4.
WATER QUALITY

4.1 Introduction

Water quality is a particularly important issue for management of estuaries along the South African coast because over 50% of South Africa's people live within 100 km of the coast. While point sources of pollution are easier to regulate, the diffuse sources are often difficult to identify and control.

It is a well-known principle in ecology that the nature of the biological community in an estuary is largely determined by a multiplicity of factors in its physical-chemical environment. This is why the fish community structure was utilised as a measure of the health of estuaries. The biotic community structure serves as an integrated measure of health, responding to wide spread long-term conditions and changes.

However, it is important to remember that water quality can change significantly over short periods of time. These episodic events may not be reflected in the fish community structure, as fish are largely mobile and may temporarily accommodate or avoid periods of water quality deterioration. In addition, biotic change will lag physical-chemical changes, and hence the water quality characteristics may foreshadow long-term trends. For example, the presence of increasing concentrations of nutrients may indicate future eutrophication with all of its attendant problems. Finally, there are some water quality characteristics which are of great importance to man which are not reflected by fish community structure. The suitability of estuaries for contact recreation is just one such example.

4.2 Background

The use of indices to condense and summarise large volumes of water quality data has increasingly gained acceptance in the last decade (Harding & Eckstein, 1996). This has come about largely because of a practical need to succinctly compare the overall water quality at many different locations. What is necessary in this respect is a simple, objective, consistent, and reproducible numeric scale on which to represent water quality information.

Indices are able to facilitate quantification, simplification and communication of complex environmental data. They also generate actions to solve the problems they summarise, because they can serve as tools for monitoring the state of environment. This approach is well known and widely applied in many fields, such as economics. Unfortunately the scientists who develop indices generally have little to say regarding how the summarised information will be used by decision makers and politicians, who are often far removed from the original data. As a consequence, the danger exists of making ill-informed decisions. However, it is generally the case that an index can interpret complex information objectively, which permits the decision maker to make a better decision than would have been taken in the absence of information.

A summary of a review of the use of water quality indices in the literature is contained in Table 4.1. It is immediately apparent that only two studies involved estuaries and this includes earlier work conducted during the course of this study (Cooper *et al*., 1994), the remainder being restricted to inland waters. Only one other study (Richardson, 1997) involved estuaries. This recent study by Richardson (1997) draws heavily from Cooper *et al.* (1994) and adapts this approach to the estuaries of New South Wales, Australia. It is important to note that the index developed by Richardson (1997) has not yet been applied to actual field data.

Table 4.1. Review of Water Quality indices in the literature, indicating the indicators utilised, the applicable aquatic system and the location applied.

Reference	Water Quality Indicators				Aquatic system	Country
	physical	chemical	bacteriological	toxic		
Brown *et al.* (1970[+])					rivers	USA
Cooper *et al.* (1994)					estuaries	South Africa
Cude (1997)					rivers	USA
Dinius (1987)					fresh water	USA
Dojilido *et al.* (1994)					rivers	Poland
Dunnette (1979)					rivers	USA
Erondu & Nduka (1993)					rivers	Nigeria
Horton (1965) [+]					rivers	USA
House (1989, 1990)					rivers	UK
Joung *et al.* (1979)					rivers	USA
Moore (1990)					rivers	South Africa
Prati *et al.* (1971)					rivers	Canada
Richardson (1997)					estuaries	Australia*
Ross (1977) [+]					rivers	UK
Smith (1989, 1990)					waterways	New Zealand
Steinhardt *et al.* (1982)					lakes	USA
Walski & Parker (1971)					waterways	USA
Wepener *et al.* (1992)					rivers	South Africa
Yu & Fogel (1978)					water treatment	USA

+ cited from Couillard & Lefebvre (1985)
* not yet applied in Australia

Figure 4.1 summarises the process used for developing the estuarine water quality index. This process is not unique but is basically the same as the approach taken by numerous investigators in this field.

As illustrated in Figure 4.1, there are four basic steps involved in the development of most water quality indices. These include:

1. selecting the set of water quality variables (indicators) of concern
2. developing rating curves for comparing indicators on a common scale
3. weighting the indicators based on their relative importance to overall water quality
4. formulating and computing the overall water quality index

Dunnette (1979), House (1989), Moore (1990), Richardson (1997), and others have thoroughly discussed and described these steps and the theory behind constructing water quality indices. However, for the purposes of this report, a brief discussion of the major concepts involved in Figure 4.1 is necessary.

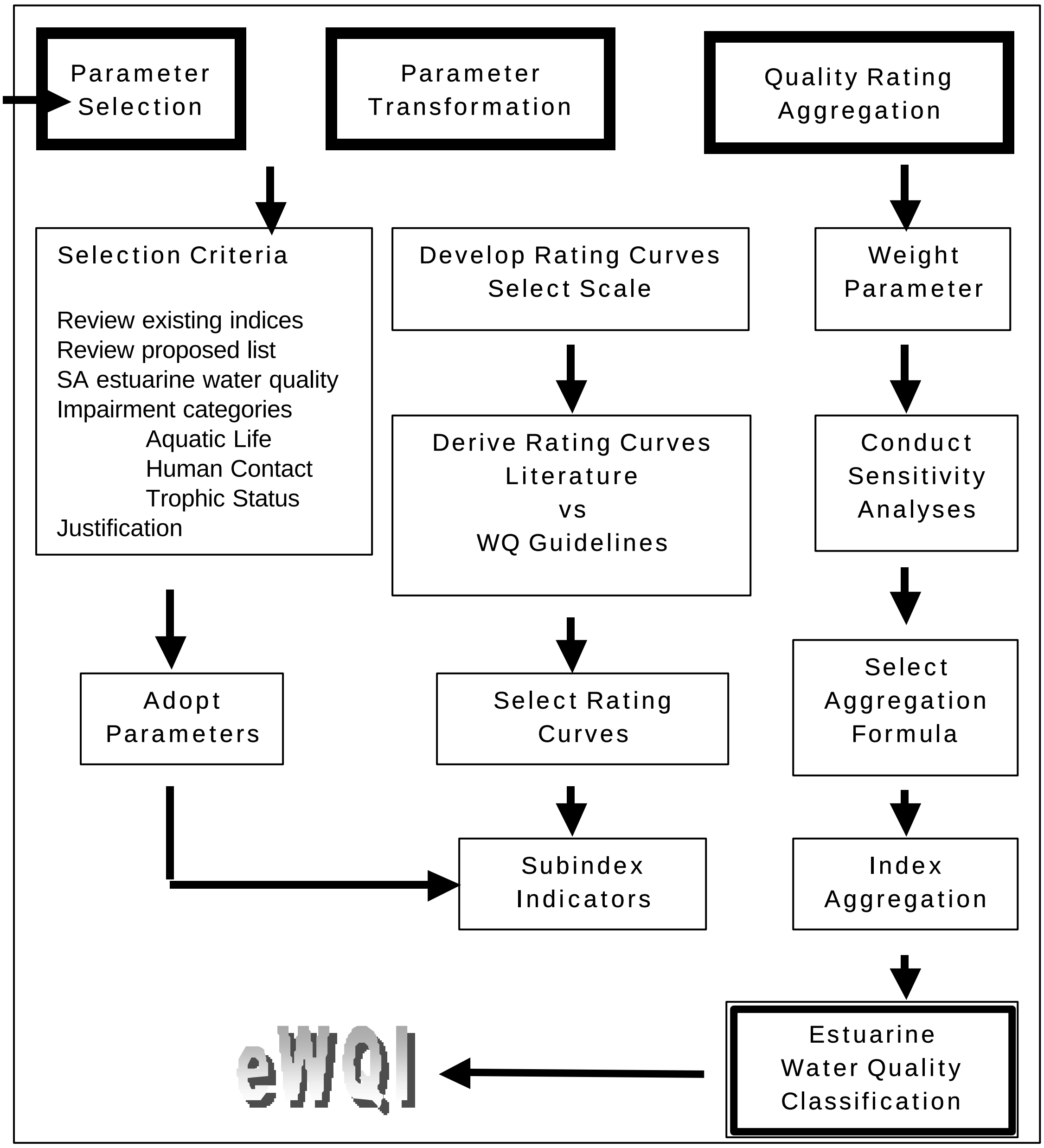

Figure 4.1. The process of development of the Estuarine Water Quality Index (eWQI). Adapted from Richardson (1997).

Selecting indicators:

In brief, Dunnette (1979) recommended that variables of concern to water quality should be selected from five commonly recognised impairment categories including: (1) oxygen status, (2) eutrophication, (3) health aspects, (4) physical characteristics, and (5) dissolved substances. It should be noted that these recommendations were based on perceived requirements of freshwater and not marine or estuarine systems. Richardson (1997) has more recently reviewed the literature and his conclusions agree substantially with those of Dunnette (1979).

Indicator transformation:

Water quality indicators are generally expressed in many different units (for example: parts per million, counts per volume, percent of saturation, etc). This makes simple aggregation impossible. As a consequence, another important step in developing an index involves the transformation of all indicators to an equal, dimensionless scale. This is generally accomplished through the use of rating curves, where indicator concentration is mapped against a dimensionless measure such as relative water quality value. Such rating curves are common in the literature, although these, in the past, have been based on the importance of an indicator to freshwater systems (Brown *et al*., 1970; Cude, 1997; House, 1989; Moore, 1990; Stojda & Dojlido, 1983; Walski & Parker, 1974; Wepener *et al*., 1992).

Indicator weighting:

It is also generally acknowledged that some indicators are more important to "average water quality" than others. It is thus necessary to weight the indicators appropriately. The assignment of weights is generally accomplished by some sort of consensus or Delphi technique and is based upon the judgement of the experts consulted.

Index aggregation formulations:

A variety of index aggregation formulas have been used by previous investigators. These (and the frequency of their usage in the literature reviewed) is summarised in Table 4.2.

Table 4.2. Summary of aggregation methods used by various investigators.

METHOD	REFERENCE	USAGE
Solway modified unweighted and weighted sum	House (1989), Moore (1990) Couillard & Lefebvre (1985)	5
Arithmetic unweighted and weighted mean	Ott (1978), Brown *et al.* (1970) Walski & Parker (1974) Stojda & Dojlido (1983)	5
Unweighted harmonic square mean	Dojlido *et al.* (1994)	3
Weighted product	Couillard & Lefebre (1985)	1
Geometric mean	Walski & Parker (1974)	2
Minimum operator	Smith (1989), Ott (1978)	1
Weighted sum	Brown *et al.* (1970), Moore (1990)	1

House (1989) conducted a review of these many different index formulations in the literature and concluded that the modified arithmetic weighted mean (Stojda & Dojlido, 1983), or Solway modified weighted sum (Couillard & Lefebvre, 1985), provides the best results for general water quality indexing. Moore (1990) further concluded that the Solway modified weighted sum was the most suitable formulation for a general water quality index in the South African context.

This formulation was considered to be most applicable by Moore (1990) because:

- it is sensitive to changes in water quality indicators throughout their range
- it lacks bias to either good or poor water quality, i.e. reflects average water quality
- it includes weighting factors as all indicators of concern are not equally important contributors to average water quality
- it is relatively easy to compute on a routine basis

Where the index takes on the range 0 - 10, this formulation can be expressed as:

$$\frac{1}{10}\left(\sum_{i=1}^{n} q_i w_i\right)^2 \qquad (1)$$

and n = number of indicators of concern

q_i = the water quality rating value of the i^{th} indicator

w_i = the weighting of the i^{th} indicator

The water quality rating value (q) for each indicator (i) is determined from a rating curve as described above, which relates the observed concentration to a corresponding water quality rating value between 0 and 100.

Richardson (1997) has recently thoroughly reviewed the various index aggregation formulas reported in the literature. He has argued in favour of the unweighted harmonic square mean formulation for the development of an estuarine water quality index for New South Wales, Australia. The merits of this approach to South African estuaries will be discussed in a later section.

4.3 Water quality surveys

For the purpose of this study, the primary objective was to obtain a "snapshot" of average water quality for comparative purposes. The possibility of applying a water quality indexing approach to South African estuaries, using existing data collected during other surveys was investigated. However, after a thorough review and evaluation of the available data, it was concluded that existing data were not suitable. Firstly, no significant water quality information existed for more than half of the estuaries. In addition, in order to obtain a meaningful synoptic comparison of the existing water quality in South African estuaries, it is necessary to have available a set of data which is internally consistent. This requires that all data are collected from comparable locations within each system, using similar techniques, and within as narrow a time window as practical. The mouth condition of each system must be noted, and where salinity layering is observed, surface and bottom samples must be collected.

To obtain such a set of internally consistent data, water quality surveys were conducted on 250 estuaries between 1992 and 1998. Logistical constraints restricted the sampling program to manageable regions of the South African coastline during this period. Table 4.3 below shows the dates for each region of coastline surveyed.

Table 4.3. Region of coastline and dates sampled.

Region	**Dates Sampled**
KwaZulu-Natal (Mtamvuna – Thukela)	October 19 - November 12, 1992
west/south-west coast (Gariep – Buffels (Oos))	January 17 - February 6, 1994
south-west/south coast (Palmiet – Sout)	June 5-27, 1994
south/south-east coast (Groot (Wes) – Great Fish)	July 26 - August 12, 1995
south-east coast (Old Womans – Great Kei)	July 9-25, 1996
Transkei (Gxara – Mtentwana)	March 3-26, 1998

It is important to clearly understand that the main objective of this study was to provide a "snapshot" of "average" water quality for internal comparison of South African estuarine systems. While the deficiencies of basing evaluation of water quality on one sample set is acknowledged, it is important to remember that, prior to this survey, no significant water quality information was available for over two-thirds of South Africa's estuaries. This survey provides the first nation-wide baseline of estuarine water quality, and must be regarded as an important beginning. Furthermore, no attempt to summarise the comparative water quality of all of the estuaries has previously been made.

Water samples and associated physical-chemical measurements were obtained from one to five sites within each system from the mouth area to the head area. The number of samples taken was based on an analysis of aerial photographs prior to the survey and on observations of each system made at the time of the survey. Where water depth was greater than 50 cm and/or salinity layering strong, samples and measurements were obtained at approximately 25 cm below the surface and 25 cm above the bottom. The following data were obtained for each site:

Table 4.4. Water quality Indicators measured during the estuary surveys.

time	dissolved oxygen	turbidity
water depth	oxygen absorbed	nitrate nitrogen
secchi depth	total ammonia	ortho-phosphate
salinity	faecal coliforms	mouth condition
temperature	pH	conductivity

Water quality measurements of temperature, turbidity, dissolved oxygen, pH and conductivity were taken *in situ* using a Horiba U-10 Water Quality Checker. Water samples were taken using generally accepted procedures and analyses were conducted within 24 hours of sample collection. Total ammonia, nitrate nitrogen and orthophosphate were determined using the Merck Spectroquant analysis system together with a Merck SQ118 photometer. Bacteriological water quality (faecal coliforms) was determined following the South African Bureau of Standards method 221 together with an ELE Paqualab system for microbiological water analysis. Oxygen absorbed was determined by titration in accordance with the South African Bureau of Standards method 220. All equipment and methods were verified prior to the field surveys by running quality control experiments of the field equipment and methods against standard laboratory equipment and methods.

4.4 Development of estuarine water quality indices

4.4.1 *Selection of variables of concern*

As noted earlier, Dunnette (1979) recommended that indicators of concern to water quality should be selected from five commonly recognised impairment categories including: (1) oxygen status, (2) eutrophication, (3) health aspects, (4) physical characteristics, and (5) dissolved substances.

It is not surprising that there is considerable variation in opinion regarding which indicators are of the greatest importance to water quality. The literature from past and current water quality indexing studies has been reviewed to summarise the relative importance assigned to each indicator, which might be potentially applied to the estuaries of South Africa. Of the various water quality indices reviewed previously in Table 4.1, forty-four separate indicators were used in these indexing studies. Two of these indicators reflected toxic substances and pesticides and were not considered further due to survey and analysis difficulties.

Those indicators, which were applied with a frequency of three or more, are shown in Figure 4.2.

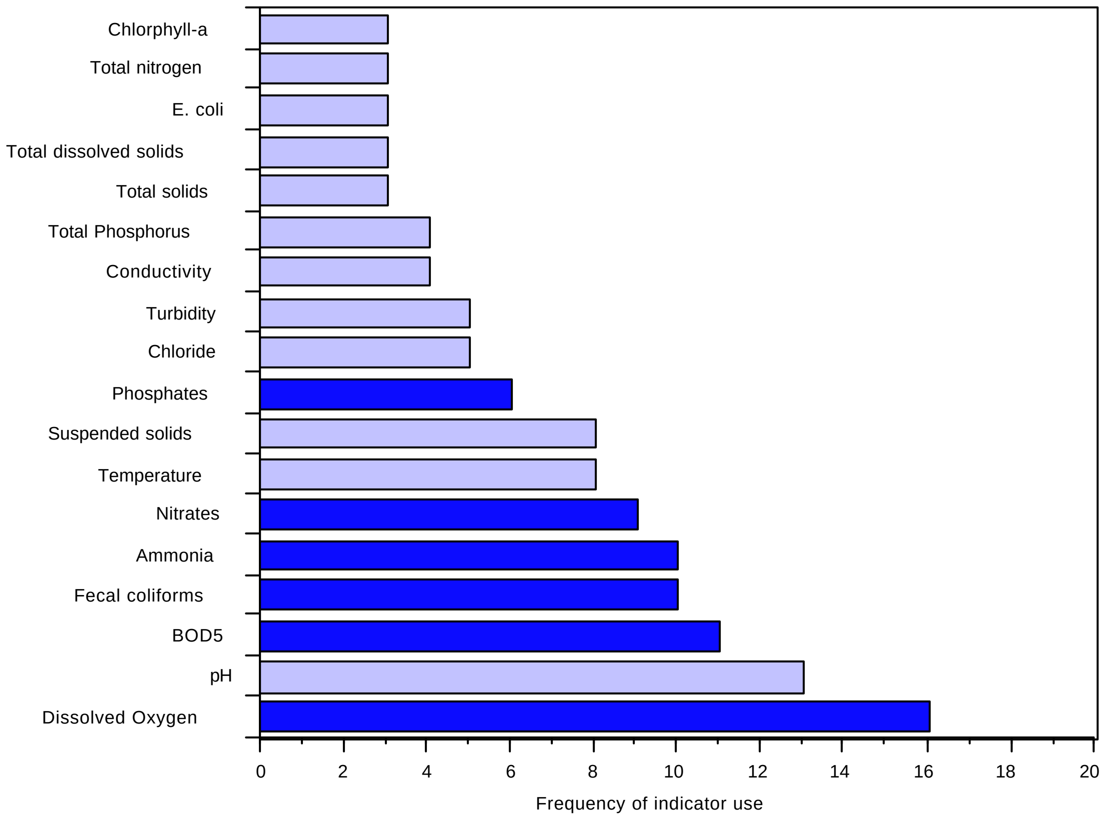

Figure 4.2. Frequency of indicators used in Water Quality Indices. Solid bars indicate parameters used in this study.

In order to determine the best indicators for the purposes of this study, the following considerations were used. While the importance of all five impairment categories is evident for freshwater systems, the meaning of physical characteristics (4) and dissolved substances (5) in terms of estuarine water quality needs to be carefully considered.

Due to the dynamic nature of estuarine water masses under "normal" conditions, physical characteristics and dissolved substances content of estuarine water are highly variable. The pH and turbidity are strongly controlled by the mixing of marine and fresh water. Given the buffering capacity of seawater, the pH of river water entering an estuary will be driven toward 8. Thus, the pH of estuarine water generally increases towards the mouth, and an average value for the estuary probably has little utility. Its importance, however, as an indicator of ionic equilibria (for example in evaluating the potential for ammonia toxicity, etc.) must be recognised.

The water quality significance of turbidity or suspended solids in estuarine water is largely unknown. The turbidity of the river water entering estuaries is probably more closely related to the nature of the catchment geology and geomorphology than to other factors. Furthermore, as this more turbid water encounters the intruding seawater a zone of maximum turbidity will often develop within the estuary. Dramatic variations in turbidity within an estuary will often develop. On one sampling occasion a vertical plane separating river and marine water masses was clearly visible. Here, the concept of mean turbidity for the estuary is meaningless, and thus contributes little to a measure of average estuarine water quality.

The major source of dissolved substances in estuaries is the intruding seawater; hence measurement of total dissolved solids (salinity) is a much more important indicator of the extent of seawater mixing than water quality impairment. In fact, it is the brackish nature of estuarine water that makes this habitat unique and contributes to its resource value.

As a consequence of the above, the five impairment categories recommended by Dunnette (1979) have been revised into three categories which are felt to be of primary importance to water quality in estuaries. These three categories, their associated indicators, and reasons for inclusion are listed in Table 4.5.

Within these categories, indicators which could be realistically measured given the time and logistical constraints imposed by the study were then determined. This resulted in the selection of the six indicators shown by the filled bars in Figure 4.2. Oxygen absorbed (OA) was chosen as a practical surrogate for BOD5, which proved impractical. Also note that chlorophyll-*a* was initially chosen as a seventh indicator but was later dropped for several reasons. This is discussed later under "Conclusions & recommendations".

It is important to note that the six water quality indicators were selected based on their amenability to field testing, their generally accepted importance to *estuarine* water quality, and their relevance as a measure of average water quality.

Table 4.5. Impairment Categories, Indicators, and their basis for inclusion in the Estuarine Water Quality index (eWQI).

IMPAIRMENT CATEGORY	INDICATOR	BASIS FOR INCLUSION
(1) suitability for Aquatic Life	Dissolved Oxygen	essential to aquatic faunal metabolism
	Oxygen Absorbed	measure of organic loading
	Unionized Ammonia	toxicity to aquatic fauna
(2) suitability for Human Contact	Faecal Coliforms	presumptive evidence for human pathogens
(3) Trophic Status	Nitrate Nitrogen	aquatic plant growth stimulant
	Ortho-Phosphate	aquatic plant growth stimulant

4.4.2. *Development of rating curves*

In order to standardise the concentrations of the selected indicators, rating curves were developed. These curves have been developed in consultation with a variety of organisations and individuals including the Department of Water Affairs and Forestry (DWAF), University of Natal, consulting firms, and CSIR. Where possible rating curves which have been developed by other investigators were utilised. The rating curves for dissolved oxygen, and faecal coliforms were taken directly from the curves developed by Moore (1990) in conjunction with the South African Department of Water Affairs.

The rating curve for oxygen absorbed (OA) was adapted from the biochemical oxygen demand (BOD) rating curve developed by Smith (1990). Observations of the relationship between BOD and OA in several estuaries in KwaZulu-Natal have suggested that there is a loose correlation between the two. In general the OA values have been approximately 2-3 times the BOD concentrations. As an approximation, Smith's (1990) BOD rating curve was appropriately adjusted by this factor.

The rating curves for ammonia and nitrate were developed from data provided by the Department of Water Affairs and Forestry. pH measurements were used to correct the data for total ammonia to unionized ammonia. The phosphate rating curve was developed by reviewing the literature on the relationships between water quality and known concentrations of ortho-phosphate. Australian standards for aquatic systems were also considered in the development of the phosphate curve.

In this regard it is important to highlight here the variance from the nutrient curves suggested by Richardson (1997) and the reasons for utilising the curves described in this study. First of all, there are currently no South African nutrient standards for estuarine waters. If the Australian standards were adopted, then virtually all of South Africa's estuaries would be classified as eutrophic. The Australian standards reflect systems which are intrinsically different to those in South Africa, where fluvial effects naturally produce relatively higher nutrient concentrations. KwaZulu-Natal is a good example where nutrient concentrations, derived from detrital sources, result in relatively high background nutrient levels. It was felt that application of the Australian standards, and likewise Richardson's (1997) ratings curves (which are based on New South Wales' guidelines) would be inappropriate.

4.4.3 *Variable weighting*

In order to arrive at a relative weighting of the six water quality variables, the three impairment categories were weighted approximately equally. Thus AQUATIC LIFE was weighted at 35%, TROPHIC STATUS at 35%, and HUMAN CONTACT at 30%. The slightly lower rating of the human contact category was used recognising that the entire weight would be accorded to one variable - faecal coliforms. This restrained the individual weighting for faecal coliforms to within the range of weights assigned to faecal coliforms by the respondents in the study by Moore (1990). The breakdown of weights assigned to each of the water quality variables of concern is shown below:

Table 4.6. Relative weights assigned to variables of concern

CATEGORY	VARIABLES	BASIS FOR INCLUSION	WEIGHT
(1) suitability for	Dissolved Oxygen	essential to aquatic fauna	0.20
Aquatic Life	Oxygen Absorbed	measure of organic loading	0.05
	Ammonia Nitrogen	toxicity to aquatic fauna	0.10
			0.35
(2) suitability for	Faecal Coliforms	presumptive evidence for human	
Human Contact		pathogens	**0.30**
(3) Trophic Status	Nitrate Nitrogen	aquatic plant growth stimulant	0.15
	Ortho-Phosphate	aquatic plant growth stimulant	0.20
			0.35

4.4.4 *Formulating and computing the water quality index*

The estuarine water quality index was formulated and computed using the rating curves and variable weightings described above and based on equation (1). In the literature most water quality indices are scaled between 0 and 100, however, for this study the eWQI index values were scaled between 0-10.

In order to provide a single water quality index for each estuary, the surface and bottom concentrations for each water quality variable were first calculated for the sites in each system. Then the following protocol for each water quality indicator was applied:

For dissolved oxygen (DO) a surface-weighted (surface DO twice as important as bottom DO) water column value was calculated. The rating curve was then applied to this ‘average’ DO concentration to obtain a water quality value for DO for each site sampled within the estuary. Two rating curves were used for DO. For DO concentrations below saturation, a DO concentration curve was applied to obtain the DO water quality value. For concentrations at or above saturation, a DO percent saturation curve was used.

For faecal coliforms and oxygen absorbed, only surface concentrations were used with the respective rating curves, to obtain a water quality value for each variable at each site within each system.

For ammonia, nitrate and phosphate, the higher of the surface or bottom value was used with the respective rating curve to obtain the appropriate water quality value for each site within each system. In practice, the surface concentrations were virtually always the higher of the two.

The water quality values for all six indicators at each site were combined according to equation (1) and using the appropriate weightings to obtain a water quality index for each site.

The water quality indices for all sites within each estuary were then averaged to obtain a mean estuary water quality index. Where two estuaries shared a common mouth, the data from sites within the respective estuaries were combined into a single mean estuarine water quality index.

4.5 Results & discussion

4.5.1 *Index testing*

Sensitivity analysis for chlorophyll-a.

Originally, chlorophyll-*a* was selected as one of the indicators to be used under the trophic status impairment category. It was felt that it was a more direct indicator of plankton activity than nutrient concentration. It thus would serve as an excellent complement to the nutrients. Having said this it should be noted that there is considerable debate among water quality specialists regarding the applicability of chlorophyll-*a* as a measure of trophic status of aquatic systems.

When field sampling began in 1992, problems were encountered with the measurement of cllorophyll-*a* in the field using the method (spectrophotometer) available at the time. In the case of the Transkei regional data, the chlorophyll-*a* values obtained were not reliable and in fact were not used for computing the draft eWQIs for that region (Harrison *et al*., 1999). It should be noted, however, that there are more robust field-adapted analytical methods now available for chlorophyll determinations.

For the sake of consistency among all of the estuaries, it is clearly preferable to compute the eWQI in exactly the same manner, using the same parameters for each system. This is also important for any future comparative studies. For this reason the merits of removing chlorophyll-*a* data from the index computation were examined.

The effects of including/removing chlorophyll-*a* as a parameter were investigated using the south-east coast (Old Womans – Great Kei) regional data set. This represented the most current data available. The WQI was computed first with, and then without the chlorophyll data. The results of this sensitivity analysis revealed that the removal of chlorophyll-*a* had no significant effect on the ranking of estuaries in the region. The removal of chlorophyll-*a* produced less than 3% average change in the eWQI. Generally its removal caused a slight decrease in the eWQIs. Furthermore, this indicator had the least overall weighting in the computation of the index and is one of the least frequently used of the fourteen indicators listed in Figure 4.2. For these reasons, and to preserve consistence from region to region, chlorophyll-*a* was eliminated as an indicator in the final eWQI.

Sensitivity of the eWQI to aggregation formulation

Richardson (1997) concluded that the unweighted harmonic mean aggregation formula was a more appropriate method than the Solway modified weighted sum method used in this study. There are a number of advantages to this formulation, the most significant of which is that no weighting of indicators must be done. This removes one of the more subjective aspects of indicator development. Richardson (1997) also indicates that this formulation is more sensitive to the indicator with the lowest score.

This may be an advantage if the index is used mainly for establishing beneficial use classes. In this case that indicator showing the greatest impairment will dictate the use class. However, the expressed main purpose of this study is to report a comparative "average" water quality for each estuary. Under these constraints, the Solway aggregate suggested by Moore (1990) is the more appropriate method for waters in South Africa.

This begs the question of how sensitive the index is to the aggregation formula. If the use of the harmonic mean formula results in a significant difference in the ranking of the estuaries, then its use must be objectively considered. In order to attempt a resolution a comparison between the Solway formulation and the harmonic mean formulation using the data from surveys of the Transkei region was run.

The harmonic mean formulation resulted in a general increase of approximately 5% in the eWQI values. However, the use of the alternative formulation did not significantly alter the ranking of the systems. As a consequence there is no compelling reason at this stage to adopt this formulation over the Solway formulation used in this study.

4.5.2 *National results*

The summary statistics of applying the formulation described in equation (1) to the water quality variables of concern for the 250 systems surveyed, using the protocol outlined above are summarised in Table 4.7.

Table 4.7. Summary statistics for 249 South African 'estuaries'.

Number of Estuaries	249
Mean eWQI	6.02
Median eWQI	6.51
Mode	5.67
Standard deviation	1.99
Variance	3.94
Minimum (Mbokodweni)	0.11
Maximum (Nyara)	9.58

The frequency distribution of the eWQI values was skewed with a mean of approximately 6.0. Although the distribution is not normal, it was used to create a general classification of average water quality in South Africa's estuaries. A one-standard-deviation range with the mean (~6.0) at its centre was used for systems classed as "Fair". Applying further one-standard-deviations above and below the limits for the "Fair" class result in "Good" and "Poor" classes respectively. Finally systems with eWQI values either above or below these limits are classified as "Very good" or "Very poor" respectively. Caution should be used when using this classification alone, as it is based on one set of samples from each system.

These five average estuarine water quality classes are summarised as follows:

Table 4.8. Five water quality classes and their eWQI values.

Water Quality Class	**eWQI value**
Very Poor	eWQI<3
Poor	3<eWQI<5
Fair	5<eWQI<7
Good	7<eWQI<9
Very Good	eWQI>9

Figure 4.4 further summarises the water quality of all 250 estuaries based on the eWQI and the above water quality classification scheme. Approximately 41% of all estuaries are classified as "Good" or "Very Good", 34% were classed as "Fair" and the remaining 26% were classified as "Poor" or "Very Poor".

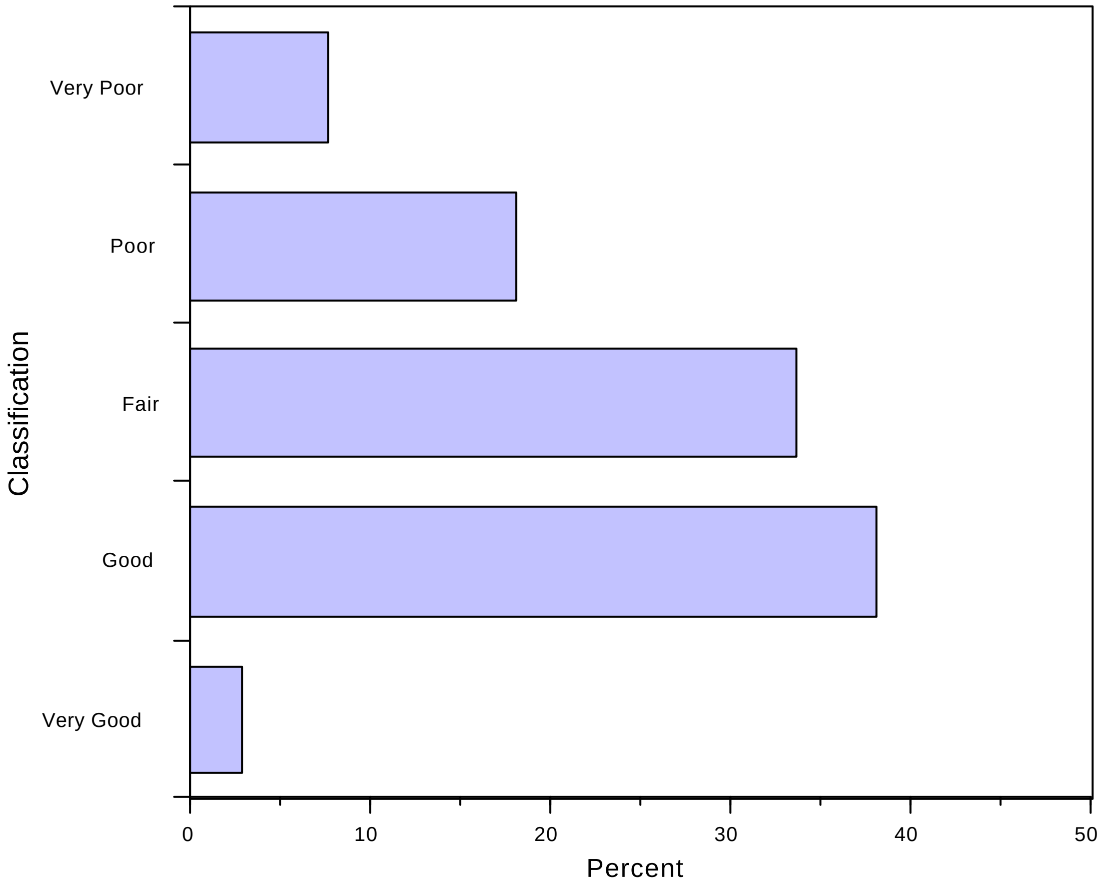

Figure 4.3. National summary of water quality of South African estuaries.

4.5.3 *Regional results*

The overall average water quality index (on a scale of 0-10) is presented for each of the 250 systems sampled, as well as a breakdown of the overall index by its three water quality subcategories (suitability for aquatic life, suitability for human contact, and trophic status). The average eWQI vales for the 250 systems are arranged geographically from the west coast (Figure 4.5), south-west coast (Figure 4.6), south coast (Figure 4.7), south-east coast (Figure 4.8), Transkei region (Figure 4.9), and KwaZulu-Natal (Figure 4.10). It must be noted that the Transkei region is under-represented due to extremely difficult access to most systems.

Only 12 systems were sampled in the west coast region (Figure 4.5). Five systems (42%) were classed as "Poor" or "Very Poor", five systems (42%) were classified as "Fair" and the remaining two systems (16%) were "Good" to "Very Good". In the south-west coast region, from the Dwars (Suid) to the Ratel, 32 systems were assessed (Figure 4.6). Thirteen systems (41%) were classified as "Very Poor" to "Poor". A total of 12 systems (38%) were rated as "Fair". The remaining seven systems (22%) were classed as "Good". A total of 52 systems were sampled in south coast region from the Heuningnes to the Sundays (Figure 4.7). Seven systems (14%) had "Poor" eWQI values, 11 systems (21%) were classed as "Fair" and the remaining 34 systems (65%) had "Good" to "Very Good" eWQI values. In the south-east coast, from the Boknes to the Great Kei, 55 estuaries were sampled (Figure 4.8). Four systems (7%) were classed as "Very Poor" or "Poor", 13 systems (24%) had "Fair" eWQI values, and the remaining 38 systems (69%) were classified as "Good" or "Very Good". In the Transkei region 43 estuaries were sampled (Figure 4.9). Fifteen systems (35%) were rated as "Very Poor" to "Poor", 24 estuaries (56%) had "Fair" eWQI values and only four systems had "Good" water quality. A total of 56 estuaries were sampled in KwaZulu-Natal (Figure 4.10). Twenty systems (36%) had "Very Poor" to "Poor" water quality, 19 estuaries (34%) were rated as "Fair" and the remaining 17 estuaries (30%) had "Good" eWQI values.

Overall, systems on the south and south-east coastal regions had the best overall water quality with a preponderance of these estuaries classified as "Good". They also contain nearly all of the systems which are classed as "Very Good". Conversely, the Transkei and KwaZulu-Natal have a relatively high proportion of systems in "Poor" condition. Again, caution must be used in applying these general conclusions without corroborating information, such as from other monitoring studies.

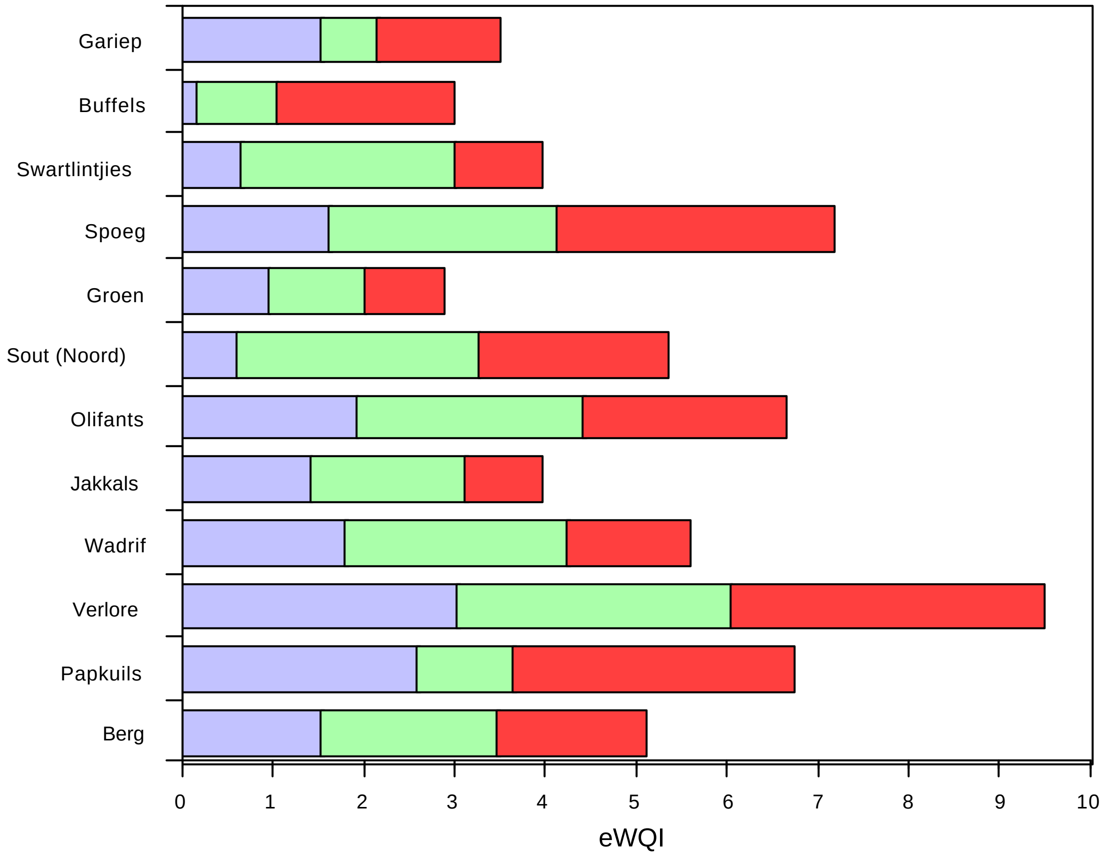

Figure 4.4. Average eWQI values for the west coast region (Gariep – Berg) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

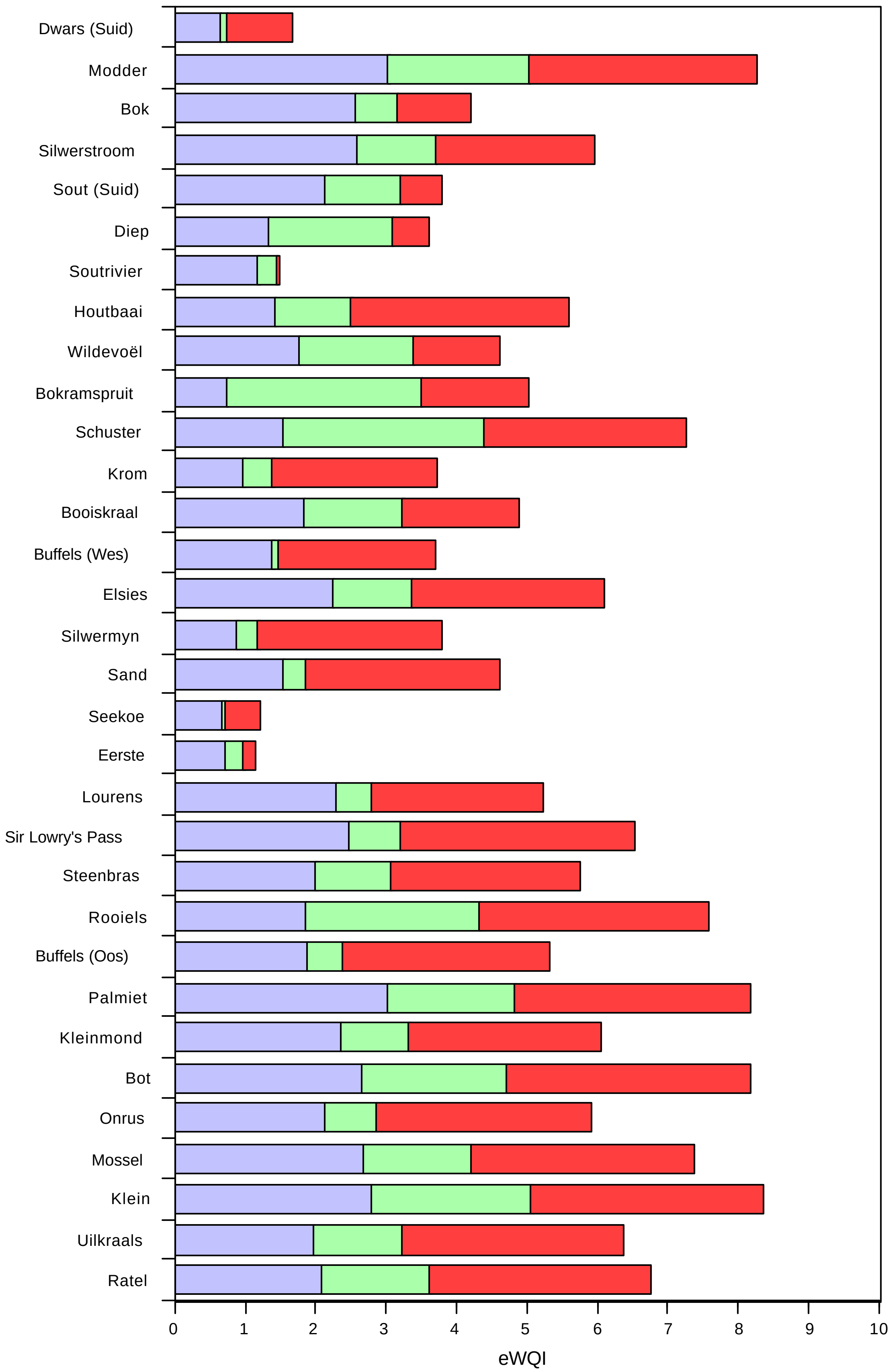

Figure 4.5. Average eWQI values for the south-west coast region (Dwars (Suid) – Ratel) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

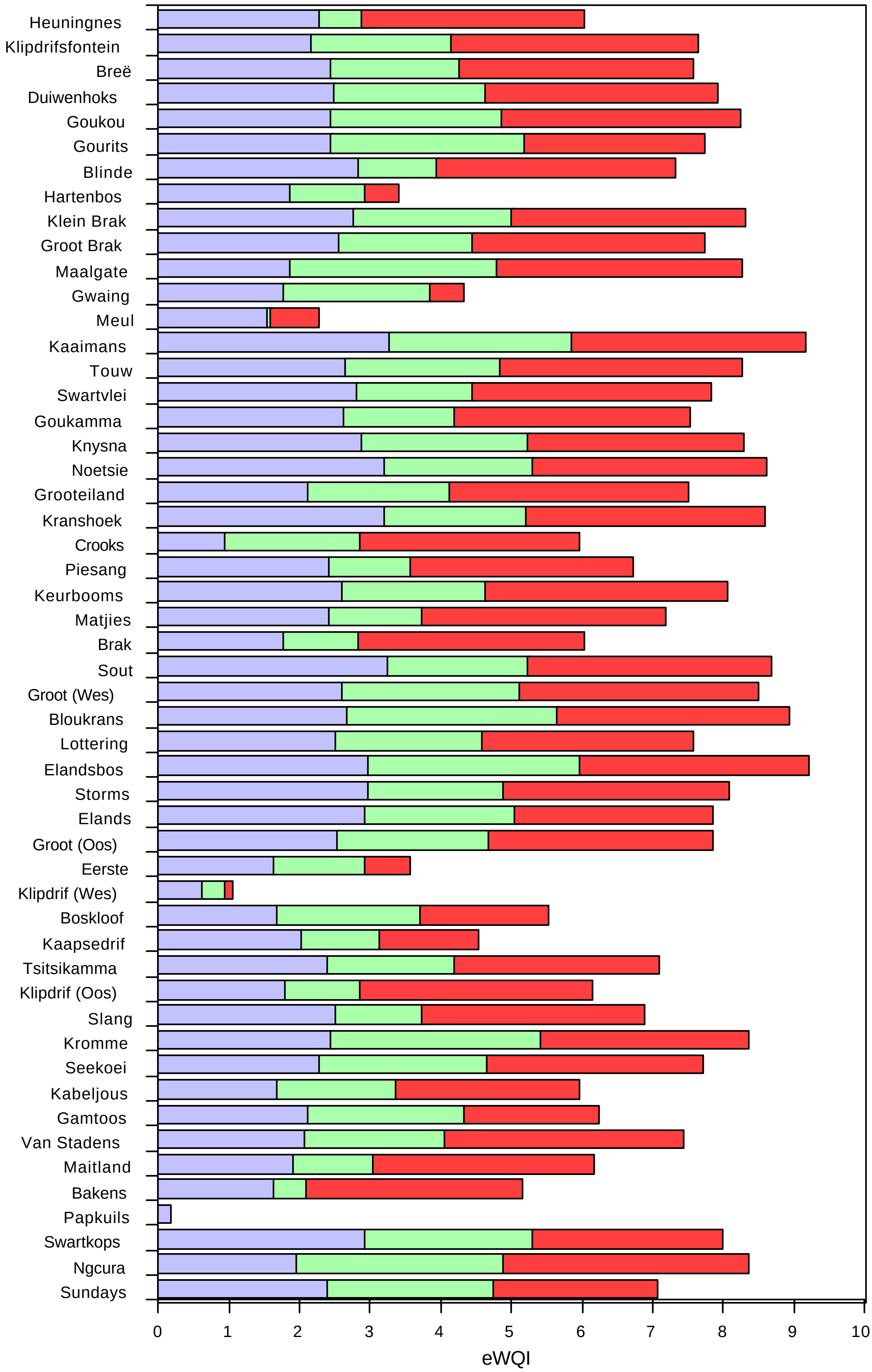

Figure 4.6. Average eWQI values for the south coast region (Heuningnes – Sundays) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

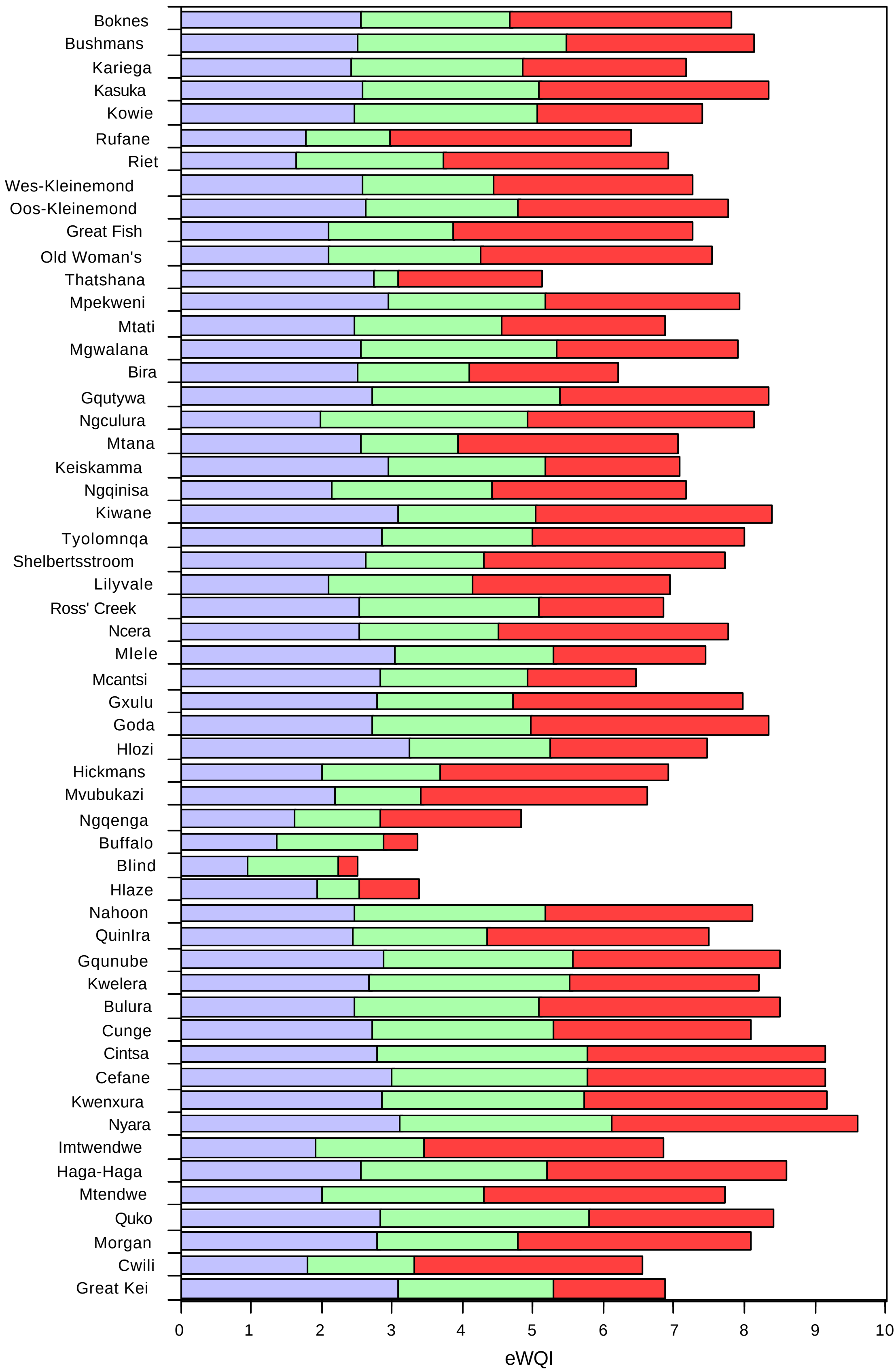

Figure 4.7. Average eWQI values for the south-east coast region (Boknes – Great Kei) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

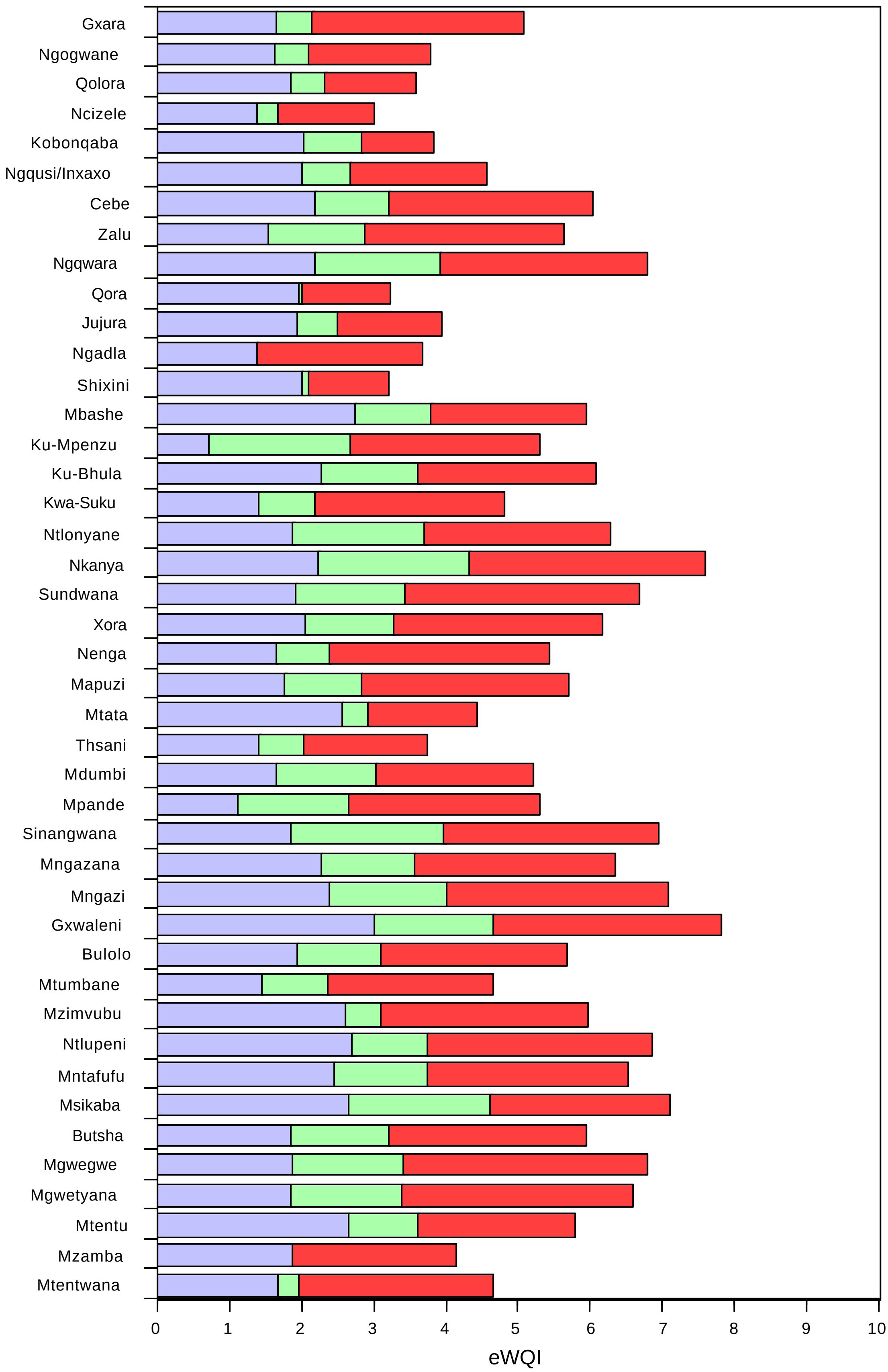

Figure 4.8. Average eWQI values for the Transkei region (Gxara – Mtentwana) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

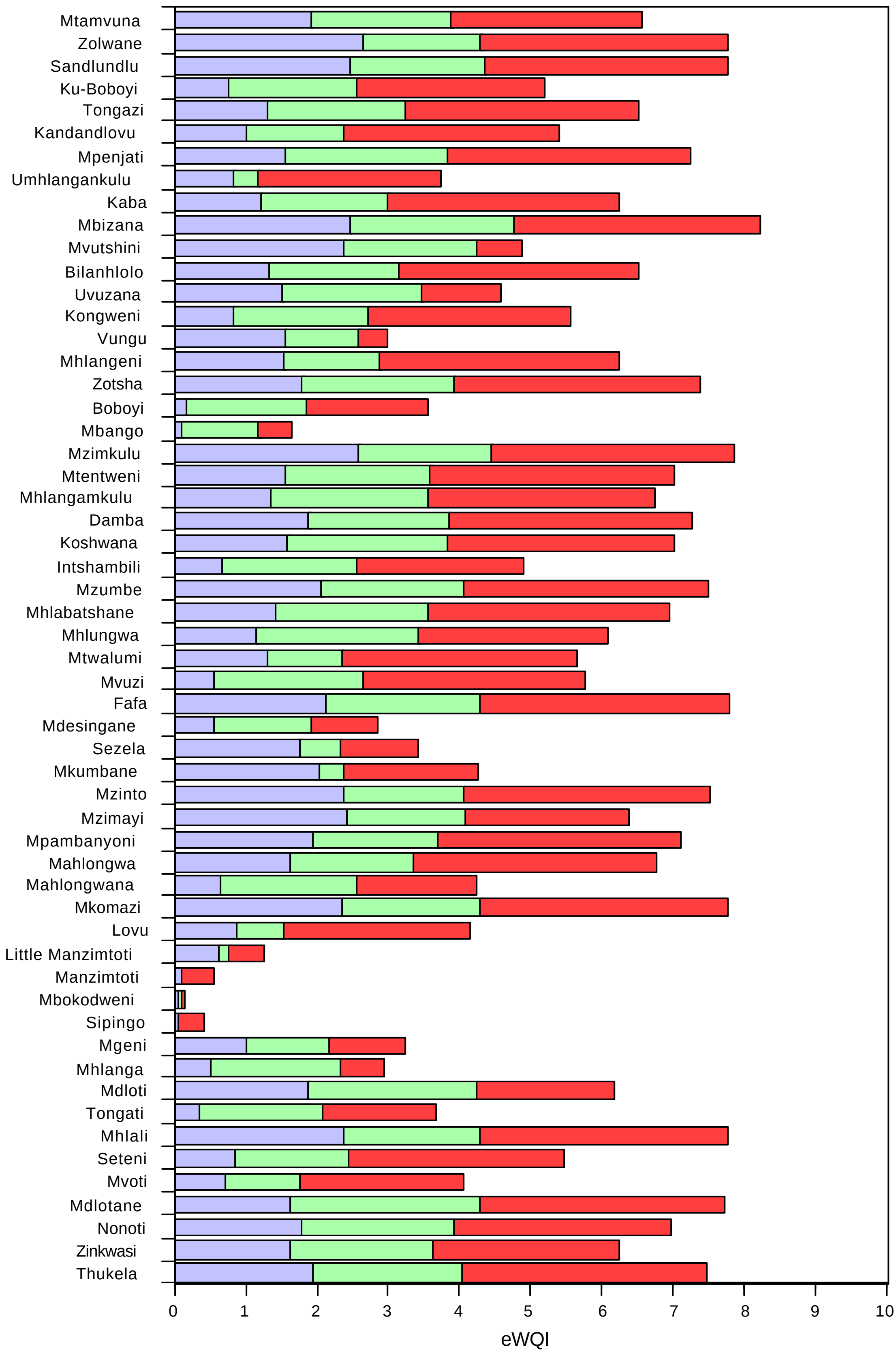

Figure 4.9. Average eWQI values for the KwaZulu-Natal region (Mtamvuna - Thukela) indicating the suitability for aquatic health, suitability for human contact and trophic status components of the index.

4.6. Conclusions & recommendations

4.6.1 *Conclusions*

General

The results of this study clearly illustrate the utility of the water quality index for succinctly identifying the relative health of South African estuaries with respect to their water quality. While the synoptic data collected over the period of these surveys is admittedly limited to one period, it is the only consistent data set of its kind, which has been collected nearly simultaneously for South African estuaries. The management applications of this type of synoptic sampling effort are readily evident when the results are focused via the index and water quality classification approach developed here.

The use of the eWQI to produce a water quality classification system for South African estuaries has great utility. This approach has also been followed successfully in Oregon in the USA (Cude, 1977) and has been proposed for New South Wales, Australia (Richardson, 1997). Given this relatively objective method for water quality classification it is imperative that more monitoring information is collected for all of the estuaries.

Specific

- Appropriate indicators can be obtained in the field, even under difficult survey conditions
- Six commonly accepted water quality indicators provide adequate coverage of traditional impairment categories
- Estuarine water quality can be effectively summarized using the eWQI.
- Impairment measured by toxics such as metals and pesticides are not accounted for in the eWQI
- The ranking of water quality by the index was not relatively sensitive to another aggregation method
- The eWQI can be used to classify estuarine water quality
- Water quality classes are useful for summarising information in order to obtain regional and national perspective

4.6.2 *Recommendations*

A physical water quality impairment category, involving such indicators as temperature, salinity, pH, and turbidity should be explored. Other investigators (Moore, 1990; Richardson, 1997) have stressed the importance of these measures to water quality. The use of some of these have been argued against while others have indirectly been incorporated, due to their impact on the present indicators (pH via ammonia, salinity & temperature via DO saturation). This must be further explored and tested against the existing database, which currently contains data on these indicators.

Related to the above, there is sound logic which suggests that water quality rating curves might be different for different geomorphological classifications, as well as for different climatic regions. This deserves further investigation. Again, the data to support such an investigation currently exists in the database. In addition the factors that control the behaviour of estuary mouths and determine the magnitude of tidal prisms may similarly impact the shape of water quality rating curves.

While, for the first time, an internally consistent set of water quality data for two-thirds of South Africa's estuaries has been collected, there are some obvious significant gaps in the baseline. First of all, data for systems in KwaZulu-Natal north of the Thukela estuary are conspicuously lacking, as are numerous important systems in the Transkei. A cohesive plan for temporal monitoring of key systems is also lacking. It would be logical to use the existing geomorphological classification to establish a monitoring programme for key systems on a rational basis. This would provide a better understanding of how estuaries of various types function, a critical requirement for effectively managing coastal issues such as artificial breaching, estuarine water requirements, eutrophication of estuaries, and related nutrient enrichment of the near-shore zone.

Finally, there exists a need to make all of the basic data, as well as various forms of summarized data, available to interested parties. This is best accomplished by (1) establishing a web-accessible hierarchical database at several scales of resolution, and (2) producing brochures (real and virtual) for the public and other end-users.