Waterways Unit
Department of Natural Resources and Environment
(Victoria)

AN INDEX OF STREAM CONDITION: REFERENCE MANUAL

Second Edition

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This manual is based on the previous ISC *Reference Manual* (CEAH and ID&A Pty. Ltd 1997).

Other publications in this series:

- White, L.J., and Ladson, A.R., 1999, **An index of stream condition: Field Manual,** Department of Natural Resources and Environment, Melbourne, April 1999.
- White, L.J., and Ladson, A.R., 1999, **An index of stream condition: Catchment Managers' Manual,** Department of Natural Resources and Environment, Melbourne, April 1999.
- White, L.J., and Ladson, A.R., 1999, **An index of stream condition: Users' Manual (second edition),** Department of Natural Resources and Environment, Melbourne (in preparation).

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FOREWARD

The development of an Index of Stream Condition (ISC) allows, for the first time, a holistic assessment of the health of the rivers and streams in Victoria. The ISC has been developed as a new and innovative tool that can be used by catchment managers and the community in:

- benchmarking the condition of streams;
- assessing the long term effectiveness of programs to maintain and rehabilitate streams; and
- setting priorities to target resources

Use of the Index will lead to improved waterway management, better allocation of resources and genuine improvement in the condition of streams. The ISC will also assist Catchment Management Authorities with their statutory reporting requirements.

The ISC was developed and trialed over a four-year period by a Specialist Reference Group (SRG) of scientific and industry experts. The initial development work included reviewing previous stream assessment methods, and consulting with experts with knowledge of hydrology, geomorphology, aquatic ecology, riparian vegetation and function, water quality, and river management policy and practice.

Following the development of the ISC concept, it was trialed in the field. Two catchments were chosen to represent different river systems: the Latrobe catchment in Gippsland and the Broken River catchment in north east Victoria. Results from the trials were discussed on site with the SRG and lessons incorporated into the ISC to make it more reliable and user friendly.

The result is a monitoring tool that is based on scientific knowledge and principles, but which is user friendly. It is designed to provide a long-term summary of all the major environmental attributes that affect stream health that can be measured at reasonable cost.

I congratulate the SRG on striking a balance incorporating scientific information into the ISC and achieving something innovative and useful.

This does not mean that the ISC can not be improved. Feedback from users will be important in refining the ISC. Future research may identify indicators that should be used to supplement or replace those already in the ISC.

The ISC is now at a stage where Catchment Management Authorities can use it. NRE has secured funding through the National Heritage Trust to facilitate the application of the ISC on a statewide basis by December 1999.

Developing the ISC has involved contributions from a large number of people, who are listed in Appendix 1 of this Manual. I would particularly like to thank the members of the SRG, the Catchment bodies for their input and Lindsay White, Tony Ladson and Paul Wilson who have been the key project officers in developing the ISC.

PATRICK McNAMARA
Deputy Premier
Minister for Agriculture and Resources

SUMMARY

This report describes an Index of Stream Condition (ISC). The ISC has been developed to be a tool to assist management of waterways in Victoria and will be used to:

- aid objective setting by catchment managers;
- benchmark the condition of streams; and
- assess the long-term effectiveness of management intervention in rehabilitating streams.

The ISC was designed to assess rural streams, and results will be reported about every 5 years for stream reaches typically between 10 and 30 kilometres long. For a stream reach, the ISC provides a summary of the extent of changes to:

- hydrology (flow volume and seasonality);
- physical form (stream bank and bed condition, presence of, and access to, physical habitat);
- streamside zone (quantity and quality of streamside vegetation, and condition of billabongs);
- water quality (nutrient concentration, turbidity, salinity and acidity); and
- aquatic life (diversity of macroinvertebrates).

A score is provided for each of these components ('sub-indices'), which is a measure of change from natural or ideal conditions. The ISC is reported as a bar chart that shows the score for each sub-index out of a maximum of ten. The overall score for the ISC is the sum of the 5 sub-index scores, and is out of a maximum of 50.

The ISC has been developed to meet some of the needs of Catchment Management Authorities (CMAs). It is ***not*** intended to provide ***all*** the information that managers may require about stream condition when planning management programs. It will flag issues and identify where more detailed investigations are needed. The ISC concept was developed by a Specialist Reference Group of stream managers and scientists, and refined by trials in Gippsland and north-east Victoria in 1996 prior to a technical review with representatives of CMAs.

This manual describes the basis of the ISC in detail and has been written for CMA boards, CMA office staff, and stream scientists. Information on how to measure ISC field data, collect and process other ISC information, and interpret and use ISC results in strategic catchment management are given in the other manuals in the series.

GLOSSARY

Term	Definition
Aggradation	A progressive build-up of the channel floor with sediment over several years.
Amended Annual Proportional Flow Deviation (AAPFD)	The main indicator in the Hydrology Sub-index, and is calculated from monthly natural and current flows. The larger the value of the AAPFD the greater the change in flow from natural conditions. This indicator characterises changes to flow quantity and seasonality.
Anabranch	A stream that leaves a river and re-enters it further downstream.
Artificial barrier	An artificial obstacle in a stream (e.g. a dam wall, weir, culvert or causeway) that affects (halts or delays) fish migration.
AUSRIVAS	Australian River Assessment System - an indicator of stream condition that is evaluated by comparing the observed aquatic macroinvertebrate taxa at a site to the taxa predicted to occur at the site in the absence of environmental stress.
Bank	The relatively steep part of a stream channel cross-section, generally considered as being above the usual water level (see figure G.1).
Bar	A relatively flat, temporary, local feature, typically on the inside of a meander bend where sediment is deposited. Vegetation that grows on a bar is usually stripped during large floods (see figure G.1).
Basin	The catchment of a large river or group of rivers. There are 29 basins within Victoria.
Bed stability	Bed stability is when the average elevation of the stream bed does not change much through time. Aggradation or degradation are the two forms of bed instability.
Billabong	A section of cutoff stream channel (e.g. an oxbow lake) usually on a floodplain. The cutoff channel will usually progressively fill with sediment over time. Most are only connected to the river during floods.
Catchment	The area of land drained by a stream and its tributaries.
Catchment Management Authority (CMA)	A regional authority set up under Victorian State Government legislation in 1997 to manage natural resources in a region generally on a catchment basis. The charter of CMAs includes implementation of waterway management activities and regional catchment strategies.
Cover	To do with vegetation density, the percentage of vegetation cover is the ratio of the area of vegetation when viewed from above to the ground surface area. Also to do with instream cover. For aquatic biologists, cover can also mean cover for fish and other animals in a stream.

Data gap	A data gap occurs where inadequate data exists to evaluate an indicator using the standard ISC methodology. Some procedures exist for filling data gaps (see *Users' Manual*).
Degradation	Degradation has a broad meaning of reduction in quality, and a specific meaning in geomorphology of general lowering of a stream bed, usually over a period of years, by erosional processes.
Desnagging	Removing large trees (usually willows and river red gum) from the bed and banks of streams.
Drowned out	An obstacle to flow (for example a weir) is drowned out if the water surface elevation immediately downstream of the obstacle is approximately equal to the water surface elevation immediately upstream, and there is no sudden change in the water surface between the two points.
Electrical conductivity	A measure of salinity. The higher the electrical conductivity of a stream the greater the salinity.
Ephemeral stream	A stream which flows intermittently, that is, it is often dry.
Erosion	Modification of the channel boundary by entrainment and removal of sediment.
Exotic vegetation	Introduced species of vegetation from other countries or from other regions of Australia (i.e. not indigenous to the region).
Flood runner	A channel that only flows during floods.
Floodplain	A flat area adjacent to a stream that is covered by floods every year or two.
Flow regime	The pattern of flows over many seasons and years that is responsible for the character of the stream system.
Flow regulation	Changes to the timing and volume of flow brought about by dams, diversions or other interference with a river.
Geomorphology	Geomorphology is the study of the earth's landforms including their origin and structure. Fluvial geomorphology is the subset that deals with streams.
Ground layer	Plants without woody stems less than 1.5 m high e.g. sedges, reeds, grasses, saltbush (see figure G.1).
Head cut	A very steep section of stream bed that migrates upstream if not held by a bed control (e.g. a rock bar, or grade control structure). Downstream of a head cut is normally incised and eroding.
Hydroelectric station	A power station that generates electricity from flowing water (also see peak loading hydroelectric station).
Incised stream	A deep narrow stream that has eroded its bed and banks and has a large channel capacity such that overbank flooding is rare.
Indigenous taxa	In general, taxa that that originated in and occur naturally in a particular region or environment.

Large woody debris	A tree, branch or root system that has fallen into or is immersed (totally or partially) in a stream.
Longitudinal continuity	An indicator in the Streamside Zone Sub-index. A measure of how continuous streamside vegetation is and the importance of discontinuities in the vegetation.
Lowland reaches	Lowland reaches are low in gradient, and the flow velocity is, on average, low. Lowland streams often have depositional features. Some lowland streams are tidal. Lowland streams typically meander across broad (greater than 1 km wide) alluvial or coastal floodplains.
Macroinvertebrate	An invertebrate (animal without a backbone) that is visible to the naked eye.
Macrophyte	A water plant that is not an alga. It may be either floating or rooted.
Major streams	Major streams are defined in the ISC as those streams with a catchment area > 30 000 hectares.
Measuring site	A length (430 m) along a stream for which field data is collected to assess most of the indicators in the Physical Form and the Streamside Zone sub-indices. There are 3 transects within a measuring site (see figure G.2).
Median	The middle number of a series. If the sequence has an even number of values, the median is the average of the two middle values. Median of monthly values are used for each indicator in the Water Quality Sub-index.
Minor streams	Minor streams are defined in the ISC as those streams with a catchment area < 5 000 hectares.
Modified catchment	A catchment that has been altered by human impact. The most common impacts include altered land use and flow regime, and the introduction of exotic plants and animals.
Morphology	Shape or form.
Natural flows	The flow that would have existed if present rainfall patterns fell on catchments before European settlement.
Peak loading hydroelectric station	A power station that generates electricity from water released at times during the day to meet peak electricity demand. These hydroelectric stations are associated with flow patterns that can cause rapid rises and falls in water level and changes in velocity in downstream waterways.
pH	A measure of acidity or alkalinity of water (based on the concentration of hydrogen ions).
Rating	In the ISC, raw data is converted to a rating (a non-dimensional number for an indicator) by looking up a rating table.
Reach	A length of stream typically 10 to 30 km long (minimum 5 km, maximum 40 km) which is relatively homogenous with regard to the Hydrology, Physical Form, Water Quality and Aquatic Life Sub-indices (see figure G.2).

Regeneration	Vegetation that has grown from natural sources of seed, from vegetative growth, or has been artificially planted. In the ISC, the regeneration indicator is based on the amount of woody vegetation less than 1 m high (see figure G.1).
Regulated stream	A stream where flows are controlled by releases from a dam.
Riffle	The high point in the bed of the stream between two pools (it is often covered in gravel or coarser material). Water is often shallow and fast flowing.
Score	A non-dimensional number for a sub-index or the entire ISC (see rating).
Shrub layer	Woody plants < 5 m tall, frequently with many stems arising at or near the base e.g. melaleuca, leptospermum, tree ferns, blackberry. Includes non-woody vegetation greater than 1.5 m high (see figure G.1).
SIGNAL	An indicator in the Aquatic Life Sub-index that measures effect of pollution on aquatic biota. SIGNAL is an acronym for Stream Invertebrate Grade Number-Average Level.
Snagging	See desnagging.
Spatial extrapolation	To fill a data gap based on data from a reach either upstream or downstream of the actual reach.
Spatial interpolation	To fill a data gap based on data from reaches both upstream and downstream of the actual reach.
Specialist Reference Group	The group of Victorian stream scientists and managers who directed and oversaw the development of the ISC (see appendix 1 for more details).
Structural intactness	An indicator in the Streamside Zone Sub-index that compares the natural and existing cover of tree layer, shrub layer and ground layer.
Sub-index	A group of indicators that measure a particular aspect of a stream. In the ISC, the five sub-indices are hydrology, physical form, streamside zone, water quality and aquatic life.
Taxa/Taxon	Taxa are groups of organisms that are part of a taxonomic division, such as family, genus or species. Taxon is the singular of taxa.
Total phosphorus	The sum of the concentrations of soluble and in-soluble phosphorus.
Tree layer	Woody plants greater than 5 m tall, usually with a single stem e.g. eucalyptus > 5 m tall, acacia > 5 m tall, and willow > 5 m tall. Note that woody vegetation species less than 5 m high are classed as shrub layer (see figure G.1).
Transect	A 30 m section of stream bank perpendicular to the stream. Some indicators in the Physical Form and Streamside Zone Sub-indices are assessed within transects during field data collection (see figure G.2).
Tributary streams	Tributary streams are defined in the ISC as those streams which have a catchment area between 5 000 hectares and 30 000 hectares.

Unmodified catchment	A catchment that has not be altered by clearing, forestry or other human activities.
Upland reaches	In the ISC, reaches are divided into two types, lowland and upland. Upland reaches have moderate or high gradients and may be cascading or have pool and riffle sequences. Bed sediments are usually coarser than sand and there will be little deposition of fine sediment. Erosional features are common.
Urban areas	Urban areas are shown as built up on current street directories. The ISC was not designed for urban reaches.
Verge	The area commencing at the top of the bank and extending from the bank to the next major vegetation or land use change (see figure G.1).
Waterway coordinator	A technical specialist engaged by a CMA who oversees an application of the ISC (amongst other duties).
Width of stream	The distance from one edge of the stream to the other during typical baseflow conditions.
Width of vegetation	Width of vegetation from edge of stream during typical baseflow conditions to adjacent land use.
Woody plants	Vegetation that has a distinct trunk and branch structure, ranging from trees to small shrubs. Generally hard and fibrous.

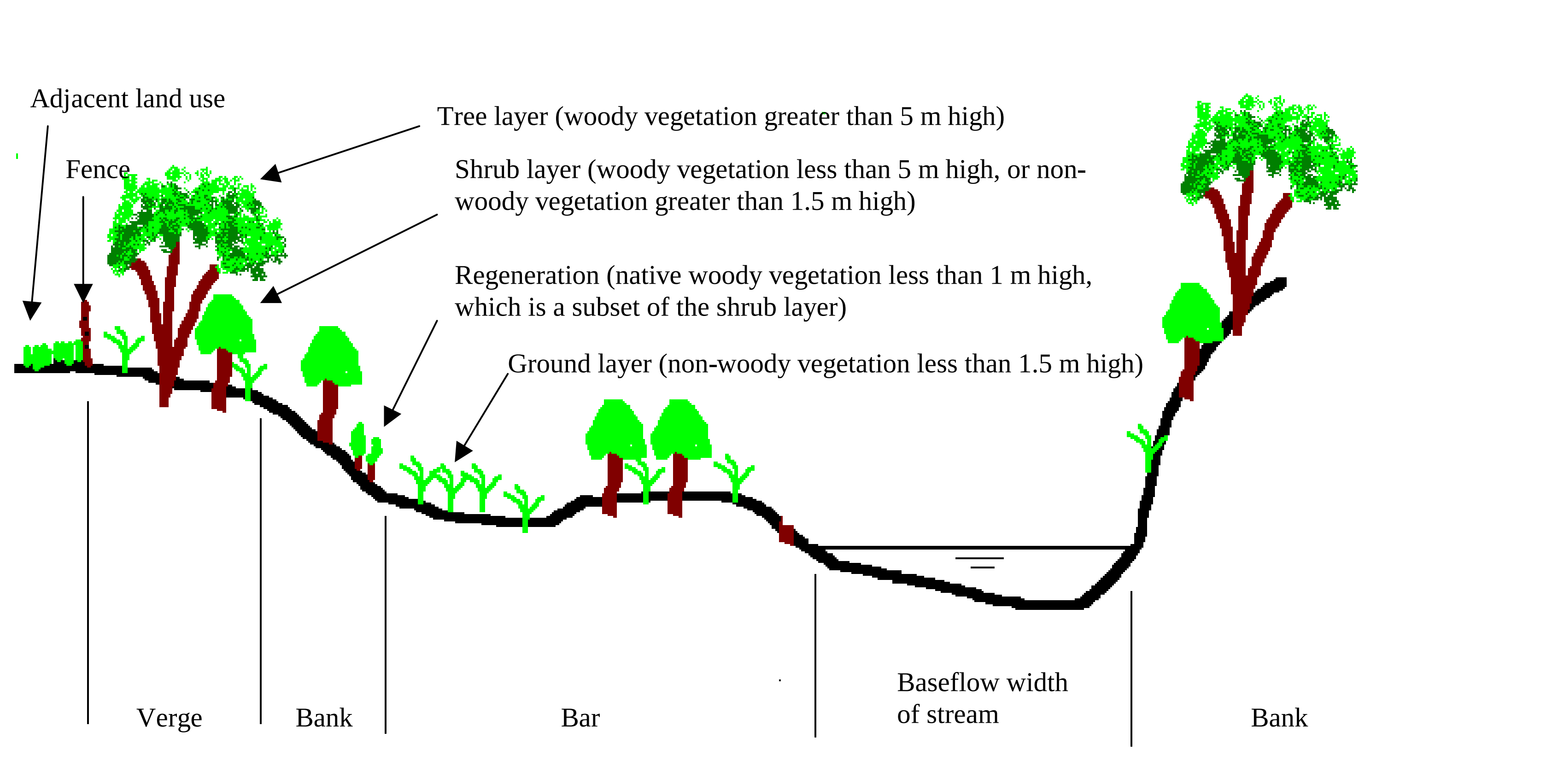

Figure G.1 - Definition diagram of selected terms used in the ISC

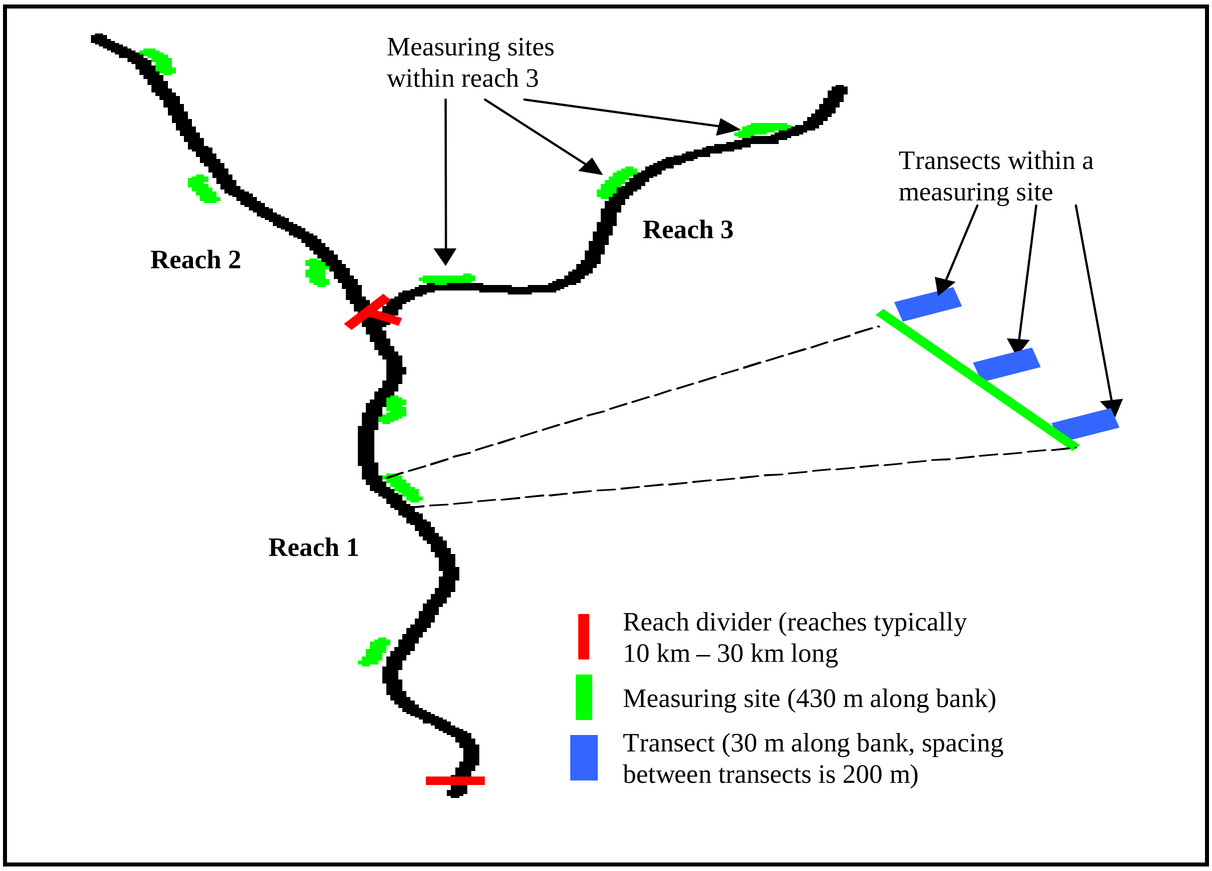

Figure G.2 - Schematic showing definitions of reach / measuring site / transect

ABBREVIATIONS

AAPFD	Amended Annual Proportional Flow Deviation
AUSRIVAS	Australian River Assessment System
CMA	Catchment Management Authority
EPA	Environmental Protection Authority
FNARH	First National Assessment of River Health
ISC	Index of Stream Condition
LWRRDC	Land and Water Resources Research and Development Corporation
MRHI	Monitoring River Health Initiative
NRE	Department of Natural Resources and Environment
NRHP	National River Health Program
SIGNAL	Stream Invertebrate Grade Number-Average Level
SRG	Specialist Reference Group

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1. INTRODUCTION

This report is one of a series that describes the Index of Stream Condition (ISC). The ISC is an integrated measure of the state of a stream and is intended as a practical assessment tool to assist managers make strategic decisions about waterway management activities.

The ISC is based on an assessment of 5 components of streams:

- hydrology (flow volume and seasonality);
- physical form (stream bank and bed condition, quality of and access to instream physical habitat);
- streamside zone (quantity and quality of streamside vegetation, and condition of billabongs);
- water quality (nutrient concentration, turbidity, salinity and acidity); and
- aquatic life (diversity of macroinvertebrates).

Each of these components (a sub-index) is given a score between 0 and 10 based on the assessment of a number of indicators. The overall ISC score is the sum of the sub-index scores and is between 0 and 50, the higher scores indicating better condition.

This manual describes why the ISC was developed and provides details of the component indicators and why they were chosen. It has the broadest scope of the manuals, providing background information rather than specifics on collection and processing of ISC data, or interpretation of ISC results. The primary audience of this manual is Catchment Management Authority (CMA) board members, technical staff, and stream scientists who seek a more detailed understanding of the ISC.

1.1 Purpose of each manual in the 1999 series

There are four manuals in the 1999 Index of Stream Condition (ISC) series, which includes this second edition of the *Reference Manual* along with the:

- *Users' Manual* (second edition) that describes how to evaluate the ISC;
- *Field Manual* that details procedures for the collecting field data to evaluate indicators in the Streamside Zone and Physical Form Sub-indices; and
- *Catchment Managers' Manual*, which provides advice on how ISC results can be interpreted and used in strategic waterway management.

1.2 Why the ISC was developed

In Victoria, broad objectives of stream management include improving the condition of degraded streams, and protecting healthy streams, to provide for the environmental, social and economic needs of current and future generations.

There are a number of government, agency and local community groups that work towards ensuring sustainability of streams, including:

- Catchment Management Authorities (CMAs);
- Landcare groups;
- the Department of Natural Resources and Environment (NRE); and
- the Environmental Protection Authority (EPA).

Programs span institutional reform, research, funding, on-ground works, and management of aspects of water quality and quantity. Each of these activities may have performance indicators that allow an assessment of whether individual **program** objectives have been met. However, there is a need for an integrated suite of indicators to detect long-term changes in **overall** stream condition over whole catchments. This will allow an assessment of the impact of the entire, integrated effort of management i.e. the cumulation of all existing management programs (figure 1.1). The ISC has been developed to meet this need. It can be used to:

- benchmark stream condition, and for reporting to local, regional, state or Commonwealth agencies;
- aid objective setting by, and provide feedback to, natural resource managers (particularly CMAs), and in particular, to assess trade-offs between utilitarian demands on streams and environmental condition;
- judge the effectiveness of intervention, in the long-term, in managing and rehabilitating stream condition; and
- review performance against expected outcomes (see figure 1.2).

The role of the ISC in strategic waterway management is discussed in more detail in the *Catchment Managers' Manual*, which includes examples of strategic planning directly linked to the ISC.

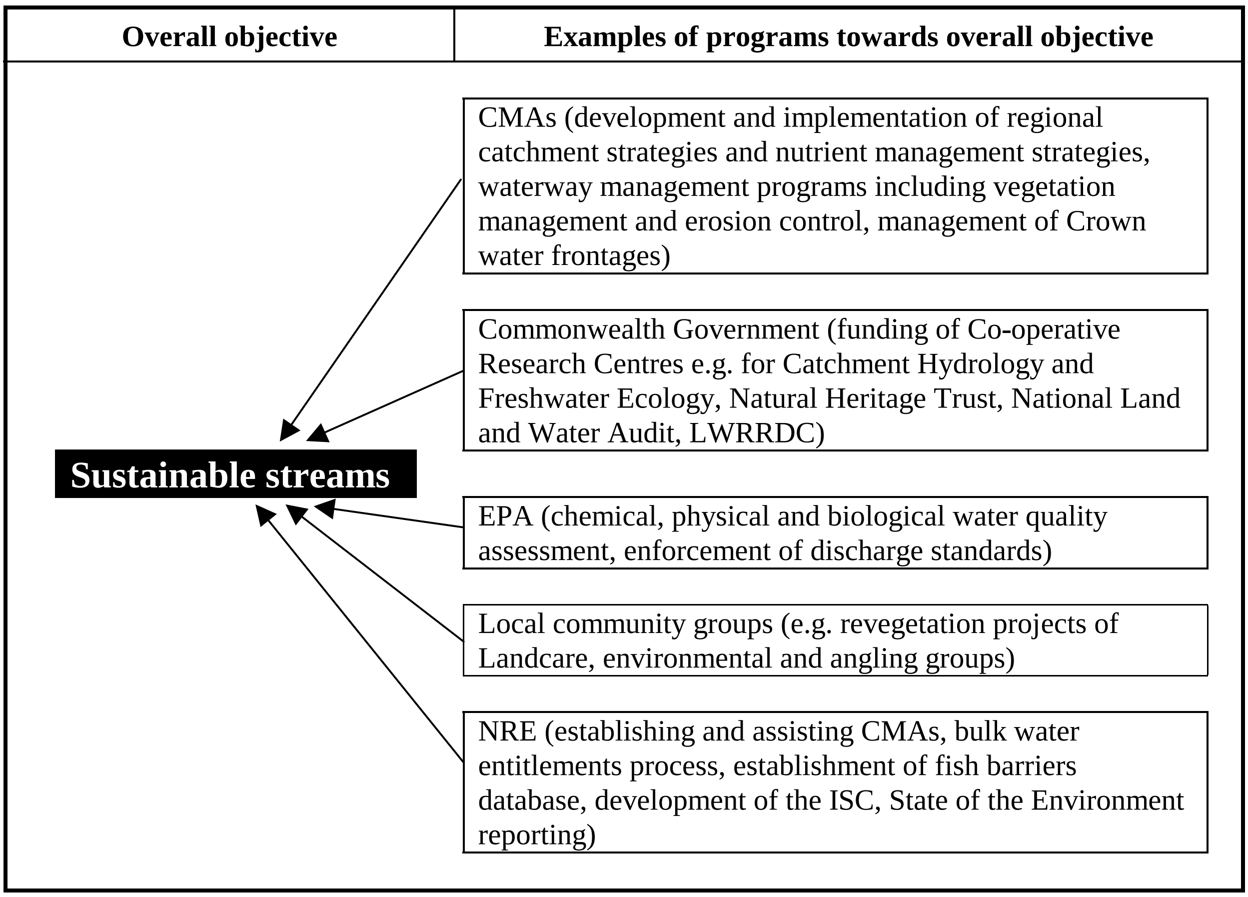


Figure 1.1 - Examples of groups and activities contributing towards the objective of sustainable streams in Victoria

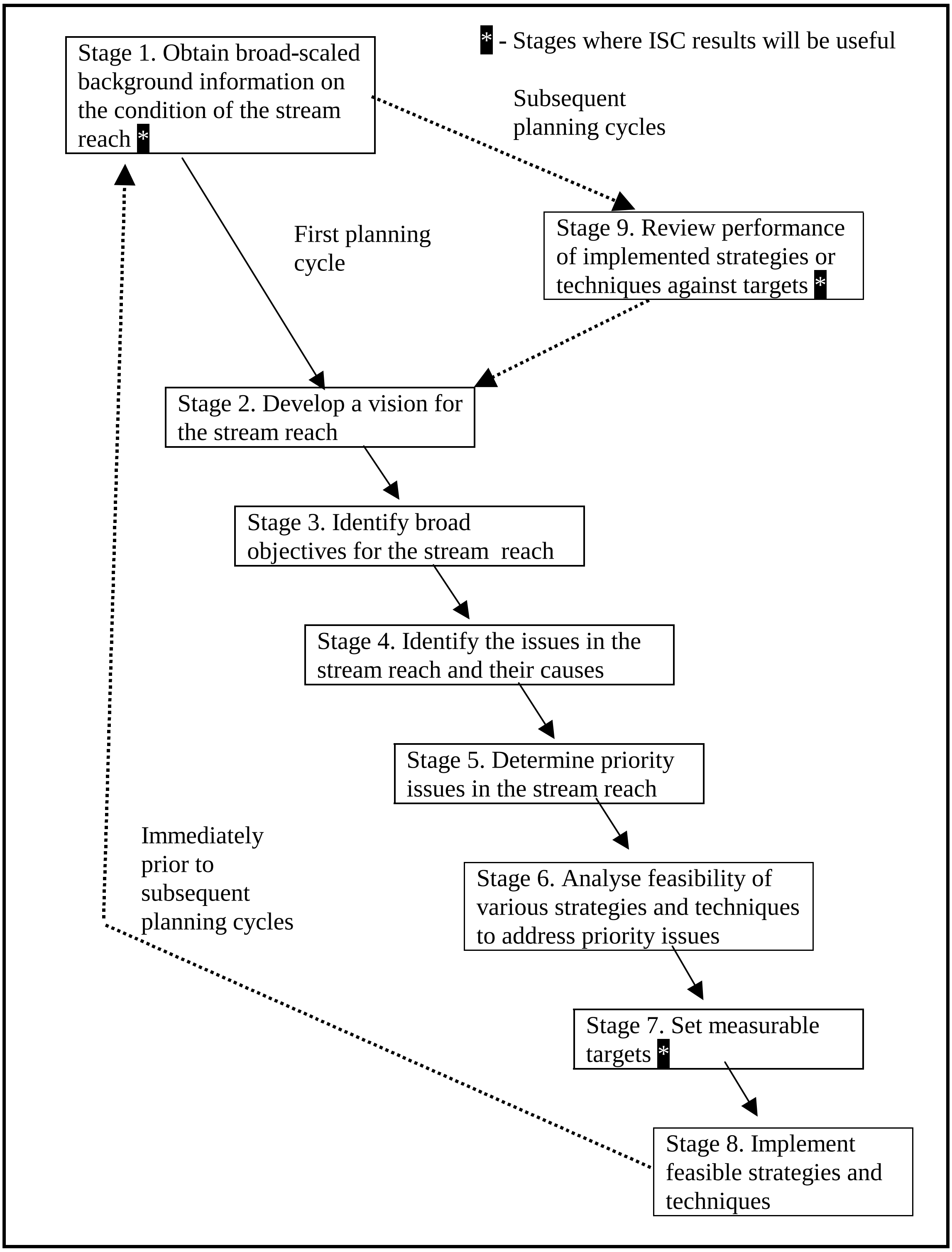


Figure 1.2 - Schematic of the stages of strategic waterway management for a planning cycle of about 5 years [see Lucas *et al*. (1999) and Ian Drummond and Associates (1995) for similar ideas on planning by catchment managers]

1.3 How the ISC was developed and will be applied

Development of the ISC involved 3 stages over 4 years and included consultation, trials, refinements and documentation (see table 1.1). The process was guided by a Specialist Reference Group (SRG) of stream managers and scientists (see appendix 1). Between 1997 and 1999 there have been substantive changes to the ISC in response to the experience of CMAs (see table 1.2).

1.4 Content of this *Reference Manual*

Following this introduction, chapter 2 provides a brief overview of the ISC and how it is applied. The next 5 chapters detail the sub-indicies of the ISC: hydrology is discussed in chapter 3, physical form in chapter 4, streamside zone in chapter 5, water quality in chapter 6 and aquatic life in chapter 7. There are 4 appendices.

- Appendix 1 provides detail on how the ISC was developed and acknowledges intellectual and financial contributions.
- Appendix 2 reviews existing approaches to measuring stream condition and identifies key lessons for the ISC.
- Appendix 3 details statistical analysis undertaken to determine the appropriate number of measuring sites and transects for field data collection within a reach.
- Appendix 4 provides further detail on the Hydrology Sub-index.

Table 1.1 - Summary of the stages of development of the ISC (see appendix 1 for more detail)

Stage	Examples of tasks	Reports
1: Development of an ISC concept (stage completed November 1995)	1. Collecting information and ideas from a literature review concentrating on alternative stream assessment techniques (Ladson and White 1999a) 2. Discussing important aspects of stream condition with experts throughout Australia 3. Collating and filtering of information prior to presentation to the SRG 4. Selecting a methodology and prototype ISC by the SRG to be refined through field trials (Ladson *et al*. 1996)	Development of an Index of Stream Condition (CEAH and ID&A Pty Ltd 1995)
2: Trialing and refinement of ISC concept (stage completed April 1997)	1. Trialing of the ISC in parts of the Lake Wellington, Broken and Goulburn catchments including the assessment of field indicators by staff of Waterway Management Authorities (Ladson *et al*. 1997) 2. Holding field workshops with the SRG to discuss the ‘reasonableness’ of the results 3. Evaluating results of the field trials and refining the ISC through further discussion with the SRG (Ladson *et al*. 1999)	1. An Index of Stream Condition: Reference Manual (CEAH and ID&A Pty Ltd 1997) 2. An Index of Stream Condition: User’s manual (ID&A Pty Ltd and CEAH 1997a) 3. An Index of Stream Condition: Trial Applications (ID&A Pty Ltd and CEAH 1997b)
3: Adapting ISC for 1999 context (stage scheduled to be complete in August 1999)	1. Conducting a technical review session with nominees of the CMAs (July 1998) 2. Presenting the ISC to conferences and workshops 3. Developing robust sampling strategies for the Physical Form and Streamside Zone sub-indices 4. Developing a protocol to generate ISC indicator ratings from physical habitat data collected for the Monitoring River Health Initiative, First National Assessment of River Health and the Regional Forests Agreement.	1. An Index of Stream Condition: Reference Manual, second edition (this report) 2. An Index of Stream Condition: Catchment Managers' Manual (White and Ladson 1999a) 3. An Index of Stream Condition: Field Manual (White and Ladson 1999b) 4. An Index of Stream Condition: Users' Manual (second edition) (in preparation)

Table 1.2 - Substantive changes to the ISC between 1997 and 1999

Substantive changes to the ISC between 1997 and 1999	**For further details, refer to the following sections of the ISC 1999 manuals**
Hydrology Sub-index ▪ Replacement of the Hydrologic Deviation indicator by the Amended Annual Proportional Flow Deviation indicator	Chapter 3, this manual
Physical Form Sub-index ▪ Inclusion of the instream physical habitat indicator for upland streams	Chapter 4, this manual
Streamside Zone Sub-index ▪ Replacement of % indigenous indicator by cover of exotic vegetation indicator	Chapter 5, this manual
Aquatic Life Sub-index ▪ Inclusion of the AUSRIVAS indicator	Chapter 7, this manual
Clarification of how ISC results should be used by catchment managers ▪ Preparation of the *Catchment Managers' Manual*, which includes discussion of links between ISC and Crown Water Frontage Review ▪ Discussion of the use of the ISC as a short-term or local performance indicator ▪ Identification of some waterway management strategies and techniques to improve environmental condition of streams	*Catchment Managers' Manual*
Data issues ▪ For modified catchments, following statistical analysis, field data is now collected at 3 randomly selected measuring sites rather than 1 'representative' measuring site ▪ Development of the *Field Manual*, with inclusion of more detail in rating tables and more reference photographs from a greater number of locations across the state ▪ Streamlining of field datasheets ▪ Development of quality assurance and control plan ▪ Development of a protocol to convert physical habitat data from US EPA field sheets to ISC ratings for a number of indicators	Appendix 3, this manual *Field Manual* *Field Manual* *Users' Manual* Ladson and White (1999b)
Changes in definitions ▪ In the Streamside Zone Sub-index, the new terms, tree layer, shrub layer, ground layer, replace overstorey, understorey and groundcover; ▪ Reaches are specified as either lowland or upland, replacing the earlier classification scheme of mountain, valley, and plain.	Glossary, this manual

2. OVERVIEW OF ISC

The ISC is an integrated suite of indicators that measure overall condition of streams in rural Victoria. The ISC is made up of assessments of each of the following 5 components of stream condition:

1. hydrology;
2. physical form;
3. streamside zone;
4. water quality; and
5. aquatic life.

The assessments are made by measuring certain key **indicators** within each of these categories. The indicators are combined to form **sub-index** scores that are further aggregated to determine the overall ISC score (see figure 2.1). The primary output from an ISC application is a bar chart summarising stream condition for stream reaches typically between 10 and 30 kilometres in length (see figure 2.2).

Objectives of the ISC are to:

- benchmark stream condition;
- aid objective setting by CMAs;
- judge the effectiveness of management intervention, in the long-term, in rehabilitating stream condition;
- provide feedback to CMAs as part of an adaptive management process; and
- indicate long-term strategic performance by CMAs.

To meet these objectives, a list of desirable features was identified during the early stages of the project. These included the need to measure the key components of stream condition, to make use of the best available scientific information and to ensure that application of the ISC was cost effective (see table 2.1). These requirements guided the selection of indicators and the determination of rating tables.

2.1 Indicators

There are 19 indicators in the ISC that are used to quantify aspects of stream condition. Related indicators make up each sub-index i.e. Hydrology, Physical Form, Streamside Zone, Water Quality and Aquatic Life (table 2.2). For each sub-index, the indicator selection process is discussed in the following chapters. The indicators determine the actual measurements that are required and these measurements are the basis of the indicator ratings.

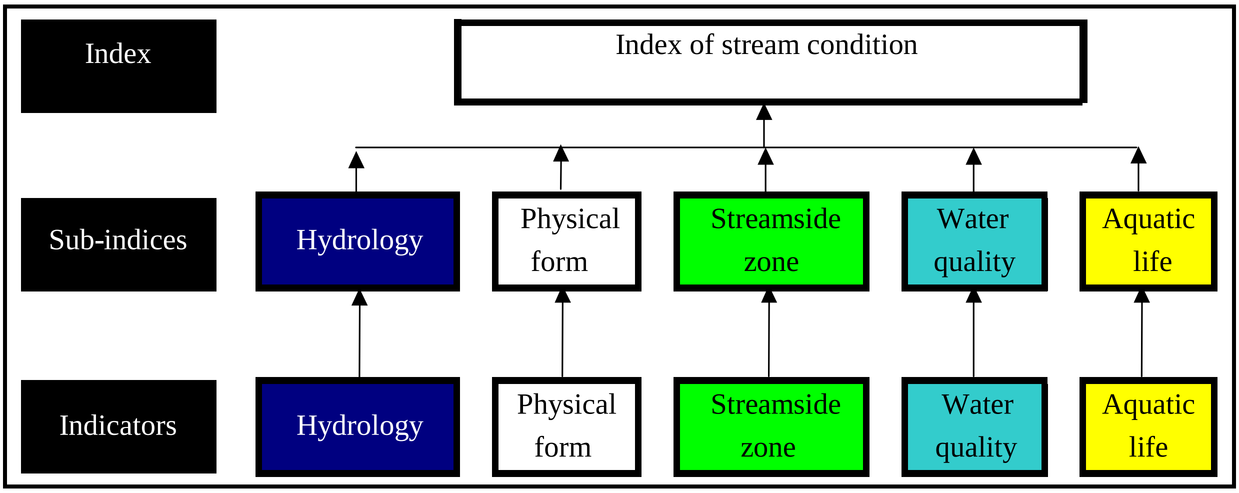


Figure 2.1 - Structure of the ISC

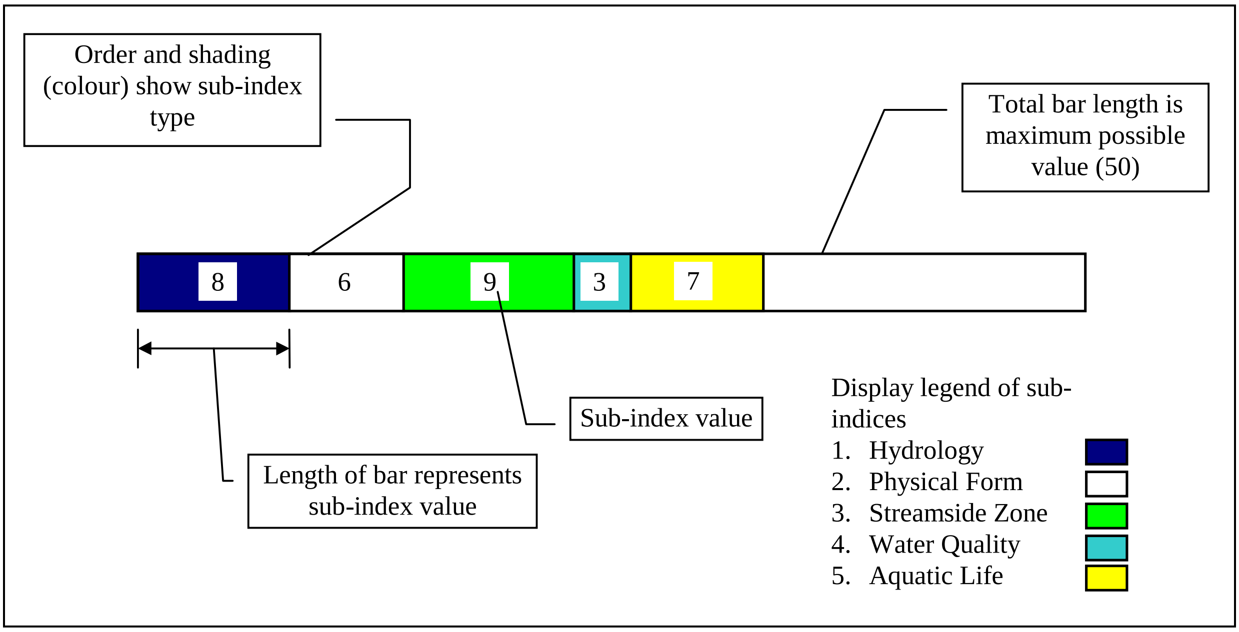


Figure 2.2 - Reporting the ISC

Table 2.1 - Desirable features when developing the ISC

Desirable features	Discussion
Indicators are key components of stream condition	Key components of stream condition include: ▪ hydrology: e.g. the amount of flow in the stream channel at different times of the year, flood frequency and magnitude; ▪ physical form: e.g. the amount of bed and bank erosion, channel width, depth, slope, fish habitat, structural barriers to fish migration; ▪ streamside zone: e.g. quality and quantity of fringing vegetation and wetlands; ▪ water quality: e.g. the amount of nutrients, cloudiness and salinity in water; and ▪ aquatic life: e.g. number and type of plants and animals present in the stream.
Methodology is founded in science	Scientists were involved in the development of the ISC. Ideas were incorporated from a number of disciplines including fluvial geomorphology, freshwater ecology, hydrology, botany and statistics.
Results are accessible to managers	The ISC was developed to be as transparent as possible. The manuals were written so that catchment managers could find any required information on the ISC rapidly. Stream managers commonly use most terms in the manuals.
Data collection methods are objective and repeatable	A quality assurance and control plan was developed to ensure measurements of consistent quality (see *Users' Manual*). To assist with repeatability, clear descriptions on how to collect data, reference schematics and photographs, were developed (see *Field Manual*).
Natural variability is considered	Many existing approaches fail to address spatial and temporal variability in water quality, streamside vegetation and geomorphology. The ISC incorporates procedures to cope with this variability. In the future, further regionalisation of indicators may be included in the ISC.
Application is cost effective	To limit cost, the SRG were realistic about data requirements, and the skills needed to collect the data. Only key indicators are measured. Where practical, data collected under existing programs are used.
Indicators are sensitive to management intervention	Indicators and methods for evaluation were selected that are sensitive to management intervention.

Table 2.2 - List of indicators in the ISC

Sub-index	Indicators within sub-index
Hydrology	Amended Annual Proportional Flow Deviation
	Daily flow variation due to change of catchment permeability
	Daily flow variation due to peaking hydroelectricity stations
Physical Form	Bank stability
	Bed stability
	Impact of artificial barriers on fish migration
	Instream physical habitat
Streamside Zone	Width of streamside zone
	Longitudinal continuity
	Structural intactness
	Cover of exotic vegetation
	Regeneration of indigenous woody vegetation
	Billabong condition
Water Quality	Total phosphorus
	Turbidity
	Electrical conductivity
	Alkalinity / acidity
Aquatic Life	SIGNAL
	AUSRIVAS

2.1.1 How the indicators are converted to dimensionless 'ratings'

For each indicator, once data have been collected they are used to determine a dimensionless rating that is a measure of the indicator's closeness to a reference state (table 2.3). Choosing a rating system is a balance between providing as much resolution as possible while recognising that precision is costly and there is limited knowledge about the relationship between a change in the indicator and environmental effects. It is probably unrealistic to use more than a 5 point rating given the current state of knowledge for **most** indicators. For some indicators, where rapid assessment was difficult, it was only possible to define a 2 point rating scale.

Indicator ratings are based on the difference between the current condition of a stream and a defined reference condition. The reference condition, where possible, was a stream in its natural state at the time of European settlement or if this was impossible to define, some other set of reference conditions was identified by the SRG. For example, the rating table for one of the water quality indicators, pH prescribes lower ratings as the pH value gets further from the ideal range of 6.5 to 7.5 (table 2.4). There is a rating table for each ISC indicator, and these are given in chapters 3 - 7.

Table 2.3 - 5 point rating system used for most indicators

Category	Rating
Very close to reference state	4
Minor modification from reference state	3
Moderate modification from reference state	2
Major modification from reference state	1
Extreme modification from reference state	0

Table 2.4 - Example of a rating table (see chapter 6 for discussion)

pH range	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

2.2 Sub-indices

The relationship between indicator rating, sub-index score and the ISC scores are shown in figure 2.1. Sub-index scores are based on the ratings for their component indicators (table 2.2). The ratings are summed and then scaled so that the sub-index value lies between 0 and 10. For example, there are 4 indicators in the Physical Form Sub-index (table 2.2). Following data collection, ratings are calculated for each of these indicators. The ratings are then combined using a formula to calculate a Physical Form Sub-index score. Further detail on the Physical Form Sub-index is given in chapter 5.

2.3 Overall ISC score

Adding the scores of each of the sub-indices and reporting in the form of a bar chart (figure 2.2) produces the overall score of the ISC. Different weighting schemes for each sub-index were discussed by the SRG but it was decided there was insufficient information to choose anything other than equal weighting. Therefore, the overall score of the ISC will be between 0 and 50 and can be used to classify stream condition from excellent to very poor (table 2.5).

Table 2.5 - Overall ISC classification scheme

Overall ISC score	Stream condition
45 - 50	Excellent
35 - 44	Good
25 - 34	Marginal
15 - 24	Poor
<14	Very poor

If it is not possible to calculate all sub-indices, (e.g. no macroinvertebrate data is available) the overall ISC rating is calculated using those sub-indices that can be assessed compared to the maximum possible score for those indicators. For example, the ratings for four sub-indices sum to 24 and the fifth sub-index can not be assessed, then an ISC score of 30 (i.e. $24 \times 5/4$) would be used, producing an overall rating of 'marginal' (see table 2.5).

Users of the ISC results should note that valuable information is provided by the individual sub-index scores, and in all cases these scores should be considered in addition to the overall score. In some cases, indicator ratings should also be examined.

2.4 Selecting stream reaches for the ISC

The ISC provides an assessment for stream reaches typically between 10 km and 30 km in length. These reaches are chosen so that they are reasonably homogeneous in terms of the 5 components of stream condition so that boundaries between reaches will be commonly based on significant changes to:

- hydrology (e.g. dams, confluences of similarly sized streams, significant diversions);
- physical form (e.g. the presence of a head cut at upstream end of an incising reach, or the presence of an artificial barrier);
- streamside vegetation (e.g. significant change in topography or land use adjacent to the stream); and
- water quality or aquatic life (e.g. the presence of point sources of pollutants, towns or drainage outfalls).

Further details on reach selection are in the *Users' Manual.*

For the 1999 application of the ISC, 937 reaches have been selected in 29 basins (table 2.6).

Once reaches have been selected, data must be accessed for each indicator. Some of this data will originate from existing sources, others will need to be assessed in the field. Field data in modified reaches is collected at 3 randomly selected accessible measuring sites within a reach (see appendix 3). Other data (e.g. water quality and macroinvertebrate data) may be obtained at other locations within the reach (preferably close to the downstream end so that the condition of the reach impacts upon the score).

For unmodified reaches, ISC information is required at one measuring site. If, for a particular reach, information has been collected by the EPA as part of the Monitoring River Health Initiative (MRHI) or the First National Assessment of River Health (FNARH) then this is used. If no existing information is available then data are collected in the field.

Table 2.6 - Reaches selected for the 1999 application of the ISC

Basin	Number of ISC reaches in 1999 application
Upper Murray	44
Kiewa	19
Ovens	47
Broken	35
Goulburn	75
Campaspe	24
Loddon	47
Avoca	20
Mallee	16
Wimmera	56
East Gippsland	37
Snowy	35
Tambo	22
Mitchell	30
Thomson	31
Latrobe	30
South Gippsland	42
Bunyip	32
Yarra	27
Maribyrnong	15
Werribee	26
Moorabool	22
Barwon	30
Corangamite	20
Otway	37
Hopkins	43
Portland	18
Glenelg	51
Millicent coast	6
Total	**937**

2.5 Scope and limitations of the ISC

The scope and limitations of the ISC are briefly discussed in box 2.1. The importance of these limitations may vary between catchments and through time. Catchment managers will need to consider the implications at a regional scale.

The ISC is intended to detect **long-term** changes in environmental condition for rural stream reaches typically **tens of kilometres** in length. It will be reported approximately every 5 years unless there is a major event (e.g. severe flood or fire) that results in previous ISC results being inconsistent with current stream condition. The ISC has not been developed specifically to assess the short-term changes from catchment management, nor to measure variations in stream condition at a specific site (see appendix 2 of the *Catchment Managers' Manual*). The ISC will not fulfil all information requirements of CMAs so other indicators will usually be required. A discussion on the difference between annual performance measures and the ISC is provided in the *Catchment Managers' Manual.*

Box 2.1 - Important considerations when using the ISC in strategic waterway management

Issues to do with the scope of the ISC

- The ISC has been developed to detect changes in the environmental condition of stream reaches typically 10 - 30 km long over a time period of approximately 5 years. The ISC may not be sensitive enough, or may be overly sensitive, for considerably longer or shorter reaches or for shorter time periods. Other indicators will generally be required to assess the local effectiveness of works in the short-term.
- The focus of the ISC is on major **Victoria-wide** environmental values - other environmental issues may be important locally for some reaches (e.g. water temperature, pesticide concentrations, acidic drainage). Other local indicators may be required to complement the ISC outputs.
- The focus of the ISC is on **environmental** values of waterways. Catchment managers may have other objectives for developing holistic waterway management programs (e.g. recreational access, flood management, protection of some key streamside assets from erosion). Catchment managers may select indicators to measure performance relative to these other objectives.
- The ISC provides base information - it does not prioritise waterway management projects although ISC outputs can be used as input into a prioritisation process.
- The ISC was primarily developed for rural streams: it may be necessary to modify the ISC if it is to be applied for urban streams.
- Care should be taken when extrapolating outputs - for example when comparing ISC outputs for streams in different catchments - or comparing streams of different geometry or character.

Issues to do with the use of indices in general

Like other indices (e.g. Consumer Price Index), or statistics (e.g. the unemployment rate), without a sufficient understanding of the ISC, the outputs can be interpreted in a number of ways by a range of stakeholders, and possibly misused.

Cost issues

- Care has been taken to achieve a satisfactory and useful quality of outputs from an ISC application whilst constraining the overall cost. To ensure satisfactory outputs, an ISC quality assurance and control plan is being implemented (see the *Users' Manual*).
- The different means by which to increase a sub-index score by a point will generally not be equal in cost. For example, to increase the Physical Form Sub-index, construction of a fishway over an artificial barrier may cost (say) $200 000 per ISC point, whereas rock bank stabilisation works may cost (say) millions per point.
- The cost of increasing each of the 5 **different** sub-indices by a point will typically not be the same. For example, the cost of increasing the Hydrology Sub-index by one (by, say, purchasing some diversion licences to return water to the environment) will typically be different to the cost of increasing the Physical Form Sub-index by one point (by, say, returning large woody debris to a reach).

3. HYDROLOGY SUB-INDEX

3.1 Statewide issues relating to hydrology

Human influences have altered the hydrology of streams in Victoria. Quantity and timing of flow has been affected by:

- dams (Phan 1994);
- diversions (White and Brander 1989);
- hydroelectric stations; and
- changes in catchment land use including urbanisation (Codner *et al.* 1988; Cordery 1976; Potter 1991).

Changes in hydrology include, but are not limited to, altered:

- flood frequency and magnitude;
- flow seasonality;
- frequency of overbank flooding;
- occurrence of low flows; and
- changes in flow peakedness.

Where there is a major change to hydrology, such as where a stream is influenced by a large dam with flow harvesting and irrigation releases, there can be changes across the whole spectrum of flows. Some flow changes will have a greater effect on stream condition than others (White and Brander 1989; Hall 1989).

The influence of changes in hydrology on stream ecology is summarised by Petts (1980), Nilsson and Dynesius (1994), Cullen (1994), Poff *et al.* (1997) and Richter *et al*. (1997) and include impacts on:

- wetlands and floodplains;
- channel morphology and substrate;
- fish populations;
- invertebrates;
- algae;
- riparian vegetation;
- water quality; and
- submerged and emergent aquatic macrophytes.

3.2 Existing approaches - possible indicators

A variety of indicators have been proposed that measure different aspects of stream hydrology and hydraulics, including magnitude and variability of high and low flows, floods, and daily, monthly and annual flows (details of some 90 hydrologic indicators are summarised in appendix 4). Several of these indicators are intended to assess biologically significant facets of a stream's flow regime (Puckeridge *et al.* 1998).

There appears to be little consensus as to the most biologically appropriate hydrologic indicators and there has been limited empirical evaluation of these indicators especially under Australian conditions. Most of the hydrologic indicators in appendix 4 are too detailed for the ISC. At present, appropriate goals for the Hydrology Sub-index are to identify streams with significant hydrologic change and to indicate where detailed investigations should be considered. A straightforward indicator is appropriate, more complex indicators could be used subsequently, as part of detailed investigations.

Work is being undertaken by the Cooperative Research Centre for Freshwater Ecology (CRCFE) to test a range of variables for identifying ecological differences between streams in south-eastern Australia and the Murray-Darling Basin. Trial indicators are drawn mainly from Puckeridge *et al.* (1998) and Richter *et al.* (1997) and results of this research may guide future refinement of the ISC.

3.3 Indicator Selection

The Hydrology Sub-index is intended to measure the change in flow from reference conditions based on a 'natural stream'. As noted above many hydrologic indicators have been proposed. Hydrologic indicators were sought that would:

- flag streams throughout Victoria that have major flow alterations;
- show whether total diversions from streams are increasing;
- show those streams that may require more detailed assessment of hydrology; and
- indicate trends over broad time scales.

Following a review of possible indicators and consultation with the SRG, it was decided that the Hydrology Sub-index should primarily be based on an indicator that could be calculated from monthly flows. At the level of detail required for the ISC, there seemed little justification for choosing indicators based on daily flows, as data was unlikely to be widely available. Indicators based on annual flows were considered but they were not sensitive to changes in flow seasonality, which is an important impact of flow regulation in Victoria.

A limitation of using monthly flows is that some changes, such as those to extreme low flows or floods, will not be detected. If such changes are suspected to be important then they should be included in a detailed hydrologic study separate to the ISC.

The Amended Annual Proportional Flow Deviation (AAPFD) was selected as the primary indicator in the Hydrology Sub-index. The AAPFD is based on a comparison of actual and natural monthly flows as explained below. There is also a need for other indicators as the AAPFD will not be capable of detecting all significant flow changes. There will be situations where flow data are not available or where changed flow conditions that are not reflected in monthly data.

Two additional indicators are included in the Hydrology Sub-index:

- Daily flow variation due to a change of catchment permeability; and
- Daily flow variation due to peaking hydroelectric stations.

These indicators are relatively coarse, and have a low weighting in the calculation of the Hydrology Sub-index score. Their inclusion in the ISC is a reminder to catchment managers of other factors that can cause changes to flow and hence alter environmental condition of streams.

3.3.1 Amended Annual Proportional Flow Deviation

Initally, three monthly flow indicators were examined in detail as part of the development of the ISC (table 3.1)

- Hydrologic Deviation (HD) (CEAH and ID&A Pty Ltd 1997);
- Ratio Flow Deviation (RFD) (A. Ladson, pers. comm.); and
- Annual Proportional Flow Deviation (APFD) (Gehrke *et al.* 1995).

Following a preliminary review of these indicators (see appendix 4), the preferred indicator was the APFD. This was because, in addition to being sufficiently sensitive to significant changes to flow, it has an ecological basis, as Gehrke *et al.* (1995) had found that the APFD was correlated with fish species diversity in 4 regulated rivers in the New South Wales portion of the Murray-Darling Basin. Greater flow modification, as reflected by higher values of the indicator, was associated with reduced diversity of fish species. However, the APFD was found computationally unstable when the natural flow for a month approached zero, which is an issue for ephemeral streams particularly in northern and western Victoria.

Table 3.1 - Hydrology indicators based on monthly flows (assuming 5 years of data are used)

Name	Verbal definition	Mathematical definition	Comments
Hydrologic Deviation, *HD*	Sum of the absolute differences between actual and natural monthly flows, divided by the annual flow and expressed as a percentage.	$HD = \frac{1}{5}\sum_{j=1}^{5}\left(\frac{\sum_{i=1}^{12}\left\|c_{ij} - n_{ij}\right\|}{\sum_{i=1}^{12} n_{ij}}\right)\times 100\%$ where ▪ c_{ij} is the actual flow for month *i* of year *j*; and ▪ n_{ij} is the natural flow for month *i* of year *j*.	This indicator was used during the early stages of the development of the ISC (e.g. CEAH and ID&A Pty Ltd 1997)
Ratio Flow Deviation (RFD)	Sum of the ratios of actual and natural flows.	$RFD = \frac{1}{5}\sum_{j=1}^{5}\left[\left(\frac{1}{12}\sum_{i=1}^{12} r_{ij}\right) - 1\right]$ where r_{ij} is the ratio of the differences between the actual flow and the natural flow adjusted to be always greater than one. $r_{ij} = \frac{c_{ji}}{n_{ij}}$ if $c_{ij} \geq n_{ij}$ and $r_{ij} = \frac{n_{ij}}{c_{ij}}$ if $n_{ij} \geq c_{ij}$ where ▪ c_{ij} is the actual flow for month *i* of year *j*; and ▪ n_{ij} is the natural flow for month *i* of year *j*.	RFD will range between 0 for an unaltered flow regime to +∞ where natural or actual flow is zero. This indicator is equally sensitive to changes in high and low flows. Not easy to deal with mathematically if actual or natural flows are zero.

Table 3.1 - Hydrologic indicators based on monthly flows (continued) (assuming 5 years of data are used)

Name	Verbal definition	Mathematical definition	Comments
Annual Proportional Flow Deviation (APFD)	Sum of the ratios of change in monthly flow (actual - natural) to natural monthly flow	$$APFD = \frac{1}{5}\sum_{j=1}^{5}\left(\sum_{i=1}^{12}\left(\frac{(c_{ij}-n_{ij})}{n_{ij}}\right)^{2}\right)^{\frac{1}{2}}$$ where ▪ c_{ij} is the actual flow for month *i* of year *j*; and ▪ n_{ij} is the natural flow for month *i* of year *j*.	APFD will range from zero for an unregulated river to 3.46 where there is a 100% increase or decrease in flow and is also responsive to seasonal changes. Gehrke *et al.* (1995) found that this indicator was related to diversity of fish species in regulated rivers of the Murray-Darling Basin. May not be a suitable indicator where natural monthly flows are zero.
The amended APFD was proposed by Gehrke (pers comm.) in 1996 to overcome the problem with the APFD that when the modelled natural flow for a month was zero the APFD could not be calculated.	Sum of the ratio of change in flow (actual - natural) to average monthly flow.	$$AAAPFD = \frac{1}{5}\sum_{j=1}^{5}\left(\sum_{i=1}^{12}\left(\frac{(c_{ij}-n_{ij})}{\overline{n}_{j}}\right)^{2}\right)^{\frac{1}{2}}$$ where: ▪ c_{ij} is the actual flow for month *i* of year *j*; ▪ n_{ij} is the natural flow for month *i* of year *j*; and ▪ $\overline{n}_{j}$ is the average monthly flow for year *j*, i.e. $$\overline{n}_{j} = \frac{1}{12}\sum_{i=1}^{12} n_{ij}$$	The greater the AAPFD value, the more modified the flow regime is relative to natural conditions. P. Gehrke (pers. comm.) recommends this indicator as an improvement over the APFD described above.

To overcome this issue, the APFD was modified by using the average monthly flow as the denominator rather than the monthly flow (see table 3.1). This indicator is the Amended Annual Proportional Flow Deviation (AAPFD) (P. Gehrke, pers. comm.).

A comparison of the AAPFD with the other 3 indicators using data from rivers with a range of levels of regulation is provided in appendix 4.

3.3.2 Flow variation due to a change of catchment permeability

The selection of an indicator based on the change to catchment permeability followed a review of the influence of land use change on hydrology. Possible indicators of flow variation because of land use change include:

- presence and size of farm dams;
- changed runoff characteristics because of forestry and agriculture; and
- impacts of urbanisation.

Presence and size of farm dams

The influence of farm dams on hydrology is an emerging issue. Consideration was given to including an indicator of the impact of farm dams in the Hydrology Sub-index. There are several research projects on hydrologic influence of farm dams underway at present.

In South Australia it has been found that the influence of farm dams is usually small in normal or wet years but a large proportion of total runoff can be stored under dry conditions, which can reduce stream flow and affect downstream users and stream ecology (Good and McMurray 1997). In NSW, concerns prompted the Government to legislate to limit the amount of water that farmers can harvest to a maximum of 10% of the average run-off from their properties. This replaced an earlier rule that set an upper limit of 7ML (*Land and Water News* 1998).

In Victoria, NRE has commissioned an investigation of this issue in the Wimmera basin. Preliminary results show that farm dams can influence yield and low flow conditions, but it is necessary to use process modelling to isolate the effects rather than just analysing flow data (R. Nathan pers. comm.). Two earlier studies also highlighted possible influences of farm dams without quantifying their effects or suggesting indicators (Good and McMurray 1997; GHD 1987).

It was decided by the SRG that farm dams be excluded from the ISC at this stage. Once research results are available it may be possible to develop a suitable indicator.

Change of runoff characteristics because of forestry and agriculture

Activities associated with forestry and agriculture can change hydrology. For example, water yields can be decreased following logging or fires (Kuczera 1987) and flood peaks can be reduced through soil conservation works (Potter 1991). It is also thought that compaction following grazing, changes to vegetation type, and cultivation can influence runoff.

The ISC does not include indicators of these impacts at this time. Most of these impacts are difficult to quantify and there is limited published information. Those that have been well studied such as the influence of fire on water yield, are local rather than statewide issues. It will be possible to include other indicators in the ISC in the future if necessary.

Change of flow because of urbanisation

Urbanisation has a number of effects on hydrology. A review by Mein and Goyen (1988) found that:

- the presence of urban areas can increase rainfall depths and frequency of thunderstorms by up to 15%;
- peak discharge can be increased by a factor of up to 20 for small events;
- catchment lag is reduced so that peak runoff occurs more quickly following rainfall; and
- catchment yield can be increased by a factor of about 2.

There are also important influences on stream ecology. A recent study by Walsh and Breen (1999) found that macroinvertebrate communities in urban streams were impoverished if greater than 12% of the catchment was impervious.

Clearly, these effects are important but only a simple indicator is warranted as the ISC is intended for streams outside major urban areas where artificial increases in impermeable area will be uncommon. The indicator selected is called the 'Daily flow variation due to changed catchment permeability'. The effect of this indicator is that 1 is subtracted from the Hydrology Sub-index score for a reach if more than 12% of the catchment area has been artificially altered to be impervious.

3.3.3 Flow variation due to peaking hydroelectric stations

Hydroelectric stations operated to supply peak demand do not change flow volume or flow seasonality but they do create water surges on a daily basis. These surges change stream hydrology and can have a significant influence on stream ecology (Cushman 1985). These peaking hydroelectric facilities are found, for example, as part of the Kiewa Hydroelectric Scheme and the Snowy Mountains Scheme. Other types of hydroelectric plants generate power opportunistically when water is released from storage for other purposes. Power stations in this category, that are less likely to influence stream ecology, include those on the Macalister River (at Lake Glenmaggie) and on the King River (at Lake William Hovell) (table 3.2).

Because of the influence of peaking hydroelectric facilities on stream flows an indicator related to their presence has been included in the Hydrology Sub-index. This indicator is called the 'Daily flow variation due to peaking hydroelectricity generation'. The effect of this indicator is that 1 is subtracted from the Hydrology Sub-index score for a reach if there is a peaking hydroelectric station at the upstream end.

3.4 Rating of indicators in the Hydrology Sub-index

3.4.1 AAPFD

A rating table for the AAPFD indicator is given in table 3.3. This rating table is based on values of the AAPFD calculated for some Victorian and NSW streams (see table 3.4 and appendix 4).

The number of categories in the rating table was increased to 11 compared to 5 in the previous version of the ISC (CEAH and ID&A Pty Ltd 1997) so that the indicator is more sensitive to change in flow regime.

Table 3.2 - Hydroelectric stations on Victorian streams (from Crabb 1997)

Hydroelectric facility	Stream	Location	Type[1]
Dartmouth	Mitta Mitta River	Dartmouth Dam	O
Eildon	Goulburn River	Eildon	O
McKay Ck	Kiewa River	Mount Beauty	P
West Kiewa	Kiewa River	Mount Beauty	P
Clover	Kiewa River	Mount Beauty	P
Lower Rubicon	Rubicon River	Rubicon	P
Rubicon	Rubicon River	Rubicon	P
Eildon pondage	Goulburn River	Eildon	O
Lake Glenmaggie	Macalister River	Lake Glenmaggie	O
Cardinia Reservoir	Cardinia Creek	Emerald	O
Lake Eppalock	Campaspe River	Heathcote	O
Cairn Curran	Loddon River	Cairn Curran	O
Lake William Hovell	King River	Cheshunt	O
Royston	Rubicon River	Rubicon	P
Rubicon Falls	Rubicon River	Rubicon	P

1 - O - Opportunistic, P - Peaking

Table 3.3 - Ratings for the AAPFD indicator

AAPFD	Rating
< 0.1	10
0.1 - 0.2	9
> 0.2 - 0.3	8
> 0.3 - 0.5	7
> 0.5 - 1.0	6
> 1 - 1.5	5
> 1.5 - 2	4
> 2 - 3	3
> 3 - 4	2
> 4 - 5	1
> 5	0

Table 3.4 - Summary of results for the AAPFD

Stream	Station	AAPFD	Rating
Gellibrand River	North Otway Pipeline 1987/88	0.24	8
Buffalo River	Lake Buffalo	0.30	8
Gellibrand River	South Otway Pipeline 1987/88	0.31	7
Gellibrand River	North Otway Pipeline 1967/68	0.34	7
Gellibrand River	South Otway Pipeline 1967/68	0.48	7
Loddon River	Laanecoorie	1.3	5
Macalister River	Lake Glenmaggie	1.4	5
Moorabool River	Bungal	1.6	4
Jackson Creek	Rosslynne	2.1	3
Tarago River	Tarago Reservoir	2.3	3
River Murray	Euston	2.5	3
River Murray	Yarrawonga	2.7	3
River Murray	Flow at SA border	2.7	3
River Murray	Barrages	3.0	3
Darling River	Burtundy	3.1	2
Loddon River	Cairn Curran	3.2	2
Edward River	Deniliquin	3.6	2
Goulburn River	Eildon	3.9	2
River Murray	Doctors Point (near Albury)	4.0	2
Mitta Mitta River	Dartmouth	4.0	2
Campaspe River	Lake Eppalock	5.0	1

3.4.2 Flow variation due to change of catchment permeability

The indicator, ‘Daily flow variation due to changed catchment permeability’, is rated as follows:

- if greater than 12% of the catchment area of a reach has been artificially altered to be impervious, then the ‘Daily flow variation due to change of catchment permeability’ indicator will equal 1; or
- otherwise, this indicator equals 0.

3.4.3 Flow variation due to peaking hydroelectric stations

This indicator, ‘Daily flow variation due to peaking hydroelectricity generation’, is rated as follows:

- if there are peaking hydroelectric stations at the upstream end of the reach, this indicator equals 1;
- otherwise, this indicator equals 0.

3.5 Calculating the Hydrology Sub-index from indicator ratings

As discussed in the preceding sections, assessment of 3 indicators is required to evaluate the Hydrology Sub-index for a reach:

- Amended Annual Proportional Flow Deviation;
- Daily flow variation due to change of catchment permeability; and
- Daily flow variation due to peaking hydroelectricity generation.

For the Hydrology Sub-index, all measurements are made at the reach scale. The Hydrology Sub-index score is calculated using equation 3.1:

$$H_r = AAPFD_r - PERM_r - PHE_r \qquad (3.1)$$

where, for each indicator, the symbol and range is given in table 3.6. The subscript *r* denotes that the Hydrology Sub-index and each indicator are assessed on a reach basis. The final score is rounded off with no decimal places and the minimum allowable score is zero.

Table 3.5 - Indicators in the Hydrology Sub-index (all indicators are measured at the reach scale)

Indicator	Symbol	Range
Amended Annual Proportional Flow Deviation	$AAPFD_r$	0 - 10
Daily flow variation due to change of catchment permeability	$PERM_r$	0 - 1
Daily flow variation due to peaking hydroelectricity generation	PHE_r	0 - 1

3.5.1 How many years of data should be included in sub-index calculations?

It is expected that the ISC, including the Hydrology Sub-index, be reported every 5 years. There are several realistic scenarios that could change the hydrology over that time including:

- implementation of environmental flow regimes;
- increasing pumped diversions;
- development of off stream storages that can be filled by summer or winter flows; and
- flow changes due to water trading.

The reported Hydrology Sub-index score will usually be the average of at least 5 years of data if available (see table 3.6). If there is a significant change in flow management during that time (e.g. agreement to adopt a 'transparent dam' policy for part of the year) then it may be appropriate to report the sub-index based on data following the change. This is because, in that case, an ISC score using an average over the 5 years may not give a realistic assessment of the actual flow regime. Similarly, if hydrologic data are difficult to obtain for a particular reach then a reasonable trade off between cost and accuracy would be to use data from one year.

Table 3.6 - Number of years of data to use when calculating the AAPFD indicator rating

Data	Major management change in the last 5 years	AAPFD indicator rating based on
Readily available	No	Average score over last five years (or longer if data is available)
Readily available	Yes	Average of years following change
Difficult to obtain	No	Choose any representative year[1]
Difficult to obtain	Yes	Choose a representative year[1] following the change

1 - In this context, a representative year is one when with no floods or droughts with an average recurrence interval of greater than 5 years.

3.6 Obtaining data on actual and natural flows

The Hydrology Sub-index requires data on both actual and natural flows if there is a change to the flow regime. Actual flows can usually be obtained from gauging records. Natural flows represent the flows that would have occurred if the same rainfall that produced the actual flow fell on an unmodified catchment. Calculating natural flows usually requires information on actual flows as well as consideration of irrigation diversions, interbasin transfers, urban offtakes, stock and domestic diversions, change in storage, and return flows.

Usually some type of hydrologic model will be required to produce estimates of natural flows. For unregulated streams this could be a based on gauged flow, then any extractions would be added and artificial inflows deleted, namely:

$$\textit{Natural flow} = \textit{actual flow} + \textit{diversions} - \textit{returns.} \qquad (3.2)$$

For regulated rivers, the situation is more complicated as changes in the amount of water stored in reservoirs is also important and the number, size and complexity of diversions and returns is usually greater. In most cases, a computer model such as REALM will be required to generate natural flows.

Some information on natural flows is available for many streams in Victoria. Hydrologic models have been developed at over 200 sites as part of the granting of bulk entitlements by NRE (Department of Conservation and Natural Resources 1995).

For streams in Victoria north of the Great Dividing Range, models are continuing to be updated annually as part of compliance with the Murray-Darling Basin Commission's cap on diversions. Sinclair Knight Merz Pty Ltd is undertaking most of this work using flow data from Thiess Environmental Services Pty Ltd and diversion information from rural and urban water authorities. Audit figures are produced each year in July or August usually for one site in each of the major rivers. These figures could provide information to calculate the ISC Hydrology Sub-index score. Flow information could be produced at other locations but would be an additional project.

For streams south of the Great Dividing Range, most modelling has been for the 15 years prior to 1990 to establish water allocations. These models have generally not been kept current and some additional work would be required to produce results for the ISC.

Most work, so far, has been on regulated rivers but NRE is now moving to develop streamflow management plans for many unregulated streams throughout Victoria that are affected by diversions.

It is likely that hydrologic models will be available for most streams within the next 4 years and could be used to provide data for future applications of the ISC. It is a requirement of Streamflow Management Plans and bulk entitlement licenses that authorities report on water use to show they are meeting specified conditions. Reporting requirements including 'Basin accounts' are being reviewed and it is possible these could provide information in the future that would be useful for stream assessment using the ISC.

3.6.1 Hydrologic information for the 1999 application of the ISC

For the 1999 application of the ISC, Hydrology Sub-index scores were calculated by NRE by estimating the components of a water balance; that is, actual flow, diversions and returns and then calculating natural flows using equation 3.2. These actual and natural flows where then used to calculate the AAPFD, a rating was obtained from table 3.3, the other indicators were evaluated and the sub-index score calculated using equation 3.1.

The first step was to estimate actual flows. Where gauging information was available for a reach, monthly flows where obtained from the Victorian Surface Water Assessment Network. For reaches without gauging stations, actual flows were estimated using a linear mass-balance approach by calculating catchment yield per unit area at gauging sites that were available and then assuming that this yield applied across the whole catchment. Catchment areas were estimated directly from maps.

To complete the mass-balance, information on diversions was required. Four types of diversions were considered; irrigation diversions, stock and domestic abstractions, commercial diversions and extractions for urban water supplies.

For irrigation diversions, the only information available was in the form of an annual total licensed volume, which was converted to monthly volumes using information on typical demands for irrigation water. There was a much smaller volume of water associated with stock and domestic supplies and again only annual licence totals were available. The monthly demand for stock and domestic water would differ from that for irrigation but sensitivity analysis showed it was not necessary to consider these diversions separately and the same demand curve was used in both cases. Where possible, large commercial diversions were separated and annual licence quantities were converted to monthly totals by assuming a constant demand.

It should be noted that the annual licensed volume is a maximum amount of water that can be extracted and, in most years, the total diverted is less than this volume. By using information from these licences, the Hydrology Sub-index rating will be consistently conservative. Sensitivity analysis showed that reducing the volume extracted to 50% of the licensed volume only changed the ratings for a small number of streams.

For bulk diversions of water from streams to non-metropolitan urban authorities, the information available was the actual annual volume of water extracted. Typical monthly demand information was calculated from several townships throughout Victoria and this was used to apportion monthly diversion volumes.

In summary, it is likely that most of the data needs for the Hydrology Sub-index during the 1999 statewide application will be met through extending the work that is already being undertaken by NRE. If there are data gaps, it may be necessary to fill them using guidelines from the *Users' Manual.*

3.7 Overview of procedure to evaluate the Hydrology Sub-index

The procedure for calculating the Hydrology Sub-index is shown in figure 3.1. If possible, the Hydrology Sub-index is to be calculated for a point near the downstream end of each reach and the value at this point is taken to represent the whole reach. More detail is provided in the *Users' Manual*.

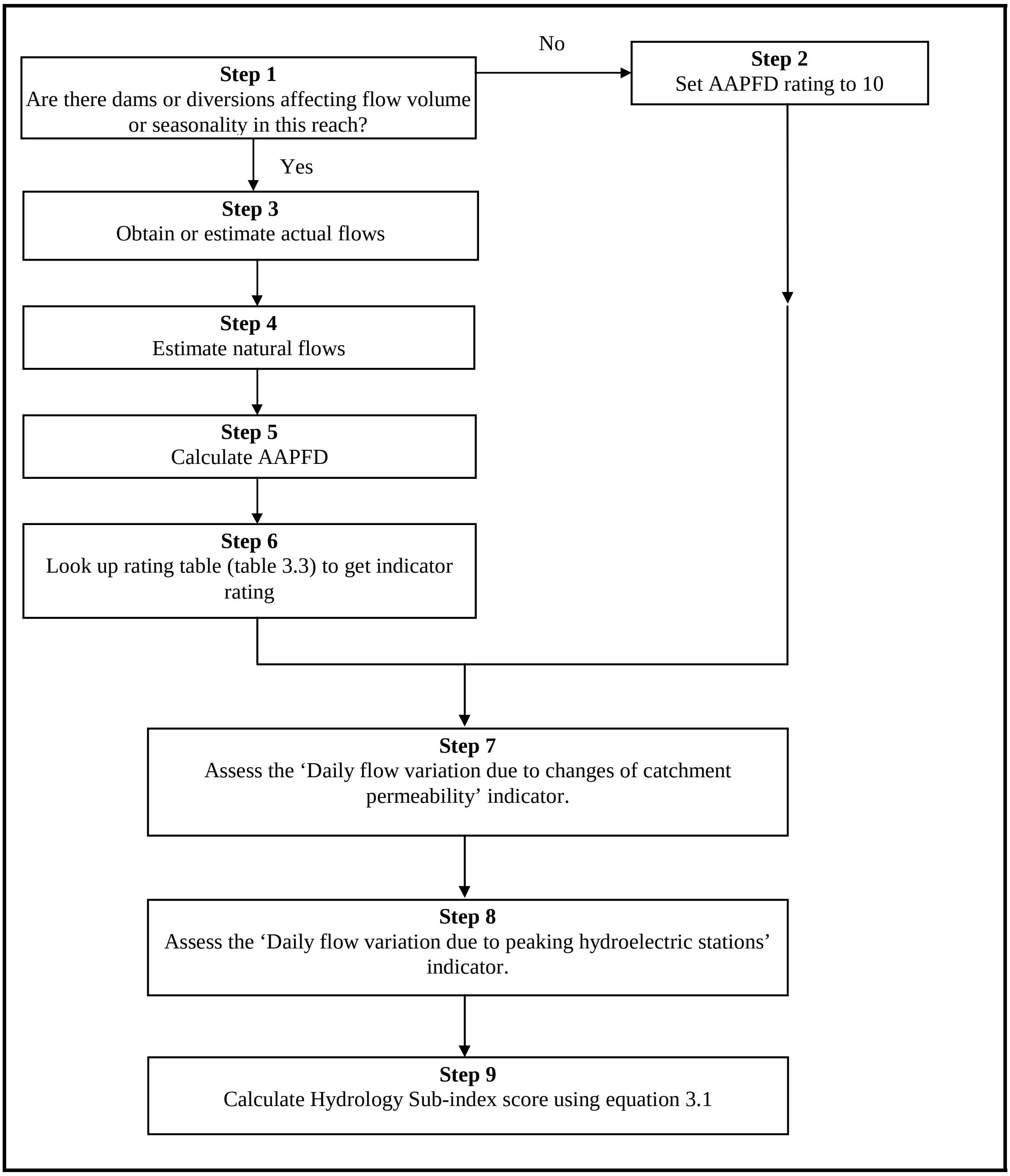


Figure 3.1 - Procedure for calculating Hydrology Sub-index score

3.8 Example application of the Hydrology Sub-index

The following is an example application of the Hydrology Sub-index to the Macalister River immediately downstream of Lake Glenmaggie (in Gippsland). This section of the river is regulated by the operation of Lake Glenmaggie and diversions into irrigation channels. Monthly actual flows and modelled monthly natural flows are shown in table 3.7 and on figure 3.2. The AAPFD is calculated to be 3.0 using the formula for the AAPFD in table 3.1 adjusted for the fact that only 1 year of data was available (i.e. the value of j is set to 1). Ideally, 5 years of data would be used if it was available. From table 3.3, the rating for the AAPFD indicator is also 3.

As less than 12% of the catchment is impervious, the 'Daily flow variation due to changes of catchment permeability' indicator rating equals 0.

As the hydroelectric station downstream of Lake Glenmaggie is opportunistic rather than peaking, the 'Daily flow variation due to peaking hydroelectric stations' indicator rating equals 0.

From equation 3.1, the Hydrology Sub-index score is 3 - 0 - 0 = 3.

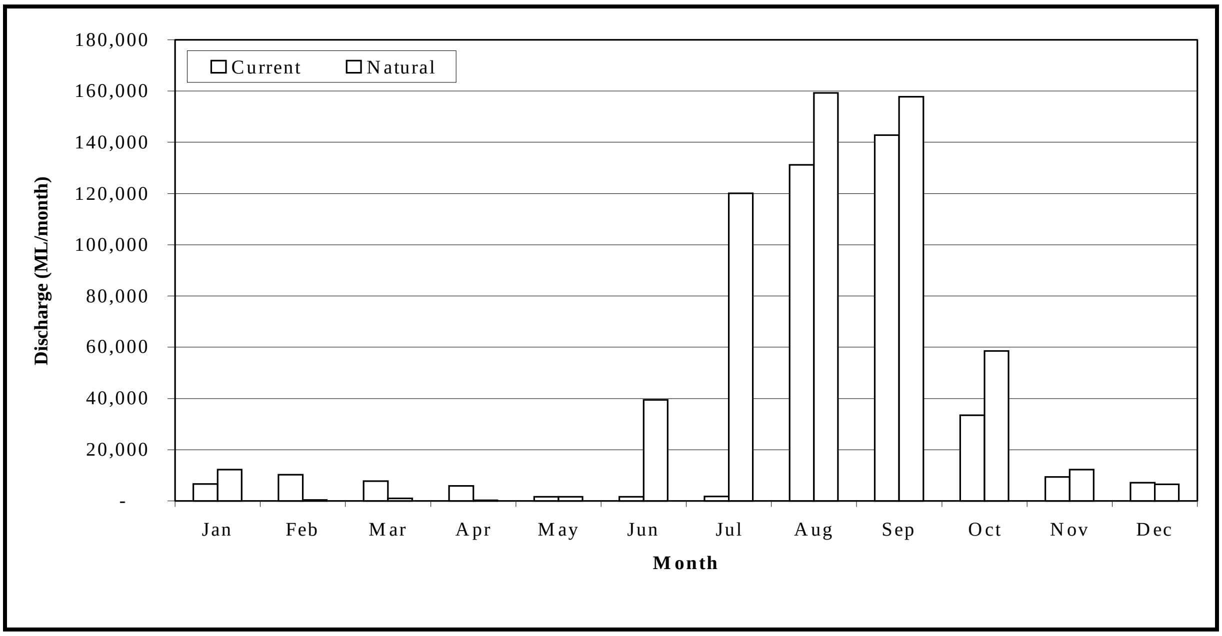


Figure 3.2 - Comparison of actual and natural monthly flows for the Macalister River immediately downstream of Glenmaggie Weir in 1991 (sources: natural flows - NRE, actual flows - Thiess Environmental Services Pty Ltd)

Table 3.7 - Actual and natural flows downstream of Lake Glenmaggie during 1991
(Symbols are defined in table 3.1: data sources, natural flows - NRE, actual flows - Thiess Environmental Services Pty Ltd)

i	**Month**	**Actual Monthly Flow (ML)** c_i	**Natural Monthly Flow (estimated) (ML)**[1] n_i	$c_i - n_i$	$(c_i - n_i)/\bar{n}$	$[(c_i - n_i)/\bar{n}]^2$
1	January	6 595	12 088	-5493	-0.11589	0.013431
2	February	10 218	338	9880	0.208447	0.04345
3	March	7 722	928	6794	0.143339	0.020546
4	April	5 851	167	58684	1.238105	1.532903
5	May	1 650	1 660	-10	-0.00021	4.45E-08
6	June	1 493	39 414	-37921	-0.80005	0.640081
7	July	1 710	120 035	-118325	-2.4964	6.232014
8	August	131 165	159 222	-28057	-0.59194	0.350395
9	September	142 765	157 803	-15038	-0.31727	0.10066
10	October	33 433	58 538	-25105	-0.52966	0.280541
11	November	9 304	12 122	-2818	-0.05945	0.003535
12	December	7 036	6 464	572	0.012068	0.000146
	Total	**358 942**	**568 779**			**9.22**
Average monthly natural flow, $\bar{n}$			**568 779/12 = 47 398**			
Amended Annual Proportional Flow Deviation (AAPFD)						**√9.22 = 3.0**

1 Natural monthly flows were estimated using a REALM model.

4. PHYSICAL FORM SUB-INDEX

4.1 Statewide issues relating to physical form

Describing in detail 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 (presence of barriers).

There was an extensive survey of the physical stream condition across Victoria in 1986 with data being gathered at 868 'representative' measuring sites across the State (Tilleard and Department of Water Resources 1986). The data collected included the size and composition of bed and bar materials, typical dimensions of bars, and origin of bed materials.

Some of this data was used by Mitchell (1990) to assess the environmental condition of Victoria's streams; that is, the condition of the stream as habitat for fish and aquatic invertebrates. This study highlighted a number of statewide issues relating to physical form. There was extensive occurrence of bed aggradation and degradation and bank erosion. Mitchell (1990) found that some basins in the west of the State had less than 10% of stream length in good or excellent condition.

Other Victoria-wide physical form issues include:

- the removal of large woody debris from many of Victoria's lowland streams;
- extensive construction of artificial barriers that interfere with fish migration and interrupt sediment transport; and
- widening, straightening, and channelisation of many streams and the building of levee banks along streams.

4.2 Existing approaches - possible indicators

Possible indicators for the Physical Form Sub-index are summarised in table 4.1. Comments are provided as to the suitability of the indicators for the ISC (section 2.1).

Table 4.1 - Possible indicators for the Physical Form Sub-index

Possible Indicator	Comment	Suitable for the ISC?
Channel alteration (Plafkin *et al*. 1989)	Useful if the ideas of Plafkin *et al*. (1989) are extended to include artificial channel changes such as barriers.	Possible
Bed composition (Rhodes 1994; Petersen 1992; Mitchell 1990; Plafkin *et al*. 1989)	Difficult to apply because there is a great deal of natural variation in bed composition throughout Victoria, even for streams with little disturbance.	No
Sediment infilling gaps in larger bed sediments (Petersen 1992), embeddedness (Plafkin *et al*. 1989)	Similar issue as 'Bed Composition'. There is naturally extensive variation in bed material in Victoria.	No
Number and occurrence of large woody debris (Gippel *et al*. 1996)	Important for instream habitat. Survey methods in the literature are too resource intensive for a statewide assessment. More rapid measurement techniques would need to be developed, which may involve some judgement.	Possible
Influence of sediment on channel structure (Petersen 1992)	Difficult to apply to a statewide assessment because of natural variation.	No
Proportion of pools and riffles (Mitchell 1990; Petersen 1992; Plafkin *et al*. 1989)	Difficult to apply because there is a great deal of natural variation in occurrence of pools and riffles in streams throughout Victoria, even under pristine conditions.	No
The amount of erosion or sedimentation (Mitchell 1990; Plafkin *et al*. 1989; Pfankuch 1975)	Assessment involves some judgement. Aids are required to ensure an acceptable level of repeatability.	Possible
Influence of artificial barriers on fish migration and stream connectivity	Potentially useful indicator. A database of barriers has been developed for Victoria with the objective of identifying barriers that are blocking stream reaches from fish migration. Barriers are known to have a detrimental effect on indigenous freshwater fish (Koehn and O'Connor 1990; Harris and Gehrke 1997). Barriers can also affect sediment movement.	Possible
Bank stability (Ian Drummond and Associates 1985)	Assessment involves some judgement. Aids are required to ensure an acceptable level of repeatability.	Possible
Channel structure: width to depth ratio (Petersen 1992; Pfankuch 1975)	Difficult to define the 'natural' or 'ideal' width to depth ratio for streams in Victoria.	No
Retention devices: log jams, rock barriers etc. (Petersen 1992)	Too much natural variation to be a useful indicator.	No

Table 4.1 - Possible indicators for the Physical Form Sub-index (continued)

Possible Indicator	Comment	Suitable for the ISC?
Stream bank structure, inherent stability (Petersen 1992; Plafkin *et al*. 1989)	Too much natural variation to be a useful indicator.	No
Stony substrate feel and appearance (Petersen 1992)	Too much natural variation in bed material to be useful.	No
Epifaunal habitat / available cover	Indicator of instream physical habitat developed by US EPA, and assessed by the Victorian EPA during recent large scale field data collection programs. Indicator tends to score higher for upland streams than lowland streams as coarse bed sediment is an important factor when assessing indicator.	Possible

4.3 Indicator selection

The ISC assesses the change between the current condition of a stream and a reference condition based on a 'natural' stream i.e. a stream prior to European settlement in Australia. The problem with many of the indicators in table 4.1 is that there is a great deal of variation in stream physical form under natural conditions across Victoria. For example, bed composition varies substantially and presumably would have varied greatly under pre-European conditions. It would clearly be a laborious and probably impossible task to determine **all** aspects of the **natural** physical form of streams and then compare this with the existing physical form. Instead four key indicators were selected and reference conditions defined for use throughout the State. These indicators pick up important changes from natural conditions and the most important aspects of physical form for aquatic habitat. The indicators are:

- bank stability;
- bed stability;
- impact of artificial barriers on fish migration; and
- instream physical habitat.

A measure of channel modification was considered. It is felt that the effects of channel modifications are adequately assessed by measurements of bank and bed stability (namely, infilling and deepening). If channel modifications do not cause bed and bank erosion then it is assumed they are not important enough to be assessed in the ISC. Catchment managers may choose to undertake a more detailed local investigation of the effects of channel modification if required.

4.3.1 Bank and bed stability

An indicator in included in the ISC for both of bank stability and bed stability. The extent of bank erosion and bed instabilities can provide a direct measure of stream changes from naturalness. Extensive erosion can occur under natural conditions but is generally more common and severe in streams where there has been a greater human impact (e.g. cutoff of bends, removal of large woody debris, clearing of riparian vegetation). Bank and bed stability are assessed by comparison with an ‘ideal’ erosion free state. To help make this assessment, reference photographs are provided in the *Field Manual* that show a range of levels of disturbance.

4.3.2 Impact of artificial barriers on fish migration

Photographs of some instream artificial barriers that may impact on fish migration are reproduced in figure 4.1. The presence of artificial barriers (weirs, dams, culverts etc.) is a direct change from natural conditions. In addition to changes to hydrology associated with many dams and weirs, an artificial barrier has an important influence on a stream’s physical form and aquatic life (as well as impacts on flow regime for large barriers). For example, artificial barriers can change sediment and energy movement along streams and cause widespread disruption to fish spawning migrations, recolonisations, general movement and habitat selection (Harris 1984a; Harris 1984b). Seventy percent of indigenous fish species in Victoria’s coastal basins need to migrate at some stage of their life cycle (Koehn and O’Connor 1990). Barriers are often implicated in indigenous fish decline (Harris and Gehrke 1997).

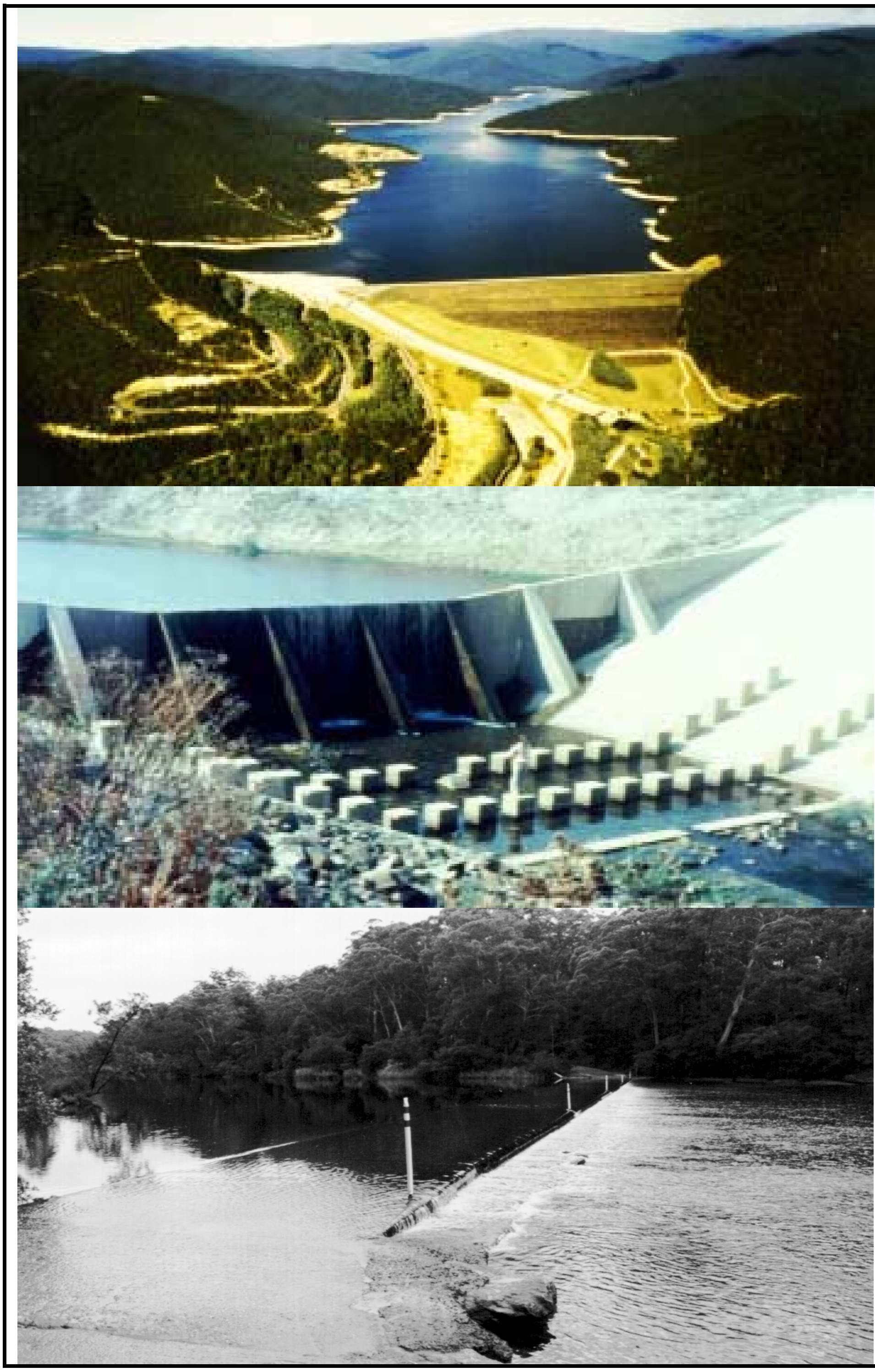
Many artificial barriers have been constructed on Victorian streams since European settlement. About 2 500 potential artificial barriers to fish migration have been identified across Victoria (Bennett 1997).

A large barrier at the downstream end of a stream system (e.g. a tidal barrage) will affect fish migration throughout all the reaches upstream of the barrier. For example, Doeg and Curmi (1990) showed that Dights Falls, an artificial barrier on the lower reaches of the Yarra River, effectively excluded all the upstream reaches from colonisation by migratory indigenous fish such as Tupong (*Pseudaphritis urvillii).*

The influence of artificial barriers on fish populations and migration is complex. It is dependent on at least some of the following:

- modification to the triggers that stimulate a fish species to migrate;
- whether the artificial barrier is trafficable by fish (e.g. drowns out) at the time that each fish species migrates;
- the behaviour and swimming abilities of the fish species at the stage of the life cycle when they are migrating (some Australian fish species migrate upstream as juveniles); and
- whether the artificial barrier excludes exotic species from the reach.

Although more research is needed into the effect of artificial barriers on fish migration (White and O’Brien 1999), it is clear large artificial barriers that are never drowned out (for example high dams) will have the greatest influence on migratory fish populations. These large artificial barriers can fragment populations of fish species and ultimately lead to local or regional extinctions of fish species (Marsden *et al*. 1997).



Large barrier: will completely prevent fish passage unless there is a fishway.

Medium size barrier: may drown out at very high flow and allow limited fish passage.

Low barrier: although this barrier will allow fish passage at medium flow it may prevent migration of some species.

Figure 4.1 - Examples of artificial barriers to fish migration

4.3.3 *Instream physical habitat*

Instream physical habitat is important for aquatic biota as it provides places to breed, feed, grow and shelter. An indicator of instream physical habitat has been included in the ISC and is assessed differently for lowland and upland reaches.

Lowland reaches

For lowland reaches, the indicator of instream physical habitat focuses on the density and origin of large woody debris.

Studies in Australian streams have shown that large woody debris is important as habitat for macroinvertebrates and fish (O'Connor 1992; Koehn 1994). It is also a feature of streams that is amenable to management. There is evidence that the quality and quantity of large woody debris has declined since settlement, particularly in lowland streams (Gippel *et al*. 1992). This decline has been through deliberate removal by desnagging and as a consequence of riparian clearing. The composition of large woody debris has also changed and is increasingly made up of material from exotic riparian species. Debris from these species does not have the same habitat quality and features as that from indigenous vegetation. For example, exotic debris is not as durable as some indigenous species.

Unfortunately, the quantitative assessment of the density of large woody debris is difficult. A line transect method has been used (Gippel *et al*. 1996; O'Connor 1992) which is accurate but time consuming and expensive. It is not suitable for a broad scale assessment that is the focus of the ISC.

For the ISC, the method for assessing the instream physical habitat indicator for lowland reaches is to visually assess the density and origin of large woody debris present under baseflow conditions compared to ideal levels in reference photographs. However, visual assessment need only be undertaken where large woody debris removal or some other major disturbance (such as channelisation or riparian clearing) has been carried out. If a reach has no history of large woody debris removal and an intact indigenous streamside zone, then the large woody debris abundance is assumed to be as it was under natural conditions. However, this is uncommon for lowland streams in Victoria.

Upland reaches

For upland reaches, large woody debris is a less important component of physical habitat and is highly variable; therefore a different indicator was adopted.

The US EPA developed an indicator known as *epifaunal substrate / available cover* as a measure of instream physical habitat that could be assessed during field data collection. The Victorian EPA has been measuring this indicator as part of two large-scale surveys of macroinvertebrates, the Monitoring River Health Initiative and First National Assessment of River Health.

A simplified version of this indicator has been adopted for use in the ISC. Assessment of this indicator involves consideration of the density and stability of a number of habitat features, including woody debris, coarse sediment and undercut banks.

4.4 Rating of indicators in the Physical Form Sub-index

Ratings for the 4 indicators in the Physical Form Sub-index are provided in this section. Further details on how to evaluate each indicator (including reference photographs) are in the *Field Manual* and *Users' Manual.*

4.4.1 Bank stability

Criteria for assessing bank stability are shown in table 4.2. This table is adapted from Ian Drummond and Associates (1985) and was developed for the assessment of streams throughout Victoria. Reference photographs are provided in the *Field Manual*.

Table 4.2 - Ratings for the bank stability indicator (adapted from Ian Drummond and Associates 1985)

Description	Rating
Stable *Typical features:* very few local bank instabilities, none of which are at the toe of the bank; continuous cover of woody vegetation; gentle batter; very few exposed roots of woody vegetation; erosion resistant soils.	4
Limited erosion *Typical features:* some isolated bank instabilities, though generally not at the toe of the bank; cover of woody vegetation is nearly continuous; few exposed roots of woody vegetation.	3
Moderate erosion *Typical features:* some bank instabilities that extend to the toe of the bank (which is generally stable); discontinuous woody vegetation; some exposure of roots of woody vegetation.	2
Extensive erosion *Typical features:* mostly unstable toe of the bank; little woody vegetation; many exposed roots of woody vegetation.	1
Extreme erosion *Typical features:* unstable toe of bank; no woody vegetation; very recent bank movement (trees may have recently fallen into stream); steep bank surface; numerous exposed roots of woody vegetation; erodible soils.	0

4.4.2 Bed stability

Criteria for assessing bed stability are shown in table 4.3. Reference photographs are provided in *Field Manual* to aid assessment. When assessing this indicator, it is important that the field data collectors focus on the bed stability over the whole measuring site, not local features.

Table 4.3 - Ratings for the bed stability indicator (adapted from Ian Drummond and Associates 1985)

Description	Rating
Stable bed *Typical features:* no evidence of infilling or deepening. For example, there is no erosion or deposition of fine sediment.	4
Limited bed instability / deepening *Typical features:* minor erosion of both banks; little mobile fine sediment (sand, silt) in bed; moderately steep bed; or **Limited bed instability / infilling** *Typical features:* same size sediment on bed as bars; channel capacity reduced marginally by fine sediment accumulation; accumulation of fine sediment at obstructions e.g. snags; bed tending to flat and uniform.	2
Extensive bed instability / deepening *Typical features:* extensive erosion of both banks; steep bed; no fine mobile fine sediment in bed; low width to depth ratio; or **Extensive bed instability / infilling** *Typical features:* channel largely blocked by fine sediment; flat bed; overbank siltation; waterlogging of adjacent land; high width to depth ratio.	0

4.4.3 Impact of artificial barriers on fish migration

Ratings for the impact of artificial barriers on fish migration is given in table 4.4. This rating table may be refined as the results of further research into the influence of artificial barriers on fish migration become available and the Victorian fish barriers database is developed further. Natural barriers to fish migration, e.g. the Cann River Falls, are not considered when assessing this indicator.

Table 4.4 - Ratings for the impact of artificial barriers on fish migration indicator

Category	Rating
In a typical year, no artificial barriers in the basin downstream of the reach interfere with the migration of any indigenous fish species endemic to the stream. Artificial barriers may be present if they are: ▪ dams or weirs with well functioning fishways (e.g. on the tidal barrage on the Barwon River (O'Brien 1997); or ▪ instream structures (e.g. a low level rock ford) that are always drowned out for at least at some stage of each day (e.g. every tidal cycle).	4
In a typical year, at least one artificial barrier in the basin downstream of the reach completely blocks the migration of indigenous fish species. Examples of artificial barriers in this category include: ▪ high dams without fishways (e.g. Dartmouth Dam or Glenmaggie Weir); and ▪ straightened concrete-lined channels in which the flow is always too shallow or too fast for fish to migrate[1].	0
Situations where there are artificial barriers in the basin downstream of the reach that do not fit into the above two categories. Examples of artificial barriers in this category include: ▪ fishways that only provide intermittent opportunities for fish passage; ▪ weirs or grade control structures that can be drowned out during higher flows in a typical year; and ▪ concrete-lined channels in which the flow is sometimes deep and slow enough to allow indigenous fish to migrate[1].	2

1 - Concrete-lined channels are rare in the rural streams for which the ISC was developed. A more detailed indicator may be developed for urban environments.

4.4.4 Instream physical habitat

For most streams, the rating table for instream physical habitat for lowland reaches is provided in table 4.5, and for upland reaches is provided in table 4.6. The rating is based on visual assessments at a measuring site and are guided by reference photographs provided in *Field Manual*.

For lowland streams in basaltic areas, there was concern that woody debris is limited under natural conditions because of the natural sparsity of woody riparian vegetation. Therefore, the instream physical habitat indicator would tend to have a low score even if the reach was undisturbed. A simple adjustment to the instream physical habitat indicator is proposed for these streams. If the stream channel is basaltic and the reach has never been desnagged, the instream physical habitat indicator will be set to 4. Under other conditions, the instream physical habitat indicator should be assessed according to tables 4.5 and 4.6. Assessment procedures are described in the *Field Manual.*

Table 4.5 - Ratings for the instream physical habitat indicator (lowland reaches)

Description	Rating
Excellent habitat *Typical features:* abundant debris from indigenous species. Site probably never desnagged and streamside vegetation probably never cleared.	4
Good habitat *Typical features:* numerous pieces of large woody debris from indigenous species. Perhaps limited large woody debris from exotic species present also. Limited impact of desnagging or streamside vegetation clearing.	3
Marginal habitat *Typical features:* moderate visible pieces of large woody debris from indigenous species in channel, or abundant pieces of exotic large woody debris in channel; moderate impact of desnagging or streamside vegetation clearing.	2
Poor habitat *Typical features:* few visible pieces of large woody debris in channel (either from indigenous or exotic species).	1
Very poor habitat *Typical features:* no large woody debris visible.	0

Table 4.6 - Ratings for the instream physical habitat indicator (upland reaches) (adapted from EPA indicators, L. Metzeling pers. comm.)

Description	Rating
Excellent habitat: Greater than 50% of stable habitat. *Typical features:* distribution of snags is relatively dense, mix of size of snags which are not newfall; stable undercut banks; cobble (stones between 64 mm and 250 mm) or other stable habitat.	4
Good habitat: 30 - 50% mix of stable habitat. *Typical features:* some large woody debris with presence of some newfall, some undercut banks (most of which are stable), bed material mostly coarse and stable.	3
Poor habitat: 10 - 30% mix of stable habitat. *Typical features:* habitat availability less than desirable; substrate frequently disturbed or removed, few snags of limited size range.	1
Very poor habitat: Less than 10% stable habitat. *Typical features:* lack of habitat is obvious; substrate unstable or lacking.	0

4.5 Calculating the Physical Form Sub-index score from indicator ratings

To assess the Physical Form Sub-index, measurements are made at 3 scales: transect, measuring site and reach. The symbol and range for each indicator is given in table 4.7.

Table 4.7 - Indicators in the Physical Form Sub-index

Scale	Indicator	Symbol	Range
Transect	Bank stability	*BANKS*	0 - 4
Measuring site	Bed stability	*BEDS*	0 - 4
	Instream physical habitat	*IPHAB*	0 - 4
Reach	Impact of artificial barriers on fish migration	*AB*	0 - 4

The Physical Form Sub-index score for a reach is the mean of the Physical Form Sub-index scores for all the measuring sites within a reach, as shown in equation 4.1:

$$PF_r = \frac{1}{N_{ms}} \sum_{ms=1}^{N_{ms}} PF_{ms} \qquad (4.1)$$

Where PF_r is the Physical Form Sub-index score for a reach, PF_{ms} is the Physical Form Sub-index score for a measuring site, the subscript, *ms*, refers to values for a measuring site, and N_{ms} is the number of measuring sites in the reach, usually 3.

The Physical Form Sub-index score for a measuring site is given by equation 4.2:

$$PF_{ms} = \frac{10}{16}\left[\frac{1}{N_t}\sum_{t=1}^{N_t}\left(BANKS_t\right) + BEDS_{ms} + IPHAB_{ms} + AB_r\right] \qquad (4.2)$$

Where PF_{ms} is the Physical Form Sub-index score for a measuring site. The subscript, *t*, refers to ratings of an indicator for a particular transect, and the subscript, *r*, refers to values for a reach. N_t is the total number of transects at a measuring site (usually 3).

4.6 Overview of procedure to evaluate the Physical Form Sub-index

An overview of the process to evaluate the Physical Form Sub-index is provided in figure 4.2.

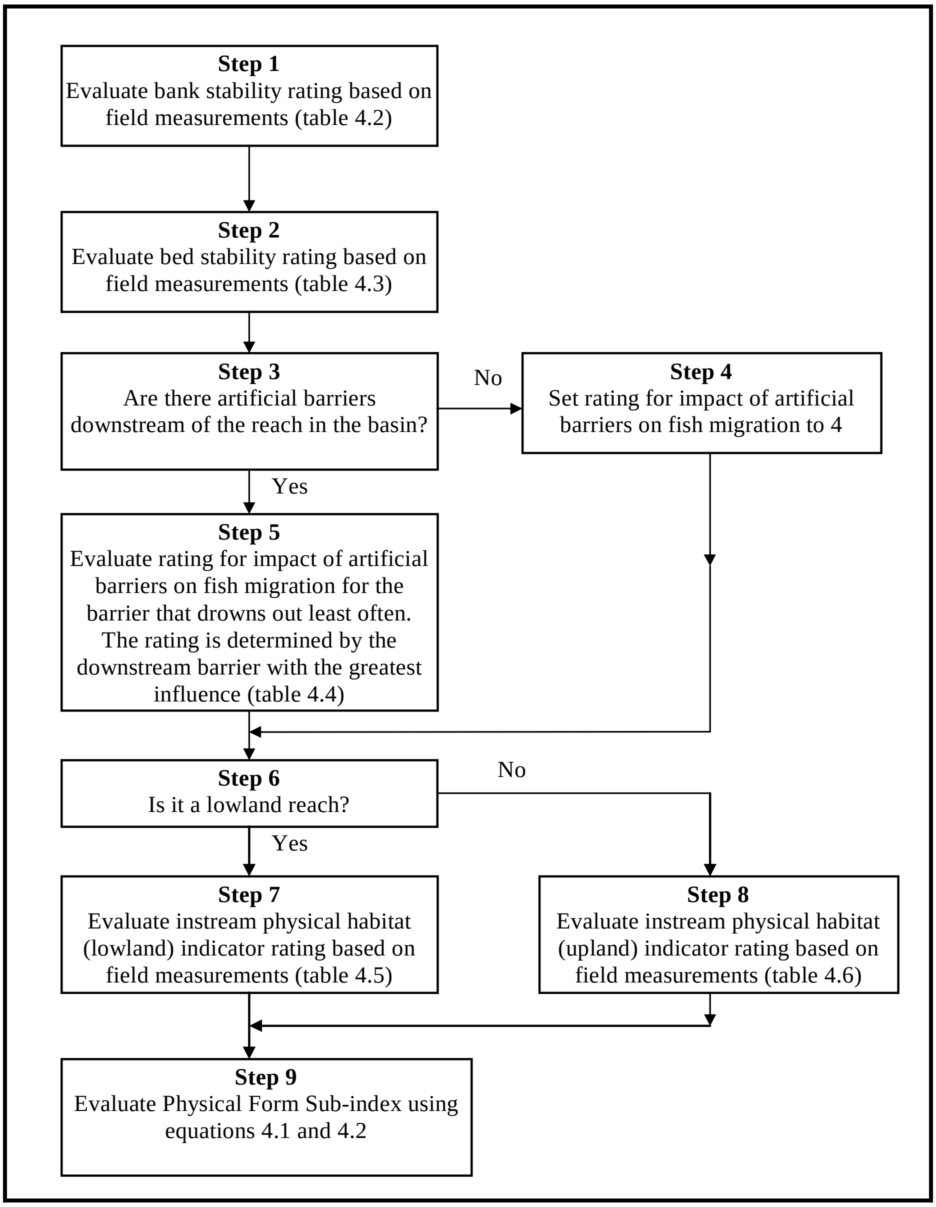


Figure 4.2 - Procedure for calculating Physical Form Sub-index score

4.7 Example application of the Physical Form Sub-index

For reaches in modified catchments, the field sampling protocol has changed significantly from that used during the trial applications of the ISC in 1997 (ID&A Pty Ltd and CEAH 1997b) (appendix 3). For example, rather than have 1 representative site with 4 transects spaced in accordance with meander characteristics as per the previous sampling protocol, the current field sampling protocol calls for data collection at 3 randomly selected measuring sites each with 3 transects spaced at 200 m. Details of the current field sampling protocol are given in the *Field Manual.*

A hypothetical example of the application of the Physical Form Sub-index is given below. The reach is in a modified catchment, so there are 3 measuring sites.

Step 1 - Evaluate rating for bank stability based on field measurements (table 4.2)

The data from the field evaluation of bank stability for the reach are given in table 4.8.

Table 4.8 - Example ratings for bank stability

	Indicator rating		
Measuring site number	**Transect 1**	**Transect 2**	**Transect 3**
1	2	3	1
2	4	3	2
3	4	4	4

Step 2 - Evaluate rating for bed stability based on field measurements (table 4.3)

The data from the field evaluation of bed stability for the reach are given in table 4.9.

Table 4.9 - Example ratings for bed stability

Measuring site	Indicator rating
1	4
2	4
3	4

Step 3 - Are there artificial barriers downstream of the reach in the basin?

There are no artificial barriers in the basin downstream of this reach.

Step 4 - Set rating for impact of artificial barriers on fish migration to 4

Then progress to Step 6.

Step 6 - Is it a lowland reach?

Yes, so progress to Step 7.

Step 7 - Evaluate instream physical habitat (lowland) indicator rating based on field measurements (table 4.5)

The data from the field evaluation of instream physical habitat indicator for the reach is given in table 4.10.

Table 4.10 - Example ratings for instream physical habitat

Measuring site	Indicator rating
1	2
2	4
3	3

Step 9 - Evaluate Physical Form Sub-index using equations 4.1 and 4.2

The aggregation of the indicator scores into a Physical Form Sub-index score is given in table 4.11.

Table 4.11 - Sample calculation of Physical Form Sub-index score

Measuring site	Score
Measuring site 1[1] $\frac{10}{16}\left[\frac{1}{3}(2+3+1)+4+4+2\right]$	7.5
Measuring site 2 $\frac{10}{16}\left[\frac{1}{3}(4+3+2)+4+4+4\right]$	9.4
Measuring site 3 $\frac{10}{16}\left[\frac{1}{3}(4+4+4)+4+4+3\right]$	9.4
Physical Form Sub-index (using equation 4.1)[2]	**9**

1 - using equation 4.2
2 - A sub-index score for a reach is reported to 0 decimal places.

5. STREAMSIDE ZONE SUB-INDEX

5.1 Statewide issues relating to the streamside zone

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

- acts as a filter modifying inputs to the stream (e.g. light, nutrients, sediment);
- acts as a source of inputs to the stream (e.g. logs, twigs, leaves);
- provides terrestrial habitat;
- contributes to bank stability; and
- provides scenery and landscape values.

Billabongs can be an important component of the streamside zone, particularly for lowland reaches.

Since European settlement, the streamside zone has been heavily modified across most of Victoria, particularly in lowland reaches. These modifications have included:

- clearing;
- introduction of livestock;
- clearing of land adjacent to billabongs and wetlands; and
- introduction of exotic species of vegetation.

5.2 Existing approaches - possible indicators

Existing approaches to measuring the condition of the streamside zone (primarily the condition of streamside vegetation) range in detail, and most are more suited for either the:

- the scientific community (including Margules and Partners 1990); or
- the public (including Petersen 1992; Mitchell 1990; Ian Drummond and Associates 1985);

than for a broad scale tool to be used by catchment managers.

Existing indices are not appropriate to report the condition of the streamside zone at the scale of the ISC as:

- approaches designed for the scientific community are too detailed and complex and required field data would take too long to collect; and
- indicators designed for the public are generally too aggregative to identify key deficiencies in the streamside zone or flag any need for management intervention.

Therefore, none of the existing indices are directly applicable for use in the Streamside Zone Sub-index of the ISC but many of the concepts have been useful. Summaries of a selection of references used to develop the Streamside Zone Sub-index are included in CEAH and ID&A Pty Ltd (1997).

5.3 Indicator selection

The indicators considered for the Streamside Zone Sub-index are given in table 5.1. Indicators are needed for both the **quantity** and **quality** of the streamside zone.

Table 5.1 - Indicators considered for the Streamside Zone Sub-index

Characteristic of the streamside zone	Possible indicator
Filter of inputs to stream (including light, sediment, nutrients)	Width of streamside zone Longitudinal continuity Structural intactness Cover of exotic vegetation Cover Land uses in catchment
Source of inputs to stream (including large woody debris, leaves, insect fall)	Ratio of streamside zone width to stream width Longitudinal continuity Structural intactness Cover of exotic vegetation Diversity of flora Billabong condition
Habitat for terrestrial fauna	Width of streamside zone Longitudinal continuity Structural intactness Cover of exotic vegetation Diversity of flora Regeneration of indigenous vegetation
Scenery and landscape values	Ratio of streamside zone width to stream width Amount of trash e.g. cans, bottles, plastic bags Landscape value indicators Regeneration of indigenous vegetation

Following consideration of the indicators in table 5.1, the SRG selected the following 6 indicators for the Streamside Zone Sub-index:

- width of streamside zone;
- longitudinal continuity;
- structural intactness;
- cover of exotic vegetation;
- regeneration of indigenous woody vegetation; and
- billabong condition.

Rating tables for these indicators are given in section 5.4. Reasons for the exclusion of other possible indicators of streamside zone condition are summarised in table 5.2.

Table 5.2 - Reasons for exclusion of some possible indicators from Streamside Zone Sub-index

Possible indicator	Reason for exclusion from Streamside Zone Sub-index
Diversity	Involves identification of taxa, which is too detailed for the ISC, difficult for many field data collectors[1] and complicated to analyse.
Adjacent land uses	Not included because the ISC focuses more on condition rather than pressures causing a change in condition.
Rubbish / trash density	Not thought to be a primary determinant of the streamside zone condition in rural areas.
Scenery and landscape value indicators	ISC measures environmental condition rather than use values.
Weediness	Cover of exotic vegetation is included in the ISC. If field data collectors have skills to identify weed taxa, then this data could be recorded and passed onto catchment managers.
Macrophyte type and cover	Macrophyte density varies across the state. Distinguishing indigenous from exotic macrophytes is difficult.
Stock access	Stock access is a pressure that can often lead to reduced streamside zone quality over time. Although this is important, the primary purpose of the ISC is to measure condition rather than pressures. A space has been provided on the field data sheet for identifying what type of stock have access to a section of stream bank, but this data is not used to evaluate the ISC.

1 - It is not required that field data collectors have botanical training. Often they will be field or technical staff of the CMA.

5.4 Rating of indicators in the Streamside Zone Sub-index

Rating of the indicators is undertaken by comparing the existing streamside zone to reference conditions. For the indicators of the quality of streamside zone, the frame of reference is usually natural conditions. For the indicators of the quantity of streamside zone, the frame of reference has been defined by the SRG. Rating tables are provided below for each of the streamside zone indicators. For two indicators (the width of the streamside zone, and longitudinal continuity) separate ratings are provided for basaltic streams in natural condition[1]. Assessment procedures are documented in the *Field Manual*.

[1] For one indicator in the Physical Form Sub-index, instream physical habitat, a separate rating is also provided for basalt streams (see chapter 4).

5.4.1 Width of streamside zone

The width of the streamside zone is important in its ability to:

- filter light;
- filter nutrients and sediment;
- provide a source of inputs to a stream;
- provide terrestrial habitat; and
- provide scenery and landscape values.

The importance of each of these roles depends, to some extent, on stream size. For the ISC, ratings are provided for two size classes of streams: smaller streams (defined for this purpose as less than 15 m wide); and larger streams (defined as greater than 15 m wide). Table 5.3 is the rating table for the width of streamside zone indicator. An exception is made for basaltic streams. If the stream channel is basaltic and the riparian conditions are undisturbed, i.e. the cover of woody debris has not been changed from natural conditions, then the rating for the width of the streamside zone indicator should be set to 4. In other cases these streams should be assessed as for all other streams (see *Field Manual).*

The following definitions are used in determining the width of the streamside zone:

- the **width of the streamside zone** is defined as the distance from the water's edge to a change of land use. (Schematics to help determine this are given in appendix 3 of the *Field Manual*); and
- the **baseflow width** is defined as the average surface width during baseflow.

Table 5.3 - Ratings for width of streamside zone indicator

Width of the streamside zone		**Rating**
Small streams (≤ 15 m wide)	**Large streams (> 15 m wide)**	
> 40 m	> 3×baseflow width	4
>30 - 40 m	1.5×baseflow width - < 3×baseflow width	3
>10 - 30 m	0.5×baseflow width - < 1.5×baseflow width	2
5 - 10 m	0.25×baseflow width - < 0.5×baseflow width	1
< 5 m	< 0.25×baseflow width	0

5.4.2 Longitudinal continuity

Longitudinal continuity is a measure of how continuous woody streamside vegetation is and an assessment of the number of gaps in vegetation cover. It has two components:

- proportion of bank length with vegetation equals or is greater than 5 m wide (the ratio of vegetated bank length with greater than 20% cover to total bank length); and
- the number of *significant discontinuities* per unit length.

The width of a discontinuity that will impede movement of fauna is species dependent. For example a Superb Blue Wren, *Malurus cyaneus,* may be prepared to traverse a larger gap in vegetation than a small marsupial. Not withstanding this concern, a single value was selected as a compromise following discussion of the SRG during a field workshop. A *significant discontinuity* was defined as a gap in the streamside vegetation of 10 metres or greater.

The **number of significant discontinuities per unit length** is defined as the number of significant discontinuities along the stream per kilometre of stream bank. In general, the length of stream bank that is actually assessed will not be exactly one kilometre so it will be necessary to scale the number of significant discontinuities in the measured distance to the number per kilometre.

The SRG developed a rating table for the longitudinal continuity indicator (see table 5.4). As with the width and instream physical habitat indicators an exception is made for basaltic streams. If the stream channel is basaltic and the riparian conditions are undisturbed, i.e. the cover of woody debris has not been changed from natural conditions, then the rating for the longitudinal continuity indicator should be set to 4. In other cases these streams should be assessed as for all other streams (see *Field Manual).*

Table 5.4 - Ratings for longitudinal continuity indicator

		Number of significant discontinuities[2] per kilometre			
		0 - 2	3 - 5	6 - 20	> 20
Proportion of vegetated bank length[1]	95 - 100 %	4	3	-[3]	-[3]
	80 - 94 %	3	2	1	-[3]
	65 - 79 %	2	1	1	0
	40 - 64 %	1	1	0	0
	0 - 39 %	0	0	0	0

1 - A bank is considered to be vegetated where the width of the streamside tree layer and shrub layer with cover greater than 20% is 5 m or greater.
2 - A significant discontinuity is a gap in the streamside vegetation 10 m long or greater.
3 - Not mathematically possible

Two examples of the application of the longitudinal continuity indicator are given in figure 5.1.

For example 1, the proportion of vegetated bank length is 85%, and there are 2 significant discontinuities in 430 m, or 5 in 1 km. The corresponding indicator rating is 2.

For example 2, the proportion of vegetated bank length is 66%, and there are 3 significant discontinuities in 430 m, or 7 in 1 km. The corresponding indicator rating is 1.

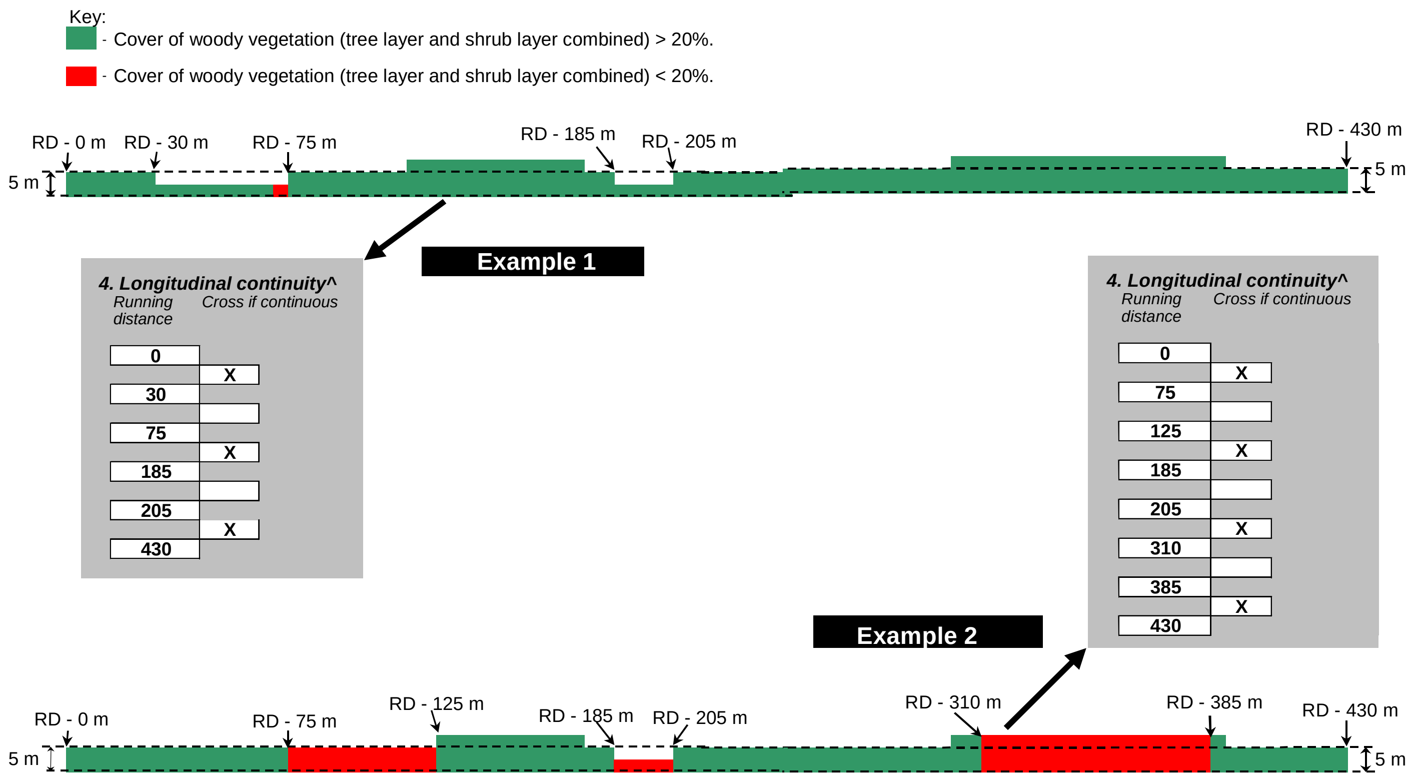


Figure 5.1 - Examples to illustrate longitudinal continuity indicator ('RD' on the schematic above indicates running distance i.e. distance from a point of origin. In these examples, all field data is collected along the same bank, which is typical. The length of a measuring site is 430 m. An extract from the ISC field data sheet is also shown).

5.4.3 Structural intactness

The structural intactness indicator is a measure of whether the natural vertical size distribution of streamside vegetation has been disturbed.

The following definitions for three structural layers of vegetation are based on those used in Melbourne Water (1995). The various layers all contribute to the characteristics of the streamside zone as listed in table 5.1.

- **Tree layer**: woody plants greater than 5 m tall, usually with a single stem (e.g. eucalypts > 5 m tall, acacias > 5 m tall, willows > 5 m tall).
- **Shrub layer**: woody plants less than 5 m tall, frequently with many stems arising at or near the base (e.g. melaleucas less than 5 m tall, blackberries, immature tree layer less than 5 m tall) along with non-woody vegetation greater than 1.5 m high. Includes eucalypts, acacias, and willows less than 5 m tall at the time of sampling.
- **Ground layer**: other plants without woody stems less than 1.5 m high (e.g. sedges, reeds, grasses, saltbush, bracken fern).

A general knowledge of the structure of the original vegetation community at a measuring site is necessary to evaluate the structural intactness indicator. This should be available from local botanists, the Catchment Management Authority or Department of Natural Resources and Environment staff. The rating relationship is applied for each structural layer (table 5.5).

The overall rating of structural intactness is calculated using the sum of ratings for each structural layer. It should be noted that this indicator is coarse, as it does not consider difference in vegetation structure between instream bars, stream banks and verge.

Table 5.5 - Ratings for structural intactness indicator

	Actual		
Natural	**> 80% cover**	**20 - 80% cover**	**< 20% cover**
> 80% cover	2	1	0
20 - 80% cover	1	2	1
< 20% cover	0	1	2

For each transect the indicator score for the structural intactness, SI_t is the sum of the scores for the tree layer, shrub layer and ground layer multiplied by two thirds. SI_t will be between 0 and 4.

$$SI_t = \frac{2}{3}\left(SI_{tree} + SI_{shrub} + SI_{ground}\right) \qquad (5.1)$$

5.4.4 Cover of exotic vegetation

Prior to European settlement, there were no exotic vegetation (or animal) taxa along streams. Some characteristics of exotic plant taxa are different to indigenous taxa and may have an adverse effect on Victorian streams, for example:

- for terrestrial fauna, exotic plant taxa may reduce food, habitat and nesting sites, and infestations can form barriers to movement;
- some exotic taxa provide large leaf fall during autumn that indigenous ecosystems have not evolved to cope with or to take advantage of (Ladson and Gerrish 1996);
- exotic ground layer can out compete and hence hinder or prevent regeneration of indigenous taxa; and
- large woody debris provided by exotic taxa (e.g. willows) generally rot much more quickly than those from other taxa (Pidgeon and Cairns 1981; Ladson and Gerrish 1996).

The rating for cover of exotic vegetation is provided in table 5.6. This is an adaptation of the *weed presence indicator* developed by Thexton and Poynter (1998). The rating table is applied for each structural layer of vegetation (i.e. tree layer, shrub layer and ground layer). Sketches illustrating cover of vegetation are in the accompanying *Field Manual.*

Table 5.6 - Ratings for cover of exotic vegetation indicator

Cover of exotic vegetation	Rating
0 %	4
1 - 10 %	3
11 - 40 %	2
41 - 60 %	1
> 60%	0

For each transect the indicator score for the cover of exotic vegetation, CEV_t is the average of the scores for the tree layer, shrub layer and ground layer.

$$CEV_t = \frac{1}{3}\left(CEV_{tree} + CEV_{shrub} + CEV_{ground}\right) \qquad (5.2)$$

5.4.5 Regeneration of indigenous woody vegetation

The regeneration of indigenous taxa in the streamside zone is an important element of its current condition. However, detection of the regeneration of ground layer taxa is difficult. Therefore, the focus of this component of the sub-index is on the detection of regeneration of indigenous woody vegetation.

The rating for the regeneration of indigenous woody vegetation is provided in table 5.7.

Table 5.7 - Ratings for regeneration of indigenous woody vegetation indicator

Description	Rating
Abundant and healthy (> 5% cover of healthy native regeneration and *typical features*: at least a few taxa of indigenous tree layer and shrub layer present; range of heights; no obvious signs of stress or extensive predation from stock, rabbits, and insects).	2
Present (between 1% and 5 % cover of native regeneration, or > 5% of unhealthy regeneration and *typical features:* few taxa present; most regeneration is about the same height; obvious signs of stress e.g. many eaten or browned leaves or extensive predation from stock, rabbits, insects etc).	1
Very limited regeneration - less than 1% cover of native regeneration	0

5.4.6 Billabong condition

For lowland reaches, billabongs and wetlands are important in the life cycles of many species of organisms. The indicator developed for the ISC is to assess whether more than 50% of billabongs and wetlands in the reach are in reasonable condition with regard to:

- quality and quantity of fringing vegetation; and
- evidence of pollution from catchment runoff (including polluted agricultural runoff).

The indicator is calculated by comparing current area of billabongs and wetlands with total area present under natural conditions. If more than 50 % of the billabongs and wetlands are in near natural condition, the indicator rating is 1, otherwise the indicator rating is 0.

The evaluation of the indicator for condition of billabongs and wetlands differs from the other 5 indicators of the Streamside Zone Sub-index as:

- it only applies to lowland reaches; and
- it is assessed over a whole reach rather than by detailed assessment at a measuring site.

This indicator of billabong and wetland condition is preliminary only. More detailed assessments may be applied in lowland reaches in the future once better rapid measurement procedures become available. An alternative would have been to ignore the influence of conditions of billabongs and wetlands on stream condition and not include this component in the Streamside Zone Sub-index. The SRG believed this condition measure should be included even in this preliminary form to raise awareness of the importance of billabongs and wetlands.

5.5 Calculating the Streamside Zone Sub-index score from indicator ratings

As discussed in section 5.4, to evaluate the Streamside Zone Sub-index for a reach, assessment of 6 indicators is required: 3 are measured at each transect, 2 are assessed over a whole measuring site, and 1 (condition of billabongs and wetlands) is measured over the whole reach (see table 5.8).

Table 5.8 - Indicators in the Streamside Zone Sub-index

Scale	Indicator	Symbol	Range
Transect	Width of streamside zone	*Wd*	0 - 4
	Cover of exotic vegetation	*CEV*	0 - 4
	Structural intactness	*SI*	0 - 4
Measuring site	Regeneration of indigenous woody vegetation	*Rg*	0 - 2
	Longitudinal continuity	*LC*	0 - 4
Reach	Billabong condition (only measured in lowland reaches)	*Bb*	0 - 1

The Streamside Zone Sub-index score for a reach is the average of the scores at each of the measuring sites, as shown in equation 5.3:

$$SZ_r = \frac{1}{N_{ms}} \sum_{ms=1}^{Nms_s} SZ_{ms} \qquad (5.3)$$

where SZ_r is the Streamside Zone Sub-index score for a reach, SZ_{ms} is the Streamside Zone Sub-index score for measuring site *ms*, and N_{ms} is the number of measuring sites, usually 3 for each reach.

The Streamside Zone Sub-index score for a measuring site is a combination of the indicators in table 2 (except that the condition of wetlands and billabongs indicator (*Bb*) is only measured in lowland reaches).

The Streamside Zone Sub-index score for a measuring site within a lowland reach is calculated using equation 5.4:

$$SZ_{ms} = \frac{10}{19}\left[\frac{1}{N_t}\sum_{t=1}^{N_t}\left[Wd_t + CEV_t + SI_t\right] + LC_{ms} + Rg_{ms} + Bb_r\right] \qquad (5.4)$$

The Streamside Zone Sub-index score for a measuring site within an upland reach is calculated using equation 5.5:

$$SZ_{ms} = \frac{10}{18}\left[\frac{1}{N_t}\sum_{t=1}^{N_t}\left[Wd_t + CEV_t + SI_t\right] + LC_{ms} + Rg_{ms}\right] \qquad (5.5)$$

where SZ_{ms} is the Streamside Zone Sub-index for a measuring site. The subscript *t* refers to ratings of an indicator for a particular transect, the subscript *ms* refers to values for a measuring site, and the subscript *r* refers to values for a reach. N_t is the number of transects within a measuring site, usually 3 in modified catchments.

5.6 Overview of procedure to evaluate the Streamside Zone Sub-index

An overview of the process to evaluate the Streamside Zone Sub-index is provided in figure 5.2. Further details are provided in *Field Manual* and *Users' Manual*.

Procedures for assessing indicators in steps 1 to 5 are documented in the *Field Manual*.

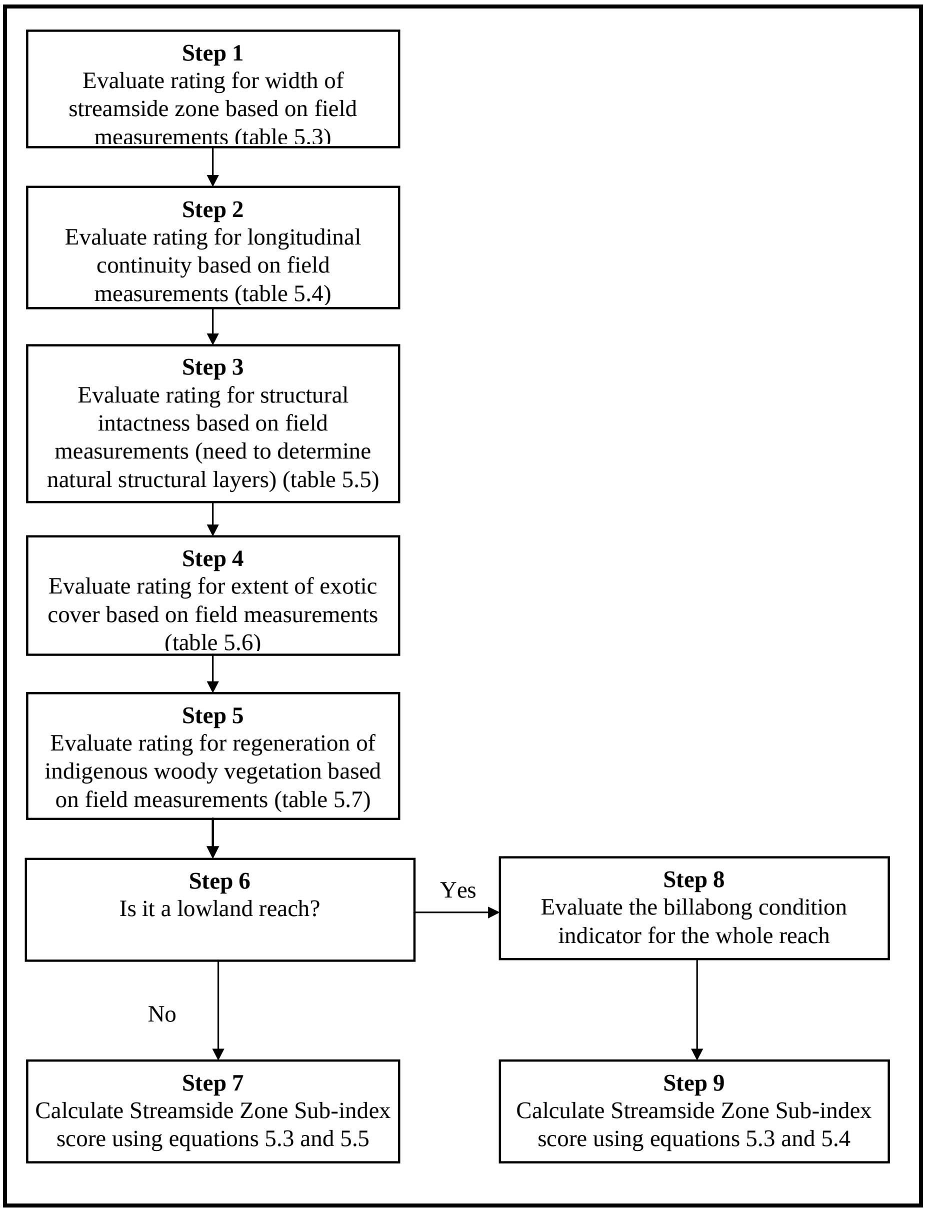


Figure 5.2 - Procedure for calculating Streamside Zone Sub-index score

5.7 Example application of the Streamside Zone Sub-index

Hypothetical data for a lowland stream reach are given below. Details on field data collection are provided in the *Field Manual.*

Step 1 - Evaluate rating for width of streamside zone based on field measurements (table 5.3)

The ratings for the width of streamside zone indicator are given in table 5.9.

Table 5.9 - Example ratings for width of streamside zone indicator

	Indicator rating		
Measuring site number	**Transect 1**	**Transect 2**	**Transect 3**
1	2	3	1
2	1	0	2
3	2	4	3

Step 2 - Evaluate rating for longitudinal continuity at each measuring site (table 5.4)

The ratings for the longitudinal continuity indicator are given in table 5.10.

Table 5.10 - Example ratings for longitudinal continuity indicator

Measuring site	Indicator rating
1	2
2	1
3	2

Step 3 - Evaluate rating for structural intactness at each measuring site (table 5.5)

The data to evaluate the structural intactness indicator is given in table 5.11. Data is collected in the field for each structural layer of vegetation (i.e. tree layer, shrub layer and ground layer) and compared to the natural structure of vegetation. The rating for a transect is calculated using equation 5.1.

Table 5.11 - Example ratings for structural intactness indicator

	Indicator rating		
Measuring site number	**Transect 1**	**Transect 2**	**Transect 3**
1	2	3	3
2	1	0	2
3	2	2	2

Step 4 - Evaluate rating for extent of exotic cover at each measuring site (table 5.6)

The data to evaluate the cover of exotic vegetation indicator is given in table 5.12. Data is collected in the field for each structural layer of vegetation and then averaged to produce an indicator score for each transect (equation 5.2.).

Table 5.12 - Example ratings for cover of exotic vegetation indicator

	Indicator rating		
Measuring site number	**Transect 1**	**Transect 2**	**Transect 3**
1	2	2	4
2	2	3	4
3	2	4	0

Step 5 - Evaluate rating for regeneration of indigenous woody vegetation (table 5.7)

The data to evaluate the regeneration of woody vegetation indicator is given in table 5.13.

Table 5.13 - Example ratings for regeneration of indigenous woody vegetation indicator

Measuring site	Indicator rating
1	2
2	1
3	0

Step 6 - Is it a lowland reach?

Yes, so move onto Step 8.

Step 8 - Evaluate the billabong condition indicator

Most of the billabongs and wetlands along the hypothetical stream are not in near natural condition. Some are currently used for treatment of dairy shed effluent, and some have been laser graded into pasture. Very few billabongs and wetlands have any natural fringing vegetation. The rating for the condition of billabongs indicator for this reach is 0.

Step 9 - Calculate the Streamside Zone Sub-index score using equations 5.2 and 5.3

The Streamside Zone Sub-index score is calculated using equations 5.3 and 5.4.

Table 5.14 - Sample calculation of Streamside Zone Sub-index score

Measuring site (using equation 5.4)	Score (out of 10)
Measuring site 1 $\frac{10}{19}\left[\frac{1}{3}[(2+3+1)+(2+3+3)+(2+2+4)]+2+2+0\right]$	5.9
Measuring site 2 $\frac{10}{19}\left[\frac{1}{3}[(1+0+2)+(1+0+2)+(2+3+4)]+1+1+0\right]$	3.7
Measuring site 3 $\frac{10}{19}\left[\frac{1}{3}[(2+4+3)+(2+2+2)+(2+4+0)]+2+0+0\right]$	4.7
Streamside Zone Sub-index (using equation 5.3)[1]	**5**

1 - A sub-index score for a reach has 0 decimal places.

6. WATER QUALITY SUB-INDEX

6.1 Statewide issues relating to water quality

Water quality is a major environmental issue across Victoria. For example:

- excess nutrients (nitrogen and phosphorus) have roles in eutrophication of receiving waters (State Government of Victoria 1995), and can contribute to cyanobacteria blooms;
- suspended sediments reduce light penetration through the water column and can smother substrate (Erskine and Saynor 1995);
- salinisation of agricultural areas causes an increase in stream salinity (Salt Force 1988); and
- decreasing pH can have a major influence on aquatic life (Brizga *et al*. 1995).

There are also localised water quality issues such as heavy metals, pesticides, and organic pollution that have important impacts on aquatic ecosystems (Dallas and Day 1993).

The purpose of the Water Quality Sub-index is to provide a concise report on the long-term condition of water quality in streams that is of interest to governments, Catchment Management Authorities and others involved in catchment management, therefore it is focused at the regional or state scale. Local water quality concerns may require monitoring of other physical and chemical properties and at different locations than required for the ISC.

As with the other sub-indices, a primary function of the Water Quality Sub-index is to flag issues rather than provide detailed information about their causes. It will not provide all the water quality information that may be required by managers. Once a water quality issue has been identified, detailed investigations and reporting may be necessary.

6.2 Existing approaches - possible indicators

There is an extensive range of water quality indicators and indices. From a literature review, an assessment of possible indicators for the ISC is summarised in table 6.1.

Table 6.1 - Assessment of possible indicators for the Water Quality Sub-index

Possible Indicator	Comments	Suitable as ISC indicator
Total Nitrogen (Office of the Commissioner for the Environment 1988; ANZECC 1992)	Important indicator of nutrient enrichment. Some research indicates that nitrogen is more often limiting to algal growth than phosphorus in Victorian streams (Chessman *et al*. 1992).	Possible
Nitrates and Nitrites (Dunnette 1979; House 1989)	Under Victorian conditions, Total Nitrogen is an adequate indicator of nitrogen status to flag any statewide issues. This indicator could be included in a more detailed investigation of water quality.	No
Ammoniacal Nitrogen (Dunnette 1979; House 1989; Smith 1990; Lee Young 1994)	As above	No

Table 6.1 - Assessment of possible indicators for the Water Quality Sub-index
(continued)

Possible Indicator	Comment	Suitable as ISC indicator
Dissolved Inorganic Nitrogen (Lord *et al*. 1995)	As above	No
Total Kjeldahl Nitrogen (Lord *et al*. 1995)	As above	No
Total Phosphorus (Lord *et al*. 1995; Office of the Commissioner for the Environment 1988; ANZECC 1992)	Important indicator of nutrient enrichment. Easier to measure than total nitrogen.	Possible
Filterable or soluble reactive phosphorus (Lord *et al*. 1995)	Indicator of biologically available phosphorus. Under Victorian conditions, total phosphorus is an adequate indicator of phosphorus status to flag any statewide issues. This indicator could be included in a more detailed investigation of water quality.	No
Turbidity (Office of the Commissioner for the Environment 1988; Smith 1990; Moore 1990; Lee Young 1994; ANZECC 1992)	Important indicator for flagging statewide water quality issues. High turbidity can indicate bed and bank erosion or catchment management concerns and is often associated with high phosphorus loads.	Possible
Suspended solids (Dunnette 1979; Dinius 1987; Office of the Commissioner for the Environment 1988; House 1989; Smith 1990)	Elevated suspended solids concentrations are flagged by elevated turbidity. Detailed investigations could include measurements of suspended solids if necessary.	No
Total Dissolved Solids (Dunnette 1979; Moore 1990)	Total dissolved solids issues are flagged by turbidity. Detailed investigations could include measurements of total dissolved solids if necessary.	No
Escherichia coli, faecal coliforms, total coliforms (Dunnette 1979; Dinius 1987; House 1989; Smith 1990, Moore 1990)	*E. coli* are of particular public interest but, in Victoria, are a local rather than a statewide issue. *E. coli* are also a public health issue more so than an environmental one. The focus of the ISC in on environmental condition.	Possible
Biochemical Oxygen Demand (Dunnette 1979; Dinius 1987; Office of the Commissioner for the Environment 1988; Smith 1990; House 1989)	More appropriate measures are available for statewide assessment e.g. Total Organic Carbon.	No
Dissolved Oxygen (Dunnette 1979; Barnes *et al*. 1986; Dinius 1987; House 1989, Smith 1990; Moore 1990, ANZECC 1992)	Is frequently cited in the literature as a useful indicator but has high natural variation that is difficult to interpret.	No

Table 6.1 - Assessment of possible indicators for the Water Quality Sub-index (continued)

Possible Indicator	Comment	Suitable as ISC indicator
pH (Dunnette 1979; Dinius 1987; Office of the Commissioner for the Environment 1988; House 1989; Smith 1990, ANZECC 1992; Moore 1990)	pH is a developing water quality issue in many areas of the State. There have been recent reports of decreasing pH in streams (e.g. Brizga *et al*. 1995)	Possible
Temperature (Dinius 1987; Smith 1990; House 1989)	Difficult to define 'natural' temperature. In Victoria temperature issues are usually associated with water released from dams e.g. downstream of Dartmouth Dam (Ebsary 1990). The Hydrology Sub-index flags the presence of dams and detailed investigation of water quality effects can be undertaken if necessary at a local or regional scale.	No
Chlorides (Dinius 1987; House 1989)	Conductivity is a more appropriate measure under Victorian conditions	No
Pesticides, Herbicides (ANZECC 1992)	Not a statewide issue. A local water quality issue in some areas of Victoria	No
Heavy Metals (ANZECC 1992)	Not a statewide issue. May be a local water quality issue in some areas of Victoria (particularly urban areas).	No
Hardness (Dinius 1987; Lee Young 1994)	Not an appropriate indicator to measure anthropogenic effects on water quality	No
Total Organic Carbon	Good indicator of organic pollution.	Possible
Conductivity (Department of Water Resources 1989a)	Increasing stream salinity is a statewide water quality issue for Victoria	Possible
Colour (ANZECC 1992)	Variable under natural conditions. Difficult to determine a natural or ideal value. There is often some relationship to turbidity.	No

6.3 Indicator selection

Table 6.1 shows a subset of the large number of possible water quality indicators that exist. Four indicators were selected by the SRG for the Water Quality Sub-index. These are:

- total phosphorus.
- turbidity;
- electrical conductivity; and
- alkalinity/acidity (pH).

The selection criteria used by the SRG for choosing Water Quality Sub-index indicators were that they must:

- identify statewide water quality issues;
- be relatively inexpensive to measure; and

- be easy to interpret.

The **minimum** number of indicators consistent with these criteria were chosen. Several other indicators were considered but not included in the final selection. The reasons for excluding these indicators are listed in table 6.2.

Table 6.2 - Possible water quality indicators not included in the Water Quality Sub-index

Indicator	Reasons why indicator was not included.
Total Organic Carbon (Can be used to identify organic pollution)	Not included because organic pollution usually results in elevated phosphorus levels that are picked up by measurements of total phosphorus.
Soluble or filterable reactive phosphorus (SRP) (Indicates phosphorus available for biological activity)	The total phosphorus indicator flags those streams with excess phosphorus. If necessary SRP can be measured during a more detailed water quality investigation.
Total Nitrogen (measure of nutrient enrichment)	The total phosphorus indicator will generally highlight nutrient enriched streams, therefore a nitrogen indicator has not been included along with the phosphorus indicator. Total nitrogen is more difficult to assess than total phosphorus.
E. coli (measure of faecal contamination of waterways)	Faecal contamination is relatively expensive to measure, and is associated with public health issues usually dealt with by Water Boards rather than natural resource management agencies.

6.4 Interpreting water quality measurements

The Water Quality Sub-index value is determined by comparing measurements of actual stream water quality with defined 'ideal' water quality for the stream. The greater the departure from reference conditions the lower the sub-index score. Reference conditions were determined through discussion with experts (particularly Professor Barry Hart) and a review of the literature.

The chosen indicators determine the water quality measurements that are required (total phosphorus, turbidity, conductivity and pH). Before the water quality measurements can be interpreted, the issues of variability in time and space must be addressed.

6.4.1 Variability in time

Water quality at a site is highly variable with discharge, and often with season. Given the broad scale of the ISC and the difficulty of interpreting water quality measurements, it is not possible to quantify water quality over the full range of flows.

As a simplification, the Water Quality Sub-index is intended to measure low flow or baseflow water quality. This is achieved by taking the median value of a series of monthly water quality measurements. Low flow water quality is important because it occurs most of the time and is interspersed by short periods of high flow.

High flow events have been monitored in the past at considerable effort and cost (e.g. Ian Drummond and Associates 1994a; Ian Drummond and Associates 1994b; Sadek 1998) and it is acknowledged that high flow water quality can be important for stream condition. However, it is not considered feasible to include an indicator of high flow water quality in the ISC at this stage. It may be appropriate to undertake a detailed study of high flow water quality if this is recognised as a particular issue in a local area.

6.4.2 Variability in space

Water quality varies along streams and between streams in different areas of the State. To take account of the variability **along streams**, ratings are specified for two zones*: upland* and *lowland* as defined in the glossary. For lowland streams that are also tidal, the electrical conductivity indicator is not used when assessing the Water Quality Sub-index score.

The issue of water quality variability **between streams** in different areas of Victoria has not been addressed in the current Water Quality Sub-index. For example, streams in western Victoria may naturally have higher salinities than those in the east of Victoria although it is difficult to know at present, as disturbance to catchments typically took place prior to the commencement of water quality monitoring programs. Research into this issue may take place before the next statewide application of the ISC (B. Hart, pers. comm.).

6.5 Rating of indicators in the Water Quality Sub-index

6.5.1 Total phosphorus

Ratings for total phosphorus are presented in table 6.3. These ratings are based on:
- *Preliminary Nutrient Guidelines for Victorian Inland Streams* (Tiller and Newall 1995);
- guidelines published by the Office of the Commissioner for the Environment (1988); and
- discussion with experts.

Table 6.3 - Ratings for 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

6.5.2 Turbidity

Turbidity typically increases from the headwaters to the lower reaches of a river. Ratings are presented in table 6.4. These are based on those developed by the Office of the Commissioner for the Environment (1988). These rating relationships were checked using median turbidity data for selected stream gauging sites in Victoria and appear to provide a reasonable assessment of water quality.

Table 6.4 - Ratings for 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

6.5.3 Salinity / electrical conductivity

Salinity typically increases downstream from headwaters so two sets of ratings are provided, one for upland and one for lowland reaches. Ratings are based on those in Office of the Commissioner for the Environment (1988) but modified following discussion with experts and an analysis of data from sites in 6 basins across Victoria (see table 6.5). For tidal reaches this indicator is not assessed.

Table 6.5 - Ratings for electrical conductivity ($\mu S\ cm^{-1}$)

Upland	Lowland	Rating
< 50	< 100	4
50 - < 150	100 - < 300	3
150 - < 300	300 - < 500	2
300 - < 500	500 - < 800	1
≥ 500	≥ 800	0

6.5.4 Alkalinity / acidity (pH)

Ratings for pH are presented in table 6.6. These criteria are based on those published by the Office of the Commissioner for the Environment (1988) but have been modified following checks against recorded water quality data and discussion with experts. The criteria are uniform along the length of streams and throughout Victoria.

Table 6.6 - Ratings for pH

pH range	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

6.6 Calculating the Water Quality Sub-index score from indicator ratings

To assess the Water Quality Sub-index, measurements are required at only the reach scale. The symbol and range of each indicator is given in table 6.7.

Table 6.7 - Indicators in the Water Quality Sub-index

Indicator	Symbol	Range
Total phosphorus	*TP*	0 - 4
Turbidity	*T*	0 - 4
Electrical conductivity	*EC*	0 - 4
Alkalinity/acidity	*pH*	0 - 4

Equation 6.1 is used to calculate the Water Quality Sub-index score (where the subscript *r* highlights that all indicators are measured on a reach basis).

$$WQ_r = \frac{10}{16}\sum\left[TP_r + T_r + EC_r + pH_r\right] \qquad (6.1)$$

For tidal reaches, electrical conductivity is not assessed so the equation becomes

$$WQ_r = \frac{10}{12}\sum\left[TP_r + T_r + pH_r\right] \qquad (6.2)$$

6.7 Overview of procedure to evaluate the Water Quality Sub-index

The procedure to evaluate the Water Quality Sub-index is shown in figure 6.1.

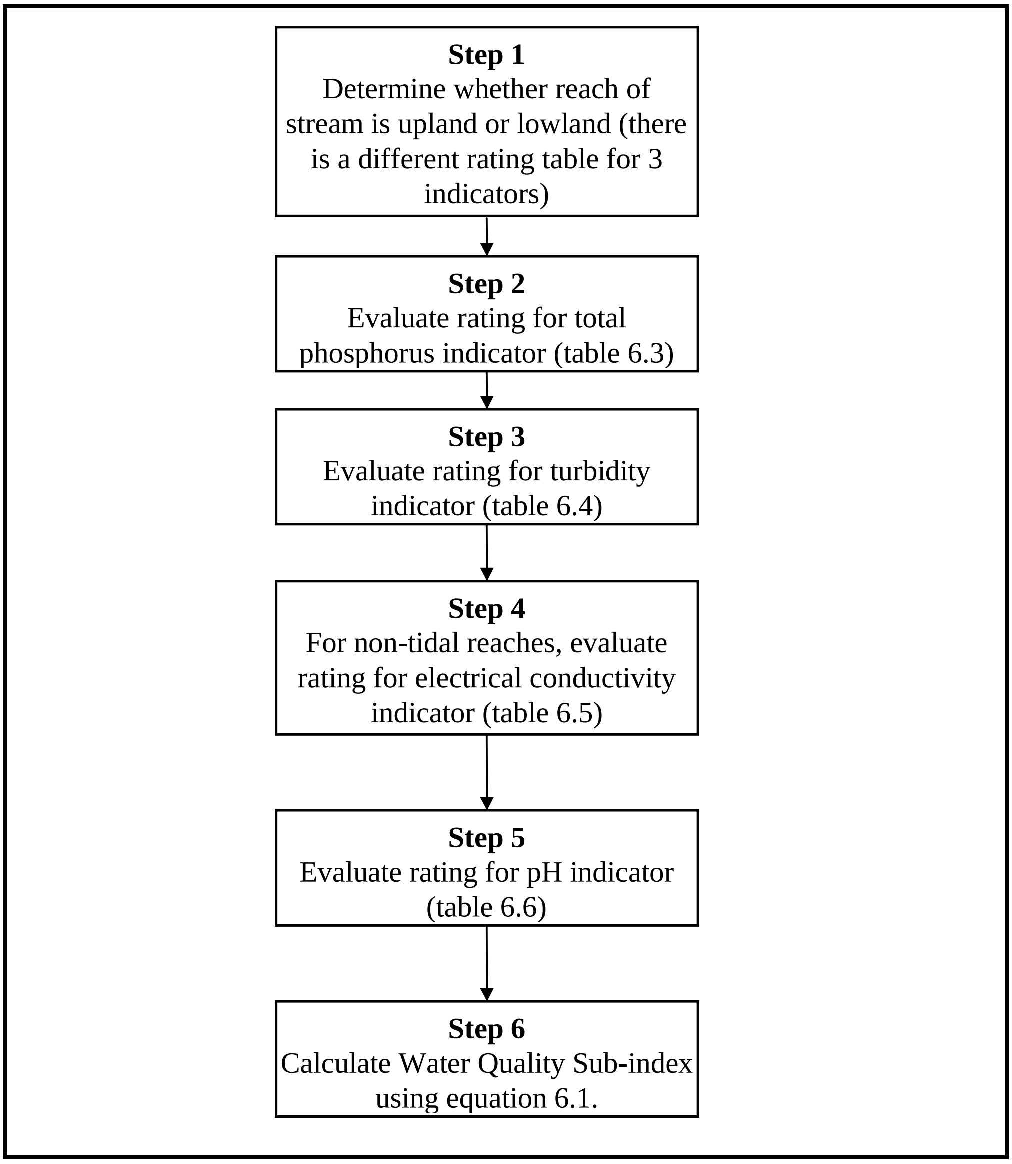


Figure 6.1 - Procedure for calculating Water Quality Sub-index score.

6.8 Example application of the Water Quality Sub-index

Details on how to apply the Water Quality Sub-index are in the accompanying *Users' Manual.* A sample application of the Water Quality Sub-index for 3 consecutive reaches of the Macalister River is given below (from the *Trial Applications* report, ID&A Pty Ltd and CEAH 1997d).

- Macalister River immediately upstream of Lake Glenmaggie (reach 17);

- Macalister River between Glenmaggie Dam and Bellbird Corner (which is a few kilometres upstream of Maffra, reach 16); and
- Macalister River from Bellbird Corner to the Thomson River (reach 15).

Reach 17 is an upland reach. Reaches 16 and 15 are lowland reaches in the Macalister Irrigation District, and it is expected that the ratings for nutrients and turbidity would reflect significant changes from reference conditions. All of these reaches are non-tidal.

The results are given in table 6.8.

Table 6.8 - Sample calculation of Water Quality Sub-index score (data source: Water Ecoscience Pty Ltd, adapted from ID&A Pty Ltd and CEAH 1997)

	Macalister River reach immediately upstream of Lake Glenmaggie Reach 17		Macalister River between Glenmaggie Weir and Bellbird Corner (near Maffra) Reach 16		Macalister River between Bellbird Corner and Thomson River confluence Reach 15	
Indicator	**Median value**	**Rating**	**Median value**	**Rating**	**Median Value**	**Rating**
Total phosphorus ($mg\ m^{-3}$)	9.5	4	23.5	3	155	0
Turbidity (NTU)	2.3	4	5	4	15.5	3
Electrical conductivity (µS/cm)	46	4	240	3	120	3
pH	7.1	4	6.9	4	7	4
Total		16		14		10
Water Quality Sub-index score [1]		**10**		**9**		**6**

1 - Sub-index scores are given to 0 decimal places.

7. AQUATIC LIFE SUB-INDEX[1]

7.1 Statewide issues relating to aquatic life

There are many types of aquatic biota - including fish, platypus, invertebrates, algae, macrophtyes and bacteria. All are necessary components of healthy aquatic ecosystems, and some of these, particularly fish, and have direct economic importance. Victoria-wide issues related to aquatic life include:

- the frequency, extent and duration of cyanobacteria (blue-green algae) blooms;
- the invasion of exotic fish species (including European carp, *Cyprinus carpio*);
- fish kills; and
- the general decline of frog and fish numbers leading to species being endangered e.g. the Trout cod, *Maccullochella macquariensis*, vulnerable e.g. Murray Cod, *Maccullochella peeli peeli* (Koehn and Morrison 1990); or threatened e.g. Southern Bell Frog *Litoria raniformus*.

7.2 Why include an Aquatic Life Sub-index in the ISC?

Aquatic biota is influenced by many environmental factors. Most notable are hydrology, physical form (including the presence of fine sediment, habitat and barriers), streamside zone (including shading and sources of energy) and water quality (including nutrients and turbidity). Therefore, the aquatic biota is strongly dependent on the other sub-indices, and possibly, other environmental factors not included in the ISC (e.g. heavy metals, water temperature). The Aquatic Life Sub-index is intended to be a 'catch-all' to detect if anything is affecting the health of the aquatic ecosystem. A deterioration of the aquatic biota may point to environmental problems even if all the other sub-indicators of the ISC score well.

7.3 Existing approaches - possible indicators

Biological assessment usually involves description of plant and animal communities, particularly in terms of diversity and abundance. There are a variety of approaches that can be used to assess the state of health of the biotic community such as indicator species, biotic indices, statistical analysis and modelling, biomarkers and others. Usually a community of organisms is chosen e.g. a taxonomic group (e.g. macroinvertebrates or algae) or functional group (e.g. predators or shredders) and the composition of this group is used as the indicator of environmental health (Hellawell 1986). Possible indicators for the Aquatic Life Sub-index are summarised in table 7.1 together with comments on their suitability for a broad scaled index like the ISC.

[1] This section has been prepared by Leon Metzeling (EPA), David Robinson (EPA), Lindsay White and Anthony Ladson (Centre for Environmental Applied Hydrology)

Table 7.1 - Possible indicators for the Aquatic Life Sub-index

Possible Indicator	Comment	Suitable
Bacteria	Mainly used in relation to human health and water borne diseases e.g. *E. coli*. Bacteriological laboratory methods are well developed but their ecological meaning is unclear. Bacteriology of clean waters is not far advanced.	No
Protozoa	Used in Europe as part of the "saprobien system" which was developed to assess organic pollution (Hellawell 1986). It requires considerable taxonomic expertise and has not been extensively used elsewhere.	No
Algae/Diatoms	This includes single celled attached (e.g. benthic diatoms) and floating algae (phytoplankton) and filamentous forms (e.g. *Cladophora*). Diatoms are often cosmopolitan, ubiquitous, have a wide range of ecological requirements and tolerance, a propensity for rapid dispersal and invasion and well known taxonomy and biology (Hellawell 1986). A high degree of taxonomic expertise is required.	No
Macro-invertebrates	This includes insects, molluscs, mites, crustaceans and worms. The advantages of using macroinvertebrates are many. They are ubiquitous, sedentary in nature and therefore reflect local conditions, have life cycles ranging from weeks to a few years, a large number of species with a wide range of tolerance to environmental conditions (Rosenberg and Resh 1993; Metcalfe-Smith 1992), well known and relatively simple taxonomy and sampling procedures. Internationally they are the most commonly used component of the aquatic biota for monitoring (Hellawell 1986) and are currently the subject of a nationwide assessment of river health (Davies 1994). Disadvantages are an indirect response to nutrients and some toxicants (e.g. herbicides), the difficult taxonomy of a few groups and local endemism.	Yes
Macrophytes	These include the larger emergent aquatic plants such as reeds and rushes and the submerged plants such as water milfoil and elodea. The advantages of macrophytes are visibility due to their relatively large size, obviously sedentary nature and well known taxonomy. The disadvantages are that they are not ubiquitous (usually absent from forested streams) and have only a relatively small number of species.	No
Fish	They have the distinction of being monitored by the general public and are the charismatic mega-fauna of aquatic ecosystems. Advantages of using fish are they are easily identified, the community can relate to fish, they occupy a position near the top of the food chain, and are highly mobile thus reflecting broad scale conditions within the river system. Disadvantages of using fish are their mobility in that they can avoid or escape from stressful local conditions, and are relatively costly to sample as a variety of methods are often required (e.g. traps, nets, electrofishing).	Possible

7.4 Indicator selection

Two indicators based on macroinvertebrates have been selected for the ISC. These are SIGNAL and AUSRIVAS. An indicator base on fish has not been included at his stage as explained in box 7.1.

The development of indicators of stream health based on macroinvertebrates has been a priority of freshwater research in the last decade. Some stream health assessment techniques have been adapted to Australian conditions, and macroinvertebrates are the preferred group for use in assessing the ISC. Hellawell (1986) reviewed various components of the biota used in biological monitoring and concluded that

> *"it is unlikely the evident popularity of macroinvertebrates is self-perpetuating but rather that this group is first choice for routine surveillance because the methodology is relatively simple yet well developed and often requires only a single operator; the taxonomy is none too difficult and keys are available for most groups; the group comprises a wide range of organisms thereby offering the possibility of varied responses to different environmental stresses and, finally, the sedentary habitats of most members of the group are conducive to spatial analyses while their relatively long life cycles permit temporal changes to be followed."*

In general, there are two approaches used in assessing macroinvertebrate data:

- calculating simple biotic indices; and
- statistical analysis and modelling.

An example of a biotic index is the Stream Invertebrate Grade Number - Average Level method (SIGNAL) developed by Chessman (1995). SIGNAL uses scores awarded to families based on their sensitivity to stream salinisation and organic pollution.

An example of the statistical analysis and modelling approach is the River InVertebrate Prediction And Classification System (RIVPACS), developed in the UK for the evaluation of the biological quality of rivers. It generates site-specific predictions of the macroinvertebrate fauna to be expected in the absence of environmental stress (Wright *et al*. 1984). A similar approach has been developed in Australia, the Australian Rivers Assessment System (AUSRIVAS) (Davies 1994; Parsons and Norris 1996).

Both SIGNAL and AUSRIVAS provide useful discrimination between impacted and un-impacted sites with AUSRIVAS being considered to be more sensitive to habitat quality and SIGNAL more sensitive to water quality. Both approaches are being actively researched and both will be used in the ISC. It is hoped that in the future, Waterwatch will be able to provide accurate enough data to assess these indicators. Further details on SIGNAL and AUSRIVAS are included in sections 7.4.1 to 7.4.4 respectively.

7.4.1 SIGNAL

The SIGNAL index has been developed for eastern Australia by Chessman (1995) and is a modification of the British Biological Monitoring Working Party score system (Armitage *et al*. 1983). In SIGNAL, numerous families of widespread macroinvertebrates have been awarded sensitivity grades by Chessman, based on published information and his personal observations on their tolerance or intolerance to various pollutants. Limitations of this approach are that species within a single family can often show considerable variation in their response to pollutants, and some families are sensitive to certain types of pollutants yet tolerant of others.

Sensitivity grades for families commonly found in eastern Australian rivers are given in table 7.2. 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. The resulting value or SIGNAL can vary from 1 to 10, and can be used to assess a site's status in terms of organic pollution. A site with typically low organic pollution would have a high SIGNAL value (>6) and a site with probable severe pollution would have a low value (<4) (Chessman 1995).

The SIGNAL index has been tested using data collected from rapid bioassessment sampling procedures (Chessman 1995 and pers. comm.; Environmental Protection Authority 1998). These procedures aim at sampling a broad range of habitats at a site resulting in a comprehensive list of species or families. Data from traditional, quantitative sampling methods (e.g. Surber sampling) has also been successfully used in calculating the SIGNAL index (Metzeling *et al*. 1996), success being measured as detection of impact due to pollution.

For the purpose of calculating the SIGNAL and AUSRIVAS indices any sampling protocol capable of providing a comprehensive list of macroinvertebrate species at a site could be used. Furthermore the sampling techniques used at various sites need not be exactly the same, however it is preferable to use a standard technique where possible. A suitable approach recommended for routine monitoring for the purpose of assessing stream condition is that used in the MRHI baseline biological monitoring program (Davies 1994).

The results of a single sampling run only could be used for calculation of SIGNAL values, however it would be preferable to use data collected from at least two seasons e.g. spring (typically high flow under natural conditions) and autumn (typically low flow under natural conditions). SIGNAL only generally requires the relatively low level of taxonomic resolution of family, which should make it straightforward to use with only a moderate level of taxonomic expertise. Chessman (1995) provides scores for the separate families of Oligochaeta (segmented worms) but as they are rarely identified to family in routine monitoring, the Victorian EPA recommend a score of 1 for all Oligochaeta. Some Oligochaeta families are listed separately in table 7.2 but are all given a score of 1. Watermites (Acarina) are not included in the SIGNAL index.

Under the National River Health Program (NRHP), Chessman has analysed data from all States and Territories and developed a National SIGNAL index by altering some of the existing scores. However, this has yet to be finalised and has not been published. Therefore, at this stage the Victorian EPA recommend using the SIGNAL scores published in 1995 supplemented by scores for families and chironomid sub-families which were not in the original publication but which have been provided by Chessman to the EPA. These are included in table 7.2.

Limitations of SIGNAL

SIGNAL has been validated for assessment of stream salinisation and organic pollution from sewage treatment plants (Chessman 1995) but its usefulness for assessing toxic pollution and other types of disturbance is uncertain. Also, its applicability to ephemeral streams and large lowland rivers is uncertain. SIGNAL was published in 1995 was developed using perennially flowing upland streams in eastern Australia as the standard, and when applied to other types of streams the ratings are likely to be less accurate. However, the development of the national SIGNAL grades has indicated that there is little variation throughout the country (Chessman, pers. comm.) suggesting that SIGNAL will be applicable to a broad range of stream types.

Table 7.2 - Pollution sensitivity grades for common families of eastern Australian river macroinvertebrates. Most grades are from Chessman (1995). Taxa marked with an * use unpublished SIGNAL values provided by Chessman (pers. comm.).

Family	Grade	Family	Grade	Family	Grade	Family	Grade
Aeshnidae	6	*Dolichopodidae	6	Hydroptilidae	6	*Perthidae	6
Ameletopsidae	10	Dugesiidae	3	Hygrobiidae	5	Philopotamidae	10
Amphipterygidae	8	Dytiscidae	5	Hyriidae	6	Philorheithridae	8
Ancylidae	6	Ecnomidae	4	Isostictidae	7	Phreodrilidae	5
Antipodoecidae	10	Elmidae	7	Janiridae	5	Physidae	3
*Aphroteniinae	7	Empididae	4	Kokiriidae	10	Planorbidae	3
Athericidae	7	Ephydridae	2	Leptoceridae	7	*Podonominae	7
Atriplectididae	10	Erpobdellidae	3	Leptophlebiidae	10	Polycentropodidae	8
Atyidae	6	Eusiridae	8	Lestidae	7	Protoneuridae	7
Austroperlidae	10	Eustheniidae	10	*Lestoididae	8	Psephenidae	5
Baetidae	5	Gammaridae	6	Libellulidae	8	Psychodidae	2
Belostomatidae	5	Gelastocoridae	6	Limnephilidae	8	Ptilodactylidae	10
Blephariceridae	10	Gerridae	4	Lumbriculidae	1	Pyralidae	6
Caenidae	7	Glossiphoniidae	3	Lymnaeidae	3	*Richardsonianidae	4
Calamoceratidae	8	Glossosomatidae	8	Megapodagrionidae	7	Scirtidae	8
Calocidae	8	Gomphidae	7	Mesoveliidae	4	Sialidae	4
Ceinidae	5	Gordiidae	7	Muscidae	3	Simuliidae	5
Ceratopogonidae	6	Gripopterygidae	7	Naididae	1	*Sisyridae	5
Chironomidae	1	Gyrinidae	5	Nannochoristidae	10	Sphaeriidae	6
*Chironominae	6	Haliplidae	5	Naucoridae	5	Staphylinidae	5
*Chlorolestidae	9	Haplotaxidae	5	Nepidae	5	Stratiomyidae	2
*Cirolanidae	6	Hebridae	6	Neurorthidae	8	Synlestidae	7
Coenagrionidae	7	Helicophidae	10	Notonectidae	4	Synthemidae	7
Coloburiscidae	10	Helicopsychidae	10	Notonemouridae	8	Tabanidae	5
Conoesucidae	8	Hydraenidae	7	Odontoceridae	8	*Talitridae	5
Corbiculidae	6	Hydridae	4	Oniscigastridae	10	*Tanypodinae	6
Corduliidae	7	Hydrobiidae	5	*Orthocladiinae	4	Tasimiidae	7
Corixidae	5	Hydrobiosidae	7	Osmylidae	8	*Temnochephalidae	6
Corydalidae	4	Hydrochidae	7	*Paleomonidae	5	Thaumaleidae	7
Culicidae	2	Hydrometridae	5	*Paracalliopidae	7	Thiaridae	7
*Diamesinae	6	Hydrophilidae	5	*Paramelitidae	5	Tipulidae	5
Dixidae	8	Hydropsychidae	5	Parastacidae	7	Tubificidae	1
						Veliidae	4

7.4.2 AUSRIVAS

AUSRIVAS incorporates water quality, habitat assessment and biological measures in predictive models that can be used to assess river health. Each model uses reference data from a single aquatic habitat from either a single season (autumn or spring) or from the two seasons combined. EPA recommends using data from two seasons combined (autumn and spring) as this is considered to give more reliable results.

AUSRIVAS 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 at a test site, in the absence of any environmental impacts, with the number of families actually found, the O/E index (observed number of families/expected number of families) can be calculated. The value of the O/E index can range from a minimum of zero (none of the expected families were found at the site) to around one (all of the families which were expected were found). It is also possible to derive a score of greater than one, if more families were found at the site than were predicted by the model. A site with a score greater than one might be an unexpectedly diverse location or, more usually, the score may indicate mild nutrient enrichment, allowing additional macroinvertebrates to colonise.

Limitations of AUSRIVAS

The computer models that are used to determine AUSRIVAS scores have undergone extensive development and are still being reviewed although they are not expected to change significantly. Some issues requiring further investigation include the sensitivity of statewide models compared with more regional models, the long-term temporal stability of the models, and the responsiveness of the AUSRIVAS scores to various impacts (e.g. the relative importance of organic pollution and habitat in influencing the scores).

A procedural limitation in Victoria is that access to the models is currently only through EPA. This is expected to change during 1999 when general access via the Internet will be made available. Currently, the AUSRIVAS web site <http://ausrivas.canberra.edu.au/ausrivas>, which is maintained by the CRCFE, can be viewed and the manual downloaded.

Box 7.1 - Why indicators based on sampling fish are not included in the ISC at this time

A number of catchment managers have questioned why indicators based on sampling the freshwater fish population are not included in the ISC at this time. The primary reason is cost: for large scale surveys using a range of gear it currently costs about $600 per site (J. Harris pers. comm., T. Raadik pers. comm.). This cost is excessive for one sub-index.

However, the ISC includes some indicators of other parameters that are known to be important determinants of the freshwater fish population. For example, the decline in abundance of native freshwater fish are commonly attributed (e.g. Harris and Gehrke 1997) to factors such as:

- general habitat degradation;
- modified patterns of streamflow;
- interrupted migratory pathways;
- reduced water quality, and pollution;
- introduction of alien fish and diseases;
- illegal fishing and commercial overfishing;
- changed energy fluxes; and
- altered biotic interactions.

Indicators of the first 4 determinants are in the ISC.

The exclusion of fish from the ISC does not mean that fish are unimportant to catchment managers (or indeed to the SRG). CMAs or other stakeholders may decide to sample fish populations if there is a regional or local issue (for e.g. the number and distribution of rare species like Trout cod *Maccullochella macquariensis* or Australian grayling *Prototroctes maraena).* The Index of Biotic Integrity is showing potential as a way to measure stream condition based solely on the fish community (Harris and Gehrke 1997).

7.5 Selecting measuring sites for the Aquatic Life Sub-index

There is already an extensive program being undertaken to monitor aquatic macroinvertebrates throughout Victoria. The Victorian EPA is participating in the NRHP and by the end of 1999 will have sampled over 800 sites across the State.

If any additional data is collected to assess the Aquatic Life Sub-index, the EPA should be consulted about the location of its sites and methodology used. It is preferable that additional monitoring be complementary with these sites to provide a broader spatial coverage and improve quality control. Ideally the sampling density would be expanded to at least one site per reach.

In general, it is preferred if the data used to assess the Aquatic Life Sub-index was collected near the downstream end of a reach, so that changes within the reach can impact upon the ratings of the SIGNAL and AUSRIVAS indicators.

Results of the Aquatic Life Sub-index can only be compared if samples are taken from the same habitat type at all sites, or if sampling is comprehensive, that is all habitat types are sampled at all sites. Habitat types include: deep pools, riffles, stream edges and logs. It is recommended that a standard subset of habitats be sampled at all sites, for example in the NRHP riffles and stream edges are sampled at all sites if available.

7.6 Ratings of indicators in the Aquatic Life Sub-index

Both SIGNAL and AUSRIVAS are to be used in calculating the Aquatic Life Sub-index. They are to be given equal weight in the sub-index with ratings from tables 7.3 and 7.4 added together using equation 7.1. It is advantageous to identify the two components of this sub-index separately, as they appear to be responsive to different types of impact - organic pollution (SIGNAL) and habitat (AUSRIVAS). SIGNAL ratings have been divided into upland, and lowland reaches of streams.

Table 7.3 - Ratings for SIGNAL indicator

SIGNAL value (upland reaches)	SIGNAL value (lowland reaches)	Rating
>7	>6	4
6 - 7	5 - 6	3
5 - 6	4 - 5	2
4 - 5	3 - 4	1
<4	<3	0

Table 7.4 - Ratings for AUSRIVAS indicator

AUSRIVAS value	Rating
>0.80	4
0.79 - 0.60	3
0.59 - 0.40	2
0.39 - 0.20	1
< 0.20	0

7.7 Calculating the Aquatic Life Sub-index score from indicator ratings

To assess the Aquatic Life Sub-index, measurements are made at only the reach scale using data from the downstream end of the reach if available. The symbol and range of each indicator is given in table 7.5.

Table 7.5 - Indicators in the Aquatic Life Sub-index (all indicators are measured at the reach scale)

Indicator	Symbol	Range
SIGNAL	*SIG*	0 - 4
AUSRIVAS	*AUS*	0 - 4

The Aquatic Life Sub-index is calculated using equation 7.1 (where the subscript *r* highlights that each indicator is assessed on a reach basis):

$$AL_r = \frac{10}{8}\sum\left[SIG_r + AUS_r\right] \qquad (7.1)$$

7.8 Overview of procedure to evaluate the Aquatic Life Sub-index

An overview of the process to evaluate the Aquatic Life Sub-index is provided in figure 7.1. The comments below relate to the assessment procedure shown on figure 7.1.

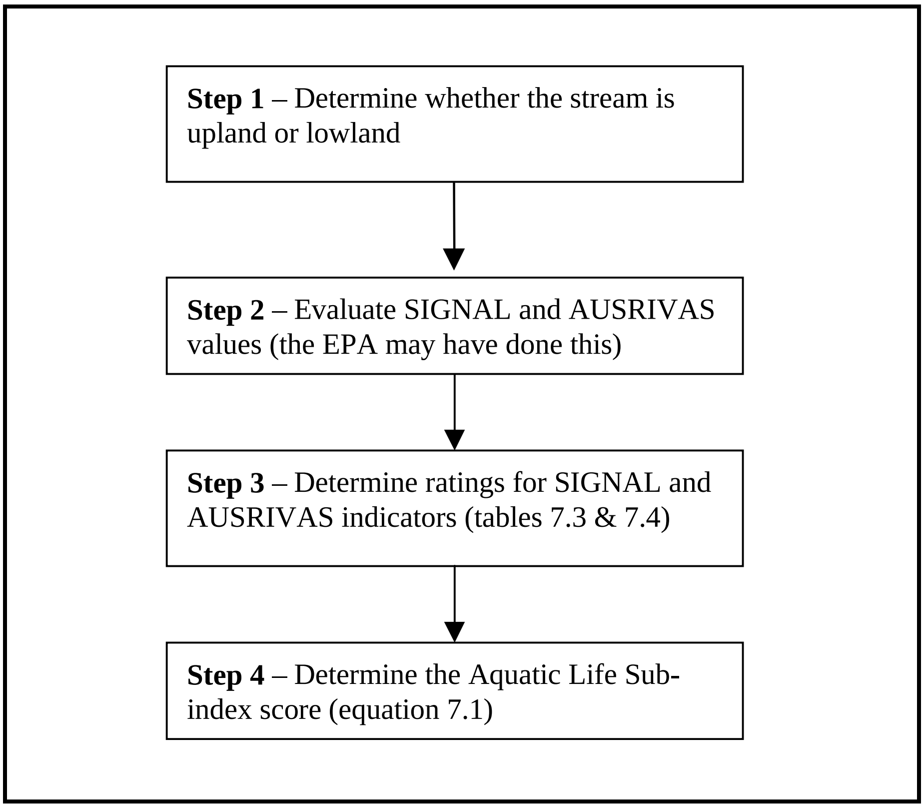


Figure 7.1 - Procedure for calculating Aquatic Life Sub-index score

7.9 Example application of the Aquatic Life Sub-index

Two examples are given of the calculation of the SIGNAL index for streams in the Avon River catchment (Thomson basin). For the locations of the reaches refer to figure 2.1 in the *Trial Applications* report (ID&A. Pty Ltd and CEAH 1997b). Reach 2 is the Avon River near Stratford, a medium sized lowland stream in an open gravelly channel with fringing vegetation in relatively poor condition. Reach 9 is the upstream end of Freestone Creek, a small upland stream with fringing vegetation in excellent condition (data source, Water Ecoscience).

Step 1 - Determine whether the stream reach is upland or lowland
Reach 2 is lowland, reach 9 is upland.

Step 2 - Evaluate SIGNAL and AUSRIVAS indicator values

The Victorian EPA undertook this - see bottom two rows of table 7.6.

Step 3 - Evaluate SIGNAL and AUSRIVAS indicator ratings

These are provided in the bottom two rows of table 7.6.

Step 4 - Determine the Aquatic Life Sub-index score

Using the ratings in table 7.6, and equation 7.1, the Aquatic Life Sub-index score for:

- reach 2 is 5; and
- reach 9 is 9.

Table 7.6 - Sample calculation of the Aquatic Life Sub-index

Reach 2 - Avon River near Stratford		**Reach 9 - Freestone Creek**	
Family of macroinvertebrates	**Grade**	**Family of macroinvertebrates**	**Grade**
Atyidae	6	Aeshnidae	6
Baetidae	5	Amphipterygidae	8
Chironomidae	1	Athericidae	7
Coenagrionidae	7	Atyidae	6
Corixidae	5	Baetidae	5
Gerridae	4	Caenidae	7
Leptoceridae	7	Calamoceratidae	8
Nepidae	5	Chironomidae	1
Notonectidae	4	Corduliidae	7
Planorbidae	3	Corixidae	5
Veliidae	4	Corydalidae	4
		Dytiscidae	5
		Elmidae	7
		Gelastocoridae	6
		Gomphidae	7
		Gyrinidae	5
		Helicophidae	10
		Hydrobiosidae	7
		Hydrophilidae	5
		Hydropsychidae	5
		Hydroptilidae	6
		Leptoceridae	7
		Leptophlebiidae	10
		Notonectidae	4
		Odontoceridae	8
		Oligochaeta	1
		Philopotamidae	10
		Psephenidae	5
		Simuliidae	5
		Sphaeriidae	6
Total of sensitivity grades	51	Total of sensitivity grades	183
Number of families	11	Number of families	30
SIGNAL value (and rating)	**4.6 (2)**	**SIGNAL value**	**6.1 (3)**
AUSRIVAS score (and rating)	**0.43 (2)**	**AUSRIVAS score (from model)**	**0.96 (4)**

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APPENDIX 1. FURTHER DETAIL ON THE ISC PROJECT AND ACKNOWLEDGMENTS

There have been 3 stages in the ISC project to date:
Stage 1 - development of a concept for an index;
Stage 2 - trialing and refining the concept;
Stage 3 - adapting the ISC to a changed context; and
Stage 4 - an application of the ISC across Victoria in 1999.

Future stages are:
Stage 5 - refinements of the ISC following assessment of results and feedback from users.

Intellectual and financial contributions during the development of the ISC are acknowledged at the back of this appendix, together with a complete list of ISC references.

Stage 1: Development of the ISC concept

The ISC was initially developed by:

- collecting information and ideas during a literature review concentrating on alternative stream assessment methodologies (Ladson & White 1999; CEAH and ID&A Pty Ltd 1995)
- discussing important aspects of stream condition with stream scientists and managers throughout Australia;
- collating and filtering information prior to presentation to a group of scientists and potential users of the ISC (the Specialist Reference Group - SRG); and
- developing a prototype ISC to be refined during field trials (CEAH and ID&A Pty Ltd 1995; Ladson *et al*. 1996).

During the literature review, many existing methodologies for assessing stream condition were considered. These approaches include:

- Conservation Value and Status of Victorian Rivers (Macmillan and Kunert 1990, Macmillan 1990);
- Estuarine Health Index - South Africa (Cooper *et al*. 1993a; Cooper *et al*. 1993a);
- State of the Environment Report - Victoria (Office of the Commissioner for the Environment 1988);
- Water Victoria Handbooks (Department of Water Resources, Victoria 1989a; Department of Water Resources, Victoria 1989b);
- River Condition Surveys - Western Australia (Water Authority of Western Australia 1995; Waterways Commission 1994);
- Rivers and Streams Special Investigation (Land Conservation Council 1989);
- A Riparian, Channel and Environmental Inventory (Petersen 1992);
- The Environmental Condition of Victorian Steams (Mitchell 1990);
- State of the Rivers Project - Queensland (Anderson 1993);
- Towards Healthy Rivers - CSIRO (CSIRO Division of Water Resources 1992);
- Stream Watch - Melbourne, Victoria (Melbourne Parks and Waterways 1995);
- Rapid bioassessment protocols - US EPA (Plafkin *et al*. 1989);

- National Water Quality Inventory - US EPA (1996); and
- Stream Condition and Resources Inventory Program - Melbourne, Victoria (Melbourne Water 1995).

Many of these stream assessment techniques are discussed in appendix 2.

Stage 1 culminated in the release of a report titled the *Development of an Index of Stream Condition* (CEAH and ID&A Pty Ltd 1995).

Stage 2: Trialing and refining the ISC

Stage 2 of the development of the ISC involved trialing and refining of the ISC concept:

- trialing ISC in parts of the Lake Wellington and Broken-Goulburn catchments (including the assessment of field indicators by staff of Waterway Management Authorities);
- holding field workshops for a few reaches with the SRG to discuss whether the results accorded with expectations;
- evaluating the results of the field trials for all of the reaches and refining the ISC through further discussion with the SRG; and
- writing a series of ISC manuals (dated April 1997).

The manuals in the 1997 ISC series were:

- *An Index of Stream Condition: Reference Manual* (CEAH and ID&A Pty Ltd 1997);
- *An Index of Stream Condition: User's Manual* (ID&A Pty Ltd and CEAH 1997a); and
- *An Index of Stream Condition: Trial Applications* (ID&A Pty Ltd and CEAH 1997b).

Over 300 copies of each of these ISC manuals were produced and distributed to all States and Territories across Australia, and at least 5 overseas countries (UK, Canada, USA, NZ and South Africa). These manuals have now been superseded by the 1999 series produced at the end of stage 3.

Stage 3: Adapting ISC for a changed context

There were a number of events between 1997 and 1999 that prompted a series of refinements to the ISC. These events included:

- feedback from a number of presentations on the ISC;
- the creation of CMAs, and consultation with CMA staff who would have responsibility for undertaking the ISC application within their area;
- physical habitat data being made available from the *First National Assessment of River Health* (FNARH) and the *Monitoring River Health Initiative* (MRHI) by the Victorian EPA; and
- a statistical analysis of whether ‘representative sites’ could be selected for the collection of field data given the variability of indicators in the Physical Form Sub-index and Streamside Zone Sub-index (see appendix 3 for details).

Some of the key changes to the ISC during stage 3 are listed in table 1.2.

Over stages 1, 2 and 3 of the project, presentations on the ISC have been given to:

- the Association of Victorian Waterway Management Authorities (AVRMA) annual conference (1995);
- the American Geophysical Union meeting in San Francisco (1995);
- the West Gippsland CALP Board and the Broken River Management Board (1996);
- the AVRMA Field Operators conference (1996);

- the 23rd and 24th Hydrology and Water Resources Symposia (1996 and 1997);
- a Workshop at Wyangala Dam of some DLWC River Managers from regional NSW;
- a meeting of EPA officers from NSW and WA (1997);
- a workshop arranged by the River Basin Management Society on indicators of catchment health;
- research fora at the University of Melbourne and Monash University;
- a science committee overseeing the First National Assessment of River Health;
- the 2nd National Workshop on Integrated Catchment Management (1997);
- the Chairs of the CMAs (1998);
- the East Gippsland, West Gippsland and Port Phillip CMAs (1998);
- the National Waterwatch Conference (July 1998); and
- the Second Stream Management Conference (February 1999).

In stage 3, a protocol was developed to convert the FNARH and MRHI data to ISC ratings for a number of indicators. This protocol is provided in the *Users' Manual.*

Stage 4: 1999 statewide application

A statewide application of the ISC will take place in 1999. A summary of the procedure follows.

- Sub-divide the state into stream basins based on the Australian Water Resources Council definitions.
- Select a number of sample reaches within each basin to represent the range and extent of stream types;
- Collect data for each sample reach, according to standardised procedures;
- Process data into information in a standardised format or where data are not available, use standardised procedures to estimate indicator values
- Store information using appropriate database procedures; and
- Use information to assist with strategic waterway management. For example query the database to obtain information required to develop an understanding of the current condition and to assess long-term trends.

The procedure will be implemented within the context of the project quality assurance and control plan (see the *Users' Manual*). Training of about 100 representatives from Catchment Management Authorities is complete.

Stage 5: Future developments

It is likely that there will be continued refinements and updates of the ISC as:

- research provides new insights into the critical aspects of stream condition;
- new stream management issues arise and new indicators are considered;
- the cost of measurement techniques are influenced by technological changes so that it may be appropriate to measure different indicators;
- rating tables are refined and regional rating tables are introduced; and
- the ISC is adapted for use outside Victoria.

ISC scores before and after changes in methodology may not be directly comparable. It may be necessary to update old spreadsheets with new formulae or data so that it is valid to compare ISC results at various points of time. Specific procedures will depend on the nature of any actual change to the ISC.

Acknowledgment of intellectual contributions

The SRG acted as the directors of the ISC project, and were the major source of intellectual input. They are listed in table A1.1, together with the affiliation of each SRG member at the time of contribution. The primary authors of the 1999 ISC manuals have been Lindsay White and Tony Ladson. Paul Wilson has managed the project for NRE. Leon Metzeling and David Robinson (Environment Protection Authority, Victoria) were the primary authors of the chapters on aquatic life. A complete list of publications on the ISC is included at the end of this appendix.

Those listed in table A1.2 also made valuable intellectual contributions to the development of the ISC.

Table A1.1 - Project Specialist Reference Group

Name	Affiliation(s) at the time of contribution
Chris Chesterfield	Melbourne Water
Lisa Dixon	EPA
Tim Doeg	NRE
Dr Jane Doolan	NRE
Associate Professor Brian Finlayson	Department of Geography and Centre for Environmental Applied Hydrology, University of Melbourne
Professor Barry Hart	Water Studies Centre, Co-operative Research Centre for Freshwater Ecology, Department of Science, Monash University
Graeme Hunter	NRE
Professor Sam Lake	Department of Ecology and Evolutionary Biology, Co-operative Research Centre for Freshwater Ecology, Monash University
Ian Morgans	Association of Victorian Waterway Management Authorities
John Tilleard	ID&A Pty Ltd

Table A1.2 - Additional contributors to development of ISC

Name	Affiliation(s) at time of contribution
Cameron Allen, Rex Candy, Geoff Claffey, Ross Hardie, Simon Robertson, Deb Rossell (dec.), Wayne Tennant	ID&A Pty Ltd
Chris Barry	East Gippsland Catchment and Land Protection Board
Paul Bennett, Katrina Fox, Wayne Gilmour, Vera Lubczenko, Stuart Minchin, Carol Roberts, Ben Shaw, John Woodland	Waterways Unit, NRE
Julie Bradley, Greg Gilbert, Noel Morgan,	Waterwatch (Gippsland)
Ian Davidson	NRE, Benalla
Pat Feehan, Dustin Lavery	Goulburn-Broken Catchment and Land Protection Board and CMA.
Tim Fletcher	Corangamite CMA
Walter Godoy, Kes Kesari, Bill Hansen	Water Bureau, NRE
Shelley Heron, Mark Batty, Scott Seymour, Roger Lord	Melbourne Water Corporation
George Kermode	West Gippsland Catchment and Land Protection Board
Boris Jawecki	University of Agriculture, Vienna, Austria
Tim Bessle-Brown, Leon Metzeling, David Robinson	EPA
Gordon O’Brien, Terry Grossman, Geoff Brennan, Max Collier, Steve Collins	Broken River Management Board
Steve Petchell, Barbara Dworakowski	Thiess Environmental Services Pty Ltd
Andrea Joyce, Greg Peters	North Central CMA
Tarmo Raadik	Marine and Freshwater Research Institute
Ian Rutherfurd, Kathryn Jerie	Co-operative Research Centre for Catchment Hydrology, Monash University
Ross Scott, Rod Johnston	Lake Wellington Rivers Authority
Julian Thompson	University of Melbourne

Acknowledgment of financial contributions

Funding of stages 1 and 2 was provided by NRE, the Commonwealth and Victorian EPA, and the Land and Water Resources Research and Development Corporation as part of the Monitoring River Health Initiative.

NRE and the National Rivercare Program (a program under the National Heritage Trust) are providing funding of stages 3 and 4.

Published information on the ISC

Ladson, A.R., White, L.J., Metzeling, L., Robinson, D. and Doolan, J.A. (1996) Index of Stream Condition as a tool to aid management of rivers. Hydrology and Water Resources Symposium, Hobart May 21 - 24. Institution of Engineers, Australia. pp. 325-331.

Ladson, A.R., White, L.J. and Doolan, J.A. (1997) Trialing the Index of Stream Condition in Victoria, Australia, 24th Hydrology and Water Resources Symposium, Auckland, NZ, 25 - 27 November, pp. 109 - 114.

Ladson, A. R., White, L. J., Doolan, J. A., Finlayson, B. L., Hart, B. T., Lake, P. S. and Tilleard, J. W. (1999). Development and testing of an Index of Stream Condition for waterway management in Australia. Freshwater Biology 41(2):453-468.

Along with the most recent copies of the ISC manuals.

APPENDIX 2. EXISTING APPROACHES FOR MEASURING STREAM CONDITION

The following review summarises overall approaches to assessing stream condition from Australian and international literature. Specific references relating to individual sub-indices are in chapters 3 - 7 of this manual.

The following studies are reviewed in this appendix:

- Conservation Value and Status of Victorian Rivers (Macmillan and Kunert 1990);
- Estuarine Health Index - South Africa (Cooper *et al*. 1993a & b);
- State of the Environment Report - Victoria (Office of the Commissioner for the Environment 1988);
- Water Victoria Handbooks (Department of Water Resources, Victoria 1989a & b);
- River Condition Surveys - Western Australia;
- Rivers and Streams Special Investigation (Land Conservation Council 1989);
- A Riparian, Channel and Environmental Inventory (Petersen 1992);
- The Environmental Condition of Victorian Steams (Mitchell 1990);
- State of the Rivers Project - Queensland (Anderson 1993);
- Towards Healthy Rivers - (CSIRO, Division of Water Resources 1992);
- Stream Watch - Melbourne, Victoria (Melbourne Parks and Waterways 1995);
- Rapid bioassessment protocols for use in streams and rivers - United States EPA (Plafkin *et al*. 1989);
- Stream Condition and Resource Inventory Program, Melbourne Water; and
- NSW State Rivers and Estuaries Policy, State of the Rivers and Estuaries, Environmental Indicators, A literature review (Department of Water Resources 1992)

The summaries provide a brief overview but then focus on those aspects that are of most relevance to developing the ISC. Important lessons for the ISC are documented for each study. Part of this review was published as Ladson and White (1999a).

A2.1 Conservation Value and Status of Victorian Rivers

Macmillan and Kunert (1990) propose a method to assess the conservation status and value of Victorian rivers. This method has been applied to East Gippsland rivers (Macmillan 1990).

Conservation assessment is based on consideration of:

- system naturalness i.e. changes in catchment and riparian land use from those under natural conditions;
- fish naturalness i.e. the extent to which exotic fish species are present; and
- the presence of geological and geomorphologic sites of significance.

Conservation value is the relative significance of a stream in national, state, regional or local terms.

The work of Macmillan is focused on protecting those streams with high conservation significance therefore only those stream systems that are ‘essentially unmodified’ or ‘slightly modified’ are rated. Streams with a greater degree of modification from natural conditions are not considered.

Lessons for the ISC

Most of this methodology was not suited to developing the ISC. The ISC will be used to aid management of stream systems where there has been extensive modification of catchments and streams from natural conditions.

A2.2 Estuarine Health Index - South Africa

An index of estuarine health has been developed and applied in South Africa (Cooper *et al*. 1993a and Cooper *et al*. 1993b). The index includes:

- an assessment of biological health
- a water quality index; and
- an aesthetic health index.

These 3 components make up a composite estuarine health index which is a single value representing the condition of the estuary.

The discussion below focuses mainly on the water quality component.

The categories measured as part of the water quality component are as follows. Seven indicators were used (Moore 1990) in 3 groupings

- **Suitability for aquatic life:**
  1. dissolved oxygen - essential to aquatic faunal metabolism;
  2. oxygen absorbed - measure of organic loading; and
  3. ammonia Nitrogen - toxicity to aquatic fauna.
- **Suitability for Human contact:**
  4. E.coli - evidence of human pathogens.
- **Trophic status:**
  5. Nitrate Nitrogen - aquatic growth stimulant;
  6. Orthophosphate - aquatic plant growth stimulant; and
  7. Chlorophyll-a - indicator of algal growth.

It was found that there was inadequate existing water quality data to evaluate the estuarine health rating. Instead, water quality was sampled specifically for use in the estuarine health index. Fifty-six estuaries in South Africa were sampled over a 4 week period.

For the Water Quality indicators, rating curves were used to convert the seven measured concentrations to standardised values between 1 and 10. The standardised values were then weighted and combined to produce a single number between 1 and 10. Higher values represented better quality water (Cooper *et al*. 1993b). The rating tables were established from the literature with review by a panel of experts.

Aesthetic health and biological health were also summarised on a scale from 1 to 10. The three values were presented as a stacked bar graph. The overall rating is from 0 to 30 but each of the components is clearly visible (Ramm, *et al*. 1994). See figure A2.1.

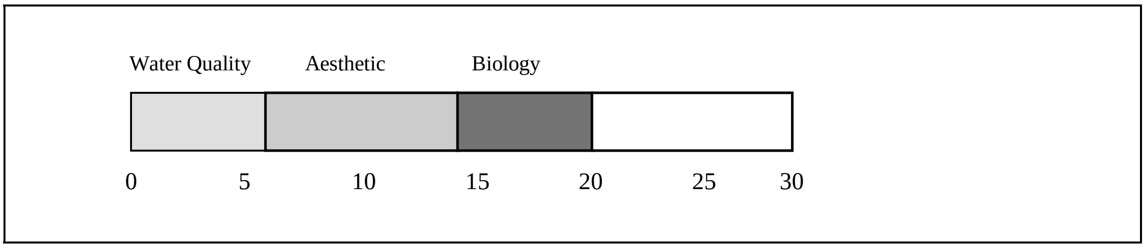

Figure A2.1 - Estuarine Health Index

Lessons for the ISC

Water quality ratings are based on water quality values measured over a 4 week period. There is no discussion of whether flow conditions during this time were typical of the rest of the year. It is likely that there will be great variation in water quality throughout the year. The procedures are useful as a "snapshot" measure of estuarine health but there is no framework for incorporating data from past or future monitoring. The graphical display of the composite health index is a clear and useful method for reporting the results of the overall assessment. A similar reporting arrangement was adopted for the ISC.

A2.3 State of the Environment Report - Victoria

In 1988 the Office of the Commissioner for the Environment prepared a report documenting the state of Victoria's Inland Waters. The report considered:

- human activities that cause environmental stresses on rivers and streams;
- environmental impacts as measured by changes in water quality; and
- environmental impacts as measured by changes in biology.

Rivers and streams were divided into 3 categories ie:

- mountain (headwaters, high gradients, steep sided valleys);
- valley (bounded by hills, moderate gradients, mixture of erosional and depositional features); and
- plain (broad alluvial or coastal flatlands, lowlands and wetlands segments).

An assessment was presented for each segment of each stream system in the state of Victoria. Results were presented as a grid with one cell for each indicator. The cell was colour coded to show condition i.e. excellent, good, poor etc.

Water Quality

The recommended statewide water quality indicators were:

- turbidity;
- suspended solids;
- conductivity;

- pH;
- Biochemical Oxygen Demand;
- total phosphorus;
- total Nitrogen;
- stream flow; and
- temperature.

It was also recommended that the following parameters be measured at specific sites where water quality is likely to be affected by land uses or human activities:

- heavy metals in sediments;
- biocides;
- residues in biota; and
- hydrocarbons in sediment.

The State of the Environment report relied on existing water quality measurements that mainly consisted of single samples collected on a monthly basis at stream gauging sites throughout Victoria. The measured values were converted to an environmental rating.

Table A2.1 shows the selection of categories for turbidity measurements. A similar procedure was used for the other water quality parameters.

The ratings for each of the parameters were then aggregated to give an overall water quality rating. For example the definition of a moderate rating was: "*slight increase in one or more of turbidity, salinity and nutrient levels; no substantial change in oxygen levels. Natural level of toxicants in water column*".

Table A2.1 - Criteria for assessing turbidity (NTU).

Rating	Mountain	Valley	Plain
Excellent	<5	<10	<15
Good	5 - 7.5	10 - 12.5	15 - 17.5
Moderate	7.5 - 10	12.5 - 15	17.5 - 20
Poor	10 - 12.5	15 - 22.5	20 - 30
Degraded	>12.5	>22.5	>30

Riparian Vegetation

Criteria are presented to assess the state of riparian vegetation. Ratings from excellent to degraded are used depending on intactness and the predominance of exotic species.

Lessons for the ISC

The simple stream classification / regionalisation system (mountain, valley, plain) and the use of rating tables is an appropriate way to provide a summary of information from raw data.

The assessments proposed in the State of the Environment Report had significant data requirements. The lack of available data meant that environmental ratings could not be given for much of the state. Reducing data requirements would be necessary to apply stream assessment more widely throughout the state.

A2.4 Water Victoria Handbooks

Aspects of stream condition are assessed in Water Victoria: An Environmental Handbook and Water Victoria: A Resource Handbook (Department of Water Resources, Victoria 1989a and Department of Water Resources, Victoria 1989b). Data are presented for all Victorian River basins.

Information includes:

- stream flow;
- water quality;
- water storages;
- erosion hazard;
- areas subject to flooding;
- riparian tree cover and adjacent land use;
- point source pollution;
- stream management works;
- fish; and
- invertebrates.

Lessons for the ISC

These reports provide important background data. A measure of stream condition would need to aggregate this type of data into an overall assessment.

A2.5 River Condition Surveys - Western Australia

The Water Authority of Western Australia has produced guidelines for assessing the value of streams. This project known as the ‘Living Streams Survey’ is based on criteria used in Victoria by Mitchell (1990). It has been modified to give greater value to factors such as shade and the presence of areas of permanent water which are more important in Western Australia.

Another project is being developed to identify representative rivers of the south west of Western Australia. This is a broad level classification system that groups reaches into 9 categories ranging from pristine to degraded. Ratings are based on the extent of degradation from natural conditions. It takes into account catchment land use, riparian vegetation, and impoundments. The classification system is more general than is intended for the development of an ISC in this report.

More detailed assessments have been undertaken in the Blackwood Catchment (Blackwood Catchment Coordinating Group 1994). Stream foreshore assessment data sheets have been developed to assess the condition of:

- a short section of river or creek (paddock scale survey); and
- a long section of river or creek (large scale survey).

The forms are designed for landholders to undertake the survey. Data are qualitative only.

Although the forms are quite simple, there seems to be some expert judgement required e.g. soil cohesion, vegetation health.

Lessons for the ISC

The methodology was not suitable for use in the ISC but the data sheets are a useful reference.

A2.6 Rivers and Streams Special Investigation - Victoria

The purpose of the Rivers and Streams Special Investigation (Land Conservation Council 1989) was to:

- make recommendations to the Government on the future uses of public land that relates to rivers; and
- to protect outstanding river values (the Heritage Rivers program).

A classification system was developed to identify stream types. This system combined geomorphic units and hydrologic regions;

- 29 geomorphic units were defined across the state; and
- 5 hydrologic zones were identified from wet with low variance to dry with high variance.

The environmental rating from the State of the Environment Report (Office of the Commissioner for the Environment 1988) was used as part of the investigation.

Lessons for the ISC

The stream classification system was considered when selecting reaches and sample sites for the ISC.

A2.7 A riparian, channel, and environmental inventory

Petersen (1992) outlined a procedure to measure the condition of small streams in lowland, agricultural areas.

The following parameters were measured:

- land use pattern beyond the immediate streamside zone (undisturbed, cleared, cultivated etc.);
- width of streamside zone from stream edge to field;
- completeness of streamside zone;
- vegetation of streamside zone within 10 m of channel;
- the occurrence of rocks and logs to retain flow;
- channel structure (width to depth ratio);
- the influence of sediment on channel structure;
- stability of bank material and whether it is anchored by vegetation;
- amount of bank undercutting;
- feel and appearance of the stony substrate (clean rounded stones perhaps with a blackened colour indicate a healthy stream);
- stream bottom, type of sediment and whether spaces between stones are filled with finer sediment;
- pool and riffle sequences;
- aquatic vegetation;

- fish type (indigenous or introduced);
- detritus whether dominated by wood and leaf debris or aquatic weeditors and algae; and
- type and number of macroinvertebrates.

Each of these parameters is given a numerical score with higher values representing better condition. The value for each site is totaled to give an overall rating and the results presented on a map showing colour coded stream reaches.

Lessons for the ISC

The rating scheme proposed by Petersen does not include a direct assessment of water quality or hydrology, so would need to be expanded to need the objectives of the ISC but the methodology of rating different aspects of streams may be appropriate.

Some of the parameters proposed by Petersen are not good measures of departures from naturalness. For example, bed sediments: Petersen gives sand bed streams a lower rating than gravel bed streams while in Victoria, some streams naturally have sandy beds.

A2.8 The Environmental Condition of Victorian Streams

Mitchell (1990) rated the environmental condition of Victorian streams. Parameters included:

- bed composition;
- proportion of pools and riffles;
- bank vegetation;
- verge vegetation;
- cover for fish;
- average flow velocity;
- water depth;
- amount of underwater vegetation;
- bed cover by organic debris; and
- amount of sedimentation and erosion.

Each was given a rating on a 5 level scale i.e. excellent, good, moderate, poor, and very poor. An overall environmental rating was produced for each site by combining all the components. Greatest weight was given to bed composition, bank and verge vegetation and the amount of cover for fish. Results are presented as bar graphs showing the stream length in each category.

Streams were categorised on the basis of catchment areas:

- minor streams - catchment area less than 5 000 ha;
- tributary streams - catchment area between 5 000 ha and 30 000 ha; and
- major streams - catchment area greater than 30 000 ha.

Ratings were produced for each stream type.

Lessons for the ISC

May of these concepts were adopted in the ISC. Mitchell does not include an assessment of hydrology, water quality and aquatic life, which are part of the ISC.

There is a great deal of natural variation in some of the indicators included in Mitchell's assessment for example, proportion of pools and riffles. Many streams that are undisturbed would not have achieved excellent ratings in this category because they naturally have few pools or riffles. The frame of reference of the ISC (as far as possible) was based on a concept of “naturalness” so that streams in undisturbed condition will rate highly regardless of the actual occurrence of (for example) pool and riffle spacing.

A2.9 State of the Rivers Project - Queensland

The aim of the State of the Rivers project is to compare stream sections in terms of their current condition and to assess changes from the original pristine condition (Anderson 1993). The State of the Rivers Project was conducted under the direction of the Queensland Department of Primary Industries.

The method depends on undertaking assessments at a large number of sites in the catchment. Assessments are made on data sheets that are set up to describe the following:

- the climate and regional land system of the catchment;
- subcatchment features - land use, soils, geology, slope, gradient;
- site features - land use, vegetation, land tenure, lowlands features;
- channel form, shape and dimensions;
- hydrology and water quality;
- banks, physical condition and process;
- bed and bars, physical condition and process;
- vegetation, aquatic, bank, riparian;
- aquatic habitat classification and condition; and
- scenic, conservation and recreational value.

For most parameters, data sheets are focused on collecting raw data. Ratings are produced using formulae that combine the data weighted in terms of their relative importance (Jackson and Anderson 1994). Ratings range from pristine (100%) to degraded (0%). The pristine condition criteria is set using a local undisturbed site as a reference.

This survey method requires very detailed assessment of a large number of parameters at each site. This detail is then reduced as the data are filtered and aggregated to produce an overall assessment of condition.

The survey method is time consuming. 44 days in the field were required to rate 507 km of the Maroochy River in south-east Queensland (Jackson and Anderson 1994).

Lessons for the ISC

This method is more detailed than what is required for the ISC, but is a useful reference.

Water quality information was not used in the development of an overall rating. The recording of water quality information is optional. Water quality data are required in the ISC.

A2.10 CSIRO - Towards Healthy Rivers

This report discusses the nature of river health and documents processes that are affecting river systems. There is particular emphasis on algal blooms. (CSIRO, Division of Water Resources 1992)

Lessons for the ISC

This report is mainly focused at developing Government policy over the whole of Australia. Some existing approaches to assessing river condition are cited.

A2.11 Stream Watch

The Stream Watch program monitors water quality in the Melbourne urban area. Melbourne Parks and Waterways coordinate the program. The first annual report was released for 1994 (Melbourne Parks and Waterways 1995).

Measured water quality parameters are:
- E.coli;
- Toxicants (heavy metals);
- Nutrients (nitrogen and phosphorus)
- suspended solids;
- turbidity;
- biochemical oxygen demand;
- dissolved oxygen; and
- pH.

Water quality results are converted to a rating from excellent to degraded based on criteria published in the Victorian State of the Environment report (Office of the Commissioner for the Environment 1988). There is no attempt to aggregate the results to an overall rating of water quality condition. Water quality measurements are related to objectives as detailed in State Environment Protection Policies.

Water quality results are displayed in map form. River segments are coloured to represent the rating.

Lessons for the ISC

The report shows that some criteria published in the State of the Environment report may not be applicable to the waterways monitored as part of the Stream Watch program. For example turbidity is rated as ‘poor’ to ‘very poor’ at most sites. The report states that ‘*high turbidity levels are common in many Australian waterways….the Yarra river has probably always been relatively muddy in its middle and lower reaches’*.

If the river is naturally turbid then it is not appropriate to set management objectives in terms of achieving turbidity in the artificially low, and probably unattainable, ‘good’ to ‘excellent’ categories. It is probably better to regionalise the categories so that realistic goals can be set.

A2.12 Rapid bioassessment protocols for use in streams and rivers - United States EPA

Plafkin *et al*. (1989) includes the following as part of habitat assessment:
- bottom substrate - available cover;
- embeddedness;
- flow velocity;
- channel alteration;
- bottom scouring and deposition;

- pool/riffle, run/bend ratio (difference between riffles divided by stream width;
- bank stability;
- bank vegetative stability; and
- streamside cover;

Plafkin *et al*. (1989) also recommends that the recording of water quality variables (temperature, dissolved oxygen, pH, and conductivity) even though these are not included in their index.

Lessons for the ISC

Indicators of physical habitat were included in the ISC to flag stream reaches where there are issues. The bioassessment protocols developed by Plafkin *et al*. (1989) (or similar methods) could be used during a more detailed investigation if that was necessary.

A2.13 Stream Condition and Resource Inventory Program

Melbourne Water (1995) has developed an extensive range of indicators in its Stream Condition and Resource Inventory Program (SCRIP) to benchmark the condition of waterways. The indicators include:

- physical form;
- riparian vegetation;
- water quality;
- hydrology;
- cultural value;
- scenic value; and
- recreational value.

Over 50 indicators are used in the SCRIP suite. No method of aggradation is used to develop a composite index to summarise results. Much of the data collected will be entered into GIS so that layers for each of the indicators can be produced.

The SCRIP suite of indicators is intended to be used at broad spatial and temporal scales.

Lessons for the ISC

SCRIP was mainly developed for assessing urban streams and was considered too detailed for rural streams that are the focus of the ISC. Further, a mechanism of aggradation is not provided for the SCRIP indicators which is necessary for the ISC.

A2.14 NSW State Rivers and Estuaries Policy, State of the Rivers and Estuaries, Environmental Indicators, A literature review

The Department of Water Resources (1992) have produced a summary of environmental indicators that could be used to give an indication of the state of rivers and estuaries.

The indicators were grouped into:

- water quality indicators;
- ecological indicators;

- geomorphic indicators;
- hydrologic indicators; and
- human indicators.

The document discusses a number of likely issues relating to the uses of possible indicators, but does not prescribe preferred indicators or provide ratings for each indicator.

Lessons for the ISC

Useful background reference for selecting indicators for the ISC.

APPENDIX 3. DEVELOPMENT OF THE ISC FIELD SAMPLING PROTOCOL

A3.1 Background

It is intended that, as far as possible, data to assess the ISC will be sourced from existing networks. For 8 indicators within the Physical Form and Streamside Zone sub-indices, supplementary field data is required. This appendix discusses the ISC field data collection protocol.

ISC scores are evaluated for stream reaches typically 10 - 30 kilometres in length that are chosen to be approximately homogeneous in terms of stream condition. That is, reaches are selected to have a reasonably consistent hydrology, water quality, and aquatic life and no step changes in physical form and streamside zone (an example of a step change would be to go from a forest to an agricultural area).

In the context of a Victoria-wide data collection program on stream condition, it is not feasible to collect data on the physical form and streamside zone along the full length of every stream reach. Instead, data must be collected by sampling at some measuring sites within the reach, and the results used to infer the condition of the full length of the reach.

Initially, it was proposed to sample at one measuring site per reach to collect the data on the physical form and streamside zone (CEAH and ID&A Pty. Ltd 1997). Under this protocol, a measuring site about 1 km long would be chosen, using local knowledge, to be representative of the longer reach (typically 10 - 30 km long). Measurements for most indicators in the Physical Form and Streamside Zone sub-indices would then be collected within this measuring site. It was hoped that this would be a quick and effective way of collecting accurate data. However, this study shows that the representative site approach may not be accurate and instead proposes a more robust approach based on random sampling at sites along a reach.

A3.2 The testing of the representative measuring site protocol

A3.2.1 Introduction

Two sources of data were available that allowed testing of the accuracy of the representative site protocol. The first data set was collected in 1996 at ‘representative measuring sites’ within the Broken River basin including the Broken River and Ryans Creek (ID&A Pty. Ltd and CEAH 1997b). The representative measuring sites were chosen by field workers of the (then) Broken River Management Board, who had extensive experience of the streams.

The second data set was collected in 1998 in a study undertaken by the CEAH, University of Melbourne[1] who collected detailed data on the physical form and streamside zone in the Broken River basin for 22 km of lowland reach on Ryans Creek; and 33 km of lowland reach on the Broken River (figures A3.1 and A3.2). Along these reaches every second kilometre was sampled using the methodology to assess each indicator described in the previous *Users' Manual* (ID&A Pty. Ltd and

[1] Boris Jawecki (from the University of Agriculture, Vienna, Austria), and Julian Thompson (from the University of Melbourne) collected the field data for this study.

CEAH 1997a) with measurements being made at 5 transects within each kilometre sampled (table A3.1).

Table A3.1 - Summary information on the streamside zone and physical form collected along Ryans Creek and Broken River.

Parameter	Ryans Creek	Broken River
Reach length (km)	22	33
Number of kilometres sampled	11	17
Number of transects per kilometre	10 (5 on each side of the stream)	10 (5 on each side of the stream)
Number of transects	110	170

A limitation of the detailed data set is that one of the streamside zone indicators - proportion of ground layer that is indigenous was not used during the analysis. When reviewing the data, this indicator seemed highly variable and following discussions with field assessors it was apparent that they did not have the skills to assess this indicator accurately under the conditions experienced. The Streamside Zone Sub-index score was calculated using the following formula, which excludes the proportion of ground cover.

$$SZ_s = \frac{10}{19}\left(\frac{1}{N_t}\sum_{t=1}^{N_t}\left[Wd_t + \frac{2}{3}\left(SIO_t + SIU_t + SIG_t\right) + \frac{1}{2}\left(PIO_t + PIU_t\right) + Rg_t\right] + LC_s + Bb_r\right) \tag{A3.1}$$

Where, SZ_s is the Streamside Zone Sub-index for a site. The subscript *t* refers to ratings of an indicator for a particular transect: *Wd* is the width rating, *LC* is the longitudinal continuity rating, *SIO, SIU*, *SIG* are the structural intactness ratings for overstorey, understorey and groundcover respectively, *PIO*, *PIU* are percentage indigenous for overstorey and understorey respectively, *Rg* is the rating for regeneration and *Bb* is the rating for wetlands and billabongs. The subscripts *r, s* and *t* refer to values for a reach, site and transect respectively. N_t is the number of transects within a site. All the indicators were rated from 0 to 4 apart from *Rg*, which was rated from 0 to 2 and *Bb* which is either 0 or 1 and was 0 for the reaches in this study.

The results for the Physical Form and Streamside Zone Sub-indices for the left and right banks of Ryans Creek and Broken River are shown in figures A3.3, A3.4, A3.5, and A3.6. Only one bank was accessed during the survey, the condition of the other bank being estimated across the stream.

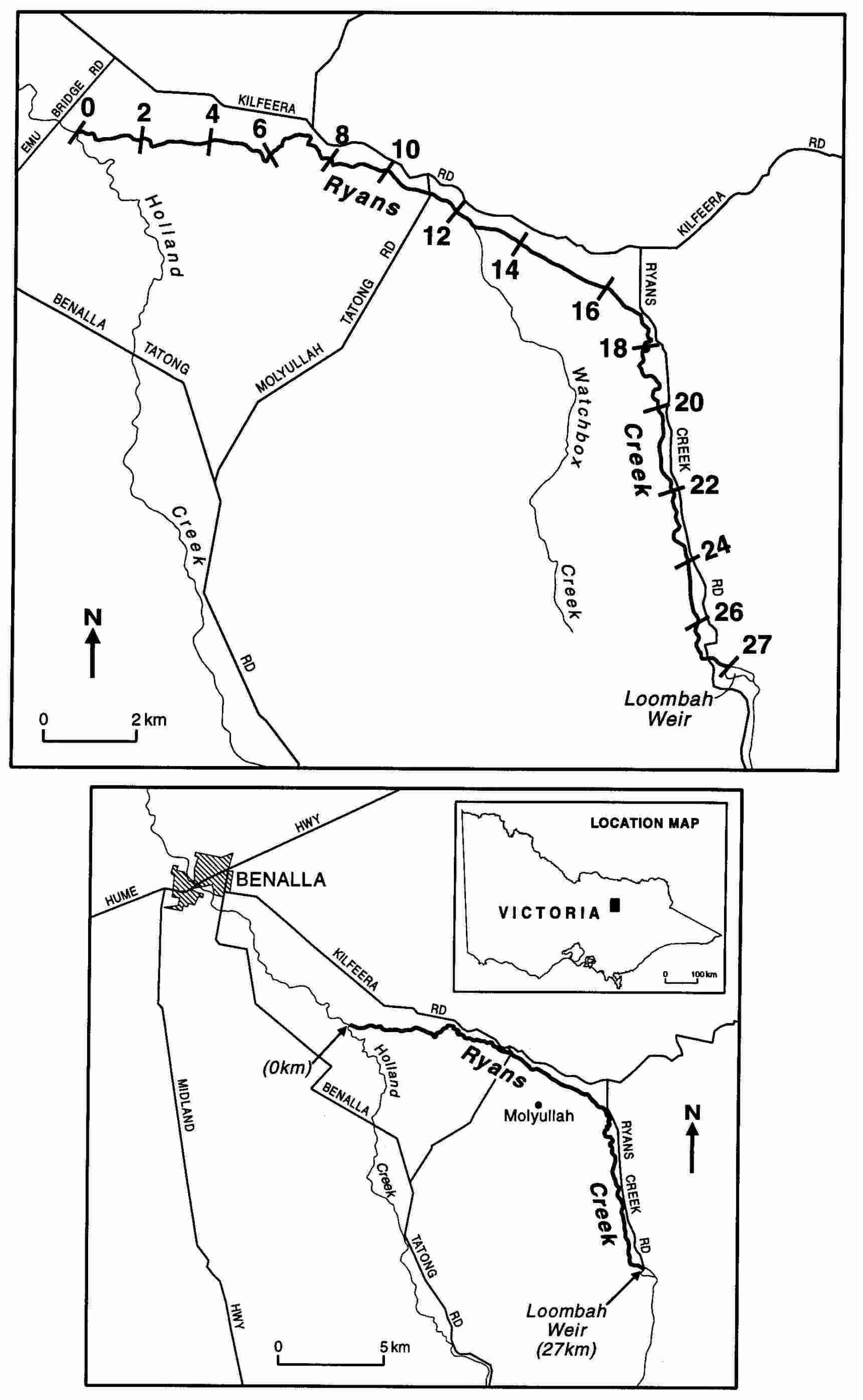

Figure A3.1 - Ryans Creek study area

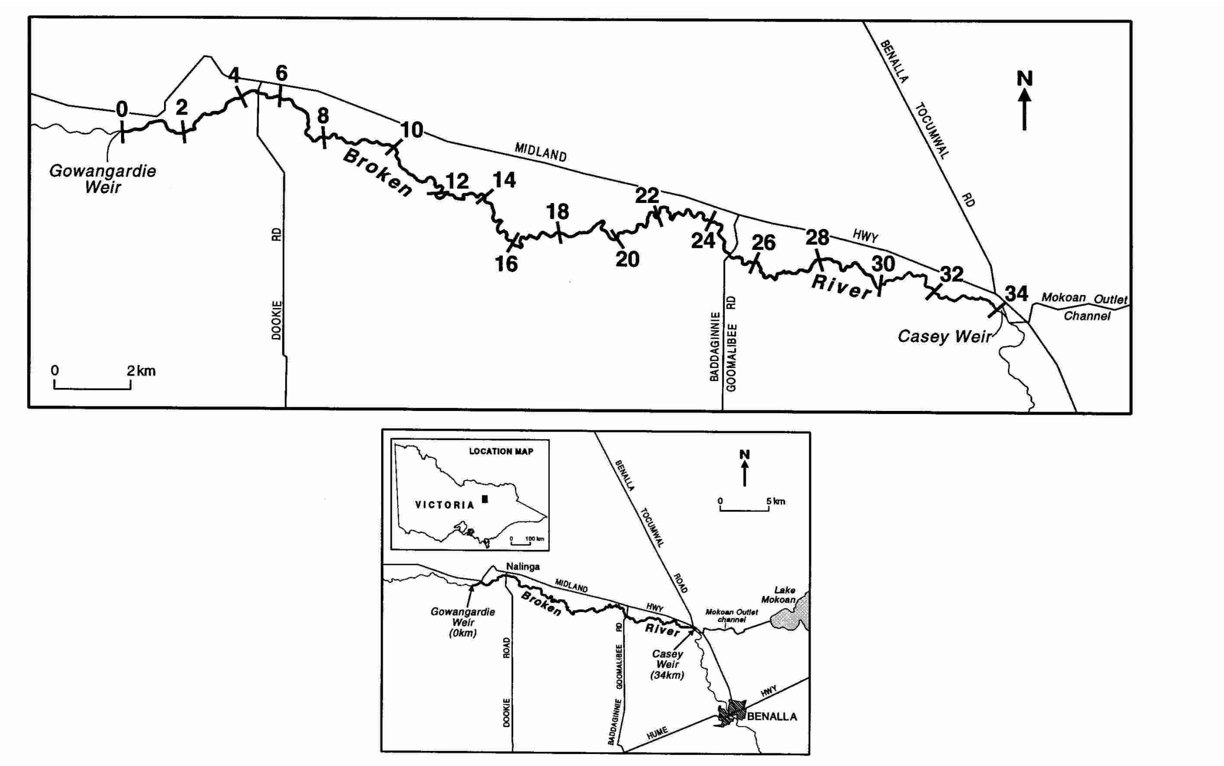

Figure A3.2 - Broken River study area

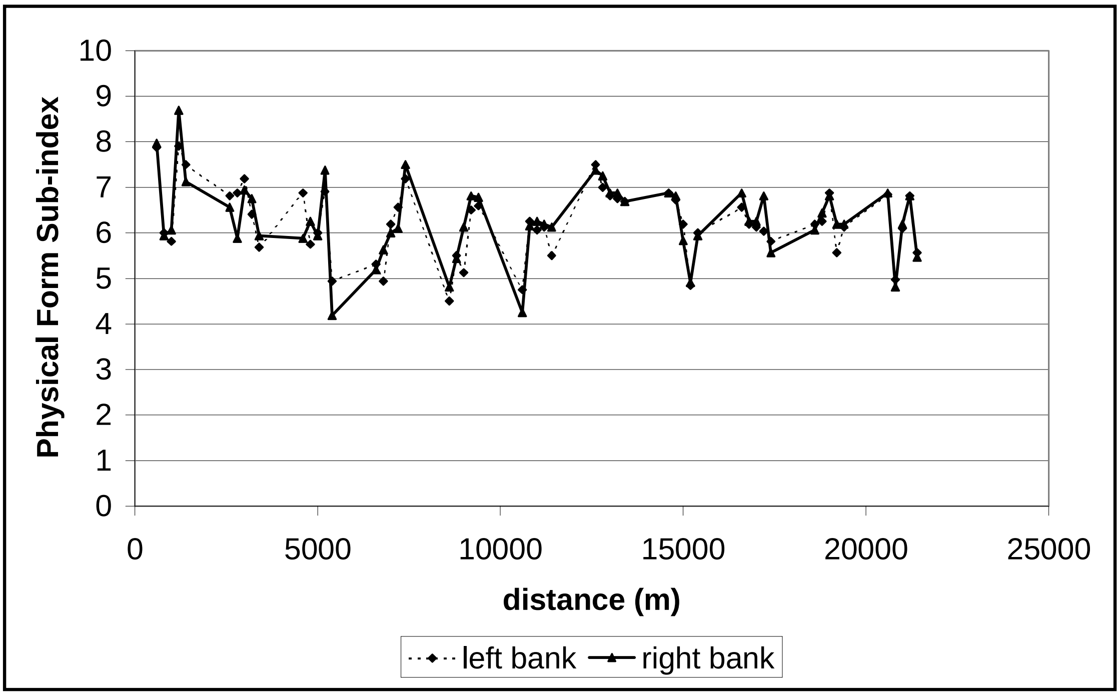

Figure A3.3 - Physical Form Sub-index for Ryans Creek

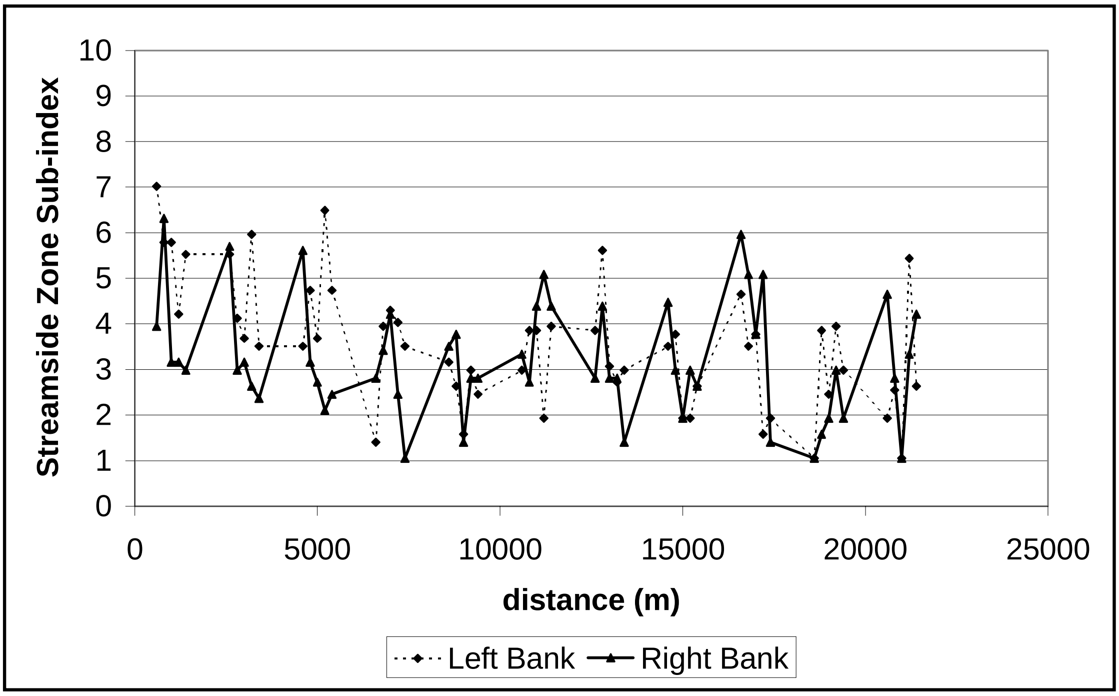

Figure A3.4 - Streamside Zone Sub-index for Ryans Creek

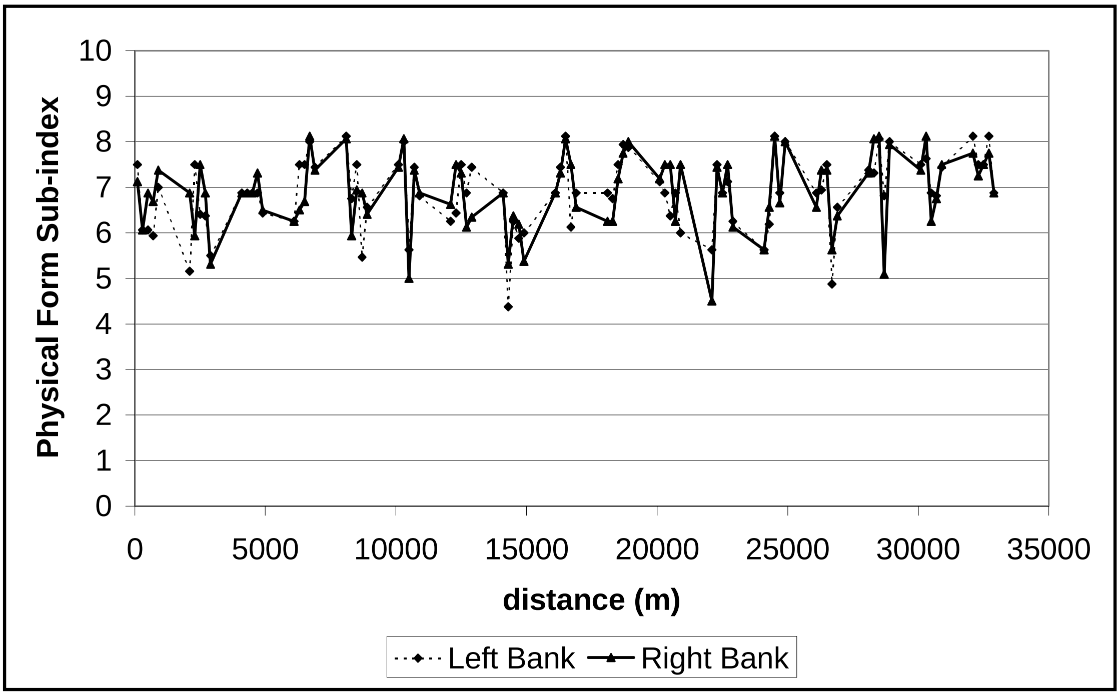

Figure A3.5 - Physical Form Sub-index for Broken River

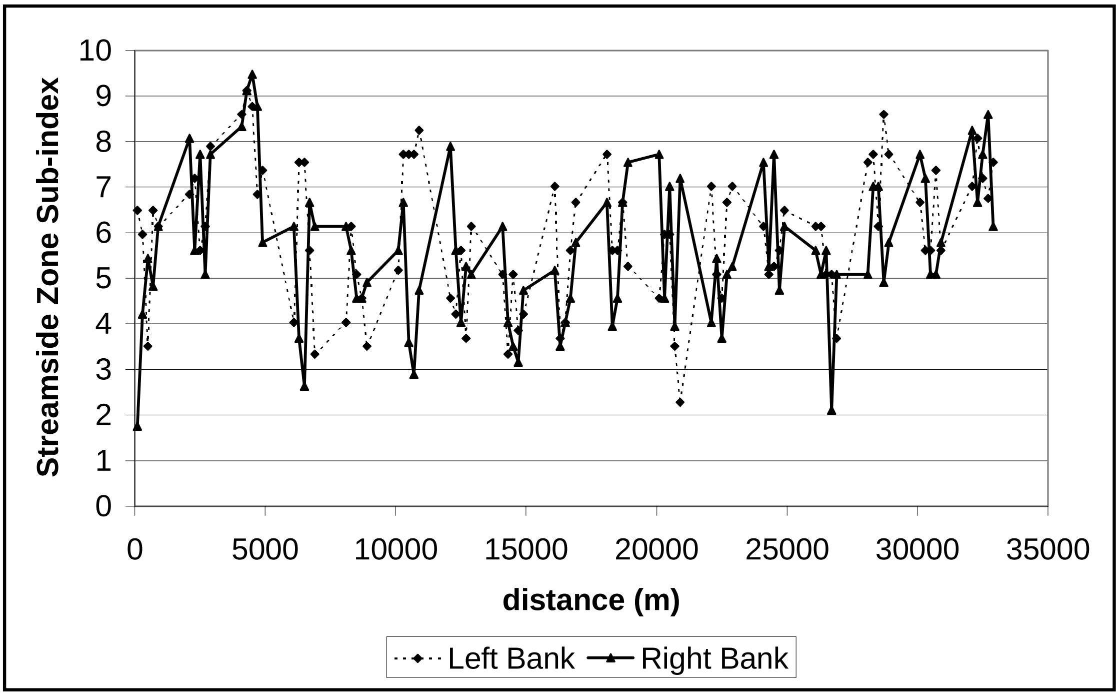

Figure A3.6 - Streamside Zone Sub-index for Broken River

A3.2.2 Were the 'representative measuring sites' truly representative?

The detailed data set on physical form and streamside zone that was gathered along the Ryans Creek and Broken River was used to test the accuracy of using a representative measuring site to assess stream condition.

The Physical Form and Streamside Zone Sub-index scores based on these representative measuring sites are shown in table A3.2 and compared with scores based on all the data from the survey. Results suggested problems with the representative measuring site approach for the Streamside Zone Sub-index. The Physical Form Sub-index scores based on the representative measuring site were the same to those based on the complete data set (when rounded to 0 decimal places) but the Streamside Zone Sub-index scores are quite different, especially for the Broken River. These results suggest that inappropriate selection of a 'representative measuring site' can result in inaccurate assessment of the condition and selecting a truly representative measuring site may be difficult.

There are other problems with the representative site approach. It is impossible to identify errors in the data or calculate confidence intervals if information is only collected at a representative site. It is also difficult to know how to use the representative measuring site when collecting data in the future. Would the same measuring site be used for repeat measurements in 5 years? What if river management works had been undertaken at the representative measuring site? A new measuring site would have to be chosen and the differences between the measuring sites would be likely to mask any overall change in condition of the longer reach.

A sampling strategy based on a representative reach approach has been used in other stream surveys; for example, the Statewide Assessment of Physical Stream Conditions (Tilleard and Department of Water Resources 1985; Mitchell 1990) but the accuracy of this approach has not been tested elsewhere. Williams (1996) alludes to problems of using a 'representative' approach to measure stream data and comments that the reliability of results cannot be evaluated statistically. The large variability suggests it would be very difficult to select transects that accurately represent reaches of any length. Using a representative measuring site selected by expert judgement also decreases the objectivity of the ISC. These problems suggest the need for an alternative field sampling protocol.

Table A3.2 - Streamside Zone and Physical Form Sub-index scores based on values from a nominated representative reach on the Broken River and Ryans Creek.

Stream	Sub-index	Representative reach (mean)	Data from entire reach	
			Mean	Standard deviation
Ryans Creek Representative reach (9.0 km - 10.0 km)	Physical form	6.3	6.3	0.8
	Streamside Zone -	2.3	3.4	1.4
Broken River Representative reach (3.5 km - 4.5 km)	Physical form	6.4	6.3	0.8
	Streamside Zone	8.9	5.8	1.6

A3.3 A new field data collection protocol

A new data collection procedure was developed based on measuring the physical form and streamside zone field indicators at randomly chosen locations within a reach and then taking the mean of these values as the score for the reach.

A3.3.1 Spatial scales

This section introduces the different scales that are used for ISC measurements. To characterise a reach, measurements are made at three scales: reach, measuring site and transect. A *reach* is typically 10 - 30 km long, a measuring *site* is about a 430 m length of stream within the reach, with 3 *transects,* which are 30m wide sections within each site (see figure A3.7). Different indicators are measured at these various scales as explained below.

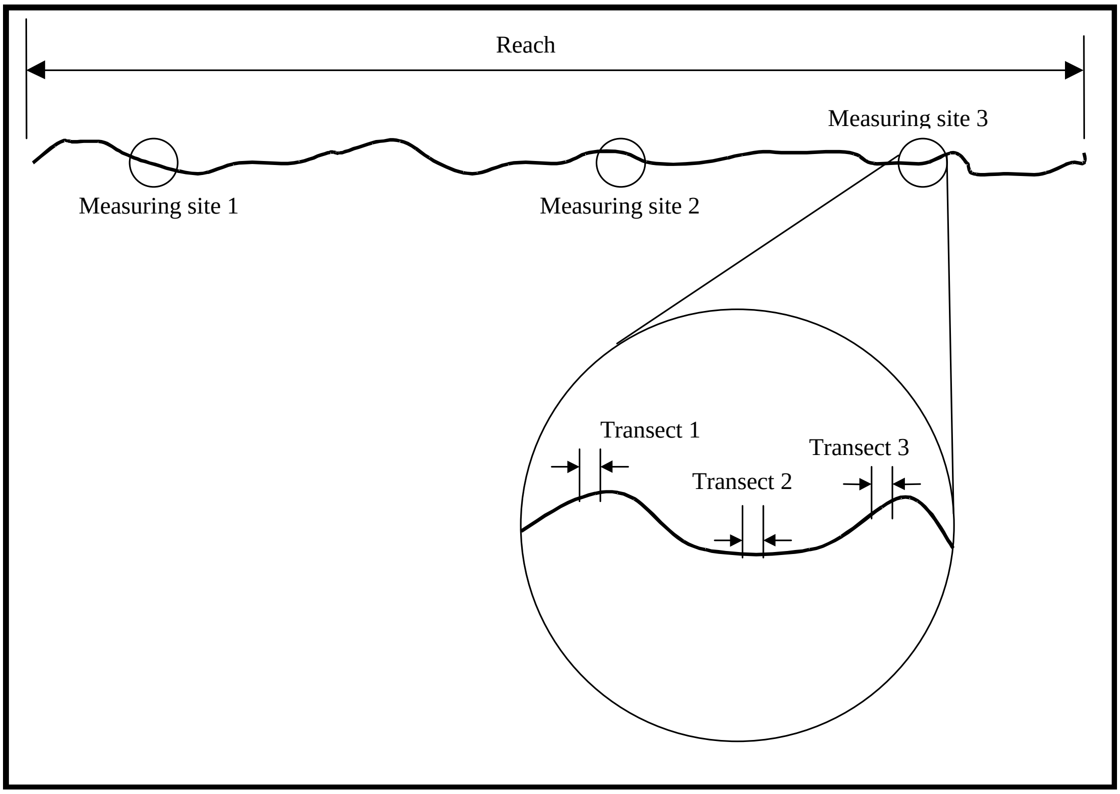

Figure A3.7 - Spatial scales within a reach. There are three measurement scales: a reach - a length of stream tens of km long; a measuring site - a length of stream about 430m long; and a transect - a length of stream about 30m long.

When developing a new field data sampling protocol, the SRG were aware of the trade off between accuracy and cost. In particular, visiting a greater number of measuring sites per reach would yield more accurate results but cost more. Measuring site visits require travel in a vehicle, access through private property, and are time consuming. Measuring an additional transect once already at a measuring site will be reasonably quick. The ISC is intended as a management tool and cost was a major constraint on the selection of a sampling protocol.

A3.3.2 Data analysis used to develop the new protocol

The detailed surveys of Ryans Creek and the Broken River were used to test a measurement procedure based on sampling the physical form and streamside zone at a number of random locations within a reach.

There are two variables of interest were:

- the number of measuring sites per reach and
- the number of transects per measuring site (see figure A3.7).

Ideally, the *true* sub-index scores would be compared with the scores produced from random sampling to assess the accuracy of alternative sampling protocols. In reality, the true score was unknown but could be estimated from the complete data set. This estimate was then compared to the condition estimate produced by the random sampling schemes. The results of this analysis are shown in figures A3.8, A3.9, A3.10 and A3.11. Random samples were drawn from the data set a large number of times to calculate information on the distribution of errors[1].

The relative accuracy of a sampling scheme with three measuring sites per reach and three transects per measuring site is shown in table A3.3. In the worst case, that is estimating the Streamside Zone Sub-index on the Broken River, the estimate will be within 1 of the true score 82% of the time.

These results can also be used to analyse the effect of sampling density, that is the effect on accuracy of the number of measuring sites per unit length of stream. The variance of the Physical Form and Streamside Zone indicators using all the data is approximately the same for the Ryans Creek and Broken River (see table A3.2) therefore, the data have been combined to compare the relative accuracy when sampling at different densities (figures A3.16 and A3.17). Results shows that for sampling densities less than 1 measuring site per 10 km, the accuracy decreases rapidly as fewer measuring sites are used. This suggests that 1 measuring site per 10 km (with 3 transects per measuring site) would be a reasonable first estimate for the minimum sampling density when assessing the ISC in these streams. The sampling density could be refined by choosing an acceptable relative error and then referring to figures A3.16 and A3.17 to determine the required number of measuring sites for a reach of a particular length. For example, if it is desired that for the streamside zone 90% of samples fall within +/- 1 of the true mean then (from figure A3.17) 1.3 samples would be required for every 10km of reach or 4 sample sites in a 30km reach. For simplicity, it was decided to adopted three measuring sites per reach irrespective of length.

[1] This random sub-sampling methodology is based on the 'Bootstrap' statistical technique (see, for example Efron and Tibshrani 1993).

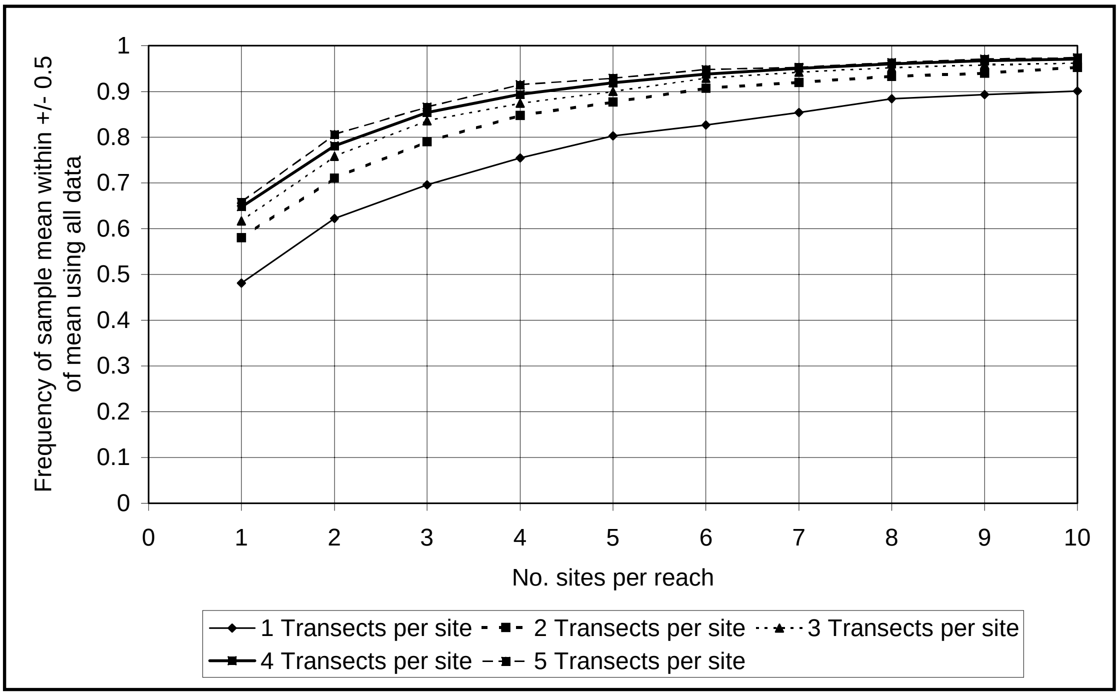

Figure A3.8 - Relative errors (+/- 0.5) associated with estimates of the Physical From Sub-index on Ryans Creek for various sampling schemes.

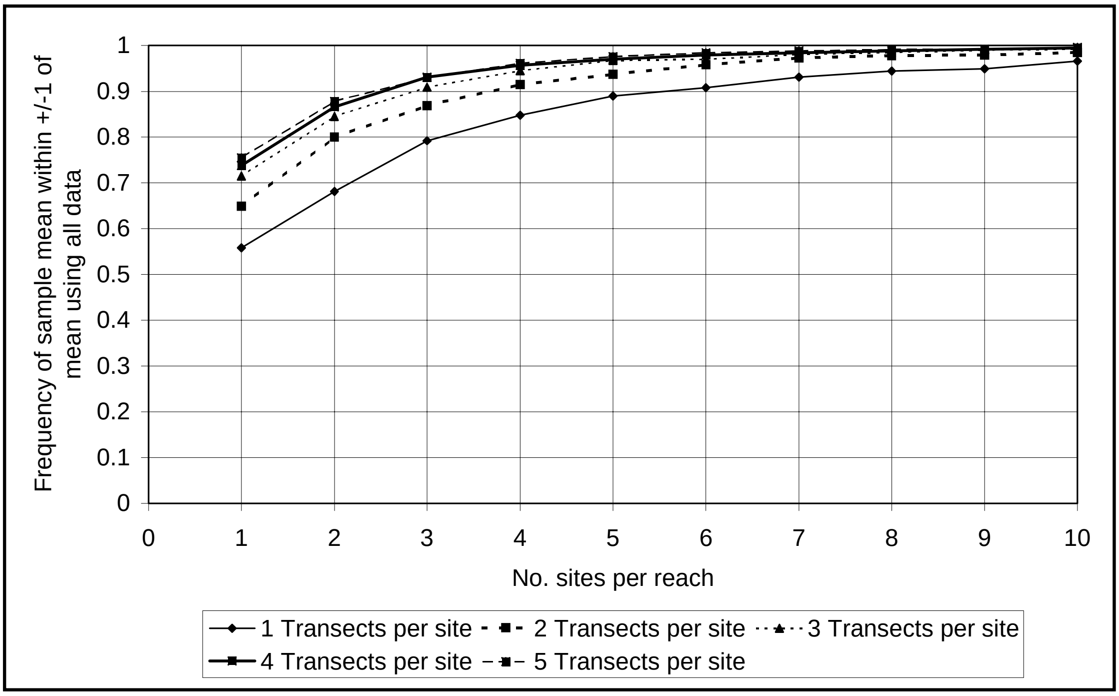

Figure A3.9 - Relative errors (+/- 1) associated with estimates of the Streamside Zone Sub-index on Ryans Creek for various sampling schemes.

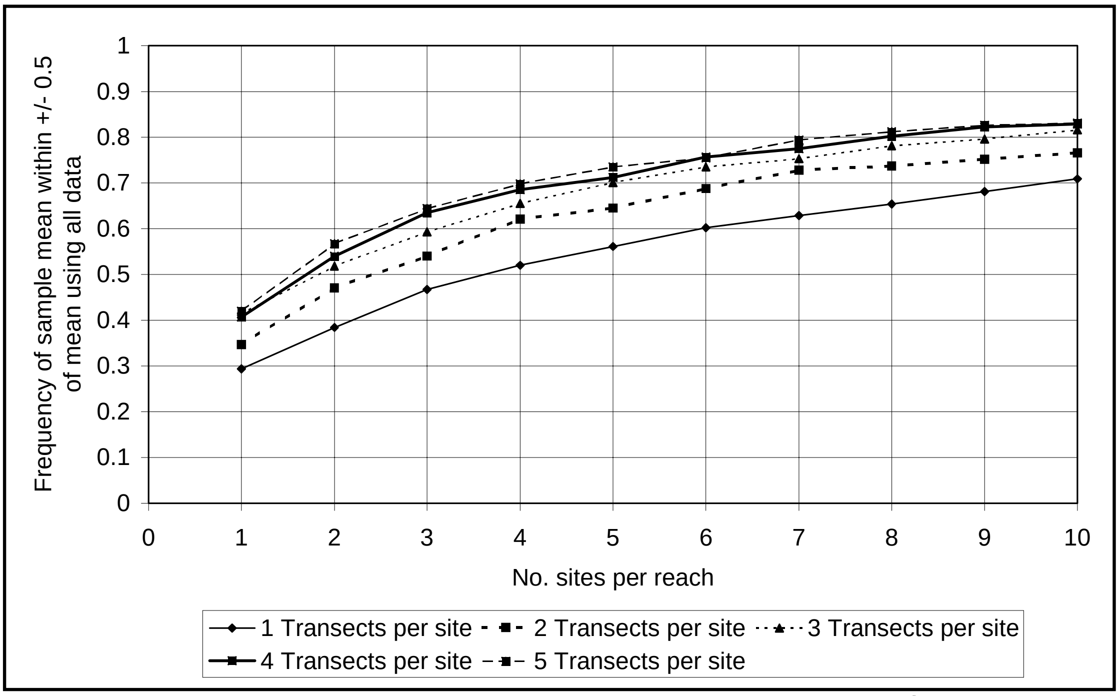

Figure A3.10 -Relative errors (+/- 0.5) associated with estimates of the Streamside Zone Sub-index on Ryans Creek for various sampling schemes.

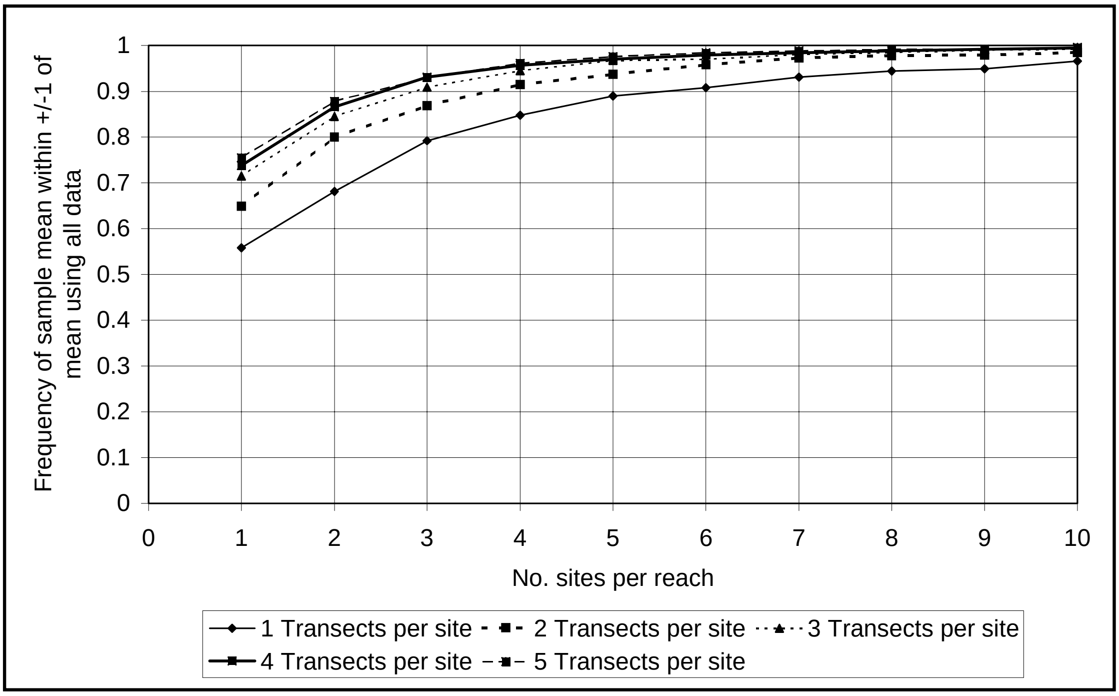

Figure A3.11 - Relative errors (+/- 1) associated with estimates of the Streamside Zone Sub-index on Ryans Creek for various sampling schemes.

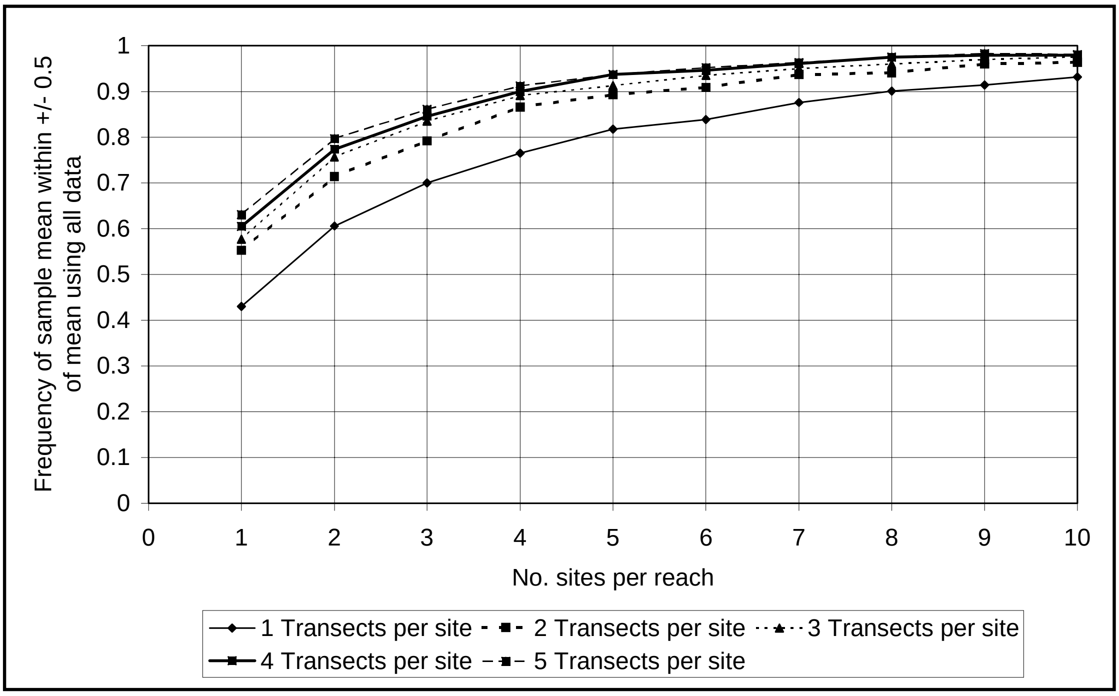

Figure A3.12 - Relative errors (+/- 0.5) associated with estimates of the Physical From Sub-index on Broken River for various sampling schemes.

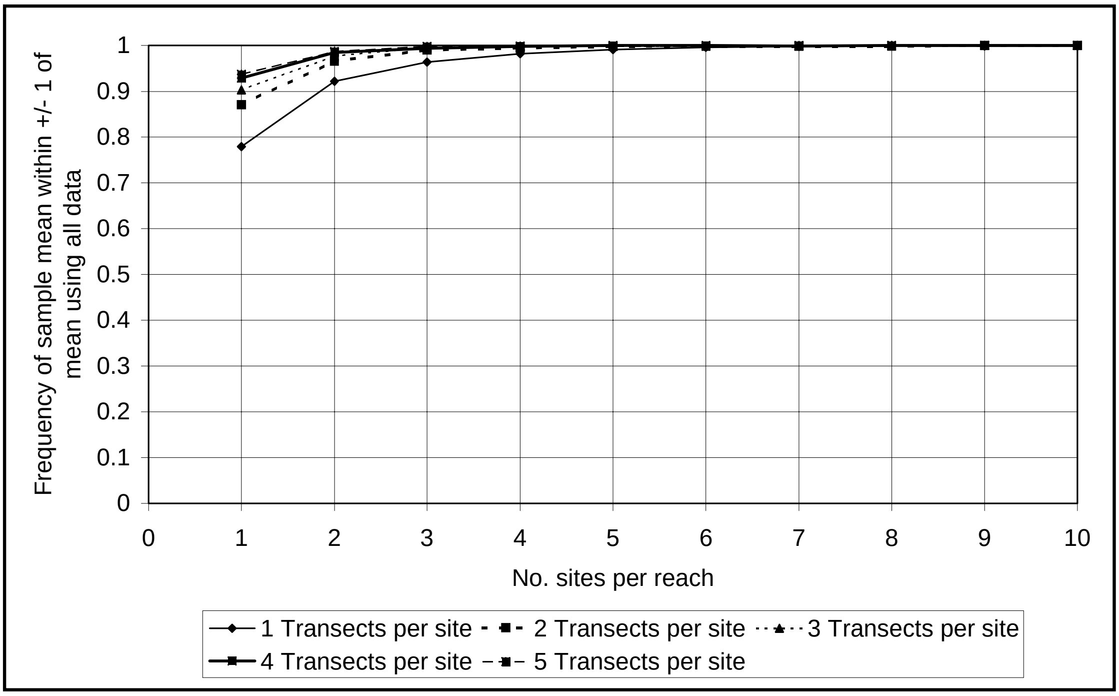

Figure A3.13 - Relative errors (+/- 1) associated with estimates of the Physical Form Sub-index on Broken River for various sampling schemes

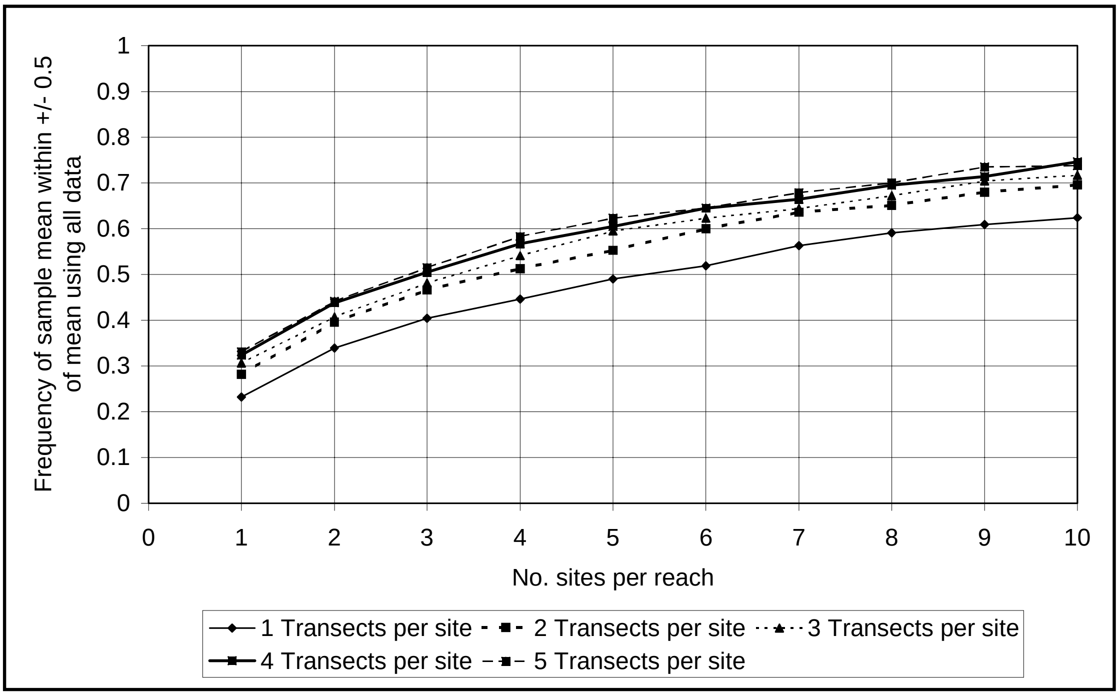

Figure A3.14 - Relative errors (+/- 0.5) associated with estimates of the Streamside Zone Sub-index on Broken River for various sampling schemes.

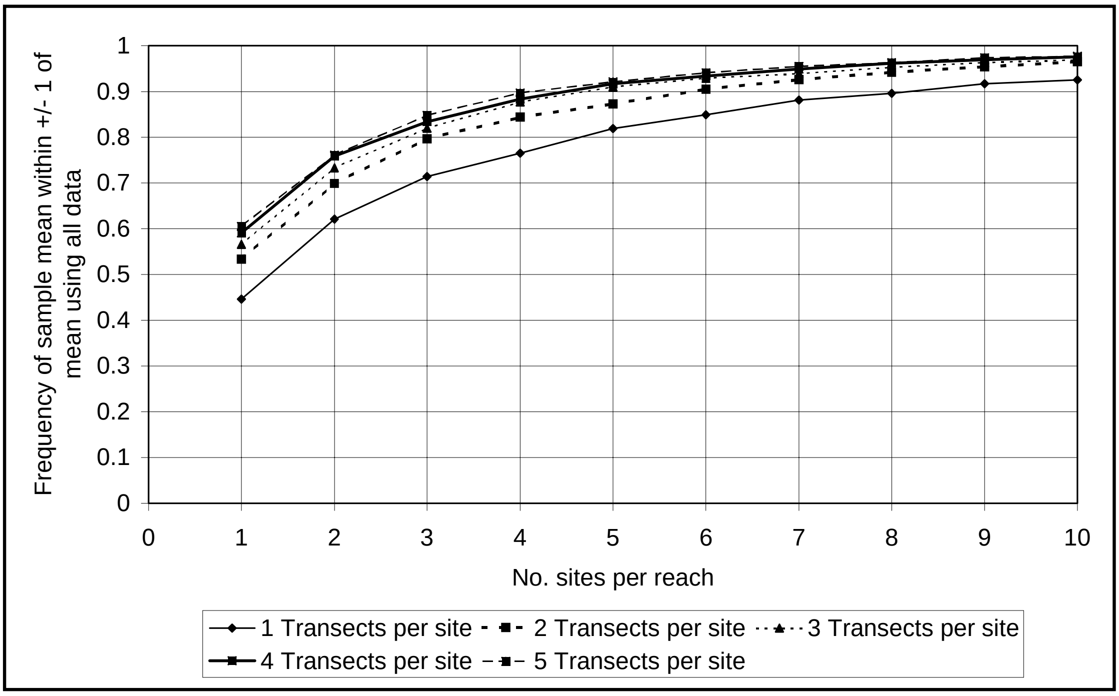

Figure A3.15 - Relative errors (+/- 1) associated with estimates of the Streamside Zone Sub-index on Broken River for various sampling schemes.

Table A3.3 - Relative accuracy of a sampling scheme based on 3 measuring sites per reach and 3 transects per measuring site

	Frequency that mean of samples is within specified range of the mean using all the data			
	Physical Form		**Streamside Zone**	
Stream	+/-0.5	+/-1	+/-0.5	+/-1
Ryans Creek	0.84	0.99	0.59	0.91
Broken River	0.84	0.996	0.48	0.82

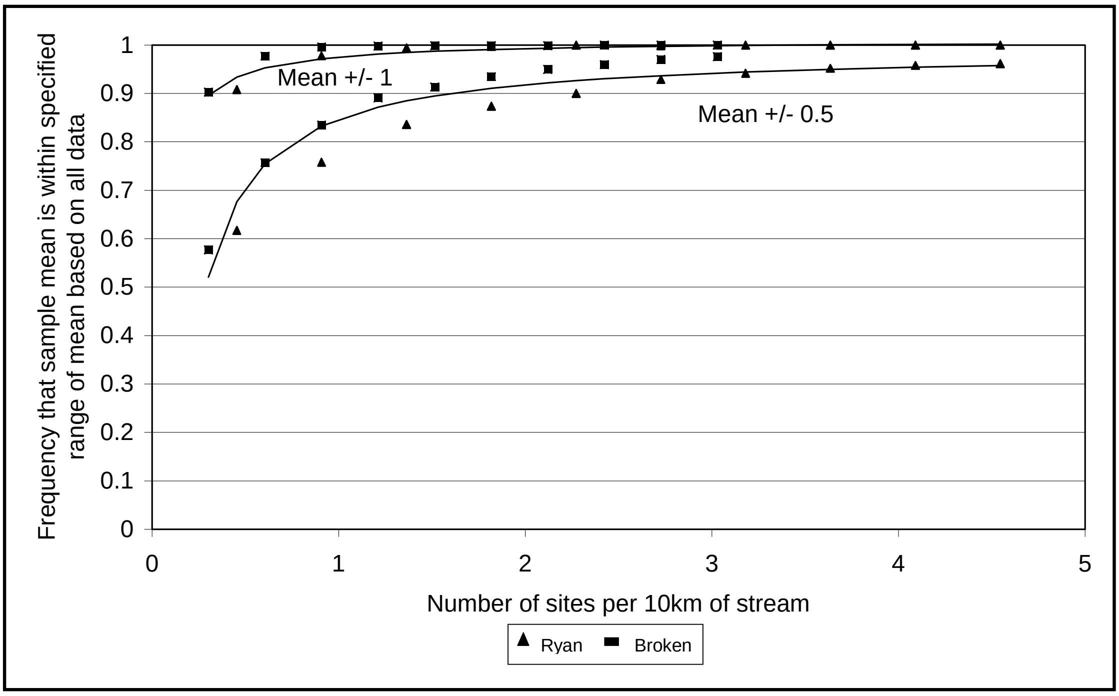

Figure A3.16 - relative accuracy of Physical Form Sub-index for sampling densities based on numbers of sites per 10 km of stream (3 transects per site).

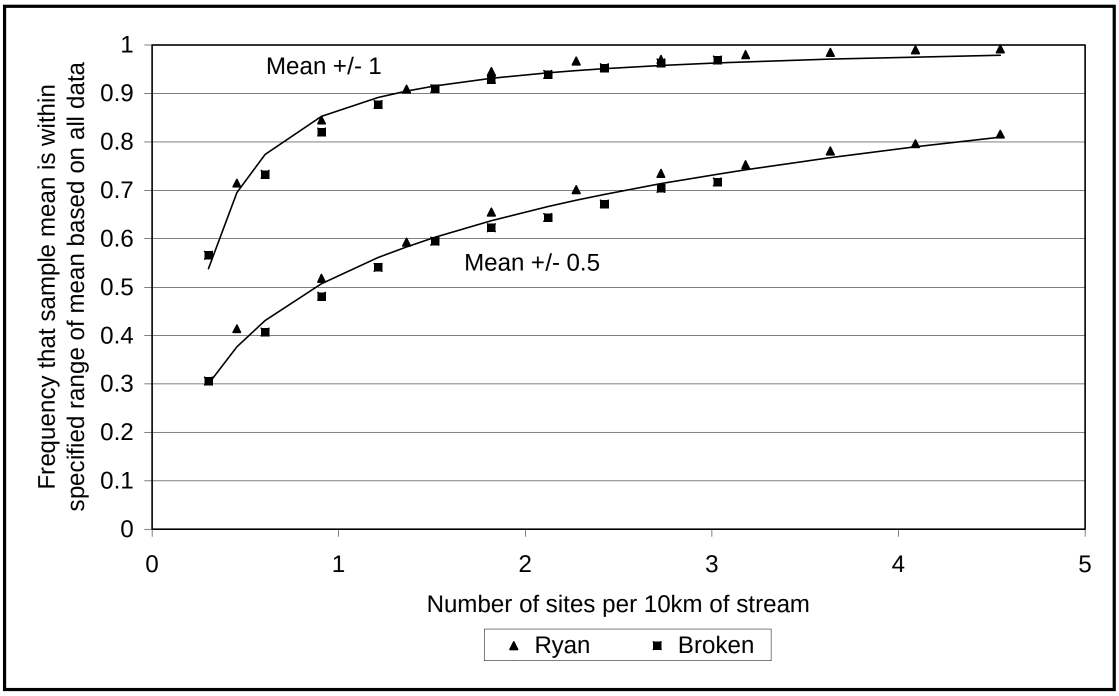

Figure A3.17 - relative accuracy of Streamside Zone Sub-index for sampling densities based on numbers of sites per 10 km of stream (3 transects per site).

A3.3.3 Other sources of data

Not all of the information on physical form and streamside zone will have to be collected in the field specifically for the ISC. Some information has been collected for other projects and it is proposed to convert this data to ISC scores. The main source of this data is information collected by the Victorian EPA as part of the Monitoring River Health Initiative and the First National Assessment of River Health. There may also be some data available from the Regional Forest Agreement and the Crown Frontage Review. Further details on this data and the conversion protocols are provided in the *Users' Manual*. The relevance of this information to the discussion on sampling is that one site per reach may be provided from other sources of data. This has implications for the cost of a random sampling strategy. It also may be appropriate to examine the quality of this data if it becomes a major source of information for the statewide application of the ISC.

A3.3.4 Costs of Sampling

The ISC is intended as a practical tool to be used to assess the condition of all the streams in Victoria so any proposed sampling strategy must be cost effective and the total cost of sampling within budget. An analysis of costs showed that using 3 measuring sites per reach and 3 transects per measuring site was of similar cost of the original sampling strategy based on the representative site approach provided information from other sources was used where possible. The relative accuracy of using 3 measuring sites per reach and 3 transects per site was discussed by the SRG and was felt to be sufficient.

A3.4 Conclusion

Results from case studies on Ryans Creek and the Broken River show that using 3 randomly selected measuring sites with 3 transects per measuring site is likely to result in reasonably accurate assessment of Physical Form and Streamside Zone sub-indices. Given the scope and context of the ISC and the variability of data within these two reaches, this accuracy is acceptable.

A3.5 Outstanding issues and limitations

The main limitation is that to use this analysis to recommend a sampling strategy for the ISC it is necessary to generalise from the results of just two streams to all the streams across Victoria. This generalisation seems reasonable, as it is likely that these streams represent close to a 'worst case' in terms of having a larger variance in indicator scores. Streams that are mostly in excellent condition will have most indicators near there maximum, so the variance will be lower. Similarly, streams that are in very poor condition will have most indicators near zero so again the variance will be lower. Streams that are in the middle of the range between zero and ten (such as these two, Ryans Creek and the Broken River) are likely to have some indicators or some sections that score near maximum and other that are near minimum, thus increasing the variance. It is likely that when using a 3 sites/3 transect approach across the state many streams will be assessed more accurately then results reproduced here indicate.

There has also been an increased emphasis on ensuring consistency of the quality of assessments since this project was undertaken. Training courses have been developed and the quality and consistency of the reference photographs improved. A quality assurance and control plan will guide the Victoria-wide application and results will be audited.

Another issue is that the modelled scenario does not exactly match the sampling strategy that was finally adopted for the ISC. There are two main differences. Firstly, the transects used in this study were 50 m whereas from field experience it is suggested that a 30 m wide transect is more appropriate for the indicators bank stability, width, structural intactness and cover of exotic vegetation. The effect of decreasing the transect width is likely to reduce the accuracy of results but the change cannot be quantified at this time. Further research is being undertaken by the North Central Catchment Management Authority to address this issue.

The second difference is that information on one site will often be supplied from other sources of data such as from the Victorian EPA. This site will not be 'randomly' selected, again reducing the accuracy but at a significant cost saving. It is hoped that in the future, sites selected by the other authorities will be randomly selected.

APPENDIX 4. FURTHER DETAIL ON HYDROLOGY

This appendix provides more information on the Hydrology Sub-index that is discussed in chapter 3 of this report. As discussed in section 3.3, the primary indicator selected for the Hydrology Sub-index is the Amended Annual Proportional Flow Deviation (AAPFD).

Many other indicators were considered before the AAPFD was selected. A literature review showed there was a large number of indicators that had been proposed to relate hydrologic change to impacts on stream ecology (see table A4.6). There is active research in this area by the Cooperative Research Centre for Freshwater Ecology and the Centre for Environmental Applied Hydrology at the University of Melbourne. Early on in the process of developing the ISC, a decision was made to restrict the hydrology indicator to one based on monthly flows. This was because monthly flow data was the highest resolution that was readily available and could be quickly processed and altered monthly flows would indicate changes to flow volume and seasonality. The ISC is meant to flag problems rather than diagnose them in detail and further studies following the ISC could involve other, more detailed indicators.
There were four monthly flow indicators that are explored in this appendix:

- Hydrologic Deviation (HD);
- Ratio Flow Deviation (RFD);
- Annual Proportional Flow Deviation (APFD); and
- Amended Annual Proportional Flow Deviation (AAPFD).

Definitions of these indicators are provided in table 3.1 of the main report. These indicators were compared for streams ranging from highly regulated to slightly regulated.

An example of a highly regulated stream is the Goulburn River downstream of Eildon Reservoir (Gippel and Finlayson 1993; Erskine 1996). Current flows are available at a gauging site downstream of the Eildon pondage and natural flows were calculated by the former Rural Water Corporation (Erskine 1996) (see figure A4.1). This data was used to calculate the four indicators (table A4.1). Results show the different sensitivities of the indicators to flow changes. The APFD is sensitive to changes in flow during naturally low flow periods, whereas the AAPFD is more sensitive to changes in flow during naturally high flow periods. Calculations for the Goulburn River show that the major contributions to the AFPD are in January, February, and March (with March being dominant). For the AAPFD, the major contribution is in August. The HD and RFD also have different sensitivities with the HD being similar to the AAPFD - sensitive to high flow changes, and the RFD being similar to the APFD. Results show that the AAPFD is similarly dominated by changes to the larger winter flows.

Similar calculations were carried out for an additional 11 regulated streams in Victoria and 8 stations along the regulated River Murray (see table A4.2 and A4.3 and figures A4.2 and A4.3). These results show the AAPFD was well behaved mathematically (unlike the RFD) and produced results in approximate agreement with the HD.

Table A4.1 - Measurement of hydrologic change for the Goulburn River downstream of Lake Eildon - adapted from Erskine (1996).

Month	Actual flow (GL)	Natural flow (GL)[1]	Absolute difference (GL)	RFD	APFD	AAPFD
Jan	200	35	165	5.7	22.2	1.5
Feb	190	20	170	9.5	72.3	1.6
Mar	210	15	195	**14.0**	**169.0**	2.1
Apr	115	30	85	3.8	8.0	0.4
May	30	90	60	3.0	0.4	0.2
Jun	25	125	100	5.0	0.6	0.6
Jul	50	255	205	5.1	0.7	2.4
Aug	80	355	**275**	4.4	0.6	**4.3**
Sep	120	270	150	2.3	0.3	1.3
Oct	160	235	75	1.5	0.1	0.3
Nov	135	110	25	1.2	0.1	0.04
Dec	165	60	105	2.8	3.1	0.6
Total	**1480**	**1600**	**1610**	**58.3**	**277.4**	**15.3**
HD			**1610/1600 =101%**			
RFD				**(58.3/12)-1 = 3.9**		
APFD					**√277.4 = 16.7**	
AAPFD						**√15.3 = 3.9**

1 - Natural flows estimated by the Rural Water Corporation for period June 1995 to September 1991 (Erskine 1996).

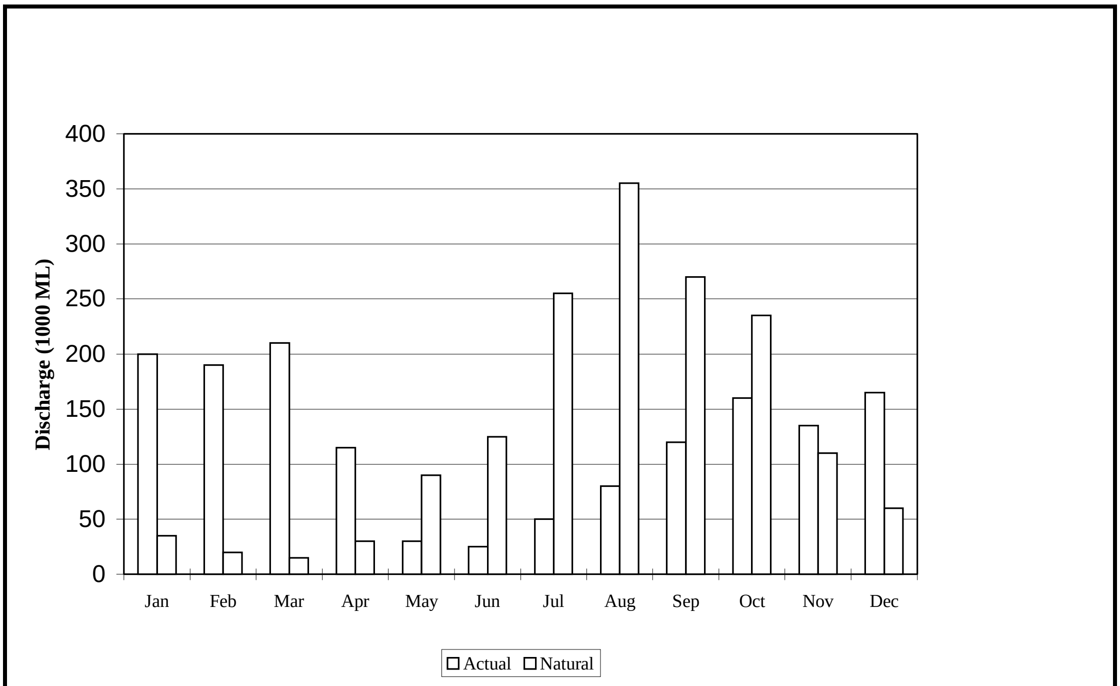

Figure A4.1 - Actual and modelled natural flows for the Goulburn River at Eildon

Table A4.2 - HD, RFD, APFD, AAPFD for 11 Victorian streams: flow data adapted from Phan (1994).

River	Upstream Dam	Post regulation period	HD	RFD	APFD	AAPFD
Buffalo R.	Lake Buffalo	1968 to 1993	8%	0.3	1.8	0.3
Loddon R.	Laanecoorie	1943 to 1993	28%	0.4	0.9	1.3
Macalister R.	Lake Glenmaggie	1975 to 1993	33%	0.6	1.3	1.4
Moorabool R.	Bungal	1973 to 1993	35%	0.9	3.5	1.6
Jackson Ck.	Rosslynne	1975 to 1993	51%	1.4	1.9	2.1
Tarago R.	Tarago Res	1970 to 1993	58%	1.7	2.0	2.3
Loddon R.	Cairn Curran	1965 to 1993	75%	4.0	23.0	3.2
Goulburn R.	Eildon	1970 to 1990	104%	4.9	26.2	4.0
Campaspe R.	Lake Eppalock	1981 to 1993	103%	30.4	39.4	5.0

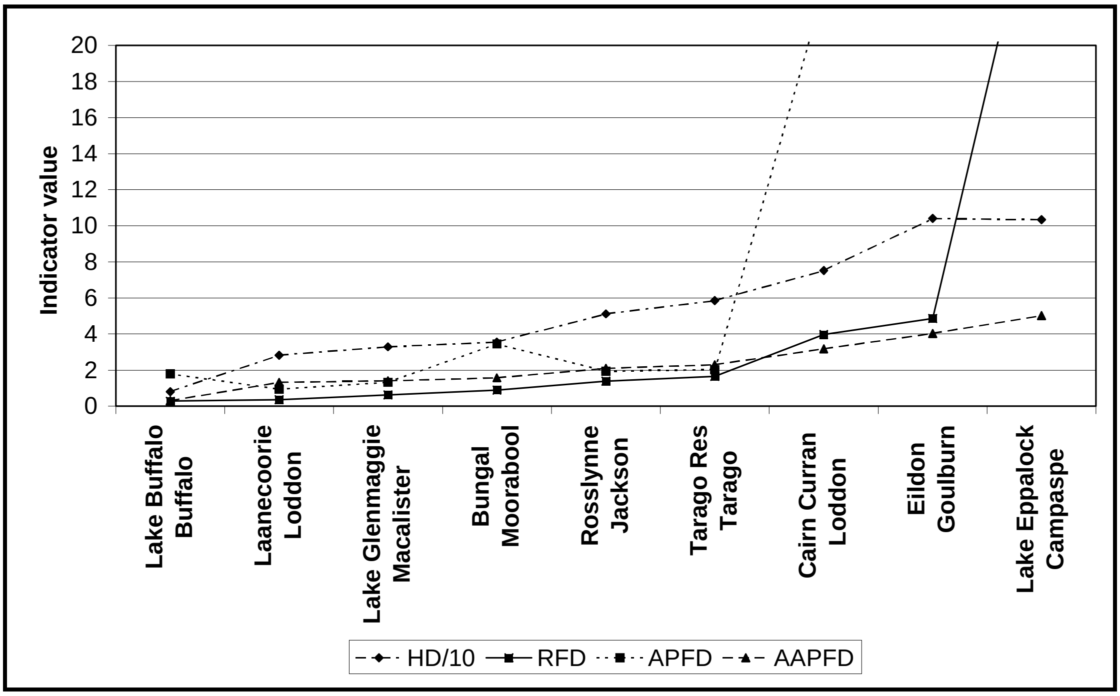

Figure A4.2 - Hydrologic indicators for some regulated streams in Victoria.

Table A4.3 - Comparison of hydrologic indicators for stations along the Murray River System (flow data from Murray-Darling Basin Commission)

Station	HD	RFD	APFD	AAPFD
River Murray at Doctors Point (Albury)	104%	2.7	10.7	4.0
River Murray downstream of Yarrawonga Weir	63%	1.3	4.1	2.7
River Murray downstream of Euston Weir	57%	1.2	1.8	2.5
Flow to SA in River Murray	68%	2.5	2.4	2.7
Mitta Mitta River downstream of Dartmouth Dam	91%	2.9	6.3	4.0
River Murray at the Barrages	77%	div by zero	2.8	3.0
Darling River at Burtundy	80%	4.9	2.8	3.1
Edward River at Deniliquin	81%	3.2	13.9	3.6

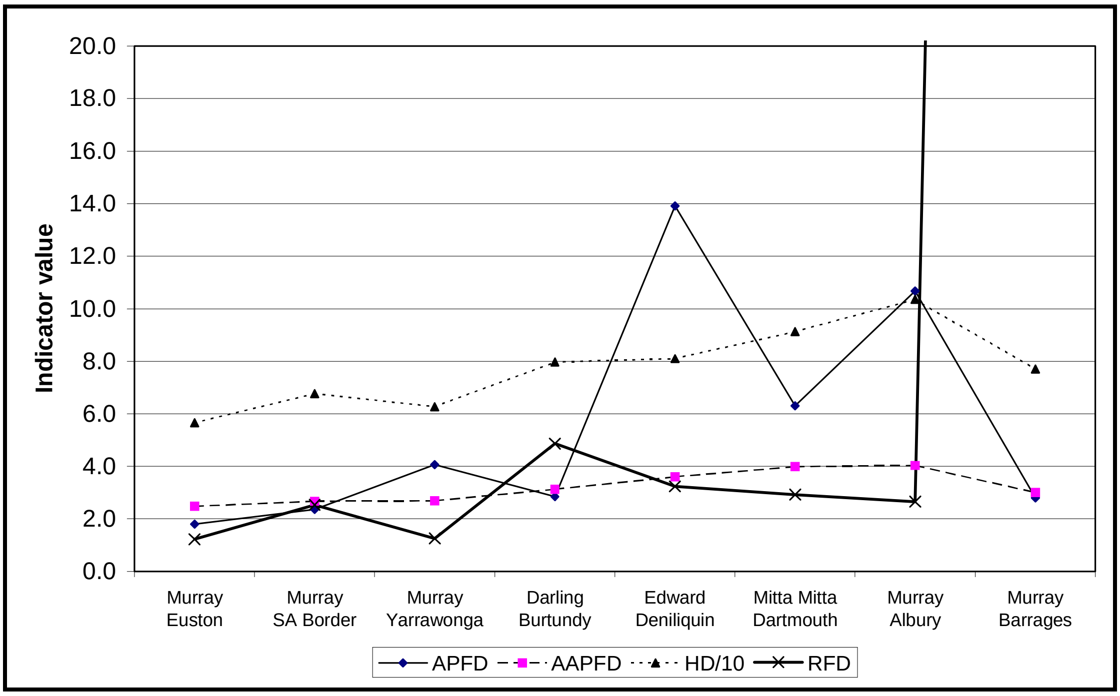

Figure A4.3 - Hydrologic indicators for stations along the River Murray

All the examples above are for highly regulated rivers. During the Victoria-wide application of the ISC, the Hydrology Sub-index will also be calculated for streams that are less intensively regulated but where flows are altered mainly through pumped diversions.

The Gellibrand River (part of the Otway basin, about 50 km west of Apollo Bay) is presented as an example of a stream that is affected by diversions for both agricultural and urban use. A streamflow management plan has been developed for the Gellibrand River, which included collection of natural flows and modelling of natural flows that have been used to calculate the four hydrologic indicators (Southern Rural Water 1998). The Gellibrand River is considered a priority stream by NRE and it is one of the first in Victoria to have a Stream Flow Management Plan developed.

Modelling of natural flows required consideration of diversion of water for irrigation, stock and domestic use, winter fill storages, and urban supply. The two major diversions are the North Otway pipeline (NOPL) that supplies water to several towns north of the basin and the South Otway pipeline (SOPL) that supplies the city of Warrnambool. Actual and modelled natural flows are available downstream of these points in the Gellibrand River.

In normal years, the diversions have little effect on the flow in the rivers but for drought years, water is limited. A modelled scenario for a one in 60-year drought (the flows in 1967/68), is shown in table A4.4 along with the calculated hydrologic indicators. Flow information for 1987/88, a one in 5-year drought, is shown in table A4.5. Results show that the greatest change from natural conditions occurs downstream of the SOPL in 1967/68. Flows for this year are shown in figure A4.4.

All the indicators suggest the amount of hydrologic change in the Gellibrand was much less than for highly regulated streams (compare indicator scores in tables A4.4 and A4.5 with those in tables A4.2 and A4.3). Even in the worst case, the 1967/68 drought, the indicator scores suggest the change is similar to that for the lightly regulated Buffalo River under average conditions. It was necessary to consider this smaller level of hydrologic change when developing a rating table for the AAPFD (see table 3.2 in chapter 3).

Table A4.4 - Natural and Actual flows for 1967/68 a one in 60-year drought (adapted from Southern Rural Water 1998).

Month	Flows (ML) passing NOPL[1] Natural	Flows (ML) passing NOPL[1] Actual	Flows (ML) passing SOPL[2] Natural	Flows (ML) passing SOPL[2] Actual
Jul	3607	3126	4802	3950
Aug	10138	9651	11760	10924
Sep	9524	9039	12126	11253
Oct	3612	2834	5046	3679
Nov	2236	1421	3098	1658
Dec	2348	1507	3253	1770
Jan	1729	816	2337	753
Feb	1082	275	1433	195
Mar	1206	422	1688	403
Apr	2384	1619	3212	1799
May	21714	21111	25382	24330
Jun	25879	25421	30524	29689
Total	**85458**	**77242**	**104663**	**90402**
HD		0.10		0.14
RFD		0.68		1.25
APFD		1.30		1.59
AAPFD		0.34		0.48

1 - North Otway Pipeline
2 - South Otway Pipeline

Table A4.5 - Natural and actual flows for 1987/88 a one in 5 year drought
(adapted from Southern Rural Water 1998).

Month	Flows (ML) passing NOPL[1] Natural	Flows (ML) passing NOPL Actual	Flows (ML) passing SOPL[2] Natural	Flows (ML) passing SOPL Actual
Jul	23600	23110	32245	31384
Aug	16330	15840	22738	21906
Sep	21270	20780	28346	27508
Oct	15180	14615	20470	19455
Nov	5290	4538	6998	5648
Dec	8114	7373	10698	9387
Jan	3067	2244	4207	2736
Feb	2020	1163	2614	1218
Mar	2290	1479	3027	1595
Apr	2415	1722	2918	1742
May	4140	3635	5868	4932
Jun	11110	10648	14588	13759
Total	**114820**	**107144**	**154715**	**141269**
HD		7%		9%
RFD		0.22		0.34
APFD		0.71		0.98
AAPFD		0.24		0.31

[1] North Otway Pipeline
[2] South Otway Pipeline

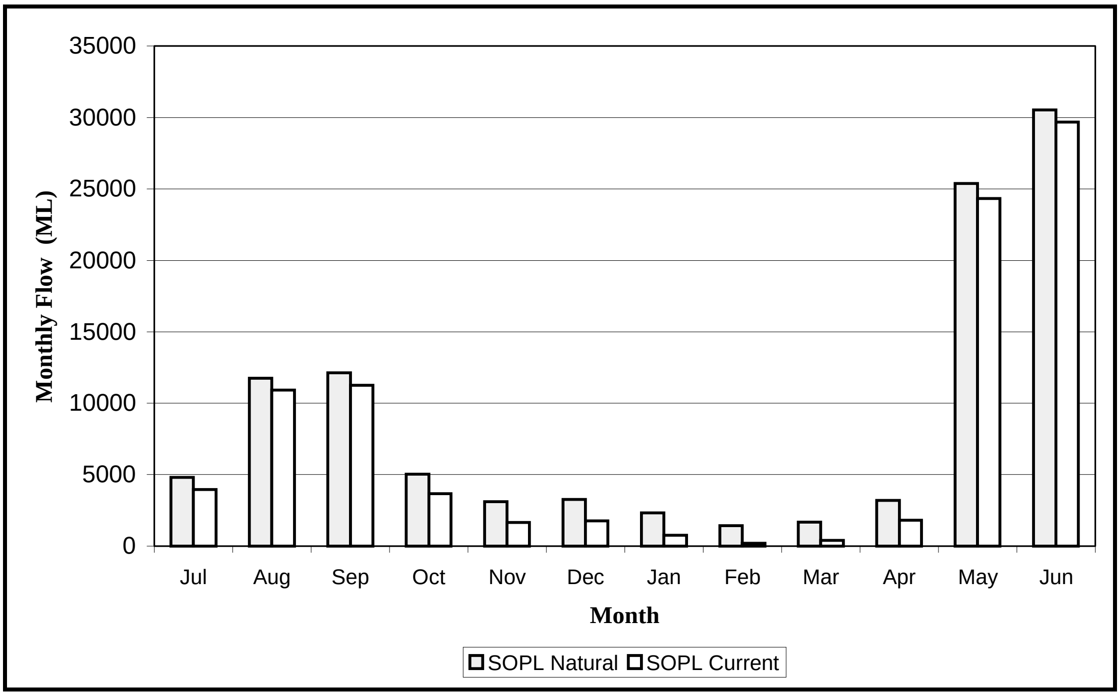

Figure A4.4 - Actual and natural flows in the Gellibrand River downstream of the Southern Otway Pipeline (SOPL) in 1967/68, a 1 in 60-year drought

There was considerable discussion on whether to include an indicator of flood regime in the ISC. Currently, the Hydrology Sub-index, does not include an indicator of changes to flood regime (frequency, magnitude, timing, or duration) caused by flow regulation. Clearly floods have a major effect on streams through their influence on channel morphology and stream ecology and many indicators are proposed in the literature (table A4.6). The main justification of excluding floods was that basing the Hydrology Sub-index on monthly flows would identify streams with altered hydrology and these streams were also likely to experience changed flood characteristics. It was not considered necessary to have a separate indicator for floods. The Hydrology Sub-index will flag potential problems and further analysis can be undertaken if appropriate.

Table A4.6 - Listing of some hydrology indicators.

Flow conditions at the time of measurement	
Snapshot of flow conditions	▪ Average flow velocity (Mitchell 1990). ▪ Water depth (Mitchell 1990).
Floods and high flows	
Flood magnitude	▪ Annual maxima 1, 3, 7, 30, and 90 day means (Richter *et al.* 1996). ▪ Q10 (Flow exceed 10% of time)/(Q_{50}) (Clausen & Biggs 1997). ▪ Q20 (Flow exceed 20% of time)/(Q_{50}) (Clausen & Biggs 1997). ▪ Flow exceeded 1% and 5% of the time (Knighton 1988). ▪ PEA(n), n = 1,..,9 (Mean peak flood)/Q_{50} using a threshold on n times the median (Clausen & Biggs 1997).
Variability of flood magnitude	▪ PEAK Variability[1] of all peak discharges (Puckeridge *et al* 1998). ▪ CVMAF Coefficient of variation of mean annual maximum flows (Jowett & Duncan 1990).
Flood volume	▪ FFI Flood flow index = (flood volume)/(baseflow volume) (Clausen & Biggs 1997). ▪ VOL(n), n = 1,..,9 (Mean volume of flood water per year)/Q50 using a threshold on n times the median (Clausen & Biggs 1997).
Flood frequency	▪ No. of high pulses each year (above a threshold e.g. the 75^{th} percentile flow) (Richter *et al.* 1996). ▪ No. of floods that exceed bankfull. Bankfull flow defined as $Q_{1.67}$ (Poff & Allan 1995) and Q_2 (Poff & Ward 1989). ▪ FRE(n), n = 1,..,9 Mean no. floods per year using a threshold on n times the median flow (Clausen & Biggs 1997). ▪ Changes in flood frequency before and after regulation (Maheshwari *et al.* 1993; Maheshwari *et al.* 1995; Knighton 1988).
Variability of flood frequency	▪ PSEA Inverse of variability[1] between months of number of pulse peaks in each month (Puckeridge *et al.* 1998). ▪ PSFRVariability[1] of number of pulses (peak to peak or trough to trough) in each year (Puckeridge *et al.* 1998).
Time between floods	▪ FLODINT Median interval (days) between floods (Poff & Ward 1989).
Duration of flood(ing)	▪ DUR(n), n = 1,..,9 Mean duration of floods using a threshold on n times the median (Clausen & Biggs 1997). ▪ Mean duration (days) of floods (Poff & Ward 1989). ▪ Mean duration of high pulses within each year (Richter *et al.* 1996). ▪ TIM(n), n = 3,..,9 Mean number of days per year in flood using a threshold of n times the median (Clausen & Biggs 1997).

Table A4.6 - Listing of some hydrology indicators (continued).

Floods and high flows (continued)	
Flood seasonality/timing	▪ Last day of the first flood of the growing season (Toner & Keddy 1997). ▪ 1st day of the second flood of the growing season (Toner & Keddy 1997). ▪ Julian date of each annual 1 day maximum (Richter *et al.* 1996). ▪ FLODTIME Median day among all days of the water year (beginning on Oct. 1) on which floods have occurred over the period of record (Poff & Ward 1989). ▪ Proportion of all floods that fall in any 60 day "seasonal window" over the entire period of record (Variable ranges from 0.167 to 1.0 perfectly seasonally predictable) (Poff and Ward 1989; Poff & Allan 1995). ▪ FLODFRE Index of flood predictability. Maximum number of days common to all years during which floods have not occurred (Poff & Ward 1989; Poff & Allan 1995).
Rate of rise	▪ Means of all positive differences between consecutive daily means (Richter *et al.* 1996). ▪ Rate of rise (Maheshwari *et al.* 1995).
Number of rises	▪ No. of rises (Richter *et al.* 1996).
Variability of rise	▪ RSAM Variability[1] of amplitude of all rising limbs (Puckeridge *et al* 1998).
Variability of duration of rise	▪ Variability of duration of all rising limbs (Puckeridge *et al* 1998).
Variability of rate of rise	▪ RSRT Variability of discharge rise per month for all rising limbs (Puckeridge *et al* 1998).
Rate of fall	▪ Means of all negative differences between consecutive daily values (Richter *et al.* 1996). ▪ Rate of fall (Maheshwari *et al.* 1995).
Number of falls	▪ No. of falls (Richter *et al.* 1996).
Variability of fall	▪ FALA Variability[1] of amplitude of all falling limbs (Puckeridge *et al.* 1998).
Variability of duration of fall	▪ FLDR Variability[1] of the duration of all falling limbs (for zero flows duration calculated to end of continuous zero flows) (Puckeridge *et al.* 1998).
Variability of rate of fall	▪ FLRT Variability of discharge fall per month for all falling limb (Puckeridge *et al* 1998).

Table A4.6 - Listing of some hydrology indicators (continued).

Low flows	
Low flow magnitude	▪ Annual minimum 1, 3, 7, 30, and 90 day means (Richter *et al.* 1996); Annual minimum 1 and 30 day flows (Knighton 1988). ▪ Flow exceeded 95% of the time (Knighton 1988). ▪ Average over all years of the annual 24-h low flow value divided by the grand mean flow of the ln-modularized data (Poff & Ward 1989). ▪ Q90 (Flow exceeded 90% of the time)/Q_{50} (Clausen & Biggs 1997). ▪ MAM (Mean annual minimum)/Q_{90} (Clausen & Biggs 1997). ▪ Minimum monthly flows (Maheshwari *et al.* 1995).
Frequency of low flows	▪ No. of low pulses each year (below a threshold e.g. the 25th percentile flow) (Richter *et al.* 1996). ▪ Frequency of post regulation occurrence of pre-regulation 10th percentile flow which signifies degraded or poor habitat conditions, 30th percentile signifies optimum habitat conditions in small streams (Tennant or Montana method) (Orth & Leonard 1990; Jowett 1997).
Skew	▪ MALF/MEDIANF Mean of annual minimum flow/(Median flow (Jowett & Duncan 1990).
Duration of low flow events	▪ Mean duration of low pulses within a year (Richter *et al.* 1996). ▪ Baseflow index (BFI) Baseflow index (baseflow as a % of total flow volume) (Jowett & Duncan 1990).
Low flow variability	▪ TRGH Variability[1] of all minimum discharges (Puckeridge *et al* 1998). ▪ CVMALF Coefficient of variation of mean annual minimum flow (Jowett & Duncan 1990). ▪ Baseflow stability Average of the annual ratios of the lowest daily flow to the mean daily flow (Poff & Allan 1995).
Low flow timing	▪ Julian date of each annual 1 day minimum (Richter *et al.* 1996).
Low flow seasonality	▪ The proportion of low flow events ≥ 5 year recurrence interval falling in a 60 day seasonal window (Poff & Allan 1995). ▪ The maximum proportion of the year during which no low flow events have ever occurred over the period of record (Poff & Allan 1995).

Table A4.6 - Listing of some hydrology indicators (continued).

Zero flow	▪ % of all months in record with zero flow (Puckeridge *et al.* 1998). ▪ Average annual number of zero flow days (Poff & Ward 1989).
Annual flows	
Magnitude	▪ Qmean - Mean flow (Clausen & Biggs 1997) (Knighton 1988). ▪ Q_{50} -Median flow (Clausen & Biggs 1997).
Skew	▪ ASKEW((Mean-median)/median) of all annual flows (Puckeridge *et al.* 1998). ▪ (Mean annual flow)/(Median flow (exceeded 50% of time) (Jowett & Duncan 1990). ▪ Skewness, SK = Qmean/Q_5 (Clausen & Biggs 1997).
Variability of annual flows	▪ ATOT Variability[1] of all annual flows (Puckeridge *et al.* 1998). ▪ ANTF Variability[1] between years of each year's variability between months (Puckeridge *et al.* 1998). ▪ MDAN Median between years of each year's variability[1] between months (Puckeridge *et al.* 1998). ▪ ANNCV Mean annual coefficient of variation. The average overall all years of the mean flow divided by the standard deviation (Poff & Ward 1989; Jowett & Duncan 1990). ▪ CV Coefficient of variation (Clausen & Biggs 1997).
Variability of multi-annual flows	▪ THRE Variability[1] of sums of every three year's total annual flows (Puckeridge *et al.* 1998). ▪ FIVE Variability[1] of the sums of every five year's total annual flows (Puckeridge *et al.* 1998). ▪ SEVN Variability[1] of the sums of every seven year's total annual flow (Puckeridge *et al.* 1998).
Monthly flows	
Magnitude	▪ Mean monthly flow Mean value for each calendar month (Richter *et al.* 1996).
Variability of monthly flows	▪ MTOT Variability of all monthly flows (Puckeridge *et al.* 1998). ▪ MDMF Median between months of each month's variability between years (Puckeridge *et al.* 1998). ▪ MNTF Variability between months of each month's variability between years (Puckeridge *et al.* 1998).
Skew	▪ MSKEW ((Mean-median)/median) of all monthly flows (Puckeridge *et al.* 1998).

Table A4.6 - Listing of some hydrology indicators (continued).

Flow regime	▪ Classification of the pattern of monthly flows into 15 regime types (Haines *et al.* 1988).
Flow deviation	▪ Comparison of recorded and natural monthly flows - Annual Proportional Flow Deviation (Gehrke *et al.* 1995), Amended APFD (Gehrke, pers. comm.); Hydrologic deviation (Ladson *et al.* 1996).
Daily Flows	
Flow duration analysis	▪ A comprehensive method of examining changes to stream hydrologic characteristics although difficult to summarise to a single index value (Maheshwari *et al.* 1995; Knighton 1988).
Predictability	▪ PREDQ Colwell's (1974) predictability for mean daily flows (Poff & Ward 1989; Poff & Allan 1995) ▪ C/P Proportion of total predictability (PREDQ) comprised by constancy C (Poff & Ward 1989). ▪ CON Constancy = natural log of daily flows divided by Q_{50} (Clausen & Biggs 1997).
Variation	▪ Coefficient of variation of daily flow ratio of the mean daily flow over the period of record to the standard deviation of daily flows (Poff & Allan 1995).
Water level fluctuations	▪ Comparison of water level fluctuations before and after regulation (Maheshwari *et al.* 1995). ▪ Spell Analysis (Gordon *et al.* 1992).

[1] Variability is defined by Puckeridge *et al.* 1998 as range/median, interquartile range/median, or 90^{th}-10^{th} percentile range/median.