Developing a composite index to describe river condition in New Zealand

A composite river condition index for New Zealand

Prepared for Ministry for the Environment

August 2012

Authors/Contributors:
Deborah Ballantine

For any information regarding this report please contact:

Deborah Ballantine
Environmental Scientist
Aquatic Pollution
+64-7-859 1890
d.ballantine@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road
Hillcrest, Hamilton 3216
PO Box 11115, Hillcrest
Hamilton 3251
New Zealand

Phone +64-7-856 7026
Fax +64-7-856 0151

NIWA Client Report No:	HAM2012-131
Report date:	August 2012
NIWA Project:	MFE12201

12 October 2012 4.22 p.m.

Contents

Tables

Figures

Equations

Reviewed by	Approved for release by
R. Davies-Colley	J. Schmidt

Formatting checked by

AB

Executive summary

During 2011, NIWA was engaged to identify what water quality variables and indicators might be suitable for river, lake and fresh and saline recreational assessment and reporting. Following that early work NIWA was further engaged for the development of tools and methodologies that would improve water quality assessment and reporting, subsequently referred to as “National Environmental Monitoring and Reporting” (NEMaR). NEMaR had three during 2011, NIWA was engaged to identify what water quality variables and indicators might be suitable for river, lake and fresh and saline recreational assessment and reporting. Following that early work NIWA was further engaged for the development of tools and methodologies that would improve water quality assessment and reporting, subsequently referred to as “National Environmental Monitoring and Reporting” (NEMaR). NEMaR had three workstreams: Indicators (on SoE reporting), Variables (on what to measure, when and how) and Networks (on where to monitor). This report arises out of the Indicators workstream.

An expert panel approach was used, and two workshops convened, for each workstream. A series of variables and indicators considered likely to fulfil national water quality assessment and reporting purposes was presented to a group of nationally and internationally recognised experts for consideration, discussion and criticism. These indicators were discussed by the expert panel in two workshops in late 2011. In addition to inviting constructive criticism of the variables and indicators proposed, the expert panel was invited to suggest alternative or additional variables and indicators.

During this process, the project team proposed that national reporting of the state of “water quality” should be based on the assessment of ecological integrity, defined as:

“The degree to which the physical, chemical and biological components (including composition, structure and process) of an ecosystem and their relationships are present, functioning and maintained close to a reference condition reflecting negligible or minimal anthropogenic impacts.“ (Schallenberg et al. 2011).

Use of the term “water quality” in this report has regard for the definition of ecological integrity cited above, is not limited to physico-chemical state, but extends to include condition, ecological health and ultimately, cultural health.

A recommendation from Step 1 was that the NEMaR process should have regard for the on-going development of three indices that have been in use for some time – the Canadian Council of Ministers for the Environment water quality index (CCME water quality index), the Victorian Index of Stream Conditions (Victorian ISC) and the Environmental Health Monitoring Programme (EHMP), currently in use in Queensland.

The purpose of this report is to document procedures involved in calculation of these indices. Where possible, calculations using actual data have been provided as examples of how the indices might be adapted for use in New Zealand. A discussion of limitations (mainly due to the availability of suitable data and limitations in monitoring networks) and areas requiring further development is included.

The Composite River Condition Index for New Zealand is expected to comprise a number of sub-indices, which, when aggregated, provide a representative picture of river condition.

Suitable sub-indices have been identified as water composition (water quality *senso stricto*), hydrology, biota (such as macroinvertebrates and fish), and habitat.

Progress with this task has highlighted gaps in information which mean that some of the sub-indices have not been calculated, for example insufficient relevant information is available to calculate a habitat sub-index, and expert panel advice is required to develop both the hydrology and fish sub-indices. Also, other sub-indices require additional development, for example, objectives for the physic-chemical water quality sub-index need further development and reference condition information is required for the fish and macroinvertebrate sub-indices.

In the future however, with further development, it will be possible to report river condition using a composite index.

1 Introduction

During 2011, NIWA investigated approaches for national water quality assessment and reporting on behalf of the Ministry for the Environment (MfE).

Following review of representative examples from the literature, Hudson et al. (2011) asserted that “single indicators” or indicators generally – “simplified representations of a more complex reality” (Environment Southland 2000), were valuable tools for “transmitting scientific information from experts to the general audience” (Terrado et al. 2010). While not intended to be exhaustive, the review of the literature on indicators for assessing and reporting water quality demonstrated that many different indicators have been developed and subsequently modified to meet specific reporting purposes.

Two of the specific challenges for MfE identified by Hudson et al. (2011) were:

- selecting the specific indicators or variables from which a composite or multimetric indicator could be developed, and
- identifying how the values for the sub-indices or specific variables should be combined to calculate an overall score.

Subsequently, NIWA was commissioned to further investigate composite indices for reporting, as one workstream (the “Indicators” workstream) of three aimed at improving regional water monitoring on which to base national reporting in what became the NEMaR (National Environmental Monitoring and Reporting) project. Two separate workshop sessions were held for the “Indicators” workstream of NEMaR during October and November 2011. These expert panel assessments are the basis for development of improved water quality reporting, which includes developing a working protocol of a composite index to report river condition in New Zealand. The outcomes (recommended sub-indices and variables) of the second expert panel workshops are provided in Table 1-1. The expert panel recognised that the data and information required to calculate some of the recommended sub-indices were not readily available and that significant development would be needed before they could be used.

Two composite indices of river condition, the Victorian Index of Stream Condition (Victoria ISC) and the South East Queensland Environmental Health Monitoring Programme (SEQ EHMP, and one potential sub-index, the Canadian Council of Ministers for the Environment water quality index (CCME WQI), were of particular interest to the expert panel. These indices and sub-indices have been in use for some time in other countries

The aim of this report is to document calculation procedures for these indices, and where possible, calculate sub-indices using New Zealand data. Limitations and areas of further development are also discussed. The eventual aim of this work is to implement a composite index to describe river condition for New Zealand and this report describes steps towards that goal which have been taken using the available data. The composite index is expected to comprise five sub-indices which will describe water quality, biological condition, hydrological status and habitat quality. Details on progress towards each of these sub-indices are provided. The process of implementing a working protocol has highlighted limitations and development needs of each of the sub-indices. While some of the sub-indices are essentially complete, others will require significant development to become operational.

Calculations in this report have been based on State of Environment monitoring data provided by Greater Wellington Regional Council, Auckland Council and Hawkes Bay Regional Council.

Table 1-1: Primary and secondary variables or sub-indices endorsed by expert panel at workshop 2 for assessing and reporting river condition in New Zealand.

Relative importance	Ecological integrity component	Variable or metric according to general class			
		Biota	**Habitat**	**Water quality**	**Hydrology**
Primary variable/ sub-index	**Nativeness**	Fish Suggested Per cent alien species Observed vs. expected for native species			
	Pristineness	QMCI EPT richness Taxon richness	Per cent sediment cover Stream Ecological Valuation (reconstructed)	Visual clarity TP, DRP, NH_4N, TN, NO_xN, Electrical conductivity *E. coli* [1]	Suggested Abstraction index Flow Connectivity
	Diversity	Taxon richness			
	Resilience	Taxon richness			
Secondary variable/ sub-index	**Optional**	Gross primary productivity Respiration Per cent periphyton cover		Temperature, dissolved oxygen concentration (continuous measurement) [2]	Climate change impacts

---

[1] Included by recommendation of the steering committee 16/02/12

[2] Retained as secondary variables – necessary for future calculation of GPP and respiration if required

2 Physico-chemical water quality sub-index

Two sub-indices will be used to describe physico-chemical water quality in this report: the Canadian Councils of Ministers for the Environment Water Quality Index (CCME 2001b, CCME. 2001), and the water quality sub-index of the Victoria Index of Stream Condition (VISC WQI). At present we do not have the data to permit calculation of the physical condition sub-index of the South East Queensland Environmental Health Monitoring Programme (SEQ EHMP) because it relies on continuous measurements of dissolved oxygen and temperature. Furthermore, nutrients are described in a sub-index of the SEQ EHMP in terms of nutrient cycling processes, based on stable isotopes of nitrogen, for which we do not have data.

2.1 Canadian Council of Ministers Water Quality Index

Details of how the CCME Water Quality Index (CCME WQI) is calculated are provided in Appendix A. In brief, the CCME WQI is an objective based index, i.e., it is based on the attainment of water quality objectives rather than on aggregation of water quality data. Actual data is not mathematically aggregated in the calculation of the index; rather the data are compared with objectives (perhaps more commonly called guidelines). The objectives can be set as reference condition or as thresholds beyond which ecological condition may be impaired. The CCME WQI is based on three attributes of water quality that relate to water quality objectives:

Scope - The number of water quality variables that do not meet objectives in at least one sample relative to the total number of variables measured during the time period under consideration.

Frequency – The number of individual measurements that do not meet objectives, relative to the total number of measurements made in all samples for the time period of interest.

Amplitude – The amount by which those measurements not meeting the objectives differ from those objectives.

The final index score is a measure of how many variables do not meet the objectives, how often these variables do not meet the objectives and by how much objectives are exceeded. Calculation procedures are outlined in Appendix A.

2.1.1 Indicator criteria

The calculation of the CCME WQI requires that at least four variables, sampled a minimum of four times, be used. The selection of appropriate water quality variables is necessary for the index to yield meaningful results. Clearly, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. It is up to the user to determine which, and how many, variables should be included in the CCME WQI to most adequately summarise water quality in a particular country or region. For the purposes of this study, variables included in the index calculation were those recommended by the expert panel, namely dissolved reactive phosphorus (DRP), total phosphorus (TP), nitrate-nitrogen (NO_x-N), total nitrogen (TN), ammoniacal nitrogen (NH_4-N), visual clarity and *E. coli*. Conductivity has been omitted because, at the time of calculation, no reference condition objective values were available (see section 2.2.1 for more information on objective values used for this report). The index can be amended at a later stage to accommodate a conductivity objective. The variables used in this exercise can be changed to demonstrate different aspects of the physico-chemical condition of rivers.

Changing index variables raises the issue of index stability over time. Tracking of water condition is probably the most important application of monitoring. Therefore, a distinction must be drawn between trend analysis using raw data for variables (stable) versus composite indicators (which may not be stable). This suggests that, if variables used in indicators change over time, index results should not be used in trend analysis.

2.2 Objective setting

2.2.1 CCME WQI objectives

To calculate the CCME water quality index, comparison of current water quality is made with objective values for each water quality variable. As the aim of this study is to show the relative quality of one water body over another, in this context, objectives are water quality benchmark values against which water quality is measured against, and not targets which a water body should aim to achieve. Targets based on values are not part of this process, however the methods used in this study may be useful as a basis for communities who are interested in setting and achieving targets.

For the purposes of this study, objectives that reflect reference condition have been used. Reference condition data, generated by McDowell et al. (2012) by modelling using regional council and NRWQN data, were used as the index objectives.

Using reference condition objectives means comparing current water quality with what might be expected in pristine undisturbed environments, as understood by the term ‘ecological integrity’. This means that impacted sites will have low scores, because many of the included variables will not meet the objectives very regularly, and pristine sites should have the highest scores.

Objectives for the water quality variables were provided for 8 River Environment Classification (REC) classes – Cold Dry Hill, Cold Dry Lowland, Cold Wet Hill, Cold Wet Lowland, Cold Extremely Wet Hill, Cold Extremely Wet Lowland, Warm Dry Lowland and Warm Wet Lowland. These are the second level REC classes with the largest number of sites. Sites were further classified according to geology: soft sedimentary, alluvial, volcanic acidic and hard sedimentary.

2.2.2 Seasonal objectives

Objectives may be set so that the same objective applies for the whole year, as has been done for this study. Alternatively, objectives may be set by season. To do this, the annual data could be split into summer and winter seasons, each with different objectives, depending on the water quality variables of concern. For example, impacts of nutrients are more important in summer when high light and temperature combine to promote plant growths (sometimes to nuisance levels) more than in winter, so it may be useful to apply a seasonal approach for nutrients.

2.3 CCME Index calculation

The CCME index has been calculated for the 2007-2010 time period. Index values are available for each of these years, and a combined index value (to represent the whole time period) has also been calculated.

F1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration (“failed variables”), relative to the total number of variables measured:

$$F1 = \left(\frac{Total\ number\ of\ failed\ variables}{Total\ number\ of\ variables}\right)\ x\ 100$$

F2 (Frequency) represents the percentage of individual tests that do not meet objectives (“failed tests”):

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right)\ x\ 100$$

F3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F3 is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion” and is expressed as follows. When the test value must not exceed the objective:

$$excursion\ i = \left(\frac{Failed\ test\ value\ i}{Objective\ j}\right) - 1$$

For the cases in which water quality increases with increasing value of the measured quantity (e.g., visual clarity, dissolved oxygen):

$$excursion\ i = \left(\frac{Objective\ j}{FailedTestValue\ i}\right) - 1$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse), is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion\ i}{\#\ of\ tests}$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

Once the factors have been obtained, the index itself can be calculated by treating the three factors as independent and thus mutually orthoganol. The sum of the squares of each factor is therefore equal to the square of the index.

The CCME Water Quality Index (CCME WQI):

$$CCMEWQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality (CCME 2001b). An EXCEL macro was used for the calculations, downloadable from http://www.ccme.ca/sourcetotap/wqi.html.

2.3.1 Categorisation of sub-index scores

Scores calculated for the index are provided in the accompanying spreadsheet. In the original CCME WQI, as adapted for Canadian Water Quality, scores are categorised into groups to permit easy interpretation of results. The index can range from zero to 100, with 100 being the highest attainable score. Categorization for the CCME WQI was based on the best available information and expert opinion, and, through on-going assessment, could be changed to be more relevant to New Zealand. The categories of the CCME WQI are excellent (95 - 100, close to pristine), good (80 - 94), fair (65 - 79), marginal (45 - 64) and poor (0 - 44).

Index scores for this study could be ranked into similar categories to permit easy interpretation of results; however the categories would need to be amended to accurately reflect water quality condition. Categories could be established either by using expert opinion, or it could be done statistically, based on the distribution of the scores and percentiles, e.g., the top 20% of scores might be classified as excellent.

For this study, scores were calculated first for four individual years, and then for the aggregated four year period. Scores ranged from 3 – 91%.

2.4 Limitations

Outputs from the index have been provided in an accompanying spreadsheet. Index values tend to be low, as may have been expected. The low scores represent the contrast between the pristine conditions expected at reference sites and the range of polluted conditions found in the rivers. Less stringent objectives would have resulted in higher index scores. Categories for this index can be set according to the distribution of scores, or in groups considered appropriate by an expert panel, rather than defaulting to the categories recommended for the CCME WQI if it is thought the categories of the CCME WQI do not reflect ambient conditions.

Reporting against reference conditions should permit changes in water quality (improvements and deterioration) to be easily recognised. Because the objectives are stringent, at most sites several variables do not meet them. The index score considers the amount by which variables fail to meet the objectives (F3). F3 will decrease if nutrient concentrations decrease, and will result in higher index scores. Comparing with reference conditions is in keeping with the definition of ecological integrity.

Objective values are based on expected reference conditions for a selection of REC groupings. Reference condition information was not available for all of the REC classes encountered at State of Environment monitoring sites in Auckland, the Hawkes Bay and Greater Wellington regions, so a small number of sites have been omitted from the analysis. If objectives are to be set by REC environmental classification grouping, I would recommend that objectives are established for a wider range of environmental classes than is currently available (if feasible), or alternatively that some ‘similar’ environmental classes are amalgamated. One approach might be to use the Level 3 REC reference condition where it has been calculated but to default to L2 information where L3 is not available. At the time of writing, reference condition information had been calculated for the first two levels of the REC, but only for selected classes at the third level.

Data are not available for all variables for all sites, for example, for some of the Auckland Council sites, visual clarity data is not available. To ensure consistent comparison, it is important to use the same variables for all sites, suggesting that, if there is a region for which a variable is missing, the list of variables should be revised to reflect the available data. Alternatively, if data for important variables are not available, monitoring programmes may need to be revised to include them. The NEMaR ‘Variables’ report (Davies-Colley et al. 2012) recommends a ‘core’ variable suite for nationally consistent regional SoE monitoring for national reporting.

At the point of writing, the modelled reference condition information and related documentation was under client review and not freely released. Until this information has been completely reviewed and validated, the information should not be widely distributed and should only be used for illustrative purposes.

2.4.1 Future developments

This index could be further developed, and I would recommend testing of the reference condition data and CCME scoring categories to ensure they accurately reflect the New Zealand environment. I would also recommend that reference data be modelled for a wider range of environmental classes, or alternatively that smaller, similar environmental classes are grouped together. Further calculations could be done to explore how to aggregate sites (e.g., by environmental class) in this index.

2.5 Victoria Index of Stream Condition Water Quality sub-index (VISC WQI)

I have also calculated the VISC WQI. In its original form, this sub-index is calculated using data from four water quality variables (total phosphorus, turbidity, pH and conductivity) that were considered to be particularly relevant for reporting water quality issues in Victoria. The sub-index is based on five years sampling data from the Victorian Water Quality Monitoring Network which comprises 183 sampling sites.

For this study, I have calculated the VISC WQI using data for DRP, NO_3-N, visual clarity and *E. coli*, for 2007 – 2010 inclusive, from Hawkes Bay Regional Council and Greater Wellington Regional Council. Auckland Council is not included as visual clarity is not routinely measured at Auckland Council State of Environment monitoring sites. The variables were selected by Ministry for the Environment, and are a subset of the variables selected by the ‘Indicators’ expert panel.

This index is based on percentiles, with 5 categories from 0 (lowest, 0 - 20%) to 4 (highest, 80 - 100%) used to describe the data. The actual data is not used in the calculations, but instead, data are compared with percentiles and allocated ratings. For this study, percentiles were calculated for the main REC classes to which data for each variable were compared and rated accordingly from 0 to 4. The total sub-index score is a score out of 10 and was calculated by summing the scores for each of the four indicators using the following equation:

Water quality sub-index = $\frac{10}{16}\ (DRP + NO_3N + clarity + E.coli)$

To facilitate comparison with the scores calculated for the CCME WQI, scores have been converted to percentages by multiplying by 10. In the Victoria ISC, sub-index scores are not categorised before being amalgamated, however, if desired, scores for the water quality sub-index could be categorised using fixed boundaries, e.g., 0 – 20 poor, 20 – 40 average, 40 – 60 good, 60 – 80 very good, 80 – 100 excellent. Alternatively, categories could be allocated depending on the distribution of scores. Sub-index scores have been provided in the accompanying spreadsheet and have been categorised according to the distribution of the scores.

Aggregation of data in this manner weights all water quality variables equally. Also, aggregation may result in ‘eclipsing’ of poor values for just one variable which strongly limits the overall ‘condition’.

2.6 Comparing CCME WQI and Victoria ISC WQI scores

Comparison of the scores from the two sub-indices shows that scores for the CCME WQI, calculated using reference condition objectives (median score 23.7), are lower than those for the Victoria ISC WQI (median score 50) (Table 2-1). Values are, as might be expected, strongly correlated (Pearson correlation co-efficient 0.874, $R^2 = 0.764$), and rankings are similar. Because more than 4 variables were selected by the expert panel for inclusion in the indicator, the CCME WQI is preferred over this index, as it can only accommodate 4 variables.

Table 2-1: Comparison of CCME and VISC WQI scores for a selection of Greater Wellington Regional Council sites.

Site name	Site ID	VISC score	VISC rank	CCME score	CCME rank
Mangapouri Stream at Bennetts Rd	RS02	25	13	13.8	10
Waitohu Stream at Forest Park	RS03	56.25	4	33.2	4
Waitohu Stream at Norfolk Crescent	RS04	18.75	14	7.2	14
Otaki River at Pukehinau	RS05	62.5	3	35.3	3
Otaki River at Mouth	RS06	50	6	31.2	5
Mangaone Stream at Sims Road Bridge	RS07	25	12	7.6	13
Ngarara Stream at Field Way	RS08	37.5	10	18.9	8
Waikanae River at Mangaone Walkway	RS09	81.25	1	40.2	1
Waikanae River at Greenaway Rd	RS10	68.75	2	37.9	2
Whareroa Stream at Waterfall Rd	RS11	50	5	21.5	7
Whareroa Stream at QE Park	RS12	37.5	9	11.9	12
Horokiri Stream at Snodgrass	RS13	43.75	7	25.6	6
Pauatahanui Stream at Elmwood Bridge	RS14	37.5	8	16.9	9
Porirua Stream at Glenside Overhead Cable	RS15	25	11	13.4	11

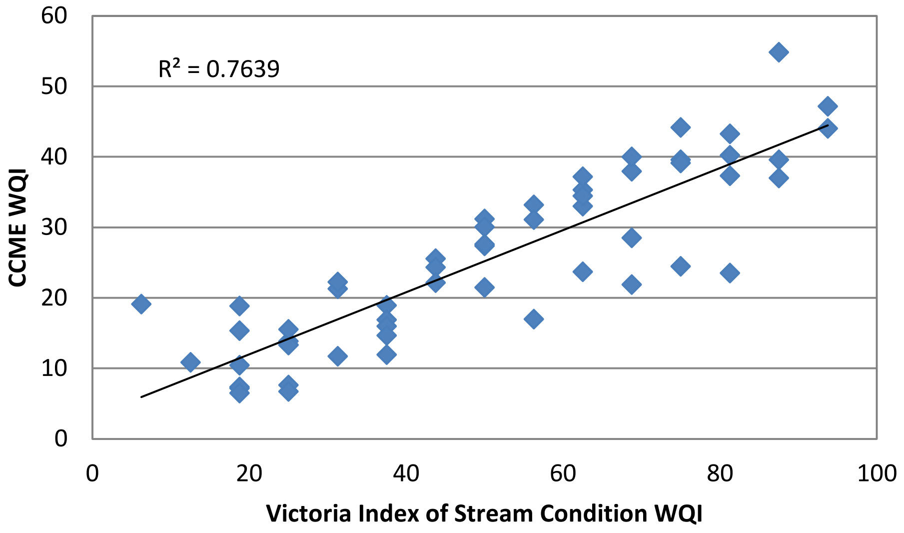

Figure 2-1: VISC WQI and CCME WQI scores.

3 Macroinvertebrate sub-index

Reporting based on water composition status alone does not give a complete picture of the status of a water body. In isolation it can be misleading as it provides only a snapshot of water quality at the time of sampling, meaning that the effects of intermittent pollution events may not be captured. Biological monitoring techniques can provide a longer-term, time-integrated picture of water quality. They are therefore useful complements to water quality monitoring.

Suitable macroinvertebrate indicators were proposed through the expert panel workshop process and by Hudson et al. (2011).

It was recommended by Hudson et al. (2011) that three individual metrics be combined into a multimetric sub-index to describe macro-invertebrate populations in rivers. The individual metrics recommended were Macroinvertebrate Community Index (MCI), EPT richness and % EPT richness. These three metrics, when standardised and combined, result in the 'Average score per metric (ASPM)' (Collier 2008).

Following workshop 1, the MCI and the Average Score Per Metric (ASPM, Collier 2008) were recommended as suitable indicators for reporting biological condition.

At workshop 2, the expert panel agreed that the Quantitative Macroinvertebrate Community Index (QMCI), EPT richness and Taxon richness should be used as biological indicators (Table 3-1). The expert panel recognised that further development might be needed before the recommended scores can be included in a sub-index.

Table 3-1: Biological variables endorsed by expert panel at workshop 1 for assessing and reporting Macroinvertebrate river quality information in New Zealand.

Indicator	Index	Description	Priority
Macroinvertebrate	Macroinvertebrate Community Index		Essential
	Soft-bottomed Macroinvertebrate Community Index		Essential
	Average Score Per Metric	EPT richness %EPT abundance MCI	Recommended

Assessment of ecological integrity requires that observed scores for biological metrics (e.g., QMCI, EPT richness, and taxon richness) are compared with expected reference scores, that is, the numbers that you would expect to find at a sampling site under pristine conditions. For the case study regions, 'observed' information (i.e., for current conditions) for these three indicators is available. At present however we do not have expected QMCI or EPT richness scores for river reaches in New Zealand, meaning that it is currently difficult to use these indicators in a biological sub-index.

Hudson et al. (2011) recommended that all councils calculate MCI rather than QMCI. Though MCI is less sensitive than QMCI to small changes in environmental quality (Stark &

Maxted 2007b), experience has shown that at a landscape scale, the two indices are strongly correlated (Stark & Maxted 2007a). MCI has several advantages over QMCI:

- The MCI is not based on abundances, which can be severely altered by floods.
- It is less intrinsically time-variable than QMCI and thus more likely to show significant differences between sites or trends over extended times (Scarsbrook et al. 2000).
- The MCI was chosen over QMCI for calculating ASPM, the multimetric index described below, (Collier 2008).

Currently, the 15 regional councils and unitary authorities doing biomonitoring calculate more than one index of macroinvertebrate condition for State of Environment reporting, and only one council combines these into a multimetric. Twelve of the 15 councils use the Macroinvertebrate Community Index (MCI) and the other three use its quantitative version, the QMCI. Thirteen councils also calculate %EPT or EPT richness. There is relatively high consistency among councils in terms of the metrics used, but there is some variation in the protocols for calculating the metrics.

In the absence of suitable reference condition data for the QMCI, and following the recommendations of Hudson et al. (Hudson et al. 2011) and the expert panel at workshop 1, we have calculated the ASPM for sampling sites in the Auckland, Hawkes Bay and Greater Wellington regions. For the time being, we consider that the ASPM is a suitable biological sub-index to be integrated in a composite index for reporting river condition in New Zealand, however as outlined below, further development is required to generate reference condition information for the three biological metrics included in the ASPM.

3.1 Calculating the Average Score Per Metric

The ASPM has been calculated using EPT taxa, % EPT and MCI scores. Soft and hard bottomed MCI scores have been used, depending on the stream classification.

To calculate the ASPM, the following steps were taken:

1. EPT taxa, % EPT and MCI scores were standardised. This was done by dividing by the highest potential scores for each (22 for EPT taxa, 96.6 for % EPT and 163.6 for MCI). These highest potential scores were based on Collier (2008) and represent reference conditions for the Waikato. In accordance with the overall aims of this project, scores should be compared against the highest potential scores by Environmental Class as defined by the REC not by geographical region. Results provided are therefore for illustrative purposes only, to show how this sub-index might work. Further development and data assessment are required to establish highest potential scores for the range of environmental classes likely to be encountered in New Zealand.
2. The median of these three scores was calculated. This was the overall ASPM score.
3. The overall ASPM score was then multiplied by 100 to get a percentage value.
4. Scores for each site were allocated to the following condition bands. Very high >68%, high 53 – 68%, moderate 37 – 52%, low 20 – 36%, very low < 20%.

These thresholds were derived by calculating quartiles of each metric between the lower SD of the reference mean and a hypothetical worst- case community comprising 100% Oligochaeta, *Chironomus,* Psychodidae or Syrphidae which all have MCI tolerance scores of 1 (Stark et al. 2001).

Example scores are provided below for a selection of Greater Wellington Regional Council sites for 2010 (Table 3-2). Further results for Auckland, Greater Wellington and Hawkes Bay sites are provided in the accompanying spread sheet and further details on calculation procedures can be found in Collier (2008).

3.1.1 Limitations

As outlined above, the ASPM was developed for use in the Waikato region, and highest potential scores reflect those possible for the Waikato. To be used for national reporting, highest potential scores (‘expected’ information for reference sites) could be calculated from existing data for each of the three included metrics for the main REC classes. This would then permit comparison of observed scores with expected reference scores.

Further development is needed before the QMCI can be used as an observed/expected score.

Table 3-2: Example ASPM scores for a selection of Greater Wellington Regional Council sites for 2010.

Site name	Site ID	ASPM score	Classification
Mangapouri Stream at Bennetts Rd	RS02	18.82	very low
Waitohu Stream at Forest Park	RS03	81.82	very high
Waitohu Stream at Norfolk Crescent	RS04	51.76	moderate
Otaki River at Pukehinau	RS05	60.89	high
Otaki River at Mouth	RS06	29.58	low
Mangaone Stream at Sims Road Bridge	RS07	0.00	very low
Ngarara Stream at Field Way	RS08	27.24	low
Waikanae River at Mangaone Walkway	RS09	77.27	very high
Waikanae River at Greenaway Rd	RS10	59.09	high
Whareroa Stream at Waterfall Rd	RS11	50.00	moderate
Whareroa Stream at QE Park	RS12	9.41	very low
Horokiri Stream at Snodgrass	RS13	59.15	high
Pauatahanui Stream at Elmwood Bridge	RS14	49.30	moderate
Porirua Stream at Glenside Overhead Cabl	RS15	41.41	moderate
Porirua Stream at Milk Depot	RS16	29.58	low
Makara Stream at Kennels	RS17	48.72	moderate
Karori Stream at Makara Peak Mountain Bi	RS18	31.82	low
Kaiwharawhara Stream at Ngaio Gorge	RS19	32.69	low
Hutt River at Te Marua Intake Site	RS20	63.64	high

4 Fish sub-index

Information on freshwater fish is available for the three case study regions. This information was provided in different forms; however all the councils provided information on the species of native fish present at sampling sites. Abundance of each species was not provided by all the councils. Further, the freshwater fish river sampling sites do not generally coincide with water quality sampling sites, meaning that a sub-index for fish cannot be calculated for each water quality site; and it is not always possible to combine the fish sub-index score with other sub-index scores. Fish sampling implies a reach, whereas water quality implies sampling at a point.

4.1 Fish sub-index calculation

From the regional council raw data, the number of native species observed at all sampling sites was calculated. The number of observed native species was compared with the number of expected native species at sampling sites, based on information from the predictive fish model developed by Leathwick et al. (2008). This model was based on the REC and predicts the probability of capture of a species by electric fishing under current environmental conditions (including current pollution and stressors) at all river reaches in New Zealand. The likelihood of each fish species being present is expressed as a probability. I emphasise that ‘expected’ fish in this model are those expected under current conditions (including pollutants and stressors), not reference conditions.

To calculate this sub-index, the following steps were taken:

- Fish data were collected from the Regional Councils.
- Spatial information (NZ Reach and grid references) from the sampling sites was matched with the information in the distribution model using GIS, so that all fish sampling sites were associated with a NZ river reach.
- Alien species and fish that were not expected to occur (i.e., those with zero theoretical probability of occurring) at the sampling sites were excluded from the calculations.
- The number of native species expected at each sampling point was added together.
- The number of native species *actually* present was calculated from the regional council data.
- An observed/expected score was calculated –

$$\left(\frac{observed\ native\ species\ present}{expected\ native\ species\ present}\right) * 100$$

- The final number represents the value for the fish sub-index at the sampling site.

4.2 Limitations of this approach

While I have been able to calculate a value for this sub-index, I would emphasise that there are limitations with this method and would recommend that the values calculated are not used for purposes other than to illustrate what can be done with data, as this is not an intended use of this model. I recommend further development of this sub-index.

It should be noted that the model developed by Leathwick et al. (2008) predicts the probability of capture of a species by electric fishing under current environmental conditions (including current pollution and stressors). It is based on presence/absence data from the New Zealand Freshwater Fish Database, and therefore can only predict probabilities of presence or absence and not abundances. As the model has been built from data collected under current environmental conditions (including environmental pollution and pressures) and not reference conditions, it does not allow comparison with reference conditions, but rather predicts what might be expected to occur under present degraded conditions. For robust national reporting, we would recommend an approach based on fish species expected to occur in reference or pristine conditions, as to report on ecological integrity, fish species present in current conditions should be compared with those expected to be present in pristine conditions.

The Fish Index of Biotic Integrity (Joy & Death 2004) provides an alternative model for predicting expected fish species and should be explored.

A panel of freshwater fish experts has been consulted on robust methods of reporting fish species and abundance. Fish metrics that might be included in the fish sub-index include % native species, observed/expected for native species, and number of introduced species. As well as considering methods for reporting on native species, suitable methods for reporting alien (sometimes referred to as ‘exotic”) fish species should be discussed. Robust information for expected alien species is not available, therefore, even though exotic species are widespread in New Zealand, they have not been considered in this study. With further development, alien species could be included in future reporting of freshwater fish. Abundance of fish at sampling sites may be included in the fish sub-index.

4.3 Fish sampling protocols

For this study, fish data was provided in different forms by the regional councils. An expert panel (comprising representatives from central government, Regional Councils, CRIs, universities and the Department of Conservation) will meet to agree on the most useful objectives for fish monitoring and how to optimise sampling effort to best achieve these objectives. Protocols for consistent methods for sampling and reporting information on freshwater fish will also be established. Looking to the future, we would hope that the overall objectives of fish monitoring for both national and regional reporting will be established through robust discussion, and that discussions will result in a clear understanding of the conclusions that can be drawn from different types of data. As a result of expert panel discussions, we would envisage greater consistency between the Regional Councils.

For fish sampling in future, we recommend that, as far as possible, sampling reaches for fish should encompass water quality sites. Fish and water quality data will never be totally co-incident because fish sampling necessarily requires reach survey compared with point sampling for water quality. At present, Regional Councils’ freshwater fish sampling and water quality sampling locations do not always match because of specific requirements for fish monitoring. Currently sampling protocols exist only for wadeable streams (David & Hamer 2010) and the expert panel recommended that these protocols be used for national reporting. For water quality sampling, samples can be taken from any river, regardless of size, channel shape, depth etc. For fish monitoring, the standardised electric fishing method (David & Hamer 2010) can only be done in streams that are less than 8 metres wide, are less than 0.75 metres deep and have a flow velocity less than 0.75 m/s, with high visual clarity (as you need to be able to see the bottom of the channel). It would therefore be difficult to carry out fish sampling at all water quality sites until there are protocols for fish monitoring of non-wadeable streams, which will have implications for development of this sub-index and subsequent amalgamation of results. The expert panel decided that sampling in non-wadeable streams was too onerous, so sampling will only be done in wadeable streams. A wider discussion on fish sampling protocols is provided in Davies-Colley et al. (2012b).

4.4 Future developments

To progress this sub-index, we recommend:

- A predictive model based on reference conditions is developed.
- A consistent approach to fish sampling to ensure all regions are collecting relevant information needs to be developed. This has been agreed by an expert panel.

5 Hydrology sub-index

A hydrology sub-index has not been calculated. As yet we do not have a clear vision of what might be appropriate for a hydrology sub-index. An expert panel of hydrologists from NIWA and the regional councils discussed options for how to progress this sub-index. The following recommendations were made by the panel:

- The actual use abstraction data from the water meter records should be used in any indicator calculations.
- Recorders/spot gauging or robust flow estimates should be made at sampling sites. Staff level gauging as recommended in the draft protocols report (Davies-Colley et al. 2012b) is not recommended as it is not robust enough.

Water abstraction, intensity of low flows, frequency of flood events and low flow duration were identified as hydrological components that potentially impact on ecology.

6 Habitat sub-index

A habitat sub-index has not been calculated, mainly because at present we do not have sufficient consistent information available to allow calculation. Important components of this sub-index need to be established (along with related monitoring protocols and guidelines), so that regional councils can collect useful information for this sub-index. A suitable scoring system also needs to be developed (Davies-Colley et al. 2012b).

Because in-stream sedimentation is increasingly recognised as one of the key anthropogenic stressors of NZ streams and rivers, we suggest that deposited fine sediment should be named as one of the key variables to be included in the Habitat sub-index. Detailed monitoring protocols and guidelines for this habitat variable have already been developed (Clapcott, Young, Harding, et al. 2011) and at least two regional councils (Horizons and ECan) have already started fine sediment monitoring using the recommended protocols (which are simple, fast and user-friendly) and are also applying the deposited sediment categorisations recommended in this report.

A recommendation from the second Indicators expert panel workshop was that the Stream Ecological Evaluation could be reconstructed for inclusion in this sub-index. Variables suggested at the first expert panel workshop included riparian vegetation % cover or shade, riparian vegetation type, riparian buffer width, bank modifications, bank erosion/stability, channel modification, diversity of flow types, and organic and inorganic substrate type.

In the future, depending on data availability, we may be able to supplement manually collected data with remote sensing including LIDAR data for this sub-index. With further development, we would hope to be able to calculate this sub-index in future.

7 Combining sub-indices

It is intended, when values are available for all of the above sub-indices, to combine them to give a final composite index value which will describe overall river condition in New Zealand. There are a variety of methods that could be used to achieve this, and examples of four possible methods are given. For the purposes of this study, all sub-indices have been standardised to produce scores between 0 – 100. For example, the VISC WQI gives scores out of 10, so they have been multiplied by 10 to result in scores out of 100.

7.1 Minimum operator approach

Using this approach, the lowest value from the sub-index calculations would be the final index value. This is based on the principle proposed by Smith (1990), who argued that the variable that most limited water quality should be the final score of a water quality index. He used single variables in his ‘suitability for use’ index. To apply this principle to this water quality index, the sub-index with the lowest value would be taken as the overall score for a particular river reach. The basis of the minimum operator approach of (Smith 1990) was that certain uses and values would be most limited by the “worst” variable. To meaningfully apply this approach assumes that specific uses and values have been identified.

Unlike all the other sub-index aggregation methods, such as those discussed below, the minimum operator completely avoids the problem of ‘eclipsing’, by which a poor value for one or a few variables (that is actually strongly limiting of river condition) is masked by good values for other variables (Smith 1990).

The minimum operator also has the great virtue of avoiding any (implicit or explicit) assumptions about the relative importance of different aspects or components of the river water. Aggregating methods implicitly assume equal importance of all the component sub-indices – unless these are explicitly weighted differently.

7.2 Averaging

Scores from each of the sub-indices could be averaged to give a final score. This is the approach that was taken in the Bay Health Index ((Williams et al. 2009). This composite index comprises two sub-indices. To arrive at each of the sub-indices, the values of the included components were averaged, meaning that each variable was equally weighted. The resultant sub-index scores were then averaged to give the final index result. The averaging approach used assumes that both sub-indices are of equal weighting in representing ecosystem health, and that there is no basis for a weighting system.

The SEQ EHMP also uses a simple averaging method to compute the final overall score.

7.3 Median

The median of the sub-index scores could be used to represent river condition at a sampling site. A median composite index would be expected to have similar features to the averaging composite index.

7.4 Inverse ranking transformation

An inverse ranking system is used to amalgamate the scores in the Victoria Index of Stream Condition. With this approach, the inverse ranking transformation results in a final score out of 10 for each sub-index. It has been developed to integrate the 5 sub-index scores of the Victoria Index. A pro-rata scoring system can be used when up to 2 of the sub-index scores are missing; at least 3 sub-index scores are required to allow pro-rata scores to be calculated. This inverse ranking method recognises that a particularly low score in one sub-index might have a limiting effect on river health even if the other sub-indices score highly (DSE 2004), the phenomenon known as 'eclipsing'. A method based on similar principles could be developed to amalgamate the scores of the New Zealand Composite River Condition Index.

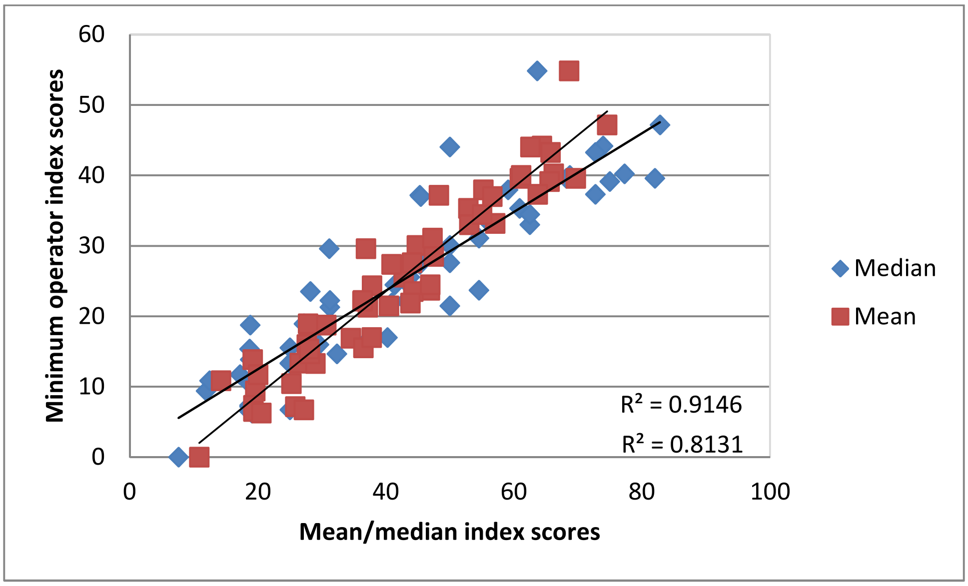

Figure 7-1: Mean/median and minimum operator scores.

Worked examples of the mean, median and minimum operator approach are provided in Table 7-1, with more complete results provided in an accompanying spreadsheet. Also, index scores are plotted in Figure 7-1, which shows that for this study, both the median (R^2=0.8131) and mean (R^2=0.9146) scores are closely related with the minimum operator scores. Further development is needed to establish a robust method which will represent composite river condition appropriately. However, the minimum operator for sub-index aggregation should be considered because:

1. No assumptions are made about relative importance of the different components or sub-indices (including the implicit assumption that they are all equally important).
2. The problem of 'eclipsing', by which one or a few variables scoring very poorly are masked, is avoided.

Table 7-1: Combined index scores for a selection of Greater Wellington Regional Council sampling sites.

Site name	Site code	ASPM score	CCME WQI	VISC WQI	Median	Average	Minimum
Mangapouri Stream at Bennetts Rd	RS02	18.82	13.84	25.00	18.82	19.22	13.84
Waitohu Stream at Forest Park	RS03	81.82	33.17	56.25	56.25	57.08	33.17
Waitohu Stream at Norfolk Crescent	RS04	51.76	7.16	18.75	18.75	25.89	7.16
Otaki River at Pukehinau	RS05	60.89	35.33	62.50	60.89	52.91	35.33
Otaki River at Mouth	RS06	29.58	31.18	50.00	31.18	36.92	29.58
Mangaone Stream at Sims Road Bridge	RS07	0.00	7.62	25.00	7.62	10.87	0.00
Ngarara Stream at Field Way	RS08	27.24	18.91	37.50	27.24	27.88	18.91
Waikanae River at Mangaone Walkway	RS09	77.27	40.19	81.25	77.27	66.24	40.19
Waikanae River at Greenaway Rd	RS10	59.09	37.94	68.75	59.09	55.26	37.94
Whareroa Stream at Waterfall Rd	RS11	50.00	21.47	50.00	50.00	40.49	21.47
Whareroa Stream at QE Park	RS12	9.41	11.92	37.50	11.92	19.61	9.41
Horokiri Stream at Snodgrass	RS13	59.15	25.56	43.75	43.75	42.82	25.56
Pauatahanui Stream at Elmwood Bridge	RS14	49.30	16.87	37.50	37.50	34.55	16.87
Porirua Stream at Glenside Overhead Cabl	RS15	41.41	13.37	25.00	25.00	26.59	13.37
Porirua Stream at Milk Depot	RS16	29.58	16.00	37.50	29.58	27.69	16.00
Makara Stream at Kennels	RS17	48.72	13.30	25.00	25.00	29.01	13.30
Karori Stream at Makara Peak Mountain Bi	RS18	31.82	7.35	18.75	18.75	19.30	7.35
Kaiwharawhara Stream at Ngaio Gorge	RS19	32.69	6.48	18.75	18.75	19.31	6.48
Hutt River at Te Marua Intake Site	RS20	63.64	32.99	62.50	62.50	53.04	32.99

8 Discussion

This study demonstrates that it is already possible to generate some of the sub-indices that contribute to a composite index to describe river condition in New Zealand. This study also demonstrates that there are limitations associated with most of the sub-indices, and that further development is needed.

8.1 Choice of composite indices

In earlier discussions with the expert panel and MfE, reference was made to the Victoria Index of Stream Condition and the South East Queensland Ecosystem Health Monitoring Programme. These two indices were considered useful examples on which to base the development of a river condition indicator for New Zealand. Complete calculations of these composite indices have not been provided at this point – and indeed cannot for lack of some required data with which to calculate sub-indices.

8.1.1 The Victoria Index of Stream Condition (VISC)

The Victoria Index of Stream Condition (a composite index including a range of properties that describe stream condition) has been developed to suit conditions in the State of Victoria, Australia. As such, the sub-indices of this indicator are comprised of variables and objectives adapted to the environment under examination. For the water quality sub-index, the variables have been chosen because they are relevant to, and are an issue in, river systems in Victoria. They are not necessarily variables of concern for New Zealand river systems, and some are not 'core' variables as defined for New Zealand (Davies-Colley et al. 2012). I have calculated the water quality sub-index for New Zealand conditions. To do this, I have used four of 'core' variables chosen by MfE (DRP, NO_x-N, visual clarity and *E. coli*). (Four variables were selected because the original VISC WQI uses four variables.) Using only 4 water quality variables means that the variables selected as important by the Indicators expert panel are not fully represented. The scoring system for this sub-index has been developed along with those for the other sub-indices of the Victoria Index of Stream Condition, and the highest possible score is 10. I have reported this sub-index as a percentage value, by multiplying by 10, to permit easy aggregation with the other sub-indices. If selected for use in New Zealand, this sub-index would require further development to include a wider range of variables.

The Aquatic Life sub-index of the VISC is comprised of components for which we do not have data in New Zealand. There is much biological data available in New Zealand, and a suitable sub-index is available in the form of the Average Score per Metric (ASPM)(as mentioned earlier, this sub-index requires further development to establish reference conditions for different environmental classes). There are other indices currently under development in New Zealand which may be appropriate for reporting biological condition, rather than using the components that make up the 'Aquatic Life' sub-index from the Victoria ISC.

The Hydrology sub-index of the VISC comprises five components to describe flow conditions. At the time of writing, guidance to support calculation of this sub-index was not available. As mentioned earlier, the hydrology sub-index of the VISC requires further development, and we are unsure if the components of the ISC would be useful to represent New Zealand conditions.

The VISC also includes sub-indices to describe physical form and the streamside zone. Both of these sub-indices consider variables that are important to describe habitats in the State of Victoria, some of which are not relevant in describing New Zealand conditions. Further, there currently is not sufficient data available to populate either the streamside zone or physical form sub-index. As already mentioned, the habitat sub-index to describe New Zealand conditions requires significant development.

8.1.2 South East Queensland Environmental Health Monitoring Programme (SEQ EHMP)

The SEQ EHMP is another example of a composite index that measures waterway health using a broad range of biological, physical and chemical indicators of ecosystem health. The included indicators were chosen because they provide valuable information about the condition of SEQ's waterways.

This composite index uses a different approach than many others, as it employs functional indicators to describe river condition. For example, the physical/chemical sub-index is made up of a small suite of variables, including dissolved oxygen and temperature. Continuous measurements of these variables are used in the sub-index. At this stage, we do not have the resources available to monitor these variables continuously; however this was highlighted by the Indicators expert panel as an area to be developed in the future.

Nutrients in the SEQ EHMP are represented not by nutrient concentrations but rather by using stable isotope measurements of N_{15} and algal assays. These procedures are not routinely carried out in New Zealand, though they might be considered in the future.

Equally, ecosystem processes are represented by components that are not currently measured in New Zealand. For example, we currently do not measure algal growth, isotopes of carbon, or benthic metabolism, however it would be useful to consider them in the future.

Aquatic invertebrates are assessed using the number of taxa present, PET richness (the number of taxa belonging to the Plecoptera, Ephemeroptera and Trichoptera orders) and SIGNAL (sensitivity to disturbance of the aquatic macroinvertebrate taxa present). For this study, because of data limitations, we chose to use an already developed New Zealand sub-index to represent aquatic health (ASPM).

Fish are included in the SEQ EHMP. As stated earlier, the fish sub-index for New Zealand requires significant development. Discussion is required about which measures might be useful for fish in aquatic systems, and it may be useful to adopt the approach used in the SEQ index to represent fish in New Zealand river systems.

Because of a lack of compatible data, for the time being, we are not able to calculate the SEQ EHMP index for New Zealand. To implement this index would require significant modifications to current monitoring in New Zealand. Aspects of this system could be implemented, e.g., the Fish sub-index, and should certainly be considered in the future.

Neither of these two composite indices include any consideration of public health; none of the sub-indices include *E. coli*.

8.2 Choice of sub-indices

8.2.1 CCME WQI

The CCME WQI was used in this study to represent physico-chemical water quality mainly because it met most of the original criteria outlined by MfE at the outset of the NEMaR project (Hudson et al. 2011) (Table 8-1). In addition, this index offers flexibility. There is freedom over which variables are included, and over which time period, which meant that the variables recommended by the expert panel could be accommodated. A minimum of four sampling events is required by the index, which means that annual reporting is possible using quarterly data (as was provided by Hawkes Bay Regional Council data is mostly quarterly). The index can equally well be applied to longer data sets. This index compares data with benchmark objectives, which for this study was modelled reference condition information for each water quality variable by REC class. Scores for each site reflect the number of variables that do not meet the benchmark objectives, how often they don’t meet them, and by how much. This index does not hide the underlying data, but rather, the output for each site, and scores for each variable, can be examined to ascertain which variables are responsible for the low scores. While I have been able to calculate scores using the VICS WQI, the CCME WQI offers a greater degree of flexibility and, except for benchmark establishment, little development to implement.

Table 8-1: Desirable criteria for a water quality sub-index (Hudson et al. 2011).

Criterion	Explanation
Descriptive	Describe state, temporal and spatial trend of resource Describe state in terms of numeric index values Accounts for reference conditions Multiple variables, including physico-chemical, biological
Objective	Accurate, complete and unbiased
Transparent	Selection of variables and calculation procedure easily understood
Reproducible	Provides consistent scores, may be applied to historic data
Credible	Concept, input data, procedure and output scientifically defensible Internationally credible
Practical	Able to monitor regularly, cost effectively using standard procedures
Relevant	Meets national, regional policy and management information requirements
Representative	Captures relevant elements of complex environment
Adaptable	Able to incorporate additional variables in future, i.e., able to respond to future information or policy requirements

If the CCME WQI is selected to represent water quality, ‘benchmark objectives’ for water quality variables have to be chosen. For national reporting, reference condition can be used as the objective, or benchmark, to measure ecological integrity. The objectives (or benchmarks) that are used in the CCME WQI are for reporting river condition state only, and are not for setting management objectives. Indeed, the focus of this report is on reporting of state, rather than setting water quality targets and objectives. Targets can then be set (by processes outside NEMaR) for specific reaches which relate to those boundaries. Various approaches exist for setting objectives for water quality. For the purposes of this study, a reference-based approach is of most interest. This involves identification of background condition, which determines the water quality potential for a geographic area, or environmental class, through current assessment of sites with minimal or the least amount of human disturbance, analysis of historical data from sites that had little human disturbance, or modelling to predict conditions associated with little human disturbance (Stoddard et al. 2006). With either of these approaches, either site, region or environmental class specific objectives can be set, based on existing data distributions (e.g., Chambers et al. 2012, Hart et al. 1999). To report ecological integrity, comparing with reference conditions is the most appropriate, however there is insufficient data to represent reference conditions across the range of environmental classes in New Zealand. For the purposes of this study, reference condition information has been modelled for the most common environmental classes.

8.3 Combining fish and macro-invertebrate information

It has been suggested that the fish and macro-invertebrate information is reported in one sub-index. I believe that it is better to keep this information as two separate sub-indices.

At present, fish sampling reaches do not always encompass macroinvertebrate sampling sites, so it may not be valid to combine the data. Fish sampling involves reaches of 100-200 m, while macroinvertebrate sampling is done at a point. For example, Greater Wellington and Auckland fish sampling sites do not coincide with State of Environment water quality sites. Where possible, fish sampling sites in the Hawkes Bay have been matched to State of Environment sampling sites in the Hawkes Bay using GIS (within 1 km of a State of Environment site).

Where the sampling does nearly coincide, I would prefer to keep them as separate sub-indices. Fish and macroinvertebrates respond differently to different stressors, e.g., Clapcott et al. (2011) observed that macroinvertebrates responded differently to land use stressors than fish, with macroinvertebrates being more responsive than fish. Fish are also more mobile than macroinvertebrates so may respond to stress by moving away. Indeed fish probably respond to whole-of-catchment catchment conditions, whereas macroinvertebrates (and periphyton) are more strongly dependent on reach-level conditions. Further, differences in physiology, life history strategies, recruitment, resilience, tolerances are likely to result in different responses. This issue, along with other fish monitoring and reporting questions, will be discussed by an expert panel.

8.4 Combining sub-index scores

Examples have been provided of how the sub-indices might be combined to give a composite index. Approaches applied include simple averaging, a median and a minimum operator approach. If it is thought necessary, it may be possible to develop a specific method for aggregating the sub-indices of the New Zealand Composite Index of River Condition, similar to what is used in the Victoria ISC.

8.5 Categories for the composite index

NEMaR's role is to measure and report information on river reaches as defined by 'ecological integrity', rather than using a values-driven approach. Applying the ecological integrity benchmark will ensure a more consistent approach, while in contrast, management targets based on values will vary in time and space. Setting management targets is beyond the scope of NEMaR. Part of the role of NEMaR however is to categorise index scores, and label bands in a meaningful way, thus permitting identification of river reaches were ecosystems are functioning well, and where they are degraded. Example descriptions for index category bands are provided in Table 8-2.

Table 8-2: Example of labelling for category bands (C. Hickey, pers. comm.).

Description of Management Class
Pristine environment with high biodiversity and conservation values
Environments which are subject to a range of disturbances from human activities, but with minor effects
Environments which are measurably degraded and which have seasonally elevated concentrations for significant periods of the year
Environments which are measurably degraded. Probably chronic effects on multiple species. Significant biodiversity reduction likely for invertebrates and migratory effects for fish.
Significant bio-diversity reduction likely.

9 Conclusions

The purpose of this report was to outline steps taken to develop a working protocol of a composite index to describe river condition in the sense of ecological integrity.

I have demonstrated that, at present, using available data it is possible to calculate a physico-chemical water quality sub-index. Validation of modelled reference condition data would further enhance this sub-index.

Further development is needed for the other sub-indices. I have been able to calculate a biological sub-index from existing data, using the ASPM, as recommended by the expert panel. While I have been able to calculate this index, if I choose to proceed with this choice, further work is required to generate reference condition so that an observed/expected ratio can be calculated. This could be done using either a data-driven or modelling approach.

A fish sub-index has also been calculated for native fish. This indicator requires further development, to decide how best to report information on freshwater fish (i.e., which indicators to use). Expert panel discussions and decisions on what to report will help in establishing protocols for monitoring freshwater fish. Expected fish species for reference conditions are needed to calculated observed/expected scores for both native and exotic fish species.

Further development is needed for the hydrology sub-index. A working group has been convened and approaches for a hydrology sub-index are under discussion.

The habitat sub-index also requires further development. It has been strongly recommended that this sub-index includes in-stream sedimentation, as this is a major driver for in-stream processes and functioning. A reconstructed version of the Stream Ecological Evaluation with a numerical scoring system could be used for this sub-index.

10 Acknowledgements

I thank Lucy Baker and Lian Potter of MfE for on-going support of the NEMaR project. Dr Jochen Schmidt (NIWA) is thanked for project oversight including report review. Dr Aroon Parshotam is thanked for data processing support. The project team thanks the NEMaR Indicators expert panel (listed below) for their valued contributions in workshops and subsequent discussion.

Alastair Suren	NIWA (now Bay of Plenty Regional Council)
Bill Vant	Waikato Regional Council
Bruno David	Waikato Regional Council
Cathy Kilroy	NIWA
Christoph Matthaei	University of Otago
Dave Kelly	Department of Conservation
David Hamilton	University of Waikato
Garth Harmsworth	Landcare Research
Joanne Clapcott	Cawthron Institute
Jon Harding	University of Canterbury
Keith Hamill	OPUS Consulting
Kevin Collier	Waikato Regional Council/ University of Waikato
Marc Schallenberg	University of Otago
Martin Neale	Auckland Council
Piet Verburg	NIWA
Russell Death	Massey University

11 References

ANZECC & ARMCANZ. (2000). Australian and New Zealand guidelines for fresh and marine water quality. October 2000 Edition. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

CCME (2001a). Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0. Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment. Winnipeg.

CCME (2001b). Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, User's Manual. Canadian environmental quality guidelines, 1999. Winnipeg, Canadian Council of Ministers of the Environment.

CCME (2001). Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, Technical Report. Winnipeg, Canadian Council of Ministers of the Environment.

Chambers, P.A.; McGoldrick, D.J.; Brua, R.B.; Vis, C.; Culp, J.M.; Benoy, G.A. (2012). Development of Environmental Thresholds for Nitrogen and Phosphorus in Streams. *J. Environ. Qual. 41(1)*: 7–20. <http://dx.doi.org/10.2134/jeq2010.0273>

Chessman, B.C. (1995). Rapid assessment of rivers using macroinvertebrates - a procedure based on habitat-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology 20(1)*: 122–129. <http://dx.doi.org/10.1111/j.1442-9993.1995.tb00526.x>

Clapcott, J.; Young, R.; Goodwin, E.; Leathwick, J.; Kelly, D. (2011). Relationships between multiple land-use pressures and individual and combined indicators of stream ecological integrity. *Department of Conservation DOC Research and Development Series 326* Wellington. 57 p.

Collier, K.J. (2008). Average score per metric: An alternative metric aggregation method for assessing wadeable stream health. *New Zealand Journal of Marine and Freshwater Research 42(4)*: 367–378. <http://dx.doi.org/10.1080/00288330809509965>

David, B.; Hamer, M. (2010). Regional Guidelines for Ecological Assessments of Freshwater Environments. Standardised fish monitoring for wadeable streams. *TR2010/09.*

Davies-Colley, R.; Verburg, P.; Hughes, A.; Storey, R. (2012). Variables for regional water monitoring underpinning national reporting. *NIWA client report HAM2012-006* for Ministry for the Environment. .

Davies-Colley, R.; Verburg, P.; Hughes, A.; Storey, R. (2012b). Freshwater monitoring protocols and quality assurance (QA). National Environmental Monitoring and Reporting (NEMaR) Variables, Step 2. *NIWA Client Report (HAM2012-092)* for the Ministry for the Environment. August 2012. 96 p.

DSE, V. (2004). ISC Scoring. Index of Stream Condition: The Second Benchmark of Victorian River Condition.

EHMP, S. Methods - Freshwater methods 2006/2007. (2006). Retrieved 11th May 2012, from http://www.healthywaterways.org/_uploads/ehmp/filelibrary/200607_methods.pdf

EHMP, S. Ecosystem Health Monitoring Program. (2012). From http://www.healthywaterways.org/EcosystemHealthMonitoringProgram/Home.aspx

Environment Southland (2000). Southland's State of the Environment Report for Water. *Publication Number 2000-21*. 49 p.

Hart, B.T.; Maher, B.; Lawrence, I. (1999). New generation water quality guidelines for ecosystem protection. *Freshwater Biology 41(2)*: 347–359. <http://dx.doi.org/10.1046/j.1365-2427.1999.00435.x>

Hudson, N.; Ballantine, D.; Gibbs, M.; de Winton, M.; Storey, R.; Verburg, P.; Hamill, K. (2011). Investigation of single indicators for water quality assessment and reporting. *NIWA client report HAM2011-066* prepared on behalf of the Ministry for the Environment. 170 p.

Joy, M.K.; Death, R.G. (2004). Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. *Environmental Management 34(3)*: 415–428. <http://dx.doi.org/10.1007/s00267-004-0083-0>

Leathwick, J.; Julian, K.; Elith, J.; Rowe, D. (2008). Predicting the distributions of freshwater fish species for all New Zealand's rivers and streams. *NIWA client report HAM2008-005* for Department of Conservation. NIWA, Hamilton.

McDowell, R.W.; Snelder, T.H.; Cox, N.; Booker, D.J. (2012). Establishment of reference conditions of chemical indicators in New Zealand streams and rivers relative to present conditions. Draft report to Ministry for the Environment. AgResearch Invermay Agricultural Centre, Mosgiel.

Office of the Commissioner for the Environment (1988). State of the Environment Report 1988: Victoria's Inland Waters. *Government of Victoria*.

Scarsbrook, M.R.; Boothroyd, I.K.G.; Quinn, J.M. (2000). New Zealand's National River Water Quality Network: Long-term trends in macroinvertebrate communities. *New Zealand Journal of Marine and Freshwater Research 34(2):* 289–302. <http://dx.doi.org/10.1080/00288330.2000.9516933>

Schallenberg, M.; Kelly, D.; Clapcott, J.; Death, R.; MacNeil, C.; Young, R.G.; Sorrell, B.; Scarsbrook, M.R. (2011). Approaches to assessing ecological integrity of New Zealand freshwaters. *Department of Conservation Science for Conservation Scientific Monograph No. 1177–9241 307* Wellington, New Zealand. 84 p., http://www.doc.govt.nz/upload/documents/science-and-technical/sfc307entire.pdf.

SKM (2011). Update of Victorian FSR Scores. Melbourne.

Smith, D.G. (1990). A better water quality indexing system for rivers and streams. *Water Research 24(10)*: 1237–1244. <http://dx.doi.org/Doi: 10.1016/0043-1354(90)90047-a>

Stark, J.D.; Boothroyd, I.K.G.; Harding, J.S.; Maxted, J.R.; Scarsbrook, M.R. (2001). Protocols for sampling macroinvertebrates in wadeable streams, New Zealand Macroinvertebrate Working Group Report No. 1 Wellington, New Zealand: Ministry for the Environment.

Stark, J.D.; Maxted, J.R. (2007a). A biotic index for New Zealand's soft-bottomed streams. *New Zealand Journal of Marine and Freshwater Research 41(1)*: 43–61.

Stark, J.D.; Maxted, J.R. (2007b). A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. *Cawthron Report No. 1166.* Cawthron Institute. 58 p.

Stoddard, J.L.; Larsen, D.P.; Hawkins, C.P.; Johnson, R.K.; Norris, R.H. (2006). Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications 16(4)*: 1267–1276. <http://dx.doi.org/10.1890/1051-0761(2006)016[1267:seftec]2.0.co;2>

Terrado, M.; Borrell, E.; de Campos, S.; Barcelo, D.; Tauler, R. (2010). Surface-water-quality indices for the analysis of data generated by automated sampling networks. *Trac-Trends in Analytical Chemistry 29(1)*: 40–52. <http://dx.doi.org/10.1016/j.trac.2009.10.001>

Tiller, D.; Newall, P. (1995). Preliminary nutrient guidelines for Victorian inland streams. Environmental Protection Agency, Government of Victoria.

Victorian DSE (2006). Index of Stream Condition. User's manual (2nd edition). Victorian Government Department of Sustainability and Environment, Melbourne. 62 p. http://www.water.vic.gov.au/__data/assets/pdf_file/0003/9921/ISCUsersManual2ndEdition01.pdf.

White, L.J.; Ladson, A.R. (1999a). An index of stream condition: catchment manager's manual. Department of Natural Resources and Environment, Victorian Government.

White, L.J.; Ladson, A.R. (1999b). An index of stream condition: reference manual (September 1999). Department of Natural Resources and Environment, Victorian Government.

Williams, M.; Longstaff, B.; Buchanan, C.; Llanso, R.; Dennison, W. (2009). Development and evaluation of a spatially-explicit index of Chesapeake Bay health. *Marine Pollution Bulletin 59(1-3)*: 14–25.

Appendix A Canadian Council of Ministers for the Environment Water Quality Index

The concept

The CCME Water Quality Index is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment. The index incorporates three elements: **scope** - the number of variables not meeting water quality objectives; **frequency** - the number of times these objectives are not met; and **amplitude** - the amount by which the objectives are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality). These numbers are divided into 5 descriptive categories to simplify presentation (CCME 2001b).

The specific variables, objectives, and time period used in the index are not specified and indeed, could vary from region to region, depending on local conditions and issues. It is recommended that at a minimum, four variables sampled at least four times be used in the calculation of index values.

The CCME WQI captures all key components of water quality, is easily calculated, and is sufficiently flexible that it can be applied in a variety of situations. The index can be very useful in tracking water quality changes at a given site over time and can also be used to compare directly among sites that employ the same variables and objectives. It can also be used for comparison when the same sites are uses but different nutrient objectives. For example, in calculating the index for a mountain stream and a prairie river, one might employ different nutrient objectives but the sites could still be compared as to their rank (e.g., both sites are ranked as “Good” under the index). However, if the variables and objectives that feed into the index vary across sites, comparing among sites can be complicated and is not recommended (CCME 2001b).

Calculating the index

Data for the index

The CCME WQI provides a mathematical framework for assessing ambient water quality conditions relative to water quality objectives. It is flexible with respect to the type and number of water quality variables to be tested, the period of application, and the type of water body (stream, river reach, lake, etc.) tested. These decisions are left to the user. Therefore, before the index is calculated, the water body, time period, variables, and appropriate objectives need to be defined (CCME 2001b).

The body of water to which the index will apply can be defined by one station (e.g., a monitoring site on a particular river reach) or by a number of different stations (e.g., sites throughout a lake). Individual stations work well, but only if there are enough data available for them. The more stations that are combined, the more general the conclusions will be (CCME 2001b).

The time period chosen will depend on the amount of data available and the reporting requirements of the user. A minimum period of one year is often used because data are usually collected to reflect this period (monthly or quarterly monitoring data). Data from different years may be combined, especially when monitoring in certain years is incomplete, but as with combining stations some degree of variability will be lost (CCME 2001b).

Calculation of the index

The calculation of the CCME WQI requires that at least four variables, sampled a minimum of four times, be used. However, a maximum number of variables or samples is not specified. The selection of appropriate water quality variables for a particular region is necessary for the index to yield meaningful results. Clearly, choosing a small number of variables for which the objectives are not met will provide a different picture than if a large number of variables are considered, only some of which do not meet objectives. It is up to the user to determine which and how many variables should be included in the CCME WQI to most adequately summarize water quality in a particular region.

F1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration ("failed variables"), relative to the total number of variables measured:

$$F1 = \left(\frac{Total\ number\ of\ failed\ variables}{Total\ number\ of\ variables}\right)\ x\ 100$$

F2 (Frequency) represents the percentage of individual tests that do not meet objectives ("failed tests"):

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right)\ x\ 100$$

F3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F3 is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows. When the test value must not exceed the objective:

$$excursion\ i = \left(\frac{Failed\ test\ value\ i}{Objective\ j}\right) - 1$$

For the cases in which the test value must not fall below the objective (e.g., visual clarity):

$$excursion\ i = \left(\frac{Objective\ j}{FailedTestValue\ i}\right) - 1$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse), is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion\ i}{\#\ of\ tests}$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors. The sum of the squares of each factor is therefore equal to the square of the index.

The CCME Water Quality Index (CCME WQI):

$$CCMEWQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality (CCME 2001b).

Worked example

Calculation of the index by hand for a large amount of data is not recommended. An Excel macro has been developed for that purpose. To better understand how the index works, it is useful to work through an example.

Data for 12 months for one river site of the NRWQN has been selected (Table A-1). Seven variables were included in the index calculation, and the ANZECC guidelines for lowland rivers were used as the thresholds for illustrative purposes.

Table A-1: Example data for CCME WQI calculation.

Site	Date	DO%	Clarity	pH	NO_x-N	TN	DRP	TP
AK1	10/01/2011	87.6	**1.26**	7.81	37	301	**15**	**53**
AK1	14/02/2011	87.4	**0.76**	7.41	213	549	**20**	**67**
AK1	14/03/2011	88.2	**1.30**	7.45	129	413	**13**	**45**
AK1	13/04/2011	92.1	**1.35**	7.45	221	445	**15**	**37**
AK1	9/05/2011	86.9	**0.40**	7.3	**552**	**1135**	**39**	**100**
AK1	13/06/2011	91	**0.43**	7.25	274	**951**	**17**	**67**
AK1	11/07/2011	92.8	**0.70**	7.4	**469**	**748**	**13**	**48**
AK1	8/08/2011	93.8	**0.78**	7.51	380	570	**11**	**36**
AK1	13/09/2011	92.4	**0.30**	7.37	382	**815**	**13**	**66**
AK1	11/10/2011	93	**0.93**	7.45	302	572	**18**	**48**
AK1	15/11/2011	93	**1.35**	7.74	175	415	**17**	**50**
AK1	13/12/2011	89.8	**1.31**	7.49	130	428	**14**	**34**
Guideline value		**> 80%**	**> 1.6**	**6.5- 9**	**<444**	**<614**	**<10**	**<33**

Calculate F1

Five variables have some failed tests. Seven variables were chosen overall. Therefore:

$$F1 = \frac{5}{7} * 100 = 71.4\%$$

Calculate F2

The number of tests not meeting the objectives is 42. The total number of tests is 84. Therefore:

$$F2 = \left(\frac{42}{84}\right) * 100 = 50$$

Calculate F3

The excursions are calculated as follows:

$$Excursion = \left(\frac{552}{444}\right) - 1 = 0.24$$

Table A-2: Calculation of excursions for failed variables.

Clarity	Clarity ex	NO$_x$-N	NO$_x$-N ex	TN	TN ex	DRP	DRP ex	TP	TP ex
1.26	0.27	37		301		15	0.51	53	0.61
0.76	1.11	213		549		20	1.00	67	1.02
1.30	0.23	129		413		13	0.29	45	0.36
1.35	0.19	221		445		15	0.54	37	0.11
0.40	3.00	552	0.24	1135	0.85	39	2.91	100	2.02
0.43	2.72	274		951	0.55	17	0.72	67	1.03
0.70	1.29	469	0.06	748	0.22	13	0.29	48	0.47
0.78	1.05	380		570		11	0.12	36	0.09
0.30	4.33	382		815	0.33	13	0.29	66	1.01
0.93	0.72	302		572		18	0.75	48	0.46
1.35	0.19	175		415		17	0.74	50	0.50
1.31	0.22	130		428		14	0.43	34	0.03
Ex total	15.31		0.30		1.94		8.60		7.70

The normalised sum of the excursions is calculated by adding all the excursions (Table A-2**)**.

$$nse = \left(\frac{15.31 + 0.3 + 1.94 + 8.6 + 7.7}{84}\right) = 0.41$$

$$F3 = \left(\frac{0.41}{0.01(0.41) + 0.01}\right) = \mathbf{29.1}$$

With the three factors (F1, F2, F3) now obtained, the index value can be calculated:

$$CCME\ WQI = 100 - \frac{\sqrt{\mathbf{71.4}^2 + \mathbf{50}^2 + \mathbf{29}^2}}{1.732} = \mathbf{47}$$

Given the category ranges suggested (see below), the water quality at this river reach would be rated as ‘marginal’.

Categories of the CCME

Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories:

Excellent: (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

Good: (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels (CCME 2001b).

Important considerations when using the CCME

This index is very flexible and the user is able to define input variables and objectives. It is important to select variables that represent and are relevant to the environment being described. It is also important to only compare index values calculated using the same variables.

The user is also able to specify the reporting time period though a minimum of a year is generally selected. Combining many years gives a more general score. It is important to only compare index outputs calculated over the same period.

Index comparisons should only be made when the same sets of objectives are being applied. To compare across different environmental classes, different nutrient objectives can be set. It is acceptable to compare index outputs calculated for different environmental classes that are based on the same set of variables.

Care should be taken with older data. Many data sets can go back to times when the sensitivity of analytical methodology was considerably less than with more modern methods. The lower accuracy of older data could influence index outputs.

Minimal data sets should not be used. The minimum data requirements are four data points for four variables (equal to one year of quarterly data) (CCME 2001a).

Appendix B Index calculation procedures for the Victoria Index of Stream Condition (Victoria ISC)

Introduction

The ISC is an integrated measure of river health. The objectives of the ISC initiative are to aid strategic waterway management by benchmarking of stream condition, support objective setting for catchment management, evaluate the effectiveness of waterway management plans and provide a basis for reporting on the environmental condition of streams to the local community and government (White & Ladson 1999a).

The index has five components or sub-indices:

- Hydrology
- Physical form
- Streamside zone
- Water quality
- Aquatic life

Calculation of the Victoria ISC

Water quality sub-index

In the index development phase, a wide range of water quality variables were assessed as possible inclusions in the ISC. Variables were selected to identify state wide water quality issues. Variables had to be relatively inexpensive to measure and data easy to interpret (White & Ladson 1999b).

In the original version of this sub-index, four variables were chosen: total phosphorus, turbidity, electrical conductivity, as they were considered to reflect specific water quality issues in Victoria. For example, total phosphorus was selected as an indicator of nutrient enrichment, turbidity was selected as it can indicate bed and bank erosion and is often associated with high phosphorus loads, pH is a developing water quality issue in Victoria (pH has been reported to be decreasing) and conductivity was chosen as an indicator of salinity (salinity is increasing throughout Victoria). The primary function of the water quality sub-index is to flag issues, rather than provide detailed information on their causes. A similar process to select relevant variables would be required in New Zealand before the ISC could be applied in a meaningful manner.

The water quality sub-index is intended to measure low flow or baseflow water quality which is achieved by taking the median value of a series of monthly water quality measurements. Low flow water quality is considered most important because it occurs most of the time and is only interspersed by short periods of high flow (White & Ladson 1999b).

To take account of variability along streams, ratings were developed for upland and lowland streams. Lowland reaches are characterised by low gradients and low flows, while upland reaches have moderate or high gradients. Erosional features are common in upland streams; they have coarse bed sediments and there is little fine sediment deposition.

Table B-1: Ratings for total phosphorus (TP).

Total phosphorus (mg m^{-3})		
Upland	**Lowland**	**Rating**
< 10	< 20	4
10 - <20	20 - < 40	3
20 - <30	40 - < 75	2
30 - < 40	75 - < 100	1
>40	> 100	0

Table B-2: Ratings for turbidity.

Turbidity (NTU)		
Upland	**Lowland**	**Rating**
< 5	< 15	4
5 - < 7.5	15 - < 17.5	3
7.5 - < 10	17.5 - < 20	2
10 - < 12.5	20 - < 30	1
> 12.5	> 30	0

Table B-3: Ratings for conductivity.

Conductivity (µS cm^{-1})		
Upland	**Lowland**	**Rating**
< 50	< 100	4
50 - < 150	100 - < 300	3
150 - < 300	300 - < 500	2
300 - < 500	500 - < 800	1
> 500	> 800	0

Table B-4: Ratings for pH.

pH	Rating
6.5 – 7.5	4
6.0 - < 6.5 or > 7.5 – 8.0	3
5.5 - < 6.0 or > 8.0 – 8.5	2
4.5 - < 5.5 or > 8.5 – 9.5	1
< 4.5 or > 9.5	0

Numerical ratings were developed for each of the water quality variables using guidelines published by the Office of the Commissioner for the Environment (1988) and Preliminary Nutrient Guidelines for Victorian Inland Streams (Tiller & Newall 1995) and agreed by experts (Table A-1 – Table A-4).

Water quality is assessed at the reach scale. Equation A-1 is used to calculate the water quality sub-index:

Equation B-1: Water quality sub-index equation.*r* highlights that variables are measured at the reach scale.

$$WQr = \frac{10}{16}\sum[TPr + Tr + ECr + pHr]$$

Summary of procedures to calculate the water quality sub-index

- Determine whether the reach is upland or lowland.
- Evaluate the rating for TP.
- Evaluate the rating for turbidity.
- Evaluate the rating for conductivity.
- Evaluate the rating for pH.
- Calculate the sub-index using Equation A-1.

Physical form sub-index

To describe the physical form of a stream would involve a discussion of at least stream bed, stream banks, instream bars, the extent of erosion and sedimentation, instream physical habitat and longitudinal connectivity (White & Ladson 1999b). In the ISC, the physical form sub-index comprises 3 indicators:

- Impact of artificial barriers on fish migration.
- Large wood.
- Bank stability.

An earlier version of the ISC also included bed stability in this sub-index; however this measure was removed from the 2004 survey because it could not be either easily or accurately measured.

Artificial barriers

Artificial barriers can impact on fish migration. Their presence is a direct change from natural conditions. The artificial barrier will have an important influence on a stream's physical form and aquatic life (as well as impacts on flow regime). Barriers can change sediment transport through river systems, and can cause widespread disruption to fish spawning migrations, recolonisations, general movement and habitat selection. Barriers are often implicated in indigenous fish decline (White & Ladson 1999b).

Barriers of different size will have different impacts. Large barriers will completely prevent fish passage unless there is a fishway. A medium size barrier may allow limited fish passage, and a low barrier will allow fish passage at medium flow but it may prevent migration of some species. Reaches are allocated ratings based on the presence and type of barrier present as shown in **Table B-5**.

Table B-5: Ratings for the impact of artificial barriers on fish migration.

Category	Rating
In a typical year, no artificial barriers downstream of the reach interfere with fish passage. Artificial barriers may be present if they are dams or barriers will well-functioning fishways or instream structures that are drowned out at least once a day (e.g., every tidal cycle).	4
In a typical year, at least one artificial barrier completely blocks the migration of indigenous fish species. Examples of such barriers include high dams without fishways and straightened concrete lined channels in which the flow is too fast for fish to migrate.	0
Situations where there are artificial barriers but which don't fit into the above two categories, for example, fishways that allow intermittent opportunities for fish passage, weirs or other structures that might be drowned out in high flow conditions and concrete lined straightened channels in which the flow is sometimes slow enough to allow fish passage.	2

Large wood

The large wood ratings take into account the presence of in-stream large wood (logs or trees that have fallen into the stream), by taking note of how much wood there is and whether it is native or exotic (Table B-6). Native wood is more valuable than exotic wood as it breaks down more slowly and provides a more natural instream habitat. It is measured at the site scale (DSE 2004).

Table B-6: Ratings for the large wood indicator.

Heading	Rating
Excellent habitat – abundant wood from native species.	4
Good habitat – numerous pieces of wood from native species, limited wood from exotic species.	3
Moderate habitat – moderate visible pieces of wood from native species, or abundant wood from exotic species.	2
Poor habitat – few visible pieces of wood, either exotic or native.	1
Very poor habitat – no wood visible.	0

Bank stability

Table B-7: Ratings for the bank stability indicator.

Description	Rating
Stable – very few local bank instabilities, none of which are at the toe of the bank; continuous cover of vegetation; very few exposed roots, erosion resistant soil.	4
Limited erosion – some isolated bank instabilities though generally not at the toe of the bank; almost continuous cover of woody vegetation; few exposed vegetation roots.	3
Moderate erosion – some bank instabilities that extend to the toe of the bank; discontinuous woody vegetation; some exposure of roots.	2
Extensive erosion – mostly unstable toe of bank; little woody vegetation; many exposed vegetation roots.	1
Extreme erosion – unstable toe of bank; no woody vegetation; very recent bank movement (fallen into stream); steep bank surface; numerous exposed roots; erodible soils.	0

Bank stability ratings take into account the amount of bare banks, the amount of erosion as well as the bank shape and density of exposed roots (Table A-7). It is measured at the transect scale (DSE 2004).

Calculating the physical form sub-index

- Determine the fish barrier rating for the reach.
- Determine the average large wood score.
- Determine the minimum bank stability score from the transect scores (to ascertain the worst scale scenario for the site). This score is used to represent bank stability for the measuring site.
- Calculate the physical form score for the reach using the following formulae:

Physical form sub-index = 10/8 x (((large wood score+fish barrier score)/2)+bank stability score)

Streamside zone sub-index

The streamside zone is the land and vegetation bordering streams. It is the link between streams and the surrounding catchment. The streamside zone:

- Acts as a filter modifying inputs to the stream.
- Acts as a source of inputs to the stream.
- Provides terrestrial habitat.
- Contributes to bank stability.
- Provides scenery and landscape values (White & Ladson 1999b).

Since European settlement, the streamside zone in Victoria has been heavily modified, particularly in lowland reaches. Modifications have included clearing, introduction of livestock, clearing of land near to wetlands and billabongs and introduction of exotic species of vegetation (White & Ladson 1999b).

The streamside zone assessment is based on a comparison between the current condition of a site compared with its Ecological Vegetation Class benchmark (EVC) (DSE 2004). An EVC is a vegetation community that is defined by its plant species and its location in the landscape and is what it would look like in its undisturbed condition, in other words, the EVC is the reference condition for the vegetation being assessed. Indicators assessed are width of streamside zone, large trees, understorey life forms, recruitment, longitudinal continuity, tree canopy, litter, logs and weeds. Comprehensive guidelines for data collection and habitat assessment of all aspects of streamside zone are provided in the User Manual (Victorian DSE 2006).

Calculating the streamside zone sub-index

Not all the streamside zone indicators carry the same weight. The weightings for each variable are given in Table B-8.

The streamside zone sub-index is calculated out of 10 using the following formulae:

SZ = (US + W + LC + Wd + LT + R + TC + LIT + LOGS)/10

Some reaches are assessed as cleared which means they are largely devoid of native vegetation. In these cases, only 3 indicators are measured: width, longitudinal continuity and weeds. The maximum score possible for cleared reaches is 4 and the following formula is used:

SZ = (W + LC + Wd)/10

When a reach does not contain any large trees, then Large Trees, Tree Canopy and Logs are not included. The sub-index is calculated as follows:

SZ = (US + W + LC + Wd + R + LIT)/8

Procedures for collecting data for the streamside zone sub-index have been revised and rather than manual surveys, LIDAR and aerial photography are used. It is thought that this procedure will give more accurate results.

Table B-8: Weightings for the streamside zone sub-index.

Code	Streamside zone indicators	Weighting (%)
US	Understorey	25
W	Weeds	15
LC	Longitudinal continuity	12.5
Wd	Width	12.5
LT	Large trees	10
R	Recruitment	10
TC	Tree cover	5
LIT	Organic Litter	5
LOGS	Logs	5
	Total	**100**

Hydrology sub-index

In 2004 the Flow Stress Ranking approach was used to provide the ISC hydrology sub-index. ISC scores were based on consideration of five FSR indicators. These indicators, calculated from monthly flows, characterise the degree of hydrologic stress in a river (SKM 2011). The five monthly indices are:

Low flow indicator Q90

This index measures lowest and second lowest monthly flows in a year, that is, the flow that is exceeded 91.7% of the time, and the flow that is exceeded 83.3% of the time.

High flow indicator Q10

This index measures the highest and second highest monthly flows in a year, that is, the flows that are exceeded 8.3% and 16.7% of the time.

Zero flow indicator PZ

This index measures the proportion of the time the stream is dry or nearly so. This index reflects the differences in the proportion of zero flow occurring under unimpacted and current conditions.

Variability indicator CV

This index reflects variability in monthly streamflows. This index measures variability across all months and compares the coefficient of variation of monthly flows between current and unimpacted conditions.

Seasonality indicator SP

This index is a measure of the shift in the maximum flow month and the minimum flow month, i.e., the seasonal timing of when low and high flows occur. The index is based on frequency distributions that reflect the percentage of years that peak and minimum annual flows fall within each given month under current and unimpacted conditions (SKM 2011).

Each of the five index values range between 0 (stressed) and pristine (10). The overall hydrology index is calculated out of 10 according to the following equation:

$Hreach= (Q90+Q10+PZ+CV+2SP)6$

The individual indices are given a uniform weighting, except for the seasonal index, which is given twice the weight of the other sub-indices. The seasonal index is weighted because it combines the flow stress attributes of five ecologically important flow components that have been shown to be highly correlated with a wide range of flow characteristics (DSE 2004).

This score is then standardised to that the final score provides a number between 0 and 10 which is then the ranking of relative flow stress. For example, a score of 7 indicates that 70% of Victorian catchments are more stressed than the one under consideration. The most stressed reach in the state would have a score of zero while the least stressed would have a score of 10. A score of 5 indicates a median level of hydrological stress. A minimum of 15 years of monthly data was required to calculate this sub-index (DSE 2004, SKM 2011).

Aquatic life sub-index

Aquatic biota is influenced by many environmental factors, most notably hydrology, physical form (including the presence of fine sediment, barriers and habitat), streamside zone (including shading) and water quality (including nutrients and turbidity). Aquatic biota is therefore strongly dependent on the other sub-indices and most likely on other environmental factors not included in the ISC. The aquatic life sub-index should be used to detect if anything is affecting the health of the aquatic ecosystem. A deterioration in aquatic life might point to environmental problems even when the other sub-indices score well (White & Ladson 1999b).

Indicator selection for aquatic life followed the same procedure as for water quality variables. A range of indicators (including macrophytes, fish, bacteria, macro-invertebrates, algae/diatoms) were considered. Many were considered unsuitable. Fish was a possible indicator but then was omitted because fish are highly mobile and can escape from local stressful conditions. Fish are relatively costly to sample as a variety of methods are often required. Two indicators based on macroinvertebrates were chosen for the ISC – SIGNAL and AUSRIVAS.

AUSRIVAS incorporates water quality, habitat assessment and biological measures in predictive models that can be used to assess river health (Davies 1994, Parsons & Norris 1996). It predicts the macroinvertebrates that should be present in specific stream habitats under reference conditions. It does this by comparing a test site with a group of reference sites which are as free as possible of environmental impacts, but have similar physical and chemical characteristics to those found at the test site. By comparing the macroinvertebrate families predicted to occur with those actually present, an O/E index (observed number of families/expected number of families) can be calculated. Values of this index fall between 0 and 1 and ratings are shown in Table B-9.

Table B-9: Ratings for the AUSRIVAS indicator.

AUSRIVAS value	Rating
> 0.8	4
0.79 – 0.60	3
0.59 – 0.40	2
0.39 – 0.20	1
< 0.20	0

In SIGNAL (Stream Invertebrate Grade Number Average Level), numerous families of macroinvertebrates have been awarded sensitivity grades by Chessman (1995) based on published information and personal observations of their tolerance or intolerance to various pollutants.

The SIGNAL index is calculated by summing the grades for all the families present at a site. The total is then divided by the number of families at the site which gives an average grade per family. Values of the index will range from 1 to 10. A site with low pollution would have a high value (> 6), while a site with high pollution will have a score of less than 4. SIGNAL ratings are divided into upland and lowland (Table B-10).

Table B-10: Ratings for the SIGNAL indicator.

SIGNAL upland	SIGNAL lowland	Rating
> 7	> 6	4
6 – 7	5 – 6	3
5 – 6	4 – 5	2
4 – 5	3 – 4	1
< 4	< 3	0

In the stream assessment, measurements are made at the reach scale, at the downstream end of the reach if possible. The Aquatic Life sub-index is calculated using Equation B-2.

Equation B-2: Aquatic life sub-index equation.

r highlights that each indicator is assessed at the reach scale.

$$ALr = \frac{10}{8}\sum[SIGr + AUSr]$$

Summary of procedures to calculate the aquatic life sub-index

- Determine if the stream is upland or lowland.
- Evaluate SIGNAL and AUSRIVAS values.
- Determine ratings for SIGNAL and AUSRIVAS indicators.
- Calculate the Aquatic life sub-index score.

Pro-rata score calculation

It is not always possible to have a score for each of the five sub-indices, due to limited data availability. The overall index can still be calculated even when a sub-index is not available. Missing sub-index scores can be calculated on a pro rata basis. At least 3 sub-index values are required to allow pro rata scores to be calculated (DSE 2004).

Calculation process for the missing scores

Calculate the total pro rata score:

Total pro rata score = 5/3 x (sum of existing sub-index scores).

If you are only missing one sub-index score, then use 5/4 instead of 5/3.

Calculate the pro rata score for each missing sub-index

Sub index pro rata score = (total pro rata score calculated as above) – (sum of existing sub-index scores)/2.

If you only need to calculate one sub-index score, do not divide by 2.

Example

To illustrate this example, the sub-index scores for hydrology, streamside zone and physical form are 10, 7 and 6 respectively. Scores for water quality and aquatic life are missing.

Total sub-index score = 5/3 x (10+7+6) = 38.33

Sub-index pro rata score = ((38.33 – (10+7+6))/2 = 7.66 rounded off to 8

Sub-index scores for water quality and aquatic life are therefore 8. If a score is a pro rata score, this will be indicated with an asterix.

Calculate the final ISC score

The final ISC score is not simply an addition of the 5 sub-index score. An inverse ranking transformation is applied to calculate a final score out of 10 for each sub-index. The inverse ranking recognises that a particularly low score in one sub-index might have a limiting effect on river health even if the other sub-indices score highly (DSE 2004). To illustrate the calculation, the sub-index values from the pro rata score example will be used (Table B-11).

Place the sub-index values in ascending order. The smallest is multiplied by 5, the next by 4, and so on, until the largest value which is multiplied by 1.

Add the 5 sub-index totals together and divide by 3.

Table B-11: Calculation of the final ISC score.

Sub-index	Score	Inverse ranking
Physical form	6	6 x 5 = 30
Streamside zone	7	7 x 4 = 28
Water quality	8*	8 x 3 = 24
Aquatic life	8*	8 x 2 = 16
Hydrology	10	10 x 1 = 10
	Total	108
	FINAL INDEX SCORE	108/3 = 36

A condition class can then be assigned (Table B-12). The condition class is a summary of the overall condition of the reach. This class is useful as an overview but the sub-index scores are the more interesting and important information.

Table B-12: Overall ISC condition classification scheme.

Overall ISC score	Condition class
0 – 12	Very poor
13 – 17	Poor
18 – 28	Moderate
29 – 36	Good
37 - 50	Excellent

Important considerations when using the ISC

When using the ISC, it is important to consider the following:

- The ISC has been developed to detect environmental condition in stream reaches that are typically 10 – 30 km long. The ISC may not be sensitive enough, or may be overly sensitive, for considerably longer or shorter reaches.
- The ISC was designed to be a performance indicator over a period of 5 years. Many of the ISC indicators may not be effective for short term assessment (annual time period), and the ISC should not be used as a short term or local performance index.
- The focus of the ISC is on environmental values of waterways. The variables and sub-indices of the ISC have been chosen to reflect values for the entire state of Victoria. Other issues may be important at the local level so other local indicators may be needed to complement the ISC.
- The sub-indices and variables/components of the ISC are relevant to Victoria. Components may not be relevant in other areas, and descriptors of components may have to be revised to suit other areas.
- The ISC was developed for rural streams.
- The ISC provides base information. Outputs from the ISC can be used in waterway management projects.
- Care should be taken when extrapolating outputs, for example when comparing streams in different catchments, or comparing streams of different character.
- Without a sufficient understanding of the index, the outputs can be interpreted in a number of ways, and possibly misread and misunderstood (White & Ladson 1999a, White & Ladson 1999b).

Appendix C South East Queensland Ecosystem Health Monitoring Programme (SEQ EHMP)

The concept

South East Queensland (SEQ) has important aquatic ecosystem assets. The waterways of the region provide a number of important ecosystem values, wildlife habitat, visual and recreational amenities. SEQ's waterways also play a role in providing commercial resources, for example for drinking water, commercial fishing, aquaculture, agriculture and industrial use. Local councils and CEOs identified that they want to protect these important assets through an integrated regional ecosystem health assessment program to ensure these assets/values are not compromised. The information collected in the SEQ EHMP is used to advise councils and land managers on areas of declining health, report on the effects of different land uses, and evaluate the effectiveness of management actions aimed at improving and protecting aquatic ecosystems (EHMP 2012).

The SEQ EHMP uses rigorous science to measure waterway health using a broad range of biological, physical and chemical indicators of ecosystem health. These indicators were chosen because they provide essential information about the condition of SEQ’s waterways.

The SEQ EHMP has three components – freshwater monitoring, estuarine/marine monitoring and event monitoring. Currently, 135 freshwater sites are monitored twice a year (in spring and autumn). Two hundred and fifty four estuarine and marine sites are also monitored on a monthly basis (estuarine and marine sites are beyond the scope of this study).

Indicators of the SEQ EHMP

Assessments for the Freshwater EHMP are based on 5 indicators: physical/chemical, nutrient cycling, ecosystem processes, aquatic macroinvertebrates, and fish. Components/variables which make up these indicators, reasons for their inclusion and methods for collecting related data are described below.

Physical and chemical indicator

The physical and chemical indicator comprises information on pH, conductivity, water temperature and dissolved oxygen (DO) concentration (EHMP 2006). Reasons for inclusion and measurement methods are given in Table C-1.

Table C-1: Components of the physical and chemical sub-index.

Components	Reason	Method
pH	Rapid changes in pH can have adverse effects on aquatic ecology, e.g., acid mine drainage inputs or agricultural runoff. Most organisms have specific pH requirements.	Readings taken with a Conductivity-pH-temperature meter
Conductivity	Conductivity is a measure of dissolved substances. Elevated levels can impact on nutrient cycling, rates of primary production and respiration, survival of riparian vegetation, aquatic macroinvertebrates and fish.	Readings taken with a Conductivity-pH-temperature meter
Water temperature	Temperature regulates aspects of both the community structure and function of aquatic ecosystems. Shifts in temperature regime can have an adverse effect on aquatic ecology	Measured every 10 minutes over a 24 hour period. 5th and 95th percentiles used as maximum and minimum temperatures. Diel range calculated using percentiles.
Dissolved oxygen (DO)	Oxygen is a fundamental requirement for aquatic organisms that respire aerobically. DO concentration affects the distribution, physiological activity and behaviour of aquatic animals.	Measured every 10 minutes over a 24 hour period. 5th and 95th percentiles used as maximum and minimum DO concentrations. Diel range calculated using percentiles.

Nutrient cycling

Components that make up the nutrient cycling indicator, and measurement methods, are provided in Table C-2 (EHMP 2006).

Table C-2: Components of the nutrient cycling indicator.

Components	Reason	Method
Nitrogen stable isotope $\delta^{15}N$	This is the ratio of ^{15}N to ^{14}N. It is used to detect changes in N cycling in a stream. An increase in $\delta^{15}N$ in aquatic plants reflects a change in water chemistry, e.g., increases in uptake of sewage nitrogen or a change in the nitrogen cycle.	The $\delta^{15}N$ of submerged filamentous algae or aquatic plants is used as the measure of $\delta^{15}N$.
Algal bioassay of nutrients (NP:C)		Measured in an *in situ* experiment. The amount of algae growing under 4 different nutrient treatments is assessed – no added nutrients, added N, added P and added N and P.

Ecosystem processes

Components included in the ecosystem processes indicator, and methods for measurement, are given in Table C-3 (EHMP 2006).

Table C-3: Components of the ecosystem processes indicator.

Components	Reason	Method
Algal growth	This is a measure of the rate of primary production within a stream. Algal growth is limited by the availability of light and nutrients. This index reflects changes in shading provided by stream-side vegetation and changes in nutrient loads.	The amount of algae growing on a control treatment of an algal bioassay of nutrients is quantified via lab analysis.
Carbon stable isotope $\delta^{13}C$	The assimilation rates of ^{13}C and ^{12}C by plants will change as environmental and biochemical conditions change. Changes in the $\delta^{13}C$ in aquatic plants will reflect changes in primary production, respiration and stream flow.	Carbon stable isotope signature of filamentous algae is determined in lab analysis.
Benthic metabolism (respiration and gross primary production)	Respiration and production increase with anthropogenic disturbance such as riparian vegetation removal or agricultural runoff.	Both are quantified from the net change in DO within 2 transparent dome shaped chambers, sealed on the stream bed.

Aquatic macro-invertebrates

Components included in the aquatic macroinvertebrate indicator, and measurement methods, are given in Table C-4 (EHMP 2006).

Table C-4: Components of the aquatic macro-invertebrate indicator.

Components	Reason	Method
Number of taxa	A direct measure of taxa richness which increases as ecological condition increases.	Each of these scores is derived from identification of species present in a sample taken from 'edge' habitat at each site. 'Edge' habitat is habitat along the water's edge where there is little or no flow, and few or no submerged macrophytes. Macroinvertebrates in the samples are counted and identified and the three components of this indicator are calculated based on this data.
PET richness	The number of families in a sample belonging to one of the three particularly sensitive orders of aquatic insects: stoneflies, mayflies, caddisflies. The abundance of individuals within PET taxa decline with anthropogenic disturbance so this is a useful indicator of a decline in stream health.	
SIGNAL score	This is a simple scoring system for quantifying the ecological health of streams. It is based on the average sensitivity to disturbance of the macroinvertebrate taxa present. Scores give an indication of the types of pollution and other physical and chemical factors affecting ecological condition of a stream.	

Fish

Fish are a common component of freshwater environments and fish communities reflect a range of natural and human-induced disturbances through changes in abundance and species composition (EHMP 2006). Fish provide an integrated measure of stream condition. Methods for quantifying fish for inclusion in the fish indicator are provided in Table C-5.

Table C-5: Methods for quantifying fish.

Component	Heading	Method
Percentage of native species expected (PONSE)	This refers to the number of native fish species expected to occur at a site expressed as a percentage of the number of native fish species expected to occur at a physically similar site under minimally disturbed conditions.	Electrofishing is used to determine the relative abundance of individual fish species at each site. Counts of the number of fish species caught are recorded as fish are captured. The three components of the Fish indicator are calculated using the data: (1) Percentage of native species expected, (2) ratio of observed to expected native species and (3) proportion of alien fish.
Ratio of observed to expected native species (O/E_{50})	This refers to the native fish species observed to occur at a site in relation to the native fish expected to occur at a similar site under minimally disturbed conditions.	
Proportion of alien fish	This refers to the number of individual fish species originating from outside of Australia expressed as a percentage of total fish catch at a site.	

Calculation of scores

Sampling of all the components that make up the indicators is done twice a year, which results in a large amount of data. Robust methods for summarising the data are needed to minimise data processing and interpretation problems.

To produce summary results, the value of each component for each site is transformed into a standardised score to take account of (1) natural spatial variation in index values across streams with different physical conditions and (2) differences in the scales of measurement for the different indices. The resulting standardised scores range from ‘0’ to ‘1’, where 0.0 indicates unhealthy conditions and 1.0 indicates healthy conditions (EHMP 2006).

Calculation of standardised scores

The calculation of standardised scores for the EHMP involves the use of a lookup table of ‘ecosystem health guideline’ and ‘worst case scenario (WCS)’ values (Table C-6).

Guideline values were derived from either the 20th and/or the 80th percentile of empirical data for minimally disturbed reference sites. These values indicate the expected values of each index for streams in ‘healthy’ condition.

Worst case scenario values were derived from either the 10th and/or 90th percentile of data for all sites. Worst case scenario values indicate the expected value of each index for streams in the ‘unhealthiest’ condition.

Streams were divided into different stream classes based on elevation, stream channel gradient, stream order and mean annual rainfall. This gave four different stream classes – Upland, Lowland, Coastal and Tannin-stained. Each EHMP site was allocated to one of these stream classes. Guideline and WSC values were derived for different stream classes and index values for a site can only be compared with guideline and WCS values for the same stream class.

Calculation of each standardised score involves a comparison of each index value with the guideline and WCS value. Index values that satisfy the criteria in the table of guideline values are scored 1.0 while those worse than/equal to the WCS value are scored 0.0.

The score for other values is calculated using the equation:

$$Score\ ij = 1.0 - \left|\frac{(x\ ij - Guideline\ ij)}{(WCS\ ij - Guideline\ ij)}\right|$$

Where: x_{ij} is the value of the index *i* at a site within a stream class *j*, Guideline *ij* is the corresponding ‘ecosystem health guideline’ value, and WCS*ij* is the corresponding ‘worst case scenario’ value.

The amount that an index value deviates from guideline or minimally-disturbed conditions is provided by $(x\ ij - Guideline\ ij)$. That deviation is expressed as a proportion of the range of values for the index by dividing $(WCS\ ij - Guideline\ ij)$. This calculation makes results comparable across indices of different measurement scales. Final substraction of the resulting value from 1.0 scales the scores to the range 0.0 to 1.0.

An example of the calculation for a standardised score follows:

Conductivity (lowland stream)

Index value = 1000 µS cm^{-1}, Guideline value = 400 µS cm^{-1}, WCS = 1870 µS cm^{-1}

$$Score\ ij = 1.0 - \left|\frac{(1000-400)}{(1870-400)}\right| = 1.0 - \left|\frac{(600)}{(1470)}\right| = 1.0 - |0.41| = 0.59$$

Summarising standardised scores

Scores generated within the Freshwater EHMP are directly comparable across indices and sites as they are standardised for the major sources of spatial variation and differences in scale across indices. Summaries of results can be produced using simple arithmetic averaging at a range of scales.

For the Annual Report Card standardised scores are averaged across several combinations of indices, sites and seasons as follows.

Standardised scores are calculated using the methods outlined above. This results in scores for all the indices at all sites for 2 seasons (the EHMP is calculated using two seasons over one year).

Scores for each indicator are averaged across indices. This results in 5 indicators (Physical/chemical, nutrient cycling, ecosystem processes, aquatic macro-invertebrates) for all sites for 2 seasons.

Each site contributes to a larger group, e.g., a complete catchment. Scores are averaged across sites within each of the reporting areas. This results in scores for the reporting areas for 2 seasons.

Scores are then averaged across seasons to provide a single score for each reporting area.

All of the summary statistics are calculated using different sequences of simple arithmetic averaging. These sequences are clearly defined as different sequences will produce slightly different results. Custom scripts have been written for calculating summary statistics by CSIRO for use in *R* (EHMP 2006).

Table C-6: Ecosystem health guidelines and worst case scenarios (WCS) used in the Freshwater EHMP (EHMP 2006).

Indicator	Index	Upland		Lowland		Tannin-Stained		Operand	Unit
		Guideline	WCS	Guideline	WCS	Guideline	WCS		
Physical & Chemical	pH - min	6.5	4.5	6.5	4.5	5	3	≥	H+
	pH - max	8.5	10.5	8.5	10.5	8.5	10.5	≤	H+
	Cond	400	1041	400	1870	400	1870	≤	µS cm^{-1}
	Temp max	18	NA	22	NA	2	NA	≤	^{0}C
	Temp range	4	NA	4	NA	4	NA	≤	^{0}C
	DO min	30	NA	20	NA	20	NA	≥	% saturation
	DO range	30	NA	50	NA	50	NA	≤	% saturation
Nutrient cycling	δ15N	5	10	5	10	5	10	≤	‰
	NP:C	4	1	4	1	4	1	≥	Ratio (number)
Ecosystem processes	Chl *a*	8	17	12	19	12	19	≤	mg chl ^{2} m^{-2}
	δ13 C	-28	-50	-28	-50	28	-50	≥	‰
	R24	0.15	0.7	0.35	1.2	0.35	1.2	≤	g C m^{-2} day^{-1}
	GPP	0.25	0.8	0.5	1.3	0.5	1.3	≤	g C m^{-2} day^{-1}
Aquatic Macroinvertebrates	No of taxa	22	0	22	0	11	0	≥	Number
	PET richness	5	0	4	0	3	0	≥	Number
	SIGNAL score	4.6	2.8	4	2.4	4	2.5	≥	Number
Fish	PONSE	100	0	100	0	100	0	≥	%
	O/E50	1	0	1	0	1	0	≥	ratio (number)
	Prop Alien fish	0	100	0	100	0	100	=	%