** | | | | **Westwater** | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| pH | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Dissolved oxygen | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Nitrite | | | ■ | ■ | | | | |
| Ammonia | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Chlorophyll *a* | | | ■ | ■ | | | | |
| Suspended solids | | ■ | | ■ | | ■ | ■ | ■ |
| Turbidity | | ■ | | ■ | | ■ | ■ | ■ |
| Fecal coliforms | | | | | | | | ■ |
| Total phosphorous | | | | | | | | ■ |
| Total chromium — water | | | ■ | ■ | ■ | | | |
| Total copper — water | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Total lead — water | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Total zinc — water | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Total copper — sediment | | ■ | | ■ | | ■ | ■ | ■ |
| Total lead — sediment | | ■ | | ■ | | ■ | ■ | ■ |
| Total zinc — sediment | | ■ | | ■ | | ■ | ■ | ■ |
| Total mercury — sediment | | | | | | | ■ | ■ |
| Average exceedance | 38% | 53% | 27% | 42% | 24% | 42% | 45% | 53% |

[1] Each scenario corresponds to the use of a different set of objectives in the calculation of the average exceedance factor. The objectives included are indicated in gray. Scenarios 1 to 4 use Ministry of Environment data, while scenarios 5 to 8 use Westwater data. Scenarios 1 and 5 and scenarios 2 and 6 use the same set of objectives and allow for a direct comparison of the two sampling programs. Scenarios 3, 4, 7 and 8 do not use a comparable set of objectives, but are provided to further illustrate the influence of the selection of parameters in the analysis.

explores this in more detail by showing various scenarios for the set of objectives included and the corresponding SWQI value. Different scenarios were chosen to allow for comparisons between the two monitoring programs while recognizing that the set of measured parameters differed somewhat. Results can be compared directly by looking at scenarios 1 and 5 (a very basic set of the exact same set of objectives) and scenarios 2 and 6 (the basic set expanded with sediment quality). The other scenarios are not as comparable, but have been included to illustrate the influence of the selection of objectives (in monitoring design and in analysis). The comparison reveals slightly higher average exceedance factors for the Ministry data, but the difference among the two monitoring programs is less than the variation among scenarios within each of the data sets. This clearly indicates that the actual numeric value of the index is meaningless in the absence of a clear description of exactly which objectives were considered. The SWQI, therefore, is not just the average exceedance factor, but also the water quality information as represented in Fig. 9a and b, and Table 7. The index values should always be accompanied by the set of objectives used in the calculations.

## Conclusions

The original assessment by the Ministry described the water quality conditions in the two main streams of the Brunette River watershed as "good" for the protection of aquatic life, suggesting a low level of concern. Most people involved in the management of the watershed would disagree. This study clearly points out that the assessment results are strongly influenced by (1) the selection of the set of water quality objectives to be used in the index calculations, (2) the selection of reference conditions, and (3) the overall monitoring design. This casts serious doubts on the original assessment by the Ministry. The results presented here suggest water quality conditions in the Brunette River watershed are far from "good" for the protection of aquatic life, especially when considering the more intense monitoring by Westwater. Perhaps the most critical missing element in the Ministry's assessment is the consideration of storm events, during which water quality conditions are at their worst, and which account for between 60 to 95% of total annual loading of most pollutants in urban areas (Bellevue 1995; Macdonald et al. 1997).

As this study has attempted to illustrate, the usefulness of the BCWQI is dependent on many factors, several of which do not seem to be in place at present. As such, the results presented in the Status of Water Quality Report should be considered with caution, and attempts should be made at improving the current design of monitoring efforts and the further development and appropriate use of water quality indices. While the BCWQI might serve the needs of provincial agencies, its use by local watershed managers to assess the effectiveness of water quality management efforts should be discouraged.

One alternative index, developed by the National Sanitation Foundation, is an excellent approach for local stream stewardship groups, but it is unlikely to meet the requirements of watershed professionals as it does not take local conditions into account.

The alternative indicator developed as part of this study, the SWQI, based on the average of objective exceedances, appears promising in overcoming some of the limitations of the BCWQI, in particular the sensitivity to monitoring design. It is also argued that the numerical value of the index is meaningless unless accompanied by a detailed description of which objectives were considered in the calculation. A suggested presentation format is developed, using a diagram of exceedance factors for each objective (Fig. 9a and b). Limitations of the proposed SWQI in its current form are the absence of a rating scheme and the fact that the index does not provide any warning signs until objectives are exceeded.

### Limitations of this Study

Before moving into recommendations, some limitations of this study should be pointed out. First, the study looked at two watersheds, encompassing several water bodies for which objectives were set, out of a total of 124 water bodies in the province. Moreover, the study only considered freshwater streams, and not large rivers, lakes, aquifers or saltwater. In addition, the Brunette River watershed is somewhat unique, since it is very heavily urbanized and only reflects a few of the six potential water uses (wildlife, aquatic habitat and recreation are identified as water uses in the Brunette while for many other areas irrigation, industrial use and drinking water are also important). The Salmon River watershed is somewhat unique because few objectives have been established for it.

Despite these limitations, an attempt is made to formulate a set of recommendations for the appropriate use of water quality indices in British Columbia, because many of the findings relate to the inherent characteristics of the index and the use of water quality objectives in general.

### Recommendations for the Appropriate Use of Water Quality Indices in British Columbia

#### Critical examination of the use of water quality objectives

Water quality objectives are a very important part of the province's approach to water quality management and some of the problems associated with the objectives should be addressed. (1) Some objectives are clearly outdated and are not so relevant (e.g., nitrite). (2) Some objectives have been set at near-detection levels for many laboratories, which limits their practical use (e.g., total copper). (3) Other objectives have been established and are relevant but are almost never measured (e.g., mercury in fish). (4) No objectives have been set for some critical water quality parameters, e.g., total petroleum hydrocarbons in urban streams. (5) Many smaller streams, considered important by local watershed managers, lack objectives, e.g., Stoney Creek and Eagle Creek in the Brunette River watershed — the Canadian Water Quality Guidelines could be used instead of excluding these streams from the monitoring program. (6) The objectives are based primarily on current and foreseeable uses of the water body. However, this in part reflects historic water quality conditions, so the objectives may not reflect the full range of potential uses in the absence of any pollution.

#### Critical re-evaluation of the conceptual design of the British Columbia Water Quality Index

Some of the BCWQI's inherent problems include high dependence on monitoring intensity, including frequency of sampling and the number of stations for each water body; poor performance in identifying spatial and temporal trends in the absence of consistent monitoring — while the BCWQI was not designed with spatial and temporal comparisons in mind, this type of application is likely to occur if the Ministry continues to use the index.

### Critical re-evaluation of the use of an index in the absence of rigorous monitoring and well-established water quality objectives

The need for a fairly simple index to express complex water quality information is evident. However, in the absence of rigorous monitoring and well-established water quality objectives, the use of an objective-driven index can be deceiving and, as demonstrated in the case study of the Brunette River watershed, send the wrong signal to local authorities, interest groups and members of the public. In this case, no index might be better than a poor index, and an alternative way to present water quality information should be attempted.

### Consideration of alternatives to the British Columbia Water Quality Index

The index is fairly complex to calculate and is highly dependent on a rigorous monitoring program and well-established objectives. Other indices may be easier and more appropriate. For stream stewardship groups, the NSFWQI is an excellent alternative and a simplified version of the NSFWQI is already in use in British Columbia. For local watershed managers, an alternative indicator was suggested in the form of objective exceedance factors, expressed in the SWQI.

### Consideration for improved reporting and presentation formats

The choice by the Ministry for presenting complex water quality information in the form of a single index with qualitative descriptions of the meaning of its values should be applauded. However, some critical elements are missing in the current presentation format, in particular a discussion of the reliability of the index itself and of the results for individual water bodies. While some more technical considerations (such as details on the sampling design, frequency of sampling, temporal and spatial variations) are perhaps best left for accompanying technical reports, the Status of Water Quality Report, which receives fairly widespread distribution outside scientific circles, should provide more information on the degree of confidence that can be placed on the end results and the appropriate use of the results.

## Acknowledgments

We thank the Tri-Council Eco-Research Program and the Fraser River Action Plan of Environment Canada for their support of this research. Comments on earlier drafts of this paper were provided by Les Swain, Water Quality Branch, British Columbia Ministry of Environment, Lands in Parks, Victoria.

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