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WATER QUALITY INDEXES FOR USE IN NEW ZEALAND'S RIVERS AND STREAMS

David G. Smith

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by

David G Smith

Water Quality Centre

Ministry of Works and Development

Hamilton

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ABSTRACT

The derivation of four suitability-for-use water quality indexes is described. They are for General, Regular Public Bathing, Water Supply and Fish Spawning (salmonid) water uses. This report presents the sub-index graphs (i.e. graphs relating sub-index scores with determinand concentration) required for index calculation. The method of aggregation of sub-index scores obtained from the graphs employs the method of the Minimum Operator. This is a robust, sensible, and flexible aggregation method and uses the lowest sub-index scores as the final Index score. Comments on the use of the indexes is furnished plus the brief rules for index calculation.

The strategy employed for the development of the indexes is also described. It is based on that used by the United States National Sanitation Foundation and uses Delphi iteration, although this strategy was not strictly adhered to. The selection of determinands for use in these indexes is based on standards for the proposed revision of New Zealand's water and soil legislation. At this stage the indexes are seen as interim only and require testing by water management agencies prior to final recommendation for use.

PREFACE

The aim of this study was to derive a water quality index (or set of indexes) for use in New Zealand.

Prior to the development of these indexes, water managers were consulted to ascertain:

1 whether indexes are being (or have been) used in New Zealand,

2 the need to develop indexes and their perceived purpose,

3 the type of index which might be used (e.g., for general or specific water uses).

The answers to these questions were obtained by sending a questionnaire to two staff members in each of the 20 regional water boards - one staff member was the Chief Executive, the other was a named water resources officer. By this means it was hoped to assess the views of senior management as well as staff dealing with the day-to-day issues of water quality management.

To ensure that the prospective questionnaire respondents were aware of topics such as what water quality indexes are, how they can be used, their advantages/disadvantages, how they can be developed, additional detail was supplied in an accompanying letter.

There was a response from 15 boards, all but one of which said they would use an index if an appropriate one were available. Only four boards had actually used one. Several reasons were given for not having used an index, one being the non-availability of one appropriate to the board's needs.

The primary role of indexes was seen as presenting information to non-scientists in a simple form for purposes such as inter-site comparisons and trend assessments. The indexes required were management not scientific tools, that is, they should assist managers disseminate the essential elements of complex water quality information to people whose understanding of the complexities of water quality data is likely to be limited.

Boards favoured the development of several dominant water-use indexes, but a sizeable minority suggested that a 'general' water-use index also has merits. Because of this, a decision was made to produce water quality indexes for various uses of rivers and streams, i.e., they should be suitability-for-use indexes. It was decided to develop indexes initially for running, fresh water largely because overseas indexes have been developed almost solely for such waters and so a basis for comparison was possible.

At this time (mid-1985), the Water and Soil Conservation Act (1967) was in the throes of Departmental review and, for freshwater, five water classes had been suggested for water classification purposes. Standards (numerical and descriptive) for these classes had already been recommended and published by the Water Quality Criteria Working Party (WQCWP, 1981). The classes are for multiple uses of water but in some instances certain uses are seen as dominant. All but one of these classes, i.e., class S (outstanding special purpose waters), appeared amenable to the development of a water quality index and it seemed that if indexes could be developed which were linked to the proposed legislation, then their use would be more relevant to management and they would be more likely to gain national acceptance.

The four water classes chosen were:

General (G)

Regular Public Bathing (R)

Water Supply (W)

Fish Spawning (F).

In the case of class F, for simplicity, salmonids only were to be considered because:

(a) there is more information available about their requirements,

(b) if an index for salmonid spawning waters (i.e., a high degree of protection required) were developed, it could probably be used for the spawning waters of many other fish.

A description of the perceived water uses for each of the classes is given in Appendix 1. This information was derived from WQCWP (1981).

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INTRODUCTION

What is a Water Quality Index (WQI)?

In the field of water management, scientists, engineers and lay people can be faced with a bewildering array of data. To the lay person this will often be completely overwhelming. In an attempt to simplify the data, recourse has been made overseas to produce just one, or perhaps a few numbers (indexes) which have been designed to integrate the data pool in some way. Most of the indexes derived to date are intended to be "general" water quality indexes, pollution indexes, or both. The index values may range from 0-100 and descriptors may accompany them, for example scores of zero and 100 may be referred to as "very bad" and "excellent" water respectively (Ott, 1978). The meanings of such descriptors are often not clear however. A WQI then is a simplification of an array of data and here the data we are referring to are physico-chemical.

WQIs can be produced by an array of techniques. In all cases the starting point is a set of water quality data which has been produced for a selected number of determinands (characteristics). The value for each determinand is used to obtain a rating score (sub-index value). Sub-index values may be ascribed a weighting which depends on the perceived importance of each determinand. Aggregation methods and use of indexes have been described by several authors (e.g. Ott, 1978; Couillard and Lefebvre, 1985).

How Can WQIs be Used and Who Uses Them?

Ott (1978) reviewed the literature and found that environmental indexes have been developed or proposed for each of the following roles;

1 Resource allocation - allocating funds and determining priorities.

2 Ranking of locations - comparing different locations/areas for suitability for certain uses (e.g. bathing beaches).

3 Envorcement of standards - specific location checking (this appears to have been confined to air pollution).

4 Trend analysis - has degradation/improvement occurred.

5 Public information - simple informative statements to the public.

6 Scientific research - data reduction.

In each of the above roles, a simple method of expressing information is attempted.

One of the major reasons for the use of WQIs is to convey information about the physico-chemical state of natural waters to the general public, politicians and administrators, i.e. #5 above. This and #2 and #4 above are seen by regional water board staff as the prime roles for WQIs in New Zealand.

WQIs are a relatively recent development in water quality management and have not received universal acclaim despite about two dozen variants being published in the literature. One of the main reasons they have not gained universal acclamation is that the role of the index does not seem to have been adequately thought through. This work attempts to redress this situation.

Brief description of the WQIs derived in this study

This publication summarises a year-long study at the Water Quality Centre and presents four suitability-for-use(s) WQIs wich to a large extent are based on proposed legislation.

In the derivation of these WQIs their role has been borne in mind throughout. That is, they are to be a simple means of conveying complex information to the lay person concerning a water's suitability for its defined use(s). They are also to be usable for site comparison and trend assessment.

Many aspects of each of the four WQIs derived are based on proposed new freshwater classes for New Zealand. These water classes have been derived for separately identifiable water uses, some of which are multiple uses (Appendix 1). Although the WQIs are based on proposed water classification, it is not necessary for waters to be classified under the proposed legislation to use the WQIs. But the use(s) of a water should be the same as those for which proposed classification standards (and hence the WQIs) have been derived. Hence current water legislation (Water and Soil Conservation Act 1967) and classification need not conflict with the WQIs, and the WQIs do not depend on proposed legislation actually becoming law.

Critical to the worth of any water quality index are appropriate determinand selection, rating curve construction, and aggregation technique. Each has been carefully addressed in this study.

For each index, a set of determinands has been produced based on the standards included in the appropriate proposed water class. Toxic substances have been deliberately excluded (see later).

Rating curves for each determinand have been drawn for an expected range of determinand values and an assessment of suitability for use(s) on a 0-100 scale (sub-index scale) where zero and 100 represent a water totally unsuited and the most suitable for the prescribed uses respectively. Values of determinands which are identical to proposed numercial standards have been assigned an arbitrary sub-index value of 60, below which a water is considered unsuitable for the desired use(s). Rating curves were forced through this point.

The most popular aggregation methods are those in which sub-index scores are combined additively or multiplicatively. One aggregation technique which has received little attention is called the Minimum Operator in which the lowest sub-index score is used as the final index value. This aggregation method was intended to be used in this study as an adjunct to the method originally selected (weighted multiplicative). However as the project progressed it became clear that the weighted mutiplicative technique contained too many inherent weaknesses to enable it to be used for a suitability-for-use type of index. Instead the Minimum Operator alone was selected. The reasons for, and benefits of, this selection and the limitations of other aggregation techniques are described more fully later.

It is the definition of a water's required use, coupled with proposed new legislative requirements (in draft form at the time of carrying out the study) and the use of the Minimum Operator which distinguish these indexes from those published in the literature.

Complete details of the study can be found elsewhere (Smith 1987a, b and c).

INDEX DEVELOPMENT

It was decided that, based on a review of the literature, the approach taken would be that of the United States National Sanitation Foundation (NSF) (Brown et al., 1970). This involved the setting up of a 'panel of experts' to obtain a group response and, using the Delphi Method (see, for instance, Linstone and Turoff, 1975), canvassing their opinions during each stage of index development. The Delphi Method involves the use of a series of questionnaires to arrive at the group response by iteration. An important feature of the Method is that at each stage subsequent to the first, panel members are sent the pooled group response for the preceeding stage and the individuals asked to reassess their previous response. This is in an attempt to obtain a higher degree of convergence of opinion. Anonymity between the panel members is preserved and questionnaires mailed.

A list of potential panel members was drawn up based, in part, on the responses to the questionnaire sent to regional water boards (referred to in the Preface). The prospective panel consisted of just 18 people (cf. NSF panel of 142).

It was seen as essential that prospective panel members were also informed at an early stage how the four water-use indexes which were envisaged were to be developed and that they were linked to the proposed water classes G, R, W and F. With the exception of one panel member, who was used to provide an initial assessment of the merits/problems of each questionnaire prior to mailing, there was usually no communication between the panel members and project co-ordinator other than sending out and returning of the questionnaires. Occasionally a panel member would phone the co-ordinator to seek a clarification. This was encouraged because it was deemed more important that questions were approached appropriately rather than the normal Delphi technique of silence being rigorously followed (with possible subsequent misinterpretations).

There were five questionnaires in all. They will be briefly described. Further details on the questionnaires and the results obtained are available in Smith (1987a and b).

Questionnaire No. 1

The purpose of this questionnaire was to obtain an indication of which water quality characteristics should be included in each of the four separate water-use indexes, and an idea of the importance of each selected characteristic. A selection of characteristics was sent and each panel member requested to indicate which should be included in each index and which should not; there was also scope for indecision. The importance of 'include' characteristics was sought on a 1-5 scale (where 1 is high). Panel members were also given scope to include other characteristics considered important by them but not included in the list. There was no restriction on the number of characteristics which could be selected.

An example of the questionnaire (for the General Index - Questionnaire No. 1a) is given in Appendix 2. The questionnaire for the other three indexes was identical. To assist panel members in their deliberations, a copy of the then current (June 1985) proposed water classification Schedule to the Ministry of Works and Development's draft Water and Soil Bill was also sent. This Schedule was superseded a year later and so is not presented here (the main change was replacement of numeric by descriptive standards for BOD_5). In the accompanying letter it was noted that characteristics for which numerical values were extremely difficult or impossible to assign (e.g. odour) were not included in the questionnaire. Also sent was additional information on the Schedule which expanded upon the water uses for each class (i.e., index) (Appendix 1).

Sixteen replies were obtained, a very good response. Not all respondents felt sufficiently competent to fill in all four parts of the questionnaire, and not all those responding with an 'include' gave an importance rating.

The responses contained considerable variability both in terms of characteristics selected for inclusion and, of these their relative importance. Of the original list of 33 characteristics few were not selected by someone.

The characteristics for which numerical standards are presented in the Schedule to the 1985 draft Bill, i.e., dissolved oxygen, pH, BOD, temperature, faecal coliforms, ammonia all feature highly in the recommendations for inclusion.

This is probably not surprising in view of their importance for a variety of water uses.

A summary of responses for the four questionnaires is presented elsewhere (Smith, 1987a). These responses formed part of the second questionnaire.

Questionnaire No. 2

This questionnaire consisted of 2 main parts plus a supplementary section to try to resolve some outstanding questions; this supplementary section was the first major departure from the NSF format and its necessity showed the weakness of the original format. It is incumbent on the co-ordinator of a Delphi iteration to respond to panel members' suggestions and queries and therefore flexibility during the project is considered essential. At the outset, a general direction is highly desirable but the co-ordinator must be prepared to change the approach as, and when, necessary.

The first main part of the questionnaire consisted of, for each index and for each panel member, a return of his response to the first questionnaire alongside of which was presented the summary of all responses. The format of this part is given in Appendix 3a (the example being that for the General index). Panel members were asked to compare their original responses with that of the group and alter their responses if desired. A reminder was issued that we are concerned here with the water per se (and not other attributes e.g., slimes on rocks).

The second part listed the characteristics in order of 'include' requests with their mean importance rating. Also given here was a list of characteristics added by the panel members but on no occasion was a particular characteristic added by more than one member. Panel members were asked to select up to 10 characteristics which they considered the most important this being considered the maximum which conventional aggregation techniques could satisfactorily cope with. The format for this part is given in Appendix 3b (the example being that for the General index).

There was also a supplementary questionnaire which addressed some panel members' desires to include aspects of perception e.g. colour, oil/grease, odour. The supplementary questionnaire (Appendix 4) addressed this, and other, issues and sought to assess:

1 the need for perception (i.e. psycho-physical) type of index say for bathing waters.

2 the value of incorporating ammonia in each index (in the Schedule to the June 1985 Bill, Ammonia was mentioned only in Class W waters as a means to ensure effective chlorination for potable supply. However, in Questionnaire No. 1 it rated highly for all indexes with panel members. The reasons for its inclusion were also sought although several panel members had already pointed out that it should be in all indexes as a toxicant notwithstanding the stated philosophy of how the indexes were envisaged to handle such substances - see p. 21).

3 the desirability of holding a panel discussion before the third questionnaire (this is not normal with Delphi but it was suggested by one panel member and considered worthy of follow up).

4 whether, if Temperature is included in each index, it should be as a difference above background, the actual temperature, or both (the proposed standards specify both whereas the present standards [Water and Soil Conservation Act, 1967] are for the former only.)

The letter accompanying Questionnaire No. 2 presented panel members with additional points of information in an attempt to assist them with the questionnaire. For example, some panel members had in Questionnaire No. 1 suggested turbidity or suspended solids concentration but not necessarily both. The possibility of determining suspended solids based on a correlation with the more easily measured turbidity was pointed out, and also that they should bear in mind the prescribed water use(s) when making a decision. Similarly the value of having both colour characteristics (Hazen and hue), and both total and reactive dissolved phosphorus was raised.

Sixteen responses were obtained for all but the Water Supply index for which there were 13.

There were very few alterations to the first part of the questionnaire and because of this no further action was taken (a further iteration was a possibility). In any case the second part of the questionnaire would probably have taken into account changes of mind.

Analysis of the 'include' results from the second part was by two methods, simple arithmetic summation and inspection, and cluster analysis (SAS Cluster package).

Analysis by number of 'include' requests is given in Table 1. It was quite evident that restricting panel members to just 10 "includes" removed the 'nice-to-know' determinands and clear preferences become more apparent. In most cases cluster analysis produced two groups of determinands which by and large corresponded with the analysis by number of 'includes' if a cut-off is made along majority/minority lines.

The results from the Supplementary section of Questionnaire No. 2 are given in Appendix 5. All panel members saw a value in attempting to produce a perception type of index for bathing waters which would incorporate psycho-physical aspects of water assessment. Two panel members expressed slight reservations, however.

For the General and Bathing Indexes, there was no clear-cut preference for inclusion of ammonia. However there was a clear preference for its use in Water Supply and Fish Spawning indexes. In all cases there was such a multiplicity of reasons that its value seems of doubt except in the clear-cut case for the Water Supply Index where its inclusion is to help ensure effective chlorination.

There was no clear-cut preference for a panel discussion although three panel members from Wellington held a brief meeting with the co-ordinator a few weeks later. During this, useful points were raised and the feeling expressed that the ideas of the coordinator and general thrust of the exercise were sound. It also seemed useful to the three panel members because some issues were clarified.

The results from the temperature question (difference, actual, or both) were thought to be insufficient to resolve the problems.

Table 1 Analysis of Questionnaire No. 2 part 2 by number of 'include' requests

	Index			
	General (16)	Bathing (16)	Supply (13)	Fish (16)
Dissolved oxygen	16	16	11	16
pH	16	15	10	16
Suspended solids	9[a]	9[a]	8[a]	13½[b]
Temperature	13	13	3	16
Nitrate	9	5	10	8
Oil and grease	11	13	9	11
BOD (unfiltered)	12	12	4	12
Ammonia	8	7	11	14
Faecal Coliforms	11	15	13	4
Turbidity (FTU)	11[a]	12[a]	7[a]	6½[b]
Phosphate (RDP)	8	4	3	6
Conductivity	6	3	4	4
Colour (Hazen)	2	4	4	3
Phosphate (total P)	2	1		3
Colour (Hue)	1	6	1	
Hardness	1		4	1
BOD (filtered)	1		3	1
Alkalinity			2	
Total coliforms		3	1	1
Fe (as Fe^{2+})	1		4	
Chloride			1	
Organic carbon			1	
COD			1	
Mn (as Mn^{2+})			1	
Magnesium			1	
Calcium			1	
Dissolved solids			1	
Substrate chlorophyll-a	1	1		1
Substrate carbon				1
Standard plate count			1	

Notes

a Either suspended solids or turbidity (FTU) requested by two panel members.
b Either suspended solids or turbidity (FTU) requested by three panel members.

Value in brackets is the number of respondents.

The upshot of the analysis of Questionnaire No. 2 was that a suggested (by the co-ordinator) selection of characteristics was developed for each index (Table 2). This, together with the copious notes to the table subsequently formed part of Questionnaire No. 3. The notes are important and provided panel members with an explanation of the co-ordinator's reasoning (responses from panel members supplied some of this reasoning).

Questionnaire No. 3

Up to this stage the NSF format had been roughly followed but panel members had been given much more guidance and direction. This was felt necessary because they seemed highly motivated and provided the co-ordinator with copious information and opinion. The exercise was not the expected simple, routine question/answer, yes/no situation.

The third questionnaire (Appendix 6) contained questions which the co-ordinator felt panel members should have a final say in resolving. At this stage simple agree/disagree responses were sought (but still not obtained in all cases!). To assist panel members answer these questions they were supplied with:

1 the analysis of Questionnaire No. 2 part 2 (Table 1) and Supplementary (Appendix 5).

2 some "suggestions for thought" (see below).

3 the relevant portion of the latest (June 1986) MWD Schedule to its Draft Water and Soil Conservation Bill (in which numerical BOD standards had been removed and in some cases replaced by a descriptive standard) (Appendix 7).

A brief paper on the proposed final form of the index was also sent to inform panel members on the, then, current thinking of the co-ordinator and how each

Table 2 Suggested characteristics list for each index[g]
(This was sent to the panel as part of Questionnaire No. 3.)

	Index			
	General	Bathing	Supply	Fish
Dissolved oxygen	X	X	X	X
pH	X	X	X	X
Suspended solids/Turbidity[a]	X	X	X	X
Temperature	X	X	X[b]	X
Nitrate	f		e	c
BOD (unfiltered)	X	X		X
Ammonia	d	d	X	d
Faecal coliforms	X	X	X	
Phosphate (RDP)	f			c

<u>Notes</u>

a Both these determinands be included and give them equal weighting within this clarity/suspended material class. For the index, if only one is available then give it twice the individual's weighting.

b Temperature should be included if only because it is important to aquatic life.

c For fish (i.e., salmonids) spawning waters, the Schedule to the Bill states that there should be no undesirable growths as a result of pollutants. Since at present there does not seem to be sufficient information to relate the development of growths to instantaneous nutrient concentrations at a particular point, I cannot see how we can include nutrients. Nitrate and RDP were requested by 8/16 and 6/16 panel members, respectively.

d Ammonia be not included because it is a toxicant and this can be covered by a 'general' toxicity assessment in the index.

e I see no prospect of nitrate being cause for human health concern in our surface, running waters, therefore omit.

f For general water use, the Bill states that there shall be no excessive slime growths as a result of <u>organic</u> substances. We have BOD included in this index (although the BOD standard is no longer in the schedule). Because of these points and the reasons given in (c) above to omit nutrients from F waters, I suggest they also be omitted from G waters. Nitrate and RDP were requested by 9/16 and 8/16 panel members, respectively.

g I have excluded oil and grease because this is largely a psychophysical issue. Is it not easy to determine and how it could be introduced in the proposed indexes is not clear.

index would be produced and used. This entailed a description of the likely final form of the Index i.e. a weighted multiplicative mean for the final Index (I),

$$I = \prod_{i=1}^{n} I_i^{w_i} \qquad (1)$$

where I_i is the score for the i^{th} determinand, referred to as a sub-index value

w_i is the weight assigned to each sub-index (and $\sum_{i=1}^{n} w_i = 1.00$)

n = number of determinands.

The possibility of also including a 'Minimum Operator' index

$$\text{i.e. } I_{min} = \min(I_1, I_2, \ldots. I_n) \qquad (2)$$

where I_{min} equals the lowest sub-index value, was also being considered as a possibility, mainly because of its simplicity.

Other index aggregation techniques, e.g. unweighted multiplicative, weighted and unweighted additive, were also considered but the weighted multiplicative (equation 1) seemed to encompass fewer problems than these (see Ott, 1978).

Thus far, toxic substances had been excluded from consideration. It was anticipated that if toxicity was known to occur then the index would reduce to zero.

The "suggestions for thought" contained brief discussion on many points which had arisen during the project and which needed to be kept in mind prior to attempting Questionnaire No. 3. Basically they expended on the statements made in the questionnaire e.g., Temperature: results from Questionnaire No. 2 Supplementary were not clear-cut so a statement 'include only actual temperature' was made to provoke reaction.

Oil/grease: this was suggested to be omitted from all indexes and an agree/disagree response sought.

Dissolved oxygen: the suggestion made was that the units to be used were the same as those in the Schedules i.e. concentration for General, Bathing and Water Supply Indexes, and % saturation for the Fish Spawning Index.

The possibility of using a sub-index scale containing narrative descriptors (definitions) was raised i.e.,

Sub-index Rating	0 – 20	20 – 40	40 – 60	60 – 80	80 – 100
Definition	Totally unsuitable for use	Inadequate for use	Marginally suitable	Suitable for use	Eminently suitable for use

Also the use of a fixed reference point on the sub-index curve was suggested, i.e, if a water of sub-index rating >60 were considered suitable for use and < 60 marginally suitable, it seemed reasonable to fix a point at (x, 60) where x is the numerical standard in the Schedule. Curves (to be drawn up later in Questionnaire No. 4) should then go through this fixed reference point. This would have the added advantage in constraining panel members in the sort of curve they would subsequently have to sketch and provide considerable conformity (previous sub-index curves, e.g., those produced by NSF panel members, were remarkable for their incredible scatter in responses [Ott, 1978]).

Responses on the choice of the value 60 for the reference point and the use of the same descriptors, as for the sub-indexes above, for a final index were also requested.

Finally the characteristics for each index as suggested in Table 2 were presented for comment.

There were 15 responses, one of which was received too late for inclusion in the analysis (Appendix 8) which was sent to panel members with Questionnaire No. 4. The results presented below are from all 15 responses.

Temperature: Nine agreed that only actual temperature be included. The six which disagreed argued sufficiently convincingly for the inclusion of temperature difference that it has also been included. Oil/grease: 10 agreed that this should be omitted. Ammonia: 9 favoured its inclusion in only the Water Supply Index in its role of prevention of chlorination difficulties. Dissolved oxygen: 14 agreed with the suggested units i.e. concentration units for General, Bathing and Water Supply Indexes, and % saturation for the Fish Spawning Index.

Sub-index scale: 13 agreed with the suggested scale and descriptors. A minor change was suggested, i.e., "20-40; inadequate for use" should be replaced with "20-40; unsuitable for use".

Fixed reference point: the fixed point of 60 on the sub-index axis was agreed to by 10 respondents. Of the others, three suggested 50 and one 80. Therefore 60 seemed about right. There was one suggestion of a further category of 100-120 (unspoiled, pristine) but this does not necessarily indicate suitability for use and would have required a considerable rethink of the index derivation.

Final index scale: only one respondent disagreed that the same scale and descriptors (as above) could be used and of those agreeing two thought that it might be premature to adopt this scheme.

The most important part of the questionnaire (i.e., the suggested characteristics for each index) was left until last (possibly not a good strategy). Seven panel members agreed with the tabulated characteristics. The remaining eight were in basic agreement but some suggested the inclusion of an additional characterisic (two for oil/grease, three for ammonia). Somewhat surprising only one person suggested inclusion of BOD_5 (unfiltered) in the Water Supply Index. This was re-addressed later.

The final determinand selection is thus that which was suggested to panel members (Table 2).

Questionnaire No. 4

After the analysis of the third questionnaire, we had a list of determinands for each suitability-for-use water quality index. The next stage was perceived to be the development of weightings and the drawing up of sub-index curves. It was still envisaged that each final index would be aggregated using a weighted multiplicative approach. This was later discounted for a variety of considerations.

This questionnaire consisted of two major parts and followed the NSF format but considerable assistance was supplied. Questionnaire 4a (Appendix 9) contained, for each index, a list of the selected characteristics with the request that the relative importance of each was to be provided. Questionnaire 4b contained the graph blanks (not reproduced here) upon which sub-index curves were to be drawn, plus some guiding information. Further information was supplied as follows:

1 The analysis of results and discussion from questionnaire No. 3 (Appendix 8)
2 A graph of Secchi Disc Depth vs. Turbidity for 27 New Zealand lakes

(to assist with the sketching of the Turbidity sub-index curves: see Smith 1987b). Additional information on Turbidity was also provided.

3 The summary section from the "Finely Divided Solids" chapter from Alabaster and Lloyd (1980) (to assist with the sketching of the Suspended Solids curves).

Questionnaire 4a contained a new term 'Suspended Material' to account for all the effects of suspended particles and for each index there was a question to assess preference for suspended solids (in the usual analytical sense) and turbidity.

For Questionnaire 4b, panel members were reminded of the use of the agreed-to fixed reference point for sub-indexes where there is a numerical standard in the Schedule to the June 1986 Draft Water and Soil Conservation Bill. These fixed reference points are presented in Table 3. It was also suggested that the agreed water quality scales and descriptors should be borne in mind when curve drawing (see Appendix 6 and slight modification on p. 19).

Panel members were also informed that:

a if a sub-index curve goes to zero, then the overall index could do likewise (because of the then proposed use of a multiplicative aggregation method).

b they were free to extend the x-axis if desired. The x-axes were very similar to those of the final graphs (see later).

It was pointed out that, because BOD_5 is now excluded from the Schedule, no reference point could be placed on the graph blanks (although it was suspected that panel members might go back to the original numerical standards for guidance).

For the Fish Spawning Index, the reference point was placed at (12°C, 60), and not (13°C, 60) in line with the Schedule. The reasons for this were provided in the questionnaire. In short, 13°C appears to be too high for brown trout and moves have been made to change the draft legislation (D. Scott, Otago University, pers. comm.).

The number of returns was 12, and not all sub-indexes were attempted by all respondents.

Table 3 Fixed reference points[1] on sub-index curves

Sub-index	Index G	R	W	F
Dissolved oxygen	5 g/m^3	5 g/m^3	5 g/m^3	80% saturation
pH	6.0 and 9.0	6.5 and 9.0	6.5 and 9.0	6.0 and 9.0
Temperature (actual)	25°C	25°C	25°C	12°C:25°C[2]
Temperature (diffce)	3°C	3°C	3°C	3°C
Faecal coliforms		200/100 ml	2000/100 ml	
Ammonia			0.2 g/m^3 as N	

[1]The sub-index reference point is at value 60, i.e. the lowest value in the suitable-for-use(s) category.

[2]During the spawning and non-spawning season respectively (see text).

Table 4 shows the averaged relative importance for each of the selected determinands for each index together with the final weighting. These are presented here for interest. They are not used in final index calculation because the weighted multiplicative aggregation approach was subsequently shown to be inappropriate - see later.

Table 4. Relative importance and final determinand weightings for the four water quality indexes

Determinand	Index							
	General (G)		Bathing (B)		Supply (W)		Fish (F)	
	Rel. imp.	Wt	Rel. imp.	Wt	Rel. imp.	Wt	Rel. imp.	Wt
Dissolved oxygen	1.33	**0.30**	2.15	**0.15**	2.38	**0.18**	1.00	**0.34**
pH	3.13	**0.13**	3.10	**0.10**	2.79	**0.15**	2.81	**0.12**
Suspended material	2.57	**0.15**	1.73	**0.19**	2.82	**0.15**	2.41	**0.14**
Temperature	3.15	**0.12**	3.78	**0.09**	3.59	**0.12**	1.35	**0.26**
BOD_5	2.20	**0.18**	2.23	**0.15**			2.48	**0.14**
Faecal coliforms	3.18	**0.12**	1.00	**0.32**	1.78	**0.24**		
Ammonia					2.59	**0.16**		

The averaged ratios obtained for preferences of suspended solids to turbidity are given in Table 5. These are presented for information only and are not used in the derivation of index values. There was considerable variation in responses for all indexes (other than R) showing that there is little agreement between respondents on the relative merits of either determinand.

Table 5. Suspended solids/turbidity ratios (averages) for the four water quality indexes

Index	SS/Turb	Stand. dev.	n
G	1.38	1.03	12
R	0.87	0.48	12
W	1.44	1.00	9
F	1.70	0.93	11

Sub-index curve derivation

For each returned curve which was legible, sensible and usable, a series of sub-index values was interpolated for no less than 13 and up to 23 determinand values. These were selected at uniform intervals except where the curve gradient was changing rapidly, in which case additional values were used. For the log-scale faecal coliform graphs, values were selected at approximately equal spacing on the log scale. For several returns, considerable interpolation, extrapolation and interpretation were required to derive the required values. For each of the selected determinand values, a corresponding mean sub-index value was calculated. The arithmetic mean was used so that each respondent could be given equal weighting. Outliers were thus allowed to have an effect. Smith (1987b) contains tables consisting of, for each index and each determinand, selected determinand values, corresponding sub-index scores, their standard deviation, weighted sub-index values, and the highest and lowest values. Such detail is not included here for simplicity. It is also unnecessary for the purposes of this report.

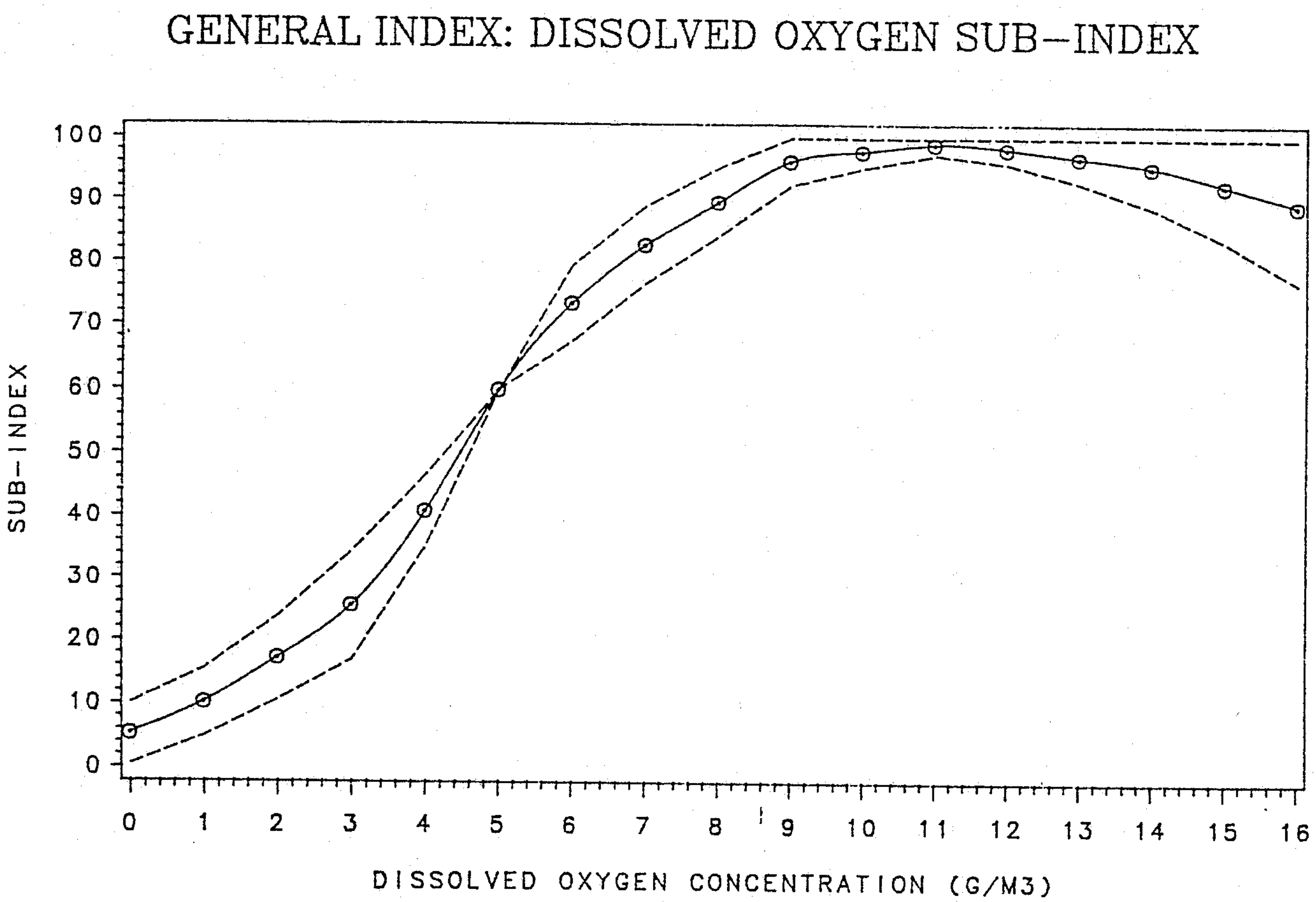
In some instances fairly large values were obtained for the standard deviation indicating that panel members showed considerable disagreement on how certain determinand values translate into suitability-for-use. It is quite clear that asking an <u>individual</u> scientist what the effects of certain concentrations (or whatever) are on a water's suitability-for-use may be an inappropriate exercise.

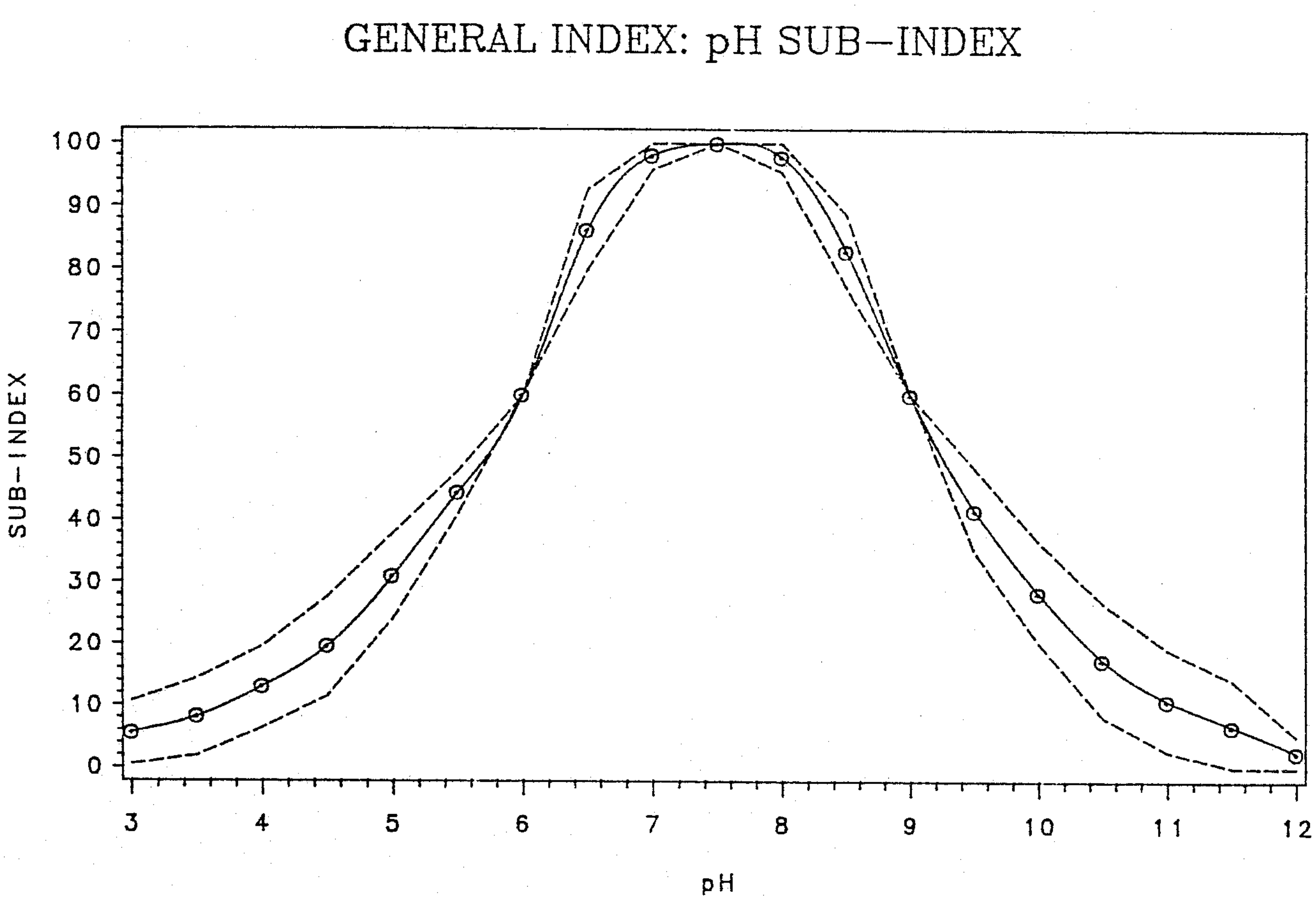
The mean values of the sub-indexes were graphed against the selected determinand values using the SAS Spline technique on the Centre's MicroVAX computer (Figs 1-4). From these can be read off any sub-index value for a measured determinand value. Extrapolation beyond the right hand limit of the x-axis should be carried out with caution. The 95% confidence interval for each point is also graphed as an indication of uncertainty; these points are joined simply with a straight line.[1] In many cases the use of the confidence interval is inappropriate because the distributions of individual data points are highly skewed. Confidence limits lying outside sub-index values of 0 and 100 are set at 0 or 100 respectively, to take some account of skewness in these regions. The use of the inter-hinge range as a non-parametric method to indicate variability was considered (and tried). However in some instances (e.g. G Index, DO subindex) the lower hinge was actually higher than the mean. It seems to be a 'no-win' situation.

Because there was so much variation in response in many parts of several curves, it is reasonable to pose the question: are the curves sensible? The short answer is, perhaps surprisingly, that most seem very sensible. Pooled knowledge appears to have produced a very useful set of information. Outliers appear to have either cancelled each other out so that the mean value is still sensible, or they have been sensible in themselves and have adjusted the mean to a more appropriate value.

[1]There is one exception to this, i.e. the lower confidence interval curve for the F Index Suspended Solids sub-index. In this case, this curve and not the curve through the means is the one recommended for Index determination (see later). The points were joined using the SAS Spline smoothing technique.

Figure 1. General Index: sub-index graphs

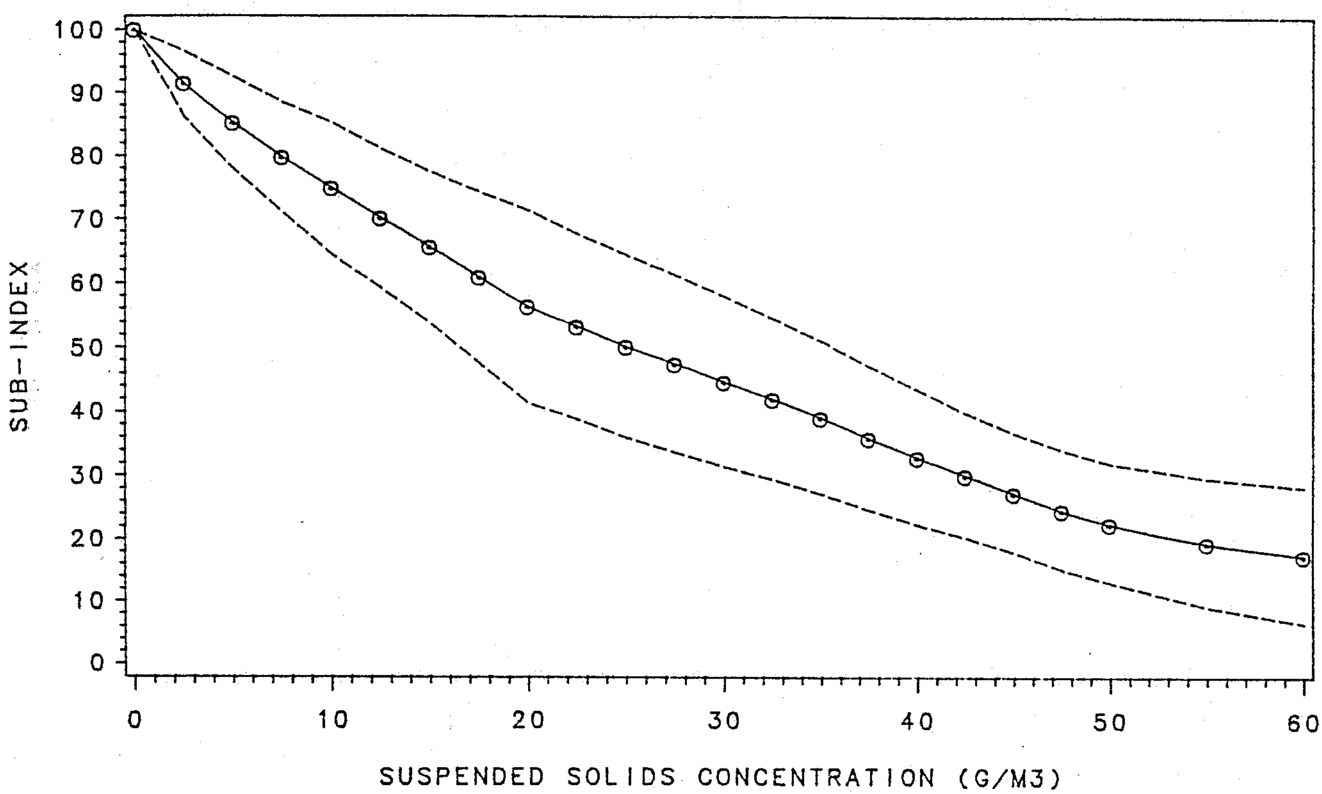




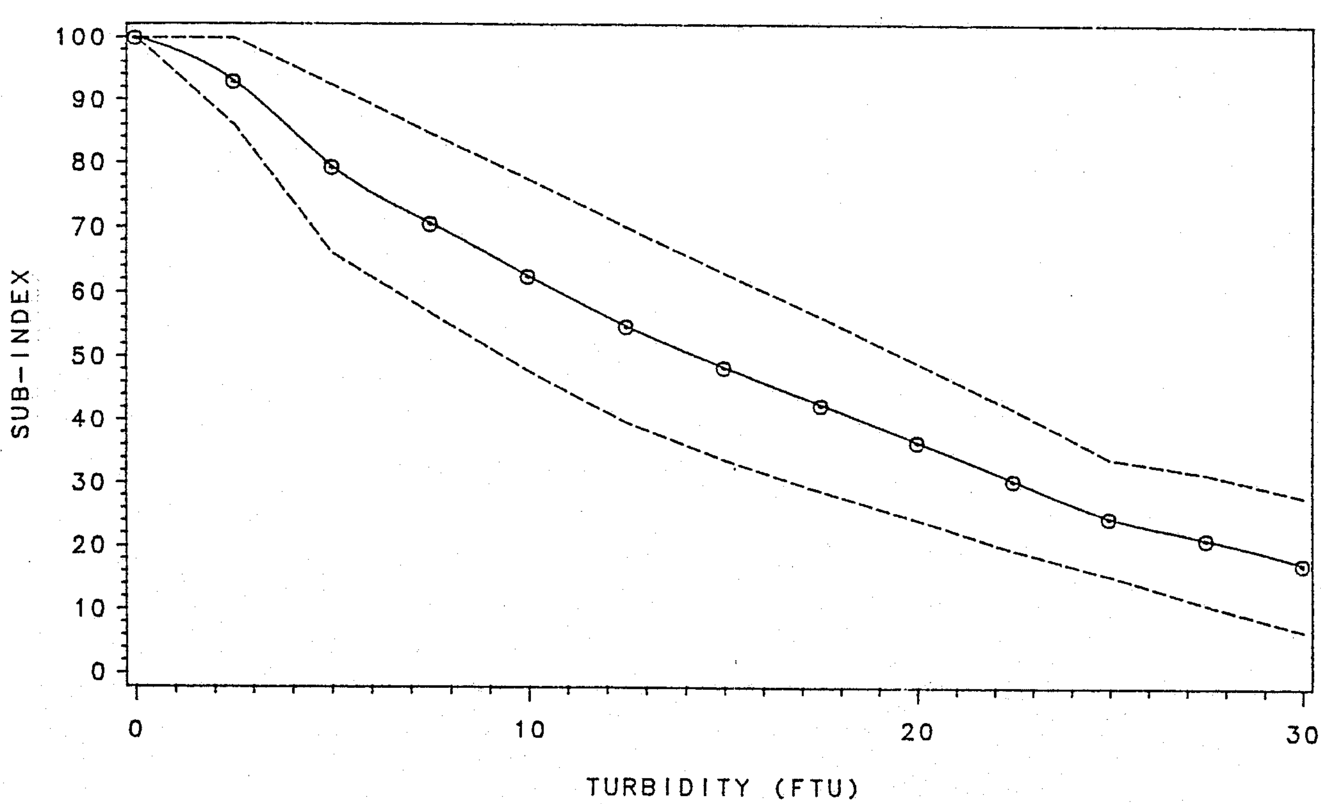
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 1 continued

GENERAL INDEX: SUSPENDED SOLIDS SUB-INDEX

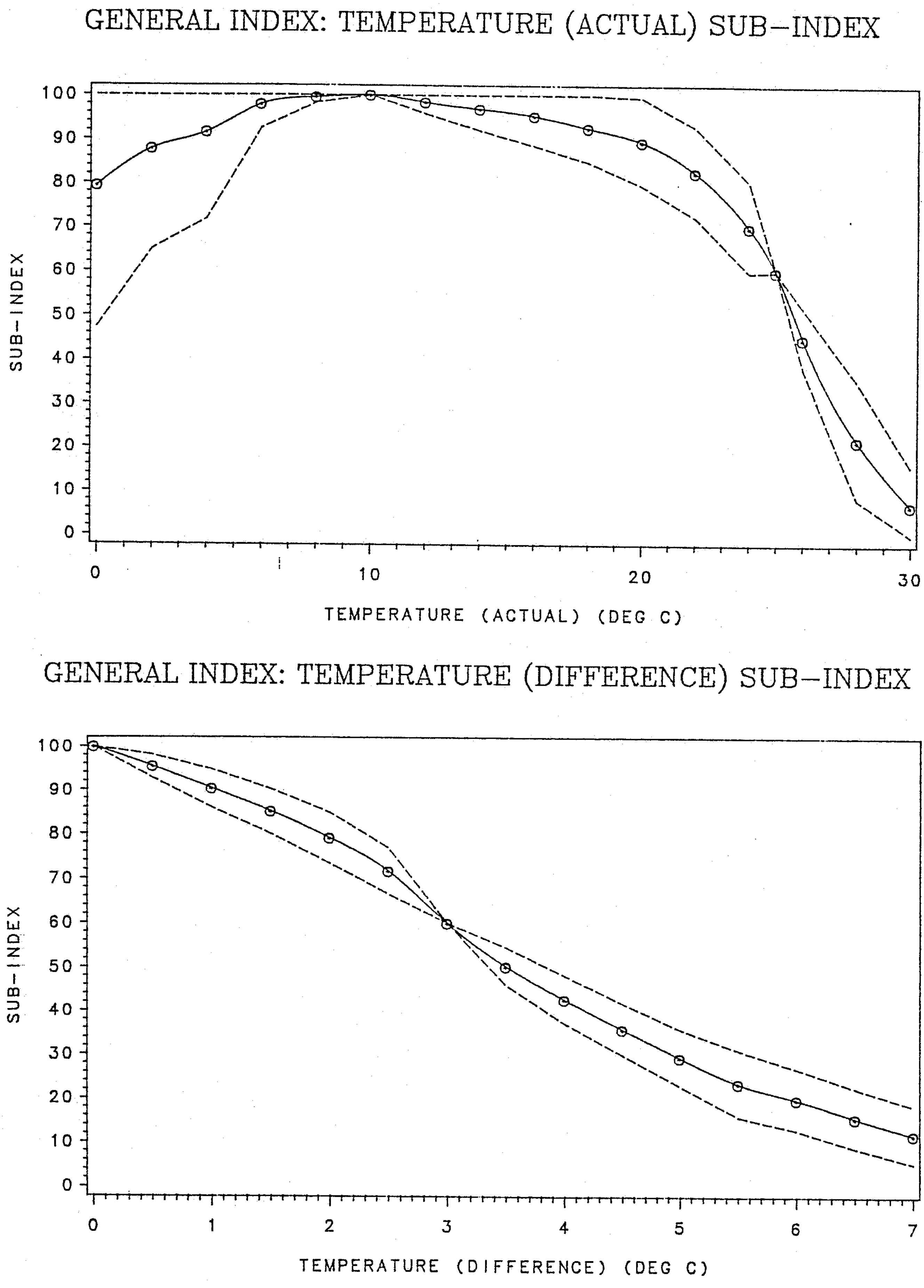


GENERAL INDEX: TURBIDITY SUB-INDEX



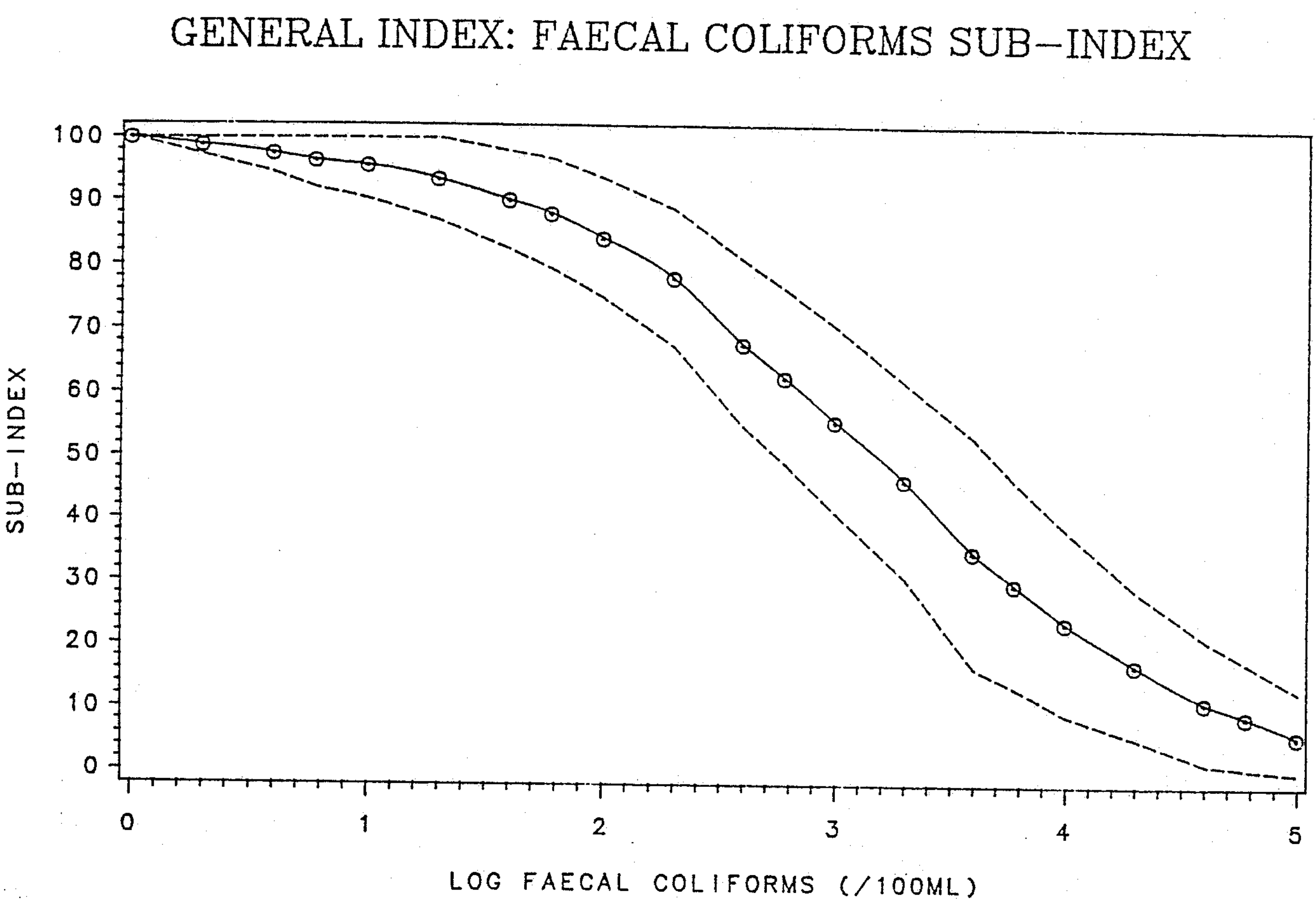
(The upper and lower curves depict the 95% confidence interval at each point)

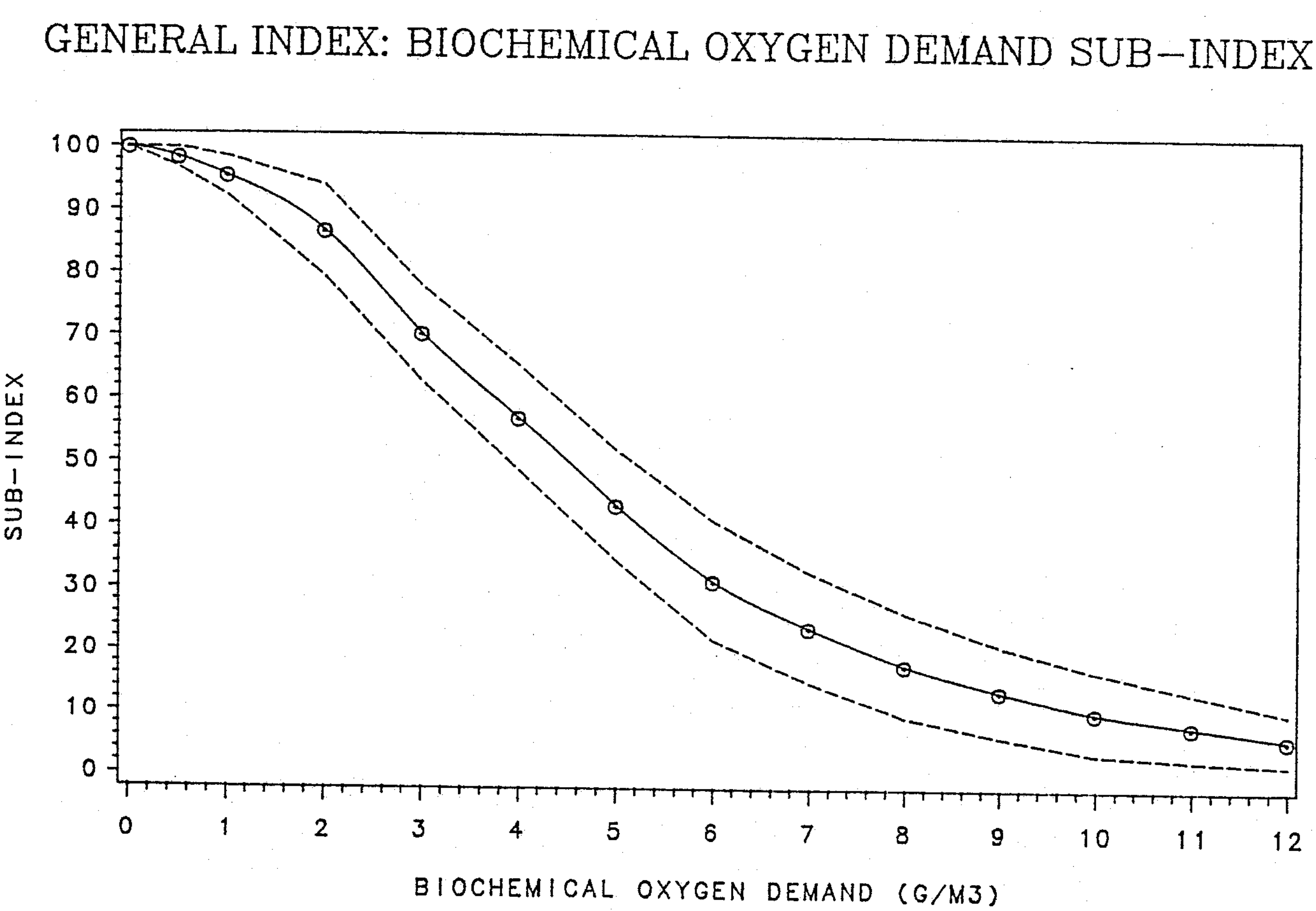
Figure 1 continued



(The upper and lower curves depict the 95% confidence interval at each point)

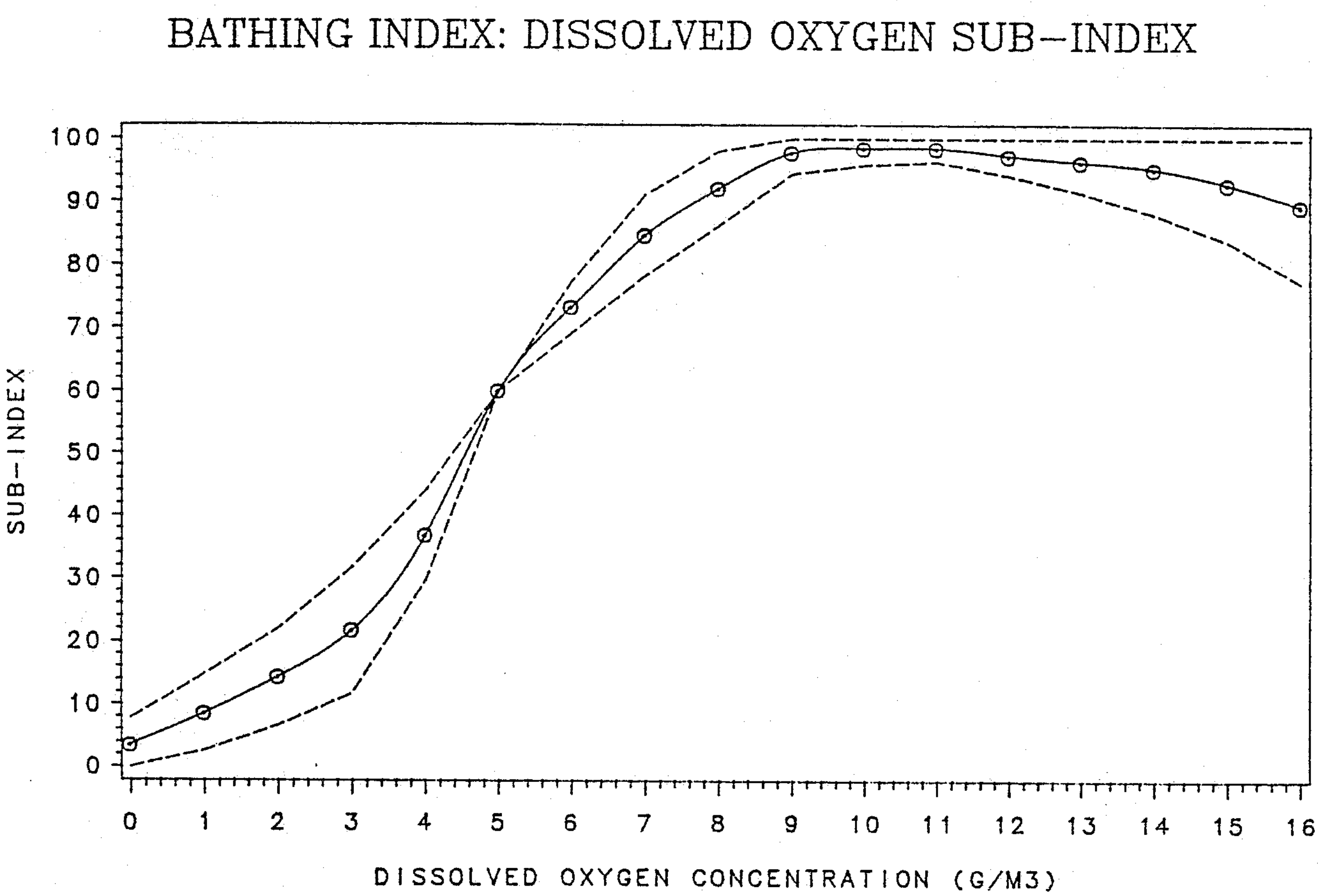
Figure 1 continued

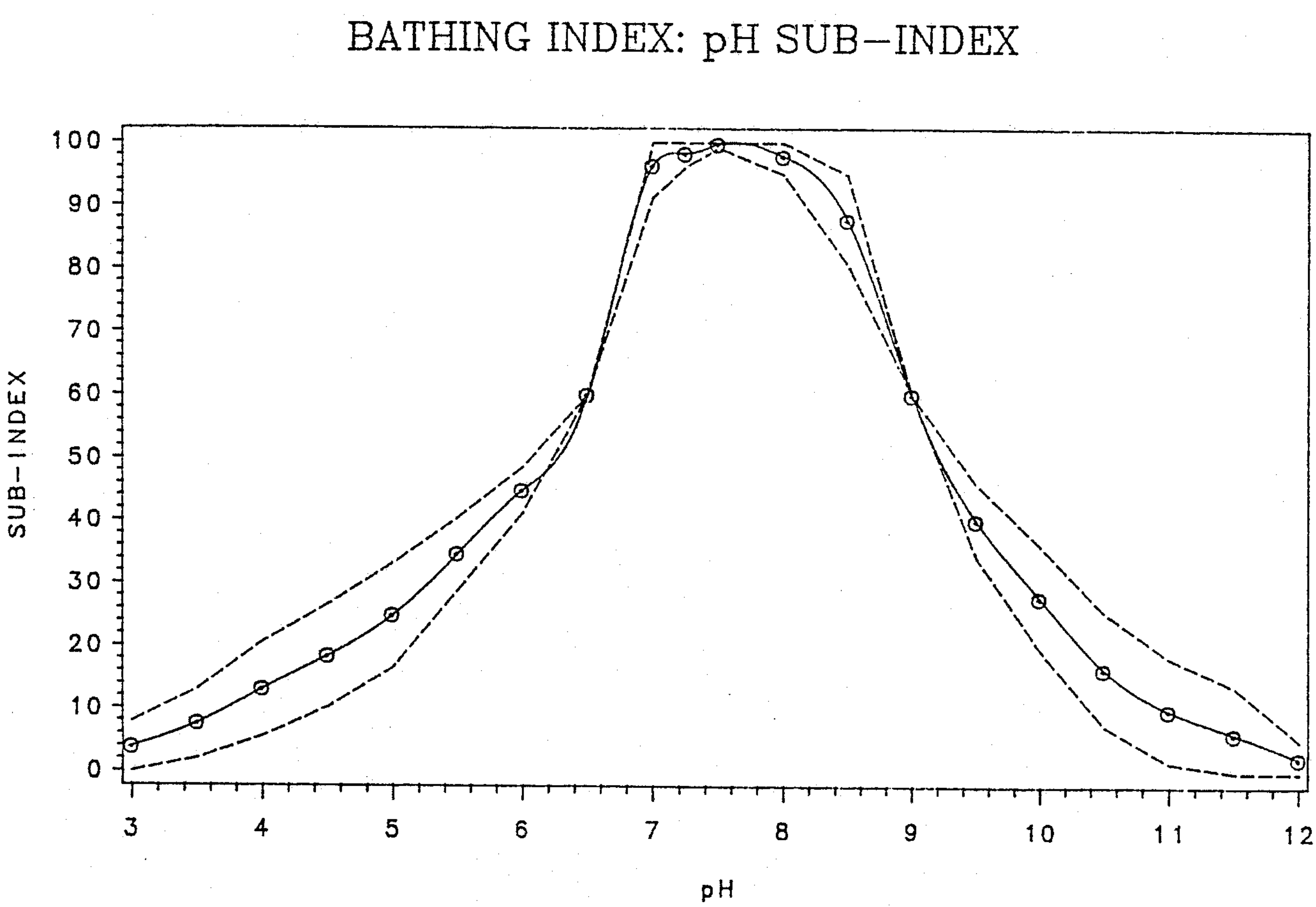




(The upper and lower curves depict the 95% confidence interval at each point)

Figure 2. Bathing Index: sub index graphs

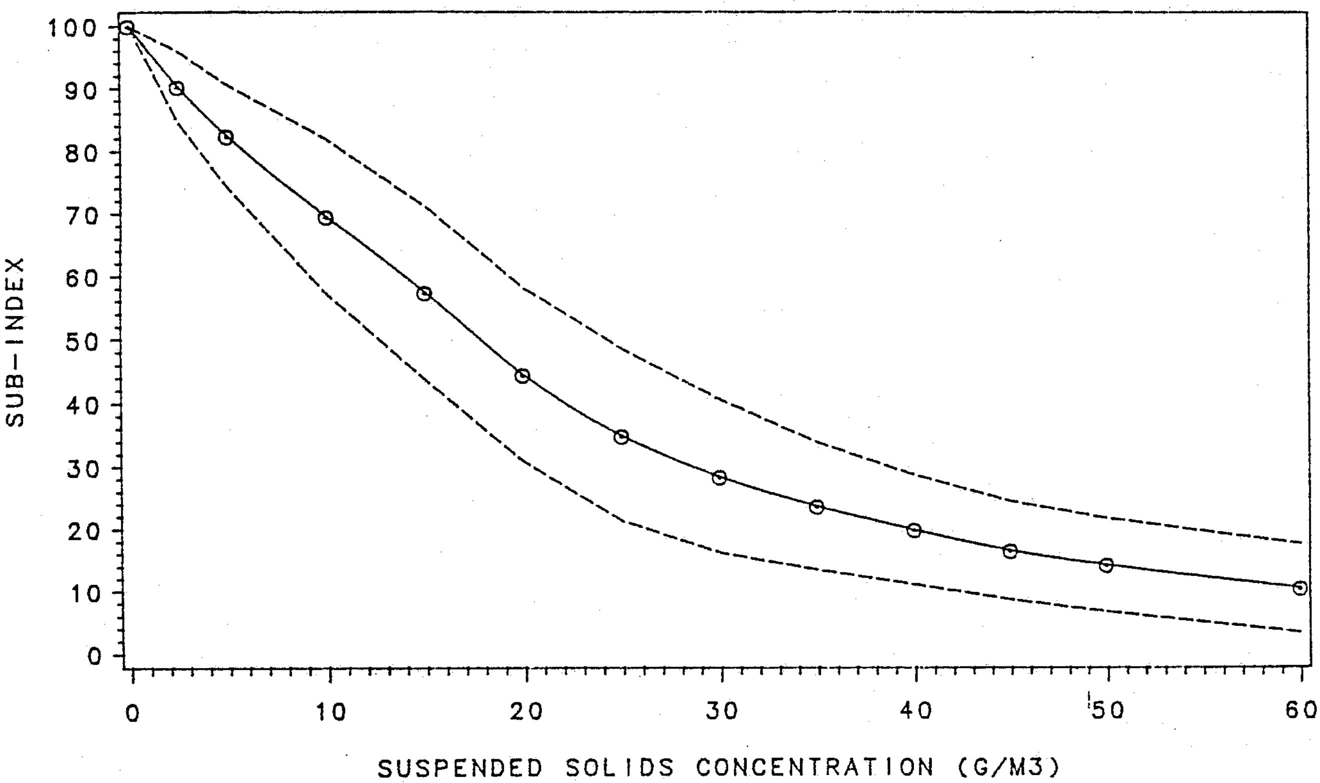




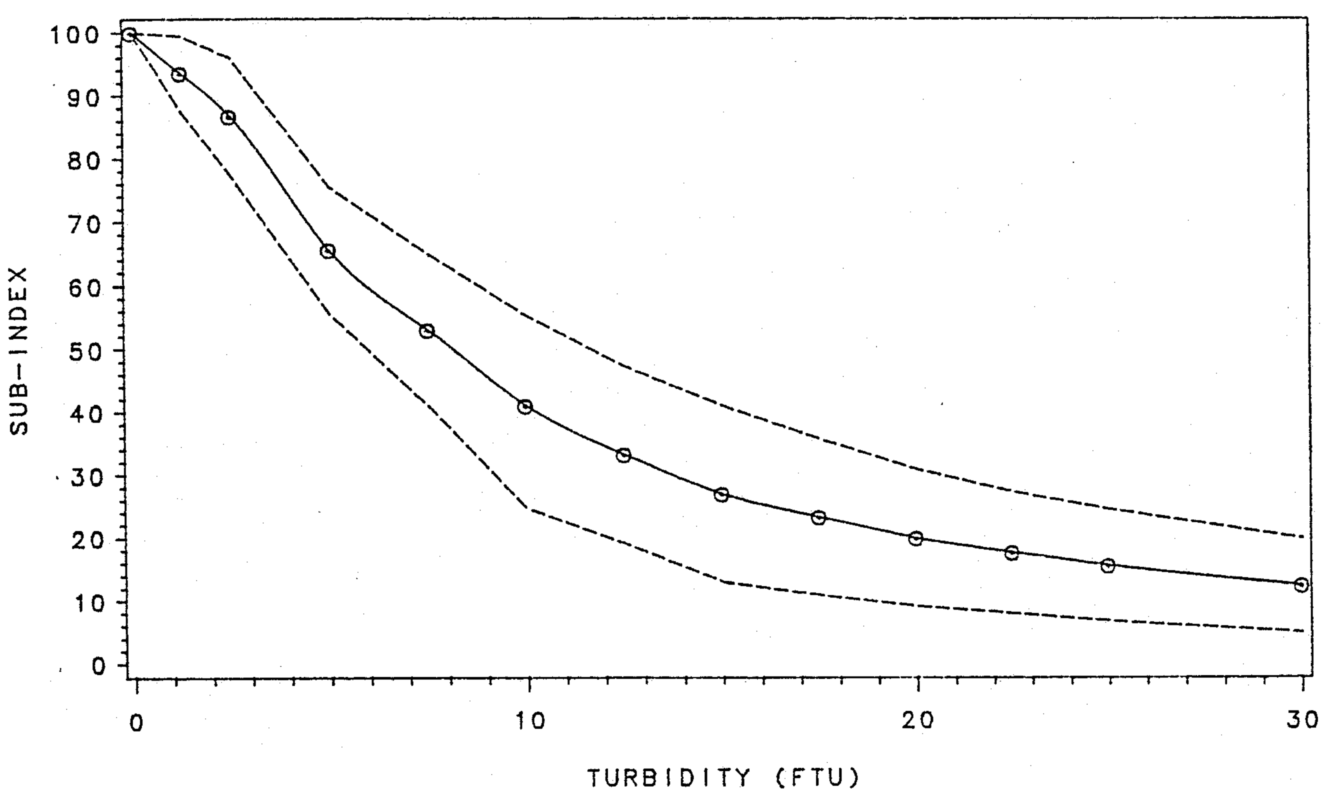
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 2 continued

BATHING INDEX: SUSPENDED SOLIDS SUB-INDEX



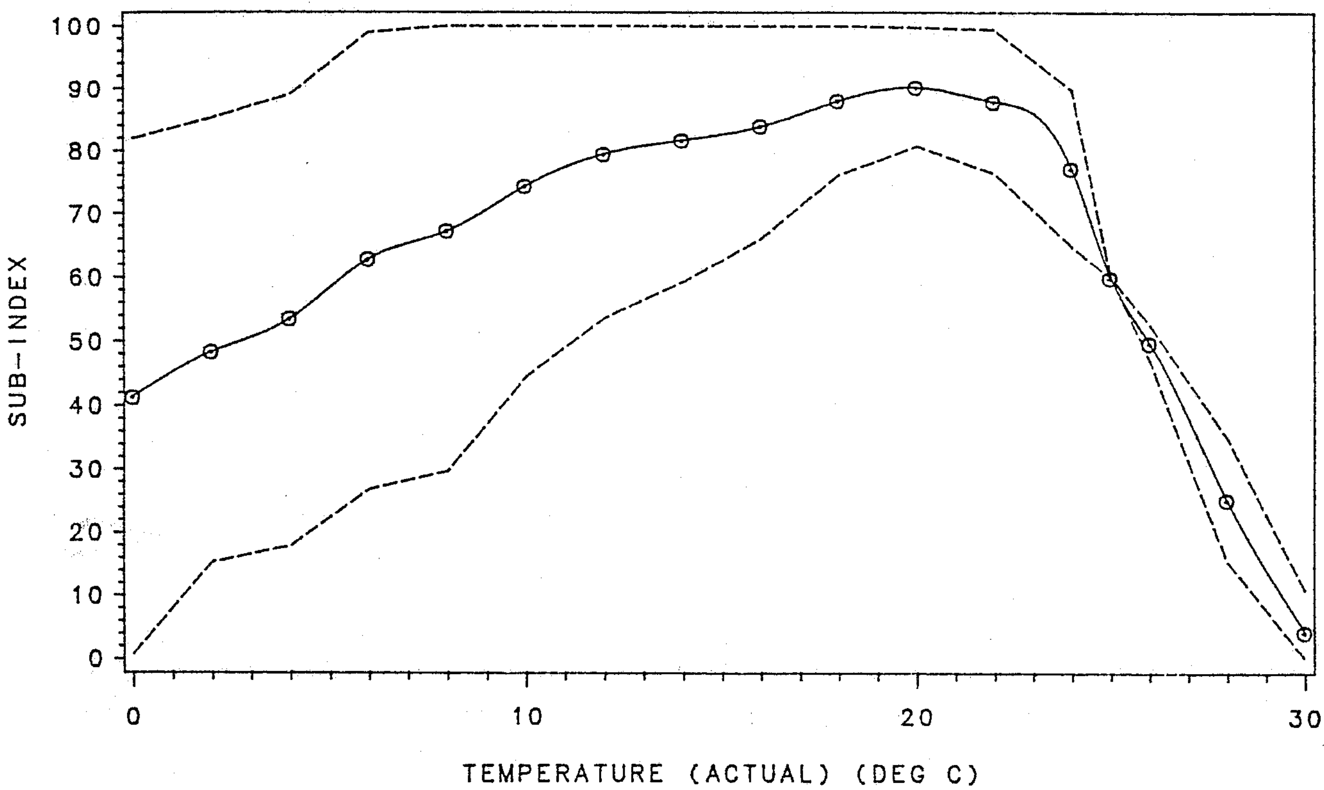
BATHING INDEX: TURBIDITY SUB-INDEX



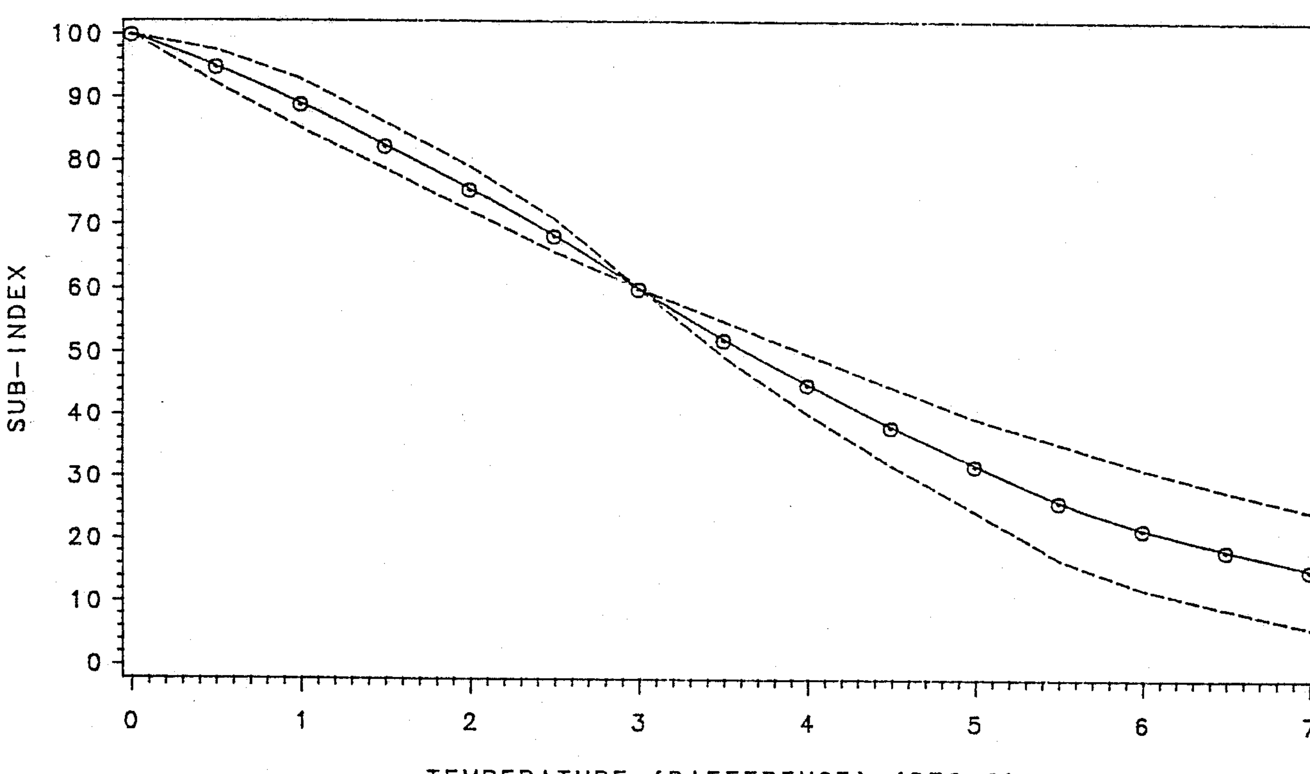
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 2 continued

BATHING INDEX: TEMPERATURE (ACTUAL) SUB–INDEX



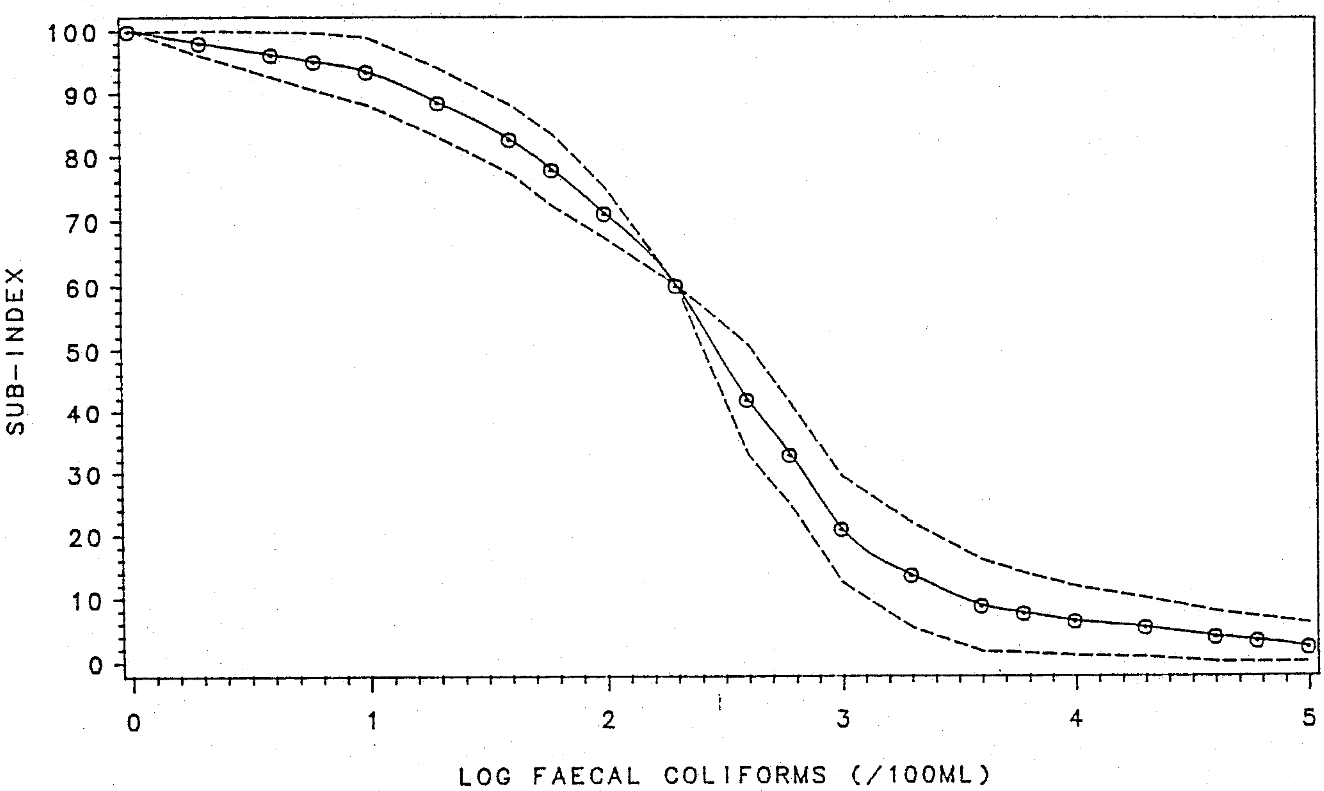
BATHING INDEX: TEMPERATURE (DIFFERENCE) SUB–INDEX



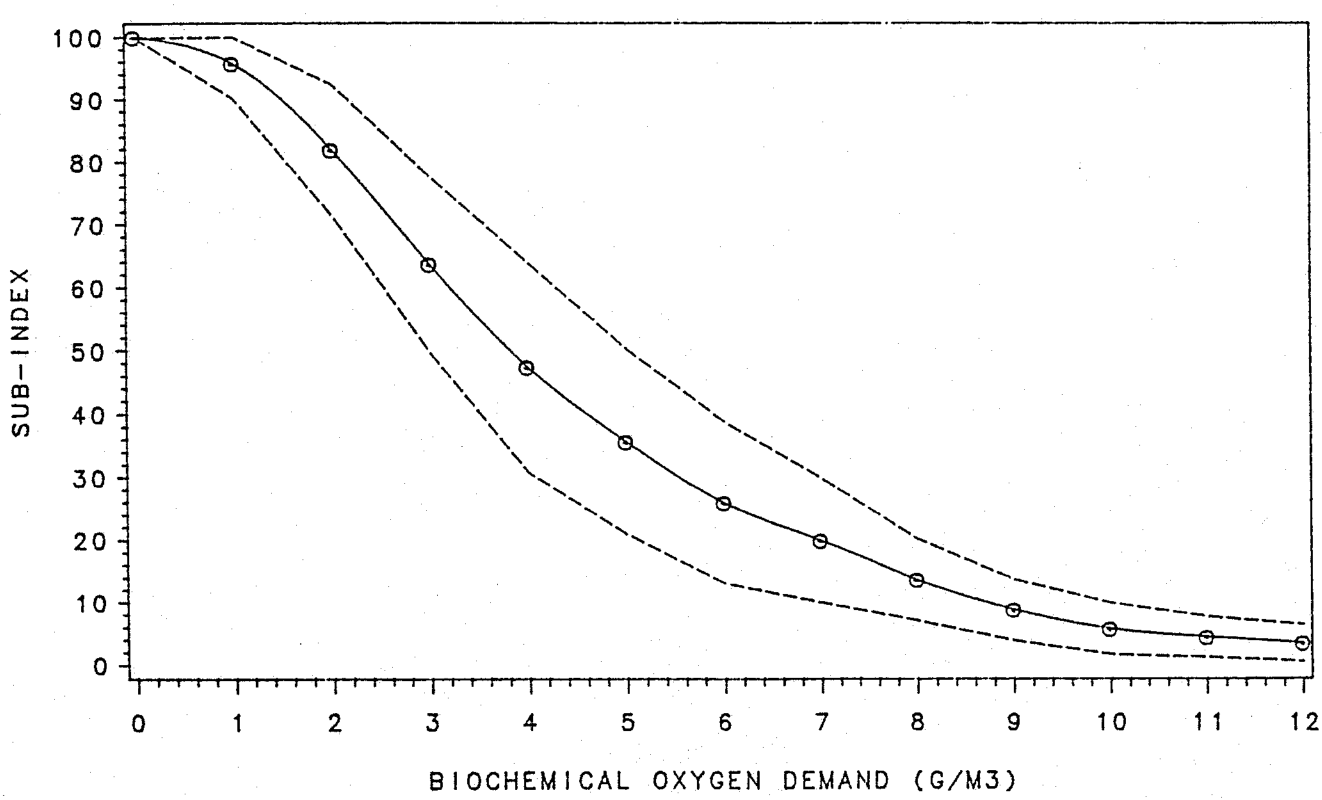
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 2 continued

BATHING INDEX: FAECAL COLIFORMS SUB-INDEX

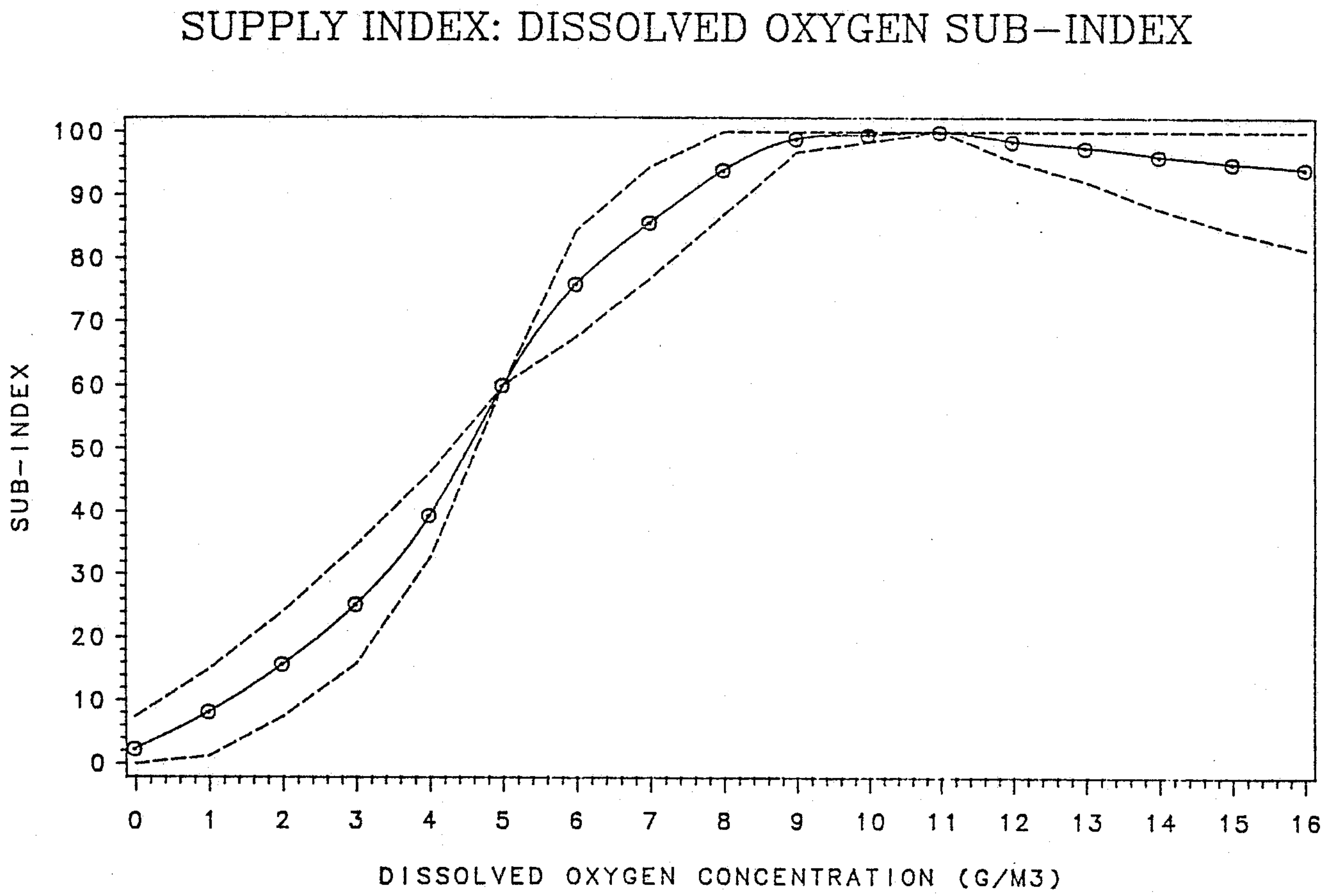


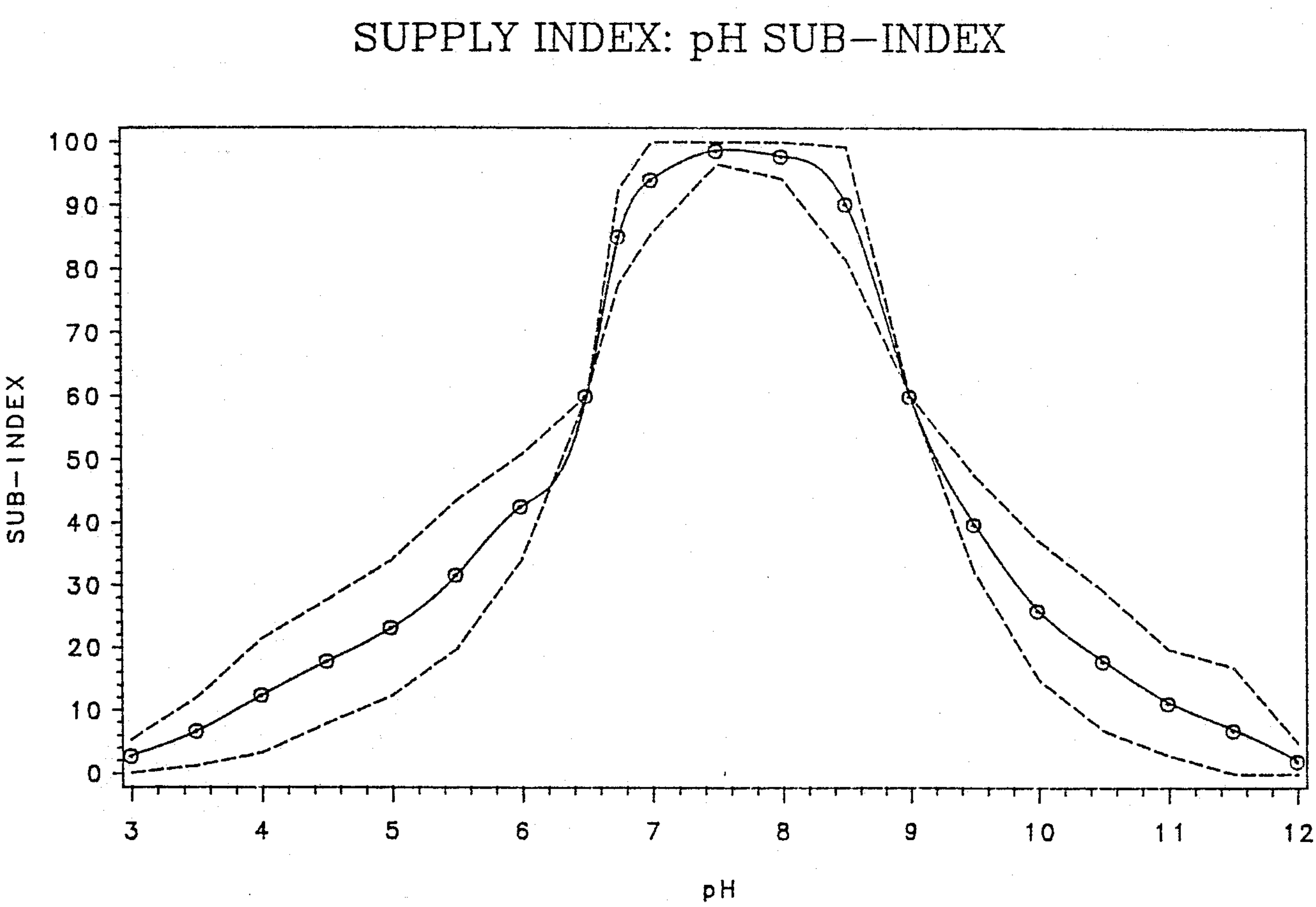
BATHING INDEX: BIOCHEMICAL OXYGEN DEMAND SUB-INDEX



(The upper and lower curves depict the 95% confidence interval at each point)

Figure 3. Water Supply Index: sub-index graphs

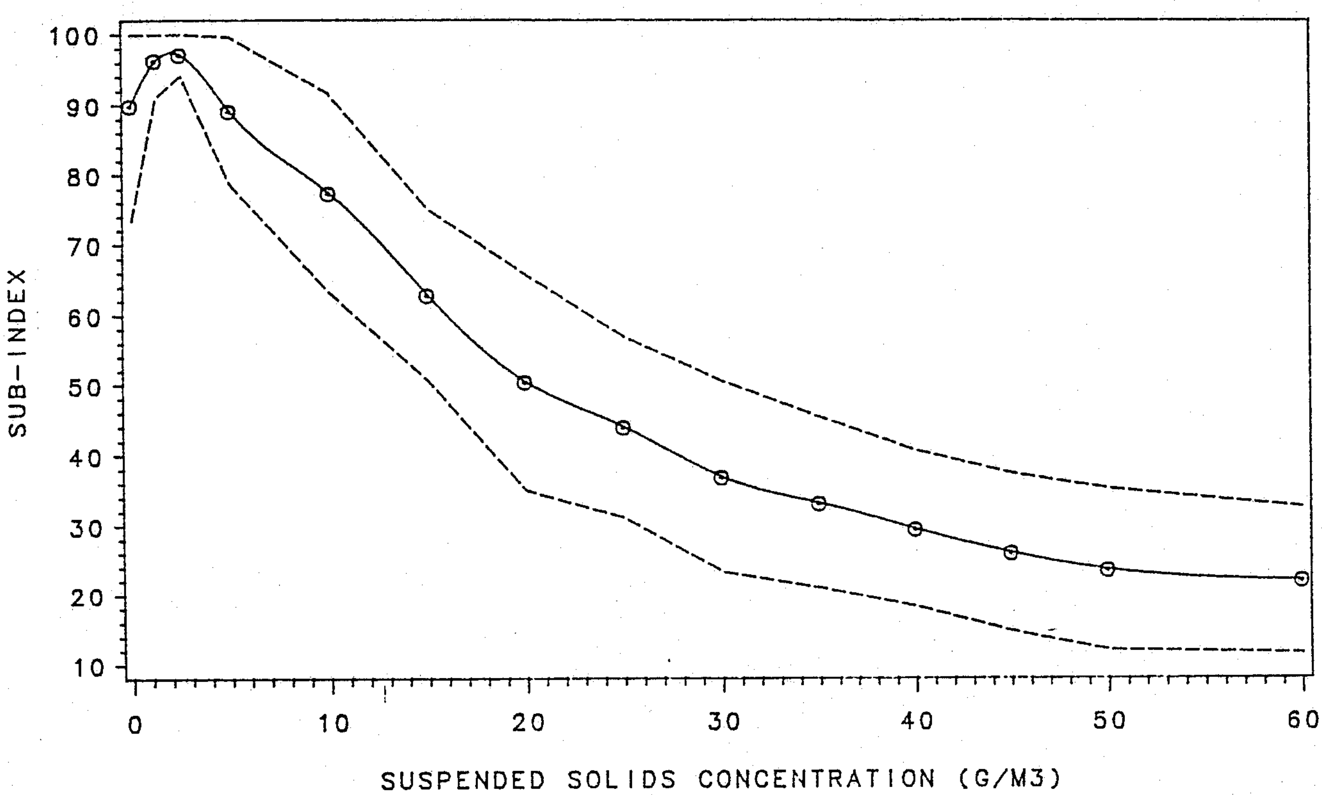




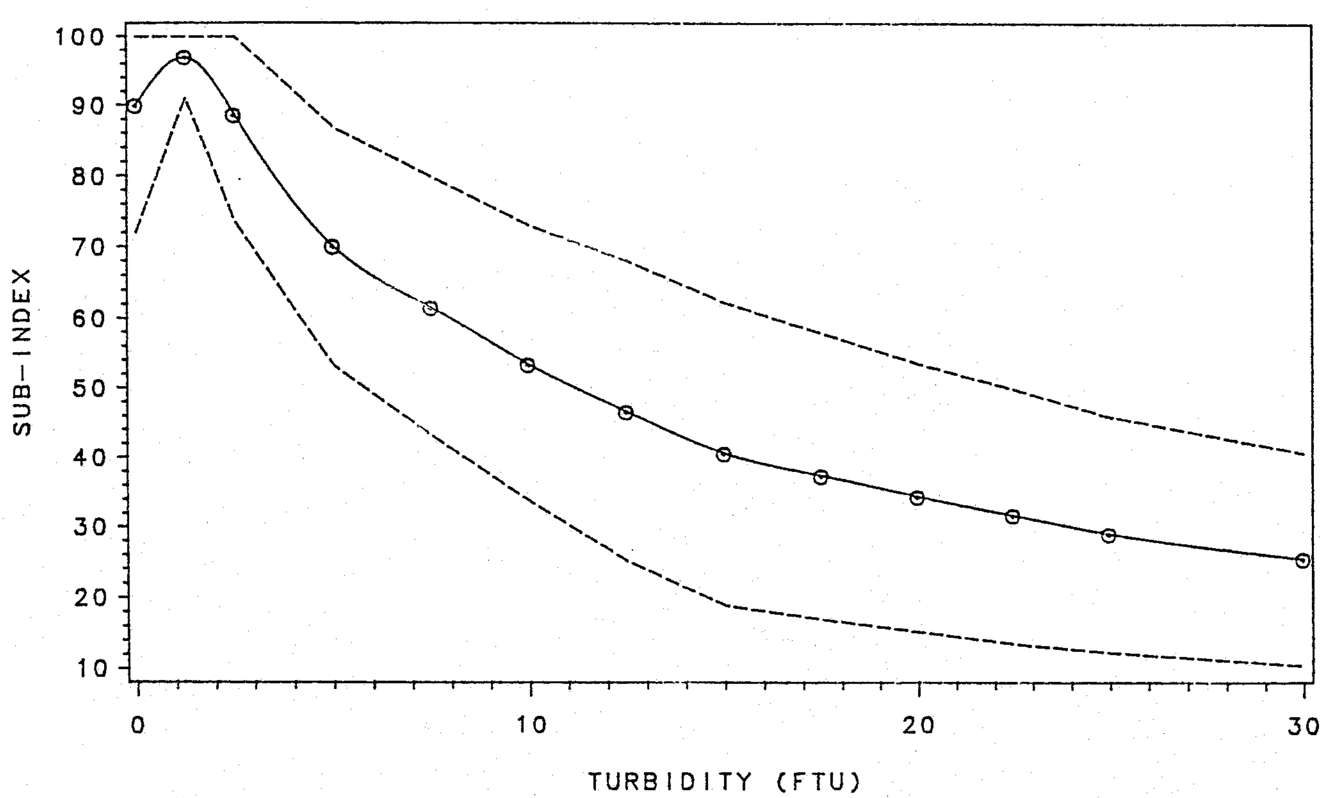
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 3 continued

SUPPLY INDEX: SUSPENDED SOLIDS SUB-INDEX



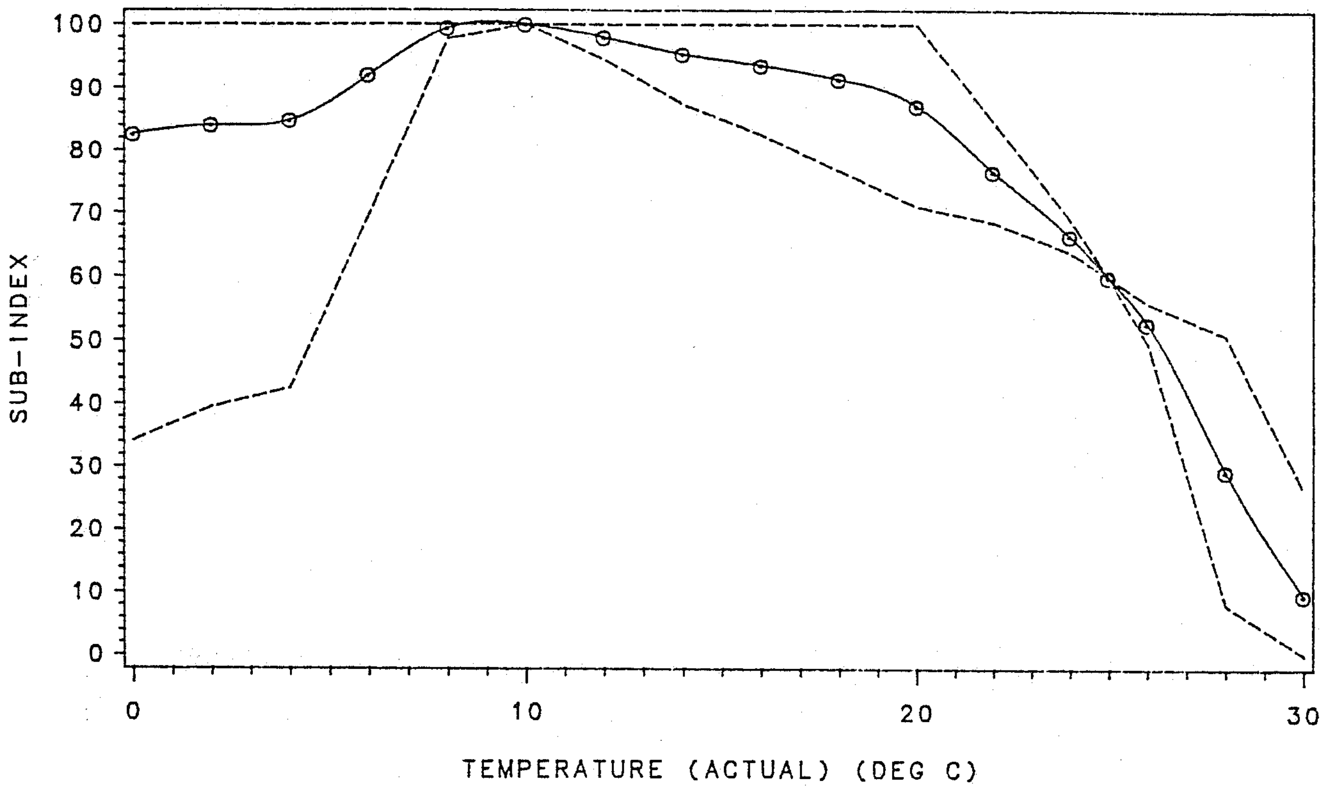
SUPPLY INDEX: TURBIDITY SUB-INDEX



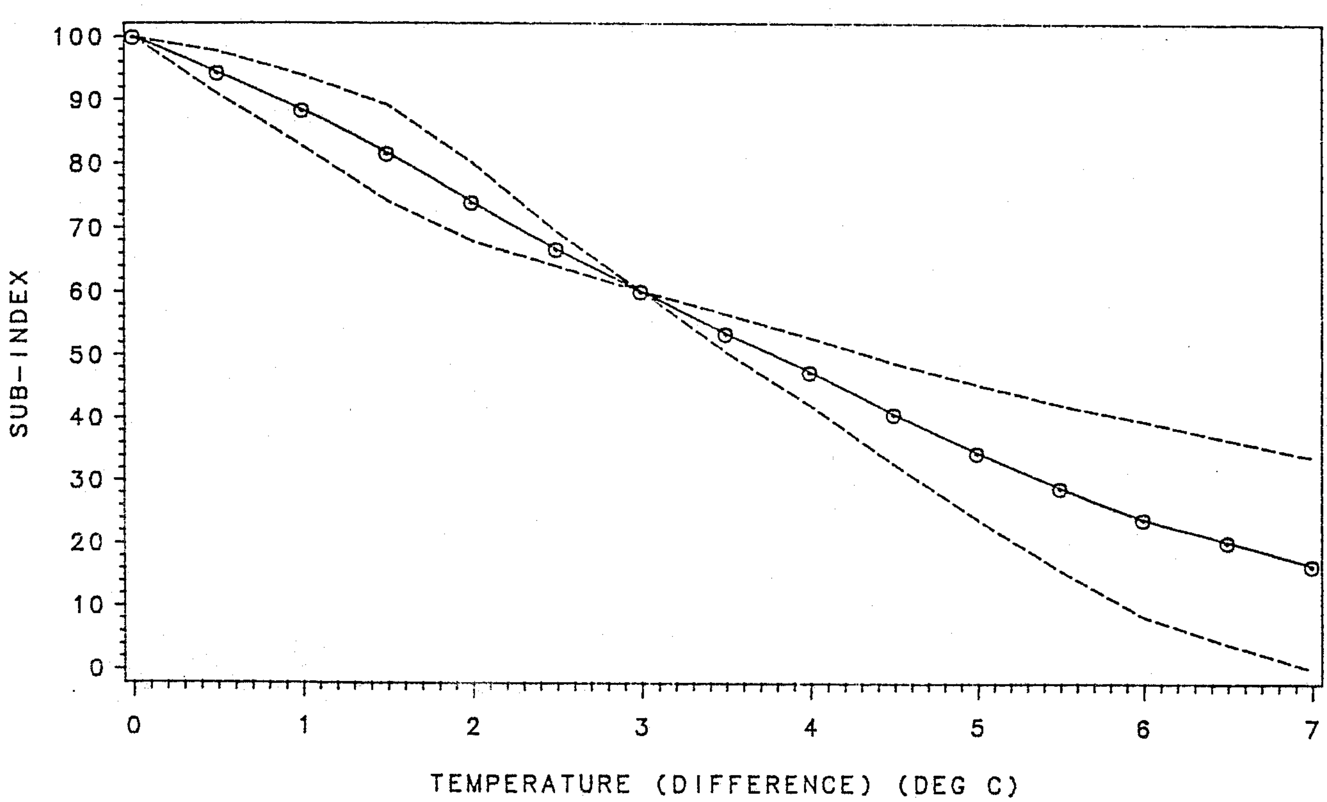
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 3 continued

SUPPLY INDEX: TEMPERATURE (ACTUAL) SUB-INDEX



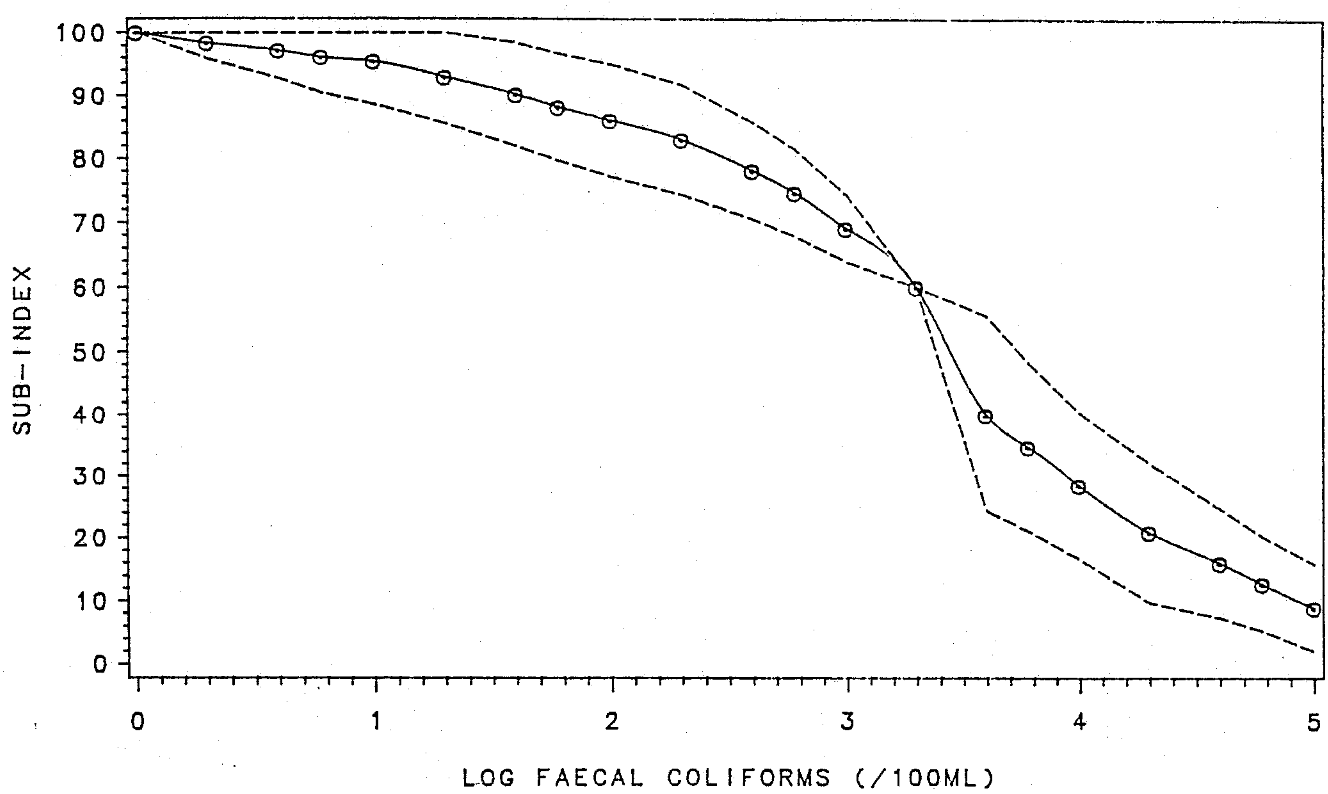
SUPPLY INDEX: TEMPERATURE (DIFFERENCE) SUB-INDEX



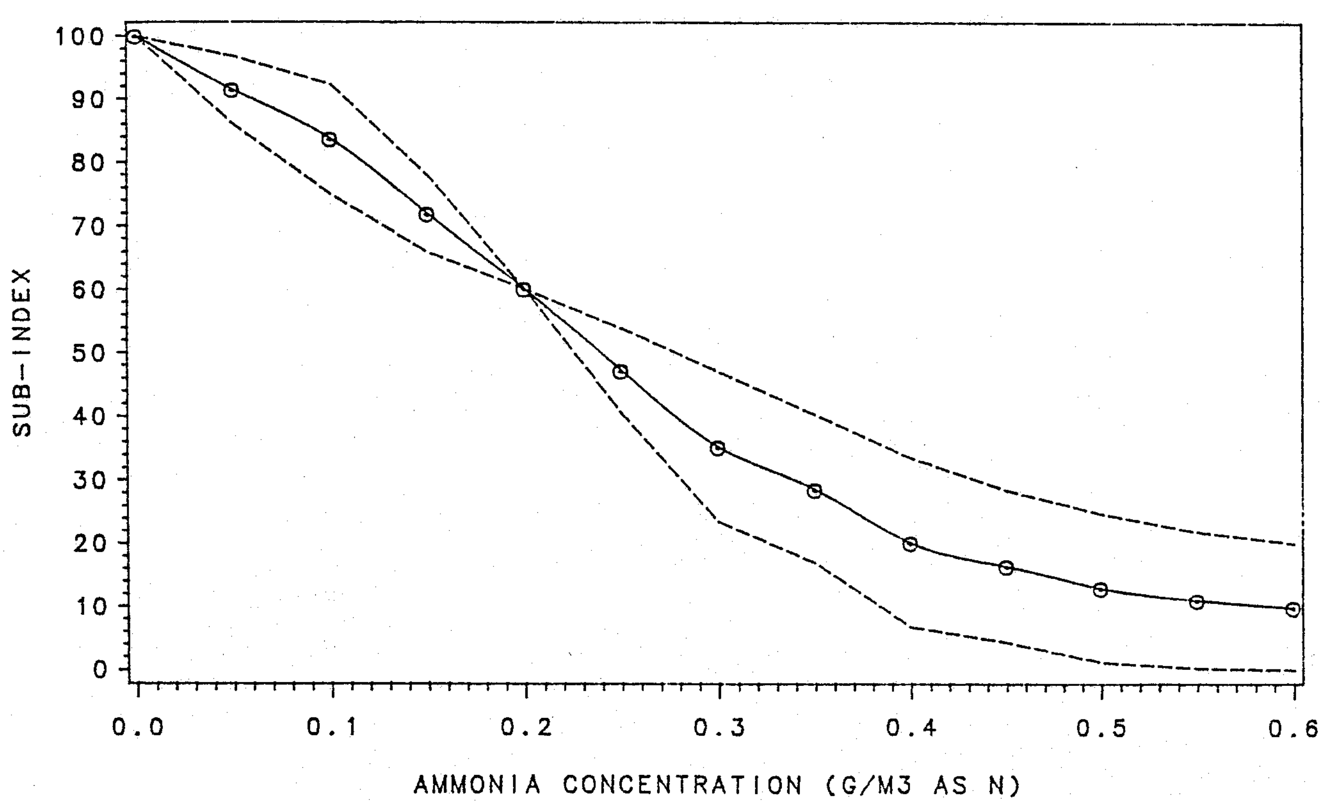
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 3 continued

SUPPLY INDEX: FAECAL COLIFORMS SUB-INDEX



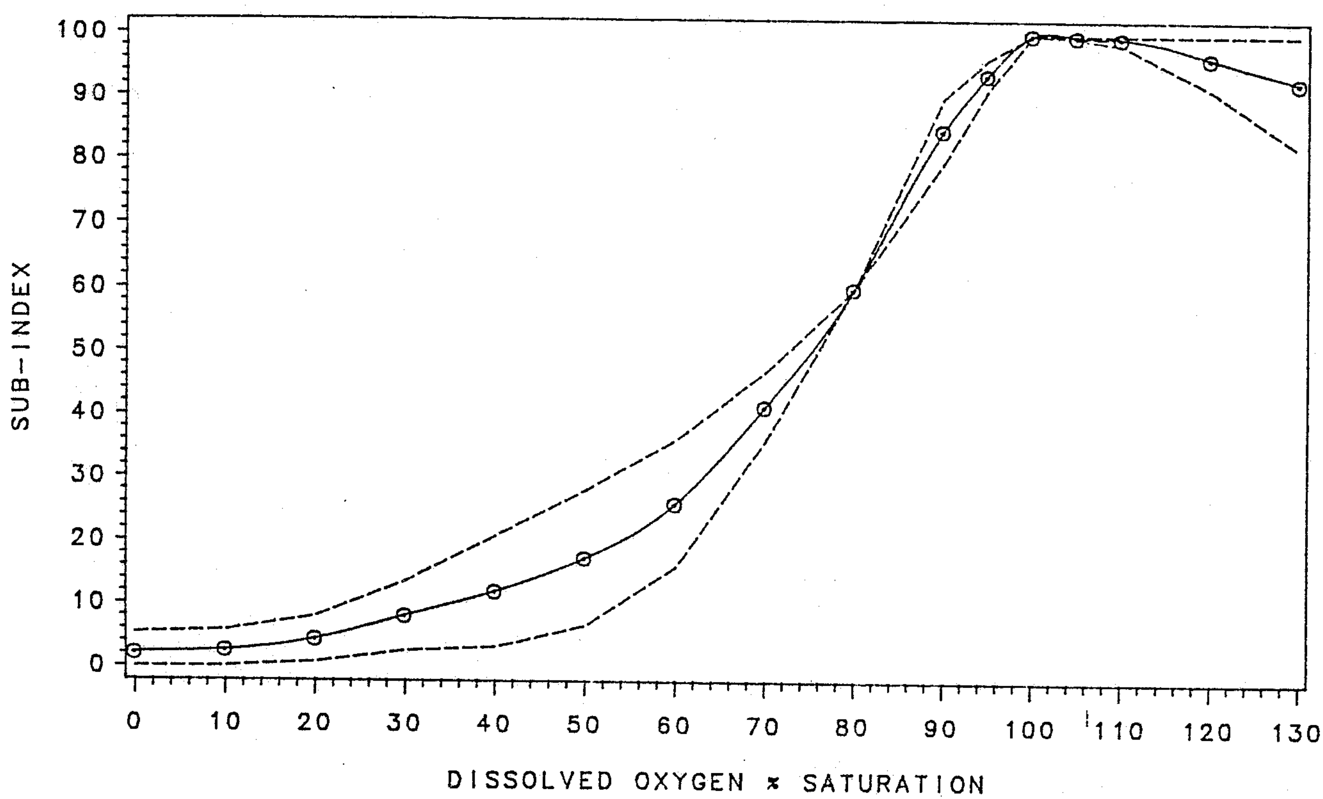
SUPPLY INDEX: AMMONIA SUB-INDEX



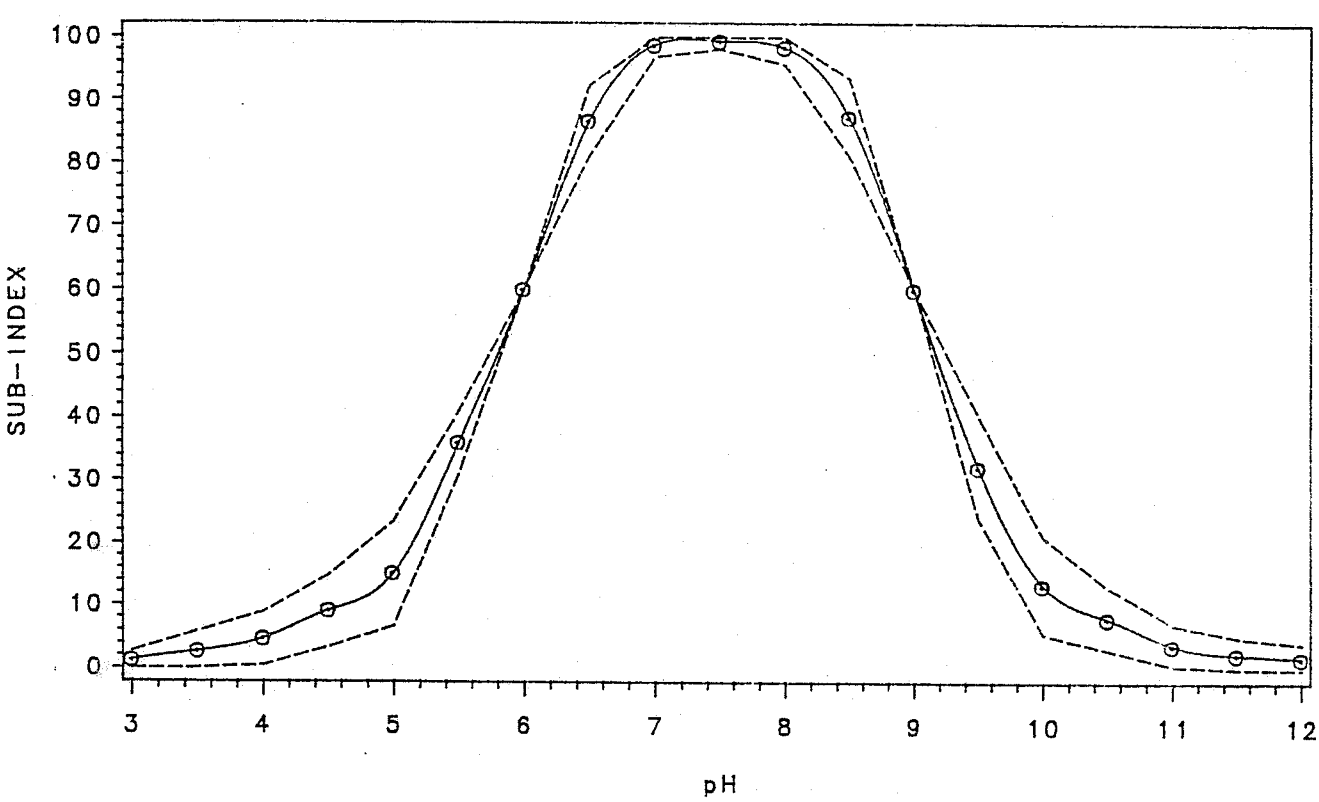
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 4. Fish Spawning Index: sub-index graphs

FISH SPAWNING INDEX: DISSOLVED OXYGEN SUB-INDEX



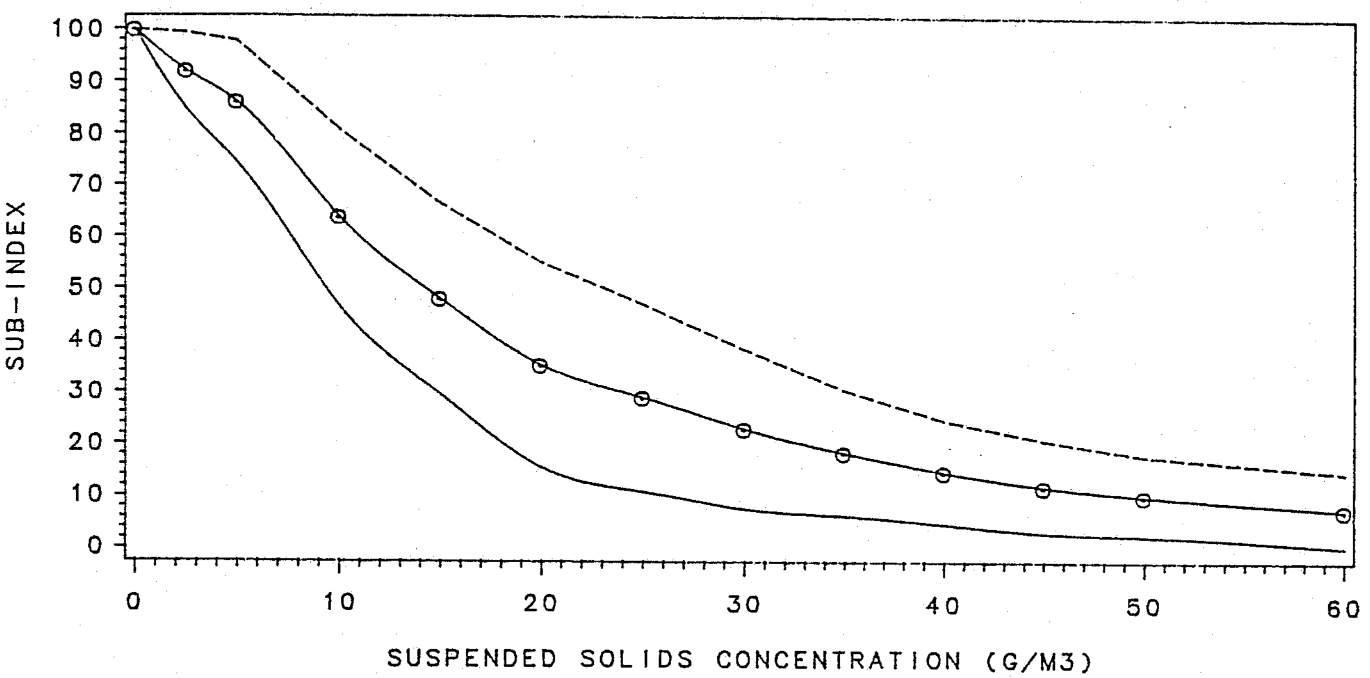
FISH SPAWNING INDEX: pH SUB-INDEX



(The upper and lower curves depict the 95% confidence interval at each point)

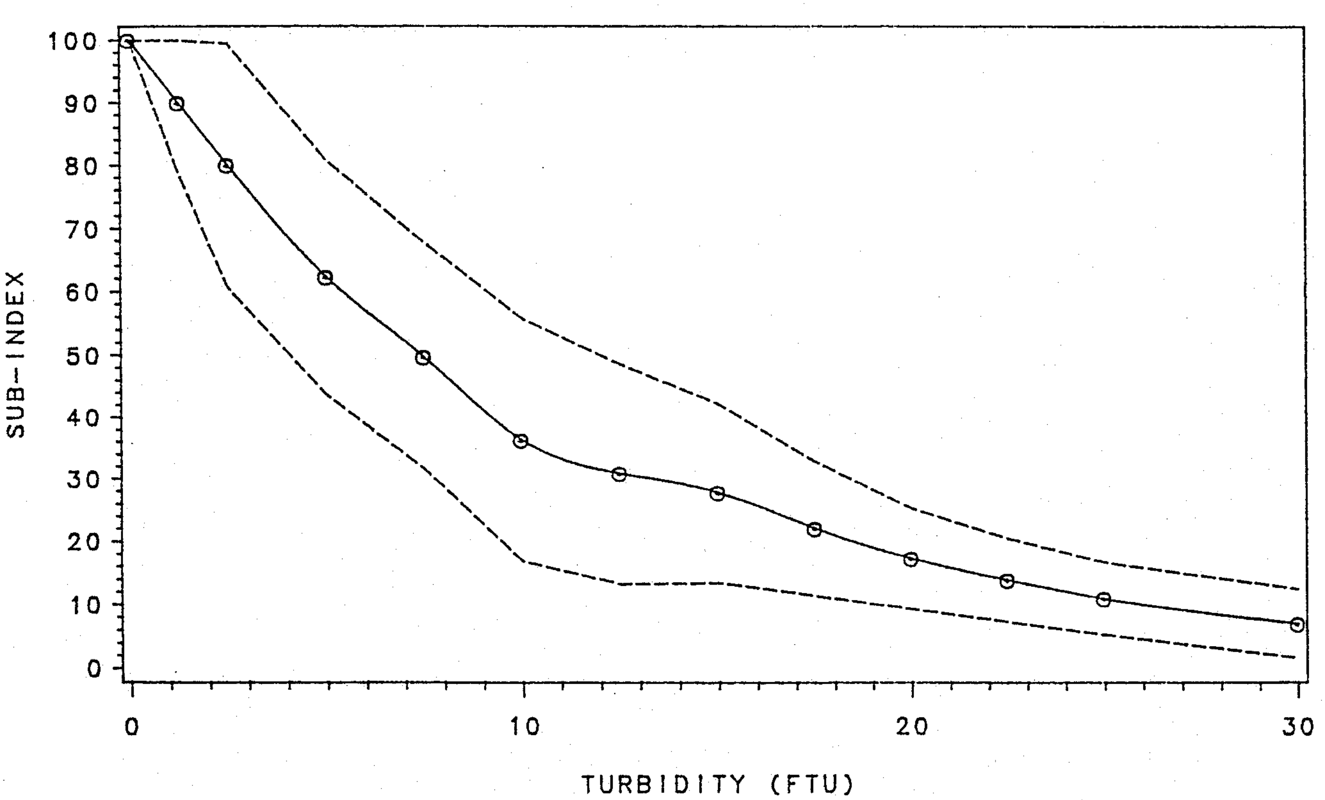
Figure 4 continued

FISH SPAWNING INDEX: SUSPENDED SOLIDS SUB-INDEX



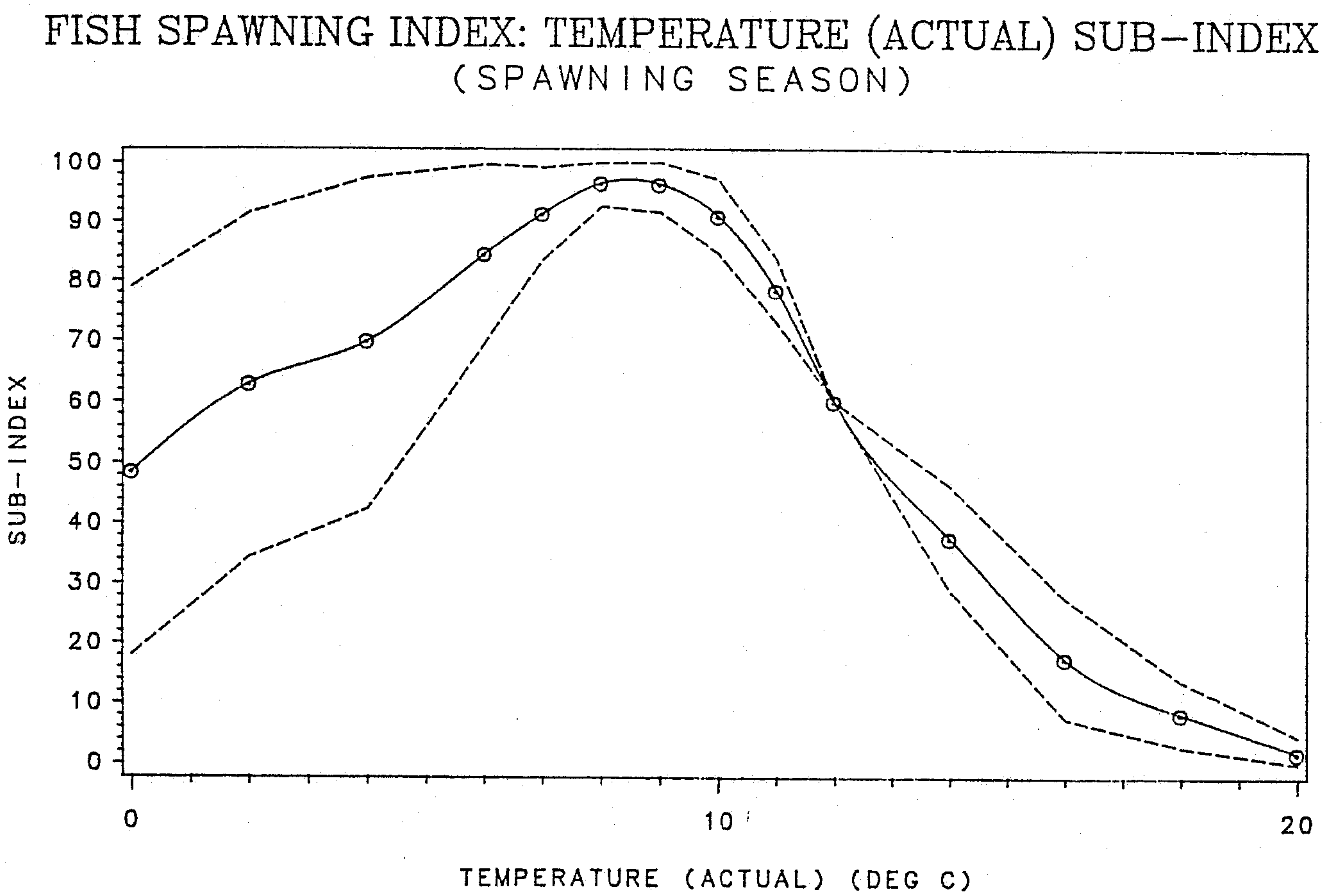
(For sub-index derivation use the bottom curve)

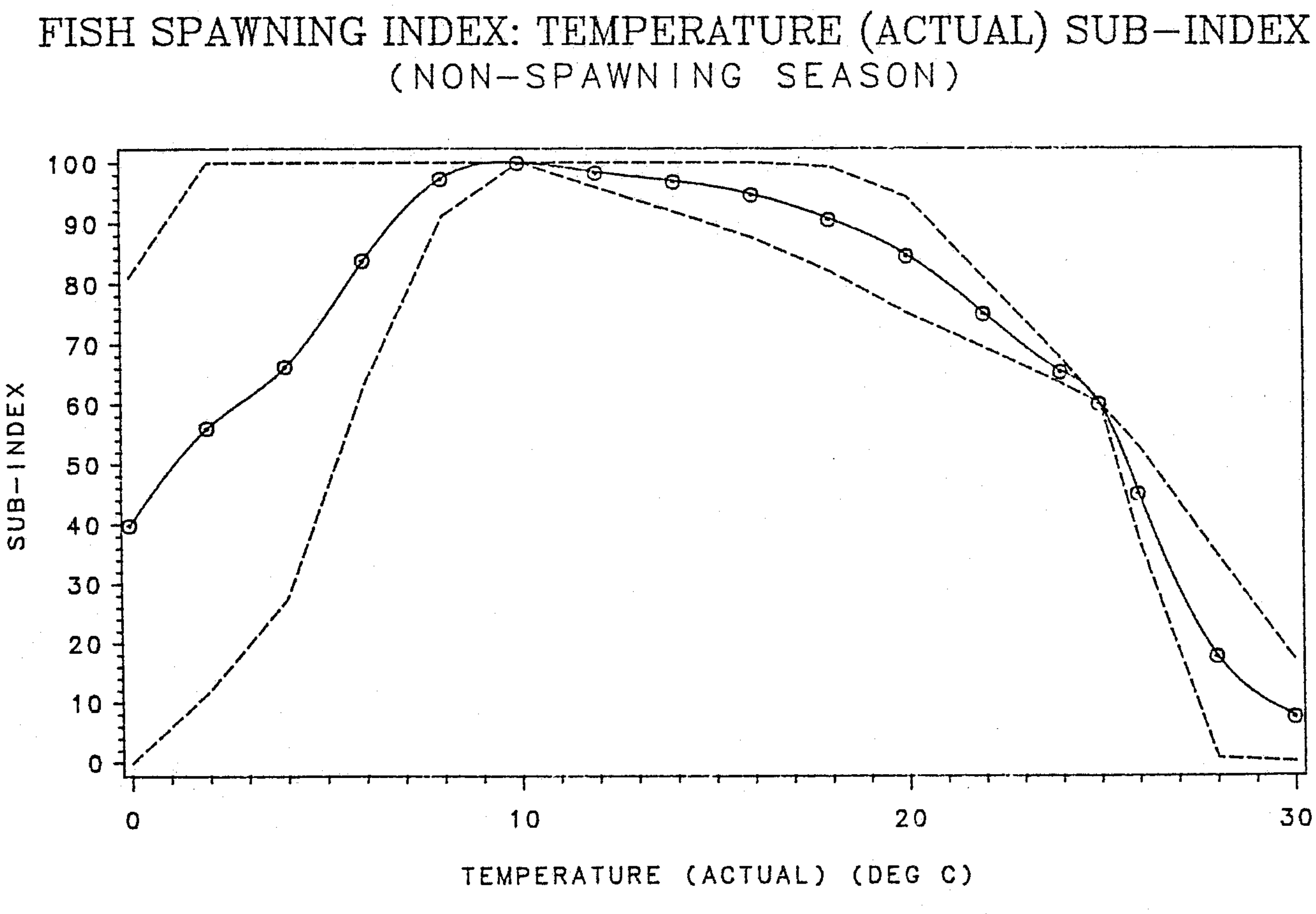
FISH SPAWNING INDEX: TURBIDITY SUB-INDEX



(The upper and lower curves depict the 95% confidence interval at each point)

Figure 4 continued

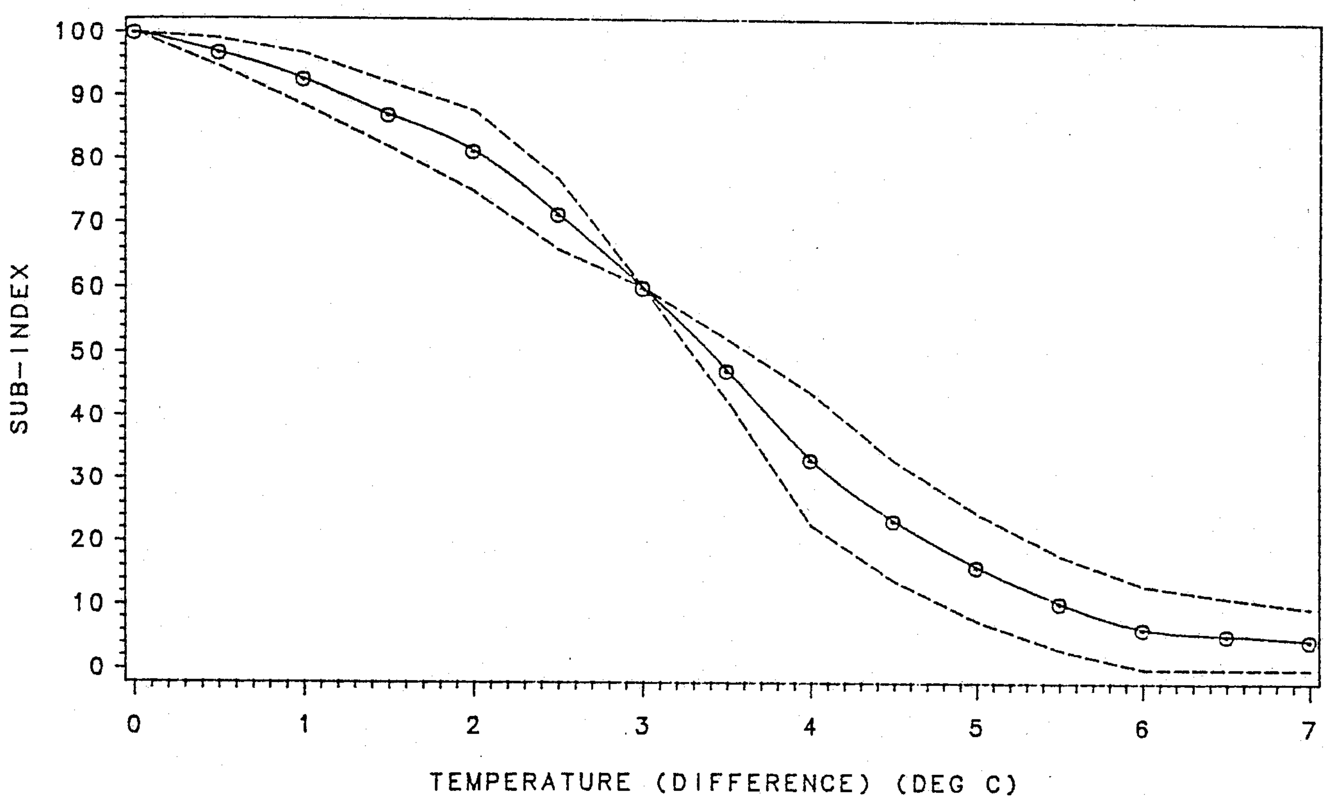




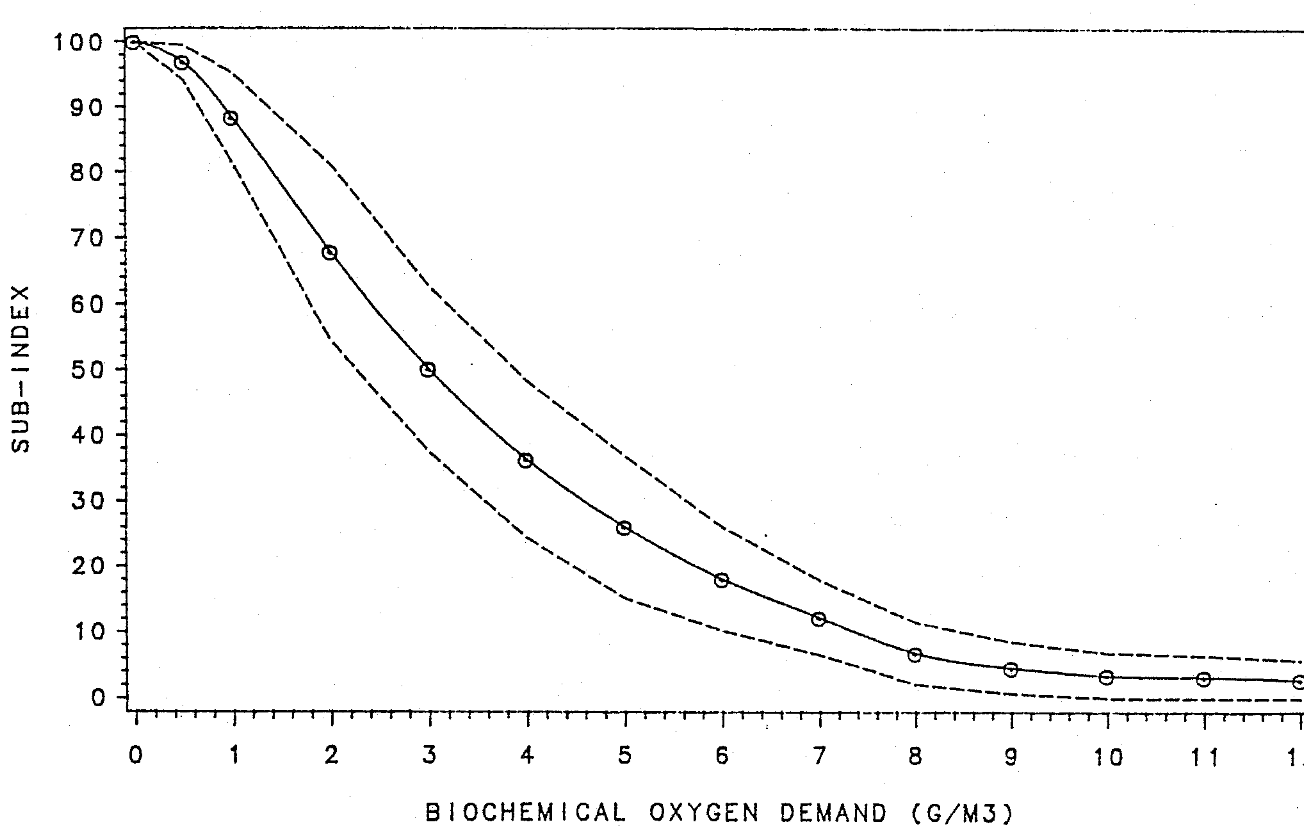
(The upper and lower curves depict the 95% confidence interval at each point)

Figure 4 continued

FISH SPAWNING INDEX: TEMPERATURE (DIFFERENCE) SUB–INDEX



FISH SPAWNING INDEX: BIOCHEMICAL OXYGEN DEMAND SUB–INDEX



(The upper and lower curves depict the 95% confidence interval at each point)

Selection of Aggregation Function (Minimum Operator)

As noted earlier, based on a literature survey, it appeared as though a weighted multiplicative aggregation function (equation 1 above) would be the most appropriate. According to Ott (1978) this type of aggregation produces few distortions and it was intended that it form the basis of a New Zealand Index. The study up to this point was geared to this.

However such an index was shown (Smith 1987b) to have problems which rendered it inappropriate for the suitability-for-use approach. Briefly, the aggregation function provides an index score which largely swamps the effect of one low sub-index score if all others are high. The greater the number of determinands in an index and the lower the weighting of the low sub-index determinand the worse this effect becomes. The index is thus insufficiently responsive to individual low sub-index values. Several alternatives were tried to remove this problem (Smith 1987b) but none was successful.

There seems to be no simple way which an index can be made more sensitive to single (or a few) 'low' sub-index values without at the same time inappropriately over-lowering the index in instances when all sub-indexes are similar.

Since no resolution of these problems is apparent, the only conclusion which could be reached is that water quality indexes using aggregation functions such as equation (1) which derive a mean and incorporate many determinands really do 'hide' too much valuable information and are therefore inappropriate in this instance.

It appears far more appropriate to use the Minimum Operator (equation 2) i.e. the final index value is simply the lowest sub-index value. Ott (1978) listed

21 characteristics that an ideal water quality index should possess. Nearly all are possessed by the Minimum Operator and this formulation has the added advantage over the more usual aggregation techniques in that it is very much more sensitive to a single determinand which could have a major impact on suitability-for-use. A Minimum Operator index is thus a limiting-value type of index (cf. the limiting nutrient concept in eutrophication studies). Also, additional determinands can easily be added to an index if required.

In addition, Landwehr (1979) and Lettenmaier et al. (1982) have pointed out that anomalous trends may be indicated using multiplicative (and additive) index aggregation techniques when no trend exists, if the underlying water quality simply becomes more variable. The use of the Minimum Operator would appear to remove this additional problem.

QUESTIONNAIRE NO. 5

This questionnaire (Appendix 10) sought the support of the panel for the sub-index curves developed and, additionally, the approach taken (i.e. use of Minimum Operator) to final index generation. Also sent in this mailing were the tables of final weightings and suspended solids/turbidity ratios (Tables 4 and 5 respectively). On reflection, the scale decriptors given above seemed to need some modification to encompass the spirit of multiple water use and the following seemed appropriate:

$I < 20$	Totally unsuitable for main and/or many uses.
$20 \leqslant I < 40$	Unsuitable for main and/or several uses.
$40 \leqslant I < 60$	Main use and/or some uses may be compromised.
$60 \leqslant I < 80$	Suitable for all uses.
$80 \leqslant I \leqslant 100$	Eminently suitable for all uses.

These descriptors were also put to the panel for comment. Also tested was the panel's response to a point made by one panel member that it seemed odd not to have a BOD sub-index for W waters while having one for other waters. It was suggested to the panel that the BOD sub-index graph for the G Index could be used to supplement the W Index if it were seen as important by an index user.

The results from Questionnaire No. 5 are presented in Table 6. There were 13 replies. Support for the graphs was overwhelming.

Table 6. Results from Questionnaire No. 5

1	Support sub-index graphs (Figs 1-4):	Yes	11
		No	2
2	Support use of Minimum Operator:	Yes	12
		No	0
		Other	1
3	Support use of BOD sub-index from G Index to supplement W Index if required:		
		Yes	12
		No	0
4	Support use of new scale descriptors:	Yes	12
		No	1

Only one respondent was highly critical of several aspects of the curves but an examination of the criticisms together with the scale descriptors showed little divergence in the spirit of the meaning of sub-index values. One major problem concerned the appropriateness of the suspended solids sub-index curve for the F Index. Consultation with several fish biologists confirmed the view of the dissenting panel member that the curve drawn through the mean points gave index values which were much too high. A more appropriate curve seems to be one drawn through the lower 95% confidence limits placed on each mean notwithstanding acceptance by all but one of the panel of the mean curve. The suggestion for use of the lower 95% confidence limit curve for deriving the sub-index in this instance was put to the panel via a separate letter and met with agreement. The main unresolved problem centres around the temperature sub-indexes for Fish Spawning waters. For example, the temperature (Actual) sub-index during the spawning season is the result of some respondents saying that a temperature of around 0°C should be rated zero, and others that it should be 100. Fortuitously, there may be some sense in the average response because experiments on hatching of salmonids (Humpesch, 1985) have shown that success of rainbow trout at low temperatures is low whereas it is very high for brown trout! The resultant curve could thus be seen as a compromise. This, of course, brings its own problems which are probably resolved only by having separate curves for each species. The value of such a compromise curve can really only be assessed by Index users.

In the Water Supply Index, just two respondent pointed out that flocculation is poor if the suspended solids concentration is very low. This was sufficient to reduce the sub-index for low suspended solids concentrations (perhaps insufficiently though).

One respondent pointed out that the temperature (Actual) sub-index for bathing waters (R Index) reaches a maximum of only 90, and that this was odd. However, it should be pointed out that we have conflicting uses for these waters and that over 20° when the water is very suitable for bathing, it is becoming less suitable for some forms of aquatic life. The group response seems to have produced a reasonable compromise curve.

The use of the Minimum Operator was very favourably received. Several comments supported the use of a limiting factor as being a sensible way to overcome aggregation problems, and better reflects the real situation which is probably dominated by limiting factors.

No respondents disapproved of the use of the General BOD_5 sub-index to supplement the Water Supply Index if required. One panel member expressed the view that additional determinands could be used if required and locally important. This, of course, is the beauty of the use of the Minimum Operator; additional sub-indexes can easily be added (unlike other aggregation techniques if weightings are used). The only (!) problem is to produce a reliable curve. Perhaps the sort of curves developed in this exercise can be of some help here. It also means that once a curve has been drawn up but found to be inappropriate in a certain region of the country it could be modified slightly to suit the region. There seems to be no real problems here provided it is flagged appropriately.

INITIAL TESTING OF THE INDEXES

Prior to dissemination of the indexes for the national testing, a preliminary test was carried out by the following means:

1 A second, totally different panel consisting of 23 members (mainly water managers, consultants and researchers) was selected.

2 To this panel was sent a questionnaire consisting of four tables of synthetic water quality data (one for each of the water uses, G, W, R, F, Appendix 11). A request was made that for each of the 10 waters in each table an index value should be derived.

3 Panel members were informed of the use of a sub-index score of 60 for determinands having proposed numerical standards, and were provided with:

a The specified uses for each water class (as in Appendix 1).

b The schedule to the MWD Draft Water and Soil Conservation Bill (June 1986) (Appendix 7).

c The scale descriptors (Appendix 10, part 4).

d A covering letter indicated the role of the indexes, their linkage to the legislation, and the use of the Minimum Operator.

4 Panel members were not, of course, provided with the sub-index graphs produced by the original panel. In this instance panel members had to produce their own assessment of a final index for each of the 40 waters listed. This is a very difficult exercise because each panel member had, in effect, to decide his/her own assessment technique.

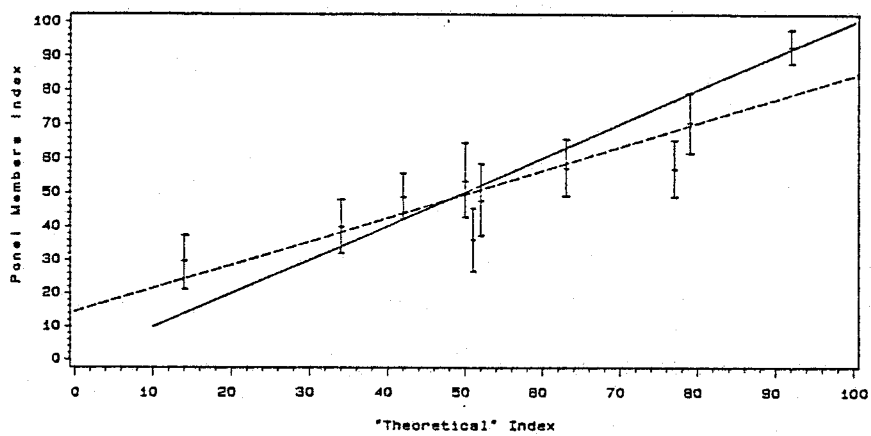
There were 17 responses received from the 23 questionnaires sent out but three were received after analysis was complete. The mean index values (and standard deviations) obtained by the panel are presented in Table 7 together with the 'theoretical' index values (i.e. those values derived from application of Figs. 1-4 to the water quality data). They are plotted in Fig. 5 together with the 95% confidence limits on the panel index values, the linear regression line, and

Table 7. Initial Index Testing: Panel member's mean index value and 'theoretical' values

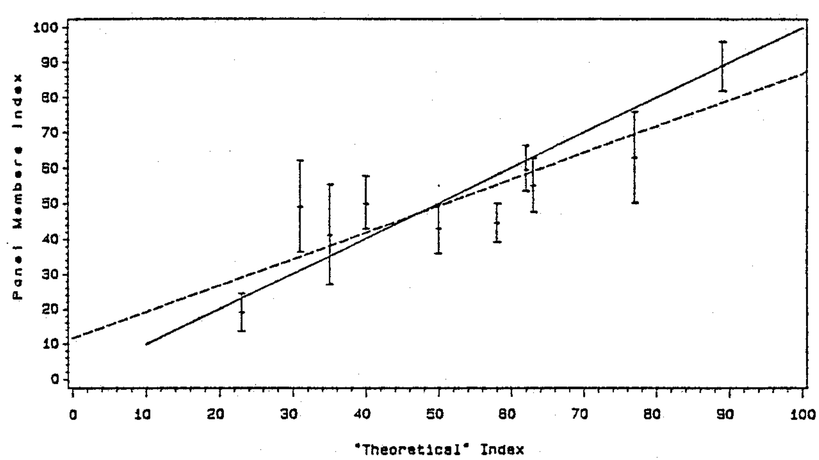
Water Code	General Index		Bathing Index		Supply Index		Fish Spawning Index	
	'Theoretical' index	Panel's index (SD)	'Theoretical' index	Panel's index (SD)	'Theoretical' index	Panel's index (SD)	'Theoretical' index	Panel's index (SD)
1	92	92.7 (8.6)	40	49.9 (12.5)	58	43.3 (17.2)	57	57.3 (22.4)
2	79	70.5 (16.1)	77	62.8 (22.2)	83	81.3 (10.7)	68	60.1 (22.1)
3	77	56.9 (14.2)	63	55.0 (13.3)	92	89.8 (10.5)	49	47.3 (10.5)
4	34	39.9 (13.9)	35	41.1 (24.3)	40	53.8 (15.0)	21	32.0 (16.9)
5	51	36.1 (15.2)	31	49.0 (22.3)	29	33.8 (13.9)	91	83.0 (22.2)
6	42	48.6 (11.7)	89	89.7 (12.1)	35	38.4 (9.8)	68	60.3 (21.2)
7	14	29.7 (14.0)	62	59.4 (10.0)	44	52.8 (15.9)	91	81.3 (22.9)
8	63	57.1 (14.3)	58	44.4 (8.1)	18	36.1 (14.0)	47	50.7 (18.0)
9	50	53.3 (19.2)	50	42.9 (12.0)	63	58.2 (12.0)	31	46.1 (18.3)
10	52	47.6 (18.7)	23	19.0 (9.0)	94	88.7 (10.2)	65	64.3 (20.8)
n		14		14		13		12

Figure 5. Initial Index Testing: panel members' index vs theoretical index

GENERAL INDEX: PANEL MEMBERS INDEX vs "THEORETICAL" INDEX



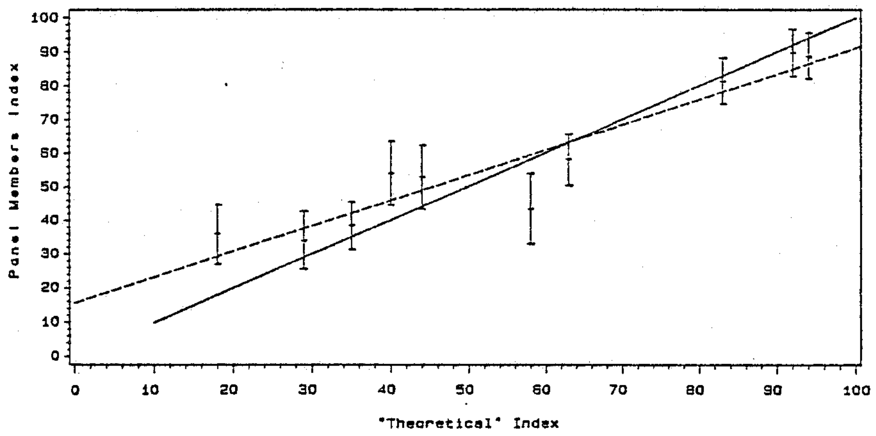
BATHING INDEX: PANEL MEMBERS INDEX vs "THEORETICAL" INDEX



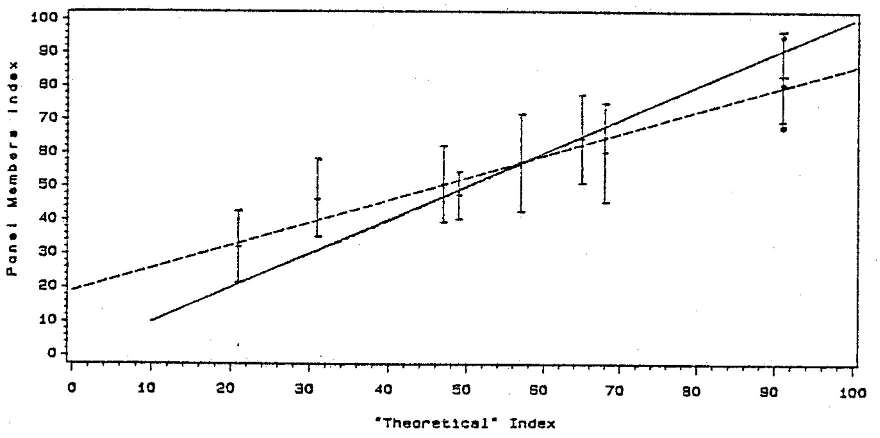
Note: The continuous line is the 'theoretical' line; the broken line is the line of linear regression for the means

Figure 5 Continued

SUPPLY INDEX: PANEL MEMBERS INDEX vs "THEORETICAL" INDEX



FISH SPAWNING INDEX: PANEL MEMBERS INDEX vs "THEORETICAL" INDEX



Note: The continuous line is the 'theoretical' line; the broken line is the line of linear regression for the means the 'theoretical' line. Values of r for the panel's G, R, W and F regressions are 0.89, 0.75, 0.94 and 0.97 respectively. In no instance was the regression line significantly different from the theoretical line ($p < 0.05$).

Panel members were also asked to assess which determinand was the limiting one. In general, their success at correct identification was very good except for 'theoretical' index values around and greater than 90 (i.e. many sub-index values will be similar). Turbidity and suspended solids index determining factors proved the most difficult to identify. The raw data for this exercise, an expansion on index determining factors, and a brief discussion of outliers is presented elsewhere (Smith, 1987c).

Based on this initial test, it was apparent that the four Water Quality Indexes were ready for nation-wide assessment.

USE OF THE INDEXES

1 Because the values of many determinands (particularly temperature, dissolved oxygen, pH may vary diurnally, for most comparison purposes measurements should be taken at a fixed time of day. Comparison of an index value derived from dawn measurements with one derived from late afternoon measurements should be made with full understanding of the processes taking place. These index values could certainly be derived but will need to be put into perspective. Perhaps mid-day values would be most suitable for within and between catchment comparisons?

2 For faecal coliforms the number to be used ought to be that generated as per the standards in the June 1986 Ministry of Works and Development's Draft Water and Soil Conservation Bill (see Appendix 7) i.e. a median value based on a minimum of one water sample taken on each of 5 separate days over not more than a 30 day period.

For other determinands, index values can be derived based on single determinand measurements. It is helpful to water management (and essential for trend detection) if sampling is regular in time, say monthly. Thus, monthly index values could be obtained (with due regard to faecal coliform sampling frequency) and a water's suitability-for-use assessed on this regular basis. Seasonal or annual index values could also be produced based on, say, a median of the monthly index values but useful information may be lost by this process. For instance, 'annual suitability' may appear satisfactory yet for several samplings (months) during the year the opposite may be the case.

Because the index uses a limiting value to assess suitability, it seems inappropriate to use a central measure of a determinand to derive an index value. Rather, the index value should be calculated for each sampling occasion and then the individual index values used to derive, say, an annual or seasonal median (or mean) (bearing in mind the caveat above).

3 The indexes take no account of potential toxicity problems. These seem to be fairly rare phenomena in New Zealand and we are probably wise to ignore them unless we know there is a problem. It would be an enormous job to include toxic materials in an index even if a simple (!) toxicity unit approach were adopted.

4 There seems to be no reason why additional determinands should not be included in an index if desirable at the local level. Clear flagging of this must be made of course. The main problem is generating an appropriate sub-index curve. It should not be the work of a single individual.

5 There seems to be no real problem in modification of curves at the local level if for some reason the 'national' curves do not do quite the right

job. This process should be carried out with caution and the resultant index flagged as 'modified'. Again, it seems unwise that a single individual does the job.

6 Missing values probably pose less of a problem with this index than others unless the missing values would have produced the lowest sub-index (in which case we have a real problem). In such circumstances the best solution may be not to produce an index value. It may be that an estimate for the determinand value can realistically be made but only detailed local knowledge can resolve this issue. Obviously effort must be made to obtain values for all determinands.

7 It seems largely inappropriate and pointless deriving an index value for a river or stream in flood. In such circumstances a high value for both suspended solids and turbidity will ensue. This will produce a low index score and the water will in all probability appear totally unsuitable for the main or many uses. In some instances, e.g. water supply, this may be useful but most of the time flood situations seem unsuited to index scoring. We are interested more in long-term base flow conditions.

8 Index users should always be aware of the limited data set used. An index value _per se_ may _not_ necessarily provide the complete suitability-for-use picture (e.g. toxic materials are not accounted for).

Index calculation

There are very few rules to apply. They are:

1 Obtain all the necessary determinand values.

2 Derive sub-indexes for each from the appropriate curves in Figs. 1-4

using the BOD sub-index curve in the General Index for the Water Supply Index if required.

3 Find the lowest sub-index value. This is the final index value.

The appropriate determinand code could follow the index value, e.g. 64(DO), meaning that the index value is 64 and Dissolved Oxygen is the limiting factor (i.e. has the lowest sub-index value). A descriptor may, if required, be used. In which case use the appropriate one from Appendix 10.

CONCLUDING REMARKS

For the Minimum Operator concept to be workable, curves need to be extremely well based because it is an individual sub-index value which produces the final index. There is no buffering by the many. Most of the curves produced by this exercise seem reasonable but it has to be pointed out that the spread of responses is disconcerting. We simply do not know enough about the effects of the values of many determinands on a water's suitability for use(s) (e.g. effects of suspended solids and turbidity). Multiplicity of uses confuses the issue still further.

In view of this uncertainty, the Indexes should at first be used with caution. Only their use and subsequent approval by water managers will validate them. Users of the Indexes are invited to submit comments on their usefulness to the author of this report. Only by this means can firm recommendations on their value for water management be made.

Finally, there are two cautionary words for those involved in water management:

1 Do not ask a single scientist which determinands should be measured without first giving a constraint in number (or cost). There are too many differences of opinion if the question is too open-ended.

2 Do not ask a single scientist what are the effects on suitability-for-use for a particular determinand value. The range of responses shown in this exercise is too great for much reliance to be placed on one opinion.

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PERCEIVED WATER USES FOR THE PROPOSED WATER USE CLASSES (WQCWP, 1981)

(This information was provided to panel members to assist with all the questionnaires in this project)

Class G water. This is water for "general use purposes". These waters have no singled-out principal use, but are subject to competing uses. These waters would be protected and maintained for the following uses:

(a) the maintenance of a substantially unaltered aquatic community;
(b) the general aesthetic amenity;
(c) fishing;
(d) stock watering;
(e) irrigation;
(f) public water supply after extensive treatment;
(g) occasional contact use such as swimming;
(h) waste assimilation.

The 'standards' for this water classification would generally be lower than for the specific uses.

Class R water. This is water for "regular public bathing". However, note that other uses, and in particular aquatic life, also require protection.

Class W water. The main use for, and expected treatment of, this water is stated in the schedule. Aquatic life is also protected, but at a lower level than for Classes R and F.

Class F water. This is water "specifically protected for fish spawning purposes". It would be easier, at a later stage in index development, to assume that these waters are salmonid waters so as to ensure the high degree of protection required.

QUESTIONNAIRE NO. 1a

Panel Member Code

Candidate characteristics for the GENERAL water use index

Please put a 'x' in the appropriate column

Characteristics	Don't include	Undecided	Include	For characteristics marked 'include', rate their importance 1 is high, 5 is low 1 2 3 4 5
Oil and grease				
Faecal coliforms				
Total coliforms				
Dissolved oxygen				
Colour (Hazen, i.e. Pt-Co units)				
Colour (Hue)				
Turbidity (FTU)				
Suspended solids				
Dissolved solids				
Total solids				
Conductivity				
Alkalinity				
Acidity				
Hardness				
Calcium				
Magnesium				
Silica				
Nitrate				
Phosphate (total P)				
Phosphate (reactive dissolved P)				
Temperature				
BOD_5 (unfiltered)				
BOD_5 (filtered)				
COD				
Organic carbon				
pH				
Chloride				
Sulphate				
Iron (as Fe^{2+})				
Manganese (as Mn^{2+})				
Ammonia				
Sodium				
Potassium				
Other(s) (specify)				

APPENDIX 3a

FORMAT FOR QUESTIONNAIRE NO. 2, PART 1

<u>QUESTIONNAIRE NO. 2a PART 1</u>　　　　　Panel Member Code

Candidate characteristics for the GENERAL water use index (i.e. for running, surface water).

Please compare your response with the summary of all responses and alter your original response if you wish (please make this very obvious).

Don't forget, we are interested in the water *per se*.

	THIS IS YOUR RESPONSE				THIS IS A SUMMARY OF ALL RESPONSES								
Characteristics	Don't include	Undecided	Include	Importance 1 is high, 5 is low 1 2 3 4 5	Don't include	Undecided	Include	Importance 1 is high, 5 is low 1	2	3	4	5	Mean
Oil and grease					3	0	12	4	4	2	0	2	2.33
Faecal coliforms					5	0	11	3	2	0	4	1	2.80
Total coliforms					12	0	3	0	0	1	1	1	4.00
Dissolved oxygen					0	0	16	10	5	0	0	0	1.33
Colour (Hazen, i.e. Pt-Co units)					7	2	7	1	1	3	1	1	3.00
Colour (Hue)					5	4	6	1	3	1	0	1	2.50
Turbidity (FTU)					4	1	10	1	5	4	0	0	2.30
Suspended solids					2	0	14	2	5	4	2	0	2.46
Dissolved solids					12	2	1	0	0	0	0	1	5.00
Total solids					13	1	0	-	-	-	-	-	-
Conductivity					5	1	9	0	1	6	1	0	3.00
Alkalinity					11	1	3	0	0	2	1	0	3.33
Acidity					13	1	1	0	0	0	1	0	4.00
Hardness					9	1	6	0	0	3	0	3	4.00
Calcium					13	1	1	0	0	0	0	1	5.00
Magnesium					14	1	0	-	-	-	-	-	-
Silica					14	1	0	-	-	-	-	-	-
Nitrate					1	1	14	0	2	3(1)	3	3	3.62
Phosphate (total P)					5	2	7	0	1	4(1)	0	3	3.21
Phosphate (reactive dissolved P)					1	4	10	0	2	3(1)	3	0	3.17
Temperature					2	0	14	2	4	6	1	0	2.46
BOD_5 (unfiltered)					1	2	11	4	4	1	1	0	1.90
BOD_5 (filtered)					9	2	3	1	2	0	0	0	1.67
COD					10	3	2	0	0	1	0	1	4.00
Organic carbon					11	1	2	0	0	2	0	0	3.00
pH					1	1	14	3	6	4	0	0	2.08
Chloride					12	1	3	0	0	1	0	2	4.33
Sulphate					14	1	0	-	-	-	-	-	-
Iron (as Fe^{2+})					11	1	3	0	0	1	1	1	4.00
Manganese (as Mn^{2+})					12	1	2	0	0	0	1	1	4.50
Ammonia					2	3	11	3	4	1(1)	0	1	2.25
Sodium					14	1	0	-	-	-	-	-	-
Potassium					14	1	0	-	-	-	-	-	-
Other(s) (specify)													

(1) indicates responses at 3.5

Note: the mean values in the extreme right column are calculated as follows; e.g. for oil and grease [(4x1) + (4x2) + (2x3) + (2x5)]/(4 + 4 + 2 + 2).

APPENDIX 3b FORMAT FOR QUESTIONNAIRE NO. 2, PART 2

QUESTIONNAIRE NO. 2a PART 2 Panel Member Code

This part of the questionnaire contains a list of candidate characteristics for GENERAL water use index ranked in order of no. of 'include' requests and secondly mean importance rating obtained from questionnaire 1a. In the blank column, please designate (use a 'x') up to 10 characteristics which you consider the most important.

Characteristics	No of respondents indicating 'include'	Mean importance rating (1 is high, 5 is low)	Designate up to 10 you consider the most important*
Dissolved oxygen	16	1.33	
pH	14	2.08	
Suspended solids	14	2.46	
Temperature	14	2.46	
Nitrate	14	3.62	
Oil and grease	12	2.33	
BOD (unfiltered)	11	1.90	
Ammonia	11	2.25	
Faecal coliforms	11	2.80	
Turbidity (FTU)	10	2.30	
Phosphate (RDP)	10	3.17	
Conductivity	9	3.00	
Colour (Hazen)	7	3.00	
Phosphate (total P)	7	3.21	
Colour (Hue)	6	2.50	
Hardness	6	4.00	
BOD (filtered)	3	1.67	
Alkalinity	3	3.33	
Total coliforms	3	4.00	
Fe (as Fe^{2+})	3	4.00	
Chloride	3	3.33	
Organic carbon	2	3.00	
COD	2	4.00	
Mn (as Mn^{2+})	2	4.50	
Acidity	1	4.00	
Calcium	1	5.00	
Dissolved solids	1	5.00	
Characteristics added by at least one panel member:			
Substrate chlorophyll-a			
Substrate carbon			
Froth			
Boron			
Lithium			
Potassium (if irrigating)			
Floating material			

*Don't forget, in the next questionnaire you will be asked to develop a rating curve for each selected characteristic. For this, the ordinate will be a 0-100 'sub-index' and the abscissa the maximum concentration range expected. The characteristics chosen must therefore be not only easily sampled and analysed for, but some assessment of the significance of each point in a range of measurements must be possible, if only approximately. Also, please remember we are dealing here with the water *per se*.

APPENDIX 4 QUESTIONNAIRE NO. 2 SUPPLEMENTARY

Panel Member code

1 Do you see a value in attempting to produce a perception type of index for bathing waters incorporating psychophysical aspects of water assessment (e.g., colour, odour, oil/grease film, site appearance)

YES/NO

Comment:

2 Do you wish that ammonia be incorporated into the following indices:

General:	YES/NO.	If yes, why?
Bathing:	YES/NO.	If yes, why?
Water supply:	YES/NO.	If yes, why?
Fish spawning:	YES/NO.	If yes, why?

Comment:

3a Do you see any value in my attempting to have a panel discussion after, say, the results from this questionnaire have been collated?

YES/NO.

3b If a panel discussion is set up, would you be able to attend?

YES/NO.

If yes, preferred location: HAMILTON/WELLINGTON.

Comment:

4 If temperature is included in a final index should it be as a difference above background, the actual temperature itself, or both

General:	DIFFERENCE/ACTUAL/BOTH
Bathing:	DIFFERENCE/ACTUAL/BOTH
Water Supply:	DIFFERENCE/ACTUAL/BOTH
Fish Spawning:	DIFFERENCE/ACTUAL/BOTH

Comment:

RESULTS FROM QUESTIONNAIRE NO. 2 SUPPLEMENTARY

1 Do you see a value in attempting to produce a perception type of index for bathing waters incorporating psychophysical aspects of water assessment (e.g., colour, odour, oil/grease film, site appearance)
YES 16; NO 0
(a couple of respondents said yes, but...)

2 Do you wish that ammonia be incorporated into the following indices.
General: YES 7; NO 8.
Reasons for inclusion were pollution index/indicator, nutrients, toxicant, measure of intensity of use.

Bathing: YES 8; NO 7.
Reasons for inclusion were pollution index/indicator, nutrient, toxicant, measure of intensity.

Water Supply: YES 14; NO 1.
Reasons for inclusion were chlorination, pollution index/indicator, toxicant, human health, nitrate formation, chloramine formation, tast, odours.

Fish Spawning: YES 14; NO 2.
Reasons for inclusion were toxicant (by almost all), enrichment indicator, pollution index/indicator, oxygen demand in gravels, acidification during nitrification, enrichment indicator.

3 The panel was split 8:8 in favour of having a panel discussion and 10/13 said they would attend, the majority favouring Wellington.

4 If temperature is included in a final index should it be as a difference above background, the actual temperature itself, or both.

General:	Difference 4, Actual 2, Both 5.
Bathing:	Difference 4, Actual 2, Both 5.
Water Supply:	Difference 2, Actual 3, Both 5.
Fish Spawning:	Difference 0, Actual 6, Both 7

APPENDIX 6 QUESTIONNAIRE NO.3

Panel Member No.

Your agreement/disagreement, plus any comments you may have, are required for the following suggestions.

1 Temperature: include only actual temperature.
Agree/Disagree
Comment:

2 Oil/grease: omit.
Agree/Disagree
Comment:

3 Ammonia: include for Water Supply Index only.
Agree/Disagree
Comment:

4 Dissolved oxygen: units should be 'concentration' for General, Bathing and Water Supply Indexes, and '% saturation' for Fish Spawning Index.
Agree/Disagree
Comment:

5 Sub-index generation. To assist panel members construct sub-index rating curves for each chosen determinand we use, as a basis, the scales
0-20 Totally unsuitable for use(s)
20-40 Inadequate for use(s)
40-60 Marginally suitable for use(s)
60-80 Suitable for use(s)
80-100 Eminently suitable for use(s)
Agree/Disagree
Comment:

6 To construct sub-index rating curves for determinands which have numberical standards we adopt a fixed reference point at 60 for the standard value (see p. 3 of my suggestions paper).
Agree/Disagree
Comment:

7 For a final index we use the same descriptors as noted in Q5 above.
Agree/Disagree
Comment:

8 The following determinands (marked with X) be used in the indexes (see Table on last page of Questionnaire No. 2 Analysis Paper).

	General	Regular Public Bathing	Water Supply	Fish Spawning (Salmonids)
Dissolved oxygen	X	X	X	X
pH	X	X	X	X
Suspended solids/turbidity	X	X	X	X
Temperature	X	X	X	X
BOD (unfiltered)	X	X		X
Ammonia			X	
Faecal coliforms	X	X	X	

APPENDIX 7 SECOND SCHEDULE TO THE MWD DRAFT WATER AND SOIL CONSERVATION BILL (JUNE 1986)

CLASS G WATER (Being water for general use purposes)

(a) The natural water temperature shall not be changed by more than 3° Celsius and shall not exceed 25° Celsius.

(b) The pH of the water shall be within the range 6.0-9.0 units.

(c) The water shall not be tainted or polluted so as to make it unpalatable or unsuitable for consumption by farm animals, or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no substantial adverse effects on the aquatic community by reason of pollutants.

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

(h) The concentration of dissolved oxygen shall exceed 5 gram per cubic metre.

(i) There shall be no excessive slime growths as a result of organic substances.

Where the water condition does not comply with these requirements, no action shall be permitted which will cause the water condition to deviate further from compliance with these requirements.

CLASS R WATER (being water for regular public bathing)

(a) The natural water temperature shall not be changed by more than 3° Celsius and shall not exceed 25° Celsius.

(b) The pH of the water shall be within the range 6.5-9.0 units.

(c) The water shall not be tainted or polluted so as to make it unpalatable or unsuitable for consumption by humans or farm animals, or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) The aquatic community shall not be adversely affected by reason of pollutants.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of pollutants.

(g) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(h) There shall be no visible oil or grease films or conspicuous floating or suspended waste materials.

(i) The median faecal coliform bacteria concentration shall not exceed 200 per 100 millilitres based on a minimum of one water sample taken on each of five separate days over not more than a 30 day period; nor shall more than 10% of samples taken on separate days during any 30 day period exceed 400 faecal coliforms per 100 millilitres.

(j) The concentration of dissolved oxygen shall exceed 5 gram per cubic metre.

(k) There shall be no undesirable biological growths as a result of pollutants.

Where the water condition does not comply with these requirements, no action shall be permitted which will cause the water condition to deviate further from compliance with these requirements.

CLASS W WATER (Being water for a source for public water supply or for the preparation and processing of food for sale for human consumption where treatment at least equivalent to flocculation, filtration, and disinfection could be reasonably expected)

(a) The natural water temperature shall not be changed by more than 3° Celsius and shall not exceed 25° Celsius.

(b) The pH of the water shall be within the range 6.5-9.0 units.

(c) The water shall not be tainted or polluted so as to make it unpalatable or unsuitable for consumption by farm animals, or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no substantial adverse effect on the aquatic community by reason of pollutants.

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) There shall be no visible oil or grease films or conspicuous floating or suspended waste materials.

(h) The median faecal coliform bacteria concentration shall not exceed 2000 per 100 millilitres based on a minimum of one water sample taken on each of five separate days over not more than a 30 day period; nor shall more than 10% of samples taken on separate days during any 30 day period exceed 400 faecal coliforms per 100 millilitres.

(i) The concentration of dissolved oxygen shall exceed 5 gram per cubic metre.

(j) There shall be no undesirable biological growths as a result of pollutants.

(k) The concentration of ammonia-nitrogen shall not exceed 0.2 gram per cubic metre.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water condition to deviate further from compliance with these requirements.

CLASS F WATER (Being water specially protected for fish spawning purposes)

(a) The natural water temperature shall not be changed by more than 3° Celsius and shall not exceed 25° Celsius. For salmonid spawning waters during the spawning season the water temperature shall not exceed 13° Celsius.

(b) The pH of the water shall be within the range 6.0-9.0 units, and within that range the maximum change shall not be greater than 1.0 unit.

(c) The water shall not be tainted or polluted so as to make it unpalatable or unsuitable for consumption by humans or farm animals, or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no adverse effect on the aquatic community by reason of pollutants.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of pollutants.

(g) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(h) There shall be no visible oil or grease films or conspicuous floating or suspended waste materials.

(i) The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(j) There shall be no undesirable biological growths as a result of pollutants.

Where the water condition does not comply with these requirements, no action shall be permitted which will cause the water condition to deviate further from compliance with these requirements.

APPENDIX 8 QUESTIONNAIRE NO 3: ANALYSIS OF RESULTS AND DISCUSSION

(This was sent to the panel with Questionnaire No. 4)

No of returns analysed = 14

1 Temperature: Although 9 favoured using only the actual temperature, I have been convinced that there is sufficient merit in using difference to include it in the index. It can be simply done in the following manner.

If w_t is the assigned weighting for temperature, we take $w_t/2$ to be the weighting for both actual and difference if both are available. If a user wishes to use only actual, then assign it the full weighting w_t.

2 Oil/grease: 10 are now in favour of omitting this from the indices. A psycho-physical index will be attempted at a later stage and oil/grease included.

3 Ammonia: 9 agree that it should only be used in the water supply index in its role of prevention of chlorination difficulties.

4 Dissolved oxygen: 13 agree that concentration be used for General, Bathing and Water Supply Indices, and % saturation be used for Fish Spawning only. So be it.

5 Sub-index scales and descriptors: 12 agreed with the suggestion. There will be just one minor charge, viz., 20-40 unsuitable for use.

6 Use of 60 as a fixed reference point: 10 agreed to this. 2 respondents said 50, 1 said 80, therefore 60 seems about right.

7 Final index scales and descriptors: 11 agreed with the suggestion, 2 basically said "give it a go", and there was one no response.

8 Index determinands: 7 agreed with the tabulated determinands. The other 7 were in basic agreement but most suggested addition of one or two determinands. However, the responses to Q2 and 3 largely resolved these issues and I believe we are at a stage of having as much agreement as is possible.

APPENDIX 9 QUESTIONNAIRE 4(a) - FINAL WEIGHTING DERIVATION

Panel Member No:

Here, we are to produce the final relative weighting for each determinand for each index. Would you please rate the relative importance of each of the determinands listed, with respect to a water's suitability for use in each of the water classes (use indices) listed. The mean ratings from Questionnaire 1, where all potential determinands were included, are given in brackets.

Note in particular the new term 'suspended material'. This takes into account all the effects of suspended particles. This step has already been agreed to (see last questionnaire) and all I have done here is to provide a new name. The earlier weightings provided under this heading are for suspended solids and turbidity respectively.

GENERAL

	Relative importance (1 is highest)				
	1	2	3	4	5
Dissolved oxygen (1.33)					
pH (2.08)					
Suspended material (SS 2.46; Turb 2.30)					
Temperature (2.46)					
BOD (unfiltered) (1.90)					
Faecal coliforms (2.80)					

If you were allowed suspended solids or turbidity as a measure of the importance of suspended material, what would be your relative preference? Give a ratio

$\frac{SS}{Turb} = \_\_\_$

REGULAR PUBLIC BATHING

	Relative importance (1 is highest)				
	1	2	3	4	5
Dissolved oxygen (2.00)					
pH (2.50)					
Suspended material (SS 2.33; Turb 1.70)					
Temperature (2.71)					
BOD (unfiltered) (2.00)					
Faecal coliforms (1.14)					

If you were allowed suspended solids or turbidity as a measure of the importance of suspended material, what would be your relative preference? Give a ratio

$\frac{SS}{Turb} = \_\_\_$

APPENDIX 9 Continued

WATER SUPPLY

	Relative importance (1 is highest)				
	1	2	3	4	5
Dissolved oxygen (2.41)					
pH (1.90)					
Suspended material (SS 2.10; Turb 2.87)					
Temperature (2.31)					
Ammonia (2.35)					
Faecal coliforms (1.75)					

If you were allowed suspended solids or turbidity as a measure of the importance of suspended material, what would be your relative preference? Give a ratio

$\frac{SS}{Turb}$ = ___

FISH SPAWNING (Salmonids)

	Relative importance (1 is highest)				
	1	2	3	4	5
Dissolved oxygen (1.00)					
pH (1.73)					
Suspended material (SS 1.64; Turb 2.20)					
Temperature (1.20)					
BOD (unfiltered) (1.67)					

If you were allowed suspended solids or turbidity as a measure of the importance of suspended material, what would be your relative preference? Give a ratio

$\frac{SS}{Turb}$ = ___

APPENDIX 10

QUESTIONNAIRE NO. 5

1 Do you support use of the attached sub-index graphs for use in water quality indexes?

Yes/No/Other.............

Comment:

2 Do you support the use of the Minimum Operator (see letter and earlier information) to derive final index values?

Yes/No/Other.............

Comment:

3 Do you support the use of BOD from the General Index to supplement the Water Supply Index if BOD is seen as important for this use by an index user?

Yes/No/Other.............

Comment:

4 Do you support the use of the following descriptors for use with a final index:

$I<20$	Totally unsuitable for main and/or many uses
$20\leqslant I<40$	Unsuitable for main and/or several uses
$40\leqslant I<60$	Main use and/or some uses may be compromised
$60\leqslant I<80$	Suitable for all uses
$80\leqslant I\leqslant 100$	Eminently suitable for all uses

Yes/No/Other.............

Comment:

APPENDIX 11 WATER QUALITY DATA USED IN THE INITIAL INDEX TESTING

Data for Class G (General Use) river water

		River code									
Determinand (units)	'Standard'	1	2	3	4	5	6	7	8	9	10
DO (g/m^3)	5.0	9.3	9.8	7.5	4.5	7.7	9.5	11.3	5.2	10.8	10.8
pH	6-9	7.5	7.8	7.7	8.1	8.5	9.5	4.1	7.5	6.9	7.5
Temp (°C)	25	18.6	14.6	13.0	20.0	23.5	22.2	10.9	15.5	7.5	11.5
Temp diff (°C)[1]	3	-	-	0.5	1.0	-	1.5	0.2	0.0	0.0	-
Susp. solids (g/m^3)		<0.5	3.9	3.4	15	24	5.0	22	7.0	25	12
Turbidity (FTU)		0.2	1.1	3.1	4.0	12.0	3.0	0.4	3.0	-	13.5
BOD (g/m^3)		0.3	0.7	1.5	5.7	1.5	0.7	0.5	3.0	0.4	1.0
F. coli (median n/100 ml, 5 samples)		2	190	220	50	912	36	5	58	80	300
Assessment of suitability-for-use Index score[2]											

Notes: 1 Temperature difference above natural value
2 See attached uses and suitability-for-use descriptors for assistance

Data for Class R (Regular Public Bathing Use) river water

		River code									
Determinand (units)	'Standard'	1	2	3	4	5	6	7	8	9	10
DO (g/m^3)	5.0	9.9	11.3	5.2	10.8	10.8	9.3	9.8	7.5	4.5	7.7
pH	6.5-9	9.5	8.0	7.5	6.9	7.5	7.5	7.8	7.7	8.1	8.5
Temp (°C)	25	22.2	10.9	15.5	7.5	11.5	18.6	14.6	13.0	20.0	23.5
Temp diff (°C)[1]	3	1.5	0.2	0.0	0.0	-	-	-	0.5	1.0	-
Susp. solids (g/m^3)		5.0	5.0	7.0	25	12	<0.5	3.9	3.4	15	24
Turbidity (FTU)		3.0	0.4	2.0	-	13.5	0.2	1.1	3.1	4.0	12.0
BOD (g/m^3)		0.7	0.5	3.0	0.4	1.0	0.3	0.7	1.5	3.2	1.5
F. coli (median n/100 ml, 5 samples)	200	35	5	58	80	30	2	190	220	50	912
Assessment of suitability-for-use Index score[2]											

Notes: 1 Temperature difference above natural value
2 See attached uses and suitability-for-use descriptors for assistance

APPENDIX 11 Continued

Data for Class W (Water Supply Use) river water

Determinand (units)	'Standard'	River code 1	2	3	4	5	6	7	8	9	10
DO (g/m³)	5.0	7.5	9.8	9.3	9.5	7.7	4.5	10.8	10.8	5.2	11.3
pH	6.5-9	7.7	7.8	7.5	9.5	8.5	8.1	7.5	6.9	7.5	8.0
Temp (°C)	25	13.0	14.6	18.6	22.2	23.5	20.0	11.5	7.5	15.5	10.9
Temp diff (°C)[1]	3	0.5	-	-	1.5	-	1.0	-	0.0	0.0	0.2
Susp. solids (g/m³)		3.4	3.9	<0.5	5.0	24	15	12	25	7.0	2.0
Turbidity (FTU)		3.1	1.1	0.2	3.0	12	4.0	13.5	-	3.0	0.4
F. coli (median n/100 ml, 5 samples)	2000	2200	190	2	36	912	50	300	80	58	5
NH_3-N (g/m³)	0.2	<0.05	-	<0.05	-	0.35	0.11	0.20	0.42	<0.05	<0.05
BOD (g/m³)[3]		1.5	0.7	0.3	0.7	1.5	5.7	1.0	0.4	3.0	0.5
Assessment of suitability-for-use Index score[2]											

Notes: 1 Temperature difference above natural value
2 See attached uses and suitability-for-use descriptors for assistance
3 Taken from G Index (BOD not specifically included in W Index)

Data for Class F (Fish [Salmonids]) spawning river water

		River code									
		Spawning Season					Rest of year				
Determinand (units)	'Standard'	1	2	3	4	5	6	7	8	9	10
DO (% sat)	80	84	96	100	56	105	100	101	74	93	99
pH	6-9	7.2	8.3	9.2	8.0	7.9	7.8	7.8	8.2	7.8	7.5
Temp (°C)[3]	12;25	5.5	3.5	7.5	11.2	8.0	23.4	18.0	15.5	17.3	20.0
Temp diff (°C)[1]	3	-	0.5	-	-	-	0.5	-	-	0.5	-
Susp. solids (g/m³)		0.5	6.2	0.9	2.2	1.2	2.1	0.5	1.2	12.5	6.8
Turbidity (FTU)		0.5	3.3	0.2	0.6	0.9	1.5	0.5	0.9	5.2	2.6
BOD (g/m³)		2.6	0.7	0.3	1.2	0.5	0.9	0.5	0.5	4.5	0.9
Assessment of suitability-for-use Index score[2]											

Notes: 1 Temperature difference above natural value
2 See attached uses and suitability-for-use descriptors for assistance
3 The proposed standards for temperature given here are for the spawning season and the rest of the year respectively. But see footnote on letter.

New Zealand Water Quality Indexes: Tabulation of Sub-Index Values

The attached tables make use of the Indexes much simpler. They have been derived by straight line extrapolation between the graphed points in Smith (1987). This is quite adequate for most purposes and is well within the error likely to be obtained by deriving sub-index values directly from the graphs.

Their use is simple. For each determinand, locate its measured value on the table and obtain the appropriate sub-index value on the same row left-hand column. For determinand values not listed, obtain the most appropriate sub-index value by interpolation. The units used are the same as in the publication.

Reference: Smith, D.G. 1987: Water quality indexes for use in New Zealand's rivers and streams. Water Quality Centre Publication No. 12, Water Quality Centre, Hamilton.

NEW ZEALAND WATER QUALITY INDEX

General Use Sub-indexes

Sub-Index	D.O.		pH		S.S.	Turb	Temp.		Temp diff	BOD	Log (FC)
100			7.5		0.0	0.0	8.0	10.0	0.0	0.0	0.0
98	10.1	12.2	7.0		0.6	0.7	6.1	12.5	0.2	0.6	0.5
96	9.0	13.6	6.9	8.1	1.2	1.4	5.4	15.1	0.4	0.9	0.9
94	8.7	14.5	6.8	8.1	1.7	2.1	4.8	17.0	0.6	1.2	1.2
92	8.3	15.2	6.7	8.2	2.3	2.7	4.1	18.4	0.8	1.4	1.4
90	8.0	15.8	6.6	8.3	3.1	3.0	3.2	19.7	1.0	1.6	1.6
88	7.8		6.6	8.3	3.9	3.4	2.1	20.4	1.2	1.9	1.8
86	7.5		6.5	8.4	4.7	3.8	1.6	21.0	1.4	2.0	1.9
84	7.2		6.5	8.5	5.6	4.1	1.1	21.6	1.6	2.2	2.0
82	6.9		6.4	8.5	6.5	4.5	0.6	22.1	1.8	2.3	2.1
80	6.7		6.4	8.6	7.4	4.9	0.1	22.4	1.9	2.4	2.2
78	6.5		6.3	8.6	8.4	5.4		22.7	2.1	2.5	2.3
76	6.3		6.3	8.7	9.4	5.9		23.0	2.2	2.7	2.4
74	6.1		6.3	8.7	10.5	6.5		23.4	2.3	2.8	2.4
72	5.9		6.2	8.7	11.5	7.1		23.7	2.5	2.9	2.5
70	5.7		6.2	8.8	12.6	7.7		24.0	2.6	3.0	2.5
68	5.6		6.2	8.8	13.7	8.3		24.2	2.7	3.2	2.6
66	5.4		6.1	8.9	14.8	8.9		24.4	2.7	3.3	2.7
64	5.3		6.1	8.9	15.9	9.5		24.6	2.8	3.5	2.7
62	5.1		6.0	9.0	16.9	10.2		24.8	2.9	3.6	2.8
60	5.0		6.0	9.0	18.0	10.8		25.0	3.0	3.8	2.9
58	4.9		5.9	9.1	19.1	11.5		25.1	3.1	3.9	2.9
56	4.8		5.9	9.1	20.2	12.1		25.3	3.2	4.1	3.0
54	4.7		5.8	9.2	21.9	12.8		25.4	3.3	4.2	3.1
52	4.6		5.7	9.2	23.5	13.6		25.5	3.4	4.4	3.1
50	4.5		5.7	9.3	25.1	14.3		25.7	3.5	4.5	3.2
48	4.4		5.6	9.3	26.9	15.1		25.8	3.6	4.7	3.2
46	4.3		5.6	9.4	28.8	16.0		25.9	3.8	4.8	3.3
44	4.2		5.5	9.4	30.6	16.8		26.1	3.9	4.9	3.4
42	4.1		5.4	9.5	32.4	17.7		26.3	4.0	5.1	3.4
40	3.9		5.3	9.6	34.1	18.5		26.4	4.2	5.3	3.5
38	3.8		5.3	9.6	35.8	19.4		26.6	4.3	5.4	3.5
36	3.7		5.2	9.7	37.3	20.2		26.8	4.5	5.6	3.6
34	3.6		5.1	9.8	39.0	21.0		26.9	4.6	5.8	3.6
32	3.4		5.0	9.9	40.7	21.9		27.1	4.8	5.9	3.7
30	3.3		5.0	9.9	42.5	22.7		27.3	4.9	6.2	3.8
28	3.2		4.9	10.0	44.3	23.6		27.5	5.1	6.4	3.8
26	3.0		4.8	10.1	46.1	24.4		27.6	5.3	6.7	3.9
24	2.8		4.7	10.2	48.1	25.4		27.8	5.4	7.0	4.0
22	2.6		4.6	10.3	50.6	26.9		28.0	5.7	7.3	4.1
20	2.3		4.5	10.4	53.9	28.3		28.2	6.0	7.6	4.2
18	2.1		4.4	10.5	58.3	29.6		28.5	6.2	8.0	4.3
16	1.8		4.2	10.6				28.8	6.5	8.4	4.4
14	1.5		4.1	10.8				29.0	6.7	8.9	4.5
12	1.3		3.9	10.9				29.3	7.0	9.4	4.6
10	1.0		3.7	11.1				29.6		10.0	4.7
8	0.6		3.5	11.3				29.9		11.0	4.9
6	0.1		3.1	11.6						12.0	5.0
4				11.8							
2											

NEW ZEALAND WATER QUALITY INDEX

Regular Public Bathing Sub-indexes

Sub-Index	D.O.		pH		S.S.	Turb	Temp.		Temp diff	BOD	Log (FC)
100	10.5		7.6		0.0	0.0			0.0	0.0	0.0
98	9.3	11.4	7.2		0.5	0.4			0.2	0.5	0.3
96	8.7	13.3	7.0	8.1	1.0	0.8			0.4	0.9	0.6
94	8.3	14.5	7.0	8.2	1.5	1.2			0.6	1.1	0.9
92	8.0	15.2	6.9	8.3	2.0	1.5	20.0		0.7	1.3	1.1
90	7.7	15.8	6.9	8.4	2.6	1.9	19.7		0.9	1.4	1.2
88	7.4		6.9	8.5	3.2	2.3	18.0	22.0	1.1	1.6	1.3
86	7.2		6.9	8.5	3.8	2.6	17.0	22.5	1.2	1.7	1.4
84	6.9		6.8	8.6	4.5	2.8	16.0	23.0	1.4	1.8	1.5
82	6.8		6.8	8.6	5.1	3.1	14.2	23.3	1.5	2.0	1.6
80	6.6		6.8	8.6	5.9	3.3	12.4	23.6	1.7	2.1	1.7
78	6.4		6.7	8.7	6.7	3.5	11.4	23.9	1.8	2.2	1.8
76	6.2		6.7	8.7	7.5	3.8	10.6	24.1	2.0	2.3	1.8
74	6.1		6.7	8.7	8.2	4.0	9.9	24.2	2.1	2.4	1.9
72	5.9		6.7	8.8	9.0	4.2	9.3	24.3	2.2	2.5	2.0
70	5.8		6.6	8.8	9.8	4.5	8.7	24.4	2.4	2.7	2.0
68	5.6		6.6	8.9	10.6	4.7	8.2	24.5	2.5	2.8	2.1
66	5.5		6.6	8.9	11.4	4.9	7.4	24.7	2.6	2.9	2.1
64	5.3		6.6	8.9	12.3	5.3	6.5	24.8	2.8	3.0	2.2
62	5.2		6.5	9.0	13.1	5.7	5.8	24.9	2.9	3.1	2.2
60	5.0		6.5	9.0	13.9	6.1	5.4	25.0	3.0	3.2	2.3
58	4.9		6.4	9.1	14.7	6.5	5.0	25.2	3.1	3.3	2.3
56	4.8		6.4	9.1	15.5	6.9	4.5	25.4	3.3	3.5	2.4
54	4.7		6.3	9.2	16.3	7.3	4.1	25.6	3.4	3.6	2.4
52	4.7		6.2	9.2	17.0	7.7	3.4	25.8	3.5	3.7	2.4
50	4.6		6.2	9.3	17.8	8.1	2.7	26.0	3.6	3.8	2.5
48	4.5		6.1	9.3	18.6	8.5	1.9	26.1	3.8	4.0	2.5
46	4.4		6.0	9.4	19.3	8.9	1.3	26.3	3.9	4.1	2.5
44	4.3		6.0	9.4	20.2	9.4	0.8	26.5	4.1	4.3	2.6
42	4.2		5.9	9.5	21.2	9.8	0.2	26.6	4.2	4.4	2.6
40	4.1		5.8	9.5	22.2	10.3		26.8	4.4	4.6	2.6
38	4.1		5.7	9.6	23.3	10.9		27.0	4.5	4.8	2.7
36	3.9		5.6	9.7	24.3	11.6		27.1	4.7	5.0	2.7
34	3.8		5.5	9.7	25.5	12.2		27.3	4.8	5.2	2.8
32	3.7		5.4	9.8	27.1	12.9		27.5	5.0	5.4	2.8
30	3.5		5.3	9.9	28.6	13.8		27.6	5.0	5.6	2.8
28	3.4		5.2	10.0	30.2	14.6		27.8	5.0	5.8	2.9
26	3.3		5.1	10.1	32.3	15.6		27.9	5.0	6.0	2.9
24	3.2		4.9	10.2	34.5	17.0		28.1	5.5	6.3	2.9
22	3.0		4.8	10.3	37.0	18.4		28.3	5.9	6.6	3.0
20	2.8		4.6	10.3	39.6	19.9		28.5	6.3	7.0	3.0
18	2.5		4.5	10.4	42.6	22.1		28.7	6.6	7.3	3.1
16	2.2		4.3	10.5	45.9	24.5		28.9	6.9	7.6	3.2
14	1.9		4.1	10.7	50.3	27.5		29.1		7.9	3.3
12	1.6		3.9	10.8	55.7			29.3		8.3	3.4
10	1.3		3.7	11.0				29.5		8.7	3.5
8	0.9		3.5	11.2				29.6		9.2	3.7
6	0.5		3.3	11.5				29.8		9.9	4.1
4	0.1		3.0	11.8						11.4	4.6
2											5.0

NEW ZEALAND WATER QUALITY INDEX

Water Supply Sub-indexes

Sub-Index	D.O.		pH		S.S.		Turbidity		Temp.		Temp diff	NH3	Log (FC)
100	10.0								10.0	10.0	0.0	0.00	0.0
98	8.8	12.5	7.4	7.9	2.5	2.5			12.0	7.6	0.2	0.01	0.4
96	8.4	14.1	7.2	8.3	2.8	1.2	1.4	1.1	13.5	7.1	0.4	0.02	0.8
94	8.0	16.2	7.0	8.3	3.5	0.8	1.7	0.7	15.6	6.5	0.5	0.03	1.2
92	7.8		6.9	8.4	4.1	0.4	2.0	0.4	17.5	6.0	0.7	0.05	1.4
90	7.5		6.9	8.5	4.7	0.0	2.3	0.0	18.7	5.4	0.9	0.06	1.6
88	7.3		6.8	8.5	5.5		2.6		19.6	4.9	1.0	0.07	1.8
86	7.0		6.8	8.6	6.3		2.8		20.2	4.3	1.2	0.08	2.0
84	6.8		6.7	8.6	7.2		3.1		20.6	2.0	1.3	0.10	2.2
82	6.6		6.7	8.6	8.0		3.4		21.0		1.5	0.11	2.4
80	6.4		6.7	8.7	8.9		3.7		21.4		1.6	0.12	2.5
78	6.2		6.7	8.7	9.7		3.9		21.7		1.7	0.12	2.6
76	6.0		6.7	8.7	10.5		4.2		22.1		1.9	0.13	2.7
74	5.9		6.6	8.8	11.2		4.5		22.5		2.0	0.14	2.8
72	5.8		6.6	8.8	11.8		4.7		22.9		2.1	0.15	2.9
70	5.6		6.6	8.8	12.5		5.0		23.3		2.3	0.16	3.0
68	5.5		6.6	8.9	13.2		5.6		23.7		2.4	0.17	3.0
66	5.4		6.6	8.9	13.9		6.2		24.1		2.5	0.17	3.1
64	5.3		6.5	8.9	14.6		6.7		24.4		2.7	0.18	3.2
62	5.1		6.5	9.0	15.3		7.3		24.7		2.8	0.19	3.2
60	5.0		6.5	9.0	16.1		7.9		25.0		3.0	0.20	3.3
58	4.9		6.4	9.0	16.9		8.5		25.3		3.2	0.21	3.3
56	4.8		6.4	9.1	17.7		9.2		25.6		3.3	0.22	3.4
54	4.7		6.3	9.1	18.5		9.8		25.8		3.5	0.22	3.4
52	4.6		6.3	9.2	19.3		10.5		26.1		3.6	0.23	3.4
50	4.5		6.2	9.2	20.2		11.2		26.2		3.8	0.24	3.4
48	4.4		6.2	9.3	21.8		11.9		26.4		3.9	0.25	3.5
46	4.3		6.1	9.3	23.4		12.7		26.6		4.1	0.25	3.5
44	4.2		6.0	9.4	24.9		13.5		26.8		4.2	0.26	3.5
42	4.1		6.0	9.4	26.3		14.4		26.9		4.4	0.27	3.6
40	4.0		5.9	9.5	27.7		15.4		27.1		4.5	0.28	3.6
38	3.9		5.8	9.6	29.2		17.0		27.3		4.7	0.29	3.7
36	3.8		5.7	9.6	31.1		18.6		27.4		4.9	0.30	3.7
34	3.6		5.6	9.7	33.8		20.3		27.6		5.0	0.31	3.8
32	3.5		5.5	9.8	36.5		22.1		27.8		5.2	0.32	3.9
30	3.3		5.4	9.9	39.2		24.0		27.9		5.4	0.34	3.9
28	3.2		5.3	9.9	42.1		26.4		28.1		5.6	0.35	4.0
26	3.1		5.2	10.0	45.0		29.3		28.3		5.8	0.36	4.1
24	2.9		5.0	10.1	49.2				28.5		6.0	0.38	4.2
22	2.7		4.9	10.2	60.0				28.7		6.3	0.39	4.3
20	2.5		4.7	10.4					28.9		6.5	0.40	4.3
18	2.2		4.5	10.5					29.2		6.8	0.43	4.5
16	2.0		4.3	10.6					29.4			0.45	4.6
14	1.8		4.1	10.8					29.6			0.48	4.7
12	1.5		4.0	10.9					29.8			0.52	4.8
10	1.3		3.8	11.2					30.0			0.59	4.9
8	1.0		3.6	11.4									
6	0.6		3.4	11.6									
4	0.3		3.2	11.8									
2	0.0												

NEW ZEALAND WATER QUALITY INDEX

Fish Spawning Sub-indexes

Sub-Index	DO(%)		pH		S.S.	Turb	Temp. spawning		Temp. Non-spawning		Temp diff	BOD
100	100	100	7.7	7.7	0.0	0.0			10.0	10.0	0.0	0.0
98	98	115	7.0	8.0	0.3	0.2			8.5	12.5	0.3	0.3
96	97	121	6.9	8.1	0.7	0.5	7.9	9.1	7.8	14.8	0.6	0.5
94	95	126	6.8	8.2	1.0	0.7	7.5	9.4	7.5	16.3	0.8	0.7
92	94		6.7	8.3	1.3	1.0	7.1	9.8	7.2	17.3	1.1	0.8
90	93		6.6	8.4	1.6	1.2	6.8	10.1	6.9	18.2	1.2	0.9
88	92		6.6	8.5	2.0	1.5	6.5	10.2	6.6	18.9	1.4	1.0
86	91		6.5	8.5	2.3	1.7	6.2	10.4	6.3	19.5	1.6	1.1
84	90		6.4	8.6	2.7	2.0	5.9	10.6	6.0	20.1	1.8	1.2
82	89		6.4	8.6	3.2	2.2	5.6	10.7	5.8	20.5	1.9	1.3
80	88		6.4	8.6	3.7	2.5	5.4	10.9	5.6	21.0	2.1	1.4
78	87		6.3	8.7	4.1	2.8	5.1	11.0	5.3	21.4	2.2	1.5
76	86		6.3	8.7	4.6	3.1	4.8	11.1	5.1	21.8	2.3	1.6
74	86		6.3	8.7	5.1	3.3	4.6	11.2	4.9	22.2	2.4	1.7
72	85		6.2	8.8	5.4	3.6	4.3	11.3	4.6	22.6	2.5	1.8
70	84		6.2	8.8	5.8	3.9	4.0	11.5	4.4	23.0	2.6	1.9
68	83		6.1	8.9	6.2	4.2	3.5	11.6	4.2	23.5	2.6	2.0
66	82		6.1	8.9	6.5	4.5	2.9	11.7	3.9	23.9	2.7	2.1
64	82		6.1	8.9	6.9	4.7	2.3	11.8	3.5	24.3	2.8	2.2
62	81		6.0	9.0	7.2	5.0	1.9	11.9	3.2	24.6	2.9	2.3
60	80		6.0	9.0	7.6	5.4	1.6	12.0	2.8	25.0	3.0	2.4
58	79		6.0	9.0	7.9	5.8	1.3	12.2	2.4	25.1	3.1	2.5
56	78		5.9	9.1	8.3	6.2	1.0	12.4	2.0	25.3	3.2	2.7
54	77		5.9	9.1	8.7	6.6	0.8	12.5	1.7	25.4	3.2	2.8
52	76		5.8	9.1	9.0	7.0	0.5	12.7	1.5	25.5	3.3	2.9
50	75		5.8	9.2	9.4	7.4	0.2	12.9	1.2	25.7	3.4	3.0
48	74		5.8	9.2	9.7	7.8	0.0	13.1	1.0	25.8	3.5	3.1
46	73		5.7	9.3	10.2	8.2		13.2	0.8	25.9	3.5	3.3
44	71		5.7	9.3	10.7	8.5		13.4	0.5	26.1	3.6	3.4
42	70		5.6	9.3	11.2	8.9		13.6	0.3	26.2	3.7	3.6
40	69		5.6	9.4	11.7	9.3		13.8	0.0	26.4	3.8	3.7
38	68		5.5	9.4	12.2	9.7		14.0		26.5	3.8	3.9
36	67		5.5	9.4	12.8	10.1		14.1		26.7	3.9	4.0
34	65		5.5	9.5	13.3	11.0		14.3		26.8	4.0	4.2
32	64		5.4	9.5	13.8	11.9		14.5		27.0	4.1	4.4
30	63		5.4	9.6	14.3	13.1		14.7		27.1	4.2	4.6
28	61		5.3	9.6	14.8	14.8		14.9		27.2	4.3	4.8
26	60		5.3	9.7	15.6	15.7		15.1		27.4	4.4	5.0
24	58		5.2	9.7	16.4	16.6		15.3		27.5	4.5	5.2
22	56		5.2	9.8	17.2	17.5		15.5		27.7	4.6	5.5
20	53		5.1	9.8	18.1	18.5		15.7		27.8	4.7	5.7
18	51		5.1	9.9	18.9	19.6		15.9		28.0	4.9	6.0
16	48		5.0	9.9	19.7	20.9		16.3		28.3	5.0	6.3
14	44		4.9	10.0	21.4	22.4		16.7		28.7	5.2	6.7
12	40		4.8	10.1	23.6	24.1		17.2		29.1	5.3	7.0
10	35		4.6	10.3	26.1	25.2		17.6		29.5	5.5	7.4
8	30		4.4	10.5	29.1	28.7		18.1		29.9	5.8	7.8
6	25		4.2	10.7	35.3			18.7			6.1	8.3
4	18		3.9	11.0	41.6			19.3				9.5
2	0		3.3	11.8	51.4			19.9				

ENVIRONMENTAL SCIENCE CONSULTANTS

R.A.Hoare & Associates

P.O. BOX 4153
HAMILTON EAST
NEW ZEALAND
PHONE (071) 62675

CALCULATING THE NEW ZEALAND WATER QUALITY INDEX

If you have read and accepted Dr D.G. Smith's report* on water quality indexes, you may be wanting to try out the ideas on your own data. To do this you must calculate the sub-index values from raw data, rather than finding the index from mean values of your measurements. Since the procedure involves interpolating in as many as 9 graphs for each sample, implementing the index on large amounts of data could be tedious and error-prone.

R.A. Hoare and Associates provide a service to remove the manual labour from the calculation of the index values, using a computerised procedure. If you send us lists of water quality data we will calculate and report the corresponding index values. (An example of the output is printed on the other side of this sheet.)

If the data is sent on IBM-PC compatible 5.25 inch floppy disks, the price will be $50 for each 100 samples, for a single index. If your data is printed on paper, an extra charge of 50¢ per sample will be required for data entry. The most convenient form of the data layout should be discussed before sending it, but an example is given over the page. Customising of the reports is possible at little or no extra cost.

* Water Quality Centre Publication No. 12 — "Water Quality Indexes for use in New Zealand's Rivers and Streams." Dr Smith defines a set of sub-indexes, based on measured values of dissolved oxygen concentration, temperature, and so on. For each sub-index, there is a curved line relationship which defines the way in which the sub-index varies with the value of a measured property of the water. The water quality index value for a sample is the minimum value of the set of sub-indexes for that sample.

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If organisations prefer to do their own calculations with the Hoare tools, they can do so by buying QUALSTORE, which is a personal computer based water quality data storage program. QUALSTORE is designed with many features to allow the exact description of the data and the sample collection conditions. Retrieval and reporting of all the water quality information that most organisations are likely to store is made flexible and easy. QUALSTORE comes supplied with the necessary spreadsheet models and print forms to calculate water quality indexes, as an accessory at no charge.

BATHING indexes for site WAIONE

Date	Minimum	D.O.	S.S.	pH	Turb	Temp (act)	Temp (dif)	BOD	F.C.
1/2/76	88	98	99	99	99	(88)	100	99	98
1/3/76	61	98	86	100	95	82	100	97	(61)
1/5/76	58	88	88	100	82	80	95	89	(58)
1/6/76	29	48	58	97	74	99	89	(29)	81
1/7/76	23	89	37	88	35	81	100	89	(23)
1/8/76	41	98	83	(41)	83	88	83	97	84
1/9/76	14	99	41	(14)	98	76	98	98	96
1/10/76	62	(62)	78	99	83	83	100	64	79
1/11/76	35	99	(35)	89	100	66	100	99	75
1/12/76	31	99	65	99	(31)	78	100	96	50

mean water use index = 44

BATHING indexes for site WAITWO

Date	Minimum	D.O.	S.S.	pH	Turb	Temp (act)	Temp (dif)	BOD	F.C.
1/2/76	41	98	83	(41)	83	88	83	97	84
1/3/76	76	99	83	100	98	(76)	98	98	96
1/5/76	62	(62)	78	99	90	83	100	64	79
1/6/76	35	99	(35)	89	100	66	100	99	75
1/7/76	31	99	65	99	(31)	78	100	96	86
1/8/76	88	98	99	99	99	(88)	100	99	98
1/9/76	61	98	86	100	95	82	100	97	(61)
1/10/76	58	88	88	100	82	80	95	89	(58)
1/11/76	48	(48)	58	97	74	99	89	61	81
1/12/76	23	89	37	88	35	81	100	89	(23)

mean water use index = 52

Input form for calculating index values
(up to 100 lines)

Site	Date	D.O.	S.S.	pH	Turb	T(act)	T(dif)	BOD	Log(F.C.
WAIONE	1/2/76	9.3	0.5	7.5	0.2	18.6	0.0	0.3	0.30
WAIONE	1/3/76	9.8	3.9	7.8	1.1	14.6	0.0	0.7	2.28
WAIONE	1/5/76	7.5	3.4	7.7	3.1	13.0	0.5	1.5	2.34
WAIONE	1/6/76	4.5	15.0	8.1	4.0	20.0	1.0	5.7	1.70
WAIONE	1/7/76	7.7	24.0	8.5	12.0	23.5	0.0	1.5	2.96
WAIONE	1/8/76	9.5	5.0	9.5	3.0	22.2	1.5	0.7	1.56
WAIONE	1/9/76	11.3	22.0	4.1	0.4	10.9	0.2	0.5	0.70
WAIONE	1/10/76	5.2	7.0	7.5	3.0	15.5	0.0	3.0	1.76
WAIONE	1/11/76	10.8	25.0	6.9	0.0	7.5	0.0	0.4	1.90
WAIONE	1/12/76	10.8	12.0	7.5	13.5	11.5	0.0	1.0	2.48
WAITWO	1/2/76	9.9	5.0	9.5	3.0	22.2	1.5	0.7	1.54
WAITWO	1/3/76	11.3	5.0	8.0	0.4	10.9	0.2	0.5	0.70
WAITWO	1/5/76	5.2	7.0	7.5	2.0	15.5	0.0	3.0	1.76
WAITWO	1/6/76	10.8	25.0	6.9	0.0	7.5	0.0	0.4	1.90
WAITWO	1/7/76	10.8	12.0	7.5	13.5	11.5	0.0	1.0	1.48
WAITWO	1/8/76	9.3	0.5	7.5	0.2	18.6	0.0	0.3	0.30
WAITWO	1/9/76	9.8	3.9	7.8	1.1	14.6	0.0	0.7	2.28
WAITWO	1/10/76	7.5	3.4	7.7	3.1	13.0	0.5	1.5	2.34
WAITWO	1/11/76	4.5	15.0	8.1	4.0	20.0	1.0	3.2	1.70
WAITWO	1/12/76	7.7	24.0	8.5	12.0	23.5	0.0	1.5	2.96