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WATER QUALITY INDICES: A SURVEY OF INDICES USED IN THE UNITED STATES

by

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Polluted air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Physical, chemical, and biological measurements of environmental quality are the most important means available for determining the state-of-the-environment. These monitoring data provide the basis for evaluating the Nation's progress in improving environmental quality and are essential to environmental managers and decision makers. Unfortunately, a gap often exists between specialists who collect the data and managers who must understand its implications. Environmental indices have been proposed as one means for bridging this gap.

This report was prepared to provide the most comprehensive summary currently available of the utilization of water quality indices throughout the United States. We hope that the extensive data base assembled in this effort will assist the Agency in establishing future policies in this area.

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ABSTRACT

This study, conducted by the U.S. Environmental Protection Agency (EPA), documents the extent to which water quality indices currently are being used in the United States. It reviews the indices published in the literature and surveys the States and interstate commissions to determine: (1) which agencies are using indices, (2) the type of index being used, (3) the purpose of its use, and (4) the attitudes of agency personnel toward indices.

Few of the more than 20 physical and chemical water quality indices published in the literature are being used in practice. One-fifth of the State and interstate agencies (12 out of 60 agencies) are classified as users of water quality indices. An "index user" is defined as an agency that has used an index in an official publication or large-scale study extending over a year or more. Of the 51 State agencies (including the District of Columbia), 10 States (20 percent) are classified as index users. The National Sanitation Foundation Index (NSFI) is the most commonly used index, accounting for 7 of the 12 index users. The remaining agencies use Harkins' index or various user-developed indices. A total of 16 additional States and 1 interstate commission indicate that they are planning to evaluate indices for possible future application, or are developing or evaluating indices at the present time; these are classified as "potential users." Most of these agencies indicate that they will be considering the NSFI.

Six new indices have been developed by water pollution control agencies, four by the States, and two by the EPA Regional Offices. Three of the State-developed indices are currently in use, and the remaining one has not reached the stage of routine application. The mathematical structures of the new indices are documented in this report.

The main purposes expressed by index users for applying their indices are preparation of the annual reports required by Section 305(b) of P.L. 92-500, public information, and analysis of water quality trends. The majority of the index users express satisfaction with their indices and rate them favorably. Most users feel that EPA should have a suggested index available (or a set of indices) for those agencies that wish to use a uniform index structure.

There is clear evidence of a trend toward increased utilization of water quality indices in the United States. If the 17 agencies classified in this study as potential users become users in the future, a total of 29 out 60 agencies (48 percent) will then be using water quality indices. Several recommendations are included in this report for meeting the needs of index users, attaining greater uniformity in water quality data analysis practices, and identifying future research needs.

This report covers a period from October 1976 to June 1977 and work was completed September 1977.

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I. INTRODUCTION

In January 1959, the Committee on National Water Policy of the Conference of State Sanitary Engineers (CSSE) proposed that a study be carried out to develop a uniform indicator for reporting information on water quality. As a result of this action, the CSSE Committee and the Conference of State and Interstate Water Pollution Control Administrators (CSIWPCA) began developing criteria for demonstrating the progress of water pollution control programs; however, no further results emerged from this effort.[1]

In 1965, the Environmental Pollution Panel of the President's Science Advisory Committee made the following recommendation:

> We recommend that the Federal Government stimulate development of a method for assigning a numerical index of chemical pollution to water samples. The method should be sensitive to most chemical pollutants, and its results should be roughly proportional to the unfavorable effects of the pollution on man or aquatic life. Such an index will allow us to follow many important changes in general water quality in a way similar to that in which the coliform count has enabled us to follow changes in pollution by untreated sewage.[2]

In that same year, Horton[3] published a simple water quality index* which he developed in conjunction with his activities with the Ohio River Valley Water Sanitation Commission (ORSANCO). A great many different water quality indices have appeared in the literature since that time. Among the best known is the Water Quality Index (WQI) developed by the National Sanitation Foundation (NSF) and originally proposed in 1970.[4]

Progress in developing and applying water quality indices generally has paralleled similar efforts in air pollution. In air pollution, indices are used to report air quality levels to the public on a daily basis in most major U.S. cities. In May 1974, Thom and Ott[5] began a national survey of the air pollution indices currently in existence, ultimately resulting in publication of a compendium documenting the diversity of air pollution index systems currently in use. The findings of this compendium contributed to a decision by the U.S. Environmental Protection Agency (EPA) to recommend, in conjunction with other Federal agencies, a nationally uniform air pollution index, the Pollutant Standards Index (PSI), for reporting air quality levels to the public on a daily basis.

*For purposes of this study, a "water quality index" was defined as any mathematical approach which aggregates data on two or more water quality variables to produce a single number.

Although a uniform air pollution index has been recommended by the Federal Government for voluntary use by State and local governments, similar steps have not been taken in the water pollution area. One possible reason is that the need to report water quality information to the public on a daily or weekly basis may be less pressing than in the case of air pollution information. In addition, the user community for a water pollution index seems somewhat less clearly defined than in the case of the air pollution index. The present study also reveals a somewhat greater uniformity in the selection of water quality indices by environmental agencies than was true for air pollution indices.

Another important difference between the data analysis activities of air pollution control agencies and those of water pollution control agencies stems from existing legislation. Section 305(b) of the Federal Water Pollution Control Act Amendments of 1972[6] requires each State to prepare a report describing its water quality on an annual basis and to submit this report to the EPA Administrator. In turn, the Administrator analyzes this information and prepares a summary report. These Section 305(b) reports from the States, with EPA's summary report, then are transmitted to Congress. Each report includes a "... description of the water quality of all navigable waters in such State during the preceding year, with appropriate supplemental descriptions as shall be required to take into account seasonal, tidal, and other variations ...."[6] This information provides a yearly overview of water quality trends throughout the Nation, and the impact of regulatory activities upon water quality. Although EPA prepares annual trend reports for air pollution, the States do not prepare individual air pollution reports similar to the Section 305(b) water quality reports.

Despite the various air and water pollution indices that have been developed and published in the literature, a 1975 report by the National Academy of Sciences (NAS) concluded that the Federal Government has made insufficient progress in developing and utilizing environmental indices:

> Environmental indices provide an important method for evaluating the state of the environment. Despite strong statements of need from all three branches of Government, progress toward the development and use of methods for evaluating environmental quality has not been satisfactory.[7]

Specifically, the NAS report recommended development of a uniform air pollution index, which has since been adopted by EPA, and increased emphasis on development of water quality indices:

> There have been fewer attempts to construct water quality indices than air quality indices, despite the importance of the Nation's water pollution control program. There appear to be no insurmountable obstacles to development of useful water quality indices and the Committee recommends their prompt construction and use.[7]

In the past 2 years, considerable interest has focused on water quality indices at the Federal level. The Council on Environmental Quality (CEQ), in cooperation with the EPA and the U.S. Geological Survey (USGS), undertook an extensive review of all the water pollution indices which had been developed.[8-11] This review included both indices reported in the literature and those developed by EPA and other organizations. The study included a computer comparison of the performance of a number of these indices on water quality data.

Although the CEQ-EPA-USGS study provided a useful discussion of the state-of-the-art for water pollution index development, it did not examine the actual applications of these indices in the field. Who are the users of water pollution indices? What indices are being used? What are they being used for? What future applications will be undertaken? Is there a tendency toward increased use of indices? What action, if any, should EPA take in this area?

The present study was undertaken to answer these questions. Planning for this study was coordinated with CEQ and with other interested organizational elements of EPA, such as the Monitoring and Data Support Division of the Office of Water and Hazardous Materials. The study consists of a survey of State water pollution control agencies, interstate water pollution control commissions, and the EPA Regional Offices. The survey sought to determine: (1) which agencies are using water indices, (2) the type of index being used, (3) the purpose of its use, and (4) the attitudes of the agency personnel toward indices. The survey was carried out by telephone calls to individuals within each agency likely to be familiar with the agency's use of indices.

II. LITERATURE REVIEW

The first review of the literature on published water quality indices appears in a doctoral thesis by Landwehr.[12] The four-volume CEQ-EPA-USGS study gives independent reviews of the literature on water quality indices in Volume I[8] and Volume II.[9] Some of the material also appears in a recent paper by Orlando, Wrightington, and Maxim.[13] A book currently in preparation by Ott[14] contains an extremely detailed literature review of this topic. This chapter is intended, therefore, to provide only a brief overview of the literature published on this topic. The primary emphasis is upon indices that can be used with data on physical and chemical variables routinely collected by water quality monitoring activities.

PHYSICAL AND CHEMICAL WATER QUALITY INDICES

The author has found it possible to classify the indices in the literature into four general categories: (1) indices of general water quality, (2) indices for specific water uses, (3) indices for planning, and (4) statistical approaches.

Indices of General Water Quality

Horton's index,[3] published in 1965, uses 10 variables,* including commonly monitored ones such as dissolved oxygen (DO), coliform count, pH, specific conductance, alkalinity, chloride content, and temperature. Carbon chloroform extract (CCE) is included to take into account the influence of organic matter, and a unique variable, "percent of the population served" by sewage treatment plants, is an attempt to assess the effectiveness of water pollution abatement activities. Another unique variable, "obvious pollution," is included to reflect the aesthetic characteristics of the water. Horton's index is computed as the weighted sum of subindices. The subindices are calculated using a table of specific subindex values corresponding to ranges of each variable. Like many indices which came after it, Horton's index ranges from 0 to 100, with "0" representing poor water quality and "100" representing perfect water quality. It has a "decreasing scale," because the index numbers decrease as pollution increases. With few exceptions, the air pollution indices are just the opposite. They have "increasing scales" in which the numbers increase as pollution increases.

In 1970, Brown, McClelland, Deininger, and Tozer[4] presented a water quality index based upon a nationwide survey of water quality experts. In

*Although the water pollution community often uses the word "parameter" to denote a measured quantity, this usage is inconsistent with that found in other scientific fields. To avoid confusion, we shall use the term "variable" to denote any physical, chemical, or biological quantity.

this work, which was supported by the NSF, a panel of 142 persons was polled using mail questionnaires. In successive mailings, respondents were asked to determine which variables should be included in a water quality index, the importance (weighting) to be given to each variable, and the rating scales (subindex relationships) to be used for each variable. In each successive mailing, respondents were given a computer summary of the group responses and were allowed to alter their replies. This approach, the Delphi[15] technique is intended to give greater convergence of opinion regarding the significance of each variable for general water quality than would be possible without this "feedback" of the group viewpoint. The resulting index, the National Sanitation Foundation Index (NSFI), is based on 77 respondents who completed all questionnaires. It includes nine variables: dissolved oxygen, fecal coliform, pH, 5-day biological oxygen demand (BOD_5), nitrates, phosphates, temperature (i.e., deviation from equilibrium temperature), turbidity, and total solids. One version of the NSFI, the sum (or additive) form is computed as the weighted sum of nine subindices, each of which is read from a graph. In another version, the product (or multiplicative) form, the weights are treated as exponents of the subindices, and results are multiplied together. Toxic substances and pesticides are included in both versions by setting the index to zero whenever any of these substances exceeds its recommended limit. McClelland[16] applied the NSFI to water quality data in the Kansas River Basin. With support from EPA's Region VII, the NSFI also has been applied in a number of other geographical areas of the Nation.

In 1970, an index based on the water quality classification systems used in a number of countries was proposed by Prati, Pavanello, and Pesarin.[17] The systems considered include ones from England, Germany, the Soviet Union, Czechoslovakia, New Zealand, Poland, and some States of the United States. The index includes 13 variables and is computed as the arithmetic mean of 13 subindices. Unlike the NSFI, which uses graphical subindex rating functions, the index proposed by Prati et al.[17] uses mathematical equations for each subindex. Unlike Horton's index and the NSFI, it has an increasing scale and ranges from "0", corresponding to good water quality (no pollution), to "15" or more, corresponding to poor water quality.

McDuffie and Haney[18] proposed an eight-variable water quality index, the River Pollution Index (RPI), which has an increasing scale and is based on the ratio of the observed value of each variable to its "natural" value. The RPI varies from 100 ("natural" levels) to 1,000 ("highly polluted" levels). The index can go below 100, making its overall range 0-1,000. The RPI was applied on a test basis to stations on streams in New York State.

In 1972, Dinius[19] proposed a water quality index as part of a larger social accounting system designed to evaluate water pollution control expenditures. This index includes 11 variables, and, like Prati's index, uses explicit mathematical equations for the subindex functions. Like the NSFI, it has a scale which decreases with increased pollution, ranging from 0 to 100. The index is computed as the weighted sum of its subindices.

The indices discussed thus far assume that "general water quality" is a concept which can be reported by a single numerical index, irrespective of the use for which the water is intended. Many critics of indices designed to report general water quality argue that different variables must be weighted differently if different water uses are to be taken into account. Dinius' approach to the problem was to propose different descriptor language for different index ranges, depending on the specific water use under consideration (Figure 1).

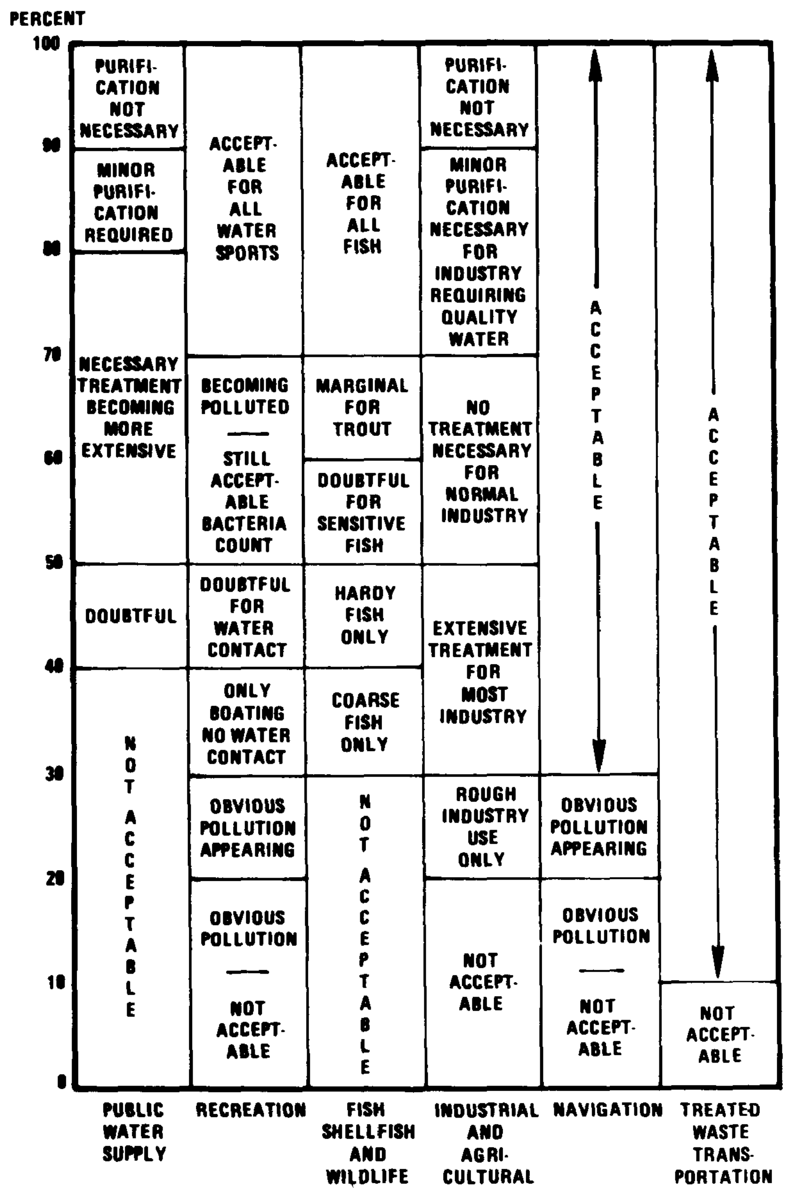

FIGURE 1. DESCRIPTIVE LANGUAGE SUGGESTED BY DINIUS[19] TO ENABLE A SINGLE WATER QUALITY INDEX TO BE APPLIED TO DIFFERENT WATER USES.

Thus, 0 to 40 is designated as "not acceptable" if the water is to be used for public water supplies, while 0 to 20 is considered "not acceptable" if the water is to be used for industry and agriculture.

Indices for Specific Water Uses

Another approach for considering water uses is to develop specific-use indices, or separate indices that are tailored to each water use. In 1971, O'Connor[20] developed two water quality indices, each designed for a very different specific water use. One, the Fish and Wildlife index (FAWL), is intended for water used to maintain fish and wildlife habitats; the other is a Public Water Supply index (PWS). Each index was developed using the Delphi[15] technique in the same manner used by Brown et al.[4], but with a much smaller panel of experts. O'Connor's purpose was to compare the performance of the specific-use indices with each other and with the NSFI using actual (and simulated) water quality data. He reasoned that if water use is important enough to merit separate indices, then these two specific-use indices should give very different results when applied to the same water quality data. He found generally low correlations between the FAWL and the PWS, but much higher correlations between either of these two specific-use indices and NSFI. He concluded that FAWL and PWS may be reporting only a subset of the information contained in NSFI. His finding apparently strengthens the case both for specific-use indices and for general water quality indices such as NSFI, since they serve different objectives.

Deininger and Maciunas[21] also have published a specific-use index for public water supplies. It was developed by using the Delphi[15] technique with 12 members of the original NSFI panel of 142. On the questionnaire, each respondent was asked to keep in mind a "free flowing stream which will serve as a source of raw water for a public water supply." Two basic index structures were considered, a product form and a sum form; each has two versions: an 11-variable version and a 13-variable version. The authors compared the performance of these indices with the additive form of the NSFI using actual water quality data. Even though the specific-use indices and the nonspecific NSFI were developed from very different concepts, the authors did not find marked differences between the two. They concluded that there does not appear to be sufficient justification for developing specific-use indices: "...Instead of developing a number of indices for the many water uses, it appears more meaningful to further develop and refine a sensitive and general water quality index."[21]

Comparing the weights of several of the (additive) specific-use water quality indices with NSFI reveals many differences (Table 1). However, these weights generally lie in the range from 0.05 to 0.20, with most of them close to 0.10 and more than half in the narrow range between 0.07 and 0.12.

TABLE 1

COMPARISON OF WEIGHTS USED IN FIVE WATER QUALITY INDICES

Pollutant variable	NSFI (Brown *et al.*[4])	FAWL (O'Connor[20])	PWS (O'Connor[20])	PWS-11 (Deininger *et al.*[21])	PWS-13 (Deininger *et al.*[21])
Dissolved Oxygen	.17	.206	.056	.06	.05
Fecal Coliform	.15		.171	.14	.12
pH	.12	.142	.079	.08	.07
BOD_5	.10			.09	.08
Nitrates	.10	.074	070	.10	.09
Phosphates	.10	.064			
Temperature	.10	.169		.07	.06
Turbidity	.08	.088	.058	.09	.08
Total Solids	.08				
Phenols		.099	.104	.10	.08
Ammonia		.084			
Dissolved Solids		.074	.084	.10	.08
Color			.054	.10	.08
Sulfates			.050		
Alkalinity			.058		
Hardness			.077	.08	.07
Fluorides			.079		.07
Chlorides			.060		
Iron					.07
Number of Variables	9	9	13	11	13

In 1974, Walski and Parker[22] presented a water quality index specifically intended for recreational water use. The index includes 11 pollutant variables grouped under four general headings (appearance; odor, and taste; effect on aquatic life; and effect on health). The index, calculated as the geometric mean of values obtained from subindex rating equations, varies from 0 (completely unacceptable water quality) to 1.0 (ideal water quality).

More recently, Stoner[23] proposed a specific-use water quality index designed to reflect two different water uses--public water supply and irrigation--by changing the weights and equations embodied in the index. This index incorporates recommended limits for certain toxic substances and can vary from a large negative number (worst possible water quality) to 100 (best possible water quality). In general, the greater the negative number, the higher the water treatment costs.

Nemerow and Sumitomo[24] have proposed three specific-use water quality indices which, when added together, give a general water quality index. Their approach is unique in that each of the three specific-use indices reflects both the mean value of its variables and the maximum value of any variable. By this approach, the index reduces the tendency toward "eclipsing" which Thom and Ott[5] discussed in connection with air pollution indices. Eclipsing occurs when some event of importance occurs (such as violation of a standard), but is not reflected in the overall index. The Nemerow and Sumitomo index is an increasing scale form which varies from 0 (good water quality) to values greater than 1.0, with 1.0 denoting pollution at the recommended administrative limits.

Indices for Planning

Another class of water quality indices is intended specifically for administrative decision-making. These "planning indices" often incorporate variables other than those routinely measured by water pollution monitoring activities. The variables usually are suited to a particular decision under consideration. For example, a planning index designed for allocating pollution abatement funds might include factors such as the "number of people" served by surface waters or the "cost of wastewater treatment."

Three different water quality indices proposed by Truett et al.[25] are intended for planning purposes. The first, the Prevalence Duration Intensity Index (PDI) is computed as the product of three variables: (1) the number of stream miles within an area which do not comply with established Federal or State water quality standards (prevalence), (2) the number of quarter-year periods for which violations of standards occur (duration), and (3) the severity of pollution in terms of its effects on human welfare and ecology (intensity). The second index, the National Planning Priorities Index, is intended to help ensure that Federal funds for municipal wastewater treatment projects are distributed in a cost-effective manner. It incorporates the PDI in its formulation, but includes other factors such as the current population of the area, the 1975-76 fiscal year investment, the "controllability" (a measure of the extent to which the pollution sources in the area can be controlled), and per capita planning costs. The third index, the Priority Action Index, is a simplified version of PDI. It incorporates four components: the PDI, controllability, downstream affected population, and current area pollution.

Dee et al.[26] have proposed a general system for evaluating the impact of large-scale water resource projects. Included in the system is a water quality index which contains 12 water quality variables plus pesticides and toxic substances. The overall system contains 78 variables, including such factors as housing, land use, noise, and vegetation. Each variable is represented in the system in Environmental Quality Units which vary from 0 (extremely poor quality) to 1 (extremely good quality). The sum of these 78 variables ranges from 0 to 1,000, with the water quality portions accounting for about one-third of this total.

Inhaber[27] proposed a water quality index intended as part of an overall environmental quality index. The index combines 2 subindices: overall effluent loading and ambient water quality. The overall effluent loading subindex includes effluent data from five sources (municipal wastes and the petroleum refining, chlor-alkali, fish-processing, and paper industries). The ambient water quality subindex includes turbidity, trace metals (cadmium, chromium, lithium, copper, and zinc), fish catch, and the mercury content of fish. Although this index originally was intended for use as a Canadian National Index, there is no evidence that it has been routinely applied in Canada.

The Pollution Potential Index, developed by Zoeteman[28] in 1973, is a planning index designed to relate changes in river water quality to the human activity responsible for these changes. It consists of the product of the number of people living in a drainage basin and the per capita Gross National Product, divided by the average flow rate of the river. This index was applied by the author to data on 160 river sites throughout the world.

Johanson and Johnson[29] have developed a planning index specifically designed for evaluating data on toxic pollutants built up in the sediments of the U.S. ports, harbors, and waterways. The index was used to screen 652 data sets from locations throughout the United States to establish priorities for removal or inactivation of these "in-place" pollutants, in accordance with Section 115 of the Federal Water Pollution Control Act Amendments. The index consists of the sum of the weighted maximum concentration of each toxic pollutant.

Statistical Approaches

In addition to the above indices, a number of statistical approaches have been suggested for evaluating water quality data. These approaches usually employ some standard statistical procedures already available in the literature. They have the advantage that they incorporate fewer subjective assumptions, but the disadvantage that they are sometimes difficult to apply and must be tailored to the data at hand.

One class of statistical approaches, correlation techniques, examines the associations among variables to determine the importance of each as a determinant of water quality. Shoji, Yamamoto, and Nakamura[30] applied "factor analysis" to the Yodo River System in Japan to examine the interrelationships among 20 variables. By comparing the correlation of each variable, and selecting those variables with the highest correlations, they identified three major factors: pollution, temperature, and rainfall. From this procedure, the investigators also determined the weights for an 18-variable Composite Pollution Index which they applied to data from each station on the Yodo River System.

In another correlation study, Coughlin, Hammer, Dickert, and Sheldon[31] examined the relationship between a water quality index and the perception and use of a stream made by nearby residents. The investigators used "principal component analysis" to examine the relationships among individual NSFI variables and such factors as distance of residence from the stream, land values, and the tendency of residents to walk along the stream or to wade or fish in it.

Another statistical approach involves ranking of water quality data. In 1974, Harkins[32] proposed that a ranking approach originally suggested by Kendall[33] could be used to evaluate water quality data in a more objective fashion than is possible with NSFI. In Harkins' approach, the values of each variable are first ranked in decreasing order of magnitude. Then the rank order numbers which result are used to calculate the index. A standard transform based on the square of the difference between a control value and the rank order number then is calculated. An index value for each group of samples then is obtained by summing the transforms for the variables comprising the group. This approach is "nonparametric"; the nature of underlying probability distribution of the data does not affect any probability statements that might be derived from the results. However, because the index is based on ranking of the values within a particular data set, the index number generated from one data set cannot be directly compared with those generated by a different data set.

Schaeffer and Janardan[34] have extended Harkins' approach by taking advantage of the nonparametric nature of the ranked data. They observe that the square root of the transform used in Harkins' index is normally distributed. Therefore, the transform itself is the square of a normally distributed random variable and has a chi-square distribution. Using this argument, they form an additional transform which has a beta distribution. Then they use this transform to create an increasing scale index which varies from 0 to 1. They examine the statistical properties of this index by means of simulation and apply it to water quality data from the State of Illinois. They also compare the index result with a biological water quality classification system and find relatively good agreement.[34] Unlike Harkins' approach, the index numbers generated by this index can be compared with those generated from a different data set.

Comparing the indices discussed shows a great many differences in the number of variables, scales, and ranges (Table 2). The number of water quality variables included in the 5 general and 6 specific-use indices shown ranges from 9 to 31. Most indices in these two groups (9 out of 11) have decreasing scales, and the majority (6 out of 11) have ranges from 0 to 100. Others have ranges of 0 to 1, 0 to 15, 0 to 1,000; and one can be negative. When the seven planning indices and four statistical approaches are considered, the variety among the different index types becomes much greater. Most of the planning indices have increasing scales, and, by contrast, few have ranges from 0 to 100. The overall picture that emerges is one of a great variety of water quality indices, each structurally quite distinct and each having a different interpretation.

Most of the above indices were designed for application to data from free-flowing surface waters. However, special problems of eutrophication (excessive plant and algal growth) can occur in nonflowing water bodies, particularly in lakes. The National Eutrophication Survey carried out by EPA in 1974[35] collected extensive data on the eutrophic conditions of over 800 U.S. lakes. Various statistical approaches were used to examine the relationships among physical, chemical, and biological variables as indicators of eutrophication, and these results were compared with field observations and professional judgment of the condition of the surveyed lakes. As part of this effort, EPA also developed a Trophic Index to rank the trophic condition of lakes using six measures: total phosphorus, dissolved phosphorus, inorganic nitrogen, Secchi disc, minimum dissolved oxygen, and chlorophyll-*a*. For the lakes surveyed, EPA was able to relate index ranges to three trophic states (oligotrophic, mesotrophic, and eutrophic).[35]

BIOLOGICAL WATER QUALITY INDICES

Although the principal emphasis of this report is on physical and chemical water quality indices, many biological indices of water quality also have been developed. In these systems, water quality is evaluated in terms of its impact on aquatic life in some form. Three basic approaches have been developed.

TABLE 2

OVERALL CHARACTERISTICS OF WATER QUALITY INDICES PUBLISHED IN THE LITERATURE

Index Name[a]	Reference	No. of Variables	Scale[b]	Range
Indices of General Water Quality				
Quality Index	Horton[3]	10	Decreasing	0 to 100
Water Quality Index	Brown *et al.*[4]	9	Decreasing	0 to 100
Implicit Index of Pollution	Prati *et al.*[17]	13	Increasing	0 to 15+
River Pollution Index	McDuffie *et al.*[18]	8	Increasing	0 to 1000
Social Accounting System	Dinius[19]	11	Decreasing	0 to 100
Indices for Specific Water Uses				
Fish and Wildlife Index	O'Connor[20]	9	Decreasing	0 to 100
Public Water Supply Index	O'Connor[20]	13	Decreasing	0 to 100
Index for public water supply	Deininger *et al.*[21]	11/13	Decreasing	0 to 100
Index for recreation	Walski *et al.*[22]	12	Decreasing	0 to 1
Index for dual uses	Stoner[23]	31	Decreasing	-100 to 100[c]
Index for three uses	Nemerow *et al.*[24]	14	Increasing	0 to 1+
Indices for Planning				
Prevalence Duration Intensity Index	Truett *et al.*[25]	d	Increasing	0 to 1
National Planning Priorities Index	Truett *et al.*[25]	d	Increasing	0 to 1
Priority Action Index	Truett *et al.*[25]	d	Increasing	0 to 1
Environmental Evaluation System	Dee *et al.*[26]	78[e]	Decreasing	0 to 1000
Canadian National Index	Inhaber[27]	d	Increasing	0 to 1
Potential Pollution Index	Zoeteman[28]	3	Increasing	0 to 1000+
Pollution Index	Johanson *et al.*[29]	d	Increasing	0 to 100+
Statistical Approaches				
Composite Pollution Index	Shoji *et al.*[30]	18	Increasing	-2 to 2
Principal Component Analysis	Coughlin *et al.*[31]	d	NA	NA
Kendall's ranking approach	Harkins[32]	d	Increasing	0 to 100+
Beta function index	Schaeffer *et al.*[34]	d	Increasing	0 to 1

[a]Where proper name for index is unavailable, index characteristic is listed.
[b]*Increasing scale:* index numbers increase with degree of pollution. *Decreasing scale:* index numbers decrease with degree of pollution.
[c]Index can be less than -100 and can become a large negative number.
[d]Any number of variables can be included.
[e]Water quality variables account for 14 of the 78 variables used in this system
NA = not applicable.

The first approach focuses on the types and quantities of certain organisms (indicator organisms) observed in the water. A simple example is enteric bacteria such as fecal coliforms that are normal inhabitants of the digestive tract of man and other warm-blooded animals. The presence of these indicator organisms usually is taken as evidence of contamination with fecal material. Another example consists of the saprobic classification systems employed in environments rich in degradable organic matter. The saprobic systems divide a stream into various zones of pollution depending principally on the type of organisms present. The various saprobic systems that have been developed are summarized by Orlando and Wrightington.[9]

The second approach concentrates on the mathematical properties of the populations of organisms. For example, some techniques use information theory to describe the diversity of species within the community. Other species diversity techniques employ various probabilistic models in their formulation. Orlando and Wrightington[9] observe that the theoretical development of some species diversity indices seems far more advanced than their practical application:

> It must be stressed that the above mathematical diversity index is highly theoretical and conceptual even though Pielou applied it to communities of forest trees. Whether or not some practical and useful information can be generated from actual sampling of aquatic environments remains to be seen. Any values developed from the information-theory-based diversity index should be correlated with some physical-chemical measurements of water pollution to be useful as water quality indicators.

The third biological approach examines biological responses such as the physiological or behavioral changes of certain organisms as a result of pollution. For example, pesticides are known to inhibit acetylcholinesterase activity in the brains of fish, and fish-brain cholinesterase activity has been used as a monitor for pesticide pollution. Behavioral changes of certain species, such an increased activity and agitation of fish in response to toxic substances, also have been studied as an indicator of environmental pollution.[9] One obvious biological indicator is the incidence of fish kills.[36]

Biological measures of pollution have the advantage that they have a "pollution integrating" effect. Fish and other organisms tend to respond to the entire historical record of water quality. Thus, if some toxic substances are present on rare occasions and go undetected in routine water quality monitoring activities, the presence of these pollutants would still be reflected in terms of their effects on aquatic organisms. Orlando and Wrightington[9] observe that this integrating feature enables biological organisms to monitor a number of pollutants at once:

> Aquatic organisms respond to a number of chemical, physical, and biological water quality variables in an integrated manner. Thus, one or a few organisms can do the work of several analysts in terms of demonstrating that a large number of variables either are or are not within the range of tolerance of aquatic life, although they do not give specific numerical values for each of the variables. A number of different industries routinely pass their effluents through a fish pond before discharge to demonstrate that the effluent is not toxic to fish. Of course, by using tolerant species such as goldfish or carp it is possible to greatly reduce the chance that toxicity would be demonstrated.

In the past, data on biological measures of water quality have not been collected as routinely as data on physical and chemical variables. However, biological monitoring activities are expected to receive greater emphasis in the next few years. This survey is limited primarily to physical and chemical water quality indices.

DISCUSSION

From the above literature review, it is clear that a great variety of water quality indices have been published. These indices differ from each other in terms of their fundamental structures and in terms of the number and types of variables that have been selected for inclusion. Why have so many different indices been developed? Is there evidence of an evolutionary process that is moving toward a single preferred index structure for the analysis of water quality data?

Scientific inquiry and development of scientific knowledge normally follow a systematic pattern in which each study builds upon the knowledge gained in the previous investigation. Usually each investigator begins by reviewing all of the work of previous investigators to determine how to structure his own study so that it will make a maximum contribution to knowledge. This process helps assure that each study will tend to advance scientific knowledge in a particular topic area.

However, the many water quality indices that have been developed in the decade 1965-1975 give little evidence of the normal evolution that one would expect to find in scientific inquiry. Rather, each index seems to emerge "full blown" from the literature. Indeed, some of the authors do not cite the work of previous authors, nor do they seem acquainted with other efforts in this field. Thus, after reviewing the literature, one is left with the impression that the authors seldom provide a sense of what has gone before. What role does their index play in the scientific literature? What problem does it solve that other indices before it have failed to solve?

The possible two exceptions to the above rule are the NSFI and the Harkins' index. The NSFI was the first index to employ a systematic opinion research procedure in its development. Follow-up studies by O'Connor[20] and Landwehr[12] have sought to answer additional questions of importance regarding characteristics of NSFI, and a number of case studies have been carried out using this index.[16] Thus, an evolutionary process has occurred in this case. Harkins' index[32] also has evolved further in work carried out by Schaeffer and Janardan.[34] Except for these two cases, a <u>proliferation of water quality indices has occurred, each differing from the next, and each showing little relationship to the one before it</u>.

III. SURVEY DESIGN

Our review of the literature indicates that the published articles provide relatively little information about the routine use of indices by water pollution control agencies. To learn which water pollution indices are in common use and to gain insight into the experiences of water pollution control agencies with these indices, an in-depth survey of these agencies was necessary. In this survey, agencies throughout the United States were telephoned and asked to provide information describing their experiences with indices, if any. The data base in this investigation was assembled from notes taken during the telephone conversations, from written materials received from the agencies, and from the 1976 Section 305(b) reports from the States.

SURVEY POPULATION

The population surveyed in this investigation included: the 50 State water pollution control agencies; the 9 interstate agencies having responsibilities in the area of water quality; and the 10 EPA Regional Offices. Information regarding the individual contact point in each agency was obtained from several sources: The "1976 Environmental Program Administrators,"[37] the "Directory of State Agencies Engaged in Environmental Monitoring,"[38] the "Directory of Regional Water Pollution Control Agencies" published by Water and Sewage Works,[39] and a listing of the EPA Regional Office coordinators for the Section 305(b) reports. Occasional difficulty was encountered in identifying the individual within an agency who was knowledgeable about water quality indices. However, in the State agencies, the proper individual was usually involved in compilation of the State's Section 305(b) report; in the EPA Regional Offices, the Section 305(b) report coordinator was contacted. The smaller size of the interstate commissions facilitated contacting the single individual who was familiar with water quality indices and data analysis procedures.

Selection of the person "most knowledgeable" about an agency's use of indices may have biased the survey so that it reflected less the view of higher level managers and more the view of technical experts within the agency. The bias appears to be inherent to the telephone survey approach. Future surveys might utilize mail questionnaires so that the "official position" of the agency may be ascertained more readily.

SURVEY APPROACH

The first step in assembling the type and quantity of information necessary for this study was to develop a telephone survey data sheet (Appendix F). Because there was considerable variation in the nature of the questions asked during the interviews, the data sheet served only as a guide. This was due partly to the wide range of respondents' experience and knowledge regarding water quality indices. In addition, as the survey progressed, the author learned more about which questions on the data sheet obtained the greatest amount of information and what additional questions were required to clarify particular points. In general, all respondents were asked whether they used an index, and, if so, what type, how it was calculated, its purpose, and its usefulness.

Telephone calls were made to the various agencies in the survey population from October 1976 to February 1977. If an agency used an index or had evaluated or developed one, the respondent was asked to supply information about the index. All agencies also were asked what they felt the Federal Government should be doing in the area of water quality indices and if they favored development of a federally recommended water quality index. The responses received to these and other questions form the basis for the brief comments given in the tables in the next chapter. All comments are summarized in Appendices A and B.

CLASSIFICATION OF NONUSER AND USER AGENCIES

Two definitions were used in classifying the agencies surveyed in this study:

Nonuser Agency

Nonuser agencies were divided into four general categories: (1) agencies unfamiliar with indices, (2) agencies that had considered or evaluated indices, (3) agencies planning to evaluate or develop indices, or (4) agencies currently evaluating or developing indices. Thus, the second category included those agencies that had decided not to use an index after they had either briefly considered various indices or had conducted a rather extensive evaluation to determine their applicability to the agency's particular need. Agencies in the third category were planning either to evaluate or to develop an index in the near future; thus, this group includes "potential" index users. Agencies in the fourth category are also potential index users, because, at the time of this study, they were in the process of evaluating or developing an index for use in the near future.

User Agency

To be classified as an "index user," the agency must have used an index in an official capacity over an extended time period. Furthermore, the index must have appeared in an official publication of the agency (for example, the Section 305(b) report, State annual water quality report, or water quality trends report) or be applied in a large-scale water quality study extending over a year or more. However, if an agency had only carried out a small-scale pilot project designed to test an index, it would not be classified as an index user; rather, the agency would be considered an "index evaluator."

IV. SURVEY RESULTS

A majority of the information gathered in this study was recorded on the index questionnaire forms used during the telephone interviews; additional information was obtained from material mailed on request. In either case, this information has provided the basis for the following discussion of survey results. This discussion is divided into two sections, nonuser and user agencies, based on the definitions in the previous chapter. Tables 3 and 4 give the current status of water quality index utilization in the States, the District of Columbia, and nine interstate commissions. Table 5 gives a summary of index utilization of both of these groups. Comments from the index nonuser and user community are recorded in Appendices A and B, respectively.

AGENCIES CURRENTLY NOT USING INDICES

Based on the comments received from the survey respondents, nonuser agencies were divided into four categories. These categories were chosen to form a continuum, beginning with agencies least familiar with indices and ending with those most familiar, namely, agencies currently evaluating or developing indices. Agencies in each of these categories are discussed in the following sections. Comments from these agencies are summarized in Tables 6-8.

Agencies Unfamiliar With Indices

Respondents from 11 State agencies and 2 interstate commissions indicated that they were, to a varying degree, unfamiliar with water quality indices (Table 5). Actually, respondents from 7 of the 11 States and both of the interstate commissions indicated that they were totally unfamiliar with indices and/or their application to interpretation of water quality data. Although respondents from two States were not familiar with either NSFI or the Harkins-type index, they were acquainted with or had used one of the biological indices.* Finally, the two other States simply stated that they were unfamiliar with water quality indices because they were opposed to use of any qualitative or generalized techniques (for example, indices) for interpreting water quality data.

Agencies That Have Previously Considered or Evaluated Indices

Most of the 18 agencies that have previously considered or evaluated indices had unfavorable views toward indices. As can be seen by examining the abbreviated comments from these agencies (Table 6), 10 of the 14 agencies felt that indices were not really a very useful tool for presenting water

*For more information on biological indices, see Reference 9.

TABLE 3

STATUS OF WATER QUALITY INDEX UTILIZATION BY STATES

Agency	Index Nonuser				Index User
	Unfamiliar with Indices	Considered or Evaluated	Planning to Evaluate or Develop	Currently Evaluating or Developing	
Alabama	•				
Alaska		•			
Arizona	•				
Arkansas	•				
California		•			
Colorado					•
Connecticut	•				
Delaware		•			
District of Columbia	•				
Florida		•			
Georgia					•
Hawaii		•			
Idaho			•		
Illinois					•
Indiana					•
Iowa			•		
Kansas				•	
Kentucky			•		
Louisiana			•		
Maine		•			
Maryland				•	
Massachusetts		•			
Michigan					•
Minnesota		•			
Mississippi	•				
Missouri	•				
Montana					•
Nebraska			•		
Nevada				•	
New Hampshire		•			
New Jersey				•	
New Mexico		•			
New York					•
North Carolina	•				
North Dakota			•		
Ohio			•		
Oklahoma					•
Oregon					•
Pennsylvania		•			
Rhode Island			•		
South Carolina				•	
South Dakota			•		
Tennessee	•				
Texas		•			
Utah		•			
Vermont			•		
Virginia	•				
Washington		•			
West Virginia	•				
Wisconsin				•	
Wyoming					•

TABLE 4

STATUS OF WATER QUALITY INDEX

UTILIZATION BY INTERSTATE COMMISSIONS

Commission	Index Nonuser				Index User
	Unfamiliar with Indices	Considered or Evaluated	Planning to Evaluate or Develop	Currently Evaluating or Developing	
Delaware River Basin		•			
Great Lakes	•				
International Joint		•			
Interstate (CN, NJ, NY)		•			
Klamath River	•				
New England Interstate					•
Ohio River				•	
Potomac River Basin					•
Susquehanna River Basin		•			

TABLE 5

SUMMARY OF WATER QUALITY INDEX UTILIZATION BY STATES AND INTERSTATE COMMISSIONS

	Index Nonusers				Index Users	Total
	Unfamiliar with Indices	Considered or Evaluated	Planning to Evaluate or Develop	Currently Evaluating or Developing		
States	11	14	10	6	10	51
Commissions	2	4	0	1	2	9
Total	13	18	10	7	12	60

TABLE 6

NONUSERS WHO HAVE PREVIOUSLY CONSIDERED OR EVALUATED INDICES

Agency	Index	Comments
Alaska	–	Insufficient data.
California	NSFI	
Delaware	NSFI, Harkins	Indices very difficult to apply generally; we have a particular problem with tidal/fresh water interface which indices cannot handle.
Florida	Biological	Used to calculate eutrophication index for lakes.
Hawaii	Biological	Used to indicate safety of public bathing areas.
Maine	–	Skeptical about applicability and understandability of indices.
Massachusetts	–	Individual variables are satisfactory for our purposes.
Minnesota	NSFI	NSFI was not adequate for Section 305(b) report so individual variables are used.
New Hampshire	–	Don't have a need for an index—it would just add another level of confusion that is really not necessary.
New Mexico	NSFI, Harkins	None of the indices which have been developed are useful here because of high stream sediment levels.
Pennsylvania	NSFI, Harkins	Indices don't cover "special" situations; one really needs different indices for the different chemical and physical variables.
Texas	Harkins	Water quality can be described more accurately without indices.
Utah	NSFI	Although there is some possibility of using an index in the future, we feel that indices in general do not represent water quality; at the present time we don't have data on all nine NSFI variables.
Washington	–	Evaluated several indices and found that, in general, they did not reflect the actual changes in water quality for our situation.

quality data. Several agencies felt that water quality could be described more accurately without indices; others stated that indices would either confuse the picture of water quality or would not be understood by the layman.

Similar comments were received from the interstate commissions, as seen in Appendix A. The comments from the New York Interstate Commission generally expressed the feelings of this group:

> One is limited only by his ingenuity in the number of ways the various water quality variables can be put together. Thus, one comes up with a different index number depending on the index used and what weights are assigned to the variables. Although the idea of a water quality index is great, water quality indices oversimplify the picture of water quality, and tend to get misused.

Agencies Planning To Evaluate or Develop Indices

Of the 10 agencies planning to evaluate or develop indices (Table 5), 8 are including the NSFI in their plans for evaluation or development of a water quality index (Table 7). In addition, most of the States indicated that one of the major uses of the index would be in the Section 305(b) report. Since these agencies were in a learning stage about indices, they yielded very little other information. Consequently, it would be of interest to interview these agencies again in the future to determine the status of their index evaluation efforts or index development activities.

Agencies Currently Evaluating or Developing Indices

In mid-1977, six State agencies and one interstate commission were evaluating or developing an index for possible use by their agencies (Table 8). In most cases, these agencies planned to use the index in the State's Section 305(b) report. Four of the six State agencies were adapting the NSFI to fit their particular data bases, and one, Nevada, was developing its own index. Maryland, which has evaluated both the NSFI and the Harkins' index, was developing a modified biological species diversity index instead of using one of the existing water quality indices. Their reason for selecting this type of index is their belief that biological communities provide a more valid measure of water quality:

> We feel that since aquatic species are subjected to water pollution and tend to integrate effects over time, biological indices are more descriptive of water quality than chemical variables, which give instantaneous values that are not necessarily valid for a whole stream and do not reflect long-term pollution. Furthermore, the layman does not understand the significance of the various concentrations of chemical variables and the statistical methods used in computing a water quality index from them. However, the average citizen can easily comprehend the relationship between water quality and the type of stream life.

AGENCIES CURRENTLY USING INDICES

To be classified as an index user, an agency must have used an index in a large-scale water quality study extending over a year or more, or it must have used one in an official agency publication.

Indices in Current Use

Of the 51 State agencies (including the District of Columbia) and 9 interstate agencies, 12 agencies (20 percent) have used a water quality index (Table 9). However, one, the Interstate Commission on the Potomac River, used an index in just one report and no longer can be classified as an index user. Thus, a total of 11 agencies (18 percent of the State and interstate agencies) is currently using a water quality index.

TABLE 7

NONUSERS WHO ARE PLANNING TO EVALUATE OR DEVELOP INDICES

Agency	Index	Comments
Idaho	–	Planning to use a system similar to Region X water quality profiles.
Iowa	NSFI	Considering use as an indicator of water quality improvement.
Kentucky	–	Anticipate development of index within a year for use in Section 305(b) report.
Louisiana	NSFI	Will develop index with fewer variables than NSFI for use in Section 305(b) report.
Nebraska	NSFI	Want to develop for use in Section 305(b) report.
North Dakota	NSFI	Now looking into possibility of using an index in the future.
Ohio	NSFI	Would like to use an index in our monthly water quality report.
Rhode Island	NSFI	Now in the process of looking into NSFI and other indices for possible use in the future.
South Dakota	NSFI	Now looking at the possible use of NSFI in the future.
Vermont	NSFI	Will be using an unmodified NSFI in the 1977 Section 305(b) report.

TABLE 8

NONUSERS WHO ARE CURRENTLY EVALUATING OR DEVELOPING INDICES

Agency	Index	Comments
Kansas	NSFI	Modified NSFI under development for use in Section 305(b) report.
Maryland	NSFI, Harkins	Biological species diversity index now under development.
Nevada	–	Fifteen variable "Combined Water Pollution Index" being evaluated.
New Jersey	NSFI	Developing modified NSFI for use in Section 305(b) report and as a public information tool.
South Carolina	NSFI	Developing modified NSFI for use in Section 305(b) report.
Wisconsin	NSFI	Developing modified NSFI for use in Section 305(b) report.
Ohio Interstate	NSFI	Evaluating NSFI for possible routine use.

TABLE 9

AGENCIES USING WATER QUALITY INDICES, JUNE 1977

Agency	Index	Characteristics	Length of Time in Use	Application
Colorado	Modified NSFI	8 variables (temperature deleted), additive form.	3 years	Statewide application on an annual basis; 13 stations in 1976, 27 stations in 1977
Georgia	Developed own index	8 variables Geometric mean of 8 subindices, with each subindex weighted according to its rank order Rating curves similar to NSFI were developed	1 year	Applied to 30 stations from statewide network of 105 stations for use in 305(b) report. Calculated once per year, applied to 5-year trends.
Illinois	Developed own index	Several indices developed by different state agencies. One index includes 6 variables, and values 1, 2, 3, 4, and 5 are assigned to different variable ranges. Current index includes 4 variables and is a statistically based ranking formula.	2 years	Statewide application. A total of 300-600 stations.
Indiana	Modified NSFI	7 variables (total solids and turbidity deleted); additive form	1 year	Applied to 52 Indiana streams and lakes where all 7 variables were available.
Michigan	Modified NSFI	8 variables (temperature deleted), multiplicative form	3 years	Statewide application to 85-100 stations on a monthly basis.
Montana	Standard NSFI	9 variables; multiplicative form.	1½ years	Applied to Yellowstone River on a pilot basis with 8-10 runs using 18-25 stations
New York	Standard NSFI	9 variables, not calculated if a variable is missing, multiplicative form	1 year	Applied to data from 162 stations representing 17 major water basins. Computed seasonally and applied to 11-year period 1964-1974.
Oklahoma	Harkins' index	7 variables; three indices were computed. a general index, a mineral index, and a nutrient index. Currently using modified version of Harkins' index with 10 variables.	1½ years	Statewide application to 99 stations having extensive variable coverage
Oregon	Developed own index	6 variables; grouped into 5 impairment categories	½ year	Applied to stations in the Willamette River Basin to give monthly water quality reports. Statewide adoption expected soon
Wyoming	Modified NSFI	Usually 8 variables (temperature deleted, BOD sometimes deleted), additive and multiplicative forms	2 years	Statewide application to 40 stations covering 5 major basins.
New England Interstate	Standard NSFI	9 variables, additive form, changing to multiplicative form	1 year	Applied to 9 stations on the Nashua River, 30 weekly stations on Interstate waters.
Potomac River Interstate	Harkins' index	4 variables total (usually 3 variables at each station).	Used for one report only.	Applied to 9 stations on the Potomac River for the 10-year period 1962-1971

Of the 51 State agencies, 10 agencies (20 percent), are classified as index users. One additional State, Nevada, is developing its own index and may become an index user in the immediate future.

Of the 11 current water quality index users, 7 agencies (6 States and one interstate commission) have chosen to use the NSFI. Three states--Georgia, Illinois, and Oregon--are using indices they have developed on their own. The new indices developed by water pollution control agencies are discussed in greater detail in Chapter V. One agency, Oklahoma, currently uses Harkins' Index,* and the Interstate Commission on the Potomac River, which no longer is an index user, previously used Harkins' index. In summary, the NSFI is the most commonly used water quality index, accounting for 64 percent (7 out of 11) of the agencies currently using indices.

The number of variables included in indices currently in use ranged from four to nine (Table 9). The preferred numbers were nine variables (3 agencies), eight variables (3 agencies), and seven variables (2 agencies). Most of the water quality indices have been adopted within the last 3 years, and nearly half (45 percent of the users) were adopted within the previous year. Thus, routine application of water quality indices is a relatively recent phenomenon. This is not surprising when one considers that the first formal physical/chemical water quality index, Horton's index[3], was published in 1965, the NSFI was presented in 1970, and most of the other indices were published in the period 1970-1975. However, probably the most important reason for the recent growth in index utilization is the requirement imposed on the States to prepare annual water quality reports under Section 305(b) of the Federal Water Pollution Control Act. Although EPA guidance does not require or encourage the use of indices in preparing these reports, it does not discourage it either. It appears that a number of States have chosen to include indices in these reports to facilitate reporting of water quality trends.

Most of the indices were applied on a Statewide basis, usually to those monitoring stations with the most data available. In three cases, the index was applied to a single river: in Montana, the NSFI was used on the Yellowstone River; in New England, the NSFI was applied to the Nashua River; and in the Virginia, Maryland, and the District of Columbia area, Harkins' index was applied to the Potomac River.

Although the NSFI is the most widely used water quality index, a number of the users tended to make minor modifications to this index, usually deleting one or more variables due to data limitations (Table 10). The most frequently deleted NSFI variable was (departure from equilibrium) temperature (3 agencies), although total solids and turbidity were deleted in Indiana. In Wyoming, BOD_5 was deleted whenever it was missing, and the weights were altered. With most deletions of variables, the user altered the weights so that they retained the same ratios as before, but still added to 1.0. One

*Recent communication with Oklahoma suggests that a somewhat modified version of Harkins' index will be used in the future.

TABLE 10

AGENCIES CURRENTLY USING THE NATIONAL SANITATION FOUNDATION INDEX (NSFI)

Agency	Variables									Form
	DO	FC	pH	NO_3	PO_4	BOD_5	Temp	TS	Turb	
Colorado	•	•	•	•	•	•		•	•	Additive
Indiana	•	•	•	•	•	•	•			Additive
Michigan	•	•	•	•	•	•		•	•	Multiplicative
Montana	•	•	•	•	•	•	•	•	•	Multiplicative
New York	•	•	•	•	•	•	•	•	•	Multiplicative
Wyoming	•	•	•	•	•	•[a]		•[b]	•	Additive and Multiplicative
New England Interstate	•	•	•	•	•	•	•	•	•	Additive[c]

[a]For stations with missing BOD_5 data, this variable was dropped and weights were altered.

[b]Total dissolved solids (TDS) was substituted for total solids (TS) when total suspended solids (TSS) was missing.

[c]Used additive form initially; currently changing to multiplicative form.

agency, the New England Interstate Water Pollution Control Commission, deleted temperature from the NSFI and conducted a special study to examine the effect of this deletion on the index values. The study usually found less than 1/2-point difference between the modified and standard NSFI. This agency concluded that the differences were negligible and, therefore, to achieve greater uniformity with other agencies, decided to use the standard NSFI rather than the modified version. No agency reported using toxic substances in its NSFI application, although the original NSFI publication discussed ways to include toxic substances.

Three agencies used the additive form of the NSFI, while three others used the multiplicative form, and one agency used both. There was a trend toward increased use of the multiplicative form of the NSFI. This trend is consistent with the published literature on NSFI, which currently promotes the multiplicative form, not the additive form of the index.

Purposes of Index Applications

In each telephone discussion with an index user, the author sought to determine the nature of the index application. What are the agency's main purposes for using the index? What needs does it serve? Can specific examples be identified that show how the index was applied to solve a problem or facilitate communication?

The primary purposes expressed by the index users for applying their indices were quite varied (Table 11). Three purposes were mentioned most frequently: preparation of the Section 305(b) annual report (9 agencies); public information (8 agencies); and analysis of water quality trends (8 agencies).

TABLE 11

PURPOSES FOR WHICH INDICES ARE BEING USED

Agency	Index type	Trend Analysis	Intensive Surveys	305(b) Report	Other Reports	Public Hearings	Public Information
Colorado	Modified NSFI	•		•			•
Georgia	Developed own index	•		•			•
Illinois	Developed own index	•		•			•
Indiana	Modified NSFI			•			
Michigan	Modified NSFI	•	•	•			•
Montana	Modified NSFI	•			•		•
New York	Standard NSFI	•		•	•	•	•
Oklahoma	Harkins' Index			•			
Oregon	Developed own index			•	•		
Wyoming	Modified NSFI	•	•	•			•
New England Interstate	Standard NSFI	•					•
Potomac River Interstate	Harkins' index[a]				•		

[a]Index used for one report only.

Although preparation of the Section 305(b) reports was the most frequently cited purpose for applying a water quality index, examination of the 305(b) reports reveals that the index results usually constituted only a small portion of the overall report. For example, Michigan's Section 305(b) report[40] uses the result of a Statewide application of the NSFI to introduce the reader to the "present state of Michigan's water quality," and the index discussion occupies four or five pages in the overall report. The index is used to give an overview of the status of Michigan's waters:

> Michigan's abundant natural resources include over 36,000 miles of rivers and streams, more than 11,000 inland lakes, and 38,500 square miles of Great Lakes waters. Michigan has selected the Water Quality Index developed by the National Sanitation Foundation to present a summary of stream quality. As shown in Figure 2, most of Michigan's river basins rate good to excellent on the water quality index scale for water year 1975 (October 1974 through September 1975). Generally, rivers in the basins shown as having medium water quality flow through more populous areas and receive waste loads from known point sources. Point source pollution control programs are underway in these

> basins which should improve water quality. Any problems that remain will have to be addressed by nonpoint source programs.[40]

The index results are illustrated in a map of the State in which areas are shaded to depict three different water quality index values (Figure 2). To deal with the problem of geographical differences in water quality between Michigan and other States, the report[40] redefines the normal range of the NSFI:

> The water quality index scale is designed to accommodate a wide range of water quality nationwide. Because of weather and natural geological conditions, it is unlikely that Michigan waters in even the most remote and natural settings will reach 100 units on the water quality index scale. By the same token, values near 90 show that Michigan water quality is within 10 units of a national ideal of the maximum attainable limit.

The Michigan Section 305(b) report also shows the mean index values and the high and low values observed in a number of selected streams around the State, ranked in increasing order (Figure 3). This result illustrates that individual streams can show great variability. For example, index values on the Carp River vary from the "poor" to the "good" quality range.

The most commonly cited public information use of a water quality index was for the purpose of communicating water quality information to the "layman." A typical remark was, "We feel that the general public needed something more in keeping with the layman's knowledge than the raw data would provide." It is not certain what form this communication took. One respondent indicated that newspaper reporters had posed a number of questions about water quality. He suggested that a typical question was, "Could you give us an interpretation of water quality in the area for the past 3 years?" He felt that a format more understandable than 10 or 25 variables was required for presenting water quality information to the public. Another respondent indicated that his agency intends to publish and distribute index reports designed for various audiences throughout the State. These respondents generally regarded their index as a useful public information tool, and they sometimes mentioned actual instances in which it had been used to present information to the public. However, documented examples of newspaper articles in which an index had been used to report water quality data to the layman or to members of the general public were not readily available. The audience of many of the reports mentioned, such as the Section 305(b) annual water quality reports, cannot be considered the "general public;" rather, judging by the content of the reports, they seem to be informed professionals and water pollution control officials. Thus, the present study was unable to find any specific examples of cases where water quality index reports have appeared in newspapers or on television. However, application of water quality indices is a relatively new field, and possibly more direct public information uses will emerge in the future.

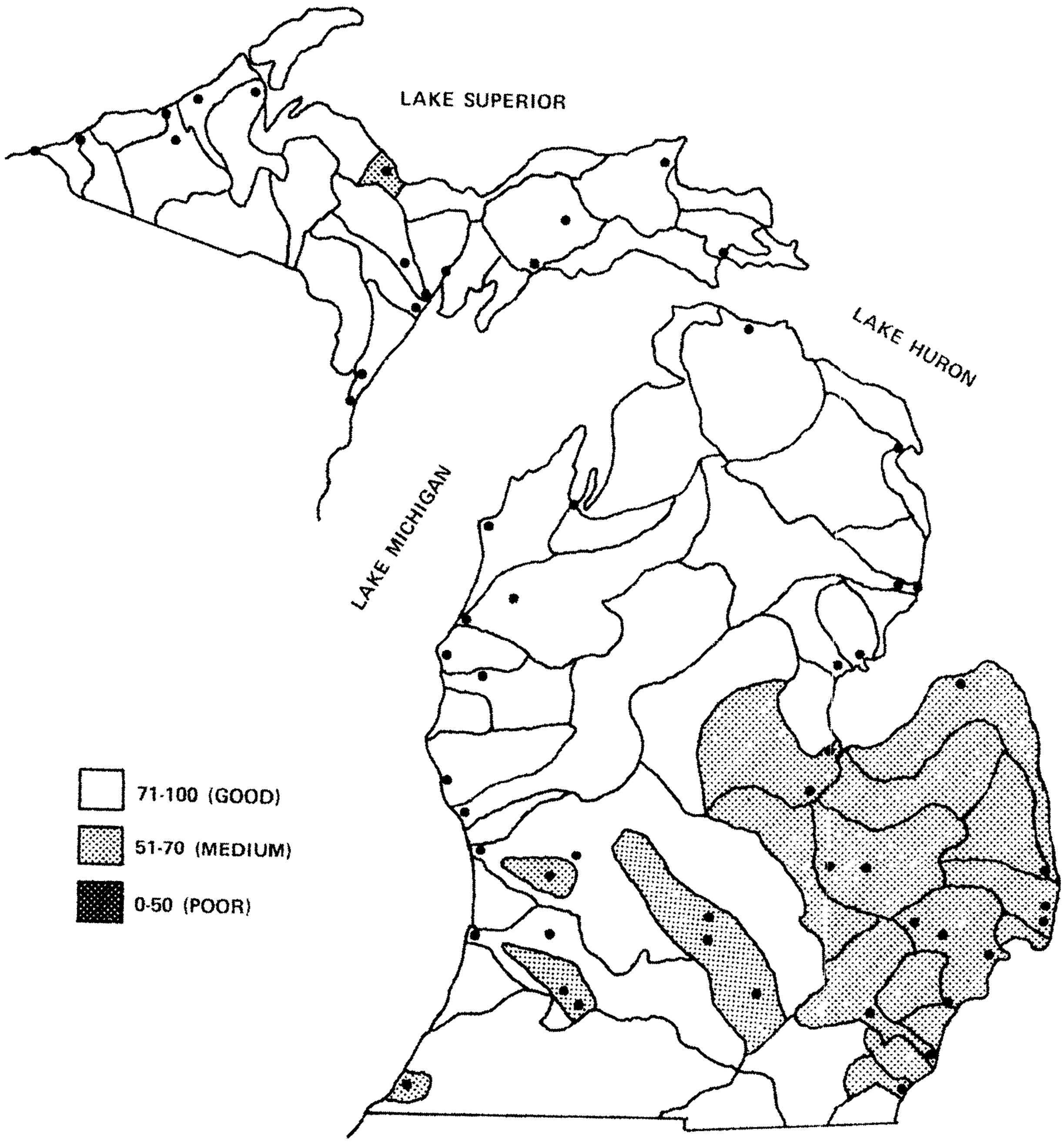

FIGURE 2. AVERAGE WATER QUALITY CONDITIONS, AS INDICATED BY THE NSFI, FOR THE STATE OF MICHIGAN.[40]

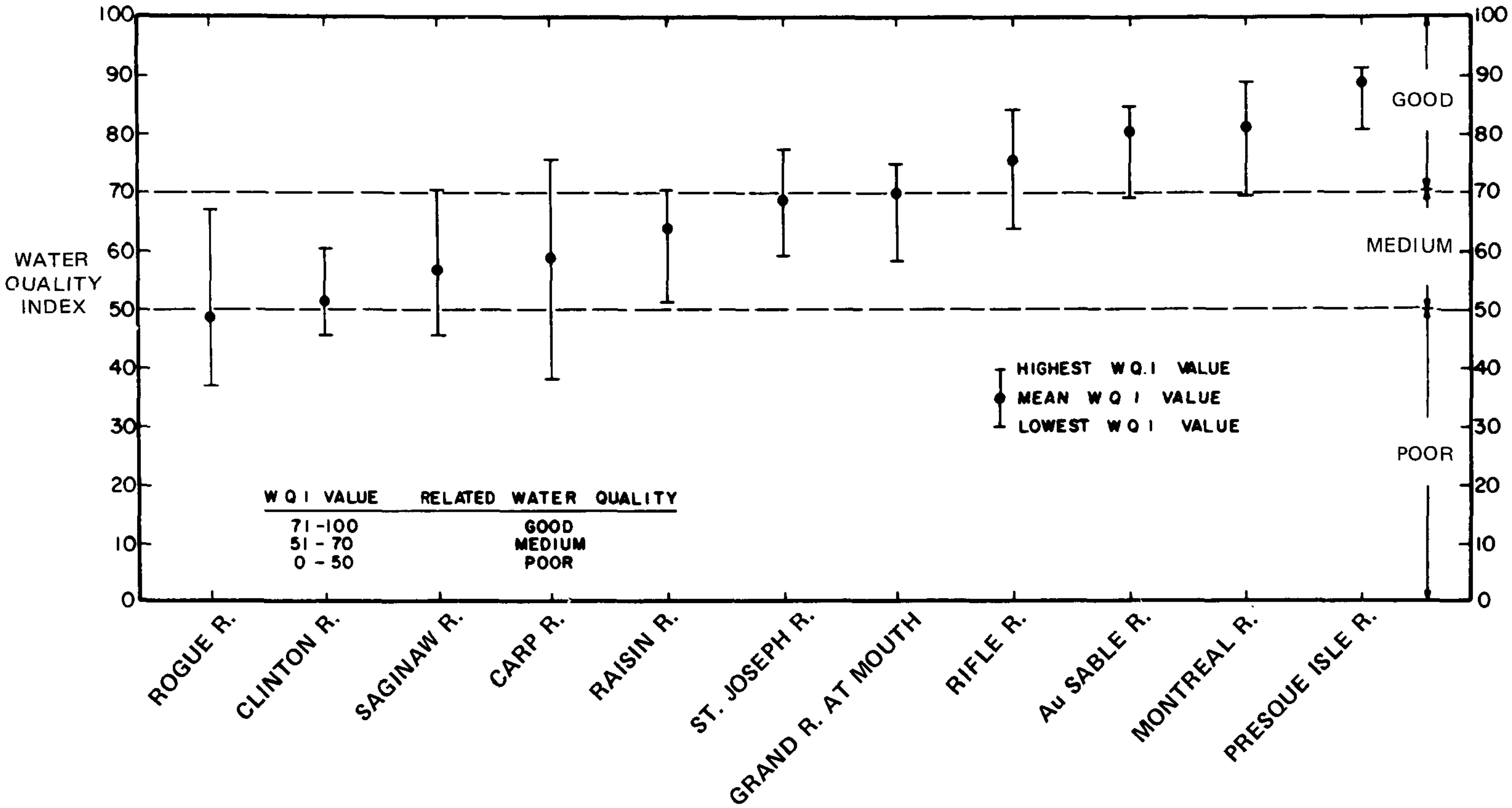

FIGURE 3. EXAMPLE OF WATER QUALITY INDEX REPORT PREPARED BY MICHIGAN FOR SELECTED RIVERS.[40]

The third major purpose cited for using a water quality index was to present data on long-term trends:

> If someone walked into my office and said,
> "Damn, we're spending a lot of money in the State.
> Are we improving water quality?" Right now I
> can't really answer that question.

This respondent also indicated he would like to examine, on a long-term basis of several years or more, the changes in the index in relation to the dollars spent. Another respondent emphasized that the index used by his agency was considered as a relative, rather than an absolute, measure of water quality. Thus, its purpose was to display changes in water quality rather than the status of water quality at any time. His agency's approach was to apply the index at one time and then again 5 years later to observe relative changes over the period. This agency referred to its index as a "trend monitoring index" rather than a "true water quality index." Another NSFI user, Wyoming, also felt that the absolute value of the index was not too useful but that the relative change provided insight into water pollution problems. Because Wyoming's water quality is generally good, this respondent felt that the index "really picks up the influences" of water pollution sources.

One specific trend application was to determine the changes in water quality in response to specific pollution control efforts. For example, the New England Interstate Water Pollution Control Commission has applied the NSFI to the Nashua River to help assess the impact of $30 million in construction of treatment facilities currently underway. This agency has applied the index for about a year, and the staff will apply it again next summer after treatment facilities are completed. Michigan also has applied the NSFI to examine water quality trends on a number of streams (Figures 4 and 5). Similarly, the New York State agency has used NSFI to display water quality trends (Figure 6).

Attitudes of Users Toward Indices

Although the survey of agencies was not designed to systematically assess the attitudes of index users, some impressions have emerged. It is important to discuss these impressions, even though it is occasionally necessary to draw many inferences from respondent comments. We present these views in the context of specific questions.

Were the index users satisfied with their indices? Nearly all users rated their indices favorably. Typical comments were: "Overall, we are generally very happy with the index," "We think it is a useful tool," and, "Thus, the index appears useful, and we will keep using it." Some users seemed reluctant to interpret indices as measures of "absolute" water quality, however, viewing their indices as useful only for examining "relative" water quality changes. Only one of the 11 agencies currently using an index indicated that it felt "fairly neutral" about its index. This agency indicated that it might not use the index again because it may not be "worth the effort."

How were the index users able to evaluate the validity of their indices? The most common remarks about the validity of indices as true measures of water quality were, "It correlated well with expert judgment," or "the water was

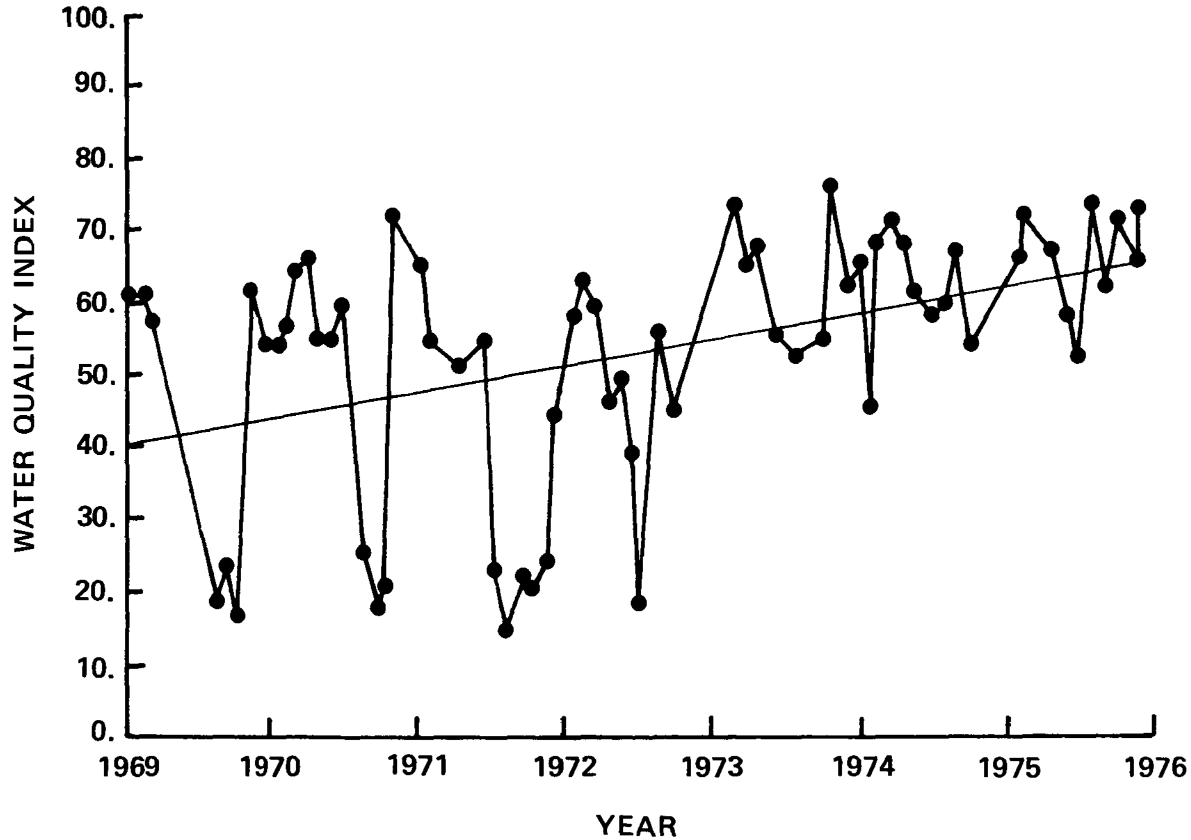

FIGURE 4. EXAMPLE OF WATER QUALITY TREND REPORT USING THE NSF WATER QUALITY INDEX ON MICHIGAN'S RAISIN RIVER AT MONROE (STATION 580046).[40]

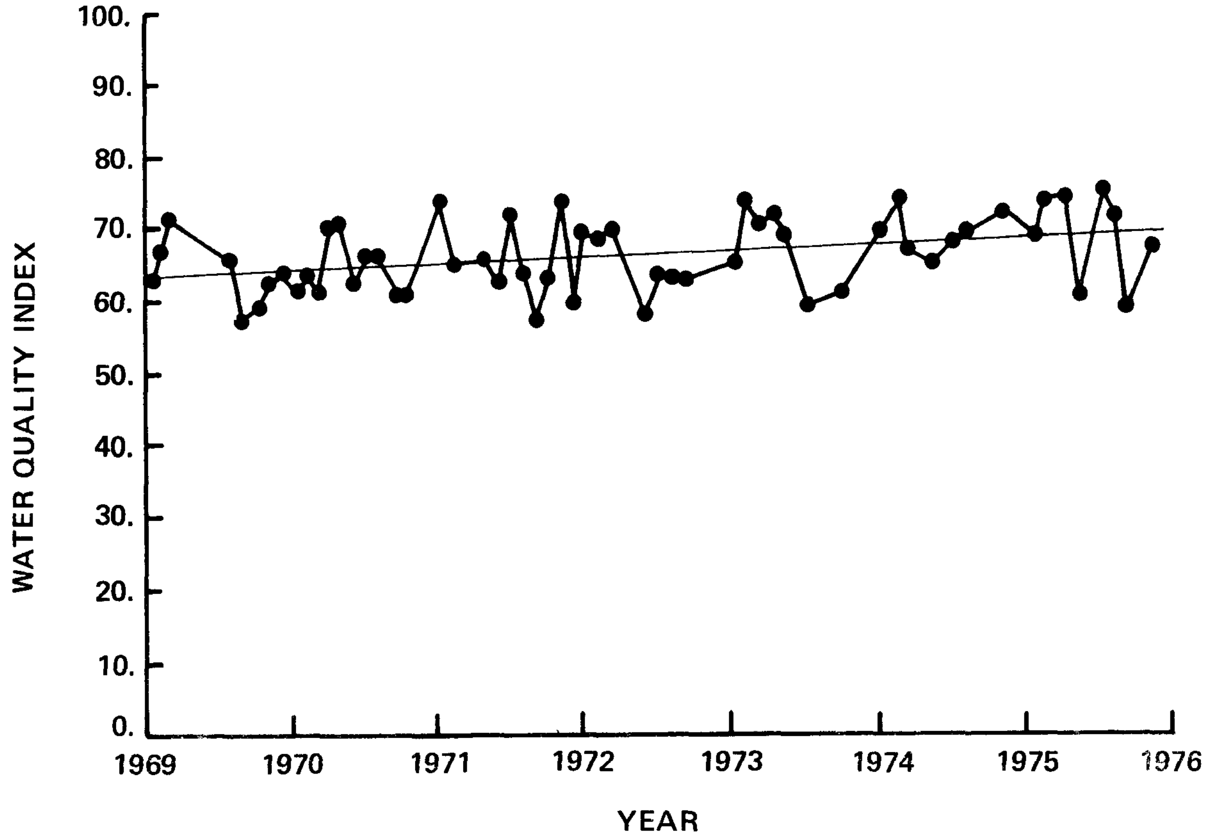

FIGURE 5. EXAMPLE OF WATER QUALITY TREND REPORT USING THE NSF WATER QUALITY INDEX ON MICHIGAN'S GRAND RIVER AT GRAND HAVEN (STATION 700026).[40]

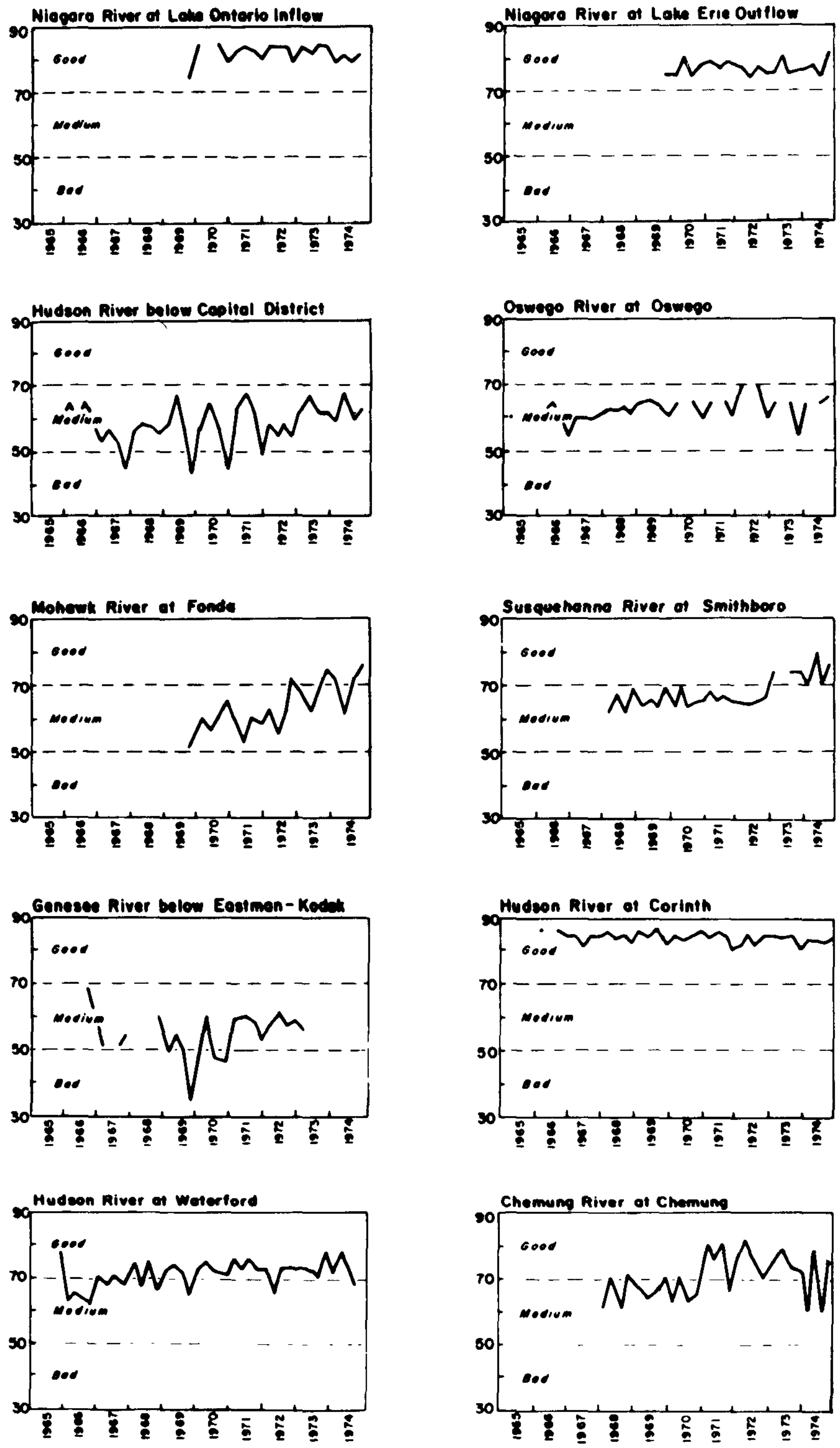

FIGURE 6. EXAMPLE OF WATER QUALITY TREND REPORT USING THE NSF WATER QUALITY INDEX ON RIVERS IN THE STATE OF NEW YORK*

*"New York State Water Quality Inventory Report," Department of Environmental Conservation, Division of Pure Waters [Section 305(b) Report], Albany, NY, May 1976.

improving in the places you would expect it to be," or "the index gave reasonable results." One respondent viewed the impact of water pollution control activities on the index as an important measure of its performance:

> We initially applied this index to determine whether it was usable to convey trends. We were very impressed with its performance. It correlated well with what you would intuitively expect. Water quality, as depicted by the index, was improving at the places where we have major investment in treatment facilities.

Another respondent indicated that his index "successfully showed distinct changes in the river where you would expect them," and, "this result seemed reasonable." Another respondent, to evaluate the validity of his index, ranked the quality of streams using the raw data. Then he compared this ranking with the values predicted by the index and found good agreement. The dirtiest streams, according to the index, "came out on the bottom of the list" and the cleanest streams "came out on the top of the list." One State agency found good correlations between biological and chemical variables and felt that its index had successfully passed this important test.

How were geographical differences in water quality handled by users? Although many geographical differences in natural quality are encountered across the Nation, most respondents (particularly NSFI users) felt that the advantages of index uniformity outweighed the disadvantages of developing customized indices for different geographical areas of the Nation. One NSFI user placed "85" at the top of its water quality index graphs and dealt with the problem of geographical differences by cautioning readers, "85 is the best you can get in this State due to natural background conditions." This respondent felt that the advantages of national index uniformity were very important: "If you're going to accept the advantages of uniformity, you have to accept the disadvantages." Typical of comments about the disadvantages was a feeling that the variables contained in a particular index were not well-suited to the respondent's geographical area. One respondent suggested that a standardized way was needed to delete certain variables where natural conditions make such deletions desirable:

> While the concept of a water quality index is good, I'm not sure that the NSFI is the best one. For example, many of the variables in the index are not as important here as they are in other areas of the Country. The organic pollutants are not a serious problem here, and the index does not place enough emphasis on total dissolved solids and salinity. We would like to add specific conductivity. We don't have thermal discharges, so we would like to omit temperature. We're thinking of a simplified index. What is needed is a standardized way to delete certain variables when they are not considered a problem. Then, at least, if users drop a variable, they'll all be doing it the same way.

Several respondents felt that indices should be custom-tailored to each specific geographical area and should be based on a detailed study of water quality data in the area. One respondent, who had developed his own index, felt that an index should evolve after many years of study of actual conditions in the area:

> We don't feel that an absolute type of index can work; there are too many geographical differences, even within a State. An index must be tailored to the specific location and it must be empirically based. We based our index on the data we have been collecting in the State over a period of years. We were able to assess the index performance in light of our actual knowledge of the geographical variation of water quality and, thus, to come up with a suitable means for detecting changes in water quality over time.

Thus, a dichotomy of opinions emerges from these index user comments. One viewpoint is that the many advantages of having a uniform index (that is uniformly applied) outweigh the problems encountered by the geographical variation in water quality. The other viewpoint is that geographical variation in natural conditions is so important that each index should evolve from, and be adapted to, the specific characteristics of waters in the geographical area where it will be used.

How are different water quality uses handled by index users? In general, the index users did not seem seriously concerned about the problem of different water uses. All of the indices currently in use were general water quality indices rather than specific-use indices. For the common purposes for which the indices were applied, such as public information and analysis of water quality trends (see previous section), the users tended to prefer a general water quality index. One respondent felt that the importance of water uses, as it concerns indices, had been greatly exaggerated:

> Many persons seem to be obsessed with "water use." The public doesn't care about water use. The public wants to know, "well, how do you rate the water?"

This limited concern expressed by the respondents toward water uses is consistent with the contentions of O'Connor[20] and Deininger and Landwehr[21] that the differences in performance and structure between general water quality indices and a specific-use index are not sufficient to justify application of a special class of specific-use indices.

Should EPA recommend a uniform water quality index, as the Agency has done in the air pollution field? There was, as one might expect, a great variety of views expressed about EPA's potential role. However, a majority of the index users expressed views suggesting that EPA <u>should recommend</u> a uniform water quality index. In fact, 8 out of 11 present index users expressed positive views on this matter. Typical of their views were the following comments, each from a different agency:

Overall, we are generally very happy with the index. It probably would be a good idea to have a uniform national index. Yes, EPA should recommend a standardized index.

It would be a good idea for EPA to recommend a standardized index to avoid user "customizing." The chief problem with customizing is that people will say, "You customized just to make yourself look good."

A uniform water quality index is a good idea if you could come up with one. It would be advantageous for us to have a proven index or a set of indices. Possibly, indices should be applied on a region-by-region basis.

An index like the NSFI would be better for national use than an index based on water quality standards. Violation of water quality standards is not a good basis for an index for national use because each State has different water quality standards.

I feel that a uniform index is a good concept. I would support the idea that EPA should support a uniform index. It would provide a basis to "educate the public" that a certain number means a certain quality. The standard NSFI appears to be a good choice for a uniform index and would allow comparisons to be made of water quality in different States.

We favor the idea of EPA recommending a uniform water quality index. We would like to see EPA come up with a hierarchy of indices: (1) a "full-blown" index covering all variables, (2) an intermediate index, and (3) a very simple index. Each index would be increasingly more complex than the next, but the more complex indices would be applied to the more data-rich situations.

A uniform index that could be recommended by the Federal Government would be a good idea. One of the best features of the NSFI is that already it has received widespread application. Thus, a certain amount of uniformity already has occurred. If EPA were to recommend a uniform index, EPA should probably first poll the users. It would not upset me greatly to use a slightly different index, unless some new variables were included. If the index software were available, it would be very easy to recalculate the values with the new index.

Selection by EPA of a uniform national index probably would be a good idea. If the structure of the index were different than those in use, it probably would be all right, just so the index is available on STORET.*

If a uniform index were to be recommended by EPA for those water pollution control agencies wishing to use indices, which index should it be? The above comments indicated considerable support for the NSFI as the preferred index structure. One important reason given was that the NSFI has received such widespread application that considerable uniformity already has been achieved. However, as the last two comments above indicate, the current index users do not seem inflexibly wedded to one particular index. They apparently would be willing to accept a different index structure than the one they are using for the sake of uniformity, just so the new index is supported by STORET and does not differ drastically from their present index. One respondent's comment (third from the last above) suggests that EPA should recommend three indices, each successively more complex, to accommodate the problems encountered with missing data and geographical differences. Missing data, which often occur because a variable is not considered a "problem" in the area, constitute one of the more serious obstacles to adoption of a uniform index. Thus, some respondents feel that EPA should develop uniform criteria, or guidelines, on the manner in which deletions of variables should be made from the uniform index. In effect, EPA would be proposing a uniform approach for customizing the index.

By a "recommended uniform index" (or set of indices), the respondents usually do not mean that EPA should promote the use of indices or attempt to convert nonusers into users. However, for those agencies that choose, on their own, to become index users, the suggested uniform structure would be available. Presumably, it would be adequately documented by EPA, with examples showing how to apply it and a discussion of its limitations. Presumably, also, such a uniform index (or set of indices) would be supported by STORET, and uniform procedures would be recommended for deleting missing variables and for evaluating the performance of the index in a given area.

Only 2 of the 11 agencies which have actually used indices expressed reservations about the concept of a recommended uniform water quality index. One of these agencies felt that uniformity on a regional basis might be desirable, however, and the other felt that a uniform water quality classification system might be worthwhile:

Rather than developing a uniform index, I think EPA should develop a uniform variable-by-variable table assigning "good," "fair," or "pass" to different ranges of the variables. Such a listing would give more useful guidance in interpreting water quality data than indices.

*STORET stands for STOrage and RETrieval of water quality data and serves as EPA's primary water quality data bank.

> The index really is too simplistic. It's useful only when you understand its limitations. I would not favor adoption by the Federal Government of a uniform index, because the waters vary considerably in different areas. Also, stream flow rates differ, and different streams react differently to different waste loads. Possibly, application of indices on a regional basis would be useful, however.

It is possible that the latter respondent may have been considering "adoption by the Federal Government of a uniform index" to mean an index that would "be used by the Federal Government" to interpret the waters throughout the Nation. The other respondents clearly were considering an index that would be used by their own agencies for the data reporting purposes discussed in the previous section (for example, public information).

In summary, a majority of the index users were satisfied with their own indices and rated them favorably. Most of the users supported the idea that EPA should have a suggested uniform index (or a set of indices) available for those agencies that wish to avoid "index customizing." However, there was some feeling that the suggested uniform structure also should include criteria for deleting variables if such deletions prove necessary because of limited data. Finally, there was a general feeling that the software for a suggested uniform index (or set of indices) should be fully documented and available on STORET, presumably as a utility program, and that EPA should support this software by giving appropriate technical assistance to index users.

DISCUSSION OF COMMENTS FROM EPA REGIONAL OFFICES

Because the role of the EPA Regional Offices differs somewhat from that of the State and interstate agencies, only limited information was assembled on the views of the Regional Offices toward indices. Instead of following the usual survey format (Appendix F), comments were obtained informally from one or more persons in each Regional Office. Because a great range of opinions and views toward indices exist in any Regional Office, the comments received are the views of the individual contacted and do not necessarily reflect the view of the entire Regional Office. The comments received were classified into one of three categories: favorable, unfavorable, and neutral toward water quality indices. A brief summary of the comments and their classification are given in Table 12. Complete comments are listed in Appendix A (nonusers of indices) and Appendix B (index users). Region VIII and X Offices have developed indices of their own. These are available for use by State agencies lying within their geographical jurisdiction.

The tabulation of opinions of the personnel contacted in the Regions is: four favorable, four unfavorable, and four neutral toward indices. A significant proportion of these respondents did not feel strongly about indices one way or the other, the overall comments ranging from very unfavorable (Region VII respondent) to very favorable (Region II respondent).

TABLE 12

COMMENTS FROM PERSONNEL AT EPA REGIONAL OFFICES

Region	Opinion/Status*	Comments
I	N	The NSFI is now being evaluated by the New England Interstate Commission (See Appendix B); however, indices in general do not adequately describe water quality.
II	F	The NSFI can be used to compare water quality on a nationwide basis.
III	U	Water systems are too complex to be described by a simplified index.
IV	N	The Regional Administrator wants to use a water quality index as a part of a Region IV Environmental Quality Profile.
V	U	Indices are subject to speculation.
VI	N	Any index should be used in conjunction with other individual variables to pinpoint problem areas.
VII	U	Water quality indices are an obsolete concept.
VIII	F (Developer)	See Chapter V and Appendix B.
IX	U,N,F	Three respondents with three opinions; see Appendix A.
X	F (Developer)	See Chapter V and Appendix B.

*Key: U = Unfavorable; N = Neutral; F = Favorable.

V. CASE STUDIES OF INDICES DEVELOPED BY WATER POLLUTION CONTROL AGENCIES

Among the ten State agencies classified as index users, three--Georgia, Illinois, and Oregon--have developed new or substantially modified indices. One additional State, Nevada, has developed its own index, but because the index has not yet been implemented, Nevada is classified as a nonuser. Finally, EPA Region VIII and X Offices have developed new water quality indices. Thus, six new or substantially modified water quality indices have been developed by governmental agencies (Table 13).

TABLE 13

AGENCIES WHICH HAVE DEVELOPED NEW OR SUBSTANTIALLY MODIFIED WATER QUALITY INDICES

Agency	Index Status
States.	
Georgia	In use
Illinois	In use
Oregon	In use
Nevada	Developmental stage
EPA Regions:	
Region VIII	Used for several reports
Region X	Modified and used annually

STATE AGENCIES

Georgia

Georgia's Department of Natural Resources (Environmental Protection Division) has evaluated two different water quality indices.[41] The first, WQI1, was similar to the multiplicative version of the NSFI, except that temperature was deleted and the weights of the remaining eight variables were readjusted (Table 14).

TABLE 14

ORIGINAL WEIGHTS USED IN GEORGIA'S WATER QUALITY INDEX[41]

Variable	Weight
Dissolved Oxygen, % saturation	0.185
Fecal Coliform, MPN/100 ml	0.170
pH, units	0.120
BOD_5, mg/l	0.120
NH_3, total mg/l as N	0.120
$NO_2 + NO_3$, total mg/l as N	0.110
P, total mg/l	0.110
Turbidity, JTU	0.075
Total	1.0

The second, WQI2, aggregated eight subindices using a novel method called "variable weighting." This method was designed to give greatest emphasis to the "worst" of the eight water quality variables. Each time the index was calculated, the subindices were ranked in decreasing order of magnitude. Subindices with the lowest values (worst water quality) were weighted more heavily than those with the highest values (best water quality). This was accomplished as follows:

The highest subindex is written down once, the second highest twice, the third highest three times, and so on until the eighth highest subindex (which is the lowest subindex) is written down eight times. This gives a total of 36 numbers which are then multiplied together, and the 36th root is taken of the product. The effect of these calculations is to substitute a new set of weights for the subindices. The weight of the highest subindex becomes 1/36 = 0.0278, and the weight of the lowest subindex becomes 8/36 = 0.2222. Thus, weights are no longer associated with a particular variable but are applied in a way that always gives greatest weight to the variable with the lowest subindex and least weight to the variable with the highest subindex.

Mathematically, the index calculation can be described as follows:

$$WQI = \prod_{i=1}^{8} I_i^{[i/36]}$$

where $I_1 > I_2 > \ldots > I_8$

The sum of the weights $w_i = i/36$ for $i = 1, 2, \ldots, 8$ is 1.0 and the water quality index varies between 0 and 100.

The eight pollutant variables used in the index are given in Table 14, but the weights in Table 14 were replaced by the variable weighting approach just described. The quality rating curves for each subindex (Appendix C) were independently developed by members of the Department of Natural Resources using empirical data from Georgia's streams.

The index is viewed by its developers as a tool for examining changes in water quality and is called the "Trend Monitoring Index" (TMI). It was applied in Georgia's 1975 Section 305(b) report to "compare water quality trends throughout the State on a common basis." In this report, the index was computed for 2 years of data at most of the monitoring stations in Georgia and for 5 years of data at selected stations. At the latter stations, the index values were compared with expert evaluations of water quality based on both chemical and biological data. From this evaluation evolved a qualitative rating scale with four categories (Figure 7).

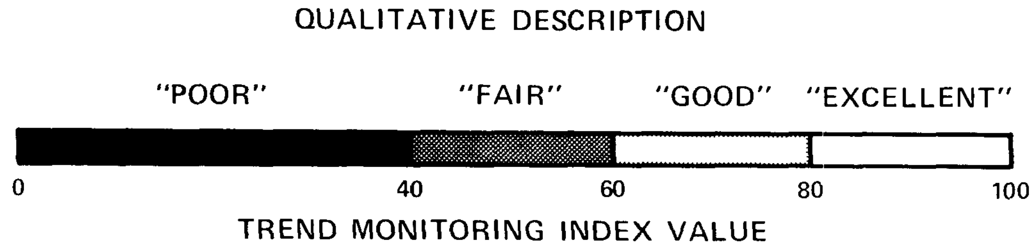

FIGURE 7. DESCRIPTORS AND RANGES USED IN GEORGIA'S "TREND MONITORING INDEX."[42]

To cope with the variation in the natural water quality from one Georgia stream to another, different "natural trend monitoring index ranges" were defined for different streams. When applied to Georgia streams, most instances in which the index was in the "fair" or "poor" range could be attributed to municipal or industrial wastewater problems. However, nonpoint sources of pollution, such as urban run-off, could reduce the index to the "fair" or even to the "poor" range for limited periods of time. Major urban and industrial areas caused the most dramatic changes in the TMI. For example, if the index is computed for sampling sites both upstream and downstream of Georgia's urban and industrial areas, the difference in index values can be as much as 50 points. Typical upstream/downstream differences have been calculated for a variety of stations (Figure 8).

Illinois

Governmental agencies within the State of Illinois have had considerable experience in developing water quality indices. In 1972, Barker and Kramer[43] of the Illinois Department of Transportation (Division of Water Resource Management) developed a simple WQI. In the process, they identified six criteria for a meaningful index:

- Water quality variables that are widely and regularly measured.
- Variables that have clear effects on aquatic life, recreational use, or both.
- Variables that have man-made sources as opposed to natural sources.
- Variables that are amenable to control through pollution abatement programs.
- Realistic ranges of each variable--from no pollution to gross pollution.
- Sensitivity to reasonably small changes in water quality.

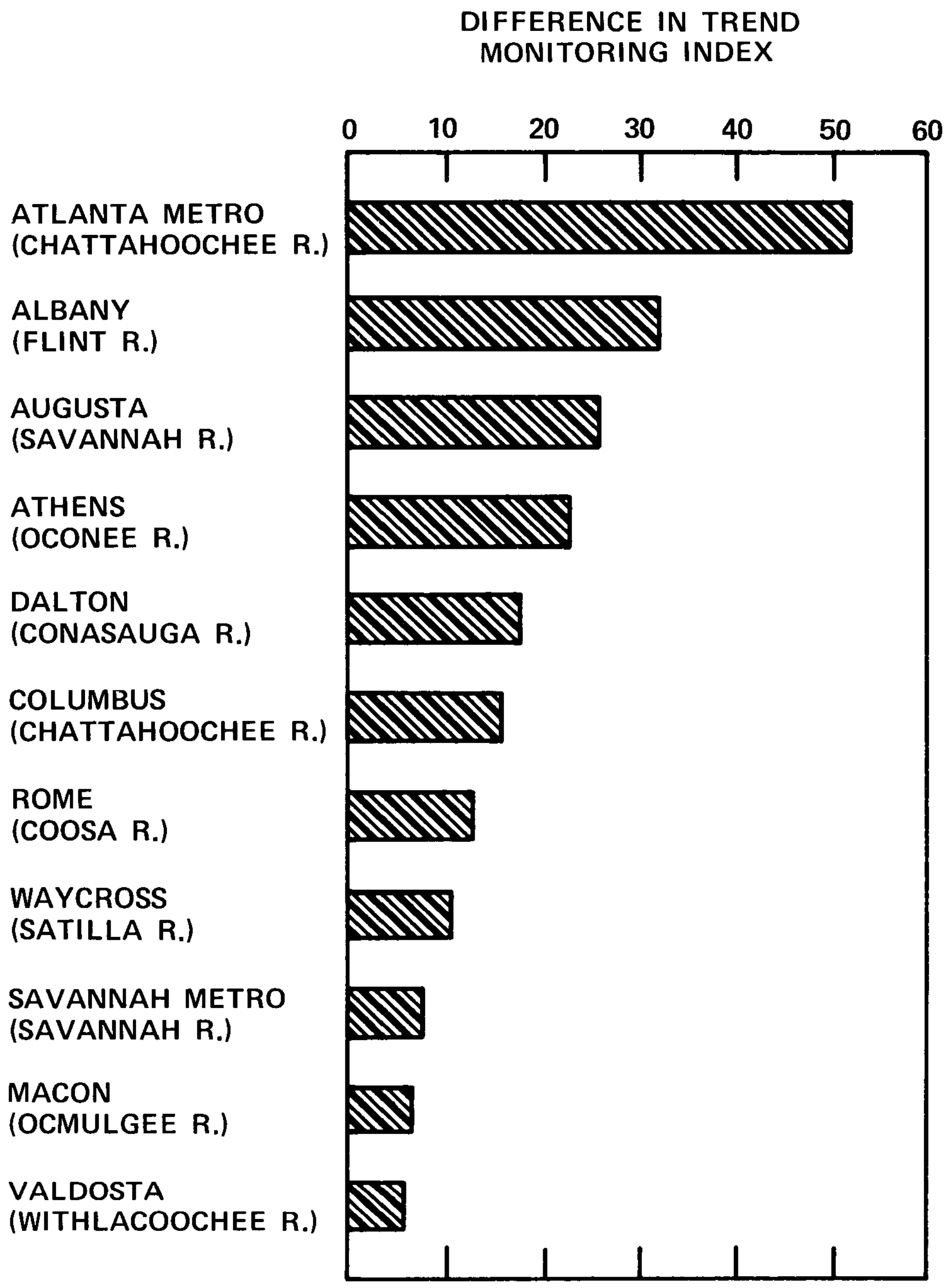

FIGURE 8. WATER QUALITY IMPACT OF GEORGIA'S URBAN AND INDUSTRIAL AREAS AS MEASURED BY DIFFERENCES IN THE TREND MONITORING INDEX FOR UPSTREAM AND DOWNSTREAM LOCATIONS.[42]

The resulting index has six ranges for five variables (Table 15). The index

TABLE 15

RANGES OF VARIABLES FOR THE WATER POLLUTION INDEX PROPOSED IN ILLINOIS BY BARKER AND KRAMER[43]

Variable[a]	Index Value					
	1	2	3	4	5	6
Dissolved Oxygen (mg/l)	>6.0	5.0-5.9	4.0-4.9	3.0-3.9	2.0-2.9	<2.0
Chemical Oxygen Demand (mg/l)	<19.0	19.0-22.9	23.0-26.9	27.0-30.9	31.0-34.9	>35.0
Ammonia, NH_3 – N (mg/l)	<0.5	0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	>4.5
Nutrients[b]						
PO_4 (mg/l)	<1.0	1.0-5.9	6.0-10.9	11.0-15.9	16.0-20.9	>21.0
$NO_2 + NO_3$ (mg/l)	<4.0	4.0-11.9	12.0-19.9	20.0-27.9	28.0-35.9	>36.0
Fecal Coliform (no./100 ml)	<20	20-199	200-1,999	2,000-19,999	20,000-199,999	>200,000

[a]Annual maximum value, except for two variables; Dissolved Oxygen, which is annual minimum value and fecal coliform, which is geometric mean.

[b]Only the larger of the PO_4 or $NO_2 + NO_3$ subindices is used.

uses the annual maximum value of each variable, or minimum value in the case of dissolved oxygen, in its calculations. For fecal coliform, the annual geometric mean is used. To apply the index, subindices for each variable are read from the table. For the nutrient category, only the larger of the subindices for PO_4 and $NO_2 + NO_3$ is used.

The Pollution Index (PI) is calculated as the sum of the five subindices:

$$PI = \sum_{i=1}^{5} I_i$$

I_i = subindex for variable i (from Table 15)

This index, which has an increasing scale, ranges from 0 to 30. The descriptors reported with the index vary from "light" pollution to "gross" pollution (Table 16).

TABLE 16

DESCRIPTORS FOR THE POLLUTION INDEX PROPOSED IN ILLINOIS BY BARKER AND KRAMER[43]

Pollutant Index Range	Descriptor
0-7	Light
8-9	Moderate
10-11	Heavy
12-15	Severe
16-25	Gross

The PI was applied on a pilot basis to monitoring stations in Illinois. Lake Michigan stations had PI values in the range 0-3, while most waterways in the Chicago area fell into the range 20-25. Barker and Kramer[43] conclude:

> This test confirms the range that knowledgeable people believe water quality has in Illinois. That is, Lake Michigan is the least polluted water and the Chicago waterways are among the most polluted.

Index values also were compared with the number and kinds of fishes found in Illinois stream surveys. Although the number of fish species generally decreased as the index increased, the overall correlation was relatively poor (Figure 9).

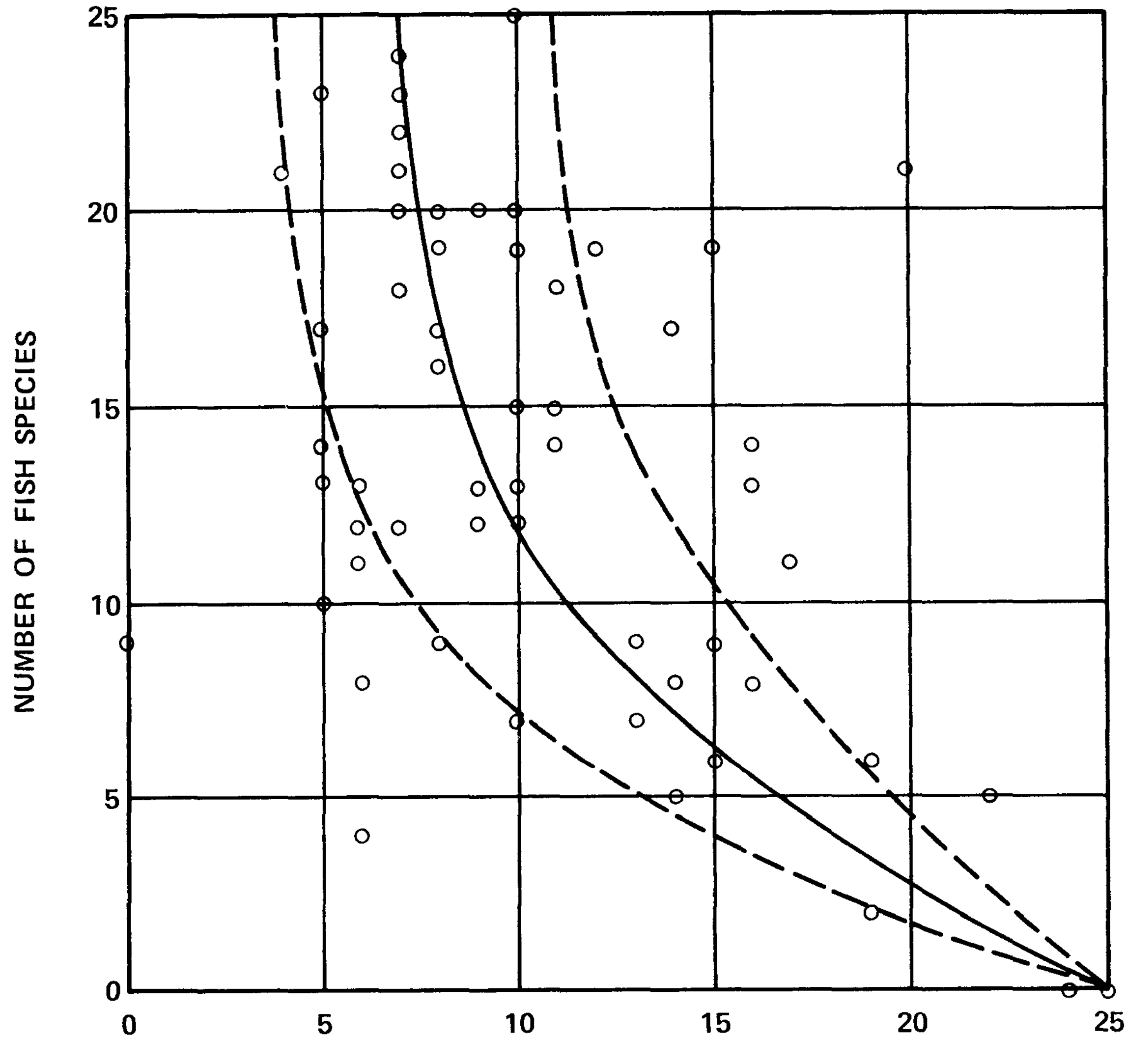

FIGURE 9. COMPARISON OF NUMBER OF FISH SPECIES AND POLLUTION INDEX VALUES FOR ILLINOIS WATER QUALITY DATA.[44]

The authors[43] attributed the poor correlation to a number of factors:

> Fish sampling techniques were not always the same; sampling results were not always reported the same way; the date of fish sampling did not always correspond to the period of water quality sampling; the number of fish species is not solely a function of pollution but also involves the nature of each stream habitat.

Although this index was applied to water quality data throughout the State, no subsequent applications of the index have been reported. A respondent from the Illinois Environmental Protection Agency indicated that, as far as he knew, PI was not being used at present. He felt that it was probably a "one-shot" effort, and that no one in Illinois may have looked at it since it was originally formulated. Barker and Kramer[43] also proposed a Water Treatment Index as a simplified first step toward computing the cost of treating public water supplies.

More recently, the Illinois Environmental Protection Agency developed and evaluated five statistically based water quality indices, and then selected one for routine use. The five original indices, proposed in a paper by Janardan and Schaeffer,[44] include three based on a chi-square-like statistic and two based on a ranking procedure similar to Harkins' approach.[32] The chi-square-like statistic is a continuous analog of the discrete chi-square statistic usually calculated for contingency tables. In the index, the columns of the contingency table are variables and the rows are the successive observations of these variables. The chi-square-like statistic is calculated from the contingency table as the sum of the square of the difference between the expected observation (E_{ij}) and the actual observation (O_{ij}) divided by the expected observation:

$$X^2 = \sum_{i=1}^{p} \sum_{j=1}^{n} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

X = chi-square-like statistic

O_{ij} = observed value

E_{ij} = expected value of the ith observation of the jth variable

n = population of values (number of sampling dates)

p = number of pollutant variables

The three chi-square indices include the above chi-square-like statistic in a mathematical relationship:

$$I_1' = \left[\frac{X^2}{T + X^2}\right]^{1/2}$$

$$I_2' = \left[\frac{X^2}{DF + X^2}\right]^{1/2}$$

$$I_3' = \left[\frac{X^2}{T\ (\min \{n-1, p-1\})}\right]^{1/2}$$

where T = sum of all observed values

DF = number of degrees of freedom

The investigators evaluated the performance of these three indices using real data and computer simulation and, for various reasons, rejected them in favor of indices based on ranked data. Both of the ranked data indices begin with the Kendall transform[33] originally proposed by Harkins[32] for analysis of water quality data. The data, including a control value (R_c), are the first ranked in order of magnitude. If the observations are repeated (tied), the repeated observations are assigned the average rank of the observations assuming no ties. If the jth value for the ith variable is better than or equal to the control value (usually the water quality standard), then R_{ij} is assigned the same rank, R_{ic}, as the standard. The resulting transform is calculated from the rank numbers:

$$z_{ij} = \frac{R_{ij} - R_{ic}}{s_i}$$

where R_{ij} = rank of the jth observation of the ith variable

R_{ic} = rank of the control value for the ith variable

s_i = standard deviation of the ranks for the ith variable

The standard deviation is calculated as follows:

$$s_i = \left[\frac{1}{12n_i} [n_i^3 - n_i - \sum_{k=1}^{m_i} (t^3 - t)] \right]^{1/2}$$

where n_i = number of values for each variable i

t = number of ties (repeated values)

m_i = number of separate occurrences of ties for the <u>ith</u> variable

Two additional values are computed from the data, the sum of all the ranks excluding the control value, and the sum of the square of the transform:

$$T = \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} R_{ij}$$

$$S = \sum_{i=1}^{p} \sum_{j=1}^{n_i} z_{ij}^2$$

Finally, the two indices, I_4' and I_5', were computed as follows:

$$I_4' = \left[\frac{S}{T + S}\right]^{1/2}$$

$$I_5' = \text{antilog}\left\{\frac{1}{N}\sum_{i=1}^{p}\sum_{j=1}^{n_i-1}\log\frac{1}{|z_{ij}| + 1}\right\}$$

The investigators note that the sum of the z-values, in the limit as n becomes large, is normally distributed by the Central Limit Theorem. Therefore, S, the sum of the squares of a normally distributed variate, has a chi-square distribution when n is large. They established the validity of these assumptions about the distributions by using a computer simulation of 2,000 samples of sets of 12 observations for four variables.

From this analysis of five indices, Schaeffer and Janardan[34] select I_4' as the index of choice for analysis of Illinois water quality data. Because of the inherent distribution of S (chi-squared) and T (approximately constant), the investigators argue that the I_4' will have a beta distribution. Thus, the index is nonparametric; it will be distributed in the same manner regardless of the underlying distribution of the raw data. In applying the index to actual data, they normalize it as follows so that its full range is from 0 to 1:

$$I_4' = \frac{1}{b}\left[\frac{S}{T + S}\right]^{1/2}$$

$$\text{where} \quad b = \left[\frac{2\sum_{i=1}^{p} n_i^2}{3\sum_{i=1}^{p} n_i^2 + \sum_{i=1}^{p} n_i - 2p}\right]^{1/2}$$

n_i = number of observations for the ith variable

p = number of variables

In evaluating this index, the investigators proposed 11 criteria that they felt were desirable and necessary characteristics for a water quality index (Table 17). They compared three other water quality indices published in the literature (Harkins, NSFI, and Nemerow and Sumitomo) with this index and concluded that it met the criteria better than any of the other three.*

TABLE 17

SOME DESIRABLE CRITERIA FOR A WATER QUALITY INDEX SUGGESTED BY SCHAEFFER AND JANARDAN[34]

Criterion	Water Quality Index			
	Janardan	Harkins[31]	NSFI[4]	Nemerow[24]
1. Definite range	yes	no	yes	no
2. Single valued and varies in systematic manner	yes yes	yes a	a a	a a
3. Responsive to changes in data values	yes	yes	yes	yes
4. Statistical properties	yes	no	no	no
5. Includes information about standard	yes	yes	yes	no
6. Dimensionless	yes	yes	yes	no
7. Insensitive to the number of variables employed	b	no	no	no
8. Insensitive to the number of observations	b, c	c	c	c
9. Usable for all or selected variables	yes	yes	yes	no
10. Allows stations to be combined	yes	yes	a	no
11. Insensitive to extreme values	yes	yes	no	no

[a]Response of the index to this property is not known.

[b]If the number of observations for each variable is the same, this index is insensitive to the number of variables used in the calculation. If the numbers of observations for the variables differ, this is no longer true. The index is corrected for the number of observations.

[c]This criterion is not meaningful for real data, and can only be applied if the number of observations is infinite.

*It should be noted that the technical reviewers of this report have raised questions about the evaluations given in Table 17. For example, the NSFI is listed by Schaeffer and Janardan[34] as including information about water quality standards, but the NSFI is based on subindex quality curves and not on standards. Rather than addressing these issues, the author has chosen to present this table exactly as it appears in the original literature reference.

Its structure was derived from Harkins' index, but its statistical properties enabled its values to be interpreted probabilistically.

This index was applied by the State of Illinois to examine water quality data on over 500 stations using four variables in the index: dissolved oxygen, fecal coliform, total dissolved solids, and ammonia nitrogen. The results are included in the State's Section 305(b) report for 1976.[45] The numerical values of the index over the 5-year period from 1971 to 1975 were compared for more than 500 stations. Of the total, 93 stations had improved, 50 had deteriorated, and 379 had remained the same. Based upon the index values, each water quality monitoring station was assigned one of four ratings in each year: "good," "average," "semipolluted," and "polluted." The index appeared to perform satisfactorily and will be used in subsequent annual water quality reports by Illinois. The index also has been used to determine whether a statistically significant difference in violations of water quality took place as a result of mild drought during 1976.[46]

Nevada

Nevada currently is in the initial stages of developing a simple water quality index. The index has an increasing scale in which 1 or less constitutes "good" water quality and 10 or more is "poor" water quality. The index is calculated as 10 times the mean value of 15 mathematical subindex functions (Table 18):

TABLE 18

SUBINDEX EQUATIONS USED IN NEVADA'S WATER QUALITY INDEX

Variable	Equation
Temperature (°C)	$I = 0.0016\ X^2$
Dissolved Oxygen (mg/l)	$I = 0.0125\ (X - 10)^2$
pH (standard units)	$I = 0.25\ (X - 7)^2 \quad 5 \leq X \leq 9$
BOD_5 (mg/l)	$I = 0.125\ X$
Chloride (mg/l)	$I = 0.140\ X^{0.5}$
Total PO_4 (mg/l)	$I = 0.33\ X$
Ortho PO_4 (mg/l)	$I = 0.40\ X$
NO_3 (mg/l)	$I = 0.20\ X$
Total Dissolved Solids (mg/l)	$I = 8 \times 10^{-6}\ X^2$
Alkalinity (mg/l $CaCO_3$)	$I = 0.005\ X$
HCO_3 (mg/l)	$I = 0.0067\ X$
CO_3 (mg/l)	$I = 0.20\ X$
Total Coliform (no./100 ml)	$I = 0.037\ X^{0.333}$
Fecal Coliform (no./100 ml)	$I = 0.058\ X^{0.333}$
Turbidity (JTU)	$I = 0.08\ X$

$$I = \frac{10}{n} \sum_{i=1}^{n} I_i$$

where I_i = subindex for pollutant variable i

n = number of pollutant variables

The index is intended, in part, to meet a need to present information to the layman in a simplified form. The index is relatively simple to apply, and its developers feel it gives useful information when comparing water quality at different locations on the same water monitoring network. As noted by Sheen[49] of the Nevada Department of Human Resources (Environmental Protection Services):

> In practice, this looks like a fairly simple tool and quite useful for trend type analyses of water quality at a set sampling point. However, again I point out that all these relationships are purely empirical and not very objective. In other words, they are subject to change depending on the particular user's feel of the actual water quality at a particular sampling site. I feel that even in the seemingly infant stages in developing these index programs, they hold a certain degree of promise for making a complex list of data a little easier to handle and understand relative to points up or downstream in the same analysis network.

At the present time, the index is being tested by Nevada officials but has not been applied routinely.

Oregon

Oregon, through its Department of Environmental Quality (DEQ), has conducted an extensive investigation over a period of several years to develop a suitable water quality index. The index was developed in a manner similar to the technique used by Brown et al.[4] in developing the NSFI, but it was carried out on a regional basis. Their approach also included additional steps designed to remove redundant variables and to "custom fit" the index to Oregon's Willamette River Basin. At the present time, the index is in use on a monthly basis with waters in the Basin applied routinely and will ultimately be applied to waters throughout the State.

As discussed in a draft manuscript by Dunnette,[47] the evolution of this index consisted of the four basic steps:

- Evaluation of water quality indices previously proposed in the literature.
- Development of criteria for rejecting unsuitable variables.

- Survey of the DEQ staff using a modified Delphi opinion assessment technique.

- Classification of variables into four general "impairment" categories to eliminate redundancy.

Oregon's evaluation of water quality indices began by considering five water quality index criteria that previously have been proposed by the Council on Environmental Quality:[48]

- Facilitate communication of environmental quality information to the public.

- Be readily derived from available monitoring data.

- Strike a balance between oversimplification and complex technical conceptualizations.

- Impart an understanding of the significance of the data they represent.

- Be objectively designed but amenable to comparison with expert judgment so their validity can be assessed.

A total of 12 published indices were evaluated according to these criteria (Table 19). Except for the NSFI and Harkins' index, the other indices do not

TABLE 19

OREGON'S EVALUATION OF 12 WATER QUALITY INDICES ACCORDING TO CEQ CRITERIA[47]

Criterion*	Proposed Indices											
	Region X	Truett	NSFI	Nemerow	Harkins	Dee	McDuffie	Inhaber	Dinius	Prati	Walksi	Horton
1	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	O	X	O	X	O	X	O	O	O
3	O	X	X	X	X	O	O	O	X	X	O	O
4	X	O	X	X	X	X	O	X	X	X	O	O
5	O	O	X	O	X	O	O	O	O	O	O	O

*Key to criteria: X - met; O - not met. The criteria, from the 1974 CEQ Annual Report,[48] are as follows:

(1) Facilitate improved communication of environmental quality information to the public;
(2) Be readily derived from available monitoring data;
(3) Strike a balance between oversimplification and complex technical conceptualizations;
(4) Impart an understanding of the significance of data they represent;
(5) Be objectively designed but amenable to comparison with expert judgment in order that their validity can be assessed.

meet all of the CEQ criteria as applied to use in Oregon. Because Harkins' index uses a ranking procedure in which all previously calculated index values must be recalculated to compare new data, it was eliminated from further consideration. Oregon used some aspects of the remaining index, NSFI, in developing the Willamette Basin water quality index (WBWQI).[47]

The process of selecting variables began with a list of 90 candidates. This list was narrowed down to 30 by rejecting some because they were (1) not present in harmful or significant amounts, (2) limited by insufficient data, or (3) of questionable significance. This list of 30 variables then was sent to 22 professional members of the DEQ staff involved in water quality work, and each member was asked to select 10 variables from the list and rate each one numerically (on a scale of one to five) in terms of its reflection of general water quality on the Willamette River Basin. A total of 15 rating forms was obtained from this survey, and the results were tabulated and distributed to the participants. After reviewing the group's ratings, each respondent was allowed to change his original ratings. This reduced the list from 30 to 14 variables.[47]

Finally, to further reduce the number of redundant variables, five general "impairment categories" were identified: (1) oxygen status; (2) eutrophication, or potential for excess algae and plant growth; (3) physical characteristics; (4) dissolved substances; and (5) health hazards. To the extent possible, the fewest possible variables were chosen that would give suitable representation to each impairment category (Table 20).

TABLE 20

WEIGHTING FACTORS USED IN OREGON'S WATER QUALITY INDEX[47]

Variable	Impairment Category[a]	Normalized NSFI Weight[b]	Final Variable Weight
Dissolved Oxygen	1	0.24	0.40
Fecal Coliform	5	0.21	0.20
pH	4	0.17	0.10
BOD	1	0.14	0.10
Total Solids	3,4	0.10	0.10
Nitrate + Ammonia	2	0.14	0.10

[a]1 = oxygen depletion; 2 = eutrophication; 3 = physical characteristics; 4 = dissolved substances; 5 = health hazards.

[b]A normalized NSFI weight was obtained by deleting three of the original NSFI variables and calculating new weights that add to one and preserve the ratios among the remaining NSFI weights.

In some cases, a given variable was represented in more than one impairment category. In summary, the choice of the variables was based on the importance rating given to them by the DEQ staff, the desire to reduce redundancy in each of the impairment categories, and the judgment of the investigator regarding availability of data and significance of the variable for Oregon streams.

The overall index is computed as the weighted sum of n subindices:

$$WBWQI = \sum_{i=1}^{n} w_i I_i$$

where WBWQI = Willamette Basin Water Quality Index

w_i = weight for variable i (from Table 20)

I_i = subindex quality function for variable i

The subindex quality functions for each of the five subindices are plotted on semilogarithmic paper (Appendix D). These functions were determined by examining historical records for six monitoring stations on the Willamette River for the period of 1973-75. The mean values of data for dissolved oxygen, BOD_5, total solids, and nitrate-plus-nitrogen were assigned subindex values of I = 80. For fecal coliform, the mean value was assigned a subindex of 70. For pH, I = 60 was assigned to both pH = 6.0 and pH = 9.0. The slopes of the subindex quality functions also were derived from historical data.[47]

Correlations between several modified forms of the WBWQI and several other indices also were examined. This comparison included a multiplicative form of the WBWQI, Prati's Index, McDuffie's Index, and six- and eight-variable versions of the NSFI and of Harkins' Index. Correlation coefficients ranged from 0.76 to 0.99, with a mean of 0.89. The investigator attributes these high correlations, in part, to the similar finding by O'Connor (Chapter II) that selection of the variables which go into an index tends to be more important than the particular shapes of subindex quality functions.[47]

This index, which may still undergo further evolution, was implemented in 1977 as a monthly reporting system to provide information on water quality conditions at each station. Oregon's approach is of particular interest because it represents an example of a "case study procedure" in which existing indices are systematically reviewed and adapted to the geographical area under study. Thus, it gives a "custom fit," on an iterative basis, of the index to the area. It is likely that other agencies following this same procedure would develop indices with very different weights, variables, and subindex quality functions. Presumably, this approach provides the best means possible for incorporating geographical differences of water quality into the resulting index. By using this approach, an agency can have greater assurance that unique geographical characteristics of its waters will be properly reflected in the index.

EPA REGIONS

Region VIII

In 1975, EPA's Region VIII in Denver, Colorado, developed an index based upon the frequency of violation of water quality standards. The evaluation of this index is described by Cogger, Payne, and Sprenger:[50]

> Aided by fresh concepts and the need for a water quality assessment required of each Region by Section 305(b) of P.L. 92-500, an index was developed building on experience earned in 1973. This index used some of the conceptual ideas developed by the National Sanitation Foundation (NSF) for its "Water Quality Index Application in the Kansas River Basin" and those of EPA's Region X in its "Water Quality Index." Tempering these concepts with the experience and knowledge of the kinds and characteristics of data in Region VIII, an index emerged that was simple and had the advantage of being reasonably unrestricted by the extensive data requirements and one that was free of statistical devices to supplement missing data.

In the index, pollutant variables were grouped into four general categories (Table 21).

TABLE 21

VARIABLE GROUPINGS USED IN REGION VIII WATER QUALITY INDEX[50]

Group I	Group 3
Dissolved Oxygen Biological Oxygen Demand	Nitrogen Phosphorus
Group 2	**Group 4**
Bacteria (Total and Fecal Coliform)	Physical and Aesthetic Factors (Salinity, Turbidity, etc.)

Temperature and pH were not included because these pollutant variables are not significant problems in the Region VIII geographical area, and violations are infrequent. The index consists of the product of five subindices raised to weights:

$$I = Z_1^{0.25}\ Z_2^{0.25}\ Z_3^{0.125}\ Z_4^{0.125}\ Z_5^{0.25}$$

where Z_1 = percent violation of DO and BOD standards

Z_2 = percent violation of fecal and total coliform standards

Z_3 = percent violation of nitrogen standards

Z_4 = percent violation of phosphorus standards

Z_5 = percent violation of criteria for physical and aesthetic standards

The subindex weights were selected by reevaluating the weights used in NSFI in light of water quality conditions in Region VIII. For example, NSFI weights for DO (0.17) and BOD (0.11) had a combined weight of 0.28. This was considered too high because few DO and BOD violations are measured on Region VIII mainstreams by fixed stations; therefore the weight for this group was reduced to 0.25. Similarly, fecal coliform has an NSFI weight of 0.16, and total coliform is not normally included in the NSFI. This emphasis was considered too low because total coliform (as a group) are somewhat more resistant to chlorination and may indicate, at least for waters influenced by sewage treatment plant wastewater, the presence of more tolerant and long-lived pathogens. Thus, the weight for fecal and total coliform was raised to 0.25. Similarly, Group 3 pollutant variables, nitrogen and phosphorus, were considered weighted too low by the NSFI; weights were increased from 0.10 to 0.125 for each, giving a combined weight of 0.25. Group 4 pollutant variables, represented in the NSFI by total solids (0.07) and turbidity (0.08), were considered as weighted too low in the NSFI. These variables are related to irrigation and, therefore, relate to difficult land use problems which are apparently worsening year by year. Toxic substances were not included in the index but were treated in a separate fashion. The presence of toxic substances and pesticides was treated as a "severe event," and individual instances were noted whenever they were observed. Because of the shortage of data on toxic substances and pesticides at the various stations, the severe event category proved a useful way to describe unusual or extremely hazardous situations.

For each group, six observations was the smallest number that was acceptable for index analysis. Unless each monitoring station had data in all four groups, it was excluded from the index calculation. The index was applied to the Region VIII area (Montana, North Dakota, South Dakota, Wyoming, Utah, and Colorado), by comparing two 3-year time periods

(July 1969-June 1972 and July 1971-June 1974). A total of 87 stations was identified within the six States as having sufficient data for both periods. Changes in water quality between the two periods were examined, and the status of water quality (including data-deficient stream segments) in the July 1971-June 1974 period was expressed on a map using a color-coded system. The index ranges selected for the color coding scheme were based upon the empirical judgment of the authors (Table 22).

TABLE 22

DESCRIPTIVE CATEGORIES USED FOR REPORTING THE REGION VIII WATER QUALITY INDEX[50]

Index	Color	Significance
>15	red	Waters or areas that have significant water quality problems
5-15	yellow	Waters or areas that have intermittent water quality problems
0-5	blue	Waters that have infrequent water quality problems
Insuff. Data	green	Waters or areas requiring data for determination of status

The index reports were supplemented by a "severe events" list. This qualitative information formed the basis for the 1975 Region VIII Section 305(b) report and will be used in subsequent reports. The index provided a useful tool for evaluating water quality standards in different States and for preparing "success story" reports for Region VIII.

Region X

An index developed by Beebe[51-53] for EPA's Region X represents one of the few attempts to incorporate both time and space into a water quality index. Beebe[51] notes that previous index development efforts have not emphasized specific ways to handle time and space:

> Other researchers in this area have proposed abstract methods and formulae, but none has proposed a concrete procedure for dealing with actual available data. For example, when one talks about a water quality index, what time period are we talking about? A day? A week? Are we talking about the quality at a specific point on a stream or lake? Or, are we talking about an entire river basin? How does one evaluate the quality or compare the quality of different waters? These and other questions have not been answered before.

Inclusion of time (percent of time that criteria values were exceeded) and space (length of stream affected by a given water quality) made the index seem somewhat more complex than many of the other indices published in the literature. Tailored for use on a computer, this index employs both a set of quality rating curves and a set of recommended limits. The quality rating curves are similar to those used in the NSFI, and Beebe[51] notes, "Most of the quality curves used in this procedure were borrowed from prior work done at the EPA or from other researchers." Recommended limits were based on State and local water quality standards and on values that appear in the National Academy of Science's Water Quality Criteria.[54]

As originally developed, the index uses pollutant variables grouped into 10 different water quality categories. For each station j, a subindex function is calculated for each category k. When data on more than one pollutant variable are available within a category, the calculation uses the maximum (or minimum) pollutant variable relative to the recommended limits. Time is taken into account by computing the relative frequency that a recommended limit is exceeded.

For each category k, a weighted quality value $Z_{j,k}$ is calculated by multiplying the quality value (which is a measure of water quality impact) by the product of the frequency of criterion violation times a weight:

$$Z_{j,k} = Q_{j,k} F_{j,k} W_k$$

where $Q_{j,k}$ = quality rating for station j and category k (Appendix E)

$F_{j,k}$ = frequency of violation of recommended limit (proportion of time that recommended limits were exceeded for jth station and the kth category)

W_k = weight for category k

For any desired river reach, the subindex for category k is formed by weighting the Z values by the distance in river miles between stations:

$$I_k = \frac{1}{2} \sum_{j=1}^{n-1} (Z_{j+1,k} + Z_{j,k}) (d_{j+1} - d_j)$$

where I_k = water quality subindex for category k along the reach

$Z_{j,k}$ = water quality value of the kth category at the jth station in the reach

d_j = river mile distance of the jth station $(d_j < d_{j+1})$

Finally, the index is formed by summing all the subindices for all reaches and categories:

$$WQI = \sum_{i=1}^{n} I_k$$

In recent years, the index has been further simplified and refined so that it could be used on water quality data from the various States within Region X.[55] The frequency term, for example, is no longer included in the index calculation. The quality rating is now computed for each separate observation, and the time-weighted average of quality ratings is computed. The distance estimates are now based on the professional judgment of the user regarding the representativeness of each station. These distance estimates of the "affected river miles" also are used to weight the index computation. This simplified version of the Region X index is now being used to prepare annual environmental quality profiles for the States in Region X.

VI. CRITERIA FOR AN IDEAL WATER QUALITY INDEX

Using this study as a basis, it was possible to identify criteria that an "ideal" water quality index, if it could be developed, should possess. These criteria have evolved from the survey data, comments from respondents, comments from reviewers, and, particularly, from the criteria discussed by Schaeffer and Janardan,[34] Barker and Kramer,[43] Dunnette,[47] and the 1974 CEQ annual report.[48] The criteria arising from these diverse sources have been merged to form the following list of 20 characteristics that the ideal water quality index should possess:

- Relatively easy to apply
- Strikes a reasonable balance between over-simplification and technical complexity
- Imparts an understanding of the significance of the data it represents
- Includes variables that are widely and routinely measured
- Includes variables that have clear effects on aquatic life, recreational use, or both
- Includes toxic substances
- Can easily accommodate new variables
- Based on recommended limits and water quality standards
- Developed from a logical scientific rationale or procedure
- Tested in a number of geographical areas
- Shows reasonable agreement with expert opinion
- Shows reasonable agreement with biological measures of water quality
- Dimensionless
- Has a clearly defined range

- Exhibits desirable statistical properties permitting probabilistic interpretations to be made

- Avoids eclipsing

- Shows sensitivity to small changes in water quality

- Applicable for showing trends over time, for comparisons of different locations, and for public information purposes

- Includes guidance on how to handle missing values

- Limitations of the index are clearly documented

No single index will completely meet all 20 criteria. However, different candidate indices will vary in terms of their proximity to the ideal, and the criteria are intended to provide a uniform system by which to judge indices. Each criterion listed above varies, of course, in terms of its importance and the significance that it should receive when evaluating indices. In addition, because of many diverse attributes demanded of a water quality index, some criteria may seem almost contradictory. When criteria conflict, such as the need for simplicity and the need for technical completeness, it is necessary to compromise.

By definition, a water quality index is a tool simplifying the presentation of data. In the process of simplification, some information inevitably will be removed. Ideally, the removal of information will not be serious enough to distort the meaning of the index to the audience for which it is intended. Thus, the index, although imperfect, will still do its job of communicating the proper information to its intended audience. If the audience consists of members of the general public, considerable distortion can occur in the interest of simplicity, and the index will still be of use. The important point in evaluating indices is to determine the target audience for which the index is intended and the ultimate context in which the index results will be used.

VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

This study documents the extent to which water quality indices currently are being used in the United States. It has sought to determine: (1) which agencies were using water quality indices, (2) the types of indices being used, (3) the purposes of their uses, and (4) the attitudes of agency personnel toward indices. The study approach consisted of a review of the indices published in the literature; a survey of 51 State agencies, 9 interstate commissions, and 10 EPA Regional Offices; and brief case studies of agencies that have developed their own water quality indices.

There is evidence of a proliferation of water quality indices in the published literature. Over 20 physical and chemical water quality indices have been published in journals, symposia proceedings, and technical reports. A great many biological indices also have been developed and appear in the literature. The present study has found it possible to classify the physical and chemical indices into four general groups: (1) indices of general water quality, (2) indices for specific water uses, (3) indices for planning, and (4) statistical approaches. These published indices greatly differ in terms of the numbers and types of variables included, mathematical structures, scales (whether the numbers increase or decrease with pollution), and overall index ranges. Rather than evolving toward a uniform structure, each published index often shows little direct relationship to previously published indices.

The agencies surveyed were classified into five groups: (1) those unfamiliar with indices [11 States, 2 commissions]; (2) those that had previously considered indices but were not interested in pursuing them further [14 States, 4 commissions]; (3) those planning to evaluate or develop indices in the near future [10 States]; (4) those currently evaluating or developing indices [6 States, 1 commission]; and (5) those agencies that were using (or previously had used) indices [10 States, 2 commissions].

These groups differed in terms of their familiarity with indices, with the first group least familiar and the last group, the index users, most familiar. The first group may or may not become index users in the future as their knowledge about indices increases. The second group seems unlikely to become index users, but Groups 3 and 4, when combined, constitute a class of "potential" index users. When the 60 agencies are regrouped in this fashion, the data can be summarized very compactly (Table 23).

TABLE 23

STATUS OF WATER QUALITY INDEX UTILIZATION IN THE UNITED STATES, MARCH 1977

Agency	Nonusers	Potential Users	Users	Total
States	25	16	10	51
Interstate Commissions	6	1	2	9
Total	31	17	12	60

Of 51 States agencies (including the District of Columbia), 10 (20 percent) are classified as index users. An "index user" is an agency that has used an index in an official publication of the agency [for example, the Section 305(b) report] or has applied it in a large-scale study extending over a year or more. Two interstate commissions also are classified as index users, although one no longer uses an index. Of the 11 agencies (10 States and one interstate commission) that currently use indices, 7 (6 States and one interstate commission) have chosen to use the NSFI. Three States are using indices that they have developed on their own, and one State, Oklahoma, uses Harkins' index. Despite the widespread use of the NSFI, many minor variations occur in the way this index is applied.

Among potential users, the NSFI is the most frequently mentioned index, with 14 of the 17 States and one interstate commission indicating that they are currently considering the NSFI or will be considering it in their future evaluations. If the 17 agencies now classified as potential users of a water quality index were to become actual users in the future, 29 out of 60 agencies (48 percent) then would be classified as index users. At that time, therefore, roughly half of the United States water pollution control agencies would be using water quality indices. Because nearly all of the present indices have been adopted over the past 3 years, there is clear evidence of a trend toward increased utilization of water quality indices in the United States.

Although a great many indices already appear in the literature, a number of water pollution control agencies have developed new or substantially modified indices. Some are empirically based systems uniquely designed to fit the conditions and water quality of a particular locale. Others are statistical procedures of considerable flexibility and sophistication. Six new indices have been developed by the water pollution control agencies surveyed, four by the States and two by the EPA Regional Offices (Regions VIII and X). Three of the four State-developed indices are currently in use (these agencies are classified above as index users), but one has not reached the stage of routine application. The EPA-developed indices have been used for a variety of reports and projects.

Although the purposes expressed by index users for applying their indices were quite varied, three purposes were mentioned most frequently: (1) preparation of the Section 305(b) annual reports [9 agencies], (2) public information [8 agencies], and (3) analysis of water quality trends [8 agencies]. Index results often appear in the Section 305(b) reports and are used to describe water quality trends, but no specific examples could be found in which any index results had appeared in newspapers, on television, or on the radio. More often, the audience is a water quality specialist or government official instead of a member of the general public. By contrast, air pollution indices usually use the mass media to report air quality data to the public on a daily basis.

The majority of the agencies currently using indices expressed satisfaction with their own indices and rated them favorably. On the other hand, they expressed a willingness to modify their indices, if necessary, in the interest of uniformity. Most index users feel that EPA should make available a uniform index, or set of indices, for use nationally by those agencies wishing to apply indices. One reason given is that a uniform index would reduce the tendency toward "index customizing," in which the user drops a variable, changes the weights, or alters the mathematical structure of the index. Some respondents feel that the suggested uniform structure also should include criteria for deleting variables if such deletions prove necessary because of limited data. Index users do not seem seriously concerned about the problem of differing water uses and tend to prefer a general water quality index to a specific-use index. Finally, there is agreement that computer software for such a suggested index (or set of indices or interpretive techniques) should be fully documented and available from EPA and fully supported on the EPA computer.

CONCLUSIONS

Water quality indices have proliferated

The literature reveals that a great number of different water quality indices have been published. However, except in a few cases, these published efforts do not reveal the normal evolution associated with scientific work. That is, few of the authors cite previous indices or build upon the work of previous authors. Rather, there is a tendency for each index to be a "new start," emerging full blown with little relationship to previous index development efforts. In addition, most of the indices in the literature, although they have sometimes been applied to water quality data on a pilot basis, have not been used routinely by water pollution control agencies or officials.

A single index, the NSFI's Water Quality Index has gained wider acceptance than any other index

Unlike the air pollution field, where nearly all of the indices were developed by users,[5] one index, the NSFI published in 1970 by Brown et al.,[4] has gained wider use in the water pollution field than any of its competitors. Roughly, one-sixth (18%) of the State and interstate agencies (11 of 60 agencies) currently are using a water quality index, and 64 percent of these (7 of 11 agencies) are using the NSFI. Thus, 7 of the 12 agencies (58%) that have used a water quality index have selected the NSFI.

Where it has been used, the NSFI seems to perform satisfactorily, meeting users' needs without major complaint

Most index users do not seem very concerned that the NSFI is not a specific-use index. In fact, some respondents feel that the problem of different water uses had been exaggerated and that specific-use indices are not necessary. The only complaint users have about NSFI is that the nine variables contained in the index are not always well suited to their particular geographical areas. Nevertheless, most users feel that the need for uniformity of an index outweighed the need to tailor it to individual geographical areas. Those index users who feel that an index should be tailored to their individual situation generally have developed their own index.

The purposes for which water quality indices are being applied differ from those for air pollution

Water quality indices, in the opinions of their users, are being applied for three basic purposes: (1) Section 305(b) reports, (2) public information, and (3) trend analyses. In the air pollution field, on the other hand, the principal purpose is to report air quality levels directly to the public on a daily basis. The air pollution field does not have legally required annual reports from the States similar to Section 305(b) reports to Congress required under the Federal Water Pollution Control Act,[6] and air pollution indices seldom are used in the analysis of air pollution trends. Although public information is a major purpose cited for using a water quality index, this purpose does not appear to be the same as reporting air quality data to the public on a daily basis through radio, television, and the newspapers. In fact, virtually no specific examples were found in which a water quality index had been used to reach the general public directly through the mass media. The audience usually consisted of water quality professionals or government officials rather than general television viewers or newspaper readers.

Of course, many other differences exist between the air and water pollution fields. In air, nationally uniform air quality standards have been adopted that greatly facilitate uniform air quality data reporting practices. Also, where water has many uses, air has one primary use: it is consumed by living systems to support life. This use is analogous to just one of the uses in the water pollution field, the supply of public drinking water.

The need for a standardized water quality index, while it may exist, is much less pressing in water pollution than it was in air pollution

Because the immediate audience of the results of water quality index applications usually consists of informed professionals rather than members of the general public, there is virtually no evidence of public confusion over the different water quality indices that have been developed. Air pollution changes occur on a daily basis, creating considerable public interest in daily air quality index reports. Unlike air, however, water is treated before it is consumed, and changes in raw water quality have less direct and immediate impact upon the public. This does not mean that the public has great interest in daily air quality levels and virtually no interest in water quality levels. The public's interest in water quality data simply appears less pressing than its interest in air quality data.

The public's interest in water quality often becomes intense, however, in situations that affect it immediately, such as a spill of toxic substances upstream. Lack of public dissemination of water quality information (by means of indices or any other approaches) also may be due partly to a lack of effort on the part of agencies to interest the media (radio, television, and newspapers) in presenting water quality data. Possibly, water quality information could be reported on a monthly or seasonal basis in newspapers along with coverage of the climate, the tides, and summary information on air quality. This hypothesis needs further investigation.

Of course, an entirely different reason that the need for a standardized index may be less pressing in water than in air is that the NSFI has been adopted by more than half of the index users. Although the total number of water quality index users is small, common use of a single index creates a degree of standardization and uniformity that was not apparent among air pollution control agencies. To achieve uniformity in the air pollution field, EPA found it necessary to recommend a standardized national air pollution index.[56] In the water field, however, it may be possible to achieve national uniformity simply by increasing the degree of communication among water pollution control agencies. Probably the best means for doing so is for EPA to establish a water quality data analysis user's group.

<u>A number of new, and often very sophisticated, data analysis techniques and indices have been developed by water pollution control agencies</u>

Various water pollution control agencies across the Nation have pioneered in development of new ways to interpret and analyze water quality data. Some of these approaches, although they may be classified as indices, represent initial applications of relatively sophisticated and powerful analytical procedures. In general, most other water pollution control agencies are unaware that data analysis procedures are available. This, in part, explains why the indices developed by the agencies are so varied. The diversity of these techniques, combined with the lack of knowledge of the agencies about each other's data analysis activities, suggests there is a need for increased communication among agency personnel engaged in analysis and interpretation of water quality data. Such improved communication would reduce duplication of effort and would allow agencies that have developed different data analysis techniques to share their knowledge and experience, thereby helping to standardize data analysis activities. Such communication would be assisted by establishment of a centrally coordinated statistical data analysis support group within EPA. Communication also would be enhanced by holding national conferences and symposia dedicated to improving data analysis techniques.

RECOMMENDATIONS

The following recommendations represent the author's opinions and are based on his review of the findings of this study and on his evaluation of comments from the agencies and from the reviewers:

The EPA should provide technical support for two candidate uniform water quality indices for those agencies wishing to use an index but should not at the present time formally adopt an index in the Federal Register

Unlike the air pollution field, where indices are used to report air quality data to millions of people on a daily basis, there appears to be relatively limited dissemination of water quality information directly to the general public. As with air, many different water quality indices exist, but, because the information generated with these indices is seldom disseminated to the general public through the mass media, there is little evidence of public confusion. In water, indices appear to be used primarily as investigative tools--techniques for studying trends and for reporting data in a simple format to water quality professionals and managers. Without evidence of widespread public confusion, the need for a formally adopted uniform national index appears less pressing for water than it was for air. However, the index users in this study generally feel that a recommended uniform index is desirable for those agencies wishing to use indices. This does not imply that use of such an index is encouraged or required; it implies merely that the index, and the computer software for its support, are more readily available than before. Adoption of an index in the Federal Register implies that EPA officially endorses the index and encourages its use as a matter of policy. Such encouragement would seem inappropriate at the present time when there is serious disagreement among knowledgeable persons over the proper index to use. Support of at least two candidate water quality indices, however, would be a useful first step in attaining greater standardization in the application of data analysis techniques to water quality data.

The EPA should take steps to increase communication among water quality specialists and professionals throughout the Nation who must analyze and interpret water quality data

A great variation is evident in the manner in which water pollution control agencies approach indices: a number of agencies are unaware of indices; some agencies are aware of indices but view them negatively; some agencies are currently evaluating them for possible application; other agencies are using them routinely; and still other agencies are developing new and more advanced indices. In the author's view, this variation results, in part, from an underlying lack of communication among specialists and professionals engaged in water quality data analysis efforts. It also suggests there may be fundamental differences of opinion regarding the way in which water quality data should be analyzed and interpreted, along with considerable nonuniformity in prevailing data analysis practices. Such nonuniformity gives rise to potential duplication of effort, redundancy, and lack of utilization of effective data analysis tools. These problems could be corrected by increasing communication among water quality professionals and specialists regarding data analysis techniques. The following steps should be considered by EPA for increasing communication: (1) publishing more examples of important applications of data analysis techniques; (2) holding data analysis conferences, symposia, and seminars; (3) developing, maintaining, and supporting special-purpose computer software of various data analysis techniques for use by EPA and State agencies; and (4) encouraging greater direct contact among data analysis specialists within EPA and the State agencies.

CEQ appears to be the appropriate agency to play a lead role, along with EPA and other interested agencies, in supporting a national data analysis conference that could benefit specialists who analyze data in air, water, and other environmental media.

<u>The EPA should create a data analysis users' group to apply analytical techniques to water quality data and to assist State agencies in developing uniform data analysis procedures</u>

Large sums of money are spent to collect environmental monitoring data, and these data provide the most important quantitative measure available for judging the effectiveness of pollution control efforts. However, the resources spent to apply proper data analysis techniques to these data are disproportionately low. Thus, maximum information on the state of environmental quality and on water quality trends is not being fully realized from today's monitoring efforts. Development of a data analysis users' group is viewed as necessary to increase the level and quality of data analysis efforts in the Nation and to gain greater benefits from current expenditures on monitoring activities. A small, centralized users' group is felt to be the most efficient means for doing so. This group should consist of highly qualified statisticians and other professionals thoroughly experienced in the analysis and interpretation of environmental data. This group should serve as a coordination point for EPA's environmental trends analyses and should carry out studies to explore the application of new interpretive techniques to environmental data. This group should have responsibility for developing and supporting the necessary software for applying these techniques and should serve as a general point of contact for assisting EPA and the State agencies in their use. The group also should support the needs of other federal agencies, such as the U.S. Geological Survey, the Council on Environmental Quality, and others. Possible examples of these techniques include time series analysis, computer programs to test for underlying probability distributions, multivariate regression analysis, nonparametric statistical procedures, quality control data screening models, simulation models, and other approaches. It is estimated that 15 positions and $400,000 in contractual monies would be adequate to maintain the environmental data analysis users' group.

<u>In addition to its other statistical procedures, the EPA data analysis users' group should support software for at least two different water quality indices</u>

One of the most efficient means for attaining uniformity of water quality index applications is central support of several carefully selected water quality indices. The EPA data analysis users' group described above, therefore, should maintain at least two very different index types: an absolute value index and a ranking index. A good example of an absolute value index is the NSFI.[4] It is relatively simple to apply, and a great degree of uniformity already has been attained simply because of its widespread application. A good example of a ranking index is the beta function index developed and applied in Illinois.[34] Based on the nonparametric procedures suggested by Harkins,[32] this approach offers a potentially powerful statistical procedure for comparing water quality data at different locations or over time.

Future research studies should be undertaken by the EPA to gain better insight into the relationship between candidate water quality indices and biological measures of water quality

Two distinctly different ways to evaluate water quality appear to have emerged: physical/chemical indices and biological systems for evaluating water quality. An important way to evaluate water quality indices is to compare them with the various biological measures. In such studies, biological evaluation of various waters should be carried out alongside water quality index calculations, and the results should be compared statistically. An effort should be made to determine confidence intervals for the indices, and the factors that affect the predictions should be carefully examined. A simple example of such a comparative study was performed by Schaeffer and Janardan[34] using a biological classification system to rate Illinois waters and comparing the rating with index predictions.

The EPA should establish a statistical methods development program to conduct research on techniques for analyzing environmental data

Many basic statistical techniques are available for data analysis, but few of these have been applied to actual environmental data. Some techniques are in their infancy and require future development. Other techniques imply certain assumptions about underlying probability distributions or independence that have not been tested or evaluated, even though the results of these techniques are being used for Agency decision-making.

At present, EPA has no scientific program for developing and evaluating statistical techniques to analyze environmental data, even though there is a need to apply these techniques to the Agency's large data bases. Although a central statistics unit will be established in Office of Planning and Management, this unit will be located in an administrative part of the Agency which does not conduct research.

There is need to establish, within the Office of Research and Development, a statistical methods development program to evaluate and develop statistical techniques, applying them to air, water, and other monitoring data to determine their statistical properties and to evaluate their potential use by the Agency. This program should be organizationally linked to the monitoring and quality assurance activities responsible for collecting the data. Its functions should include not only development of practical tools for analyzing environmental data, but also research on models to combine data from banks in different media (air, water, drinking water, disease variables), stochastic models for decision-making, time series approaches for forecasting environmental variables, techniques for making long-range projections, indices, indicators, and other interpretive techniques. It is estimated that 5 positions and $550,000 in extramural funds would be sufficient to implement this program.

VIII. REVIEWER COMMENTS

When the first draft of this report was completed, it was circulated to a select group of reviewers both within and without EPA. A number of excellent comments were received from these reviewers, and most of these resulted in changes to the original manuscript. It was not possible to respond to all of the reviewer comments, however. Because of the controversial nature of the topic and the relevance of many of the comments, some of them are included here. Although these comments are taken from written memoranda[57-61] received from the reviewers, it was decided not to identify each individual reviewer. Thus, the reviewers are identified only as Reviewer A, Reviewer B, etc. Although the comments are taken out of context from these materials, they give insight into the controversy surrounding this topic and in the opinion of the author should be presented as part of this report.

Overall, the reviewers seemed generally pleased with the contents of this report and felt that the subject had been handled satisfactorily:

> I am very impressed by the thoroughness, clarity, and objectivity of your report. I believe it adds considerably to the useful literature on the subject of water quality indices. It performs an analysis which should have been done a long time ago concerning the actual use of indices, and it serves to put into perspective the voluminous work which has been done in the past. [Reviewer A]

> ... I have reviewed the manuscript of the report on water quality indices, and am returning it with my comments. The report is well-written and very informative. I think the inclusion of (positive and negative) professional opinions expressed about the indices by the regional and state program personnel is especially useful. [Reviewer B]

Some reviewers felt, however, that the need for a nationally uniform index was not given sufficient emphasis in the report:

> I disagree that the need for standardizing a water quality index is less pressing than that for air. It is very difficult to undo "tradition" and "experience"; it is much better to start cleanly. If everyone starts using their own form then it will be impossible to undo this state and the prime goal of national comparability will be lost. [Reviewer C]

Other reviewers, by contrast, disagreed with the concept presented in an earlier draft of this report that EPA should formally adopt a uniform index:

> ... I tend to disagree with your first recommendation ... that we should support a uniform water quality index. I believe that EPA should support the development and use of more uniform analysis techniques, and your recommendations two and three would go a long way toward achieving this goal. [Reviewer A]

This reviewer felt that the positive views expressed by respondents toward water quality indices may stem more from their underlying need for improved data analysis techniques than for indices themselves:

> I suspect that many of the needs expressed by State and Regional personnel for "indices" are really needs for any kind of water quality analysis techniques which will help them analyze trends and help make decisions. The result is that your report may be biased in the direction of encouraging usage of indices, when the real needs for the water pollution control program may be broader. [Reviewer A]

One reviewer, from the State of Oregon, disagreed with the concept of a uniform water quality index because it would not permit the necessary customizing which "is essential for a valid index." This reviewer felt that an index should be custom-tailored to individual situations to best reflect the "geographical, hydrological, and demographic characteristics" of each area. Such a customized index was developed for Oregon (Chapter V):

> I believe EPA should support a general approach to index design only. Of course, I believe my approach is most suitable. I do not think EPA should or will ever support a single WQI. The WQI must be based on existing conditions. [Reviewer D]

Some reviewers felt that the report overemphasized the positive features of the NSFI, and others felt that the NSFI received too little emphasis. One reviewer felt that the popularity of the NSFI was not very surprising since it exhibits a number of desirable features:

> I think that you could stress that the popularity of the NSF index is not too surprising since, (1) It is extremely simple in construct; (2) It behaves in a very expectable and understandable manner; (3) Among other indices, it has had the most continuous level of development, study, and application; (4) Computer packages for interface with STORET are available; and (5) In the absence of any leading effort or guidelines by a federal agency, users have chosen to use the form which suits their needs and for which the most PR work has been done. [Reviewer C]

Another reviewer felt that the report tended to overemphasize the widespread usage of the NSFI, giving the impression that the NSFI is desirable simply because it is widely used:

> I think you make too much of the wide use of the NSFI. It is used widely because it is easy to use and has been widely promoted. To claim that it is satisfactory or the best available because it is widely used is parallel to claiming that the best automobile made is a Ford because there are so many, or the best food available is a McDonald's hamburger because so many are sold. I realize that the purpose of your report was to compile what people are using, but I believe your recommendation goes too far in suggesting that what is used most is the best. [Reviewer E]

Some reviewers strongly objected to the concept of a "general" water quality index; that is, one that does not report water quality in the context of specific water uses:

> I firmly believe that the opinion that a water quality index should not be applied to a particular use is erroneous .... Please note that ... [criteria and standards for various trace metals] ... in many cases range over two orders of magnitude or more, and some are unclearly defined as a fraction of the 96-hour LC50. It is erroneous to put on blinders and ignore these differences and try to melt them all into a single index that attempts to consider all uses. The same error should be avoided in selecting the particular constituents that go into an index. Again, considering the metals, each one of the eleven listed has some kind of a criteria or limitations. In rivers the concentrations of the metals vary as a function of the geology of the terrain and individual pollutants. They do not correlate well with each other or with other water quality characteristics, and in order to judge the suitability of a water through an index, that index must consider every one of these metals. In order to use the index it is necessary to have data for every water quality characteristic for which there are standards or criteria. It is just plain foolish to narrow down to an index that considers only eight variables and claim that people generally agree that these are the important ones. If they were the only important ones we wouldn't have the long lists of standards and criteria that we now have. [Reviewer E]

One reviewer noted that general water quality indices often have difficulties with each individual subindex function:

> A general use index concept is fine but as soon as one is required to define the "subindex quality function", he runs into trouble, e.g., the NSF and Georgia oxygen curves (and most others) appear adequate for general aquatic life but are not for the capacity of natural waters to assimilate wastes. Where significant quantities of oxygen-demanding wastes are present, supersaturation may be of benefit in reducing oxygen demand and therefore protecting aquatic life from low oxygen concentrations. Similar arguments may be made for other parameters, i.e., pH, turbidity and nutrients. Conditions have been documented in which increased turbidity served to control algae growth by limiting light penetration. These curves depict a black and white situation. It is not black and white. I would like to see you discuss some of these problems in your paper so that the problem and complexity of index development can be appreciated. One can go through these recommended curves and suggest literature supported reasons why these curves are invalid for many situations. These are some of the reasons why a valid uniform and absolute index is not feasible. [Reviewer D]

It was noted that, although the report gives evidence of a trend toward increased use of water quality indices, EPA is moving away from simple trend analyses and toward more in-depth, problem-oriented studies:

> The paper reports a trend in the direction of increased use of indices by States, and implies that the 305(b) report is a causal factor. While this may be true, it should be pointed out that EPA is now pushing the States to use the 305(b) report as a more integral part of the water quality management process. One result of this effort will be to emphasize analyses which are more specific with respect to problem identification, including more use of intensive surveys, or cause and effect relationships will be required in order to make decisions and develop strategies for cleanup. All of these factors suggest that the emphasis will shift from simple trend analyses, for which indices are potentially useful, to more sophisticated problem oriented analyses, for which a wider range of analytical techniques are appropriate. [Reviewer A]

Finally, the reviewers generally accepted the notion that additional research on water quality indices would be desirable, as indicated by the following comment:

> The idea of doing further research on water quality indices as expressed in recommendation five is a good one, particularly in light of the objective of Public Law 92-500. I would also suggest that indices need to be further evaluated according to broader criteria than simply technical adequacy. If they are to be useful for decision makers, the entire process of technical evaluation, management use, and public reaction (if appropriate) must be evaluated. [Reviewer A]

REFERENCES

1. McClelland, Nina I., "Water Quality Index Application in the Kansas River Basin," U.S. Environmental Protection Agency, Kansas City, MO, EPA-907/9-74-001, February 1974.

2. "Restoring the Quality of Our Environment," a report of the Environmental Pollution Panel of the President's Science Advisory Committee, the White House, November 1965.

3. Horton, Robert K., "An Index-Number System for Rating Water Quality," Journal of the Water Pollution Control Federation, vol. 37, no. 3, March 1965, pp. 300-306.

4. Brown, Robert M., Nina I. McClelland, Rolf A. Deininger, and Ronald G. Tozer, "A Water Quality Index - Do We Dare?" Water and Sewage Works, October 1970, pp. 339-343.

5. Thom, Gary C., and Wayne R. Ott, "Air Pollution Indices: A Compendium and Assessment of Indices Used in the United States and Canada," Ann Arbor Science Publishers, Ann Arbor, MI, 1976.

6. "Federal Water Pollution Control Act Amendments of 1972," Public Law 92-500.

7. "Planning for Environmental Indices," a report of the Planning Committee on Environmental Indices, National Academy of Sciences, Washington, DC, February 1975.

8. Rosen, Richard H., Ron Beck, Valerie P. Bennett, Joseph A. Orlando, and Robert B. Wrightington, "A Review and Evaluation of Water Quality Indices and Similar Indicators, Volume I: Summary and Users Guide," prepared for the Council on Environmental Quality by Energy Resources Co., Inc., Cambridge, MA, and Mathematica, Inc., Philadelphia, PA, September 1976.

9. Orlando, Joseph A., and Robert B. Wrightington, "A Review and Evaluation of Water Quality Indices and Similar Indicators, Volume II: A Review of Available Indices," prepared for the Council on Environmental Quality by Mathtech, Inc., a subsidiary of Mathematica, Inc., Cambridge, MA, September 1976.

10. Rosen, Richard H., Ron Beck, Raymond T. Pierrehumbert, Jarre H. Harris, and Gregg Heacock, "A Review and Evaluation of Water Quality Indices and Similar Indicators, Volume III: Evaluation of Available Indices," prepared for the Council on Environmental Quality by Energy Resources Co., Inc., Cambridge, MA, September 1976.

11. Akeley, Roger P., Phillip E. Chase, Franz J. Mogdis, and James H. Soalberg, "A Review and Evaluation of Water Quality Indices and Similar Indicators, Volume IV: Nonpoint Sources and Indicators - a Special Case," prepared for the Council on Environmental Quality by the Bendix Corporation, Ann Arbor, MI, September 1976.

12. Landwehr, Jurate Maciunas, "Water Quality Indices - Construction and Analysis," Ph.D. thesis, University of Michigan, 1974 (University Microfilms 75-10,212).

13. Orlando, J. A., R. B. Wrightington, and L. D. Maxim, "Water Quality Indices - A Review of Available Indicators," presented at the 171st National Meeting of the American Chemical Society, New York, NY, April 8, 1976.

14. Ott, Wayne R., Environmental Indices: Theory and Practice, to be published by Ann Arbor Science Publishers, Inc., Ann Arbor, MI, in 1978.

15. Dalkey, Norman C. "Delphi," Report No. p-3704, The Rand Corporation, Santa Monica, CA, October 1967.

16. McClelland, Nina I., "Water Quality Index Application in the Kansas River Basin," U.S. Environmental Protection Agency, Kansas City, MO, EPA-907/9-74-001, February 1974.

17. Prati, L., R. Pavanello, and F. Pesarin, "Assessment of Surface Water Quality by a Single Index of Pollution," Water Research, vol. 5, pp. 741-751, 1971.

18. McDuffie, Bruce, and Jonathan T. Haney, "A Proposed River Pollution Index," presented at the spring 1973 meeting of the American Chemical Society, Division of Water, Air, and Waste Chemistry, NY, April 13, 1973.

19. Dinius, S.H., "Social Accounting System for Evaluating Water Resources," Water Resources Research, vol. 8, no. 5, October 1972, pp. 1159-1177.

20. O'Connor, Michael Fredrick, "The Application of Multi-Attribute Scaling Procedures to the Development of Indices of Water Quality," Ph.D. Dissertation, University of Michigan, 1972 (University Microfilms No. 72-29,161).

21. Deininger, Rolf A., and Jurate Maciunas Landwehr, "A Water Quality Index for Public Water Supplies," unpublished report, Department of Environmental Health, School of Public Health, University of Michigan, Ann Arbor, MI, July 1971.

22. Walski, Thomas M., and Frank L. Parker, "Consumers Water Quality Index," Journal of the Environmental Engineering Division, American Society for Civil Engineering, June 1974. pp. 593-611.

23. Stoner, Jerry D., "Water Quality Indices for Specific Water Uses," unpublished report, U.S. Geological Survey, Oklahoma City, OK, 1976.

24. Nemerow, Nelson L., and Hisashi Sumitomo, "Benefits of Water Quality Enhancement," prepared for the U.S. Environmental Protection Agency by Syracuse University, Syracuse, NY, Report 16110 DAJ, December 1970.

25. Truett, J. B., A. C. Johnson, W. D. Rowe, K. D. Feigner, and L. J. Manning, "Development of Water Quality Management Indices," Water Resources Bulletin, vol. 11, no. 3, June 1975, pp. 436-448.

26. Dee, Norbert, Janet Barker, Neil Drobny, Ken Duke, Ira Whitman, and Dave Fahringer, "An Environmental Evaluation System for Water Resources Planning," Water Resources Res, 9(3): 523-535, June 1973.

27. Inhaber, H., A National Environmental Quality Index for Canada, Technical Edition, Internal Report to the Canadian Department of the Interior, Ottawa, Ontario, 1974.

28. Zoeteman, B. C. J., "The Potential Pollution Index as a Tool for River Water Quality Management," Technical Paper No. 6, World Health Organization, International Reference Center for Community Water Supply, The Netherlands, 1973, cited by Landwehr, Reference 12.

29. Johanson, Edward E., and Jaret C. Johnson, "Identifying and Prioritizing Locations for the Removal of In-Place Pollutants," prepared for the U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, DC, May 1976.

30. Shoji, Hikaru, Takeo Yamamoto, and Takakazu Nakamura, "Factor Analysis on Stream Pollution of the Yodo River System," Air and Water Pollution International Journal, vol. 10, 1966, pp. 291-299.

31. Coughlin, Robert E., Thomas R. Hammer, Thomas G. Dickert, and Sallie Sheldon, "Perception and Use of Streams in Suburban Areas: Effects of Water Quality and of Distance from Residence to Stream," Regional Science Research Institute, Philadelphia, PA, Discussion Paper No. 53, March 1972.

32. Harkins, Ralph D., "An Objective Water Quality Index," Journal of the Water Pollution Control Federation, vol. 46, no. 3, March 1974, pp. 588-591.

33. Kendall, Maurice, Rank Correlation Methods, Charles Griffin & Co., Ltd., London, 1975.

34. Schaeffer, David J., and Konanur G. Janardan, "Communicating Environmental Information to the Public; A New Water Quality Index," Journal of Environmental Education, vol. 8, no. 4, summer 1977, pp. 18-26.

35. "The Relationships of Phosphorus and Nitrogen to the Trophic State of Northeast and Central Lakes and Reservoirs," U.S. Environmental Protection Agency, Las Vegas, NV, Working Paper No. 23, 1974.

36. Leutner, Frederick, "Sports Fishing Catch Data as a Water Quality Indicator," U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, DC, April 1975.

37. "Environmental Program Administrators," U.S. Environmental Protection Agency, Office of Regional and Intergovernmental Operations, Washington, DC, May 1976.

38. "Directory of State Agencies Engaged in Environmental Monitoring," U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC, December 1973.

39. "Directory of Regional Water Pollution Control Agencies," Water and Sewage Works, 1976, pp. 232-251.

40. "Water Quality and Pollution Control in Michigan," Michigan Department of Natural Resources, Bureau of Water Management [Section 305(b) Report], Lansing, MI, April 1976.

41. Neal, Larry A., "A Water Quality Index for Georgia-Update of Technical Memorandum of October 29, 1975," Technical Memorandum, Department of Natural Resources, Environmental Protection Division, Atlanta, GA, December 30, 1975.

42. "Water Quality Control in Georgia 1975," Georgia Department of Natural Resources, Environmental Protection Division [Section 305(b) Report], Atlanta, GA, 1975.

43. Barker, Bruce, and Paul Kramer, "Water Quality Conditions in Illinois," Appendix A to Chapter III, "Water Quality Management," Statewide Water Resource Development Plan, Illinois Department of Transportation, Division of Water Resource Management, 1972.

44. Janardan, Konanur G., and David J. Schaeffer, "Development and Applications of Five New Water Quality Indices," Illinois Environmental Protection Agency, Springfield, IL, unpublished manuscript, February 1977.

45. "Illinois Water Quality Inventory Report 1976," Illinois Environmental Protection Agency [Section 305(b) Report], Springfield, IL, 1976.

46. Hudson, LeVerne D., and David J. Schaeffer, "Effects of the 1976 Drought on Illinois Water Quality," Illinois Environmental Protection Agency, presented at the American Water Resources Association, Illinois Section, Fifth Annual Water Resources Conference, June 10-11, Chicago, IL, February 1977.

47. Dunnette, David A., "Water Quality Index Development and Application for the Willamette Basin, Oregon," Department of Environmental Quality, Water Quality Division, Portland, OR, unpublished manuscript, July 1976.

48. "Environmental Quality," Fifth Annual Report of the Council on Environmental Quality," Washington, DC, December 1974, pp. 333-334.

49. Sheen, Jackson R., letter to Wayne Ott, State of Nevada Department of Human Resources, Environmental Protection Services, Carson City, NV, January 19, 1977.

50. Cogger, William J., Marshall L. Payne, and Lester D. Sprenger, "Water Quality Inventory," U.S. Environmental Protection Agency, Region VIII, Surveillance and Analysis Division, Denver, CO, October 1975.

51. Beebe, James A., "WQI A Water Quality Analysis System," U.S. Environmental Protection Agency, Region X, Seattle, WA, unpublished manuscript, May 1, 1975.

52. Beebe, James A., "WQI A Water Quality Data Analysis System User Guide," U.S. Environmental Protection Agency, Region X, Seattle, WA, unpublished manuscript, July 1975.

53. Beebe, James A., "WQI A Water Quality Data Analysis System Program Documentation," U.S. Environmental Protection Agency, Region X, Seattle, WA, unpublished manuscript, July 1975.

54. "Water Quality Criteria 1972," a report of the Committee on Water Quality Criteria, National Academy of Sciences, Washington, DC, 1972.

55. Personal communication with Ray Peterson, Sanitary Engineer, U.S. Environmental Protection Agency, Region X, Surveillance and Analysis Division, Seattle, WA, August 1977.

56. "A Recommended Air Pollution Index," a report of the Federal Interagency Task Force on Air Quality Indicators, Council on Environmental Quality, U.S. Environmental Protection Agency, and Department of Commerce, Washington, DC, December 1976.

57. Leutner, Frederick D. (Acting Director, EPA Monitoring and Data Support Division), "Comments on Water Quality Indices Report," memorandum to Wayne Ott, dated August 1, 1977, Washington, DC.

58. Weber, Cornelius I. (Chief, Aquatic Biology Section, EPA Environmental Monitoring and Support Laboratory), "Review of Report on a Survey of Water Quality Indices Used in the United States," memorandum to Wayne Ott dated June 17, 1977, Cincinnati, OH.

59. Landwehr, Jurate M. (U.S. Geological Survey), "Review of Report 'Water Quality Indices': A Survey of Indices in the United States," memorandum to Wayne Ott dated June 17, 1977, Reston, VA.

60. Dunnette, David A. (Special Projects Coordinator, Oregon Department of Environmental Quality), letter to Wayne Ott dated June 24, 1977, Portland, OR.

61. Ficke, John F. (Quality of Water Branch, U.S. Geological Survey), letter to Wayne Ott dated June 28, 1977, Reston, VA.

APPENDIX A

COMMENTS FROM NONUSERS OF WATER QUALITY INDICES

APPENDIX A. INFERRED COMMENTS FROM RESPONDENTS*

AGENCIES NOT USING INDICES

AGENCY NO. 1

We performed a preliminary analysis on several indices, including the NSFI, and found all indices to be inadequate for use in the Section 305(b) report. Therefore, we look at the values of specific variables in evaluating water quality for the Section 305(b) report and for other purposes.

AGENCY NO. 2

Several years ago we looked at the Harkins index and the NSFI, but neither was useful for describing our waters. This is because of the high amount of sediment and phosphate in our streams; thus, these indices would have to be modified before we could use them. However, we now use individual variables in determining water quality for our Section 305(b) report and find this method more than satisfactory.

AGENCY NO. 3

Although they may be useful for administrators, water quality indices really don't give a proper picture of water quality because there exist many special stream situations. To describe water quality adequately using an index, one would need to use different indices for different variables; water quality indices also should distinguish between the chemical and physical nature of water quality variables; for example, salinity *vs.* conductivity.

AGENCY NO. 4

We are now evaluating the NSFI and hope to use it in our next Section 305(b) report. However, we do not have data for all of the NSFI variables, but will obtain values for these by a correlation with other variables. In our preliminary analysis of the NSFI, we found that the NSFI curves are invalid in salt and coastal waters, and that different indices will be required for lakes and streams.

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*These are interpretations by the investigators of views expressed by respondents during telephone conversations. They do not necessarily reflect the official viewpoint of the agency contacted. Specific quotations of the respondents are given in quotation marks.

AGENCY NO. 5

Water quality indices are good for public relations purposes since they give a "black and white" number which is easily understood by the layman. However, indices really don't tell the quality of water because they don't take all factors into account; for example, they often exclude biological data. We looked at one index recently and found it unsatisfactory for our purposes because it indicated only whether or not the the water quality standards are being met. Thus, we have come to the conclusion that, for our purposes, we are better off not using an index.

AGENCY NO. 6

We have looked briefly at several indices for possible use in monitoring BOD reduction and several other problems. However, none of the indices were able to adequately treat the waters in the tidal/fresh water interface. As a result, we have not been able to utilize water quality indices and feel that their general application would be very difficult.

AGENCY NO. 7

We developed an index for use in our 1976 Section 305(b) report. However, we were not very pleased with the performance of the index for two reasons: First, some of the variable values which went into the index calculation were arbitrary due to incomplete data on some of our streams. Second, if one of the variable values is out of line, then the index (i.e., stream) looks bad. We feel that indices are too simplistic and are only useful when you completely understand the many limitations of an index; some of the factors which must be taken into consideration in interpreting index values are stream flow rates, the fact that streams react differently to waste loads, and the fact that water quality naturally varies as a function of geographical area.

AGENCY NO. 8

Water quality indices are of value in that they can be used: (1) to reflect the attainment of water quality standards; (2) to rate the priority of sewage treatment construction grants; and (3) to focus the use of water resources in the proper areas. We anticipate developing an index within a year or so to use in our Section 305(b) report. The index will be based on a model developed at the University of Kentucky.

AGENCY NO. 9

We wanted to use the NSFI in the 1975 Section 305(b) report to indicate the percent of water quality violations and give a graphical representation of stream water quality. However, we could not because, until this year, we did not have the capability to collect data on all of the NSFI variables. If we have insufficient data for the NSFI this year, we will either use an index with fewer variables or develop an index of our own.

AGENCY NO. 10

One respondent: The specific water quality variables for each geographical area are more useful than the "mash number" given by an index. Accordingly, we have divided our State into 200 water quality regions and are mapping the streams within each region. These maps will indicate the stream's problem pollutant, its concentration, and the level above the corresponding water quality standard.

Second respondent: We have reviewed some of the more common water quality indices to determine how they are used and which one might be suitable for our use. After an extensive evaluation of several indices, we have decided to use an index in our 1977 Section 305(b) report. However, the index will not be a standard water quality index based on chemical variables, but will be a modified biological species diversity index. We feel that since aquatic species are subjected to water pollution and tend to integrate effects over time, biological indices are more descriptive of water quality than chemical variables, which give instantaneous values that are not necessarily valid for a whole stream and do not reflect long-term pollution. Furthermore, the layman does not understand the significance of the various concentrations of chemical variables and the statistical methods used in computing a water quality index from them. However, the average citizen can easily comprehend the relationship between water quality and the amount and type of stream life. With regard to the NSFI, we feel that "the National Sanitation Foundation has attempted to move its index to a level of sophistication that it is not capable of meeting."

AGENCY NO. 11

We are now working on adapting the NSFI for use in our Section 305(b) report. We may be able only to use an eight-variable modified version of the NSFI because our coverage of turbidity is inadequate. In general, indices are not universally applicable because there are different water uses and characteristics.

AGENCY NO. 12

We have watched the development of water quality indices with interest and would like to see a useful index developed. However, much more work is needed before an adequate index can be developed because those currently in existence have faults. There is obviously a need for a straightforward method for comparing the water quality of two rivers or the same river over time. Indices have a simplistic beauty which fulfills this need; however, existing indices are deceptively beautiful, creating, in some cases, illusions about true water quality.

AGENCY NO. 13

We have examined water quality indices in many different ways and have found that "one is limited only by his ingenuity in the number of ways that the various water quality variables can be put together." Thus, "one comes up with a different index number depending on the index used and what weights are assigned to the variables." "Although the idea of a water quality index is great, water quality indices oversimplify the picture of water quality, and tend to get misused." This problem is reflected in the fact that no single index can be used to characterize water for different uses, since the required water quality is different for each use. Of course, individual indices can be employed for each use; but if this is done, one may as well use individual variables instead of an index.

AGENCY NO. 14

Although no index can describe water quality completely, the NSFI appears to be an adequate general indicator of water quality. We looked briefly at the NSFI, but could not use it because we did not have data for all nine variables. However, we feel that in the future the NSFI variables will be of secondary importance when compared to toxic substances.

EPA Region A (Surveillance and Analysis Division)

The NSFI is currently being evaluated by the New England Interstate Commission (see comments in Appendix B) to determine its applicability to the Nashua River. After this evaluation is complete, we will decide whether or not to use a modified NSFI in Regional Office evaluations of all New England rivers. However, our general feeling toward indices is that they do not adequately describe water quality, particularly in the evaluation of short-term changes of water quality. Consequently, their primary value appears to be in the evaluation of seasonal and long-term trends.

EPA Region B (Management Division)

The NSFI has been used by New York in its Section 305(b) report for the last three years; New Jersey is now modifying the NSFI for use in its 1977 Section 305(b) report. The NSFI is also being used by New York City for the Section 208 planning and water quality assessment reports. We think that the NSFI can be used to compare water quality on a nationwide basis; however, in tidal areas, some adjustment in the TDS or salinity variable may be necessary.

EPA Region C (Water Division)

Although water quality indices were developed as public information tools, they "don't serve the purpose for which they were intended." This is primarily because water systems are too complex to be described by a simplified index. As a result, we are not in favor of using indices and feel that EPA should not spend time developing a water quality index, and we further feel that it really can't be done.

EPA Region F (Water Division)

Although we haven't used an index, we have looked at both the Harkins and the Region X indices. In some situations, an index works well but, since it does not take all things into consideration, any index should be used in conjunction with other individual variables which pinpoint problem areas. In this respect, any index developed or recommended by EPA must be flexible enough to enable water quality from different types of streams to be described.

EPA Region D (Surveillance and Analysis Division)

Our Regional Administrator wants to use some type of water quality index in the development of a Region IV Environmental Quality Profile, similar to the one developed in Region X. In fulfilling this request, we have looked briefly at the NSFI, Harkins, Florida, and Georgia indices. We feel that indices are useful in describing water quality to the public, but they cannot be used as a substitute for the reports of individual variable analyses required by technical people.

EPA Region E (Water Division)

Indices are subject to speculation because they are "based on varying assumptions which do not accurately reflect water quality." Many States, due to the fact that they conduct only random sampling and not intensive surveys, take a lot of 'half' data and establish an index. Thus, they avoid the need for extensive monitoring programs.

EPA Region G (Water Division)

Water quality indices are an old concept developed by sanitary engineers. Concepts have changed greatly since the NSF developed its index, and the index has not responded to these changes. For example, PCB's and other toxics have become increasingly important, but these are not handled by the NSFI. In general, although water quality indices may be an easy way to transmit information, they do not tell where or what pollution problems are -- is it an industrial, municipal, or nonpoint source problem? For the Section 305(b) reports, we use specific variables and "plain English," so that we can correctly respond to problems. Water quality cannot be compared on a nationwide basis, and, although the use of water quality indices by geographical area may not be a bad approach, it only has marginal benefits.

EPA Region I (Water Division)

One respondent: Water quality indices are probably valuable _if_ you use them with extreme care. Although they are not absolute indicators of water quality, they may be useful to show water quality trends.

Another respondent: We have not found water quality indices useful, but maybe we haven't tried hard enough. Water quality indices do not necessarily represent water quality and are generally not very revealing.

For example, although an index might indicate good water quality, potential or existing problems might not be clearly identified. Specifically, water quality indices don't reflect the problems we have and tend to be misleading when applied to our class of water. Our water is now classified on the basis of indirect variables which may or may not be a part of any index.

Third respondent: The NSFI is an excellent tool to indicate trends in water quality and to display data to the uninitiated. We will hopefully be using this index in conjunction with other individual water quality variables.

APPENDIX B

COMMENTS FROM USERS OF WATER QUALITY INDICES

APPENDIX B. INFERRED COMMENTS FROM RESPONDENTS*

AGENCIES USING INDICES

AGENCY NO. 1 — INDEX TYPE: Modified NSFI

We threw out temperature and reweighted the index because temperature was not a major problem here. The index was useful in comparing which streams appeared dirty and which appeared clean. We looked at the raw data for these streams and compared them with the index results. I think the index gave a "reasonable result." You can look at those streams which came out dirtiest, and, from the raw data, they came out on the bottom of the list. Similarly, the cleanest streams, according to the index, came out on the top of the list. Thus, the index appears useful, and we will keep using it, probably increasing our coverage from 13 stations to 27 stations. Selection by EPA of a uniform national index probably would be a good idea. If the structure of the index were different than those in use, it probably would be all right, just so the index is available on STORET.

AGENCY NO. 2 — INDEX TYPE: Developed own index

We developed two indices, evaluated them, and selected one for our use. We used it in our Section 305(b) report. We do not consider it a "true water quality index," but rather a "trend monitoring index." Our goal is to apply it now and then again later to follow water quality changes over a five-year basis. We don't feel that an absolute type of index can work; there are too many geographical differences, even within a State. An index must be tailored to the specific locale, and it must be empirically based. We based our index on the data we have been collecting in the State over a period of years. We were able to assess the index performance in light of our actual knowledge of the geographical variation of water quality and thus to come up with a suitable means for detecting changes in water quality. Even then, it is not necessarily a finished technical product, and further refinement is needed. However, "we feel that the general public needed something more in keeping with the layman's knowledge" than the raw data would provide. Unfortunately, an index is "like nuclear energy." It is "extremely powerful or extremely dangerous, depending on how you use it."

*These are interpretations by the investigators of views expressed by respondents during telephone conversations.

AGENCY NO. 3 INDEX TYPE: Developed own index

Some years ago, we developed five water quality indices. We selected the best one of these and are now using it on a Statewide basis, particularly in the Section 305(b) report. Another agency in the State also has developed and applied a water quality index, but that was just a "one-shot" effort. Our current index is similar to the Harkins index, but it overcomes some of the limitations of the Harkins index. We have carried out comparisons between biological and chemical variables and found good correlations. Our index varies from 0 to 1 and it represents one of the few cases where an index matches up well with biological variables.

AGENCY NO. 4 INDEX TYPE: Modified NSFI

We have used the index, but we feel fairly neutral about it. We included it in our 305(b) report, but I'm not sure it will be used next year. I'm not really sure it's worth the effort. Sometimes one variable may be out of line, and the index makes the streams look bad, causing an erroneous interpretation. The index really is too simplistic. It's useful only when you understand its limitations. I would not favor adoption by the Federal Government of a uniform index, because the waters vary considerably in different areas. Also, stream flow rates differ, and different streams react differently to different waste loads. Possibly application of indices on a regional basis would be useful.

AGENCY NO. 5 INDEX TYPE: Modified NSFI

In our index, we routinely ignore temperature, because we don't have any power plants that are sources of thermal pollution. The water quality index is just one part of our larger computerized water quality display system. The Section 305(b) report was an important factor in choosing to use an index, but not the only one. There were a number of questions by newspaper reporters. For example, the newspaper and television stations came to us and asked, "Could you give us an interpretation of water quality in the area of this city for the past 3 years?" Their readers just were not able to understand 25 variables. The technical people often don't realize that the public wants a simpler result. The "Daily Gazette" requires a more understandable format for presenting water quality information. We like the NSFI variables. These can be controlled by waste treatment processes. We know, however, that the index is designed to accommodate a nationwide range of variables, and we solve the problem of geographical differences by simply cautioning readers, "85 is the best you can get in this State due to natural background conditions." We just put "85" at the top of all the graphs. We are very satisfied with the NSFI, although we suggest that some research on biological variables would be useful. A uniform index which could be recommended by the Federal Government would be a good idea. One of the best features of the NSFI is that it already has received widespread application.

Thus, a certain amount of uniformity already has occurred. If EPA were to recommend a uniform index, EPA should probably first poll the users. It "would not upset me greatly to use a slightly different index," unless some new variables were included. If the index software were available, it would be very easy to recalculate the values with the new index. Geographical differences can be handled by redefining the range of the scale. "If you're going to accept the advantages of uniformity, you have to accept the disadvantages." Some technical people object to making the data easy to understand through an index simply because they prefer keeping it as complex as possible. Different water uses are not a problem with this index. I would expect the index values to lie in certain ranges for certain water uses. I suggest that this hypothesis be tested in a study.

AGENCY NO. 6 INDEX TYPE: Standard NSFI

We have been applying the index to one of our major rivers on a pilot basis. We found that it successfully showed distinct changes in the river where you would expect them. On the upper reaches, it was 85-90; on the lower reaches, it was 50. This result seemed reasonable. We are currently planning to use the index in our annual report on water quality to the Department of Natural Resources. They will prepare a series of reports for various audiences. The index results will be published and distributed to "the citizens of the State." We applied the index manually so far, but we are thinking about programming it on a computer so that it can be applied to the entire State. We feel that the index has been useful in our application to this river. We feel very strongly that the index is an excellent idea. An index is especially useful for assessing long-term trends where the layman needs answers to obvious questions: "If someone walked into my office and asked, 'Damn, we're spending a lot of money in the State. Are we improving water quality?' Right now, I can't really answer that question." I would like to examine, on a long-term basis of several years or more, the change in the index for the dollars spent. While the concept of a water quality index is good, I'm not sure this index is the best one. For example, many of the variables in the index are not as important here as they are in other areas of the Country. The organic pollutants are not a serious problem here, and the index does not place enough emphasis on total dissolved solids and salinity. We would like to add specific conductivity. We don't have thermal discharges, so we would like to omit temperature. We're thinking of a simplified index. What is needed is a standardized way to delete certain variables when they are not considered a problem. Then, at least, if users drop a variable, they'll all be doing it the same way. We favor the idea of EPA recommending a uniform water quality index. We would like to see EPA come up with a hierarchy of indices: (1) a "full-blown" index covering all variables, (2) an intermediate index, and (3) a very simple index. Each index would be increasingly more complex than the next, but the more complex indices would be applied to the more data-rich situations.

AGENCY NO. 7 INDEX TYPE: Standard NSFI

We use the multiplicative form of the NSFI. It is exactly the same as the published version which was applied to the Kansas River Basin. We initially applied this index to determine whether it was usable to convey trends. We were very impressed with its performance. It correlated well with what you would intuitively expect. Water quality, as depicted by the index, was improving at the places where we have major investments in treatment facilities.

I realize that there is much controversy surrounding water quality indices. Many persons "seem to be obsessed with 'water quality use.' The public wants to know, 'well, how do you rate the water?'" Probably one or two or three variables will dominate the index, but so what? It would be a good idea for EPA to recommend a standardized index to avoid user "customizing." The chief problem with customizing is that people will say, "You customized just to make yourself look good."

We have used results from the index in the Section 106 presentation, and we have distributed the index results at public hearings. We also have written several articles using the index in the Department's magazine and in the Water Pollution Control Federation Journal. Overall, we are generally very happy with the index. It probably would be a good idea to have a uniform national index. "Yes, EPA should recommend a standardized index."

AGENCY NO. 8 INDEX TYPE: Harkins

We used Harkins' approach in the Section 305(b) report to compute three indices: (1) a general index with 7 variables; (2) a mineral index using chloride, sulfate, and total alkalinity; and (3) a nutrient index using pH, DO, nitrogen, and phosphate. We had originally attempted to develop our own indices based on county data, but we were not able to do what we had hoped because of lack of data and manpower restrictions. This year we will be using a variation of Harkins' index, and the index results will be used in the 1976 and 1977 Section 305(b) report. A uniform water quality index is a good idea if you could come up with one. It would be advantageous for us to have a proven index or a set of indices. Possibly, indices should be applied on a region-by-region basis.

AGENCY NO. 9 INDEX TYPE: Modified NSFI

We used an additive form of the NSFI last year; next year we will use both the additive and multiplicative forms. We usually use just 8 variables, omitting temperature because our stations are so far apart that we can't determine departure from equilibrium. For some stations, we don't have BOD data, so we drop BOD and adjust the weights to add to 1.0. We also add total suspended solids and total dissolved solids; where total suspended solids are missing, we use total dissolved solids.

We feel very favorable about the index application; "We think it is a useful tool." It helps explain the data to the Congressman and layman. They can easily understand the concept that 100 = "good" water quality, and 0 = "bad" water quality. It seems useful, and it gives reasonable results. The absolute value of the index really is not too useful, however, but the relative change really shows up pollution problems. Because most of the State's water is generally good, the water quality index "really picks up influences."

An index like the NSFI would be better for national use than an index based on water quality standards. Violation of water quality standards is not a good basis for an index for national use, because each State has different water quality standards.

AGENCY NO. 10 INDEX TYPE: Standard NSFI

We originally applied the NSFI with one change: we deleted temperature and modified the weights accordingly. We then did a study comparing the modified NSFI with the standard version, and we usually found less than 1/2 point difference. Thus, we decided that modification was not necessary, and we are now using the original version. Now we're satisfied that the original weights are good.

We use the index primarily as a public information tool. It can be used to show the people in the basin their water quality. The river basin where we are applying the index is very polluted. We have applied the index for about a year, and we will run it again next summer after treatment facilities are completed to get before/after results. It should help assess the impact of $30 million in construction of treatment facilities currently underway.

I feel that a uniform index is a good concept. "I would support the idea that EPA should support a uniform index." It would provide a basis to "educate the public" that a certain number means a certain quality. The standard NSFI appears to be a good choice for a uniform index and would allow comparisons to be made of water quality in different States.

AGENCY NO. 11 INDEX TYPE: Harkins

We did use Harkins' index in our previous water quality report, but we did not intend to use it again. I felt the results with Harkins' index were very good. I think this index is one of the best I've seen. However, like all the indices, it requires interpretation. This is the problem with indices: they require interpretation, so why use them?

One problem with Harkins' approach is that it is a "ranking index." Thus, depending on the other data in the set of observations, a pH of 6.0 may come out "good" or "bad." It may look good when it is not really good. One advantage to this index, however, is that it is "open-ended." You can easily add another variable; you're not locked in. Two drawbacks to the NSFI are that (1) it is "closed" rather than open-ended, and (2) it contains subjective weights.

Indices attempt to simplify too complex a situation. It is like going to the doctor and asking for an index of one's health. It probably would be meaningless, because there are so many factors that affect health. The same is true for streams. It depends whether you're dealing with a stream or an estuary. Then it depends whether it is a freshwater or brackish estuary. Can your index tell you if you have algal blooms or fish kills? Also, if you have different water uses, you have to consider that.

Rather than developing a uniform index, I think EPA should develop a uniform variable-by-variable table assigning "good," "fair," or "pass" to different ranges of variable values. Such a listing would give more useful guidance in interpreting water quality data than indices.

EPA Region H — INDEX TYPE: Developed own index

We developed a water quality index based on the percent of the time that different water quality standards are violated. We have applied the index to the data from several of our States and have used the index in a number of reports. The index is now available to any of the States within the Region and they are welcome to use it.

EPA Region J — INDEX TYPE: Developed own index

Our original water quality index developed by Beebe was based on the incidence and location of violations of water quality standards. We have since simplified the original Beebe index to make it more "production item than a research item." The new version is simpler and uses a different approach for selecting the stations. Perhaps we have retreated somewhat from the original Beebe index, which uses a better calculation procedure, but the present version works well for our purposes. We now use the index to prepare annual environmental quality profiles for each State in the Region.

APPENDIX C

QUALITY RATING CURVES FOR GEORGIA'S WATER QUALITY INDEX

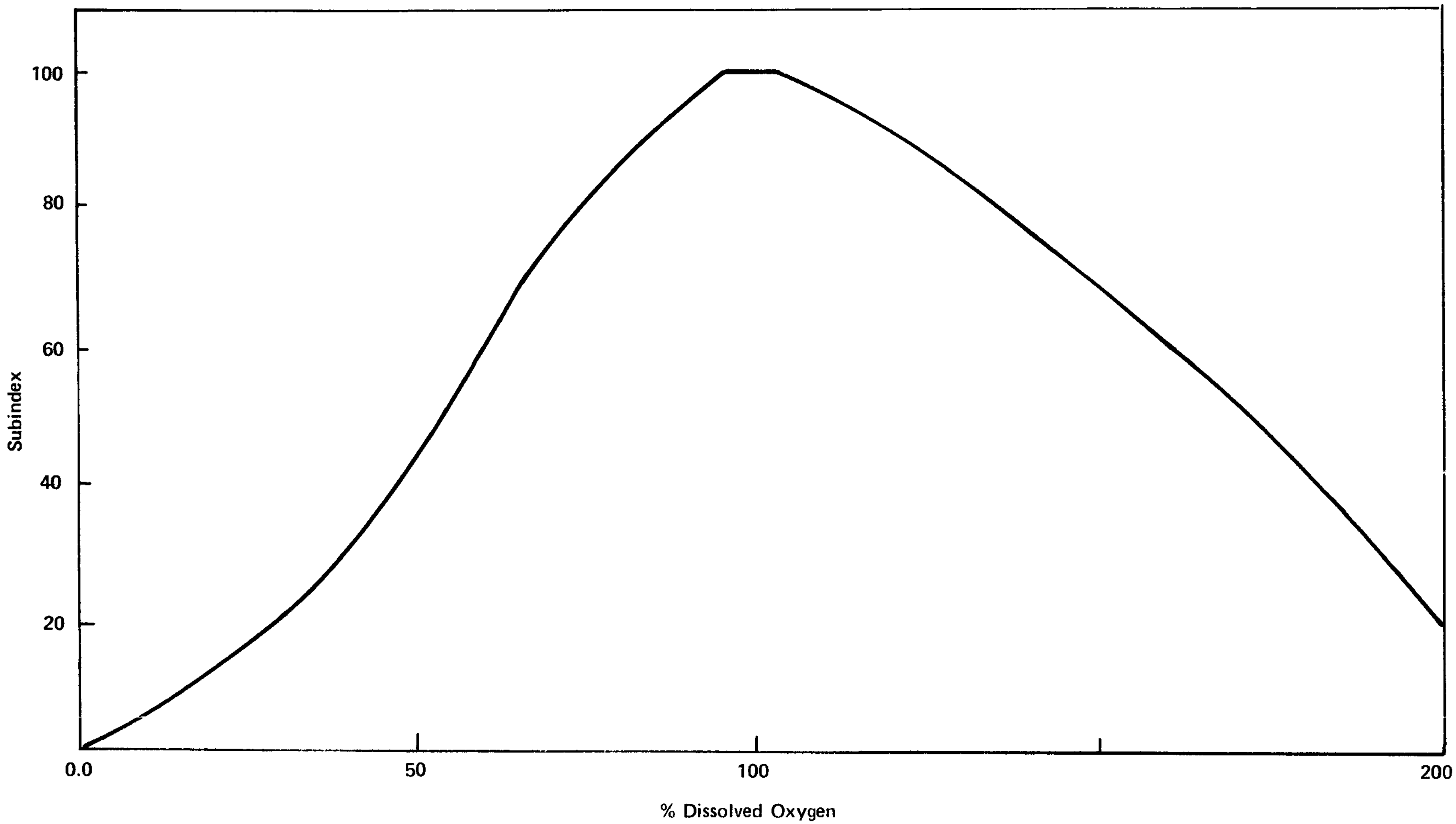

Figure C1. Subindex quality function for dissolved oxygen.

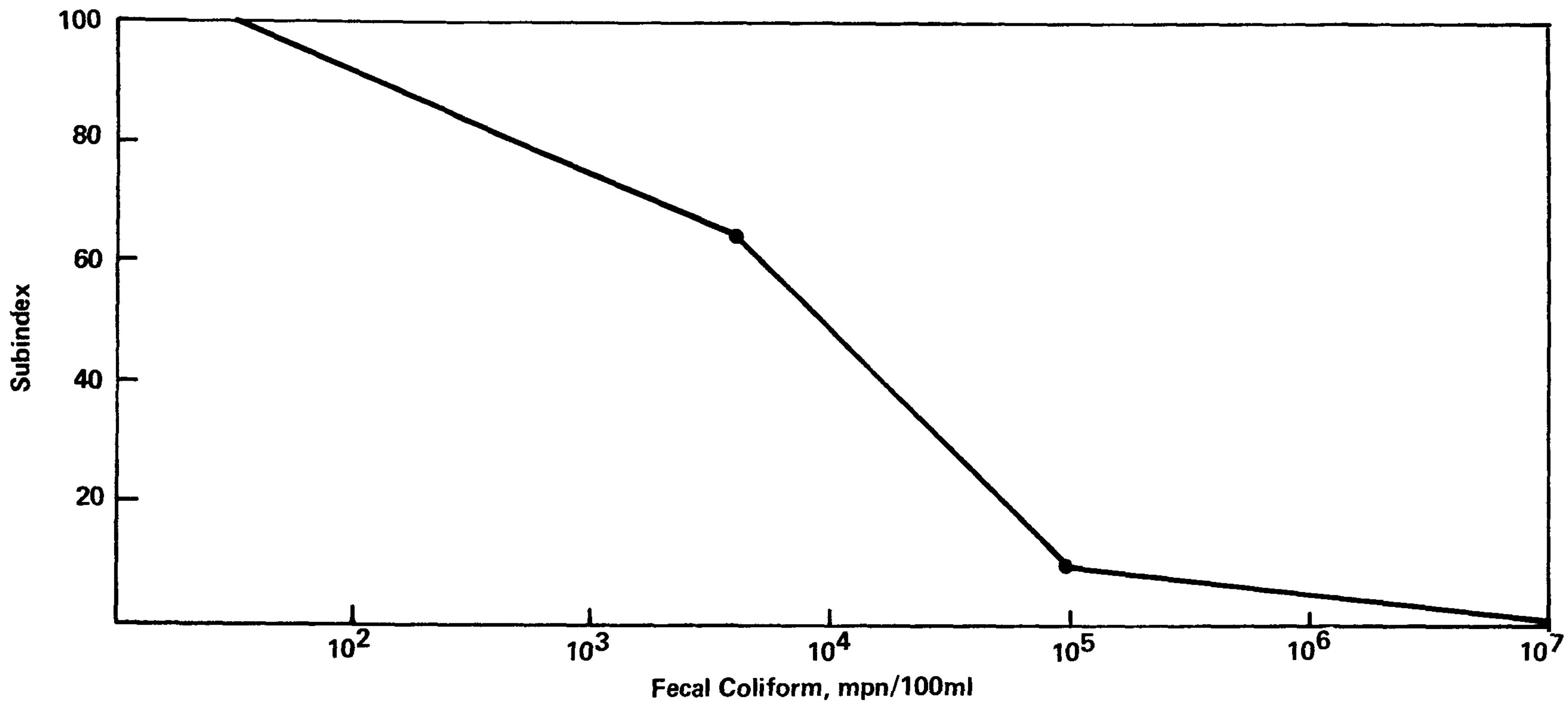

Figure C2. Subindex quality function for fecal coliform.

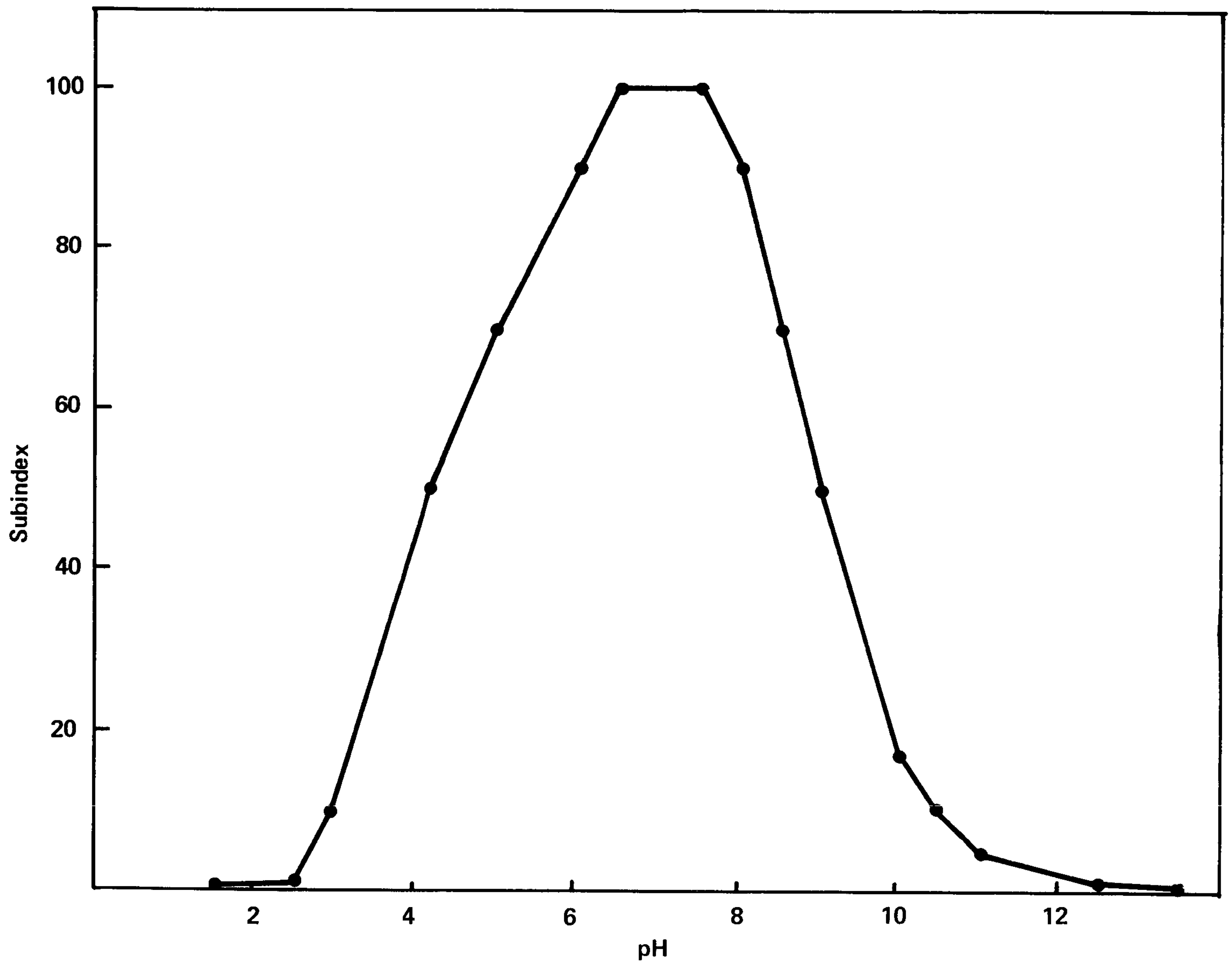

Figure C3. Subindex quality function for pH.

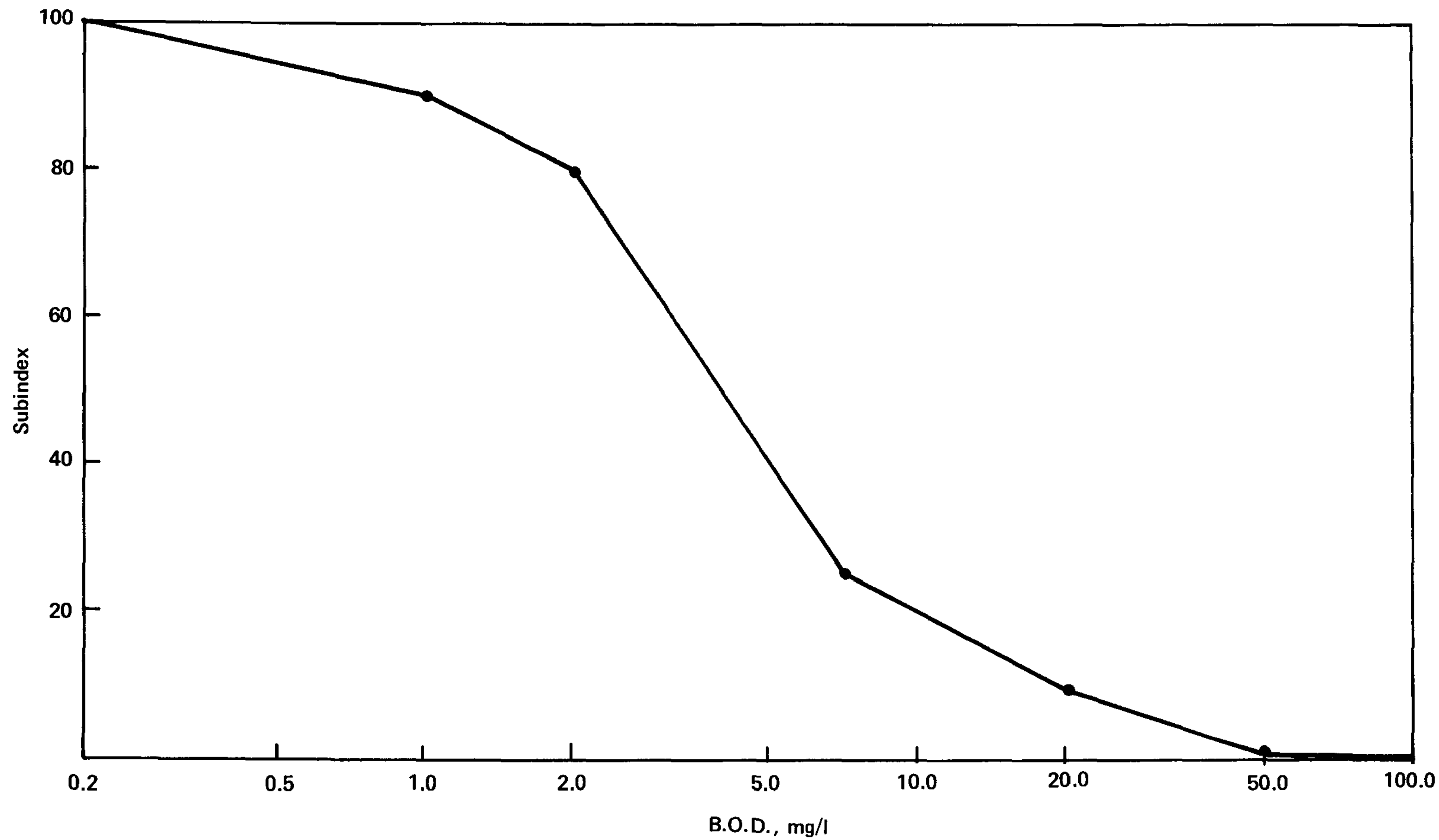

Figure C4. Subindex quality function for B.O.D.

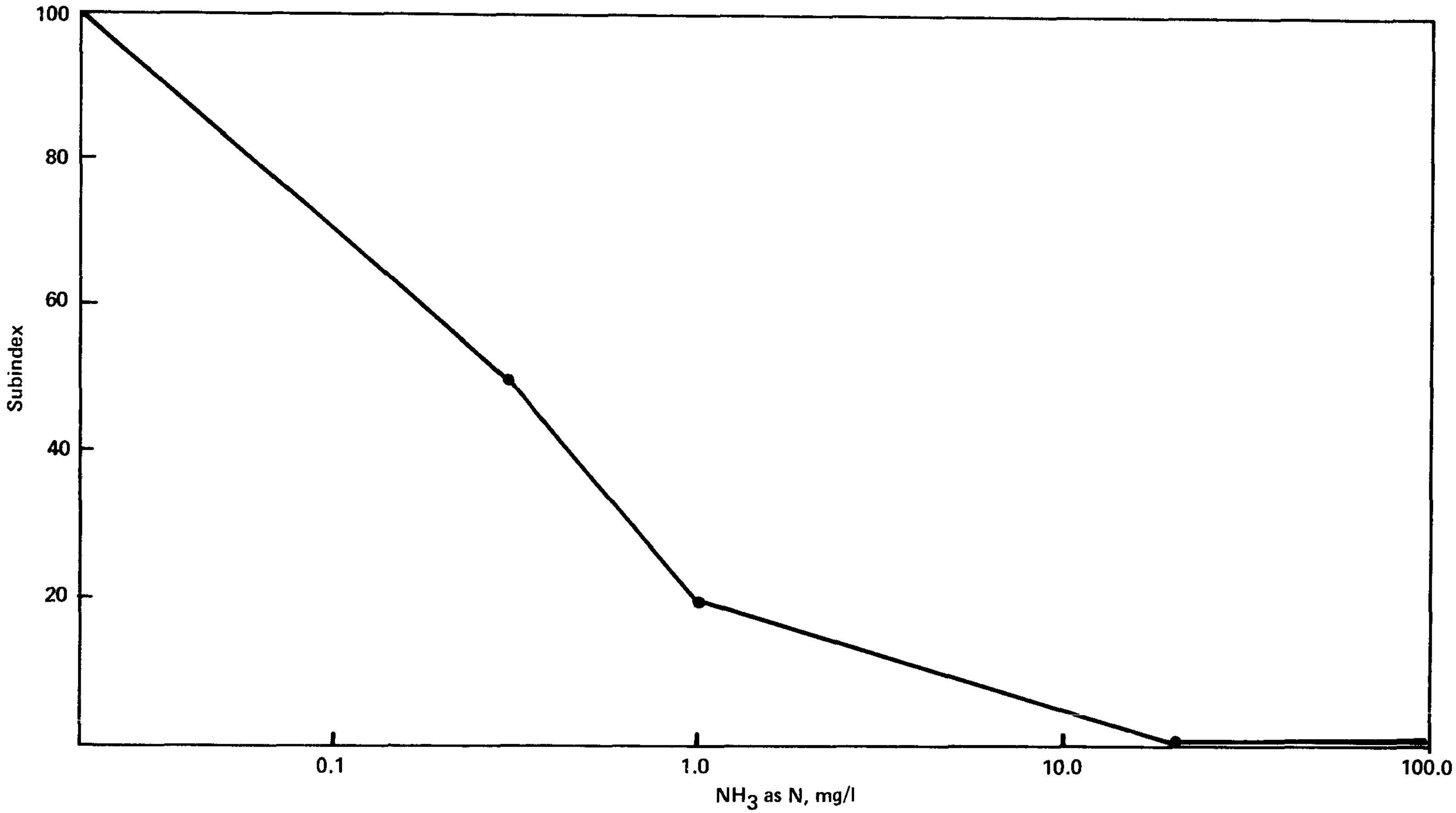

Figure C5. Subindex quality function for ammonia

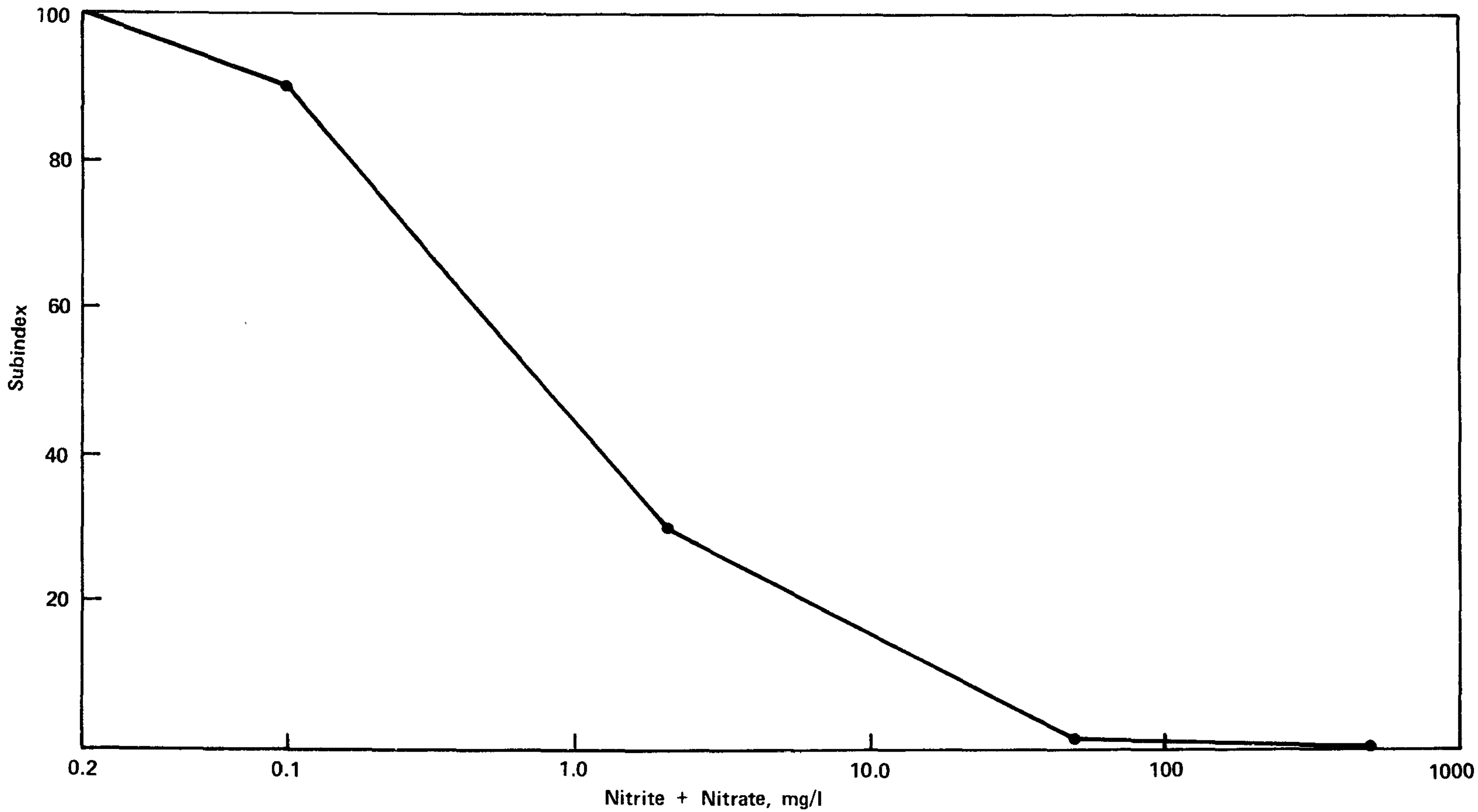

Figure C6. Subindex quality function for nitrite + nitrate.

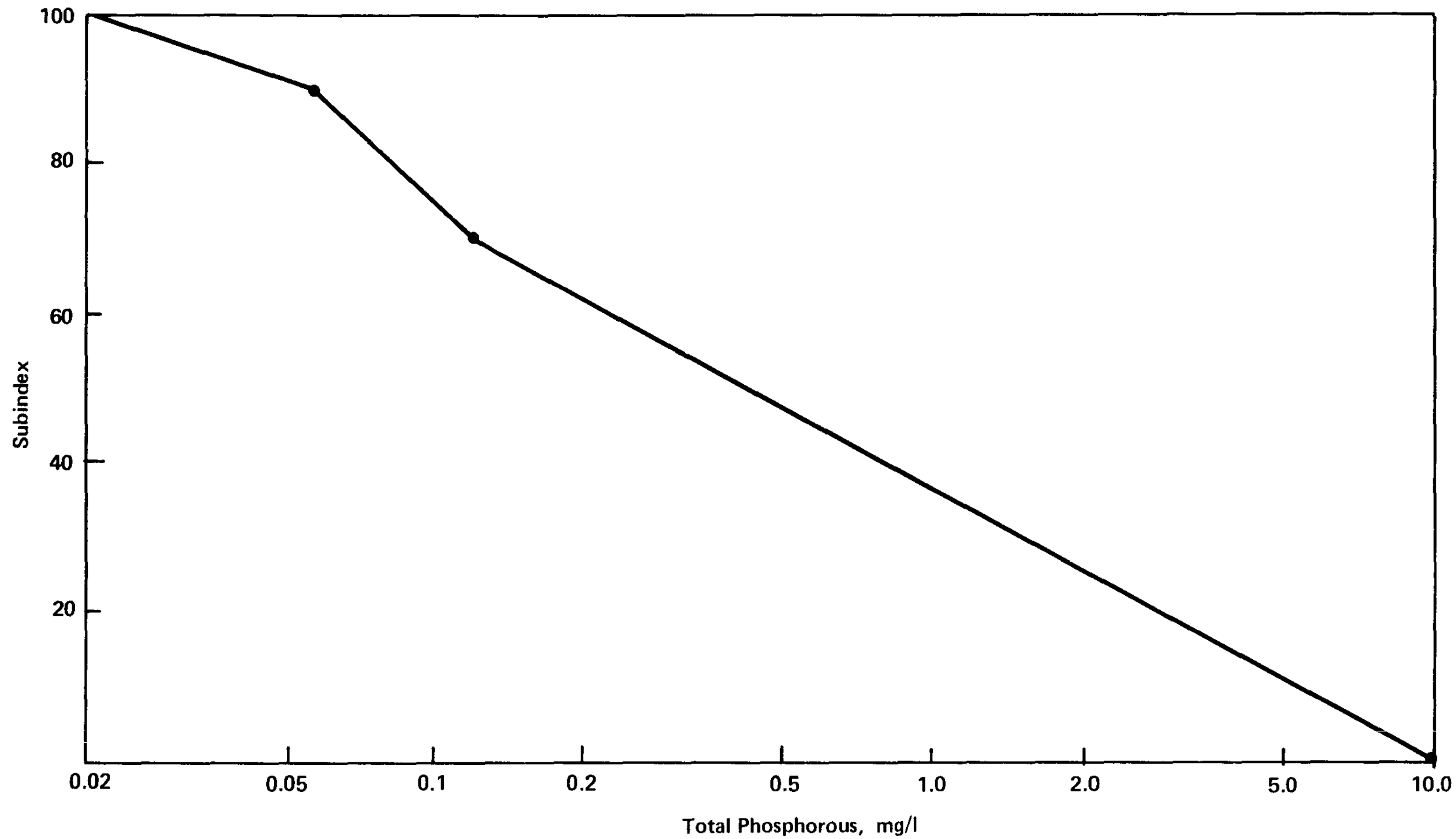

Figure C7. Subindex quality function for total phosphorous.

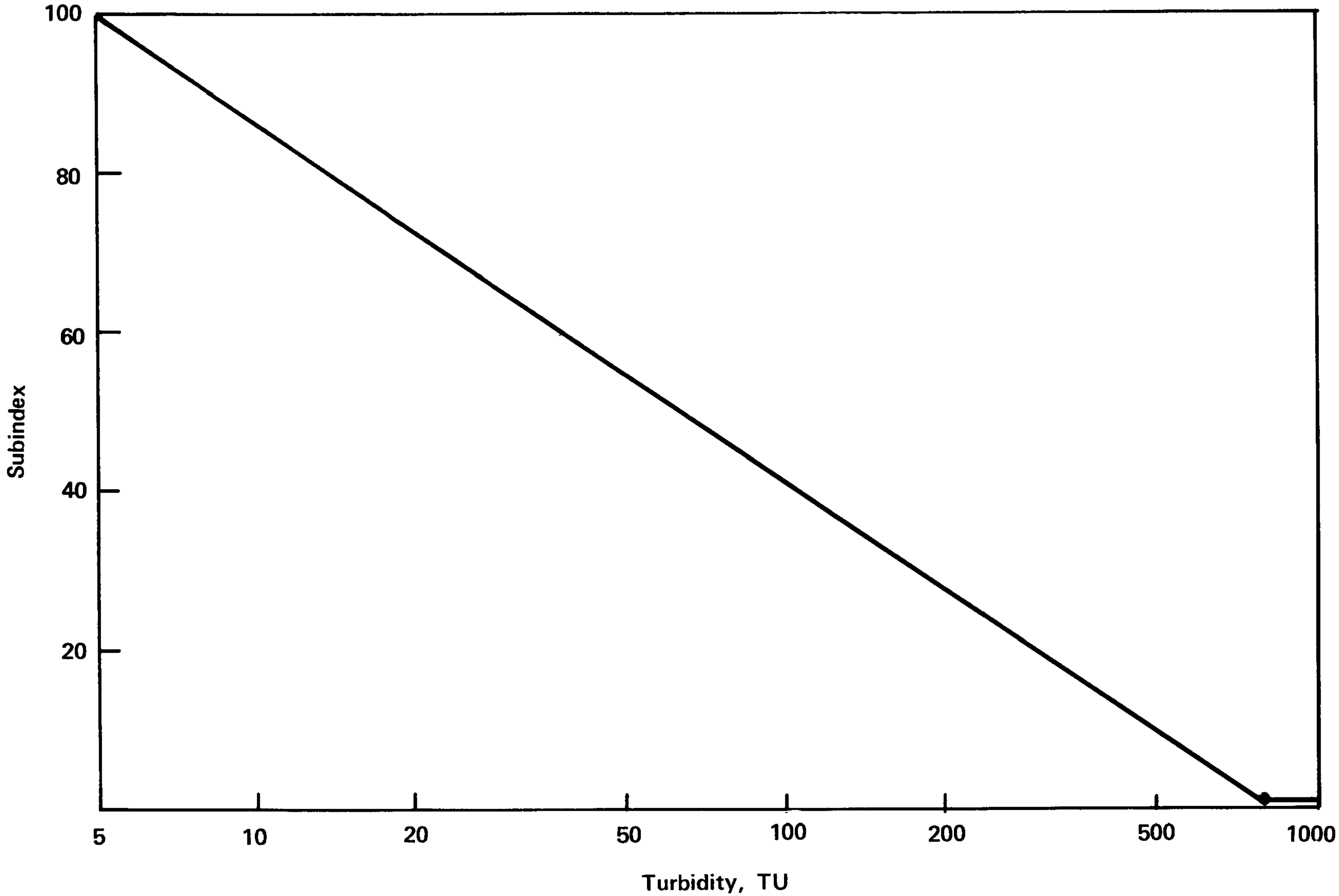

Figure C8. Subindex quality function for turbidity

APPENDIX D

QUALITY RATING CURVES FOR OREGON'S WATER QUALITY INDEX

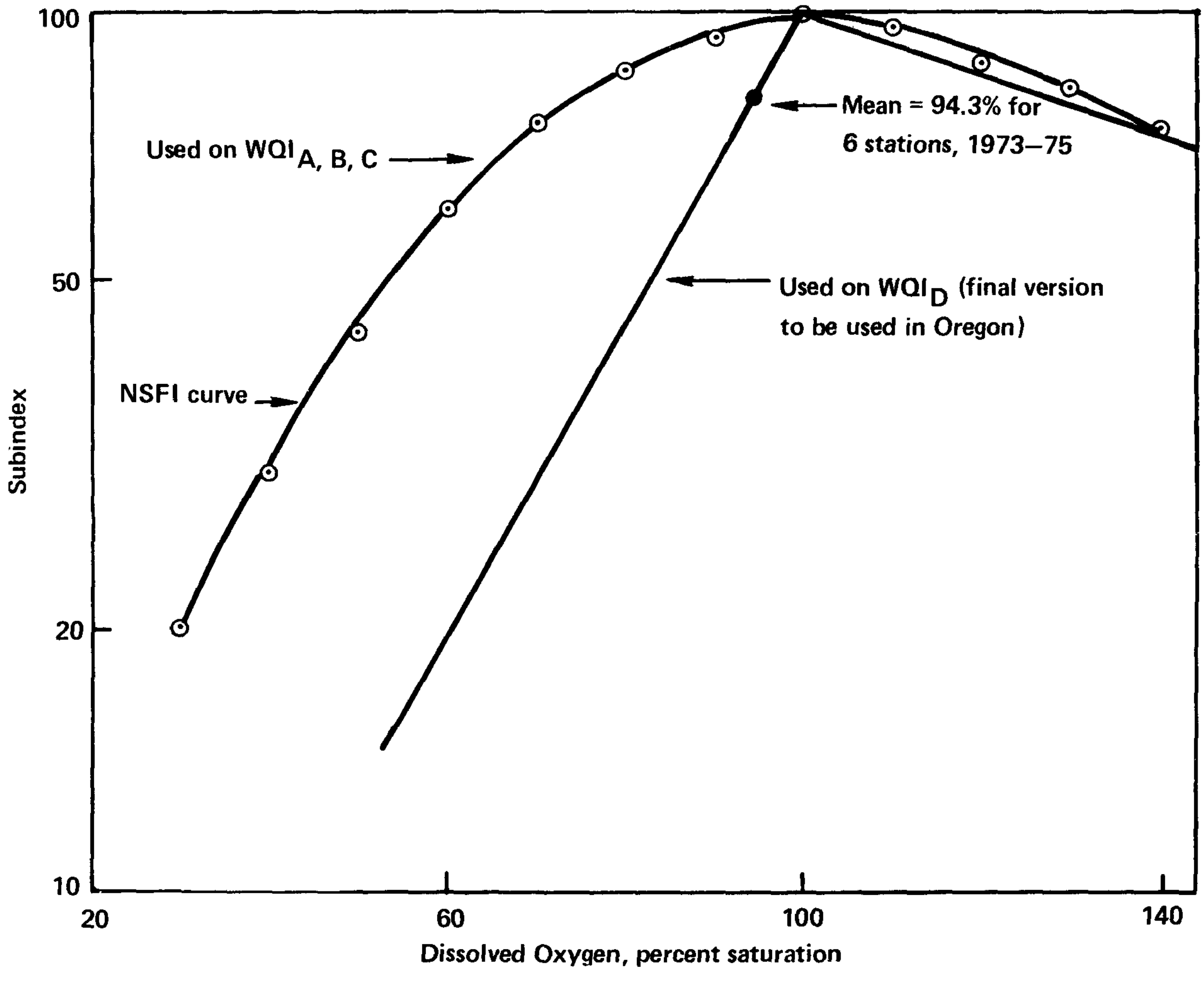

Figure D1. Subindex quality function for dissolved oxygen.

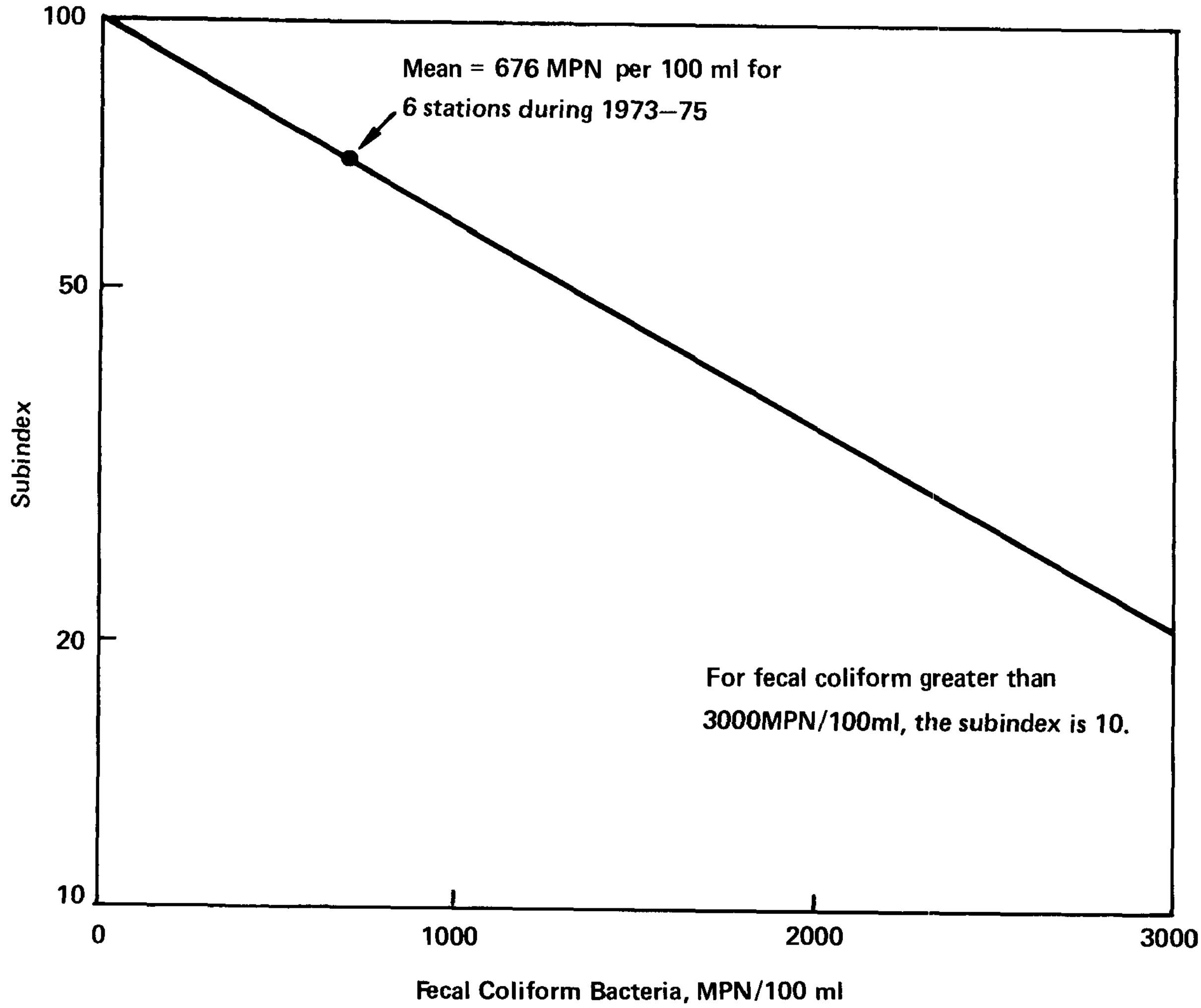

Figure D2. Subindex quality function for fecal coliform.

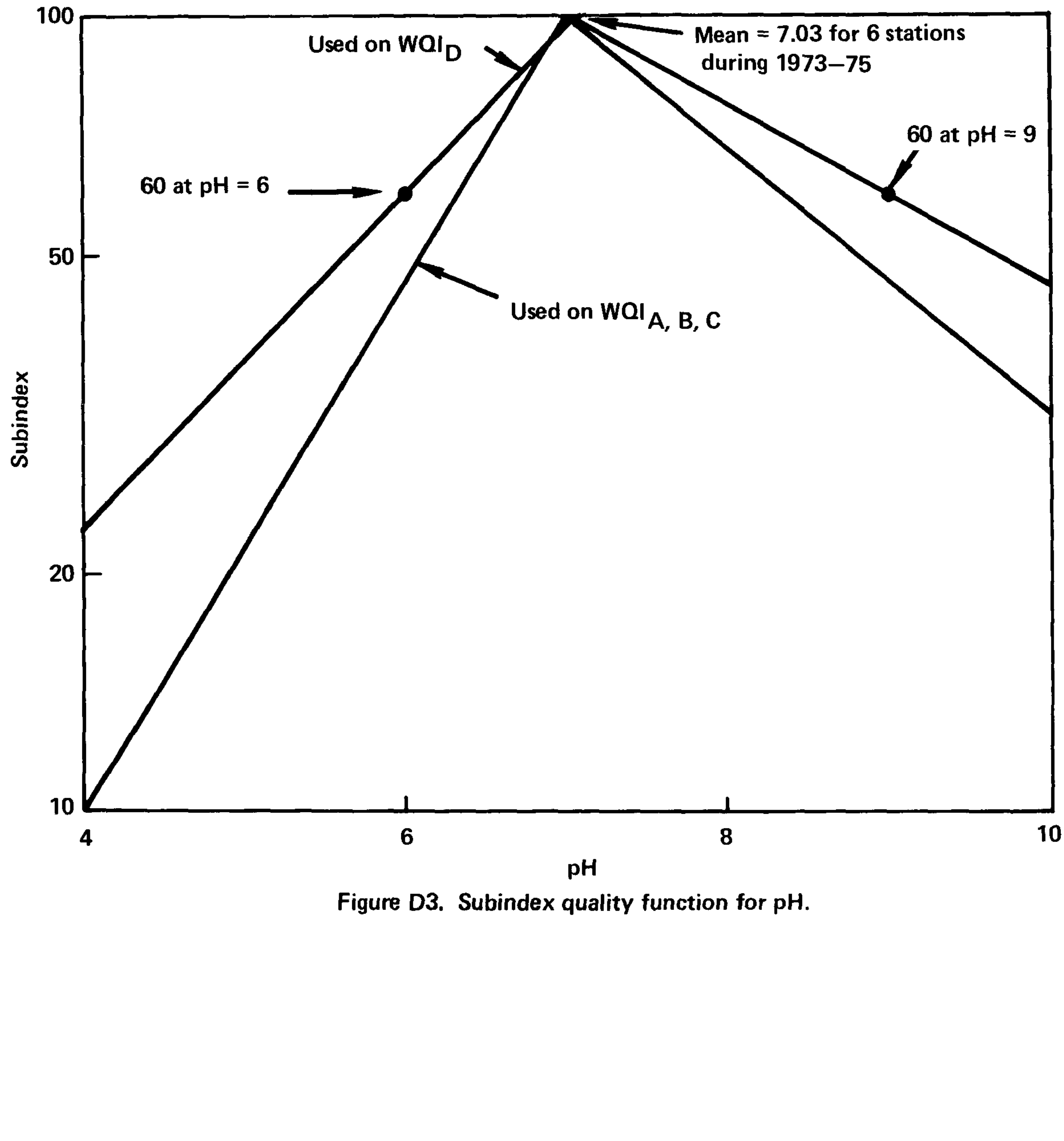

Figure D3. Subindex quality function for pH.

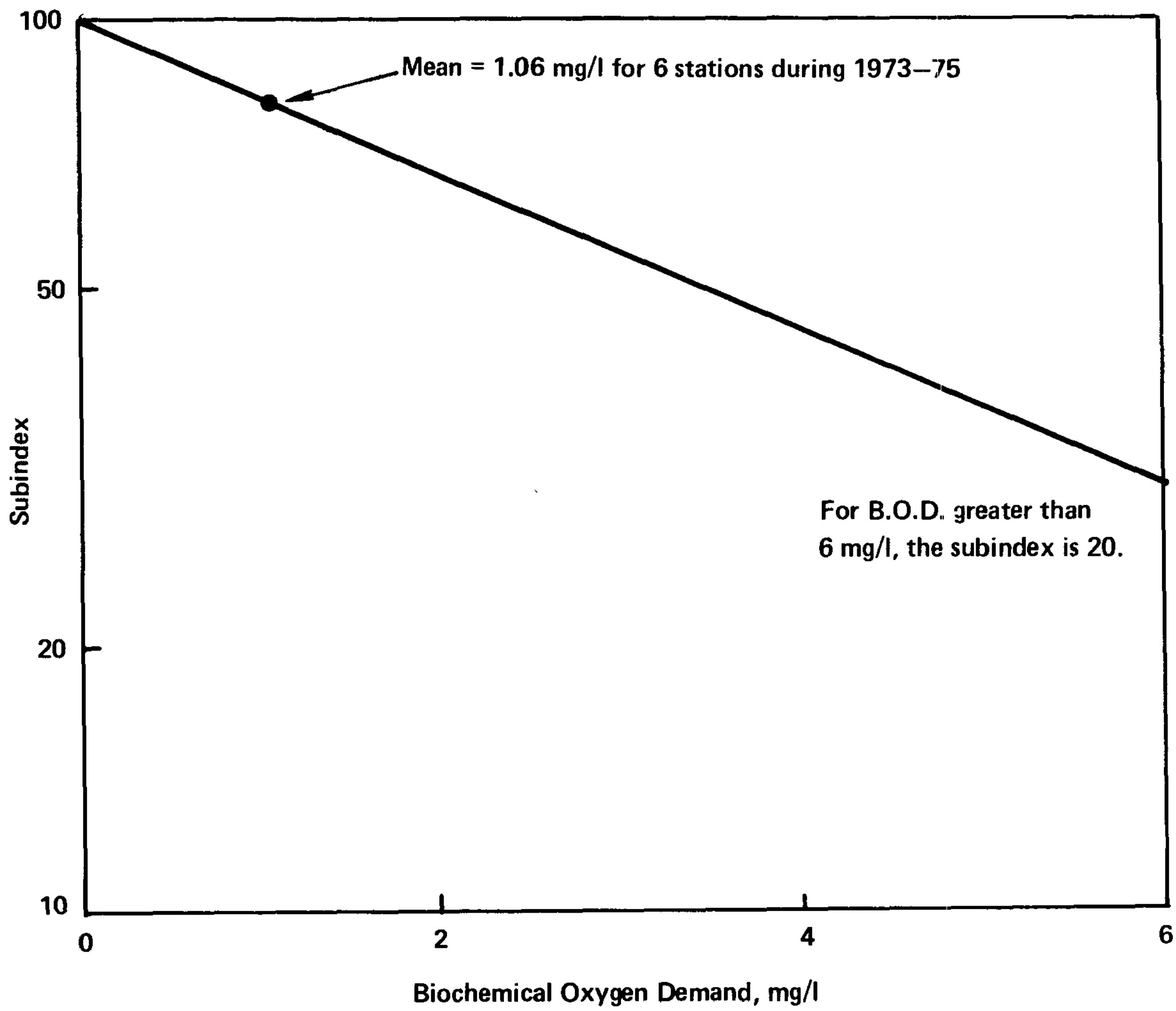

Figure D4. Subindex quality function for B.O.D.

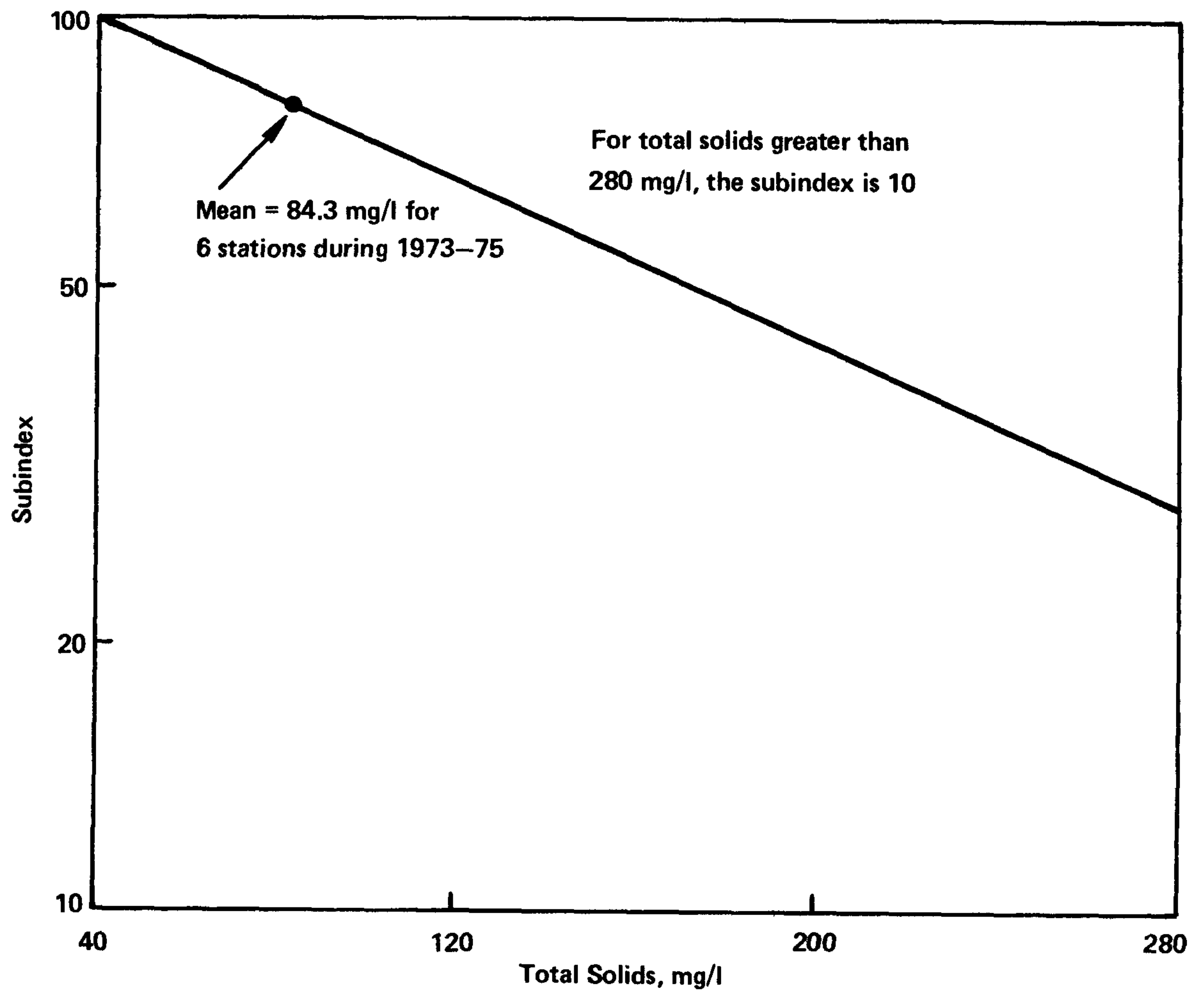

Figure D5. Subindex quality function for total solids.

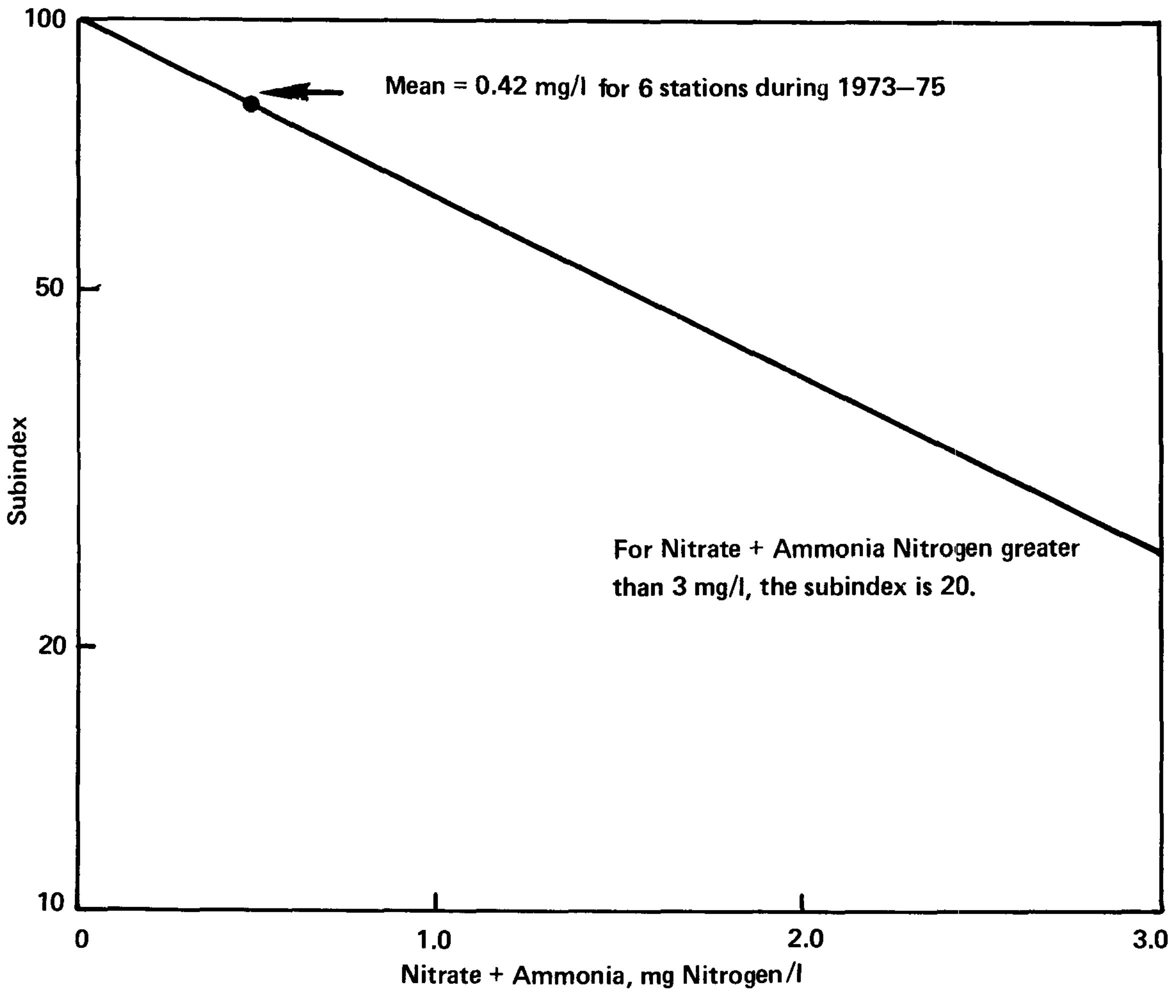

Figure D6. Subindex quality function for nitrate + ammonia.

APPENDIX E

QUALITY RATING CURVES FOR THE REGION X WATER QUALITY INDEX

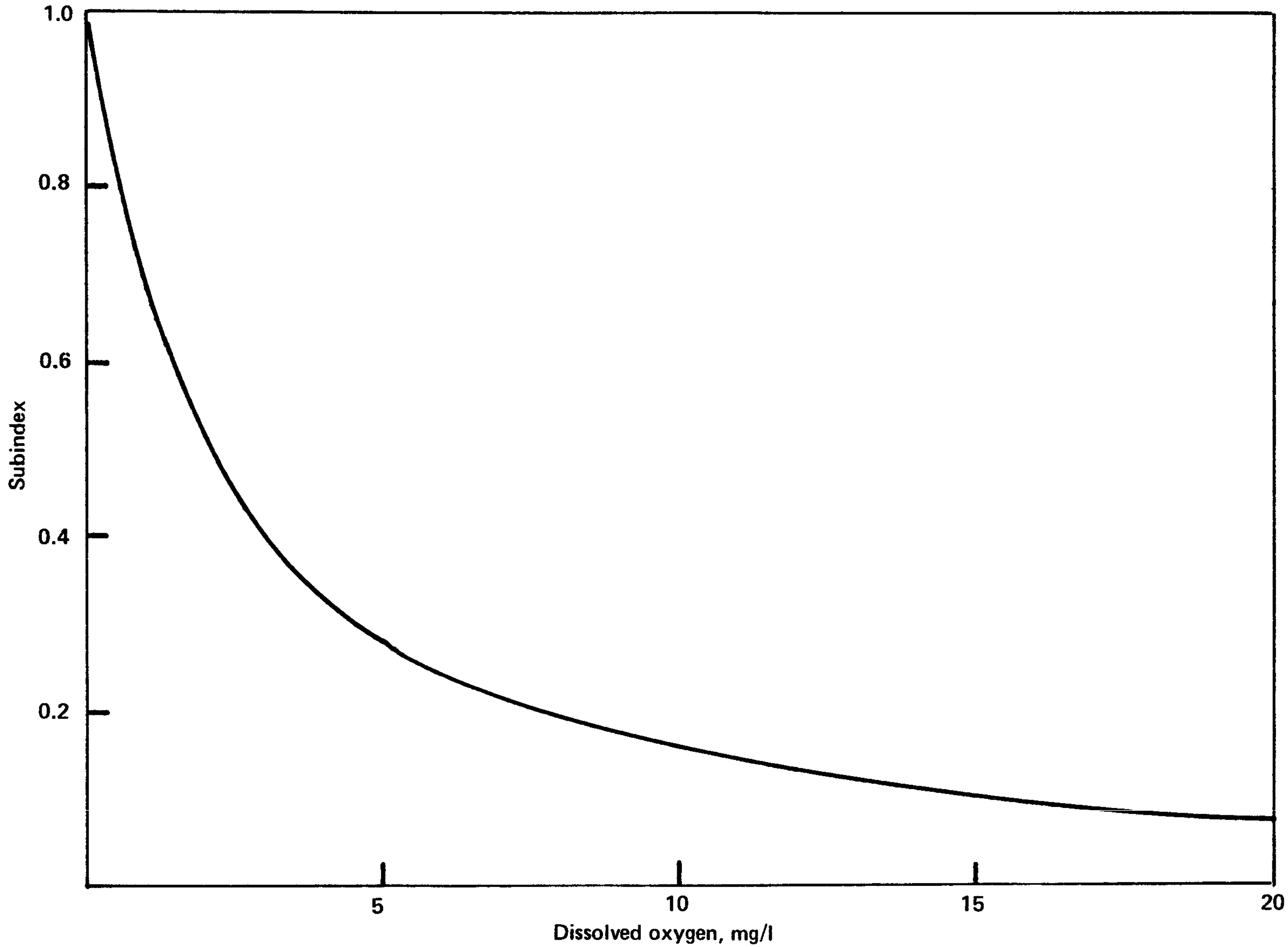

Figure E1. Subindex quality function for dissolved oxygen concentration.

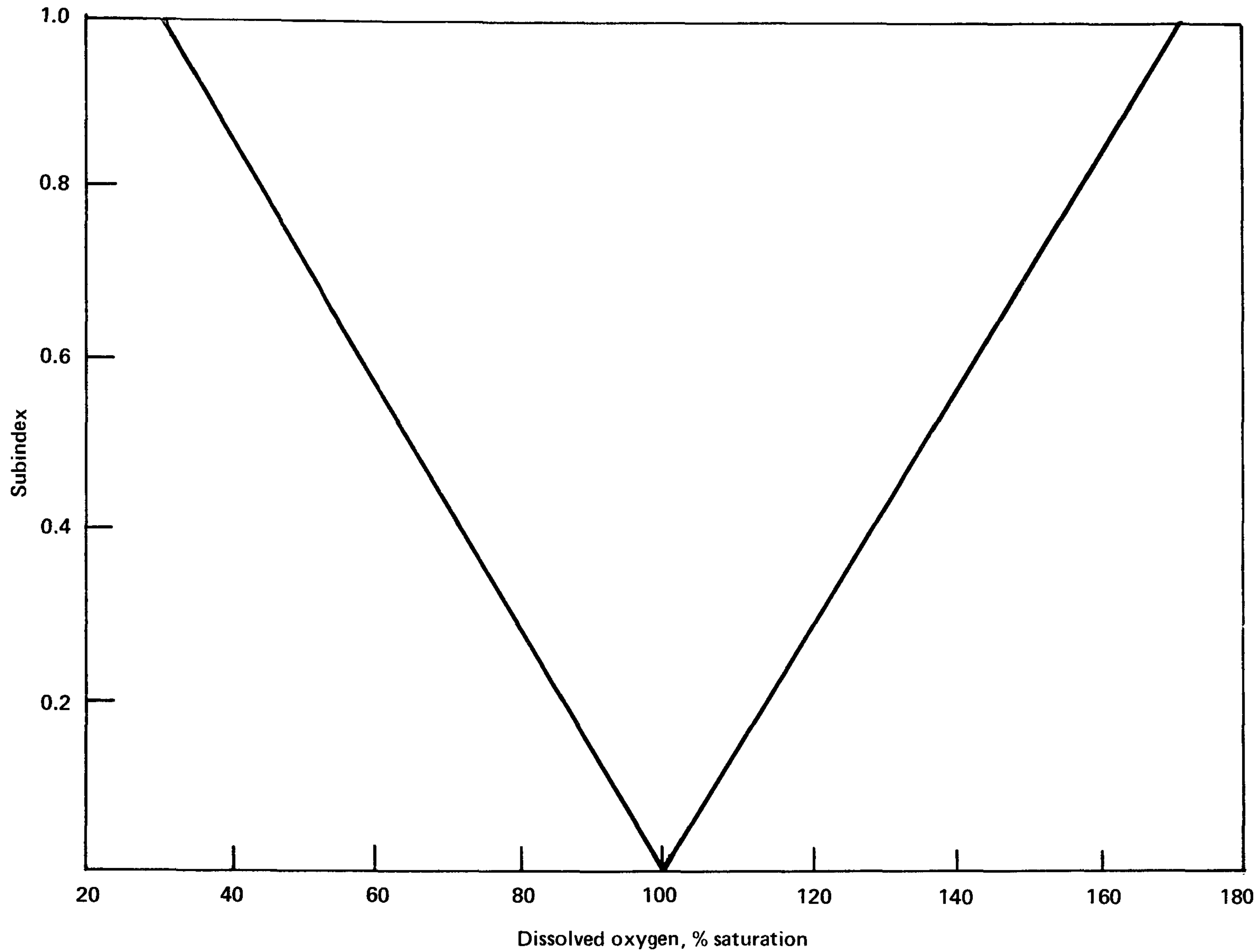

Figure E2. Subindex quality function for dissolved oxygen saturation.

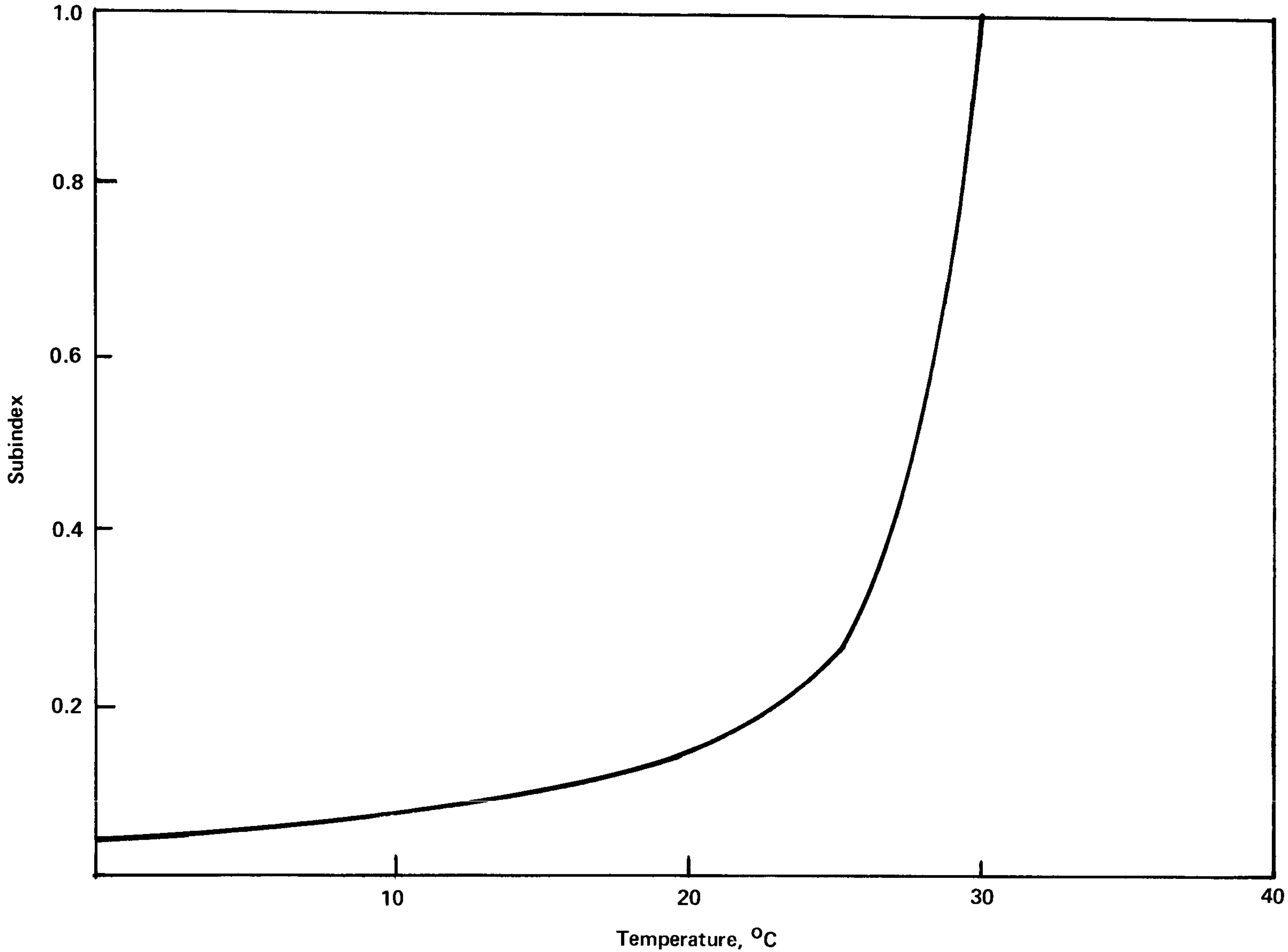

Figure E3. Subindex quality function for temperature.

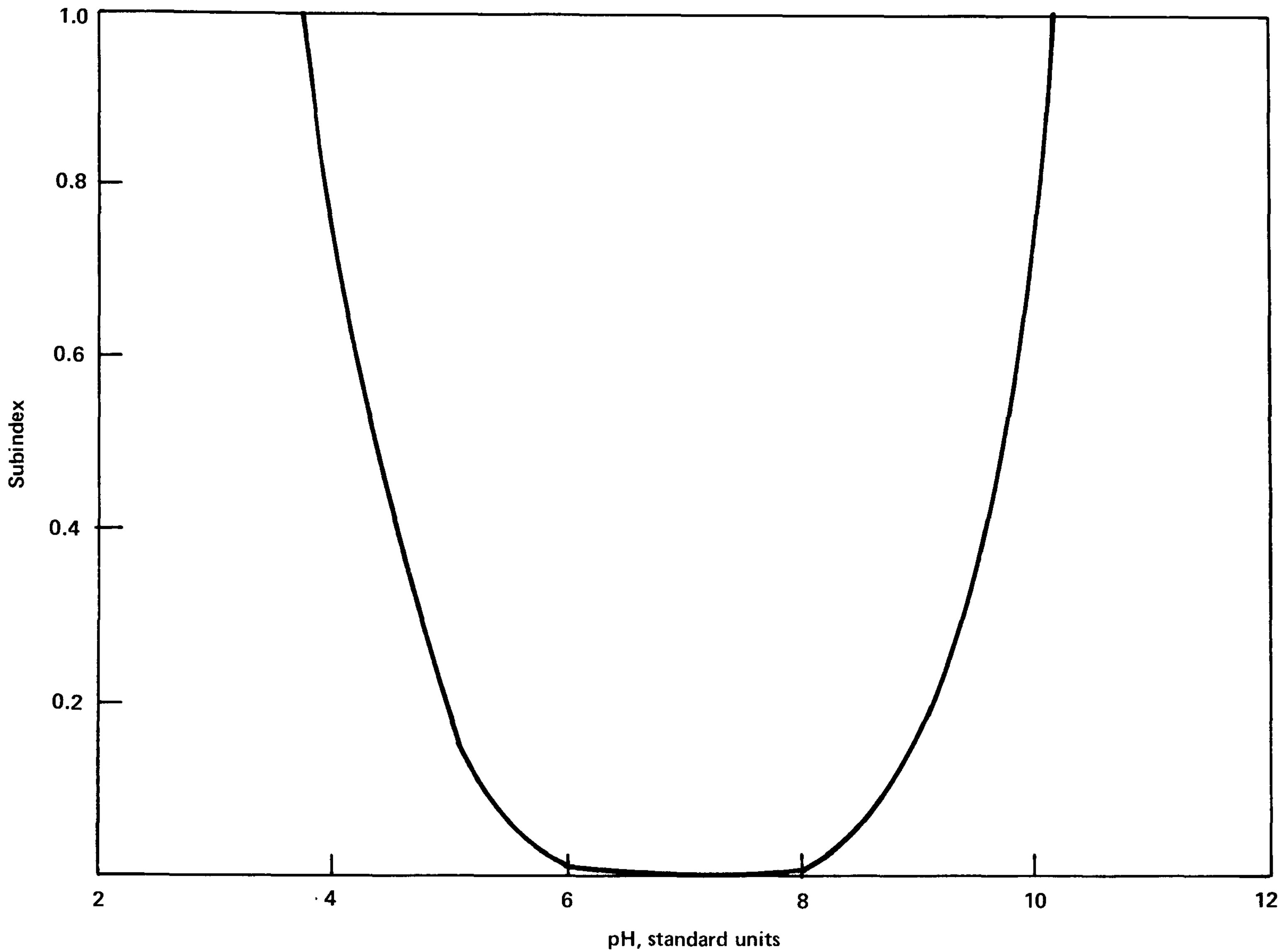

Figure E4. Subindex quality function for pH.

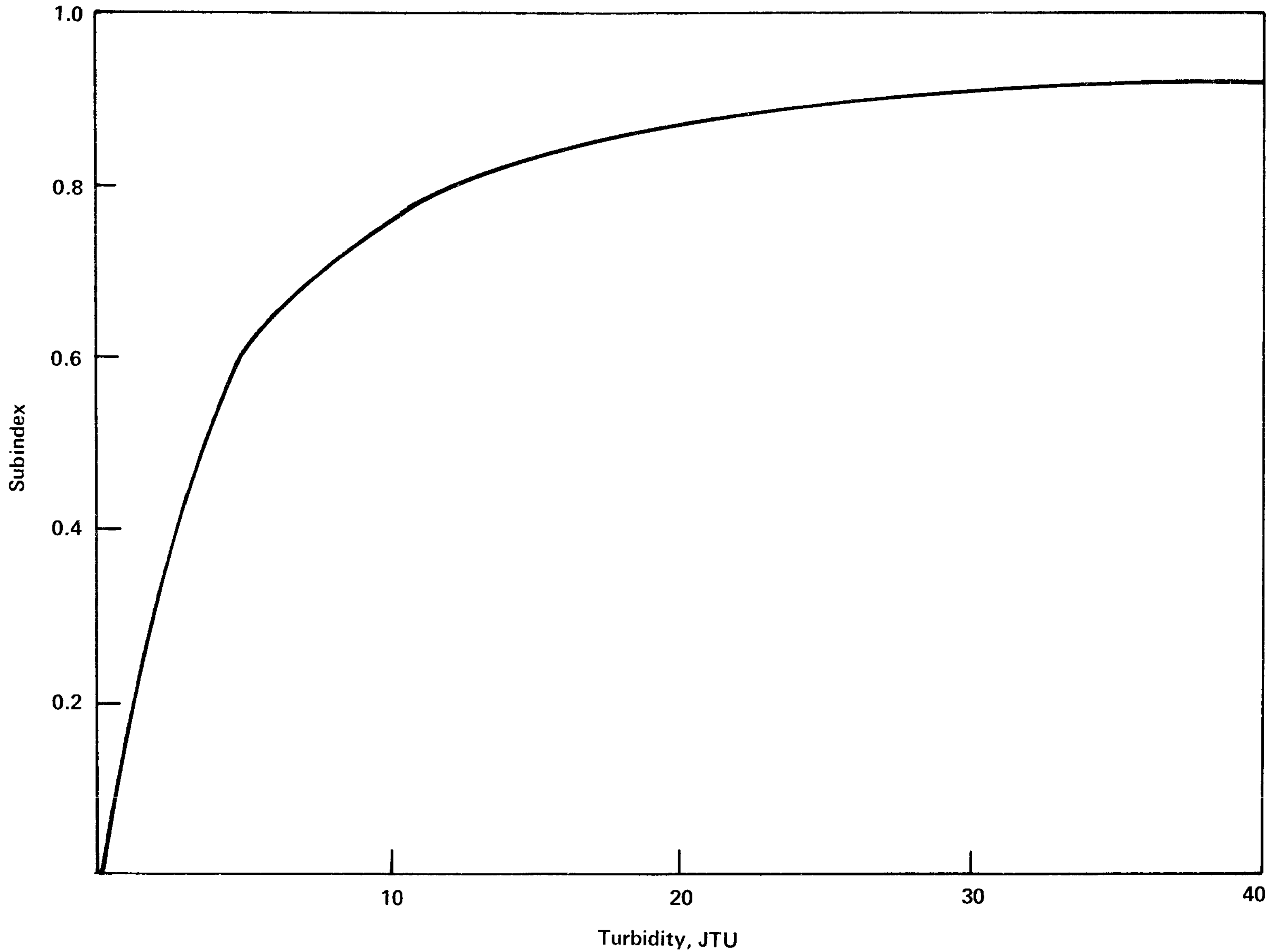

Figure E5. Subindex quality function for turbidity

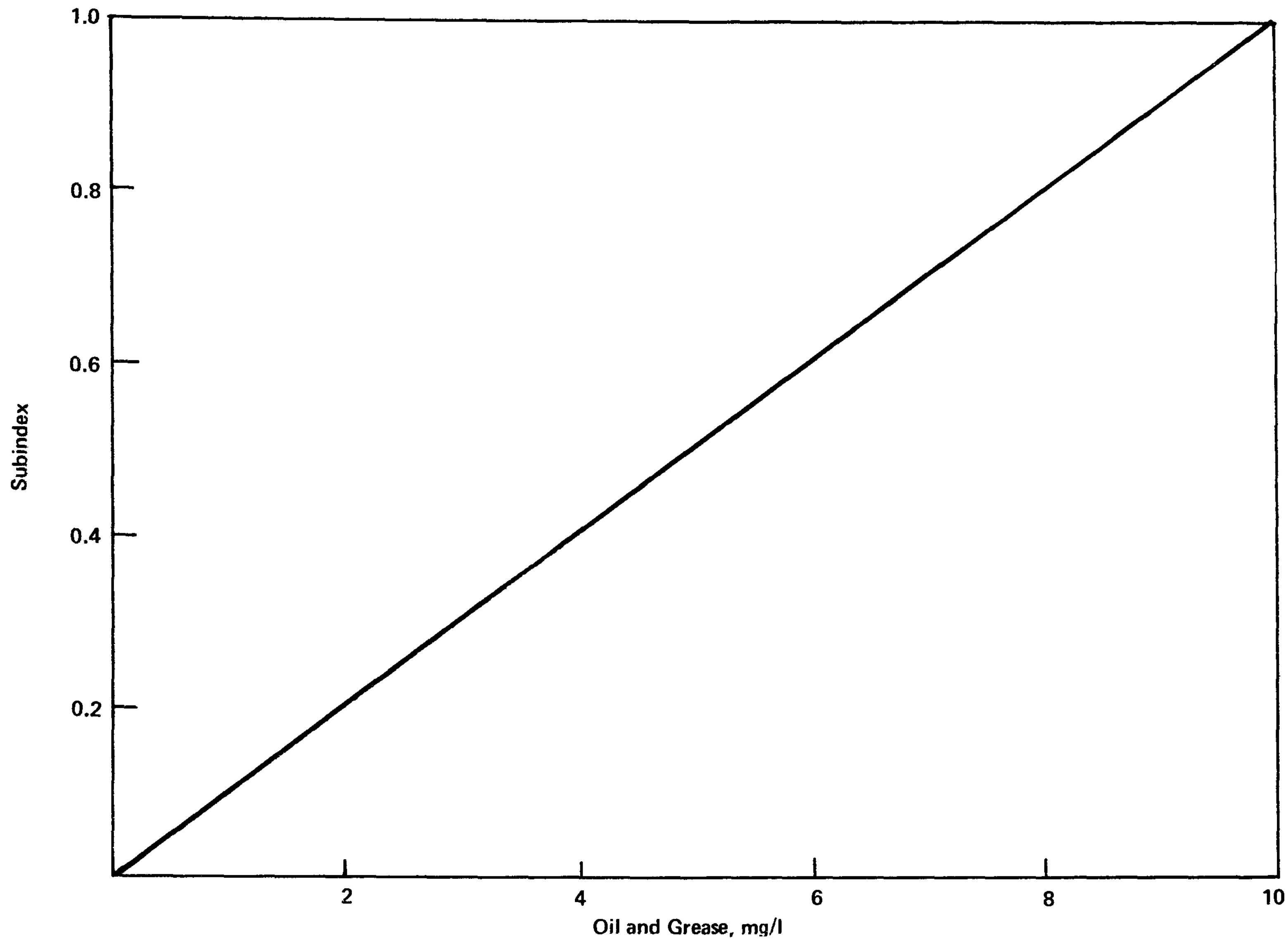

Figure E6. *Subindex quality function for oil and grease.*

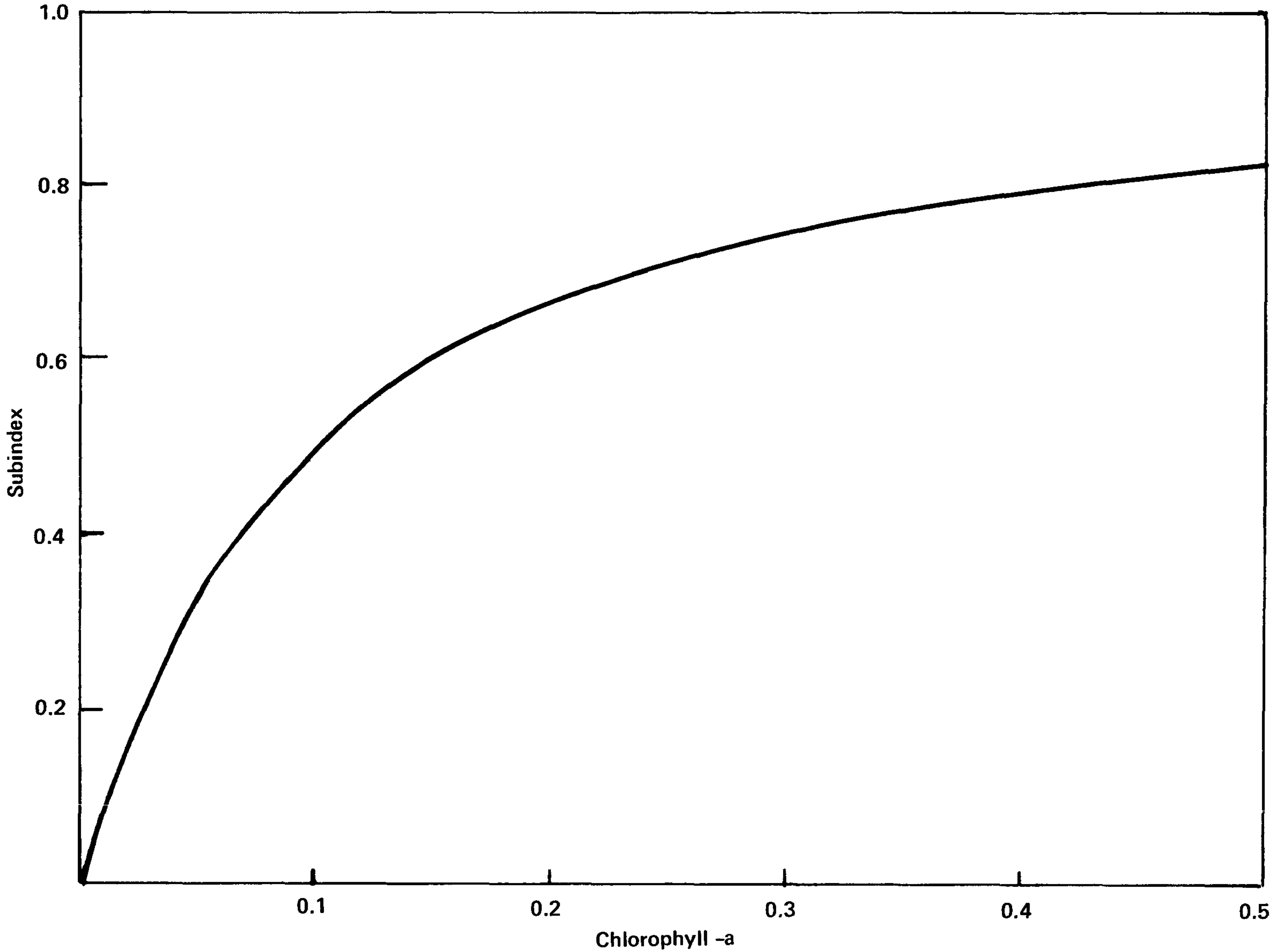

Figure E7. Subindex quality function for chlorophyll -a.

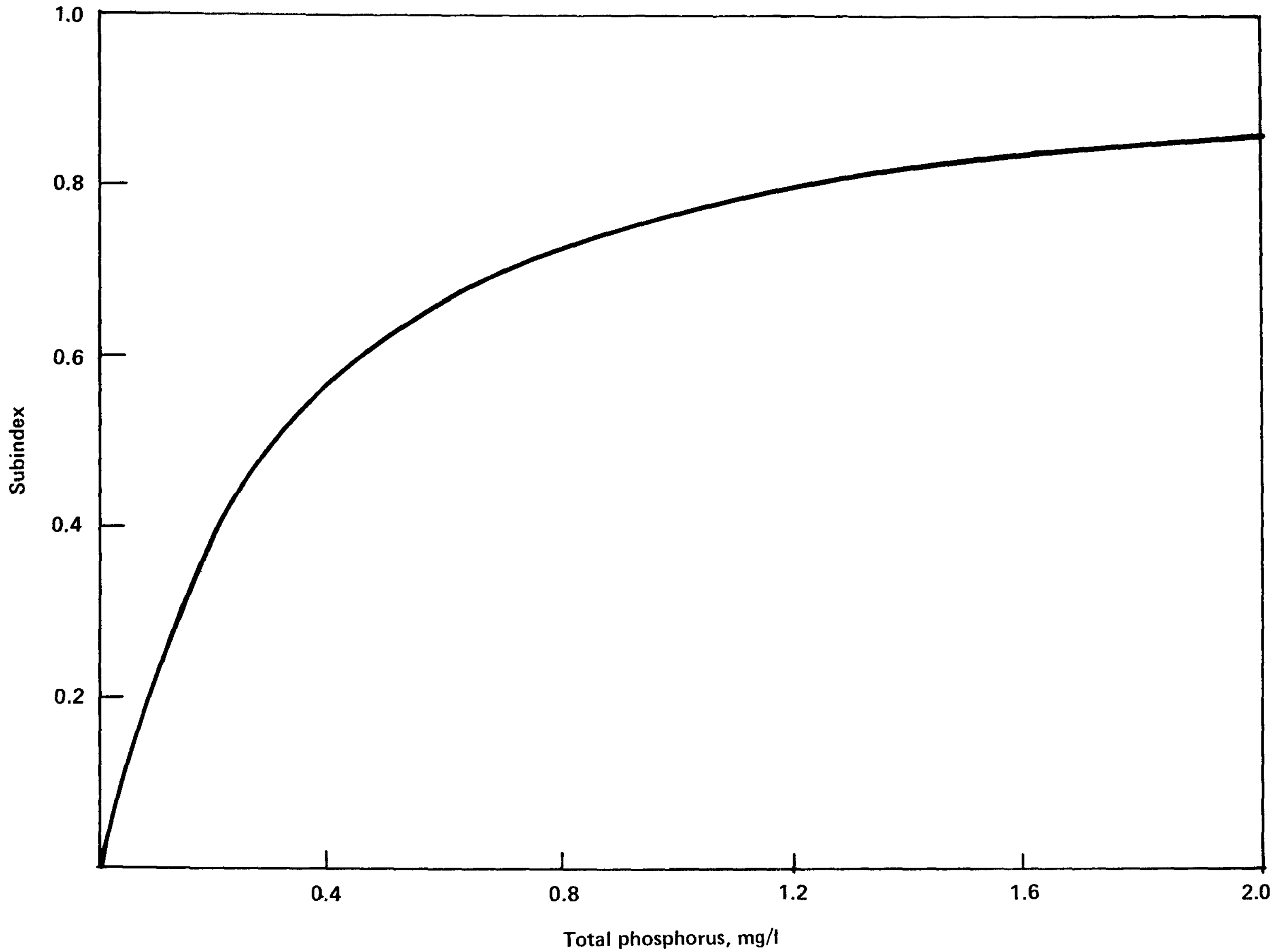

Figure E8. Subindex quality function for total phosphorus.

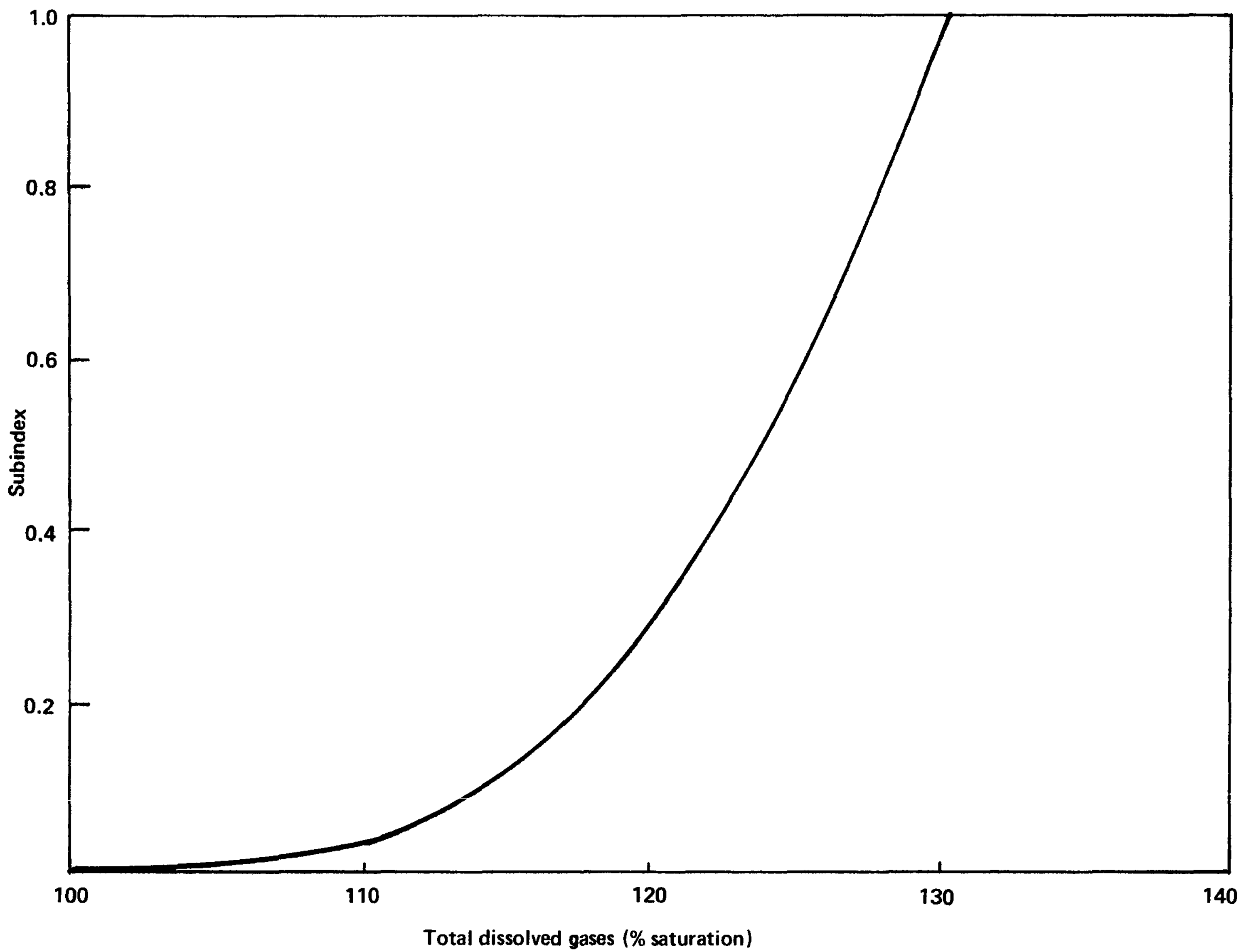

Figure E9. Subindex quality function for total dissolved gases.

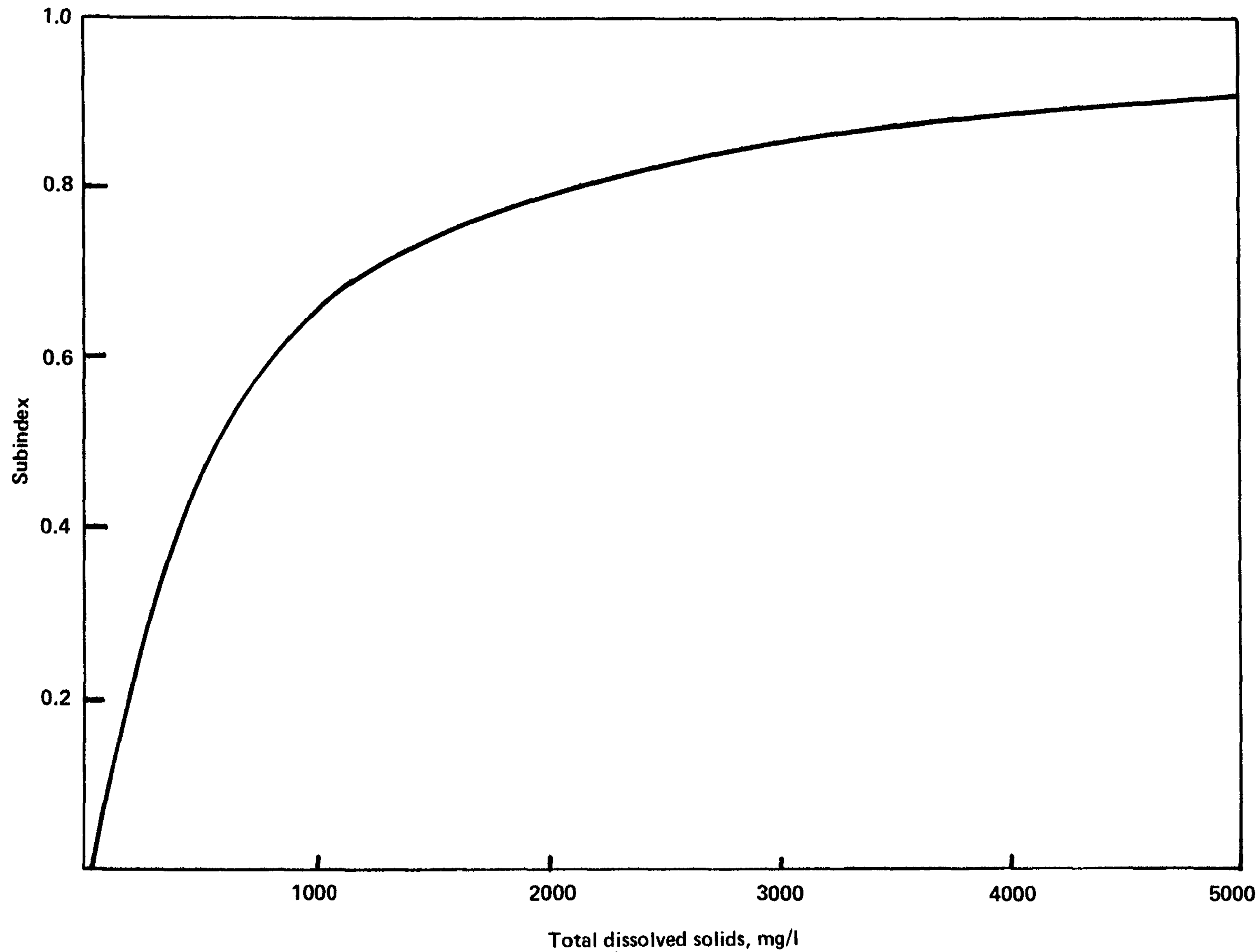

Figure E10. Subindex quality function for total dissolved solids.

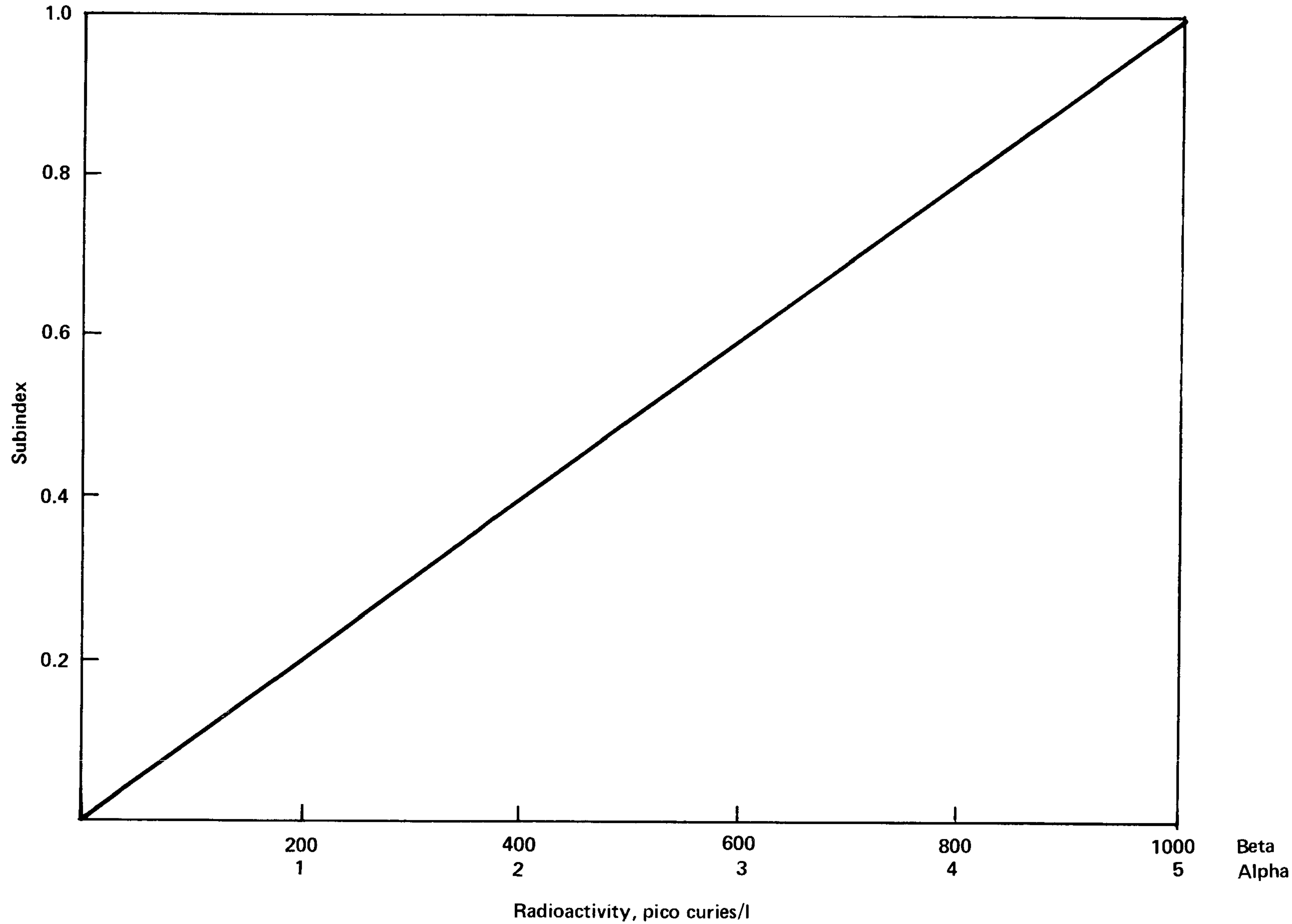

Figure E11. Subindex quality function for radioactivity.

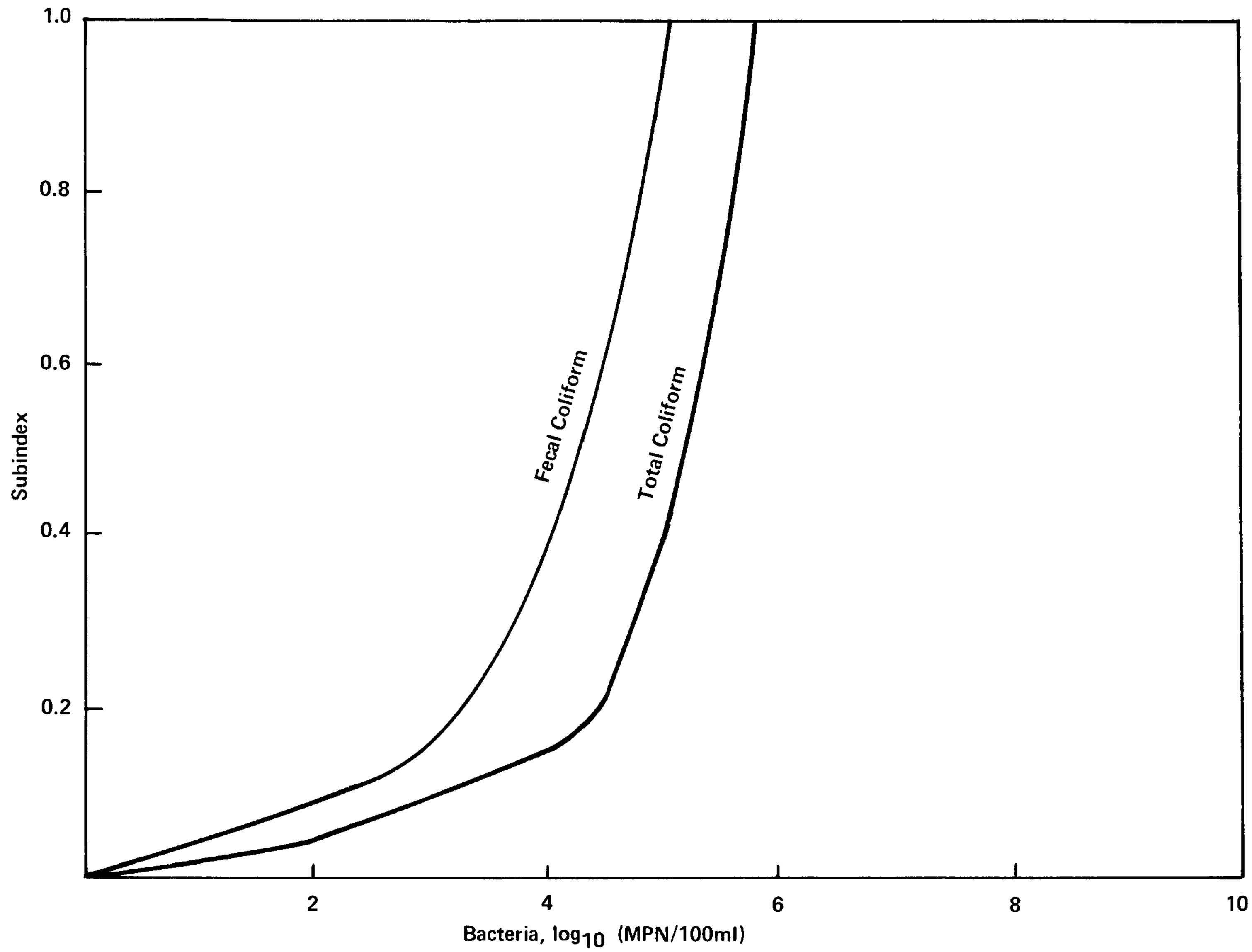

Figure E12. Subindex quality function for bacteria.

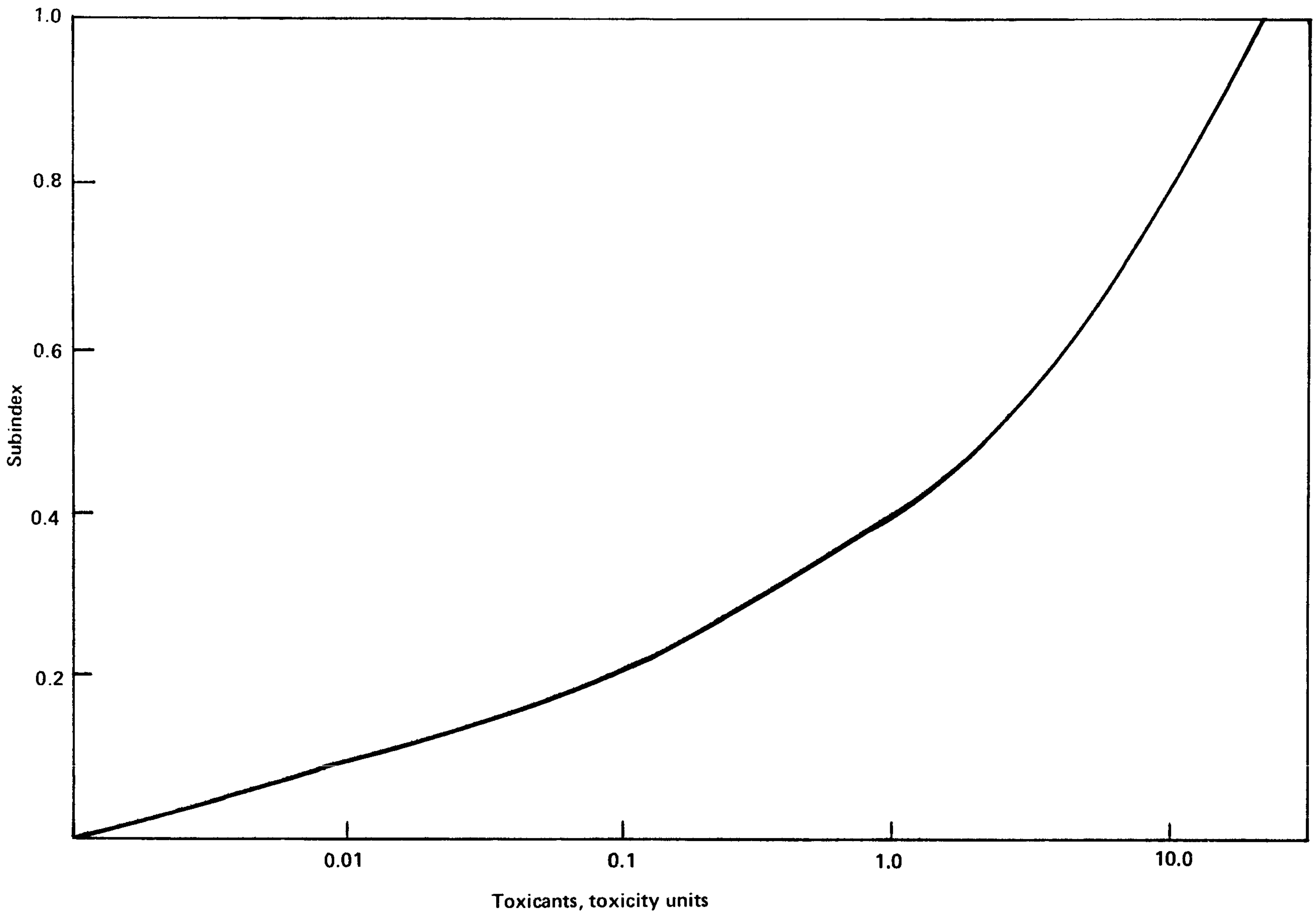

Figure E13. Subindex quality function for organic and inorganic toxicants.

APPENDIX F

WATER QUALITY INDEX DATA SHEET

APPENDIX F

WATER QUALITY INDEX DATA SHEET

Agency Name: ____

Address: ____

____

Telephone: ____

1. Was the agency/office currently using water quality index? ______
(yes: see #2-9)
______
(no: see #10)

IF YES:

2. What was the length of time the index had been used?

_____ less than one year _____ 1 year _____ 2 years _____ over 3 years

other: ____

3. What type of index was used?

_____ NSF _____ Walski

_____ Modified NSF _____ Harkins

_____ PDI _____ Other

Description: ____

____

Variables included: ____

____

4. How many stations were included in the calculation of the index?

____

5. For what specific purposes was the index intended?

_____ Trend Analysis _____ Intensive Surveys _____ 305(b) report

_____ Public Information _____ Other: ____________________

Examples: ____

6. What time interval was covered in the index calculation?

____ less than one year ____ 1 year ____ 2 years ____ 3 years

____ 4 years ____ 5 years ____ Other: ____________________

7. Was a literature write-up or other description of the index available?

____ ____ Material: ____________________
(yes) (no)

8. How were the general success and usefulness of the index rated?

____ Very Unfavorable ____ Unfavorable ____ Favorable

____ Very Favorable ____ Other: ____________________

Comments: ____________________

____

____

9. Were any future studies planned regarding the development, use and/or application of indices?

____

IF NO:

10. What other means were used to display and report water quality data?

____

____

ALL RESPONDENTS:

11. Was the development of a uniform water quality index which might be endorsed by the Federal Government favored? ____ ____
(yes) (no)

If no, why? ____________________

____

____

____

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-78-005	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE WATER QUALITY INDICES: A SURVEY OF INDICES USED IN THE UNITED STATES		5. REPORT DATE January 1978 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Wayne R. Ott		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS SAME AS BELOW		10. PROGRAM ELEMENT NO. 1HD621 11. CONTRACT/GRANT NO. In-house
12. SPONSORING AGENCY NAME AND ADDRESS Office of Monitoring and Technical Support Office of Research and Development U.S. Environmental Protection Agency Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED 10/76 - 6/77 14. SPONSORING AGENCY CODE EPA/600/19

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This study documents the extent to which water quality indices currently are being used in the United States. It reviews the indices published in the literature and surveys the States and interstate commissions to determine: (1) which agencies are using indices, (2) the type of index being used, (3) the purpose of its use, and (4) the attitudes of agency personnel toward indices. One-fifth of the State and interstate agencies (12 out of 60 agencies) were classified as users of water quality indices. Of the 51 State agencies (including the District of Columbia), 10 States (20 percent) were classified as index users. The National Sanitation Foundation Index was the most commonly used index, accounting for 7 of the 12 index users. The remaining agencies use Harkins' index or various user-developed indices. A total of 16 additional States and 1 interstate commission indicated that they are planning to evaluate indices for possible future application, or are developing or evaluating indices at the present time; these were classified as "potential users." Six new indices have been developed by water pollution control agencies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Mathematical, Computerized simulation, Statistical, Pollution, Environmental engineering, Civil engineering	Mathematical models, Systems analysis, Data analysis, Sanitary engineering, Environmental indices, Water quality indices, Statistical analysis, Environmental decision making.	57 H 43 F 43 Ø 68 D 72 F 91 A

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