PRACTICABILITY OF A WATER QUALITY INDEX FOR ONTARIO RIVERS

Ontario

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of the
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INTRODUCTION

In May 1974, the Program Planning and Evaluation Branch of the Finance and Administration Division issued a report entitled "The Capital Construction Program: An Analysis and Assessment". Based on the analysis made, it was recommended that the Ministry develop a water quality index.

The November 1974 Report of the Implementation Task Force on the Capital Construction Program suggested that the Water Resources Branch should continue the development of a suitable index and should make recommendations regarding its implementation.

Based on these reports, two uses of a water quality index were considered:

i) Use as a measure of effectiveness for the MOE Capital Construction Program, and

ii) Use as a general (quantitative) measure of water quality.

The need for a general measure of water quality includes additional analyses and summaries of water quality data. An accrued benefit which may result from an easily followed water quality index is a heightened public awareness or interest in environmental quality.

Within the context of the above two uses, this paper discusses the practicability of a water quality index for Ontario streams and rivers, (the practicability of a lake water quality index is not assessed at this time in light of the differences between inland lakes and streams). The concept of an index and its usefulness, advantages and disadvantages are first discussed. Evaluation of the use of an index as a measure of effectiveness for the Capital Construction Program is then presented as well as recommended alternatives to an index. Evaluation of the use of an index as a measure of general water quality is discussed together with the importance of water quality data analysis. Finally, an approach to augment on-going water quality data analysis is recommended.

WATER QUALITY INDEX

<u>Definition of a Water Quality Index (WQI)</u>

A "Water Quality Index" may be defined as a scheme that transforms (weighted) values of individual water pollution related parameters (e.g. BOD or suspended solids) into a single number or a set of numbers. Ideally, a water quality index is a numerical rating which reflects the composite influence of a number of individual quality characteristics on the overall water quality situation. A number of water quality indices are obtained by aggregating and summarizing available water quality data. For example, a water quality index proposed by Brown *et al* (1974) takes the form:

WQIM (Multiplicative Water Quality Index) .

$$= \prod_{i=1}^{9} T_i (P_i)^{W_i}$$

$$= \prod_{i=1}^{9} Q_i^{W_i} \qquad [1]$$

where:

P_i = Measured value of the i th parameter,

T_i = The quality rating transformation (curve) of the i th parameter value P_i , into a quality rating Q_i , such that $T_i(P_i) = Q_i$,

W_i = Relative weights of the i th parameter such that

$$(0 \leq W_i \leq 1 \text{ and } \prod_{i=1}^{9} W_i = 1)$$

The nine parameters (P_i in Equation 1) chosen for inclusion in the WQIM index are dissolved oxygen, fecal coliform density, pH, biochemical oxygen demand, nitrate, phosphate, temperature, turbidity and total solids. These nine parameters, the quality rating transformation T_i and the relative weight W_i in Equation 1 were established from opinion research which obtained information from a group of water quality experts (for details of the procedure see Brown *et al*, 1974).

The above example is a representative approach to the development of a water quality index. Essentially, the approach consists of four steps:

a) Selection of parameters which are felt to be most important in revealing the quality status of a water body.

b) Scaling of the range of values for each selected parameter on a unitless scale (e.g. 0-100 for BOD_5 values 0-30 mg/L).

c) Assigning weights for the selected parameters, with the weights assigned reflecting the relative significance of the selected parameters.

d) Combining the scaled values and the associated weights to give a numerical index value (e.g. multiplicative combination in Equation 1).

Following this general approach, investigators have developed a few water quality indices in recent years. A general review of these indices is included in a study by Orlando *et al*, (1976). The existing indices vary in the number of parameters included, methods of combination (i.e. linear or non-linear combination of scaled parameter values and/or weights), water use-specific or non-water use specific (see Brown *et al*, 1974 for an example of a general water quality index and see Keilani *et al*, 1974 for an example of a use-specific index).

At the present time, a comparative evaluation of the water quality indices developed to date is difficult to conduct since these indices are still in their early stage of application and refinement and have not been tested extensively. Perhaps for these reasons, the developed water quality indices have not been widely utilized by government agencies in spite of the apparent need for such indicators (Council on Environmental Quality, 1975).

Usefulness of a Water Quality Index

Accurate and timely information on the status of and trends in water quality is needed to develop and to implement water resources programs efficiently. Information on water quality can be presented to decision makers or the public in a format which lies anywhere along a continuum ranging from raw data at one extreme to a single water quality index on the other. While raw data contain the most detailed information, they are, in most instances, the least understandable to policy makers and the general public. Further, because of a lack of adequate resources for data analysis, much useful water quality data lie on computer data tapes and are used only rarely. Therefore, it has been argued that the use of water quality indices, by aggregating and summarizing available data, could illustrate major trends and highlight the existence of significant water quality conditions (Council on Environmental Quality, 1973).

The U.S. Council on Environmental Quality (1973, 1975) has been advocating the development and application of water quality indices and other environmental indices. Although, the development of water quality indices has been slow, several investigators have attempted to apply developed water quality indices to water quality data and to examine the sensitivity and validity of a few indices. Most significantly, both New York State and Michigan State have recently made use of an index to quantify water quality status. In their annual water quality reports submitted to the U. S. Environmental Protection Agency (required by the 1972 Amendments to the Federal Water Pollution Control Act), index values are included to show variation in water quality among river basins and the time trends in water quality at different stations. Comparisons are made for one station over time, within one river system or between river basins. Although the validity of the water quality index is somewhat uncertain, the reports clearly illustrate that a water quality index is a potentially powerful tool for aggregating and summarizing water quality information and an effective way to communicate information of water quality status and trends.

Advantages and Disadvantages of a Water Quality Index

Table 1 lists the advantages and disadvantages of a water quality index. Each advantage has a corresponding disadvantage. In view of these advantages and disadvantages, a water quality index appears to meet the requirements as a tool designed to advise decision makers and the public of the water quality levels but does not show the specific pollution problem of a water body. In other words, an index will provide a general indication of water quality but will not indicate which pollution related parameters exceed the required criteria, which uses are impaired, and why a particular poor (or good) condition exists.

TABLE 1: Advantages And Disadvantages of a Water Quality Index.

	Advantages	Disadvantages
1.	Measures general water quality	Does not measure water pollution
2.	Single number for overall water quality	Insensitive to individual problem parameters
3.	Good for communicating with the layman	Poor for addressing particular technical problems
4.	Standardized so that different geographic areas can be directly compared	Does not take into account local natural background water quality effects
5.	Many water experts' opinions taken into account when formulating WQI	Somewhat arbitrary and lack of a firm scientific basis

Water quality is a qualitative concept subject to personal interpretation. The above mentioned approach to the development of a water quality index attempts to quantify this concept through aggregating related parameters. An index is designed to measure water quality, not to predict water quality. In essence, a water quality index should be viewed as a way to interpret raw water quality data or as a level of data analysis. This level of analysis is different from the study of individual water quality parameters in that it is more general and incorporates a greater degree of subjectivity. Because of this subjective nature, development of a meaningful index is very difficult, not to mention its verification. Based on the experience gained in the development and application of air pollution indices (Ott and Thom, 1976), a widely-accepted water quality index would have to possess the following important features:

- be easily understood by the public,
- include major pollutants and be capable of including potential pollutants,
- relate to water quality criteria and goals for different water uses,
- not be inconsistent with the perceived water quality levels,
- be based on a reasonable scientific premise,
- be calculated in a simple manner using reasonable assumptions.

At the present time, an index meeting the above features or criteria is non-existent. It is apparent that further refinement, verification and application of the existing indices are needed before they can be relied upon for measuring water quality, and in turn, for generating public concern for the aquatic environment.

EVALUATION OF THE USE OF AN INDEX AS A MEASURE OF PERFORMANCE FOR MOE CAPITAL CONSTRUCTION PROGRAM

Up to this point, discussions are related to the general aspects of an index. As a basis for evaluating the use of a WQI for the Capital Construction Program, a detailed study has led to the conclusion that a water quality index is not suitable for this purpose. The reasons for this finding are outlined below.

1. <u>Complexity of Pollutant Sources</u>

Sources other than treated domestic wastes such as storm and urban runoff, agricultural runoff, industrial discharges, septic tank leachate, etc. can impair water quality. As a result, stream water quality data are a composite quality indicator of all point and non-point sources in a drainage area. Separation of individual sources in the data is difficult to achieve. Thus an index based on stream water quality data would often be unable to distinguish whether or not a capital construction project had improved water quality, since input from other sources might mask the effect. As outlined later in this paper, quality measurement of effluents is the most direct approach for judging the effectiveness of capital construction projects.

2. Variabilities in Water Quality

In general, water quality data show seasonal and/or hydrologic variabilities which may be greater than the water quality improvement derived from a capital construction project. For example, a poor quality effluent can be masked during periods of high streamflow. To isolate seasonal variabilities from "real" improvement in a water quality index appears to be quite difficult, based on the limited time trend analysis of a water quality index reported in the literature (Michigan Department of Natural Resources, 1976).

3. Uncertainty Associated With an Index

A well-tested and verified index is not in existence. The sensitivity of a few indices have been investigated to only a limited extent (Landwehr, 1974). To make use of these crude indices at this point appears to be risky. Furthermore, existing indices generally were not developed for measuring the effectiveness of capital construction programs and are not sensitive enough to detect or measure changes in water quality due to point source treatment.

4. Intrinsic Difficulties Associated with the Development and Application of a Water Quality Index

In addition to the above, intrinsic data, manpower and resource constraints are major factors which preclude the development and application of an MOE water quality index at the present time:

(a) A Lack of Representative Data Base - Some of the network monitoring data may be biased toward reflecting poor water quality conditions. Many of the MOE monitoring stations are in fact located immediately downstream of sewage treatment plants and were selected specifically to evaluate conditions in potential or existing problem areas. A 1970 evaluation of these water quality data indicated that the water quality was not acceptable for many uses. When these data are used in the computation of a water quality index, the localized areas of impairment would give a false impression by misconstruing the overall quality of Ontario waters; this could result in bad publicity for the Ministry. Along the same line, it must be noted that a decision to provide analyzed water quality information to the public must involve a commitment to include the bad with the good, recognizing that the Ministry could at times suffer adverse public opinion. If the Ministry is not prepared to accept this, then publication of information should not be a need that influences the extent and type of analysis done.

Selective use of MOE historical data and re-locations of monitoring stations are possible measures of acquiring additional representative data. Thus, a screening of data is required before index application.

(b) Manpower and Financial Requirements - development, verification and application of an index is a lengthy and expensive process which requires major manpower input. Both the National Sanitation Foundation (Michigan, U.S.A.) and the Inland Waters Directorate, Environment Canada have invested significantly in the development and limited applications of their indices over a five or six year period. Currently, the Inland Waters Directorate, Environment Canada, is waiting for comments from its regional offices regarding the application of an index - Water Quality Economic Index (WQEI). It was learned that the regional offices are quite skeptical about the value of an index and its application primarily because of its uncertain nature (i.e. an index is somewhat arbitrary) and manpower and resource considerations.

To develop an "adequate" index for the Ministry, one or two full-time professionals with adequate technical and effective EDP support over a period of five years appear to be a reasonable estimate of manpower requirement.

The Systems Development Section, Administrative Services Branch, has estimated the development costs for design and EDP programming services for water quality index reporting to be approximately $10,000. This preliminary estimate does not include the operating costs of the developed program. It should be recognized also that some of the historical network water quality data have to be further checked before their application to the index program because some of the data stored in the computer system may be of questionable value (i.e. any computerized data storage system may contain possible errors generated by transcription, keypunching or any other conceivable reasons). Checking of historical water quality data can be done either manually or with the help of a computer, but in either case will be a time-consuming and expensive exercise.

(c) Regional Response - An earlier draft of this report was sent to regional offices and four other branches of the Ministry for comments in May last year. By the end of August, comments from two branches and four regions had been received. Almost all respondents agree that the effectiveness of the MOE Capital Construction Program cannot be adequately assessed by means of a water quality index primarily for the reasons listed above. Moreover, because of manpower and resource limitations, the respondents generally consider the water quality index project to have a low priority.

In view of the above shortcomings and limitations, it is felt that a water quality index cannot be utilized as a means of assessing the effectiveness of the Capital Construction Program by establishing a direct relationship between the construction of sewage works and the resulting water quality in streams. Therefore a water quality index is not recommended as a measure of performance for the Capital Construction Program.

ALTERNATIVE MEASURES OF EFFECTIVENESS FOR THE MOE CAPITAL CONSTRUCTION PROGRAM

To ensure effective MOE capital construction activities, two controls are essential:

(i) careful evaluation of proposed construction activities,

(ii) routine monitoring for improvement of the performance of capital construction projects.

Two ongoing Ministry programs appear to provide a suitable alternative to an index.

1. The Evaluation System for Construction Activity was developed by the Management by Results (MBR) Task Force in 1974, and was designed as a measurement of the objectives for the Capital Construction Activity. Essentially, the Evaluation System is a procedure which assigns assessment values to projects based on the gradings for eight Construction Activity Objective Units (MOE, December, 1974). The assessment values are used as a project ranking (i.e. projects with high assessment values are given a high priority). In addition, projects are classified according to a status classification which provides an overriding feature to the project assessment ranking. Using this evaluation system, the MBR Working Group currently reviews project proposals to ensure that the granted projects are consistent with the mission of the Ministry and its environmental goals. Thus, the Evaluation System is an effective device for allocating financial resources to Capital Construction Projects Prior to their initiation. Moreover, environmental assessments are now required for many provincial projects and will certainly supplement the Evaluation System for Capital Construction Activity. It is felt that with these planning mechanisms available, future approvals of Capital Construction Projects can be well-justified and effective.

2. The Utility Water Pollution Monitoring Module, which is now under development and expected to be operational in early 1977, will process information on the performance of sewage and water facilities for a number of Ministry purposes. The module will report on loadings in and out of sewage works in order to facilitate operational controls, report on loadings being discharged to receiving waters and will appraise effectiveness of various types of facilities. With this information available it is possible to routinely assess the performance of sewage treatment plants by comparing actual plant loadings and allowable loadings to improve plant performance wherever necessary. It is felt that the 8 use of the Utility Monitoring Module is a more direct and effective control or measure of plant performance than the use of a water quality index, which may mask specific problems or

benefits associated with a sewage treatment plant.

EVALUATION OF THE USE OF AN INDEX AS A QUANTITATIVE MEASURE OF WATER QUALITY

In recent years, concerns over environmental quality have generated a large number of water quality monitoring activities and a wealth of data has been accumulated. Although interpretations of these data have been attempted by many investigators, a single, reliable water quality indicator or index has not yet been developed for decision makers and the general public. Most water quality studies report their results in terms of individual parameters, not in terms of an index. Further, data analysis and reporting are often limited to a few parameters (e.g. N, P, BOD, DO) even though data of fifteen or more parameters are generally collected. In fact, accumulation of data at a high rate and a lack of data analysis are the major concern of many water quality management agencies.

The use of a water quality index which can aggregate a large number of parameters is an attractive idea and has been suggested by a number of agencies in the U.S. and Canada. However, it is a level of data analysis more sophisticated than basic statistical summaries, since basic summaries are the prerequisite to all data analysis including a water quality index. Although data analysis has always been recognized as important, historical circumstances led to greater emphasis being placed on data collection. Increasingly, additional efforts are being directed toward data analysis. As analytical capabilities will, be improved in the future, a water quality index may eventually become a tool of data interpretation. At the present, an index is somewhat premature in light of data management capabilities.

Within the MOE, works are underway to strengthen data management capabilities. Given time, application of an index may be feasible. However, from a practical view point, an independent MOE project of index development for general water quality data analysis does not appear to be a priority project primarily because of the following considerations:

(a) the uncertainty associated with existing indices, and the manpower and resources requirements discussed earlier in this report are constraints which are also applicable to the use of an index for water quality data analysis.

(b) Although some works to improve data analysis capability have been completed in the Ministry and others are proceeding, improvement does not come rapidly in light of the limited manpower and resources available for data analysis and the large scale of the network program. Thus, with the given circumstances, the application and development of an index for general water quality measurement is not likely to be readily feasible in the near future. Moreover, there is a consensus among the regional staff that, instead of an index, there is a greater need for additional data analysis and summaries, and that additional effort along these lines would be of considerable value and benefit. To expedite further improvement in analysis capability thus appears to be a more logical step to take at this point than the application of a water quality index.

(c) development of an index may be better as a national project aiming at a uniform index which can be applied nationwide and can minimize the confusion created by a large number of indices among regions (i.e. one can be confused by moving from province to province using different indices an experience learned from the applications of air pollution indices; see Ott and Thom, 1976).

In brief, a water quality index is a potentially valuable tool of data analysis and may be useful in the future. In light of the above limitations it is therefore recommended that MOE staff pay continuing attention to the development and application of indices elsewhere, particularly in Canada and the United States.

Recognizing the importance of additional data analysis to both the regional offices and to the potential eventual application of an index, a recommended course of action is outlined below.

A RECOMMENDED APPROACH TO WATER QUALITY DATA ANALYSIS

Analysis of network water quality data is a difficult task since a large number of stations (some 900 stations) and a long period (more than 10 years) of water quality records are involved. Computerization of data processing is a prerequisite. Several EDP systems which are virtually operational will improve data analysis capability. Building on the existing EDP capabilities, the following is an approach for future water quality data analysis which will provide important summaries of water quality status for Ontario waters with less manpower and resource investment than a WQI, and will improve data handling capabilities.

Briefly, the recommended approach is a flagging procedure which will report on the frequencies (i.e. percent of water quality samples) of violation of criteria for different water uses in a data period. The procedure involves:

(a) Comparing each of the water quality samples collected in a period with the criteria for major water uses; and

(b) Computing for each of all the (applicable) parameters, the percentage of all samples violating the criterion for each of all the water uses.

Table 2 illustrates a hypothetical example report, several features of which are noteworthy:

1. Large amounts of data can be condensed into summaries which can be examined readily; for example, the percentages shown in Table 2 for each parameter would be computed from 100 water quality samples in the data period.

2. Water uses and the associated criteria are included in the reporting process and the frequencies of violation provide valuable information for water quality management.

3. With reports of this type, comparison of water quality can be made between stations and for different time periods, thus trend analysis and regional water quality analysis can be carried out. Figure 1 shows a possible presentation of the end results of such an analysis.

4. Although the recommended approach does not directly relate plant performance to stream water quality, it would certainly provide an opportunity for the examination of certain water quality parameters. For example, if the dissolved oxygen levels frequently violate the water quality criteria at a location before implementation of sewage treatment for organic waste loads then the violation frequency may be decreased after sewage treatment, indicating an improvement in water quality.

5. Subjective weighting, scaling and a selection of water quality parameters are not required for the recommended approach, whereas the water quality index is largely subjective in nature.

Compared to the development and application of a water quality index, the recommended approach is relatively straightforward to conceive and implement. A few data management elements are essential to the implementation. Some of these elements are currently being implemented or under active consideration by the Hydrology and Monitoring Section and the Systems Development Section, such as basic statistical summaries of water quality data through the Sample Information System, data checking and editing, and data file reformatting. In addition, a computer program is required to execute the flagging procedure for multiple parameters and uses.

Building on the existing EDP capabilities, the recommended approach requires little investment in computer software, scientific research or development. However, the approach will only be effective and meaningful when it becomes a routine or regular Ministry program. In other words, the flagging procedure should be implemented for both the historical water quality data and data to be collected in the future so that trend and regional analysis can be performed and the findings can be useful to the Ministry programs for

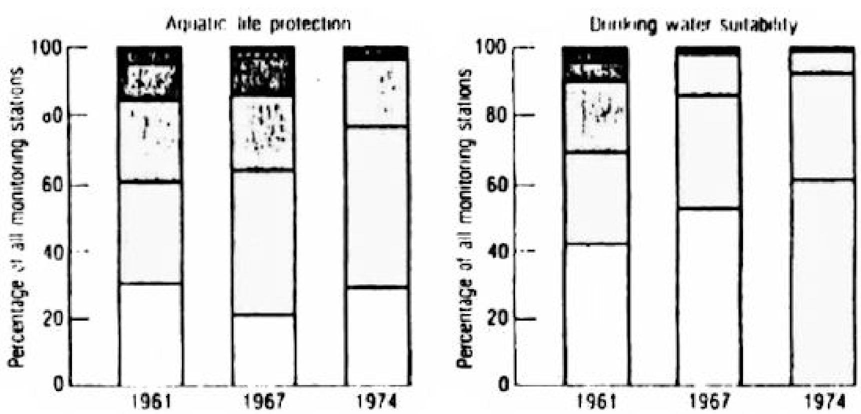
TABLE 2: An Example Report For The Recommended Flagging Approach.

Station: Big Creek, Ontario
Data Period: April 1974-March 1975

	% Samples Violating Water Quality Criteria for Water Uses			
	Public Water Supply	Aquatic Life	Agricultural (Irrigation)	Agricultural (Livestock)
Temperature	-	-	-	-
Fecal Coliform	-	-	-	-
Arsenic	3	5	1	1
Chloride	1	10	2	*
Ammonia	-	-	*	*
Nitrate	-	-	*	-
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Nickel	1	2	-	-
Chromium	1	2	-	-

* not applicable - No violation

FIGURE 1. Trend and regional analysis - Parameter: Arsenic



Severe: 80-100 percent of all observed levels exceeded criteria or reference levels

Very poor: 60 80 percent of all observed levels exceeded criteria or reference levels

Poor: 10-60 percent of all observed levels exceeded criteria or reference levels

Fair: 20-40 percent of all observed levels exceeded criteria n reference levels

Good: 0-20 percent of all observed levels exceeded criteria or reference levels water quality protection and enhancement. It is desirable that reports similar to Table 2 can be compiled and analyzed periodically, or can be condensed into formats like the bar charts shown in Figure 1. Such compiled reports and figures can be used in decision making and conceivably could be released for public information purposes instead of a water quality index.

Additional professional staff with adequate support would be required to carry out the recommended approach as a routine data analysis program satisfactorily.

CONCLUSIONS AND RECOMMENDATIONS

1. A water quality index may be a valuable technique of data analysis. However, existing indices are still in their early stage of development; verification, refinement and extensive application of these indices are required before they can be relied upon for measuring water quality and in turn, for generating public concern for the aquatic environment.

2. Because of the complexity of pollutant sources (separation of point and non-point sources in stream quality data is difficult), a lack of representative data base, the uncertainty associated with an index (i.e. it is somewhat subjective and arbitrary), variability in water quality data, and manpower and resource constraints, it is concluded that a water quality index can not be an adequate measure of effectiveness for the MOE Capital Construction Program.

3. Two ongoing Ministry programs - (i) the Evaluation System for Construction Activity, and (ii) the Utility Monitoring Module - appear to provide more direct controls of MOE capital construction projects than the use of an index; these programs would ensure that future approvals of capital construction projects are effective, and that the projects are adequately monitored for improvement.

4. Due to manpower, data manipulation capability (a prerequisite to data analysis and to the application of an index), and resource constraints, an independent MOE project of index development for water quality data analysis is not warranted at the present time. Instead, a flagging approach to data analysis is recommended which will improve data manipulation capabilities and will also provide important summaries of data for Ontario rivers and streams.

5. Both the federal government and some U.S. agencies are involved in index development and application. As the use of an index may eventually be feasible in the future, it is therefore recommended that continuing attention be given by Ministry staff to index development outside the Ministry.

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