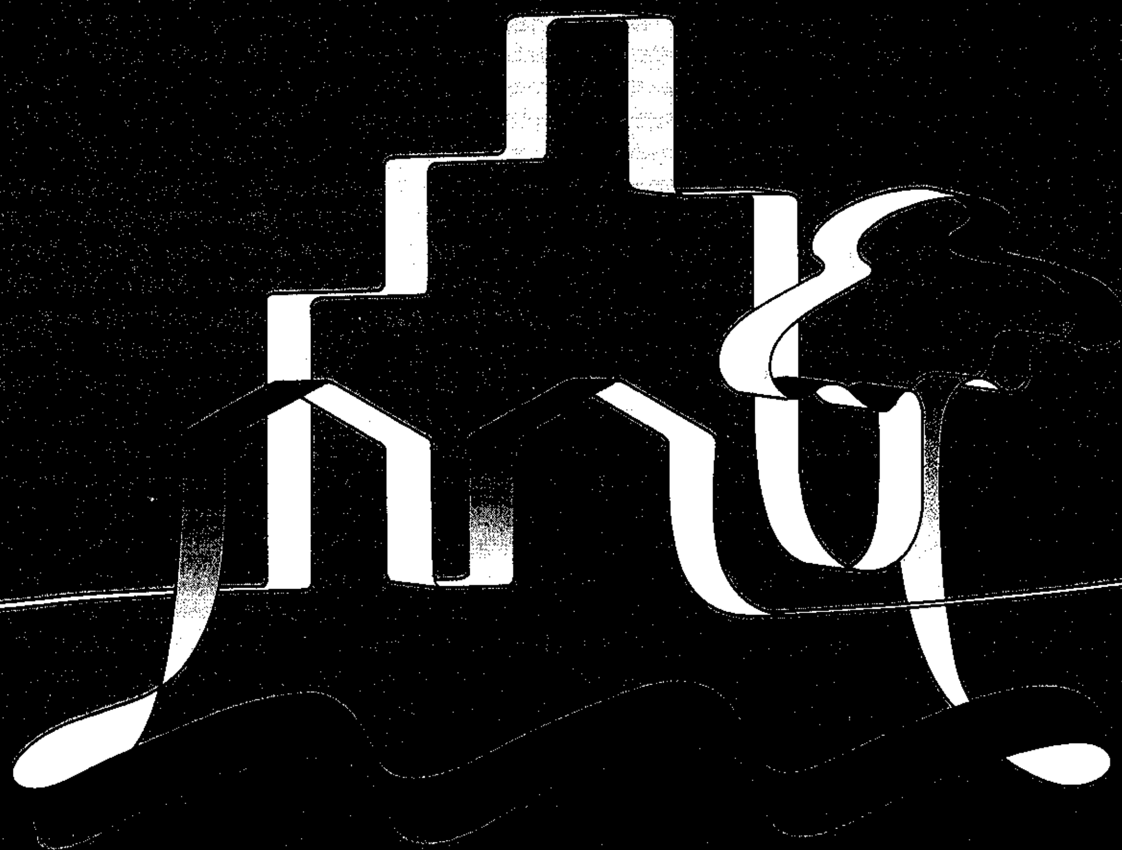
Urban Water Research Association of Australia

Formation of a Practical and Informative Management and Public Communication Tool for Information on Drinking Water Quality



URBAN WATER RESEARCH ASSOCIATION OF AUSTRALIA (UWRAA)

The Association is a Division of the Water Services Association of Australia. UWRAA has the charter to develop and manage a portfolio of research to support the business plan for the urban water industry developed by the Water Services Association of Australia.

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Foreword

This is the final report for UWRAA Research Project No. CS-8 "Formation of a practical and informative management and public communication tool for information on drinking water quality".

Organisational responsibility for the project was as follows:

Sponsoring Authority:	ACT Electricity and Water
Project Officer(s):	Dave Butlers, Wayne Harris, and Cary Reynolds
Research Agency:	Aquatech
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The project was funded by the Urban Water Research Association of Australia, ACT Electricity and Water, and Aquatech.

Synopsis

Information on drinking water quality often involves the collection of a wide range of microbiological and physico-chemical characteristics. This wide range of characteristics makes it difficult to present the information on drinking water quality in a summary form, suitable for:

- Management decision making.
- Communicating with the public.

Similarly complex economic information has been successfully summarised in the form of an index (e.g. the Consumer Price Index for goods and services, and the All Ordinaries Index for stocks).

This project investigated if it was possible to use an indexing process for the presentation of summary information on drinking water quality. In particular, the project investigated the formation of a practical and informative management and public communication tool for information on drinking water quality.

The project identified and addressed the main issues that impacted upon the formulation of a drinking water index, such as:

- The importance of the microbiological measures of water quality in any proposed index.
- The need for an index that was:
    - **Specific** enough to be able to accommodate local variability, and allow each drinking water authority to 'create' an index that best addressed their particular needs and concerns. Such an index had to be able to provide answers to such questions as:
        - Generally, is drinking water quality better in part A of the system, as opposed to part B?
        - Generally, is drinking water quality better this year than last year?
        - Generally, is drinking water quality better this season than last season?
        - Generally, has drinking water quality improved since change X was implemented.
    - **General** enough to be applicable in many different drinking water distribution systems, and allow different drinking water authorities to use the same indexing procedures. Such an index had to be able to provide answers to such questions as:
        - Generally, is drinking water quality better in one system than another.

The project suggests the formation of a:

- A **specific** index with the following characteristics:
    - Total of 100 points (based on the relative information value of the various parameters in the index).
    - Pass/fail value of 50 points.
    - Microbiological characteristics contributing 60 points to the total score (consisting of parameters specifically selected for the particular system).
    - Physico-chemical characteristics contributing 40 points to the total score (consisting of parameters specifically selected for the particular system).
    - A list of parameters suited to the needs of each particular drinking water authority.
- A **general** index with the same characteristics as the abovementioned specific index, but with a standard set of 6 water quality characteristics (2 microbiological and 4 physico-chemical) which are monitored by most drinking water authorities.

The report discusses the use of the proposed drinking water index in terms of:

- Management decision making.
- Communicating with the public.

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Abbreviations

ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand
AUSRIVAS	Australian River Assessment Scheme
ASX	Australian Stock Exchange
AWRC	Australian Water Resources Council
CFU	Colony forming unit
CPI	Consumer Price Index
mg/L	milligrams per litre
mL	millilitre
NHMRC	National Health and Medical Research Council
NTU	Nephelometric turbidity unit
QA/QC	Quality Assurance/Quality Control
RIVPACS	River Invertebrate Prediction and Classification Scheme
TQM	Total Quality Management
UK	United Kingdom
UWRAA	Urban Water Research Association of Australia
WHO	World Health Organisation
WSAA	Water Services Association of Australia

1. Introduction

1.1 The indexing process

The management of drinking water quality is an important public health and economic issue for water authorities. The scientific assessment of this quality involves considerable resources, and can cover a wide range of microbiological, physico-chemical and radiological characteristics (NHMRC and ARMCANZ, 1996). Unfortunately, the wide range of characteristics (or parameters) often makes it difficult to present the information on drinking water quality in a form suitable for management decision making, or for communicating with the public. It is often difficult to provide answers to relatively general but often asked questions, such as:

- Comparisons within a distribution system, for example:
  - Is drinking water quality better in one part of a system than another?
  - Is drinking water quality better this year than last year?
  - Is drinking water better this season than last season?
  - Has drinking water quality improved since a particular change was implemented?

- Comparisons between different distribution systems, for example:
  - Is drinking water quality better in one system than another?

Such questions are often difficult to answer not because the drinking water quality information is never collected, but rather because the information is too complex to be presented without an appropriate summarisation (or indexing) process (Maher *et al.*, 1997).

Similarly complex economic information has been successfully presented to managers and the public in the form of an index. For example, the Consumer Price Index (CPI) is a composite summary of several separate numbers, which indicate the percent price change in the value of regularly purchased goods and services. It is generally understood that a positive CPI represents inflation (or increasing prices for goods and services), and a negative CPI represents deflation (or decreasing prices for goods and services). Individuals who may not know or understand all the different components of the CPI index can nevertheless make use of the summary information. Of course, some of the detail that is used to make up the summary number is lost in the process. For example, the summary number will not indicate the increase or decrease in the value of the individual items used to make up the index (e.g. a change in the price of mortgages, bread or petrol). Furthermore, the summary index will not indicate more complex changes in the value of the individual items (e.g. a decrease in the price of mortgages and an increase in the price of petrol and bread). However it is generally agreed that the summary provides a useful single number, which can be used to answer some general questions.

Similarly, the All Ordinaries Index is a composite summary of the value of selected Australian stocks, listed on the Australian Stock Exchange (ASX). It is generally understood that if the index has increased then stock prices overall have increased, and if the index has decreased, then stock prices overall have fallen. Once again, individuals who may not know or understand all the different stocks that make up the All Ordinaries Index can nevertheless make use of the summary information. As with the CPI example, some of the detail that is used to make up the summary number is lost in the summarisation process. For example, the overall index will not indicate the change in the value of individual stocks. However, once again, it is generally agreed that the summary provides a useful single number, which can be used to answer some general questions.

Through the use of an indexing procedure, both the Consumer Price Index and the All Ordinaries Index have allowed a larger cross-section of the community to follow and make use of economic information. It is possible that through the use of an indexing procedure a wider cross-section of the community would be able to follow and make use of drinking water quality information.

1.2 Background information

The Water Services Association of Australia (WSAA) is the peak industry body representing the Australian urban water industry. WSAA publishes on an annual basis key information on the standards used by the Australian drinking water industry, as well as the percentage compliance with those standards (WSAA, 1997). In 1997 the percentage compliance amongst the different drinking water supplies ranged from 70% to over 99%, using a number of guidelines such as:

- NHMRC and AWRC (1980).
- NHMRC and AWRC (1987).
- WHO (1994).
- NHMRC and ARMCANZ (1996).

In terms of the abovementioned guidelines NHMRC and AWRC (1980) is the oldest and the least detailed. It was the first Australia-wide document on drinking water guidelines (with an approximate length of 8 pages). These nation-wide guidelines were updated and expanded with the issue of NHMRC and AWRC (1987). This document was longer (about 33 pages) and more detailed than the 1980 document. It also specified a greater range of water quality characteristics and more stringent values for those characteristics than the 1980 document.

The WHO (1994) document was a comprehensive international effort at formulating drinking water quality guidelines.

Australian drinking water guidelines were further updated with the issue of NHMRC and ARMCANZ (1996). This document has about 300 pages, and is considerably more detailed than the previous Australian guideline documents. It specifies a wide range of water quality characteristics and a more stringent value for those characteristics than the 1987 document. It also incorporates relevant aspects of WHO (1994), and represents the most comprehensive and stringent guidelines document available for Australian drinking water systems.

Because of the differences in the various standards used, and in the levels of compliance obtained, it is relatively difficult (even for drinking water professionals) to benchmark the performance of different drinking water supply systems.

Consequently, forming some informed estimate of performance is even more difficult for those who are not within the drinking water profession, but nevertheless have a legitimate interest in drinking water quality (e.g. government organisations, members of the media and consumers).

Thus, a method of measuring and comparing performance is important to drinking water authorities as well as to consumers. Such an estimate of performance may be used for a number of purposes, including:

- **Management action**. Changes in operation as a result of individual sample results.
- **Internal comparisons**. Reporting of results for a period (often annual) or for a geographical area (zone) within a water business. These results are often used to identify trends and may lead to operational changes to improve performance.
- **External comparisons**. Annual reporting and comparison with other water businesses.
- **Consumer information**. Water quality reports to inform consumers of performance (sometimes related to "Customer Contracts").

An index of drinking water quality should be constructed in such a way as to make it possible to use the index for each of the above purposes, that is, it should provide a report on a single sample and also summarise the annual results covering thousands of samples.

1.3 Aims of current project

This research project examined if it was possible to use an indexing process for the presentation of summary information on drinking water quality. The project was particularly interested in the formation of a practical and informative management and communication tool for information on drinking water quality. The aims of the project were to:

- Review and summarise previous efforts (published and unpublished) in compiling a drinking water quality index, and assess the suitability of these efforts.
- Identify the issues that are to be considered and addressed in the formulation of a drinking water quality index.
- Compile the water quality characteristics required for such a potential index.
- Determine a suitable form of the index for management decision making.
- Determine a suitable form of the index for communicating information with the public.
- Indicate if such an index is feasible and practical, and if so, provide a manual for its possible implementation by a water authority.

Subsequent sections of this research report describe these aspects in more detail.

2. Previous efforts in compiling a drinking water quality index

The indexing process has been used relatively successfully to summarise complex economic information. The indexing process has also been used to provide summary information in the area of water management (Barbiroli *et. al.*, 1992; Kung *et. al.*, 1992). Reports have provided:

- **An index of river water quality.**
  Such indices have often combined physico-chemical, microbiological and biological characteristics to provide a summary of river water quality (Fleituch, 1992; Valdecasas and Baltanas, 1990). Other river water quality indices have used a particular grouping of organisms, such as macroinvertebrates to provide an index of river health. An example of such indices include the RIVPACS classification system for the UK (NRHP, 1994) or the AUSRIVAS classification system for Australia (Schofield and Davies, 1996; and Wright, 1995). Examples of particular river water quality indices have included:
  - Bhargava (1983 and 1987), for the Ganga River in India.
  - Tyson and House (1989), for the North West Water Authority in the UK.
  - Egborge and Benka-Coker (1986), for the Warri River in Nigeria.
  - Lohani and Mustapha (1982), for the Linggi River in Malaysia.
  - Costa *et. al.* (1985) for surface waters in Brazil.
  - Smith (1989), for rivers and streams.
  - Oda *et. al.* (1991), for river basins in Japan.
  - Lohani and Todino (1984), for the Chao Phraya River in Thailand.
  - Dunnette (1979), for the Willamette River in Oregon.

- **An index of wastewater quality.**
  A number of wastewater treatment plants use a combination of water quality characteristics to determine a wastewater quality index. Such an index is then used to estimate the overall impact of the discharged wastewater on the receiving environment. Examples of such indices have included:
  - Inhaber (1975), which is a general industrial and municipal effluent index, that can be used in national environmental reporting.
  - Harkins (1974), which compares the impact of wastewater on upstream and downstream stations.

- **An index of irrigation water quality.**
  Several studies have provided an index of irrigation water. These have included:
  - Joung *et. al.* (1979), for the Carson Valley.

- **An index of lake water quality.**
  A number of water quality characteristics have been combined to provide indices of lake water quality. Such indices have been used to predict the eutrophication status of lakes, as well as the numbers and types of fish species inhabiting a particular type of lake. These indices have included:
  - Vollenweider (1969), for predicting eutrophication in lakes.
  - Schaeffer and Janardan (1977), for predicting eutrophication in Lake Michigan.
  - Steinhart *et. al.* (1982), for the Great Lakes.

- **An index of groundwater quality.**
  Groundwater quality has also been expressed in the form of an index. For example, Martin *et. al.* (1991), used an intrusion index to measure and indicate groundwater quality.

- **An index of beach water quality.**
  A number of studies have compiled an index that provides information on beach water quality to swimmers, and beach users. An example of such an index is the one used by the EPA NSW in its Beachwatch program (EPA NSW, 1993). The index uses information on surf conditions, currents, tide and visible water quality parameters to predict (or indicate) the suitability of beaches for swimming.

Although indices have been used to convey summary information about river water, wastewater, irrigation water, lake water, groundwater and beach water, it was not possible to identify in the literature any examples of a drinking water quality index. This was despite an extensive search of the published and unpublished literature. However, most water authorities used some combination of water quality characteristics to provide themselves with internal water quality performance indicators (e.g. Munns, 1993 for Hunter Water Board).

3. Issues to be considered in the formulation of a drinking water quality index

Although indices have been used to provide summary information on some types of waters, there are a number of issues particularly important to drinking water management that need to be considered in the formation of a drinking water quality index. These include:

- The index has to be easily interpreted. This can best be achieved by using a system that most people are relatively familiar with, such as an index with a maximum value of 10 or 100 or 1000. Generally, an index with a maximum of 10 points may not have enough of a spread of values for drinking water management. Conversely, an index with a maximum of 1000 points may have too much spread of values for drinking water management. An index with a maximum of 100 points may be about right for conveying summary information on drinking water quality.

- The index has to provide sufficient importance to the microbiological characteristics of drinking water quality. Results for total coliforms and/or thermotolerant (faecal) coliforms are very important to the operation of any drinking water distribution system. Thus any practical and informative drinking water quality index has to ensure that microbiological characteristics such as total coliforms and thermotolerant coliforms are given a very high level of importance in the formation of an index.

- It should be possible to calculate the index for a single water quality sample. It should also be possible to give a summary value for a geographical area (e.g. a distribution zone) or for a specific time period (e. g. last year), or both.

- The overall procedures used to construct a drinking water index have to be able to accommodate local variability in terms of the characteristics measured and the accepted values of those characteristics in a particular system (De Zuane, 1997; Geldreich, 1996; Evins *et. al.*, 1990). At the same time the procedures have to be relatively universal and applicable in many different drinking water distribution systems. The paradoxical requirement for an index that is able to accommodate local variability, yet at the same time is applicable in many different drinking water distribution systems, is a central component of a good indexing process.

The process selected for further examination in this project was based on a 'relative information value' approach, using a:

- **Specific** index which allowed comparisons to be made within different areas or times in a particular distribution system, using water quality characteristics and guideline values which are specific to that particular system.

- **General** index which allowed comparisons to be made within, as well as between distribution systems, on a core set of water quality characteristics and guideline values that are applicable to drinking water systems across Australia.

Consequently, two numbers are proposed, both scored out of 100, and consisting of a:

- **Specific** index (for comparisons within a particular distribution systems, using the specific characteristics that are important in that particular system).
- **General** index (for comparisons within, as well as between different distribution systems, using general characteristics important in most systems).

3.1 Specific index

The 'relative information value' approach for the specific index consisted of the following main processes:

1. **Determine the list of water quality characteristics in a particular drinking water distribution system which are the important parameters for that system.**
   Typically this would consist of the parameters regularly measured in that particular system for compliance and for operational monitoring. In most distribution systems this would probably consist of a list that contained 2-8 microbiological parameters (such as total coliforms, thermotolerant coliforms, heterotrophic plate count bacteria and possibly a range of specific microorganisms), and 10-20 physico-chemical parameters (such as turbidity, pH, free residual chlorine, trihalomethanes, colour, hardness, taste and odour, total dissolved solids, a range of metals, and possibly a range of chlorination by-products and/or pesticides).

   To compile an index for a particular drinking water distribution system, it is best to use the particular parameters which are generally monitored in that system. At the end of this selection process there may be 12-20 water quality characteristics on the list (depending on which characteristics are measured in the particular system).

2. **Allocate points to each of the water quality characteristics selected on the list, based on the relative information value of that characteristic, with the total of the points being 100.**
   One approach would be to allocate the 100 points equally between the water quality characteristics on the list. This would assume that they are all equally important in terms of their relative information value, and thus in terms of drinking water quality. If we had 10 water quality parameters from step 1 above, then in this approach each parameter would receive 10 points.

   However, the various parameters measured are generally not regarded as being of equal information value. As indicated previously, the microbiological parameters are generally regarded as providing critical information about water quality. Thus it would be inappropriate to allocate 10 points out of a hundred for total coliforms and similarly 10 points out of a hundred for thermotolerant coliforms.

   The relative information value of a parameter is best obtained from the system managers of a particular distribution system

3. **Allocate a range of guideline values (or acceptable values) for each of the parameters.**
   If the particular parameter is within its designated guideline value (or acceptable value), then points are allocated towards the index value. If the particular parameter is outside of the designated guideline value (or acceptable value), then no points are allocated towards the index value.

4. **Add up the relative information values of the various parameters.**
   Add up the various values allocated to each parameter.

3.2 General component

The relative information value approach for the general index consists of the same main processes as the specific index, except it uses a predetermined list of characteristics and relative information values for those characteristics. This proposed general index is based upon the characteristics and guideline values present in NHMRC and ARMCANZ (1996). Most of the parameters in the general index are already monitored by most drinking water authorities in Australia.

4. Water quality characteristics in a specific and a general index

4.1 Specific index

The relative information value approach described in section 3 focuses more on the principles used in the construction of the index. In fact, the principles allow for variations in the composition of a specific index of the drinking water quality. Essentially, the principles allow for the formation of a specific index that is uniquely suitable to a particular distribution system.

Consequently, the water quality characteristics (or parameters) required for the specific index will largely consist of the water quality characteristics already being monitored in that system. Thus the relative information value approach makes full use of the already available monitoring information. Presumably, the already monitored parameters provide some valuable information on the system.

For example, a particular drinking water authority may monitor the following characteristics:

- Microbiological (total coliforms, and thermotolerant coliforms).
- Physio-chemical (turbidity, pH, free residual chlorine, colour, iron, and manganese).

The abovementioned parameters would be appropriate as the water quality characteristics (or parameters) to be used in the specific index for that particular system. However, other parameters may be added (if they are regularly measured in the particular distribution system). It is also possible to use the health related guideline parameters indicated in the 1996 Australian Drinking Water Guidelines (NHMRC and ARMCANZ, 1996), provided that those parameters are measured in the particular distribution system.

As indicated above, the issue of which water quality characteristics are used in a potential index for a particular distribution system is largely already determined by:

- Existing information (i.e. currently sampled monitoring program parameters).
- Other information sources (e.g. 1996 Australian Drinking Water Guidelines).

However, the 'relative information value' of each water quality characteristic which may be used in the index is generally not already available or determined. Different distribution systems may use the same list of water quality characteristics, but have very

different 'relative information values' placed on each parameter. This is where a particular specific index can be specially constructed for a particular distribution system. For example, turbidity may be a parameter used in the index of two different systems. One distribution system may be in an area of moderate and constant rainfall, where there is a low level of catchment erosion. In this system turbidity may be an important water quality characteristic, but in terms of relative importance may only represent 4 points out of a 100 point specific index. The second distribution system may be in an area with highly unpredictable rainfall and high catchment erosion rates. In this system turbidity may be regarded as a very important water quality characteristic, and in terms of relative importance may represent 12 points out of a 100 point specific index.

Because the 'relative information value' of the parameters selected for the specific index are generally not already available, some additional work will be required by each water authority before an index can be completed. This work will have to focus on the 'relative information value' of each of the parameters used in the specific index, within the particular distribution system of interest. This information can best be provided by the managers of the particular system, by trying to answer questions such as:

(a) Amongst the parameters on the list provided, can you indicate the one you feel is the most important for managing the system.

(b) If for some reason you did not have the sampling information on the parameter you selected in (a), which would you regard as the next important parameter for managing the system. Relative to the parameter you selected in (a), how valuable is the information provided by the parameter you selected in (b).

(c) If for some reason you did not have the sampling information on the parameters you selected in (a) and (b), which would you regard as the next most important parameter for managing the system. Relative to the parameters you selected in (a) and (b), how valuable is the information provided by the parameter you selected in (c).

The above process can be repeated until all the parameters on the supplied list are addressed. Once the above process is completed for all the important parameters, it becomes a basic mathematical exercise to allocate points to each parameter on the list, based on their 'relative information value'. For example, if there are 40 points available out of a 100 point index for six physico-chemical parameters, then the most important parameter may be 15 points and the least important 5 points. The other parameters would receive somewhere between these two values.

4.2 General index

The proposed general index is based upon six parameters that are important in most distribution systems. In some cases, the parameters in the general index may be a subset of the longer list of parameters used in a particular specific index. The parameters in the general index are regarded by the study team as important in most drinking water distribution system, and therefore are also monitored in most systems. These characteristics have been selected and allocated a relative information value, based on the interpretations of the study team, using:

- several guideline documents (particularly the 1996 Australian drinking water guidelines), and
- information in the drinking water management literature.

The parameters and their relative information values are indicated in table 1. The reasons for their selection are indicated below the table.

Table 1: Proposed general index of drinking water quality.

Characteristics	Guideline value	Relative information value for the particular parameter Overall value	Variations to overall value
Microbiological			
Total coliforms	0 CFU/100mL	15 points	
Thermotolerant coliforms	0 CFU/100mL	45 points	
Physico-chemical			
Turbidity	1 NTU	16 points	up to and including 1 NTU = 16 above 1 NTU to 2 NTU = 14 above 2 NTU to 3 NTU = 12 above 3 NTU to 4 NTU = 10 above 4 NTU to 5 NTU = 8 above 5 NTU = 0
pH	6.5 - 8.5	4 points	
Trihalomethanes	0.10 mg/L	14 points	up to and including 0.10 mg/L = 14 above 0.10 mg/L to 0.15 mg/L = 12 above 0.15 mg/L to 0.20 mg/L = 10 above 0.20 mg/L to 0.25 mg/L = 8 above 0.25 mg/L = 0
Iron	0.3 mg/L	6 points	up to and including 0.10 mg/L = 6 above 0.10 mg/L to 0.20 mg/L = 4 above 0.20 mg/L to 0.30 mg/L = 2 above 0.30 mg/L = 0
Overall possible total		100 points	

The characteristics included in the proposed general component of the index included:

- **Total coliforms**, which were selected because they represent a key microbiological indicator of drinking water quality. The value of 0 CFU/100mL has been proposed for the index, as this is the value in the most recent Australian drinking water guidelines (NHMRC and ARMCANZ, 1996). A relative information value of 15 points has been allocated to this parameter, as it is regarded as relatively critical but not as critical as thermotolerant coliforms, which have been allocated a relative information value of 45 points.

- **Thermotolerant coliforms**, which were selected because they also represent a key microbiological indicator of drinking water quality (i.e. recent human faecal contamination). The value of 0 CFU/100mL has been proposed for the index, as this is the value in the most recent Australian drinking water guidelines (NHMRC and ARMCANZ, 1996). A relative information value of 45 points has been allocated to this parameters, as it is regarded as more critical than total coliforms.

- **Turbidity**, which was selected because it is an important characteristic of water quality, because it can relate to:
  - the aesthetic appeal of the water as consumers partly judge water on its visual characteristics.
  - the amount of microorganisms in the water, as turbidity can provide nutrients and attachment sites for microorganisms.
  - the ability of the water to maintain a chlorine (disinfection) residual.

  The index value of 16 points for turbidity is allocated between zero and 5 NTU. Even though the most recent Australian drinking water guidelines (NHMRC and ARMCANZ, 1996) contain a value of 5 NTU, a range of values has been proposed for this index because the value of 5 NTU may be revised downwards in future Australian guidelines. For example, in the US, turbidity management is becoming a key issue for both:
  - Satisfactory microbiological quality (Pontius, 1996).
  - The maintenance of chlorine residuals in the distribution system without increases in disinfection by-products (Arora *et. al.*, 1997; Pontius, 1996 and 1997; Robertson *et. al.*, 1995).

- **pH**, which was selected because it represents an important general water quality parameter which has both an upper and a lower guideline value. When pH is below 6.5 or above 11, water can corrode pipes and plumbing. Furthermore, chlorination disinfection efficiency is impaired above pH 8.0. Also, above 9.5 the water can taste bitter, and cause skin irritations. The pH value of raw water is generally between 6.5 and 8.5, although concrete and cement-mortar lined pipes can significantly increase pH to values over 9.0 (especially during the first 5 years of service). The range of 6.5 - 8.5 has been proposed for the index, as this is the range in the most recent Australian drinking water guidelines (NHMRC and ARMCANZ, 1996). A relative information value of 4 points has been allocated to this parameter, as it is regarded as about half as important as trihalomethanes or turbidity.

- **Trihalomethanes**, which were selected because they represent a wide range of suspected or proven human carcinogenic compounds. Even though their concentrations in drinking water may be relatively low, they are consumed over many decades by most individuals in the population. The most effective way of reducing trihalomethanes in drinking water is to reduce the amount of organics in the water just prior to chlorination (Pontius, 1996; Robertson *et. al.*, 1995).

  The index value of 14 points for trihalomethanes has been allocated between zero and 0.25 mg/L. Even though the most recent Australian drinking water guidelines (NHMRC and ARMCANZ, 1996) contain a value of 0.25 mg/L, a range of value has been proposed for this index because the value of 0.25 mg/L maybe revised downwards in future Australian guidelines. For example, in the US, the current value is 0.10 mg/L, and it is in the process of being revised downwards in the next 2 years to a value of about 0.07 mg/L. This proposed lower value is based on public health findings that concentrations of trihalomethanes above 0.07 mg/L may increase the rate of miscarriages (Swan *et. al.*, 1998; Waller *et. al.*, 1998).

- **Iron**, which was selected because it represents an important aesthetic water quality characteristic (both in terms of taste and visual appearance). The index value of 6 points has been allocated between zero and 0.30 mg/L. Even though the most recent Australian drinking water guideline (NHMRC and ARMCANZ, 1996) contains a value of 0.30 mg/L, a range of values has been proposed for this index because iron levels can be an important aesthetic parameter. A relative information value of 6 points has been allocated to this parameters, as it is regarded as slightly more important than pH, but not as important as turbidity or trihalomethanes.

5. Suitable form of the index for management decision making

The proposed specific and general index is in a form that is suitable for management decision making in that:

- The index has a total of 100 points. This is a relatively easy system to use, as conceptually it would already be familiar to most people.

  In well functioning drinking water distribution systems, most samples would record a value between 50 and 100. The exact value for the system could be averaged for the year (or any other period longer or shorter) by averaging the individual index values obtained for each sample.

- The specific index can be used to compare drinking water quality within a distribution system. This is because it is essentially a composite number representing performance on a range of water quality parameters, with the importance of each parameter weighted in terms of the special characteristics and conditions that apply in that particular distribution system. As a performance indicator the proposed specific index can be used in a number of situations. For example, it can be used to provide answers to otherwise difficult questions, such as:
  - Generally, is drinking water quality better in part A of the system, as opposed to part B?
  - Generally, is drinking water quality better this year than last year?
  - Generally, is drinking water quality better this season than last season?
  - Generally, has drinking water quality improved since change X was implemented?

  Such questions are difficult to answer when a list of 10-20 parameters have to be considered at the same time. Such questions are especially difficult when not all the parameters move in the same direction. For example, total coliforms may be generally lower in system A than in system B, but turbidity and iron may be generally higher in system A than in system B.

  However, as the proposed specific index can provide answers to the abovementioned questions, it can be used as a suitable performance indicator.

- The general index can be used to compare drinking water quality between different distribution systems. This can provide information relevant to benchmarking. For example, it can be used to provide answers to otherwise difficult questions, such as:

- Generally, is the drinking water quality better in one system than another?

- The specific as well as the general index can be used in Total Quality Management (TQM) as a quality assurance/quality control system (QA/QC). For example, it can be used to calculate annual performance and then used to try and improve performance (i.e. the total quality of the drinking water supplied to the customer).

  Both the specific and the general index can also be used to set a certain value that is regarded as the minimum acceptable quality level for any particular sub-section of a distribution system.

- Both the specific and the general index can be used to allocate resources to different parts of the distribution system. Presumably, areas of a system with a lower index need to be allocated resources on a preferential basis, compared to areas of the system with a higher index. The nature and extent of such a resource allocation question is difficult to answer without the type of index proposed in the discussion. Without an index a manager has to simultaneously consider a range of parameters. Once again, such a task is made more difficult if not all the parameters move in the same direction at the same time.

The abovementioned items indicate that both the specific and the general index would be in a form that is suitable for management decision making. Either index would be a practical and informative management tool as it is essentially a composite number representing performance on a range of water quality parameters, with the importance of each parameter weighted in terms of its relative information value.

6. Suitable form of the index for communicating water quality information with the public

The proposed specific and general components of the index are in a form that is suitable for communicating information with the public in that:

- The index has a total of 100 points. This is useful in communicating information with the public as it is a relatively easy system to use, mostly because conceptually it would already be familiar to most people. Although a member of the public may not know (or indeed wish to know) how the actual index was derived, he or she would nevertheless be able to use the index. A member of the public would readily understand that a value of say 85 was better water quality than a value of say 75.

- Both the specific and the general index can be used as a performance indicator, but in this context from the public's point of view. For example, the public would be able to use the values provided by the index to:
  - Ascertain if part A of the system had better drinking water quality than part B.
  - Ascertain if particular years had better drinking water quality than others.
  - Ascertain if particular seasons had better drinking water quality than others.
  - Ascertain if particular changes resulted in better drinking water quality.
  - Ascertain if one distribution system had better water quality than another.

  Once again, even though a member of the public may not know (or indeed wish to know) how the actual index was derived, he or she would nevertheless be able to use the index value generated to answer the question for themselves.

- Both the specific and the general index can be used to communicate resource allocation issues to the public. For example it may be determined that in a given distribution system it may require $Y million to raise the index from a general value of say 75 points to say 90 points. As this would no doubt require an increase in rates for the customers of the distribution system, a resource allocation issue needs to be answered not just by the water authority, but by its customers (usually the public). It may be decided that the community is willing to pay the $Y million to raise general drinking water quality from an index of 75 to 90. Alternatively, the community may decide that it is willing to continue with a drinking water quality index of 75 and save $Y million.

In some cases a community may decide to lower its drinking water index, in return for a saving of $Z million (although the long term wisdom of such a move may be difficult to understand). Irrespective of the input the public may provide into a decision, both the specific and the general index would be a practical and informative public communication tool for information on drinking water quality.

7. Manual for possible implementation by a drinking water authority

This section of the report discusses the steps taken in the implementation of the previously described water quality index by a drinking water authority. The main steps are:

- Determine the water quality characteristics important to the management of the system.
- Allocate relative information values for each characteristic in the index.
- Allocate a range of guideline values for each characteristic in the index.
- Calculate the index value(s).

These are addressed in more detail below.

7.1 Determine the water quality characteristics important to the management of the system

The water quality characteristics important to the management of a particular drinking water distribution system are probably the same as (or at least similar to) the characteristics which are presently measured for compliance and for operational monitoring. The list would generally include:

- Microbiological characteristics such as:
  - Total coliforms.
  - Thermotolerant coliforms.
  - Others (such as heterotrophic plate count bacteria at 20°C or 35°C, opportunistic pathogens etc).

- Physico-chemical characteristics such as:
  - Turbidity.
  - Colour.
  - Free residual chlorine.
  - pH.
  - Others (such as iron, manganese, hardness, taste and odour, temperature, inorganic chemicals, organic disinfection by-products, organic chemicals, and radiological measures).

7.1.1 Specific index

Select from the abovementioned list the water quality characteristics which are particularly important for the management of the system and use these in the specific component of the index.

7.1.2 General index

Use the characteristics which have been already selected for the proposed general index.

7.2 Allocate relative information values for each characteristic in the index

7.2.1 Specific index

Allocate relative information values to the list of particularly important characteristics (compiled in the step above), used in the specific index.

Allocate points up to a total of 60 points for the microbiological characteristics, and up to a total of 40 for the physico-chemical characteristics.

Determine the 'relative informative value' of each of the characteristics using information from the managers of the particular system, by trying to answer questions such as:

(a) Amongst the parameters on the list provided, can you indicate the one you feel is the most important for managing the system.

(b) If for some reason you did not have the sampling information on the parameter you selected in (a), which would you regard as the next important parameter for managing the system. Relative to the parameter you selected in (a), how valuable is the information provided by the parameter you selected in (b).

(c) If for some reason you did not have the sampling information on the parameters you selected in (a) and (b), which would you regard as the next most important parameter for managing the system. Relative to the parameters you selected in (a) and (b), how valuable is the information provided by the parameter you selected in (c).

Repeat the above process until all the parameters on the supplied list are addressed, and the 'relative information value' of each of the parameters on the list has been determined.

Allocate a range of guideline values for each characteristic in the specific index. For this process it is probably best to use (wherever possible) the NHMRC and ARMCANZ (1996) Australian drinking water guideline values. These guideline values have

undergone an extensive compilation and assessment process, and consequently can be (and should be) used to allocate the guideline values for each characteristic in the specific component of the index. For some parameters the points allocated may show some variation based on the observed value of the parameter (please see table 1 for examples of this for turbidity, trihalomethanes and iron).

7.2.2 General index

Use the characteristics proposed in the general index, together with the guideline levels and the relative information values allocated to those characteristics, as shown in table 1.

7.3 Calculate the index value(s)

Calculate the values for the specific and the general index for each sample obtained as part of the monitoring program.

Some samples will receive the full 100 points (on both the specific and the general component) of the index. However, other samples may receive a lower number of points, which may be anywhere from 0 to just below 100.

Calculate the average value for:

- Specific component (based on the specific index value calculated for each sample).
- General component (based on the general index value calculated for each sample).

Use the average value obtained for the **specific** index to provide summary information for comparisons **within** the particular distribution systems.

Use the average value obtained for the **general** index to provide summary information for comparisons **within** as well as **between** different distribution systems.

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