Development of a Framework for the Sustainable Rivers Audit

A Report to the Murray Darling Basin Commission

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Executive Summary

Preamble

The Sustainable Rivers Audit (Audit) is being established to overcome the lack of consistent and detailed information on the health of the Murray-Darling Basin’s rivers. At the Basin scale this lack of information has made it difficult to identify the effectiveness of land and water management or justify major policy initiatives aimed at improving the riverine environment. With water becoming an increasingly scarce and valuable resource, the Basin community seeks assurance that water is being managed according to the principles of ecologically sustainable development.

The Audit is being designed to be an annual and comprehensive five-yearly review of the condition of waterways, to inform debate among the Basin community. The Audit will assist the setting and monitoring of valley targets for catchment and river health and provide a trigger to review threats to the rivers of the Basin and, where appropriate, review management actions required to address these threats.

Approach

Key challenges for the Audit are to assess the existing health of the Basin’s rivers, to detect trends in health through time and predict the long-term ecological consequences of these changes. To meet these challenges, the assessment framework recognises the critical elements and processes that contribute to river health, and develops indices to describe them. Conceptual models of river function have been developed to identify these elements and processes and to assist with the development of indicators. These functional models are based on geomorphic divisions of the river valleys. To detect long-term changes ongoing funding must be committed to the Audit for sampling and reporting repeatedly over a long time-scale.

The Audit framework recommends river health be synonymous with ecological integrity, and that river health be measured as the degree to which aquatic ecosystems sustain processes and communities of organisms and habitats relative to the species composition, diversity, and functional organisation of natural habitats within a region. Therefore, the framework has adopted a referential approach for assessing river health for all indicators, where existing site condition is assessed relative to the expected natural condition at that site. *The use of a referential approach does not equate with the objective of returning rivers to a pristine condition.* It is up to the community to choose both an acceptable level of condition and an appropriate target for river condition. Targets for river health are being developed for the Murray-Darling Basin as part of the Ministerial Council’s ICM Strategy, ‘ICM in the Murray-Darling Basin 2001–2010—Delivering a Sustainable Future’ (MDBMC 2001).

There are several State and national programs that report river health in the Murray-Darling Basin. However, existing programs do not fully satisfy the information and reporting requirements of the proposed Audit. A lack of uniformity in assessments and reporting between jurisdictions does not generally allow Basin-wide inter-valley comparisons. Very few programs have on-going funding commitment. Many of the sites in existing programs were selected for monitoring the impacts of specific operations and so cannot be used to provide an unbiased assessment of river health at the valley scale.
Consequently, while the Audit attempts to build on available data, the collection and analyses of appropriate data will require significant investment in new sites.

The Audit framework recognises biota (fish and macroinvertebrates) and biological processes as the fundamental measures of river health and has developed indices for these. The hierarchical model of river health adopted in the proposed framework predicts that the biota are influenced by the condition of landscape and local features within the catchment. Hydrological, habitat and water quality indices have been developed to assess the condition of the landscape and local features that influence the biotic indices.

Environmental Themes
Protocols have been developed for the following environmental themes; all are based on a referential approach where existing condition is expressed as a difference from natural condition. The environmental themes for which indicators were to be developed were specified in the Project Brief.

- **Macroinvertebrate Index** — it is proposed that AUSRIVAS O/E taxa, using existing models, be used in the first year of sampling and that a more robust form of SIGNAL be developed. After that, scores for both AUSRIVAS O/E taxa and SIGNAL can be used to derive the macroinvertebrate score. To report at the river-valley scale it is recommended that the macroinvertebrate index be assessed annually at 30 sites per river valley.

- **Fish Index** — it is proposed that a fish bioassessment protocol be developed as an integral part of the Audit. Much of the background work required to develop a standardised methodology has been done. However, several aspects still require completion and evaluation. This will require dedicated funding and ongoing coordination during the first five-year term. This development can be done as part of the proposed Pilot Audit.

- **Water Quality Index** — it is recommended that two types of physical and chemical water quality indicators of river health be measured: potential modifiers of ecological processes (flow, temperature, SS, nutrients (TP, TN), salinity) and indicators of outcomes of ecological processes (TOC and composition, DO, pH and chlorophyll 'a', alkalinity, residual nutrients (NO₃, NH₄, DRP)). Reference condition would be based on flow duration condition comparable to that prevailing at the test site at the time of sampling. To report at the river-valley scale it is recommended that the water quality index be assessed annually with 4–6 sampling occasions per year at 18 sites per river valley.

- **Hydrology Index** — it is recommended that a hydrological index be defined in terms of four sub-indices: Mean Annual Flow, Flow Duration Curve Difference Index, Seasonal Amplitude Index, and Seasonal Period. The hydrology index would then be defined as the Euclidean Distance between unimpacted hydrology condition and the condition defined by the four sub-indices in a four-dimensional space. It would be expressed on a scale of 0–1, with 1 being unimpacted. It is recommended that the hydrological index be calculated at least once in each five-year period, with significant events (e.g. significant new infrastructure or environmental releases) triggering a new assessment of the hydrology index.

- **Physical Habitat Index** — it is recommended that physical habitat be assessed at three spatial scales: floodplain (km), channel feature (100 m) and in-channel patches
The assessment protocol uses a combination of remote sensing and field data collection. The major habitat categories include the vegetation and the geomorphological, and hydraulic characteristics of each habitat type. The protocol includes a separate assessment of processes that either maintain or degrade physical habitat, such as erosion or isolation. An O/E score will be generated for each spatial scale using the E-Ball technique, which requires development. To report at the river-valley scale it is proposed that physical habitat be assessed once every five years at 20 sites per river valley.

Reporting Scales
Natural resource management at the Basin scale requires information on resource condition to be measured and reported at a commensurate scale. The Audit framework is designed to report health at the river-valley scale; Cap compliance is reported at a similar scale. The Audit framework is also designed to report river health within river-valley scales. These reporting scales are defined by areas along a river with similar geomorphology and hydrology. For example, the Valley Process Zone scale reports river health for the upper, mid-slopes and the lowland parts of the river separately. The study design developed for the Audit does not report river condition at a site.

Site Selection
It is recommended that the Audit should be based on a stratified random sampling design, stratified by geomorphological characteristics (Valley Process Zones). The allocation of sites to Valley Process Zones will be catchment area weighted, which will result in approximately 70% of sites occurring in the lowland parts of the Basin’s rivers. It is recommended that reference sites for each environmental theme be selected (where possible) from the existing pool of 300 reference sites identified for the First National Assessment of River Health (FNARH).

The study design described in this report is efficient with respect to the total number of sites sampled; however, it is acknowledged that it will often not be possible to reconcile existing monitoring stations with this approach. There will inevitably be pressure to compromise on the ‘randomness’ of sites to include existing sampling stations, and indeed this may be a sensible approach. However, this will impact to varying levels on the precision of the assessment. This report recommends that the Independent Sustainable Rivers Audit Group (ISRAG) review the site selection process undertaken by the jurisdictions as part of the Pilot (and prior to sampling) to ensure a workable compromise between the recommended study design and existing monitoring stations.

Sampling Intensity
The number of samples required and the frequency of sampling are driven by a number of factors including the magnitude of the desired detectable change, the confidence in detecting that change, the initial condition score, the variability in the indicator and the reporting scale.

Existing data sets, augmented with modelled data, have been used to determine the number of samples required to detect a recommended change of 10% for habitat (20 sites per river valley) and macroinvertebrates (30 sites per river valley), and 20% for water quality (18 sites per river valley) with a power of 0.8 (80% chance of detecting a difference) and significance level of 0.1 (a 90% chance of drawing the correct conclusion) in each index at the river-valley scale.
Interpretation
It is recommended that environmental theme scores for individual sites be aggregated to the reporting scale using two types of statistics: averages and proportions.

The aggregated environmental theme score can be reported as a median with the 25th and 75th percentiles. The percentiles would indicate the condition of the best and worst quarter of sites in the river valley thus giving an indication of the range of scores for that indicator.

The aggregated environmental theme score may also be reported as a proportion of sites impaired. Because of the sample design, this statistic can be interpreted as the proportion of that river valley that is ‘impaired’ for each environmental theme. Reporting a proportion of impairment requires a judgment about what level of departure from natural is considered impaired. Statistical techniques are available to do this (e.g. AUSRIVAS protocol).
Examples of these statistics and their reporting are provided in a desktop Audit using existing data for the Ovens, Murrumbidgee and Condamine-Balonne valleys.

Indicative Cost
Determining the total cost of undertaking a complete Sustainable Rivers Audit according to the proposal in this report is not possible at this stage of its development. However, indicative costing for data collection, analysis and model development has been estimated for the recommended sampling intensity and reporting scales.

The estimated total cost for sampling, analyses and further model development for the Audit is approximately $8.3M over five years, using the recommended sampling sizes for river-valley assessment based on sample sizes required to detect a difference of 10% (20% for water quality) with a power of 0.8 and significance level of 0.1. This sampling effort, and therefore cost, will allow reporting at the Valley Process Zone scale, but with an associated loss of confidence.

The indicative cost of $8.3M represents the cost of sampling the sites required for a river-valley-scale assessment. These costs were calculated based on standard commercial rates obtained from several laboratories in SE Australia. The estimated cost also includes costs associated with development of several models and analysis tools required for undertaking the project.

The indicative costs do not include the costs of abstracting the hydrology data from existing models and databases. Also they do not include provision for costs associated with project management (either within the Commission or within the jurisdictions), with reporting or with the ISRAG. These costs may be significant, depending upon the efficiency of the respective groups.

Pilot Audit
The Sustainable Rivers Audit Taskforce (SRA Taskforce) recommended to the Commission that there be a pilot run of the Audit that reports in 2003. During the Pilot, all indicators would be developed and trialled, most likely in four river valleys across the Basin.

The Pilot is a logical step in implementing the full Audit and provides the following benefits:
• Data from the Pilot can be used to determine how to improve the efficiency of the indicators. For example, does everything that is being measured need to be measured?

• The number of samples required and the frequency of sampling are driven by a number of factors, including the magnitude of the desired detectable change, the confidence in detecting that change, the initial condition score, the variability in the indicator and the reporting scale. While the sample size estimates presented in the report are based on best information available to the Project Team, a number of assumptions about the behaviour of the indicators have been made. Better estimates of sample size can be made once the behaviour of the indices is better known through the Pilot processes.

• The Pilot will provide an opportunity to assemble and train the technicians required for undertaking the monitoring to an appropriate standard.

• The Pilot will enable the analysis and reporting of the assessment to be trialled; these are monitoring elements that are often overlooked.

• The Pilot will enable a more accurate assessment of the costs of a full implementation.

Outlook

This report presents a realistic framework for the Sustainable Rivers Audit that will provide a comprehensive annual review of the condition of the Basin’s waterways. The framework recognises that indices for environmental themes are at different stages of development and allows for staged implementation and reporting, with indicator development being undertaken during the Pilot phase and full reporting occurring thereafter.

To achieve a comprehensive assessment at the Basin scale, the ISRAG will need to provide strong leadership and the Commission will need to provide substantial project management. Successful implementation of the Audit will also require considerable inter-jurisdictional cooperation.
Contents

EXECUTIVE SUMMARY ................................................................. 1

BACKGROUND TO THE AUDIT .................................................. 8

PURPOSE OF THE AUDIT .......................................................... 9

THE AUDIT WILL ................................................................. 9
THE AUDIT WILL NOT ............................................................ 10

THE APPROACH ................................................................. 10

RIVER HEALTH ................................................................. 10
REFERENCE CONDITION APPROACH ........................................... 11
CONCEPTUAL MODEL FOR AUDIT .................................................. 12
BUILDING ON EXISTING PROGRAMS ........................................... 14
ENVIRONMENTAL THEMES FOR WHICH INDICES ARE DEVELOPED .... 15

GENERAL METHODS FOR AUDIT ASSESSMENT ......................... 16

ADAPTIVE CAPACITY ............................................................ 16
FITTING WITH EXISTING PROGRAMS ........................................... 17
ENVIRONMENTAL THEME INDICATORS ........................................... 17
Macroinvertebrates ............................................................... 17
Fish .................................................................................... 19
Water Quality ........................................................................ 20
Hydrology ............................................................................ 21
Physical Habitat ..................................................................... 21

ACCOUNTING FOR LONGITUDINAL VARIABILITY — GEOMORPHIC ZONES .................................................. 22
REPORTING SCALES ............................................................. 26
Spatial Scale .......................................................................... 26
Temporal Scale ....................................................................... 28

SAMPLE SIZES ................................................................. 29
SITE SELECTION ................................................................. 33
Reference Sites ....................................................................... 34
Test Sites ............................................................................... 34

AGGREGATION ................................................................. 35
INTEGRATION ................................................................. 37

INDICATIVE COSTING ............................................................ 39

ALTERNATIVE COSTING AND BENEFITS ................................. 40

EXAMPLE AUDIT WITH NL&WRA DATA ............................. 43

INTERPRETATION ............................................................... 43
Ovens ................................................................. 43
Murrumbidgee ............................................................. 44
Condamine-Balonne ......................................................... 44

FURTHER TASKS REQUIRED TO UNDERTAKE THE AUDIT ................................................................. 47

DEFINITIONS / GLOSSARY ..................................................... 48
WORKSHOP PARTICIPANTS .................................................................51
REFERENCES ........................................................................................53

APPENDIX 1 Review of existing programs that measure and report river health in the Murray-Darling Basin
Peter Liston ...........................................................................................51

APPENDIX 2 Functional Process Zone conceptual models of river function
Martin Thoms, John Foster, Julie Coysh ................................................53

APPENDIX 3 Macroinvertebrates: Review and development of aquatic macroinvertebrate protocols
Julie Coysh, Richard Norris, Wayne Robinson .........................................53

APPENDIX 4 Fish: Review and development of fish assessment protocols
Peter Davies ............................................................................................53

APPENDIX 5 Water quality: Review and development of physico-chemical indicators
Ian Lawrence ..........................................................................................53

APPENDIX 6 Hydrology: Review and development of hydrological indicators
Martin Thoms and Fiona Dyer ..................................................................53

APPENDIX 7 Physical habitat: Review and development of physical habitat assessment protocols
Ben Gawne .............................................................................................53

APPENDIX 8 Response to SRA Taskforce questions on Draft Report ..............53
Background to the Audit

Extensive reforms of the water industry have been introduced across the Murray-Darling Basin to improve efficiency in the way water is used and to provide basic protection for the aquatic ecosystems. Recognition of the ongoing deterioration of the riverine environments contributed to the introduction of the Cap on diversions. The Cap seeks a balance between protection of the riverine environment and consumptive use of water. Since the introduction of the Cap, diversions have been reported annually; however, a Basin-wide assessment of river health has never been systematically made or reported. This lack of consistent and detailed information on the health of the Basin’s rivers has made it difficult to identify the effectiveness of existing river management or justify major policy initiatives aimed at improving the riverine environment. To address this deficiency, the Review of the Operation of the Cap (MDBC 2000) recommended an annual assessment of river health in the form of a Sustainable Rivers Audit (hereafter called Audit).

After considering a scoping study to assess the feasibility of an ongoing Basin-wide assessment of river health, the Ministerial Council, at its meeting of 25 August 2000, agreed to develop an Audit using the Scope of the Sustainable Rivers Audit (Cullen et al. 2000) as a guide to developing the Project Brief. The project brief required that indicators be developed for the following environmental themes: macroinvertebrates, fish, water quality, hydrology and habitat. The Council also noted the establishment of the Sustainable Rivers Audit (SRA) Taskforce to guide the development of the Audit. The CRC for Freshwater Ecology was contracted by the SRA Taskforce to undertake the project ‘Development of a Framework for the Sustainable Rivers Audit’.

In undertaking the project to develop an Audit framework, the CRC for Freshwater Ecology (CRCFE) actively involved jurisdictional representatives (identified by the SRA Taskforce) in the development of the Audit’s indices and framework. This occurred through participation in workshops, consultation about existing and future river health programs, and review of draft material. The indices and the framework reported here are therefore the culmination of both the input from the workshop participants and the work of the CRCFE team. Because the final product may not entirely accommodate all the issues that were identified by all the workshop participants and Taskforce members, the CRCFE assumes sole responsibility for the Audit framework.

The National Strategy for Ecologically Sustainable Development (ESD) (Commonwealth of Australia 1992) defines ecologically sustainable development as ‘using, conserving and enhancing the community’s resources so that the ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased’. Therefore, ESD refers not only to the quality of the ecological system but also to the quality of life of the community. The Audit is focussed only on assessing the condition of the ecological system and does not attempt to measure ‘sustainability’ in the broader context as defined in the National Strategy for ESD.
Purpose of the Audit

The Purpose and Principles for the Audit, as presented to the Ministerial Council Meeting 58, on 13th March 2001 are:

PURPOSE

The Sustainable Rivers Audit should:

The SRA will provide consistent, basin-wide information on the health of rivers to enable and enhance sustainable land and water management by:

- developing a common reporting framework using comparable information, through time and across catchments;
- reporting against a consistent and scientifically robust set of river health indicators;
- triggering further investigation or action in response to evidence of deteriorating river health;
- informing the development of targets for river health, and monitoring of progress towards achieving those targets.

PRINCIPLES

The Sustainable Rivers Audit should:

- Build upon available information and draw upon activities already being undertaken by partner governments;
- Use independent auditors with appropriate skills to review information and comment on river health;
- Publicly report audit findings on a regular basis, with assessment and interpretation of indicators at appropriate time-intervals (to be determined);
- Compile and report information to assess river health at the river-valley scale, to inform priorities for policy and programs at a Basin scale. (footnote: Audit results may trigger a more comprehensive investigation which may inform intra-valley management but State and Territory programs will normally guide intra-valley management);
- Report annually to Ministerial Council on the implementation of the SRA to inform discussions on river health.

The Audit will …

- provide an annual Basin-wide commentary on the health of the Basin’s rivers. Accordingly, the Audit framework has been developed to generate a scientifically robust and systematic assessment of river health that provides information on the likely cause(s) of ill-health.
- supply information for public and government debate on river health. Audit assessments will provide information for the setting and monitoring of valley targets.
for catchment health and river health developed as part of the Integrated Catchment Management Framework and other MDBC and State initiatives.

- trigger reviews of threats to the rivers of the Basin and where appropriate, review management actions required to address these threats;
- require considerable investment in new data and sampling locations, particularly in the western regions of the Basin.

The Audit will not …

- specifically assess the ecological impacts of the Cap, or of any other management activity in isolation from catchment management. While the proposal for an Audit originated from the Review of the Operation of the Cap (MDBC 2000), the Audit assessment integrates the impacts of land and water management at the river-valley scale. The Audit therefore reports on the ecological outcomes in the rivers resulting from existing management at the valley scale—not necessarily from individual management actions.
- report river health of each reach and tributary in the Basin. The Audit framework is designed to provide a statistically robust assessment of river health at three broad geographic scales: for the Basin, the river valley and Valley Process Zones. The adopted approach is optimised for these scales and does not allow for efficient or statistically robust reporting at smaller scales (e.g. reaches or tributaries).
- replace existing compliance monitoring for specific operations, for example monitoring required to assess discharge quality of irrigation tail-water;
- set targets for riverine health. Rather the Audit will supply information for the target setting process by providing an on-going Basin-wide assessment of river health.

The Approach

River Health

The Audit will assess and report river health. While river health is a concept that has meaning to most in the Basin community its definition generates extensive debate in the scientific community (see Norris and Thoms 1999, Norris and Hawkins 2000). River health is generally understood to be shorthand for ecological condition; for the Audit, river health and ecological condition are synonymous.

There are several ways of assessing river health. River health can be assessed solely by ecological criteria (Haskell et al. 1992) or by the river’s ability to meet community expectations and uses (Meyer 1997, Fairweather 1999, Karr 1999). A river that is not in a natural condition (and, by definition, ecologically impaired) may still provide for the community’s expectations and uses and therefore can be deemed ‘healthy’ by the latter definition but not by the former.

Communities and governments are currently considering and debating an appropriate mix of environmental and other uses of the Basin’s rivers. Their decisions will be reflected in the targets currently being developed for riverine and catchment health. The outcomes of
these deliberations are likely to vary between communities and over time. An objective of
the Audit is to provide a consistent framework for assessing river health across the Basin
and through time. Thus it is not appropriate to base a Basin-wide assessment of river
health on the ability of rivers to meet specific, and in many cases not yet articulated,
community values. It must be recognised however, that management objectives across the
Basin generally reflect the maintenance and rehabilitation of rivers to supply the
consumptive uses expected by the community while maintaining some of the natural
ecological values and services. Therefore, care will be needed in reporting and interpreting
the Audit to acknowledge that the Audit reports ecological criteria, not the rivers’ abilities
to meet community expectations, targets or uses.

The most appropriate criterion for assessing river health for the Audit is the concept of
ecological integrity. Ecological integrity has been defined as the capacity to support and
maintain a balanced, integrated, adaptive biological system having the full range of
elements and processes expected in the natural habitat of a region (Frey 1977, Boulton and
Brock 1999, Norris et al. 2001). Maintaining a natural ecosystem structure and function is
the least risky way of ensuring that the widest possible range of uses and amenities is
supported (Norris et al. 2001). The Audit, by reporting ecological integrity as the measure
of river health, will inform the community of the ecological elements and processes that
are potentially being lost as a result of existing river management. Whether the loss of
these elements and processes is acceptable can then be debated.

For the purposes of the Audit, river health is synonymous with ecological integrity and
will be measured as:

the degree to which aquatic ecosystems support and maintain processes and a
community of organisms and habitats relative to the species composition,
diversity, and functional organisation of natural habitats within a region.

Two key points emerge from this definition:

- River health refers to the maintenance of community structures and ecosystem
  processes; and
- Ecological attributes of the biota observed at a damaged site will differ from those
  that would be expected if the site were not damaged — the Audit is adopting a
  referential approach.

Reference Condition Approach

A comparative (referential) approach provides a powerful framework in which to assess
river health. It enables robust assessment without requiring a full definition and functional
understanding of the components of the ecosystem.

For the purpose of the Audit, reference is defined as natural condition. Extensive
development of most of the Basin’s rivers, particularly in the lower reaches, has resulted
in few, if any, sites in natural condition. Therefore, reference condition is based on ‘best
available’ natural habitats. Additionally, a variety of sources including anecdotal data,
historical references and expert opinion have been used to improve the description of
‘reference’. This information has been incorporated into the conceptual models of river
function, which have been developed to describe ‘natural’ condition. River health and the
The operational definition of reference condition should be reviewed after five years because the community’s aspirations and understanding of river health are likely to have changed.

_The use of a referential approach does not equate with the objective of returning rivers to a pristine condition._

The referential approach allows a quantification of the existing condition of the river. What is an acceptable level of condition and what is an appropriate target for river condition are community decisions. For example, an acceptable target for an indicator may be two-thirds of natural condition.

**Conceptual Model for Audit**

Key challenges for the Audit are to:

- assess existing health of the Basin’s rivers,
- monitor trends in health, and
- predict the ecological consequences of these trends.

To meet these challenges, the assessment framework must recognise the critical elements and processes that contribute to river health and develop indices to describe them. Ideally, the Audit should provide a framework to assess the outcomes of the changes to these key elements and processes. To do this requires a clear articulation of how rivers function. With our existing understanding this is best achieved through the development of conceptual models.

Conceptual models of river function are fundamental to the Audit design, the selection and interpretation of appropriate indicators, the assessment tools and sampling programs. Models allow questions such as the following to be answered: What are the critical habitats and how do they change along the river system? How does our understanding of river function impact on sampling location and site selection?

Models of river function have a critical role in the interpretation and presentation of data collected for the Audit. Models of river function:

- assist in understanding the implications of a poor score for river health, and provide a framework to convey this information to the Basin community. Models can be drawn to visually show existing condition, how it is changing and the impact of management actions.
- assist in setting targets for river health and prioritising appropriate management actions;
- make explicit the links between what the Audit is measuring and key elements and processes that are not being directly measured by the Audit;
- indicate additional key process and structural indicators that could improve our understanding of river health. This information will guide research and management agencies in developing future indicators, and provide a structure for these to be included in developments of the Audit.
provide a framework for the inclusion of river health information collected in existing jurisdictional programs into future Audits;

allow a description of natural condition that assists in defining reference.

There are several conceptual models of riverine function in the literature, including the River Continuum Concept (RCC), Flood Pulse Concept (FPC) and Riverine Productivity Model (RPM). While these models make differing predictions of factors that are important in determining the structure and function of lowland rivers, they also share three elements:

- habitat heterogeneity — all models implicitly acknowledge that the biotic community is structured by the availability of habitat and at a broad level there is a relationship between biodiversity and habitat heterogeneity;

- connectivity — the RCC emphasises the importance of longitudinal connectivity, the FPC emphasises lateral connections with the floodplain while the RPM acknowledges the linkage between riparian vegetation and in-stream ecology;

- metabolic functioning — these models are based on the bottom-up template, namely that the source and amount of organic matter produced will have a significant effect on the food web.

This report proposes a broad conceptual model that builds on the above models for the Audit. The model assumes that if habitat, connectivity and metabolic functioning are maintained in their natural state, then a river’s ecological integrity will be maintained. According to the model, a healthy riverine ecosystem has evolved to utilise the material and energy entering the system efficiently to maintain its structure and function. A decline in the health of the system occurs when the system loses some of its capacity to capture and dissipate the energy and material entering the system. This disruption may be manifest as lower rates of primary production, the failure of consumers or predators to harvest the energy and material available in the trophic level below them or failure of the system to adjust to changes in the delivery of energy, material and information. In structural terms, the loss of species from the system (not species replacement) would be expected to lead to a loss of capacity to undertake these ecosystem functions.

These general properties of a healthy ecosystem can be used as a template for the development of conceptual models for different parts of the river system, where the fluxes of energy, material and information may be different because of the constraints imposed by the landscape. The general ecosystem model also allows the proposal of hypotheses about the structural elements and processes that are typical of a healthy river.

The general ecosystem model allows us to make some predictions about the response of rivers to different forms of disturbance. River health is influenced by the condition of landscape features within the catchment. Across the MDB, the condition of these landscape features has been radically altered. At the catchment scale, widespread clearing has occurred: cropping and grazing systems have replaced native vegetation; alien plants and animals have been introduced. At the river reach scale, riparian vegetation has been cleared or damaged and channels modified by bank slumping, erosion and sedimentation. Levees, weirs and dams have reduced the connectivity along the rivers and between the rivers and their floodplains. Water quality and the processes that affect water quality have altered. At the local scale there is habitat loss through desnagging and sedimentation with localised losses of plants and animals.
We do not understand the full impact on the Basin’s rivers of the modifications that we have made to the landscape, or how, over time, these modifications will continue to have an impact. But we do recognise that the Basin’s rivers have changed and will continue to do so. For example, salt concentrations will continue to rise in the medium term despite extensive management intervention. We realise that these changes reflect existing and past management practices.

According to the general ecosystem model, catchment management has had a significant impact on the riverine ecosystem. The resultant changes will be most clearly quantified by assessing the fish and invertebrate communities, hydrology, water quality and physical habitat.

**Building on Existing Programs**

An extensive review of State and national programs that report river health in the Murray-Darling Basin has been undertaken (See Appendix 1: Review of Existing Programs). Reviews of existing methods for assessing indices were undertaken for each environmental theme. (See Appendices 3–7).

The review of existing programs specifically focussed on programs that assessed river health:

- Water Allocation and Management Planning (Queensland);
- State of Rivers Approach (Queensland, NSW);
- Integrated Monitoring of Environmental Flows (NSW);
- Pressure Biota Habitat Approach (NSW);
- Stressed Rivers Assessment (NSW);
- NSW Rivers Survey (NSW);
- Index of Stream Condition (Victoria);
- MDBC Water Quality Monitoring Program (MDBC);
- National State of the Environment Reporting (Commonwealth);
- Assessment of River Condition (Commonwealth);
- Wild Rivers (Commonwealth);
- National River Health Program (Commonwealth, State and Territory); and
- Waterwatch (Commonwealth).

There are a number of other programs in the Basin that report on elements that may be included in an assessment of river health. While these programs have not been reviewed in full, representative data from them have been assessed (Appendix 1).

The review of existing programs highlighted that:

- Most programs provide a snapshot of river health with no commitment to follow-up assessment and reporting. Therefore future trends in river health will not be determined with existing programs in the Basin.
- Few programs have on-going funding commitment.
• There is little uniformity in the spatial scale at which programs report. Spatial scales
range from individual sites to river valleys.
• There is a wide range of components measured by programs, with little uniformity in
approach between programs.
• Programs differ in the extent to which the procedures used have been codified. In the
past, poor codification has rendered considerable monitoring data useless.
• The degree of expertise required to complete an assessment varies widely between
programs — from unskilled to highly skilled experts.
• There is a need to give more consideration to spatial and temporal variability in
developing assessment programs than has generally occurred previously.
• Most programs depend on a reference condition approach for interpreting existing
condition.

Programs currently being undertaken by the partner governments do not fully satisfy the
information and reporting requirements of the Audit for the following reasons:
• Significantly, the lack of uniformity between river health assessments between
jurisdictions does not generally allow inter-valley comparisons across the Basin
using existing programs.
• Very few of the programs have an ongoing commitment and so they are not likely to
provide data into the future.
• Many of the sites in these programs were selected specifically to detect or monitor
the impact of point sources or other river management operations and so would
provide a biased picture of river health.

The Review did identify indicators and data sources that can provide a base from which
the Audit framework can be developed. For example, the macroinvertebrate sampling
based on the AUSRIVAS approach undertaken for First National Assessment of River
Health (FNARH) has produced a significant database, by virtue of its standardised
protocol, for the Audit to build upon.

Environmental Themes for which Indices are Developed
The Project Brief for the Development of a framework for the Audit clearly states that
indicators to be developed by the CRCFE for the framework were: macroinvertebrates,
fish, water quality, hydrology and habitat. These indicators were recommended in a
scoping study (Cullen et al. 2000) undertaken prior to this project, which used the
following criteria to identify suitable indicators:
• they build upon existing programs and data as much as possible;
• they are consistent with the conceptual models of river function developed for the
functional process zones;
• they are responsive to disturbance;
• they are capable of rapid measurement and analysis (analysis is built into reporting of
the indicator);
standardised methods are available and are technically appropriate for State agencies to undertake;
their output can be interpreted relatively unambiguously;
the indicator has meaning to the wider Basin community.

There are a number of other environmental themes that if developed could have value to the Audit in the future years. For example, the Audit has not developed indices for benthic algae or waterbirds. Methods for using these as part of river and wetland health assessments are being developed in various research programs and have been adopted by some. The Comprehensive Sustainability Audit provides a mechanism for including these and other indicators for which data have been collected and analysed and for reviewing the development of these for future Audits.

The indices developed for these environmental themes can be broadly classified into driver and outcome indices. Driver indices describe the state of the physical environment and provide a diagnostic function for the condition reported by the biotic and biological process (outcome) indices. The conceptual models derived to interpret indices recognise that physico-chemical indicators (e.g. water quality and habitat) are either significantly modified by, or are the result of biological activity, and in a number of cases are considered outcome indicators; for example, the water quality sub-indices that report outcomes of ecological processes (e.g. diurnal range in DO).

General Methods for Audit Assessment

Adaptive Capacity

The science underpinning ecological assessment will continue to improve through knowledge gained from research projects and experience with assessment programs such as the National Land and Water Resources Audit, Index of Stream Condition, and Integrated Monitoring of Environmental Flows. As new knowledge becomes available the Audit requires the flexibility to respond to it. Tempering this is the need to acquire comparable data over long periods so that changes in river condition can be assessed. Adjustments to the types of indicators and how they are measured will need to be undertaken cautiously so as not to compromise the ability of the Audit to monitor long-term trends in condition.

Balancing the need for adaptability with the constancy required to detect long-term changes is a complex task and one that should be the responsibility of the Independent Sustainable Rivers Audit Group (ISRAG).

The Pilot Audit provides an excellent opportunity to review the indicators and to undertake various analyses to determine if they are optimised. Under the guidance of the ISRAG, the five-yearly Comprehensive Sustainability Audit is also an appropriate time to review the performance of the indices.
Fitting with Existing Programs

The Audit framework described in this report has been designed to be a statistically rigorous assessment of river health. To achieve this objective the design recommends that a prescribed number of randomly selected sites (stratified by Valley Process Zone) be assessed at various temporal scales for each environmental theme. The study design described in this report is efficient with respect to the total number of sites sampled, but it is acknowledged that it will often not be possible to reconcile existing monitoring stations with this approach. There will inevitably be pressure to compromise on the ‘randomness’ of sites to include existing sampling stations and indeed this may be a sensible approach. However, this will have varying levels of impact on the precision of the assessment.

This report recommends that the ISRAG review the site selection process undertaken by the jurisdictions prior to the first assessment as part of the Pilot, to ensure a workable compromise between the recommended study design and existing monitoring stations.

Environmental Theme Indicators

Indices for the five environmental themes have been developed for this framework in accordance with the Project Brief. Reports of this work are presented in Appendices 3–7 with brief summaries presented below.

The indices developed for the Audit build on previous experiences of assessing and reporting river health. Methods for sampling most individual metrics are generally well established. However, there has been little standardisation of sampling methods in previous surveys across the Basin. In addition, there has been little development of a standardised manner of either reporting or analysis of these data.

After reviewing previous approaches to assessing and reporting river health, the framework recommends that the Audit adopt a referential approach, in which indices are reported as departure from natural on a scale of 0–1+, with 1 representing natural. This approach is well developed and widely adopted for macroinvertebrate assessment, but not so for other indicators. Consequently, the efforts required to fully develop each of the indicator themes vary considerably — from adopting existing protocols, to developing new methods of analysis and interpretation and recommending the adoption of standard protocols for sampling.

For this report, the development of indicators has progressed as far as is possible with existing data-sets within the Basin. The data and experience from the Pilot Audit will enable these indicators to be refined.

Macroinvertebrates

See Appendix 3

Two indicators of condition for the macroinvertebrate theme are proposed: AUSRIVAS O/E taxa and a form of SIGNAL score. O/E SIGNAL and raw SIGNAL as currently calculated have been demonstrated to be insensitive to impacts and consistently to overestimate condition. Therefore it is recommended that the AUSRIVAS O/E taxa score be used as the macroinvertebrate indicator for the first year of the Audit. It is proposed that a more robust form of SIGNAL be developed in the first year of the Audit by testing regionalised raw SIGNAL scores and calculating O/E SIGNAL using all taxa.
It is recommended that existing AUSRIVAS models and associated sampling and processing protocols should be used for assessment in the first year. Existing regional models should be used in preference to statewide models where available and appropriate. Concurrently, existing models should be evaluated using a stepwise process to ascertain whether the existing model is the most appropriate model in each case. Development of regional models for the Basin where appropriate is proposed for the first year of the Audit.

The frequency of assessment should maximise the power of the sampling design to detect spatial and long-term temporal trends. Single season models are therefore recommended where taxa numbers are high enough, as sampling density can be increased for the same cost. In Western regions, however, combined season models are recommended to provide an adequate taxon list.

Existing Victorian data and models will be used to test the effect of increased taxonomic resolution on taxon richness in lowland zones. The accuracy of assessments can be analysed with existing Victorian models by examining the change in reference sites over time. After testing, genus or species models may be adopted where appropriate.

Analysis of both AUSRIVAS O/E taxa and SIGNAL will use comparison to a reference condition. The macroinvertebrate theme should incorporate a measure of departure from reference, and a measure of departure of reference from natural to account for the varying definitions of reference condition currently used. Options proposed to measure the departure of reference from natural include using the River Disturbance Index, conceptual models of river function or a narrative description. To measure the departure of a site from reference condition, scoring against reference criteria and measuring the departure of the O/E value from 1 have been proposed. These measures would then be turned into alternative health indicators and tested for sensitivity to known disturbances, allowing existing reference sites and models to be used, and providing comparability between different standards of reference.

Caution should be used in integrating indicator scores to produce a single score. Preferably, indicators should be reported separately, as they represent different information about the health of a stream. Where a single score is required, reporting of the indicator score that is the furthest away from reference is recommended. Only the O/E taxa indicator will be reported in the first year. Aggregation will follow the general principles outlined for reporting of theme condition, using the median score for a river valley.

Valleys and Valley Process Zones have been proposed as reporting scales. A number of options for sampling design and precision have been proposed, and a decision is required of the SRA Taskforce about them. The recommended level of change detectable at the river-valley scale for an AUSRIVAS O/E score is 10% and for a SIGNAL score 5%. These are considered appropriate and meaningful levels at which a change should be detectable.
Fish

See Appendix 4

This report recommends a program of work to be conducted within the Audit, aimed at:

- finalising standard methodology for fish bioassessment across the MDB; and
- conducting the first Basin-wide assessment (Pilot) of river health using fish data.

A specialist workshop, focussed on fish-based bioassessment for the Audit, was attended by key personnel from the relevant Murray-Darling Basin agencies (MDBAs) in April 2001. Key issues discussed at the workshop were:

- the absence of and the need for standardised sampling methods across the Murray-Darling Basin (MDB);
- the need for a standard set of variables and derived measures (‘metrics’) that describe fish communities at a range of levels of organisation, from the individual to the community level;
- the difficulty in defining reference conditions for fish within the MDB;
- the need for a single analytical method (‘framework’) for making comparisons of metrics against expectations or reference conditions;
- the need for outputs from the assessment which are readily understood and communicable to river managers in the MDB.

All the issues were discussed and agreement was reached on a program of activities and surveys to be conducted in the first five-year Audit period in order to implement fish-based bioassessment within the Audit.

All fishery agencies within the MDB use a suite of active and passive fishing gear with survey programs involving varying combinations of electrofishing, nets and traps, with the exception of South Australia which relies only on collection of recreational and commercial fishery data. There was little agreement between MDBA representatives at the workshop on a single sampling methodology, with technical constraints potentially limiting the application of all methods across the diverse range of river types within the MDB. It was agreed that two sampling approaches should be jointly trialled and evaluated in a preliminary phase of the Audit survey — electrofishing (boat and backpack) and passive gear (fyke and gill nets and baited light traps). Formal comparison of catches from the ‘electrofishing only’ and ‘all gear’ (electrofishing plus passive gear) options at the end of the ‘first round’ (2001–2002) of sampling was recommended, with one of the two options to be selected for further sampling rounds within the first five-year term of the Audit. This will allow all data from the first round to be compatible with ensuing sampling rounds.

Sampling for all surveys will be conducted once at each site in the low flow summer–autumn periods. Site lengths will be consistent with the NSW Rivers Survey, but will also be evaluated following the first sampling round. Insufficient data were available to the workshop participants and for this study to allow a detailed evaluation of the number of sites required to be sampled within each river valley for the Audit. A ‘design’ project is therefore recommended to collate all existing and new fish survey data from major MDBA programs, and to conduct power analyses relevant to agreed ‘effect sizes’. This project
will recommend final numbers of sites for each river valley which will allow detection of changes in fish assemblage measures with a known sensitivity. The project must be completed in the 2001/2002 financial year.

A suite of fish and environmental variables was recommended for measurement on each sampling occasion. The fish data will be used to derive values for a total of 29 ‘metrics’ chosen to quantify fish assemblage condition at community, population and individual levels. The metrics will include measures of abundance; biomass; native fish biodiversity; aliens; representation of habitat guilds, trophic, reproductive and migratory guilds; tolerances; abnormalities; and size distribution.

Two analytical frameworks were identified as being potentially suitable for fish-based bioassessment in the Audit — multimetric analysis and multi/univariate predictive modelling. Both frameworks have recently been applied to stream fish assemblages in or adjacent to the Basin. Two methods have been developed within each of the two frameworks:

- multimetric — the Index of Biological Integrity, and two fish metrics developed under the NSW DLWC MARA program; and
- multivariate predictive — AUSRIVAS/RIVPACS (multivariate), and the regression tree approach (univariate).

None has been fully evaluated and all are still in active development. It was recommended that a project be funded to conduct a comparative assessment of the methods, using Audit fish survey data, whose primary aim will be to develop a final ‘unified’ framework and methodology. The methodology and the form of final outputs will be subject to peer review prior to adoption. The project should also be asked to analyse the data from the first three Audit fish survey rounds using the final recommended method.

Intrinsic to both analytical frameworks is the concept of reference condition and the need to define it quantitatively in terms of metrics and variable values that are regionally based and representative of an ‘undisturbed’ or ‘least disturbed’ condition. It was recommended that two approaches be used — a ‘best available’ approach using data from the best reference sites or reaches within the MDB following screening for human impacts, and a ‘historical’ approach using expert knowledge and historical sources to define lists of species known to occur in each river valley prior to agricultural development in the MDB. A small review and workshop project is recommended to define the reference condition for fish within the Basin.

**Water Quality**

*See Appendix 5*

The selection of physico-chemical indicators is based on the capacity of streams to transform catchment inputs into food forms sustaining higher trophic levels in the stream, and to recycle the in-stream generated detritus.

The indicators reflect the key ecological processes (primary and secondary heterotrophic production and the mineralisation of organic material), and the potential modifiers of these processes (temperature, light or nutrient limitation or stimulation, salinity).
Except in cases of sampling sites established to monitor point-source discharges, monitoring sites are predominantly based on ‘mixed zones’ (riffles, reaches). In addition, given the low frequency of significant flow events, the routine nature of sampling for monitoring purposes means that data are predominantly for low- to medium-flow conditions. The proposed Audit approach builds on this existing monitoring approach, with data interpreted as reflecting outcomes of in-stream processes.

The adoption of a ‘reference’-based Index (O/E) for assessment of values for the test sites is proposed. In the case of the lowland Valley Process Zones, it is generally not possible to identify pristine reference conditions. It is proposed in this case to use process-based models to simulate ‘pre-development’ physico-chemical reference conditions.

Appendix 5 elaborates on the specific indicators to be measured, the structure of the physico-chemical sustainability index on a Valley Process Zone basis, the required number of sites and frequency of sampling, and the estimated annual cost of monitoring across the Basin.

**Hydrology**

*See Appendix 6*

It is recommended that a hydrological index be defined in terms of four sub-indices: Mean Annual Flow, Flow Duration Curve Difference Index, Seasonal Amplitude Index, and Seasonal Period. It is recommended that these indices be reported separately. If a single hydrological index is required, it should be calculated as the Euclidean Distance between unimpacted hydrology condition and the condition defined by the four sub-indices in a four dimensional space, and be expressed on a scale of 0–1, with 1 being unimpacted.

It is recommended that the hydrological index be calculated at least once in each five-year period. Significant events should trigger a new assessment of the hydrology index; for example, significant new water infrastructure, environmental flow allocations or significant improvements in modelling capacity.

**Physical Habitat**

*See Appendix 7*

It is recommended that physical habitat be assessed at three spatial scales: the floodplain (km), channel feature (100 m) and in-channel patches (1 m) scales. The assessment protocol uses a combination of remote sensing and field data collection. Each river valley assessment will be undertaken once in each five-year period, as most of the variables change over relatively long time periods.

Within each spatial scale there is an assessment of the type, area and diversity of physical habitat. The major habitat categories include the vegetation, and the geomorphological, and hydraulic characteristics of each habitat type. The selection of indicators has been based on an explicit conceptual model with consideration given to the cost of data collection, our limited understanding of the important characteristics of physical habitat, and ecological rigour. The protocol includes a separate assessment of processes that either maintain or degrade physical habitat, such as erosion or isolation.
An O/E score will be generated for each spatial scale using the E-Ball technique. This will allow separate determination of floodplain and stream feature components. The score for each scale should be reported individually. The lowest of the three spatial scale assessment scores should be used to derive a single physical habitat score.

**Accounting for Longitudinal Variability — Geomorphic Zones**

Implicit in the Audit’s assessment of river health is the ability to identify, measure and interpret the key ecological processes and communities in a valley compared to reference. This is difficult in large river systems because ecosystem processes and community structure change along a river — the headwaters are different from the lower reaches.

The Audit has adopted a geomorphic approach, stratifying valleys into similar zones at two scales: Functional Process Zones (FPZs; Figure 1) and Valley Process Zones (VPZs; Figure 2). Stratification at these scales enables like to be compared with like (with respect to natural hydrology and geomorphology). These zones provide suitable geographic units at which to report river health — the choice being determined by the resolution required.

Functional Process Zones are lengths of a river that have similar discharge and sediment regimes. Their gradient, stream power, valley dimensions and boundary material define them. The characteristics of FPZs are summarised in Figure 3, and detailed descriptions of the geomorphic characteristics for each of the FPZs can be found in Appendix 2. For each FPZ — they are typically tens to hundreds of kilometres in length — a model of river function describing the key ecosystem processes and structures has been developed (See Appendix 2). Functional Process Zones and associated models provide a:

- suitable geographic template in which to develop conceptual models of river function (see Appendix 2);
- basis for identifying VPZs, which have been used in developing a reporting scale for the Audit;
- framework in which to assess the relevance of indicators to each section of the river; for example, what are suitable indicators in each FPZ?;
- help define and describe reference condition.

Valley Process Zones (VPZs) are geomorphically similar regions within a river valley, identified broadly by their sediment transport characteristics. These are described as regions of sediment source, sediment transport and sediment deposition (see Table 1) and were mapped and defined using FPZs\(^1\). Most river valleys in the Basin have three VPZs, with sediment source regions in the east and sediment deposition regions in the west, and with the slopes being sediment transport zones. These are mapped in Figure 3. Valley Process Zones provide a suitable reporting scale for the Audit that does not compromise the statistical integrity of the valley scale assessment. Sampling can be stratified by VPZ.

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\(^1\) Repeating units of sediment characteristic (e.g. sediment source, transport, source, etc.) do not allow the strict mapping of FPZs into VPZs without sometimes having repeating VPZ types in the one river valley. Since VPZs are used to stratify the valley for a reporting framework at a broad scale we did not want repeating patterns of VPZs. To overcome this, VPZs were mapped using the following convention. Mapping started at the bottom of the valley. The FPZ at the bottom of the valley defined the first VPZ. Moving upstream, the first FPZ from the next VPZ became the boundary for that VPZ, and so on. If an FPZ from a downstream VPZ was encountered, this was included in the current VPZ. The outcome of this is that occasionally an FPZ will be allocated to a VPZ of different sediment transport characteristics (e.g. a depositional FPZ in a transport VPZ).
Figure 1

SRA river valleys and functional process zones

River valleys

Functional process zones
- Confined
- Mobile
- Meandering
- Pool
- Armoured
- Anabranch
- Distributary
- Low-confined

[Map showing SRA river valleys and functional process zones with a legend indicating different types of zones and a scale in kilometers.]
Figure 2

SRA river valleys and valley process zones
<table>
<thead>
<tr>
<th>Geomorphological Units</th>
<th>Upland zones (sediment supply)</th>
<th>Mid-slope zones (sediment transfer)</th>
<th>Lowland zones (sediment deposition/storage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pool</td>
<td>Upland Gorge</td>
<td>Armoured</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valley gradient/Long profile</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
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<td><img src="image10" alt="Diagram" /></td>
<td><img src="image11" alt="Diagram" /></td>
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<tr>
<td>Valley profile</td>
<td><img src="image17" alt="Diagram" /></td>
<td><img src="image18" alt="Diagram" /></td>
<td><img src="image19" alt="Diagram" /></td>
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<td><img src="image26" alt="Diagram" /></td>
<td><img src="image27" alt="Diagram" /></td>
</tr>
<tr>
<td>Floodplain features</td>
<td>No floodplain</td>
<td>No floodplain</td>
<td>Minimal floodplain development. Some high level terraces.</td>
</tr>
<tr>
<td></td>
<td><img src="image33" alt="Diagram" /></td>
<td><img src="image34" alt="Diagram" /></td>
<td><img src="image35" alt="Diagram" /></td>
</tr>
<tr>
<td>Planform</td>
<td>Valley Controlled</td>
<td>Valley Controlled</td>
<td>Sinuosity = &lt; 1.2</td>
</tr>
<tr>
<td></td>
<td><img src="image41" alt="Diagram" /></td>
<td><img src="image42" alt="Diagram" /></td>
<td><img src="image43" alt="Diagram" /></td>
</tr>
<tr>
<td>Stream power</td>
<td>Low</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td><img src="image49" alt="Diagram" /></td>
<td><img src="image50" alt="Diagram" /></td>
<td><img src="image51" alt="Diagram" /></td>
</tr>
<tr>
<td>Dominant sediments</td>
<td>Bedrock, boulder</td>
<td>Bedrock, boulder, cobble</td>
<td>Cobble and gravel surface layer protecting poorly sorted finer sub-sediments</td>
</tr>
<tr>
<td></td>
<td><img src="image58" alt="Diagram" /></td>
<td><img src="image59" alt="Diagram" /></td>
<td><img src="image60" alt="Diagram" /></td>
</tr>
<tr>
<td>Function</td>
<td>Relatively immobile source area</td>
<td>Highly mobile source area</td>
<td>Mobile source area</td>
</tr>
<tr>
<td></td>
<td><img src="image66" alt="Diagram" /></td>
<td><img src="image67" alt="Diagram" /></td>
<td><img src="image68" alt="Diagram" /></td>
</tr>
<tr>
<td>Key aquatic habitats</td>
<td>Pool, riffle chutes</td>
<td>Riffle and pool substratum, high flow floodrunners, riparian vegetation, snags</td>
<td>Riffle and pool substratum, point and lateral bars, incised benches, floodrunners, woody debris (snags), macrophytes</td>
</tr>
<tr>
<td></td>
<td><img src="image74" alt="Diagram" /></td>
<td><img src="image75" alt="Diagram" /></td>
<td><img src="image76" alt="Diagram" /></td>
</tr>
<tr>
<td>Major components of carbon supply</td>
<td>Allochthonous inputs, dominant: CPOM and FPOM, minor primary production: microalgae, some submerged and emergent macrophytes</td>
<td>Allochthonous inputs, dominant: CPOM and FPOM, minor primary production: microalgae</td>
<td>Allochthonous inputs, dominant: CPOM, FPOM and logs, minor primary production: periphyton</td>
</tr>
<tr>
<td></td>
<td><img src="image82" alt="Diagram" /></td>
<td><img src="image83" alt="Diagram" /></td>
<td><img src="image84" alt="Diagram" /></td>
</tr>
<tr>
<td>High flow</td>
<td>Pool depth increases, flushing flows, valley restricts lateral connection</td>
<td>Riparian vegetation inundated, scouring and flushing flows</td>
<td>Small floodrunners inundated increasing habitat, flushing and scouring flows</td>
</tr>
<tr>
<td></td>
<td><img src="image90" alt="Diagram" /></td>
<td><img src="image91" alt="Diagram" /></td>
<td><img src="image92" alt="Diagram" /></td>
</tr>
<tr>
<td>Low flow</td>
<td>Pool depth decreases, no major habitat loss</td>
<td>Habitat area decreases</td>
<td>Habitat area decreases</td>
</tr>
<tr>
<td></td>
<td><img src="image98" alt="Diagram" /></td>
<td><img src="image99" alt="Diagram" /></td>
<td><img src="image100" alt="Diagram" /></td>
</tr>
</tbody>
</table>
Table 1. Criteria for mapping Valley Process Zones

<table>
<thead>
<tr>
<th>Valley Process Zone</th>
<th>Functional Process Zones</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source zone</td>
<td>Pool, Upland gorge, Armoured</td>
<td>Sediment source upland</td>
</tr>
<tr>
<td>Transport zone</td>
<td>Mobile, Meander</td>
<td>Sediment transport mid-slope</td>
</tr>
<tr>
<td>Deposition zone</td>
<td>Anabranch, Distributary</td>
<td>Sediment deposition lowland</td>
</tr>
<tr>
<td></td>
<td>Lowland gorge</td>
<td></td>
</tr>
</tbody>
</table>

Reporting Scales

Natural resource management at the Basin scale requires information on resource condition to be measured and reported at a commensurate scale. Questions such as: ‘What is the condition of the Basin’s rivers? Is this condition changing, and what is the likely cause of this?’, are best resolved with large-scale programs that aggregate information over appropriate spatial and temporal scales. Reflecting this, the framework for the Audit is designed to assess river health at the broad scales required for informing Basin-wide public and policy debate.

Spatial Scale

At the direction of the Ministerial Council, the Audit framework is designed primarily to report river health at the river-valley scale — the same scale at which Cap compliance is reported. Cap compliance is reported for 21 designated river valleys across the Murray-Darling Basin. However, the designated river valleys in Schedule F of the Murray-Darling Basin Agreement are not an ideal reporting unit for the Audit for a number of reasons:

- river valleys with differing levels of development are combined — e.g. Kiewa, Ovens and Murray valleys;
- State boundaries are used to define river valleys — e.g. NSW portion of Paroo and Queensland portion of Paroo;
- NSW and Victoria have different Murray valleys — NSW includes Lower Darling and Victoria includes Kiewa and Ovens; and
- a designated river valley does not always define a river valley — e.g. Metropolitan Adelaide and other uses of the River Murray in South Australia.

The Audit framework also allows river health to be reported for VPZs. To report at the VPZ scale with the same statistical power as the river-valley scale will require approximately three times the number of samples (and will therefore incur approximately three times the sampling cost — see discussion later).

While there is a strong desire to keep the Audit framework compatible with the Independent Audit Group’s reporting of Cap compliance, it is important that the Audit reports in an ecologically defensible framework.

The Australian Water Resources Commission (AWRC) basins were used to define the river valleys for the initial Audit as they comprise the only national set of catchments (Table 2, Figure 4). Unfortunately they suffer from a number of deficiencies. Their principal shortcoming is that the AWRC basins do not reliably follow catchment boundaries.
Figure 4

SRA Basins and main rivers
Table 2. River valleys and catchment areas identified for the Audit

<table>
<thead>
<tr>
<th>River Valley</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoca</td>
<td>21538</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>81040</td>
</tr>
<tr>
<td>Broken</td>
<td>10935</td>
</tr>
<tr>
<td>Campaspe</td>
<td>6319</td>
</tr>
<tr>
<td>Castlereagh</td>
<td>23817</td>
</tr>
<tr>
<td>Condamine-Culgoa</td>
<td>207808</td>
</tr>
<tr>
<td>Darling</td>
<td>188233</td>
</tr>
<tr>
<td>Goulburn</td>
<td>26393</td>
</tr>
<tr>
<td>Gwydir</td>
<td>35355</td>
</tr>
<tr>
<td>Kiewa</td>
<td>2956</td>
</tr>
<tr>
<td>Lachlan</td>
<td>130868</td>
</tr>
<tr>
<td>Loddon</td>
<td>24216</td>
</tr>
<tr>
<td>Lower Murray</td>
<td>84098</td>
</tr>
<tr>
<td>Macquarie</td>
<td>103956</td>
</tr>
<tr>
<td>Mallee</td>
<td>108375</td>
</tr>
<tr>
<td>Murray-Riverina</td>
<td>22742</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>121742</td>
</tr>
<tr>
<td>Namoi</td>
<td>56977</td>
</tr>
<tr>
<td>Ovens</td>
<td>12372</td>
</tr>
<tr>
<td>Paroo</td>
<td>97144</td>
</tr>
<tr>
<td>Upper Murray</td>
<td>23653</td>
</tr>
<tr>
<td>Warrego</td>
<td>79256</td>
</tr>
</tbody>
</table>

In some areas the river itself forms the boundary between AWRC basins, for example the River Murray defines the boundary between two basins in South Australia, one on either side of the Murray. In these situations it is not clear to which basin a river (and its associated data) should be assigned.

In other parts of the Basin a detailed examination of the streamline network, and of digital elevation models, shows that there are errors in basin boundaries even where they ostensibly follow catchment boundaries (e.g. the Warrego basin). AWRC basins do not reflect biogeophysical zonations, and in consequence basin boundaries may not reflect the processes that influence river conditions. Additionally, AWRC basins vary greatly in size making some inter-basin comparisons difficult or meaningless.

It is recommended that the Commission review the AWRC basin boundaries with a view to refining them to provide an appropriate reporting base for the Audit. An alternative that should be considered is the set of catchments defined as a component of Theme 7 of the National Land and Water Audit. A major advantage in using these catchments as a start for defining new basins is that they are spatially consistent with the reaches being used to identify sampling sites within each Valley Process Zone.

Temporal Scale

At the direction of the Ministerial Council, the Audit framework is designed to report annually. However, there is limited value in measuring all indicators every year. The framework discusses and recommends a sampling frequency for each indicator — these are summarised in Table 3. While some indicators will be assessed annually, it is critical that all indicators are assessed at least once in each five-year period. However, each
annual Audit should report the most recent assessment for each environmental theme, indicating the year of sampling (dd/mm/yy). For example, an annual report may have scores for water quality, hydrology and macroinvertebrates collected in the previous twelve months, fish scores from two years previously and habitat scores from four years previously.

Table 3. Recommended sample sizes for a river-valley assessment based on the sample sizes required to detect differences of 0.1 (±10%) with a power of 0.8 and significance level of 0.1 (see Appendices 3–7 for discussion). To report at the Valley Process Zone scale for the same values for $\alpha = 0.05$ and Power = 0.80 will require significantly more sites (see Table 5).

<table>
<thead>
<tr>
<th>Environmental theme</th>
<th>Sample size</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroinvertebrates</td>
<td>30</td>
<td>Lowland reaches 2 per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other reaches 1 per year.</td>
</tr>
<tr>
<td>Fish</td>
<td>To be determined from trial</td>
<td>50 sites across Basin in first year</td>
</tr>
<tr>
<td>Water quality*</td>
<td>18</td>
<td>Sampled 6 per year</td>
</tr>
<tr>
<td>Habitat</td>
<td>20</td>
<td>Sampled 1 in 5 years</td>
</tr>
<tr>
<td>Hydrology</td>
<td>All reaches</td>
<td>Using modelled data</td>
</tr>
</tbody>
</table>

*for water quality sample sizes required to detect differences of 0.2 with a power of 0.8 and significance level of 0.1. Calculation based on data from a single Valley Process Zone.

Sample Sizes

The number of samples required (sites per reaches assessed) for the Audit depends on the:

- spatial reporting scale of the assessment,
- variability of the indicator,
- initial condition score of the indicator,
- aggregation and reporting statistics used,
- desired level of change to be detected, and
- desired confidence in detecting that change.

The Audit framework attempts to explicitly identify the implications and tradeoffs associated with these sample design issues.

To measure the condition of rivers in the Murray-Darling Basin the spatial scale of inference for a measure could be determined and the number of those spatial units that fitted into the largest spatial unit for reporting calculated. For example, if an AUSRIVAS OE50 score is determined to be representative of a 10 km section of river and there are 77358.2 km of river in the MDB, then to sample the MDB precisely would take at least 7736 sites. Obviously this is an unrealistic number of sites and so a sampling regime must be determined that allows inferences to be made at a broad scale (e.g. river-valley), even though measurements need to be made at the small scale (e.g. site).

For some indices it may be possible to adjust the size of the sampling unit to the reporting scale. For example, imagine a new index based on freshwater molluscs: the index may be calculated based on presence or absence of taxa at a site, or within a reach, or within a functional process zone or within the river valley itself. But the statistical distribution of
the measurement will also be scale-dependent and so the type of sampling used needs to be adjusted accordingly. Nearly all the indicators proposed for the Audit require small-scale sampling units (e.g. the AUSRIVAS OE50 requires sampling of 10 m at a site). Reporting at the river-valley scale therefore requires a number of sites within each river valley to be sampled, but the number is dependent on the variability of the index and the type of impairment in that valley.

Therefore, to design an effective sampling strategy, knowledge is required of the distribution of the index at each scale — site, reach, process zone and river valley zone.

The sample sizes required for each environmental theme (Tables 3, 4) are based on an analysis of existing data-sets where they are available. The most comprehensive data-set for this style of analysis is the macroinvertebrate data collected for the First National Assessment of River Health (FNARH). The Ovens, Murrumbidgee and Condamine river valleys were sampled in enough detail at each of the three Valley Process Zone scales to allow estimates of sample sizes required to make inference at the river-valley and Valley Process Zone levels, but not at finer resolutions (see Table 5).

**Table 4.** Indicative number of sampling sites required in each State* for reporting at the river-valley scale with values of $\alpha = 0.05$ and Power = 0.80.

<table>
<thead>
<tr>
<th></th>
<th>Number of Water Quality sites</th>
<th>Number of Habitat sites</th>
<th>Number of Macroinvertebrate sites</th>
<th>Number of Hydrology sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland</td>
<td>72</td>
<td>80</td>
<td>120</td>
<td>see note 1</td>
</tr>
<tr>
<td>4 river valleys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New South Wales</td>
<td>234</td>
<td>260</td>
<td>390</td>
<td>see note 1</td>
</tr>
<tr>
<td>13 river valleys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Victoria</td>
<td>162</td>
<td>180</td>
<td>270</td>
<td>see note 1</td>
</tr>
<tr>
<td>9 river valleys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Australia</td>
<td>18</td>
<td>20</td>
<td>30</td>
<td>see note 1</td>
</tr>
<tr>
<td>1 river valley</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>486</td>
<td>540</td>
<td>810</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: The Hydrology index will be based on data from existing gauging stations, augmented with modelled data for nodes in each FPZ.

*There are a number of river valleys that span two States (e.g. Paroo). Sites for these river valleys have been ascribed to both States so there is some duplication in the total number of sampling sites. Also, note that the number of sites for a Fish Index has not yet been determined.

Many individual Functional Process Zones (FPZs) within some river valleys were not sampled during the FNARH, but each FPZ category was sampled often enough ($n \geq 10$) within at least one river valley at least once. On 17 occasions, a reasonable estimate of variation of the OE50 within-FPZ within a river valley could be obtained, thus allowing for estimates of sample sizes required for reporting at the river-valley and the FPZ scales. To report at the FPZ scale with the traditional values of $\alpha = 0.05$ and Power = 0.80 would require between 8 and 61 sites per FPZ, depending on the condition and variability (Table 5).
To further understand the variability of the AUSRIVAS OE50 under a wide range of impairment types a simulated data-set (see Appendix 8) was generated for a fictitious river valley with three VPZs, 75 reaches (25 per VPZ) and 600 sites (eight per reach). This was used for estimating variation in the O/E statistic at the site scale, reach scale, process zone scale and river valley zone scale.

The advantage of using the real data is that it allows estimation of the actual sample sizes (i.e. how many sites to sample) in each of the Valley Process Zones. This allows exact sample size estimates for these three particular river valleys at the river-valley, the VPZ or the river-valley + VPZ scales of reporting.

The initial average condition score for the indicator influences the number of sites required to detect a level of change. In general, the more degraded an index, the more variable it is and the greater the number of samples required to detect a change. It is worth noting that the three trial river valleys displayed different types of impairment: the Ovens showed considerable variation between VPZs; the other two had relatively even proportions of...
impaired sites between VPZs. Overall, between 0.26 and 0.50 of all sites in each river valley were impaired in the trial data. This suggests that, in the final analysis, the sampling strategy may have to be determined individually for each river valley. Therefore, the sampling strategy should be reviewed after the first round of sampling, when individual river-valley variability is better understood.

The major finding from the sample size calculations is that considerable variability can be encountered in the sample sizes required, particularly within and between river valleys. For the artificial data-set, between 10 and 70 sampling sites were needed for reporting at the river-valley scale when the common use values of $\alpha = 0.05$, Power $(1-\beta) = 0.80$ were chosen, and the aim was to detect a change in the OE50 of 0.1 (Appendix 3). Obviously the type and location of impairment immensely influences the variability of the OE50, depending on the scale at which sampling is carried out at. Analysis of the trial data found that 21 sites were needed for reporting at the river-valley scale in the Ovens River, and 28 sites for the other two river valleys. If reporting was also required at each Valley Process Zone, the sample sizes were 45, 68 and 83 per river valley (Table 5).

Summary

The exact sample sizes required to detect changes in the AUSRIVAS OE50 score cannot be precisely calculated in advance of a pilot study because;

- the true within-site variability of the OE50 score is unknown;
- the sample sizes required at the proposed sampling or reporting scale (river-valley) vary considerably, depending on the types and levels of impairment;
- the finer the scale of impairment, the more variable the indicator at higher reporting scales;
- the sample sizes required at the proposed sampling or reporting scale (river-valley) will certainly be different for each river valley but, based on existing data, 30 sites per river valley would achieve an acceptable level of precision.

All these issues can be addressed after the first round of sampling.

Recommendations

We may speculate that the three trial data-sets are representative of the expected variability in the 29 river valleys to be sampled. This is reasonable because the Ovens is a smaller river valley (1000 km of river) and has a relatively high proportion of Source process zone (percentage of catchment area that is Source:Transitional:Deposition = 48:21:32); the Condamine is one of the largest river valleys (11 000 km) with a relatively large proportion of Deposition process zone (7:34:59) and the Murrumbidgee is in between (6500 km) but has a relatively small proportion of Transitional process zone (22:6:72).

Without considering the cost–benefit aspect it is therefore recommended that the ideal sample size for the first round of sampling is 30 sites per river valley. This includes the 28 as determined in the sample size analysis of the trial data, and two extra sites to compensate for rounding in the stratification process and to ensure that a minimum of three sites are positioned in any given VPZ. The MDBC can then be 95% confident of obtaining the true average AUSRIVAS OE50 score for each river valley, knowing that future sampling rounds will also be able to detect changes in river condition at the river-valley scale.
Table 6. Catchment area in each Valley Process Zone (VPZ) of the river valleys identified for the Audit. River valleys may be stratified into one, two or three VPZs, depending upon catchment geomorphology. Of the total Basin area, 71% of the river is deposition zone, 16% is transport zone and 13% is source zone. Because the sampling sites are stratified by area in each VPZ, approximately 70% of sampling sites will be located in the deposition zones of the Basin, in the lowland river areas.

<table>
<thead>
<tr>
<th>River Valley</th>
<th>Deposition VPZ (area in km²)</th>
<th>Source VPZ (area in km²)</th>
<th>Transport VPZ (area in km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoca</td>
<td>16300</td>
<td>1226</td>
<td>4012</td>
</tr>
<tr>
<td>Border Rivers</td>
<td>31788</td>
<td>25656</td>
<td>23596</td>
</tr>
<tr>
<td>Broken</td>
<td>7456</td>
<td>1114</td>
<td>2364</td>
</tr>
<tr>
<td>Campaspe</td>
<td>602</td>
<td>3831</td>
<td>1886</td>
</tr>
<tr>
<td>Castlereagh</td>
<td>10414</td>
<td>159</td>
<td>13244</td>
</tr>
<tr>
<td>Condamine-Culgoa</td>
<td>122641</td>
<td>14347</td>
<td>70820</td>
</tr>
<tr>
<td>Darling</td>
<td>188233</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goulburn</td>
<td>2185</td>
<td>7984</td>
<td>16224</td>
</tr>
<tr>
<td>Gwydir</td>
<td>15785</td>
<td>7919</td>
<td>11651</td>
</tr>
<tr>
<td>Kiewa</td>
<td>469</td>
<td>712</td>
<td>1774</td>
</tr>
<tr>
<td>Lachlan</td>
<td>102762</td>
<td>15663</td>
<td>12442</td>
</tr>
<tr>
<td>Loddon</td>
<td>13955</td>
<td>6812</td>
<td>3449</td>
</tr>
<tr>
<td>Lower Murray</td>
<td>84098</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macquarie</td>
<td>43615</td>
<td>27682</td>
<td>32658</td>
</tr>
<tr>
<td>Mallee</td>
<td>106777</td>
<td>188</td>
<td>1410</td>
</tr>
<tr>
<td>Murray-Riverina</td>
<td>22742</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>87363</td>
<td>26446</td>
<td>7934</td>
</tr>
<tr>
<td>Namoi</td>
<td>26226</td>
<td>11194</td>
<td>19557</td>
</tr>
<tr>
<td>Ovens</td>
<td>3951</td>
<td>5855</td>
<td>2567</td>
</tr>
<tr>
<td>Paroo</td>
<td>97063</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Upper Murray</td>
<td></td>
<td>23653</td>
<td></td>
</tr>
<tr>
<td>Warrego</td>
<td>62961</td>
<td>8823</td>
<td>7472</td>
</tr>
</tbody>
</table>

**Site Selection**

Two types of sites are required for the Audit: reference sites and test sites.

It is recommended that environmental themes be assessed from randomly selected sites, stratified by Valley Process Zones (VPZ), within each basin. The Review of Existing Programs (Appendix 1) shows that indicators of river health have been collected from a large number of sites across the Basin. Many of these sites were selected specifically to detect or monitor the impact of point sources or other river management operations. Therefore, extreme caution is required when attempting to use existing sites to develop an assessment program.
As a principle, the Audit should attempt to assess indices for environmental themes from a common suite of sites. For example, sites sampled for the fish assessment should be selected from those that have been used to sample for macroinvertebrates.

Reference Sites

The First National Assessment of River Health (FNARH) selected and assessed 300 reference sites in the MDB using the AUSRIVAS protocol. Reference sites in each jurisdiction were selected using similar criteria of minimal disturbance. It is recommended that these reference sites form a pool of reference sites from which each environmental theme selects reference sites.

Ideally, the same reference sites will be used for each environmental theme, but it is recognised that environmental themes have different reference site requirements. For example, reference for the fish index has to be a certain distance from the nearest bridge (because of fishing pressure) whereas this is not an issue for water quality. Other reference sites, particularly in the west of Basin, will need to be identified for some indices.

Test Sites

The protocol for selecting test sites is as follows.

i) Determine the total number of test sites \( N \) required for each indicator, depending on the required precision, reporting scales and the variability of that indicator.

ii) To randomly select test sites, first divide the river valley into river reaches. The National Land and Water Audit Theme 7 River Reach Database provides a suitable

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2 The NLWA Theme 7 River Reach Database was developed as part of the National Land and Water Assessment. The reaches were determined in a three-step process; modelling the elevation of the land surface of Australia, identifying links (our basic stream network unit), and then concatenating links to form reaches.

The elevation of the land surface of Australia was modelled using a digital elevation model to determine which way water would flow across this surface. This information was used in geographic information software to generate a flow accumulation network of Australia. The flow accumulation network was fragmented into a set of links using the following rules:

1. a link requires a minimum contributing area of 50 sq.km (so links only start when the upstream area exceeds 50 km²);
2. a link is that section of stream between tributaries (i.e. where each tributary link joins the stream a new link starts).

Reaches are formed by concatenating one or more network links, joined according to the following rules:

1. links are compared in terms of the product of link slope and drainage area (a stream power surrogate). If links have a ‘stream power’ that differs by less than two they are joined to form the one reach.
2. for junctions where there are two upstream tributaries with similar drainage areas, if the ‘power’ of the downstream link is more than twice the power of both the upstream links then the downstream link is the start of a new reach. Otherwise the downstream link is appended to the upstream link whose power is closest to that of the downstream link.
3. for junctions where upstream tributaries have dissimilar drainage areas, if the power of the downstream link is more than twice the power of the upstream link with the largest drainage area then the downstream link is the start of a new reach. Otherwise the downstream link is appended to the upstream link with the largest drainage area.

As a check, reaches were compared with the streamlines recorded on the AUSLIG 250 000 topographic map series. In this process, only named streams in the AUSLIG database were used for comparison as this subset includes all but the smallest streams. If reaches did not coincide with a named stream they were not included in the database.
template for this task. Determine the total catchment area in each VPZ of the river valley, using Table 6. Round the number of sites required to the nearest larger integer (for example, round 2.3 sites up to 3 sites, rather than down to 2). Then allocate the required $N$ samples across the river valley into proportional $n$ samples per VPZ, and randomly select the desired $n$ reaches per VPZ.

iii) For each randomly selected reach, determine if an existing sampling station exists. (For example, macroinvertebrates were assessed at 1130 sites in the Basin as part of FNARH and the River Reach Database identifies 4609 river reaches in the Basin. Therefore, there is a 25% chance of selecting an existing FNARH sampling station.) If a sampling station does exist and it is deemed to be representative (i.e. it has not been deliberately sited below a known point source to measure the impact of that source) then that site is deemed adequate for that reach. If there are multiple existing sites within a reach, then one can be chosen at random, and if none exist in a reach then a site will be chosen at a random distance from one end of the reach.

These sites will then become the Audit test sites. The test sites, once chosen will be become permanent sites that are repeatedly sampled for each Audit assessment.

**Aggregation**

Aggregation is the process by which site data are scaled up for reporting at the river-valley, VPZ and FPZ scales.

The Audit is designed to report at large geographic scales. The framework is designed to allow site data to be aggregated to the appropriate reporting scale — river-valley, Valley Process Zone or Functional Process Zone. The environmental theme score for the site or reach can then be aggregated to the desired scale using two types of aggregating statistics: averages and proportions.

Theme condition can be reported as the median river valley score. Only sites selected as test sites should be used to calculate the median river valley score (i.e. reference sites should be excluded). Associated descriptive statistics include the 25$^{th}$ and 75$^{th}$ percentiles for theme score for a river valley. These percentiles indicate the condition of the worst quarter and the best quarter of sites in the river valley.

Reporting average indices or scores or, as in this case, medians, has traditionally been recommended for aggregating scores for river health, and the calculations of sample size have so far been based on this premise. However, this method appeals only because of its simplicity; it is not necessarily the best method for achieving the aims of the Audit. Intuitively, the mean score across a river valley can offer very little information about the distribution of scores, e.g. as depicted in Figure 5.

Traditionally in environmental monitoring studies, such as those carried out by State bodies (e.g. EPA), the measure is reported annually, as a proportion of compliance. This usually takes the form of proportion of time that compliance was achieved or alternatively proportion of the spatial zone (reach, river, catchment, etc.) that was non-compliant. If we think of impairment as having a similar meaning to compliance, then this reporting method intuitively lends itself to the framework required for the Audit. In other words, reporting can be made in terms of proportion of impairment rather than averages. Reporting a proportion
Figure 5. Three possible distributions for indices having the same mean (85/100). Note that the top graph has 34% of sites below 0.8 (which for this example may be considered as impaired), and the second graph has 18% of sites below 0.8, while the third has none. In the top figure the distribution is severely skewed, which it is assumed will happen if the AUSRIVAS OE50 Index scores are set to a maximum of 1. The remaining two are based on normal distributions for simplicity of display.
impaired requires a judgement about what level of departure from natural is impaired. This can be done using statistical techniques (as in the AUSRIVAS protocol) or it can reflect community targets for river health, once they are set. The proportion could represent temporal or spatial scales such as kilometres of river or area of catchment impaired.

A disadvantage of this method, however, is that if it is desired to detect a difference in the proportion of, say, a river valley that is impaired between two sampling times (say annually) then the sample size required is greater than that required to detect changes in medians (or means). See Table 7. For example, using traditional values of $\alpha = 0.05$ and $\text{Power} = 0.80$, between 44 and 103 sites would be required, compared to 30, for reporting averages for macroinvertebrates.

Table 7. The number of samples required for detecting change in proportions (detect a change of either 4 (0.04), 6 (0.06), 8 (0.08) or 10% (0.1)) for two levels of power with either 80% (0.8) or 90% (0.9) chance of the analysis detecting a effect

<table>
<thead>
<tr>
<th>Power</th>
<th>Initial score</th>
<th>0.1</th>
<th>0.08</th>
<th>0.06</th>
<th>0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0.6</td>
<td>134</td>
<td>208</td>
<td>365</td>
<td>811</td>
</tr>
<tr>
<td>0.7</td>
<td>119</td>
<td>183</td>
<td>321</td>
<td>713</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>92</td>
<td>142</td>
<td>248</td>
<td>549</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>55</td>
<td>84</td>
<td>146</td>
<td>318</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>0.6</td>
<td>103</td>
<td>159</td>
<td>277</td>
<td>613</td>
</tr>
<tr>
<td>0.7</td>
<td>91</td>
<td>140</td>
<td>245</td>
<td>539</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>72</td>
<td>110</td>
<td>190</td>
<td>416</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>44</td>
<td>66</td>
<td>113</td>
<td>244</td>
<td></td>
</tr>
</tbody>
</table>

Integration
Integration is the combining of aggregated theme scores into a single value of river health.

It is recommended that a combined score of river health should not be calculated using a mathematical function of the five indices, for several reasons:

- the statistical distributions of the indices are unknown and unlikely to be compatible; for example, AUSRIVAS outputs are skewed to the left;
- incompatible information would be combined; there are no theoretically robust methods for combining scores for physical and chemical themes with biotic themes;
- sites with very different levels and types of impairment may end up with the same score.

It is recommended that individual environmental theme scores be reported. Apart from the difficulties of integration discussed above, integration of indices leads to a loss of information.

Two approaches are recommended for overcoming this: (i) reporting proportion impaired, or (ii) using biotic theme scores as a river health score (Table 8, Figures 6, 7). Combining
information on the impairment status of sites in a reporting region (either river valley or FPZ) can be used for assessing overall river health at the valley scale. These data would certainly allow for statistical quantification of river health at the river-valley and Basin levels.

Table 8. Proposed output using a hypothetical data-set at the river-valley scale. In this case the valley ‘river health score’, using the worst biotic indicator which in this case is fish, is 0.81. However, more than half of the river had at least one impaired theme and a quarter had two impaired themes. Proportion of sites impaired is calculated assuming that a difference of 0.2 from reference shows impairment (i.e. $0.8 > score > 1.2$). These data have been used to prepare Figures 6 and 7.

<table>
<thead>
<tr>
<th>Site</th>
<th>Theme Score</th>
<th>Biological Score</th>
<th>Overall Score</th>
<th>Number of impaired themes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fish</td>
<td>Inverts</td>
<td>WQ</td>
<td>Hydro</td>
</tr>
<tr>
<td>Valley A Site 1</td>
<td>0.93</td>
<td>0.96</td>
<td>0.92</td>
<td>0.87</td>
</tr>
<tr>
<td>Valley A Site 2</td>
<td>0.75</td>
<td>0.79</td>
<td>0.87</td>
<td>0.81</td>
</tr>
<tr>
<td>Valley A Site 3</td>
<td>0.71</td>
<td>0.965</td>
<td>0.89</td>
<td>0.75</td>
</tr>
<tr>
<td>Valley A Site 4</td>
<td>0.81</td>
<td>0.71</td>
<td>0.9</td>
<td>0.84</td>
</tr>
<tr>
<td>etc.</td>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valley A Site n</td>
<td>0.84</td>
<td>0.94</td>
<td>0.89</td>
<td>0.74</td>
</tr>
<tr>
<td>Valley A Score [Median]</td>
<td>0.81</td>
<td>0.94</td>
<td>0.89</td>
<td>0.81</td>
</tr>
<tr>
<td>[1st Quartile]</td>
<td>0.74</td>
<td>0.77</td>
<td>0.885</td>
<td>0.7475</td>
</tr>
<tr>
<td>[3rd Quartile]</td>
<td>0.8175</td>
<td>0.94625</td>
<td>0.8925</td>
<td>0.8175</td>
</tr>
</tbody>
</table>

Proportion of sites impaired on at least one theme

<table>
<thead>
<tr>
<th>1 theme</th>
<th>2 themes</th>
<th>3 themes</th>
<th>4 themes</th>
<th>5 themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.56</td>
<td>0.21</td>
<td>0.08</td>
<td>0.03</td>
<td>0</td>
</tr>
</tbody>
</table>

The proportion of sites impaired (which can be expressed as area of catchment or length of river impaired) can be reported graphically for each reporting unit. It is necessary for interpretation that the five environmental themes be always reported alongside any combined score.

If an overall condition score is required for a river valley or Valley Process Zone, then it is recommended that the two biotic theme scores (fish or macroinvertebrates) be used to represent river health. This approach assumes that the biota integrate the combined effects of alterations in the biotic and abiotic environment. The scores for both biotic themes should be reported. If only one score is to be reported it should not be the mean of the two — rather it should be the worse of the two scores. Choosing the worse of the two themes, rather than an average or the best, is consistent with the precautionary approach. The disadvantage of this approach is that the factor(s) driving a low score in one biotic index
may not be driving a low score in the other. Thus, remedial action (say instillation of fishways) may dramatically improve the score of the fish index, but may not alter the macroinvertebrate index score. If the macroinvertebrate score was the lowest prior to installation of the fishway, then the improvement in fish populations will not be reflected in river health score.

Regardless of the approach taken to reporting, the individual theme scores should always be reported as they allow interpretation of the river health scores reported this way.

**Figure 6.** Summary of river health based on the proportion of river with impaired ecological themes using data from Table 8.

**Figure 7.** Summary of river health expressed as (a) Median Index Score and (b) proportion of river impaired for each environmental theme using data from Table 8.

**Indicative Costing**

Determining the full cost of undertaking the Audit is not possible at this stage of development because several key decisions about the Audit model have yet to be made. Better estimates of costs can be calculated once critical decisions about the sampling design have been agreed and sampling sites have been identified.
The indicative cost of $8.3M (Table 9) represents the cost of sampling the sites required for a river-valley scale assessment. These costs were calculated based on standard commercial rates obtained from several laboratories in SE Australia. The estimated cost also includes costs associated with development of several models and analysis tools required for undertaking the project. The indicative costs do not include the costs of abstracting the hydrology data from existing models and databases.

The indicative costs do not include provision for costs associated with project management (either within the Commission or within the jurisdictions), with reporting or with the ISRAG. These costs may be significant, depending upon how the respective agencies administer this program. While some allowances have been made for this, factors such as remoteness and access will influence individual site sampling costs.

Indices are sampled at differing frequencies, from monthly to once in each five-year period, and so the annual cost for the Audit will vary from year to year depending on the indicators assessed in that period.

Alternative costing and benefits

The major trade-off in costing occurs when reporting at finer scales or when detecting small changes in the indicator score. The differences between using type I error rates of 0.05 or 0.1, or type II error rates of 0.1 or 0.2 are small relative to the difference in reporting scales (Figure 8). Using the macroinvertebrate indicator as an example, the approximate costing for reporting the macroinvertebrate index at the river-valley scale using the significance level ($\alpha$) of 0.05 and Power of 0.8 is $714,500 (see Figure 8). However, to report with the same levels of type I and type II error and level of detection as above, but at the river valley and Valley Process Zone level results in a basin wide cost of $1.62M whilst the river valley and Functional Process Zone level reporting is projected to cost $ 3.01M (Figure 8).
Table 9. Estimated cost of the sampling and analysis components of the Audit using recommended sample sizes for river-valley assessment based on the sample sizes required to detect difference of 0.1 (± 10%) with power of 0.8 and significance level of 0.1. This assessment can be reported at the Valley Process Zone scale but with a reduced level of confidence.

<table>
<thead>
<tr>
<th>Environmental Theme</th>
<th>Number of sites per valley</th>
<th>Cost/site</th>
<th>Frequency of sampling</th>
<th>Annual cost - river valley</th>
<th>Cost per assessment</th>
<th>Five-year Basin cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroinvertebrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowland</td>
<td>10 sites</td>
<td>$750</td>
<td>2 p.a.</td>
<td>$15,000</td>
<td></td>
<td>$60,000</td>
</tr>
<tr>
<td>Slopes/upland</td>
<td>20 sites</td>
<td>$750</td>
<td>1 p.a.</td>
<td>$15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 ref sites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$30,000</td>
<td></td>
<td>$654,500</td>
<td></td>
<td>$3,332,500</td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 1</td>
<td></td>
<td></td>
<td></td>
<td>$100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 2&amp;3</td>
<td></td>
<td></td>
<td></td>
<td>$400,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design review</td>
<td></td>
<td></td>
<td></td>
<td>$50,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref. review</td>
<td></td>
<td></td>
<td></td>
<td>$25,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis review</td>
<td></td>
<td></td>
<td></td>
<td>$75,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$100,000</td>
<td></td>
<td>$650,000*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td>18 sites</td>
<td></td>
<td>6 p.a.</td>
<td>$37,674</td>
<td>$678,132</td>
<td>$3,390,660</td>
</tr>
<tr>
<td>Physical Habitat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field &amp; Imagery</td>
<td>20 sites</td>
<td>$1940</td>
<td>1 in 5 year</td>
<td>$853,000</td>
<td>$50,000</td>
<td>$903,600</td>
</tr>
<tr>
<td>E-ball **</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrology***</td>
<td></td>
<td></td>
<td>1 in 5 year + trigger</td>
<td></td>
<td></td>
<td>Not determined</td>
</tr>
<tr>
<td>5 Year Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~$8,276,760</td>
</tr>
<tr>
<td></td>
<td>- sampling and analysis only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The cost reported for the Fish indicator includes the indicator development costs. Until the first three rounds of sampling are complete, true on-going costs cannot be calculated.

** E-ball model required for data analysis with approximate development cost $50,000.

*** Hydrology uses modelled data from existing sites that are managed for other purposes. The costs associated with extracting and supplying these data have not been calculated, though they are expected to be minimal relative to the Total Audit Cost.
Figure 8. Trade-off between Total Basin Cost and Scale of reporting for the macroinvertebrate theme for the Audit. Note that the vertical axes are different for each figure. Dotted lines indicate recommended cost for first round sampling.
Example Audit with NL&WRA data

A trial Audit has been undertaken using existing data for three river valleys, the Condamine-Balonne in NSW/Queensland, the Murrumbidgee in NSW/ACT, and the Ovens in Victoria.

The data for this trial come from existing databases of hydrology and macroinvertebrates collated for the Assessment of River Condition as part of the National Land and Water Audit (NL&WRA). The trial could not be undertaken for the water quality, physical habitat or fish environmental themes because existing data for these indices were not available to this study at both the spatial scale and in the format (expressed as a change from natural) required. The hydrology and macroinvertebrate data used in this trial have been collected by the jurisdictions; and permission has been granted for the use of this data-set for the purpose of trialling the Audit framework. However, Taskforce members have expressed some concerns over the quality of the NL&WRA data used in this trial. It is beyond the scope of the trial to test the quality of these data sets. Consequently, the trial Audit output should only be considered as indicative of an Audit output, and should not be used for auditing purposes without further consultation with the jurisdictions that supplied the data.

*Without the express permission of the jurisdictions, this trial output cannot be reported as a river health assessment for the Condamine-Balonne, Murrumbidgee and Ovens valleys.*

For the purposes of the trial, in all unregulated reaches, hydrology indices were set to 1. Particularly in the case of the Murrumbidgee, where considerable abstractions occur in some unregulated streams, this will result in an over-estimation of the hydrology index. While this has not been done for the trial (as the information was not available to the Project Team), for the Audit it is recommended that significant abstractions be recorded for all reaches and included in the calculation of the hydrological indices.

The results from the macroinvertebrate trial data are able to be displayed at the Valley Process Zone scale (Tables 10, 12, Figure 10) only because the sample sizes were large enough. If the audit uses only 30 sites at the river-valley level, then presentation of results at the VPZ level will be compromised. Also it should be noted that the descriptive statistics presented for the trial data at the river-valley level (Table 11, Figure 9) included all available data and as such do not compensate for varying catchment area within each VPZ (i.e. the sampling strategy was not stratified for the trial). Subsequently, the results displayed for the trial should be treated as a sample results and not treated as precise values for future comparisons.

*Interpretation*

**Ovens**

Across the Ovens basin the Biological Index varied between 0.61 and 1.16 with a median of 0.98 (Table 11). Three-quarters (74%) of the sites were equivalent to reference condition and none of the 42 sites was severely impaired (Table 11). The median of the index was at least as good as reference condition in both the Source and Transport process zones with only 4 of the 27 sites in these two zones being impaired (Table 12). In the
Depositional process zone the median index score was close to impairment at 0.83 and seven of the 18 sites were impaired, although none was considered severe (Table 12) while hydrological index was equivalent to reference. The hydrological index score for the entire river valley, and in each of the Valley Process Zones, was equivalent to reference (Table 10).

**Murrumbidgee**

In the Murrumbidgee basin the biological index scores varied from severely impaired at 0.29 to reference equivalent at 1.14. Fifty per cent of sites were in reference condition and five of the 60 sites (8%) were severely impaired (Table 11). The impaired sites were evenly distributed between the three process zones with 45% impairment in Deposition, 50% in Transport and 64% in Source zones (Table 12). Two of the Source zone sites and three of the Deposition zone sites were severely impaired. The hydrology index scores were uniformly poor in each Valley Process Zone (Table 10).

**Condamine-Balonne**

Biological index scores in the Condamine-Balonne basin varied between 0.32 and 1.14 with a median value close to impairment at 0.82 (Table 11). Nearly half (46%) of sites were impaired and six of the 56 sites were severely impaired (Table 11). The levels of impairment were evenly spread through the Valley Process Zones with 41%, 48% and 54% impairment in the Deposition, Transport and Source process zones respectively (Table 12). The hydrology index scores showed a progressive downstream degradation, from close to reference in the source regions to a score of 0.71 in the depositional reaches (Table 10).

**Table 10. Trial Hydrology Index for three river valleys**

<table>
<thead>
<tr>
<th>Valley</th>
<th>Reaches</th>
<th>Hydrology Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovens valley</td>
<td>33</td>
<td>0.96</td>
</tr>
<tr>
<td>Source</td>
<td>15</td>
<td>0.95</td>
</tr>
<tr>
<td>Transport</td>
<td>11</td>
<td>0.97</td>
</tr>
<tr>
<td>Deposition</td>
<td>7</td>
<td>0.97</td>
</tr>
<tr>
<td>Murrumbidgee valley</td>
<td>399</td>
<td>0.52</td>
</tr>
<tr>
<td>Source</td>
<td>106</td>
<td>0.53</td>
</tr>
<tr>
<td>Transport</td>
<td>26</td>
<td>0.58</td>
</tr>
<tr>
<td>Deposition</td>
<td>267</td>
<td>0.51</td>
</tr>
<tr>
<td>Condamine-Balonne valley</td>
<td>610</td>
<td>0.81</td>
</tr>
<tr>
<td>Source</td>
<td>56</td>
<td>0.93</td>
</tr>
<tr>
<td>Transport</td>
<td>299</td>
<td>0.88</td>
</tr>
<tr>
<td>Deposition</td>
<td>255</td>
<td>0.71</td>
</tr>
</tbody>
</table>
Table 11. Summary statistics for Macroinvertebrate Indicator of river health in the three Audit trial river basins. Impaired sites are arbitrarily determined by Index score of 0.8 or less and severely impaired by an OE score of 0.5 or less.

<table>
<thead>
<tr>
<th>River Valley</th>
<th>Ovens</th>
<th>River Valley Murrumbidgee</th>
<th>Condamine-Balonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites</td>
<td>42</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>Median Index Value</td>
<td>0.98</td>
<td>0.8</td>
<td>0.82</td>
</tr>
<tr>
<td>Number of Impaired sites</td>
<td>11</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Proportion of Impaired sites</td>
<td>0.26</td>
<td>0.50</td>
<td>0.46</td>
</tr>
<tr>
<td>Number of severely Impaired sites</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 9. Relative frequency histograms for the Macroinvertebrate Indicator of river health, representing the number of sites in each impairment class. Green indicates good condition, yellow indicates moderate condition and red indicates severely impaired.
Table 12. Summary statistics for Macroinvertebrate Indicator of river health in Valley Process Zones within the three Audit trial river basins. Impaired sites are arbitrarily determined by an Index score of 0.8 or less and severely impaired by an OE score of 0.5 or less.

<table>
<thead>
<tr>
<th>River Valley</th>
<th>Valley Process Zone</th>
<th>Source</th>
<th>Transport</th>
<th>Deposition</th>
<th>Source</th>
<th>Transport</th>
<th>Deposition</th>
<th>Source</th>
<th>Transport</th>
<th>Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>17</td>
<td>10</td>
<td>18</td>
<td>14</td>
<td>6</td>
<td>40</td>
<td>13</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Median Index value</td>
<td></td>
<td>1.05</td>
<td>1.04</td>
<td>0.83</td>
<td>0.74</td>
<td>0.78</td>
<td>0.81</td>
<td>0.77</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>Number of Impaired sites</td>
<td></td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>9</td>
<td>3</td>
<td>18</td>
<td>7</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Proportion of Impaired sites</td>
<td></td>
<td>0.18</td>
<td>0.10</td>
<td>0.39</td>
<td>0.64</td>
<td>0.50</td>
<td>0.45</td>
<td>0.54</td>
<td>0.48</td>
<td>0.41</td>
</tr>
<tr>
<td>Number of severely Impaired sites</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 10. Relative frequency histograms for the Macroinvertebrate Indicator of river health, representing the number of sites in each impairment class. Green indicates good condition, yellow indicates moderate condition and red indicates severely impaired.
Further tasks required to undertake the Audit

Implementing the full Audit at the Basin scale is a complex undertaking. The steps needed to report the first full Audit can be broken down into a number of discrete tasks. These tasks include articulating the objectives of the program, and then designing a study to meet these objectives that includes discussion of sampling, analysis and reporting. The tasks are documented in this report.

The purpose and principles of the Audit as agreed by the Ministerial Council have been clearly articulated (see page 9). This framework describes a study design to meet these objectives. The framework recommends:

- an assessment approach that reports river health (defined as ecological integrity);
- environmental theme indicators developed with reference to conceptual models of river function;
- a statistically robust sampling design that can report at the Basin scale, river-valley scale, Valley Process Zone scale and Functional Process Zone scale depending upon the number of sites assessed;
- methods for analysing data;
- protocols for aggregating and integrating indices; and
- approaches to reporting.

However, prior to the first Audit, considerable effort will be needed to operationalise this framework. The tasks required to do this should not be underestimated. Experience with the introduction of the Index of Stream Condition program in Victoria and the development of Integrated Monitoring of Environmental Flows in New South Wales has demonstrated that issues of on-ground site selection and access, training and production of methods manuals are complex and are resource intensive.

After receiving the Draft Final Report, the SRA Taskforce recommended to the Commission that a Pilot Audit be undertaken prior to the first full Audit. There is considerable merit in this proposal. The Pilot Audit will allow the recommended methods to be tested under field conditions. The Pilot will provide data on indicators so that their behaviour under field conditions can be assessed. This will allow a thorough examination of the relationship between sample number and statistical confidence. The Pilot Audit will also provide an opportunity for training technicians from each jurisdiction in sampling methods.

As a guide, these are the major tasks remaining to be undertaken during the Pilot (and before the first full Audit):

- achieve agreement on the desired reporting scale(s) by the Commission;
- achieve agreement on the levels of detectable change, statistical power and confidence (determining the reporting scales and acceptable levels of detectable change may require a cost–benefit analysis to be undertaken by the Project proponents);
- select test and reference sites using the protocol outlined in this report;
- produce and adopt standardised methods manuals and analysis tools for water quality and physical habitat;
• adopt existing protocols for macroinvertebrates;
• adopt the development plan proposed for fish assessment;
• modify the existing AWRC basins in the Murray Darling Basin to provide suitable river valleys that can form the reporting base for the Audit — essentially minor modifications are required along the main stems of the Murray and Darling rivers so that these sections of river are adequately represented in a reporting framework;
• investigate costs — the costs calculated in this report are gross estimates for data collection only; costs associated with management of the program by both the jurisdictions and the Commission have not been included; cost associated with collating the hydrological data has not been determined; cost savings associated with synergies with other programs or by coordinating sampling between indicators also need to be investigated;
• develop a reporting matrix for the States to report against for the Audit group;
• develop methods and templates for graphically representing Audit results; this will require an analysis of intended audience (e.g. ISRAG, MDBMC, etc.) and outputs tailored to these;
• improve conceptual models of river function so the core elements and processes that make a healthy river can be better defined; these models will help in refining the indicators and aid in communication of river health;
• establish an Audit Review protocol;
• undertake statistical analysis on the Pilot data. While the sample size estimates are based on best available information, a number of assumptions have been made about the behaviour of the indicators. Better estimates of sample size can be made once the behaviour of the indices is better known (i.e. after the first sampling run).
• ensure consistency of sampling and reporting across the Basin by undertaking training workshops for each indicator.

Definitions / Glossary

The review of existing programs (Appendix 1) highlights the inconsistent use of terminology for describing exactly what is being reported and how, in the assessment of river health. Terms such as indicator are used interchangeably for a range of purposes, from single site-specific measurements to complex integrations of several types of measurement through time and space. To avoid confusion we recommend that the Audit adopt the terms and definitions presented in Table 13.
### Table 13. Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregation</td>
<td>Aggregation is used to denote combining measures of the same indicator in different places into a measure at a larger spatial scale, e.g. aggregating measures of the macroinvertebrate index for a group of sites to provide a measure of the macroinvertebrate index for a river valley.</td>
</tr>
<tr>
<td>Assessment tool</td>
<td>An assessment tool is used to measure the state or condition of the indicator. The output from the assessment tool is an indicator. For example, AUSRIVAS, pH meter, etc.</td>
</tr>
<tr>
<td>Audit (see also SRA)</td>
<td>Sustainable Rivers Audit</td>
</tr>
<tr>
<td>AUSRIVAS</td>
<td>Australian River Assessment Scheme which is a tool for undertaking macroinvertebrate-based assessment of river condition</td>
</tr>
<tr>
<td>AWRC</td>
<td>Australian Water Resources Commission</td>
</tr>
<tr>
<td>CRCFE</td>
<td>Cooperative Research Centre for Freshwater Ecology</td>
</tr>
<tr>
<td>CSA</td>
<td>Comprehensive Sustainability Assessment proposed to be undertaken five-yearly</td>
</tr>
<tr>
<td>DOM</td>
<td>Dissolved organic matter</td>
</tr>
<tr>
<td>DRP</td>
<td>Dissolved reactive phosphorus</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity — a measure of salinity</td>
</tr>
<tr>
<td>Environmental Index</td>
<td>This index represents the state or condition of an environmental theme or integration of indices. Integrating indicators derives an index. For example, various water quality indicators combine to give an index for the environmental theme ‘water quality’.</td>
</tr>
<tr>
<td>Environmental Theme</td>
<td>Environmental themes are the broad process or structure elements of the environment for which an index is being developed.</td>
</tr>
<tr>
<td>FNARH</td>
<td>First National Assessment of River Health</td>
</tr>
<tr>
<td>FPOM</td>
<td>Fine particulate organic matter</td>
</tr>
<tr>
<td>FPZ</td>
<td>Functional Process Zone — lengths of river with similar discharge and sediment regimes</td>
</tr>
<tr>
<td>IAG</td>
<td>Independent Audit Group of the Murray-Darling Basin Ministerial Council</td>
</tr>
<tr>
<td>IBI</td>
<td>Index of Biotic Integrity — an international assessment method developed for NSW using fish</td>
</tr>
<tr>
<td>IMEF</td>
<td>Integrated Monitoring of Environmental Flows — a NSW-designed assessment for determining effectiveness of environmental flows in regulated rivers</td>
</tr>
<tr>
<td>Indicator</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>An indicator</td>
<td>Indicates the state or condition of an environmental parameter; for example, O/E, Signal, [N], DO, etc.</td>
</tr>
<tr>
<td>Integration</td>
<td>Denotes combining measures of different indicators at a given scale to generate an index, e.g. various measures of water quality.</td>
</tr>
<tr>
<td>ISC</td>
<td>Index of Stream Condition — used in river health assessment in Victoria to assess river management priorities</td>
</tr>
<tr>
<td>ISRAG</td>
<td>Independent Sustainable Rivers Audit Group</td>
</tr>
<tr>
<td>MDBC</td>
<td>Murray-Darling Basin Commission</td>
</tr>
<tr>
<td>MDBMC</td>
<td>Murray-Darling Basin Ministerial Council</td>
</tr>
<tr>
<td>NL&amp;WRA</td>
<td>National Land and Water Audit, which has a waterway condition component</td>
</tr>
<tr>
<td>NRHP</td>
<td>National River Health Program</td>
</tr>
<tr>
<td>O/E score</td>
<td>Output of AUSRIVAS — the ratio of observed to expected macroinvertebrate taxa</td>
</tr>
<tr>
<td>PBH</td>
<td>Pressure–Biota–Habitat — a NSW-designed assessment for unregulated streams</td>
</tr>
<tr>
<td>River Health Index</td>
<td>A river health index will be compiled for each river valley (or other appropriate spatial reporting scale) by integrating indices developed for the environmental themes.</td>
</tr>
<tr>
<td>SRA (see also Audit)</td>
<td>Sustainable Rivers Audit proposed to be undertaken annually</td>
</tr>
<tr>
<td>SS</td>
<td>Suspended solids</td>
</tr>
<tr>
<td>TN</td>
<td>Total nitrogen</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon</td>
</tr>
<tr>
<td>TP</td>
<td>Total phosphorus</td>
</tr>
<tr>
<td>VPZ</td>
<td>Valley Process Zone</td>
</tr>
</tbody>
</table>
Workshop Participants

In undertaking the project to develop an Audit framework, the CRC for Freshwater Ecology actively involved jurisdictional representatives (identified by the SRA Taskforce). This occurred through participation in workshops, consultation about existing and future river health programs, and review of draft material.

Five workshops were undertaken: three were held at the University of Canberra and two were ‘virtual’ workshops. Participants in the workshops are listed in Table 14.

Table 14. Workshop participants

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Participants</th>
</tr>
</thead>
</table>
| Macroinvertebrate Index 20 March 2001 | Eren Turak, EPA, NSW  
                                           Natasha Waddel, EPA, NSW  
                                           Bruce Chessman, DLWC, NSW  
                                           Greg Keen, Environment ACT  
                                           Brian Wilkinson, Environment ACT  
                                           Satish Choy, DNR, QLD  
                                           Peter Goonan, EPA, SA  
                                           Leon Metzeling, EPA, VIC  
                                           Sue Grau, MDBC  
                                           Brian Lawrence, MDBC  
                                           John Whittington, CRCFE  
                                           Peter Liston, CRCFE  
                                           Julie Coysh, CRCFE  
                                           Richard Norris, CRCFE |
| Physical Habitat Workshop 26 March 2001 | Ben Gawne CRCFE  
                                           Paul Wilson, NRE VIC  
                                           Sally Boon, NRM QLD  
                                           Bruce Chessman, DLWC NSW  
                                           David Outhet, DLWC NSW  
                                           Simon Treadwell, SKM  
                                           Trish Bowen, CRCFE  
                                           John Whittington, CRCFE  
                                           Brian Lawrence, MDBC  
                                           Peter Goonan, EPA SA (written comments) |
<table>
<thead>
<tr>
<th>Event</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Index Workshop</td>
<td>Peter Davies, Freshwater Systems, Tas&lt;br&gt;David Moffatt, NRM QLD&lt;br&gt;Peter Gherke, Fisheries NSW&lt;br&gt;Ivor Growns, Fisheries NSW&lt;br&gt;Tarmo Raadik, NRE VIC&lt;br&gt;Mark Lintermans, Environment ACT&lt;br&gt;Mark Kennard, CRCFE&lt;br&gt;Paul Humphries, CRCFE&lt;br&gt;Bruce Chessman, DLWC NSW&lt;br&gt;John Harris, CRCFE&lt;br&gt;Richard Norris, CRCFE&lt;br&gt;Alison King, CRCFE&lt;br&gt;Claire Petekin, DPI QLD&lt;br&gt;Sean Sloan, SA&lt;br&gt;Leon Barmuta, UTAS&lt;br&gt;Brian Lawrence, MDBC&lt;br&gt;Jim Barrett, MDBC&lt;br&gt;John Whittington, CRCFE&lt;br&gt;Julie Coysh, CRCFE</td>
</tr>
<tr>
<td>Water Quality Index Virtual Workshop</td>
<td>Ian Lawrence, CRCFE&lt;br&gt;Klaus Koop, EPA NSW&lt;br&gt;H. Daly, DLWC NSW&lt;br&gt;Paul Wilson, NRE VIC&lt;br&gt;Peter Goonan, DEH SA&lt;br&gt;Neil Rovert, Environment ACT&lt;br&gt;Jenny Edwards, DNR QLD&lt;br&gt;Jean Chesson, EA&lt;br&gt;Barry Hart, CRCFE&lt;br&gt;Bill Maher, CRCFE</td>
</tr>
<tr>
<td>Hydrology Virtual Workshop</td>
<td>Tom Vanderbyl, NMR QLD&lt;br&gt;Darren Barma, DLWC NSW&lt;br&gt;Penny Knights, DLWC NSW&lt;br&gt;Greg Keen, Environment ACT&lt;br&gt;J. Barratt, DEH SA&lt;br&gt;A. Herbert, DEH SA&lt;br&gt;Paul Wilson, NRE VIC&lt;br&gt;Brian Wilkinson, Environment ACT&lt;br&gt;Dan Diaconu, Environment ACT&lt;br&gt;Fiona Dyer, CRCFE&lt;br&gt;Brian Lawrence, MDBC&lt;br&gt;David Cresswell, SA&lt;br&gt;Martin Thoms, CRCFE</td>
</tr>
</tbody>
</table>
References


Appendix 1

Review of existing programs that measure and report river health in the Murray-Darling Basin

Peter Liston
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>58</td>
</tr>
<tr>
<td>2 General description of programs</td>
<td>59</td>
</tr>
<tr>
<td>2.1 Index of Stream Condition (ISC)</td>
<td>59</td>
</tr>
<tr>
<td>2.2 Integrated Monitoring of Environmental Flows (IMEF)</td>
<td>60</td>
</tr>
<tr>
<td>2.3 Pressure/ Biota/ Habitat Approach (PBH)</td>
<td>60</td>
</tr>
<tr>
<td>2.4 State of Rivers (SOR)</td>
<td>61</td>
</tr>
<tr>
<td>2.5 MDBC Water Quality Monitoring program</td>
<td>61</td>
</tr>
<tr>
<td>2.6 National State of the Environment Reporting (SOE)</td>
<td>62</td>
</tr>
<tr>
<td>2.7 Water Allocation Management Planning (WAMP) ecological assessment</td>
<td>62</td>
</tr>
<tr>
<td>2.8 Assessment of River Condition (ARC)</td>
<td>62</td>
</tr>
<tr>
<td>2.9 NSW Rivers Survey</td>
<td>63</td>
</tr>
<tr>
<td>2.10 Wild Rivers</td>
<td>63</td>
</tr>
<tr>
<td>2.11 QLD EPA Guidelines for Waterway Conservation/Ecological Values</td>
<td>64</td>
</tr>
<tr>
<td>2.12 National River Health Program (NRHP)</td>
<td>64</td>
</tr>
<tr>
<td>2.13 Stressed Rivers Assessment</td>
<td>65</td>
</tr>
<tr>
<td>2.14 Waterwatch</td>
<td>65</td>
</tr>
<tr>
<td>2.15 Other State and Territory water quality, hydrology and fish</td>
<td>65</td>
</tr>
<tr>
<td>monitoring programs</td>
<td></td>
</tr>
<tr>
<td>3 Cost</td>
<td>66</td>
</tr>
<tr>
<td>4 Spatial classification of rivers (same program breakdown as in section 2)</td>
<td>66</td>
</tr>
<tr>
<td>5 Components measured by river health programs (same program</td>
<td>70</td>
</tr>
<tr>
<td>breakdown as in section 2)</td>
<td></td>
</tr>
<tr>
<td>6 Data documentation and level of expertise required (same program</td>
<td>78</td>
</tr>
<tr>
<td>program breakdown as in section 2)</td>
<td></td>
</tr>
<tr>
<td>7 Spatial and temporal variability (same program breakdown as in</td>
<td>80</td>
</tr>
<tr>
<td>section 2)</td>
<td></td>
</tr>
<tr>
<td>8 Sampling conducted in the MDB (same program breakdown as in section 2)</td>
<td>84</td>
</tr>
<tr>
<td>9 Reference Condition (same program breakdown as in section 2)</td>
<td>91</td>
</tr>
<tr>
<td>10 Programs monitoring specific Audit components</td>
<td>93</td>
</tr>
<tr>
<td>11 Summary of approaches (same program breakdown as in section 2)</td>
<td>98</td>
</tr>
<tr>
<td>12 References</td>
<td>104</td>
</tr>
<tr>
<td>State contacts for Tasks 1, 3–7</td>
<td>105</td>
</tr>
</tbody>
</table>
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Programs specifically monitoring “river health”</td>
<td>59</td>
</tr>
<tr>
<td>Table 2</td>
<td>Spatial reporting scale of river health approaches</td>
<td>69</td>
</tr>
<tr>
<td>Table 3</td>
<td>River valleys for which there is ISC data relevant to the Audit or CSA</td>
<td>84</td>
</tr>
<tr>
<td>Table 4</td>
<td>River valleys for which there is IMEF data relevant to the Audit or CSA</td>
<td>85</td>
</tr>
<tr>
<td>Table 5</td>
<td>River valleys for which there is State of the Rivers data relevant to the Audit or CSA</td>
<td>85</td>
</tr>
<tr>
<td>Table 6</td>
<td>River valleys for which there is WAMP data relevant to the Audit or CSA</td>
<td>86</td>
</tr>
<tr>
<td>Table 7</td>
<td>River valleys for which there is ARC data relevant to the Audit or CSA</td>
<td>86</td>
</tr>
<tr>
<td>Table 8</td>
<td>River valleys for which there is NSW River Survey data relevant to the Audit or CSA</td>
<td>87</td>
</tr>
<tr>
<td>Table 9</td>
<td>River valleys for which there is Wild Rivers data relevant to the Audit or CSA</td>
<td>87</td>
</tr>
<tr>
<td>Table 10</td>
<td>River valleys for which there is NRHP data relevant to the Audit or CSA</td>
<td>88</td>
</tr>
<tr>
<td>Table 11</td>
<td>River valleys for which there is Stressed Rivers data relevant to the Audit or CSA</td>
<td>89</td>
</tr>
<tr>
<td>Table 12</td>
<td>River valleys for which there is data from other monitoring programs relevant to the Audit or CSA</td>
<td>89</td>
</tr>
<tr>
<td>Table 13</td>
<td>Macroinvertebrate monitoring</td>
<td>94</td>
</tr>
<tr>
<td>Table 14</td>
<td>Fish monitoring</td>
<td>94</td>
</tr>
<tr>
<td>Table 15</td>
<td>Hydrological measures</td>
<td>95</td>
</tr>
<tr>
<td>Table 16</td>
<td>Water quality</td>
<td>96</td>
</tr>
<tr>
<td>Table 17</td>
<td>CSA components currently assessed in the Murray-Darling Basin</td>
<td>96</td>
</tr>
</tbody>
</table>
1 Introduction

The “Scope of the Sustainable Rivers Audit” (Cullen et al. 2000) recommended that the development of the Sustainable Rivers Audit (Audit) and Comprehensive Sustainability Assessment (CSA) should be comprehensive, and build on and add value to what is being already collected in State and National programs. Consequently a major challenge in developing the Audit and CSA is the identification of common threads across the range of assessment programs that could contribute to meeting the requirements of the Audit. The purpose of this review is to collate information on existing State, Territory and Commonwealth approaches to assessing river health. This information will be used to guide the development and trial of Audit indicators throughout this project.

The scoping document identified five ecological themes for which indices would be developed to comprise the Audit; fish, macroinvertebrates, hydrology, physical habitat and water quality. In addition the CSA would include further habitat structure and biological measures. Proposed biological themes included measures on aquatic invertebrates and fish communities. Water quality indices might include measures on parameters such as total phosphorus, electrical conductivity, turbidity and pH and other water quality parameters. The habitat structure indices were proposed to include measures on connectivity, riparian conditions, woody debris in streams, geomorphic and wetland elements. Other biological elements notionally identified for inclusion in the CSA were measures on algal growth and blooms, riparian vegetation, aquatic plants, aquatic and riparian weeds, wetland area and condition, and water birds.

In the Audit and CSA scoping document the concept of river health has a specific focus. Although this term has been used to denote attainment of a range of values in relation to rivers, in the Audit and CSA the scoping document identifies river health to be synonymous with ecological integrity. The working definition of river health used in this review is:

| the degree to which aquatic ecosystems support and maintain processes and a community of organisms and habitats relative to the species composition, diversity, and functional organisation of natural habitats within a region. |

The initial starting point for this review was the suite of assessment programs identified in the scoping document. Advice was sought from State, Territory and Commonwealth representatives on additional programs that were specifically aimed at assessing “river health” or at the indicators recommended for inclusion in the Audit and CSA (see Table 1). In the course of this review the intention has been to provide an overview of the programs that could potentially contribute elements to the audit. It was not intended to produce an exhaustive review, particularly as recommendations on specific indicators to be used in the audit will come from subsequent tasks under this brief (Tasks 3-7). In particular, it should be noted that monitoring methods reviewed in this document are mainly Federal and State government programs and that considerable data has been collected by local councils and community groups.
Table 1  Programs specifically monitoring “river health”

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Specific river health programs</th>
<th>Funding Status</th>
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<tr>
<td>Queensland</td>
<td>• Water Allocation Management Planning (WAMP) ecological assessment</td>
<td>To be advised</td>
</tr>
<tr>
<td></td>
<td>• State of Rivers approach</td>
<td></td>
</tr>
<tr>
<td>New South Wales</td>
<td>• Integrated Monitoring of Environmental Flows (IMEF)</td>
<td>• till June 2001 – likely to be ongoing</td>
</tr>
<tr>
<td></td>
<td>• Pressure/ Biota/ Habitat Approach (PBH)</td>
<td>• till June 2001 (trials only)</td>
</tr>
<tr>
<td></td>
<td>• NSW Rivers Survey (IMEF rivers only)</td>
<td>• till June 2002</td>
</tr>
<tr>
<td></td>
<td>• Stressed Rivers Assessment</td>
<td>• complete – no funds</td>
</tr>
<tr>
<td></td>
<td>• State of Rivers approach</td>
<td>• no funds</td>
</tr>
<tr>
<td>ACT</td>
<td>No specific program but data relevant to the Audit and CSA has been</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>collected.</td>
<td></td>
</tr>
<tr>
<td>Victoria</td>
<td>• Index of Stream Condition (ISC)</td>
<td>Streamside zone and physical form – ongoing (CMAs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The Water quality and hydrology – ongoing (State agencies)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquatic life – possibly ongoing (State agencies)</td>
</tr>
<tr>
<td>South Australia</td>
<td>No specific program but data relevant to the Audit and CSA has been</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>collected.</td>
<td></td>
</tr>
<tr>
<td>Commonwealth</td>
<td>• National State of the Environment Reporting (SOE)</td>
<td>Note 2: Monitoring has ceased. Collation of data continuing under NHT to June 2002</td>
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<td></td>
<td>• Assessment of River Condition (ARC)</td>
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<td></td>
<td>• Wild Rivers</td>
<td>Note 2</td>
</tr>
<tr>
<td></td>
<td>• National River Health Program (NRHP)1</td>
<td>Monitoring has ceased. Collation of data continuing under NHT to June 2002</td>
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<td>• Waterwatch</td>
<td></td>
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<tr>
<td>Murray-Darling Basin</td>
<td>• MDBC Water Quality Monitoring program1</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Commission</td>
<td></td>
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</tr>
</tbody>
</table>

Note 1: These programs are joint State, Territory, Commonwealth initiatives.
Note 2: These programs are not primary sources of data collection. Compiled data from other primary data bases are collated to comply with the requirements of these Programs.

In addition to the programs identified above, there is a range of programs monitoring indicators identified for inclusion in the Audit, particularly hydrological, water quality and fish monitoring. These programs occur in each of the States and Territories in the Murray-Darling Basin and provide a widespread and long-term data set.

2 General description of programs

2.1 Index of Stream Condition (ISC)

Where used: Victoria
Agency responsible: Department of Natural Resources and Environment
When developed: 1995
Principal focus: Measurement of river environmental condition
Principal documentation:

*An Index of Stream Condition: Reference Manual* (White and Ladson 1999a)

*An Index of Stream Condition: Field Manual* (White and Ladson 1999b)

*An Index of Stream Condition: Catchment Manager’s Manual* (White and Ladson 1999c)


The ISC was developed as a tool to provide a holistic measure of river health that could be used by managers and the community to benchmark river condition, assess the effectiveness of rehabilitation and to set priorities for management action.

The intention of the ISC is to provide measures of the health of both the aquatic biota and the drivers that may impact on the health of the biota.

### 2.2 Integrated Monitoring of Environmental Flows (IMEF)

Where used: NSW

Agency responsible: Department of Land and Water Conservation (DLWC)

When developed: 1998

Principal focus: Ecological responses to environmental flows in regulated rivers

Principal documentation: Not yet available (Design report awaiting approval to publish; first major technical report in preparation)

The IMEF approach was established as part of the State water reform package to assess the ecological responses to improved flows. A hypothesis driven approach was taken, with ecological responses to environmental flows being predicted in a series of testable hypotheses. Nine priority hypotheses are being tested in one or more river valleys. The intended outcomes of the project are an understanding of the existing state and trends over time in hydrology, morphology and ecology in the major river systems, and evaluation of the likely contributions of environmental flows to these changes through the construction of predictive models.

### 2.3 Pressure/Biota/Habitat Approach (PBH)

Where used: NSW

Agency responsible: Department of Land and Water Conservation

When developed: 1999

Principal focus: Conservation value, ecological health and pressures on ecological health for unregulated rivers

Principal documentation: Not yet available (Report on trial implementation being drafted for review commencing February 2001)

The PBH approach is a general framework that has been tested through a multi-faceted, rapid procedure for the assessment of ecological conservation values and ecosystem stress in small and medium size streams. The PBH approach uses three kinds of variables: human generated pressure on rivers, components of the biota, and aspects of bio-physical habitat. These variables are used to generate indicators of richness, rarity, native abundance, alien biota, sensitivity, physical structure, water extraction and water quality. These indicators are wrapped up into indices of conservation significance, biological stress (or condition) and stressors. It is explicitly designed to provide information for
management prioritisation, for strategic river management by describing the properties of river systems and identifying key issues, and for general performance monitoring/environmental auditing. The PBH approach has been trialled by DLWC and the trial results will be reviewed in early 2001.

2.4 State of Rivers (also called Riverine Habitat Audit Procedures – RHAP)
Where used: Queensland, more recently NSW
Agency responsible: Queensland Department of Primary Industry (now Department of Natural Resources)
When developed: 1993
Principal focus: Assessment of riverine habitat
Principal documentation:

The State of the Rivers assessment procedure was developed to provide the Queensland Department of Primary Industry (DPI) with a tool to assess physical and environmental health of rivers and streams. DPI required objective information on river condition to participate in the integrated catchment management program adopted as a State policy. Although the DPI already had programs for monitoring water quality and stream flow, these were seen as restricted in scope and a wider assessment with an ecosystem focus was required. Data is collected largely by field survey.

This approach focuses on collection of habitat data (geomorphology, and vegetation). There are intentions to integrate hydrology, water quality and biota assessment into this approach.

Although this approach provides a snapshot of riverine condition, repeated sampling could be used to assess trends, e.g. the Maroochy River has been resampled 5 years after the initial sampling.

2.5 MDBC Water Quality Monitoring program
Where used: Murray-Darling Basin
Agency responsible: Murray-Darling Basin Commission
When developed: 1978
Principal focus: Water quality in River Murray

Under its charter the MDBC is required to monitor the water quality of the River Murray and the lower reaches of its tributaries. The MDBC established a monitoring program in 1978 which continues to the present. Three types of data are collected; physico-chemical, phytoplankton and macroinvertebrate data. Actual monitoring is conducted by State agencies; NSW Department of Land and Water Conservation, and SA Water, or by consultants; Australian Water Technologies Victoria.
2.6 National State of the Environment Reporting (SOE)

Where used: Australia  
Agency responsible: Environment Australia  
When developed: 1996  
Principal focus: Physical, chemical, biological and socio-economic condition of rivers  
Principal documentation:  

National SOE reporting is undertaken to provide information on the environment as a foundation for ecologically sustainable development. It allows regular reports on indicators of changes in environmental condition and provides a means of monitoring the performance of government policies against actual outcomes.

National SOE reporting is conducted approximately every five years. An initial assessment was conducted in 1996, and the second report is planned for completion in 2001. Reports are largely compiled from data collected by other State and Federal agencies.

2.7 Water Allocation Management Planning (WAMP) ecological assessment

Where used: Queensland  
Agency responsible: Department of Natural Resources  
When developed: Varies with Basin  
Principal focus: Ecological condition of rivers in a Basin in relation to flow  
Principal documentation: WAMP documentation specific to Basin

The purpose of this process is to provide an ecological baseline for a catchment principally from the perspective of the impacts that flow abstractions or diversions have caused, or future abstractions or diversions may cause. The WAMP covers all streams in a catchment but focuses on the main trunk. Data is normally acquired from other programs though baseline and survey type data may be acquired during the WAMP process to supplement existing data. The WAMP process for each basin is specific to that basin and so the outputs may differ from those of other basins.

2.8 Assessment of River Condition (ARC)

Where used: Australia  
Agency responsible: National Land and Water Audit office  
When developed: In development  
Principal focus: Ecological health of rivers  
Principal documentation: Not yet available

The ARC project will provide an overarching view of the quality of rivers across Australia. It will do so by drawing together information from river and catchment attributes. It is intended to be used as both a measure of river condition and as a tool to
identify management options for rivers. Outputs from the project will be a system for assessment of river condition, and, using that system, an Australia-wide assessment of waterway condition.

2.9 NSW Rivers Survey

Where used: NSW
Agency responsible: NSW Fisheries and CRC Freshwater Ecology
Principal focus: Ecological status of fish in NSW rivers
When Developed: 1995-1997, development on-going as part of IMEF (note: not in interstate catchments)
Principal documentation:

The NSW Rivers Survey was a collaborative project between NSW fisheries and the CRC for Freshwater Ecology with five specific objectives:
- Study the distribution and abundance of native fish of NSW rivers
- Determine the abundance, distribution and habitat use of carp and other alien species in NSW rivers
- Develop understanding of the ecological effects of river regulation and establish hypotheses for further study of environmental flows
- Establish and test a standardised predictive model for monitoring river health using fish community assessment
- Establish a standardised survey structure for use in other studies.

The NSW River Survey also provided data for an assessment of the performance of the Index of Biotic Integrity (IBI) as a river-health indicator. The IBI analysis produces relative assessments, rather than an evaluation of absolute condition, which can be used to assess spatial and temporal changes in the relative health of rivers within regions and river types. This IBI analysis may provide a baseline for monitoring river health using fish. NSW Fisheries recommends further analysis of IBI as well as other interpretative models of fish survey data before indicator measures for the Audit are endorsed.

2.10 Wild Rivers

Where used: Australia
Agency responsible: Australian Heritage Commission
When developed: 1998
Principal focus: Assessment of ecological and landscape values of rivers
Principal documentation: *The identification of wild rivers: Methodology and database development.* Stein, J.L., Stein, J.A. and Nix, H.A. A report for the Australian Heritage Commission by the Centre for Resource and Environmental Studies, Australian National University.
The Wild Rivers project arose from a commitment by the Commonwealth to assist State and Territory agencies to identify rivers in near pristine condition, to encourage protection and proper management of their catchments. The approach uses data on human disturbances within a catchment and to the river’s channel directly, to assess the potential of a river to be a “wild river”. Elements chosen for inclusion include both those important to ecosystem functioning, and others of a more visual landscape basis. Although the focus of the project was originally on near pristine rivers, the approach is applicable to rivers across the entire spectrum of degraded to pristine.

The assessment of wild rivers is based on a modelling approach using remotely sensed and cartographic information.

### 2.11 QLD EPA Guidelines for Waterway Conservation/Ecological Values

Where used: Queensland  
Agency responsible: Queensland Environment Protection Agency  
When developed: In development  
Principal focus: Assessment of ecological values  

The purpose of the Conservation/Ecological Value Guidelines is to provide a systematic, comprehensive and flexible method to describe the ecological values of waterways and floodplains. The Guideline is designed to support both conservation planning and development assessment. This method has been trialled in the Burnett catchment, with the results of the trial yet to be evaluated.

### 2.12 National River Health Program (NRHP)

Where used: Australia  
Agency responsible: Environment Australia  
When developed: 1994 - present  
Principal focus: Assessment of the ecological status of streams using in-stream macroinvertebrate fauna  

The National River Health Program arose to support the environmental component of the COAG Water Reform Framework. The objectives of the program are to:
- Provide a sound information base on which to establish environmental flows
- Undertake a comprehensive assessment of the health of inland waters. Macroinvertebrates were used as the initial main indicator of river health but other potential indicators, e.g. fish and diatoms, were assessed under the NRHP.
- Consolidate and apply techniques for improving the health of inland waters.

As part of this program the first Australia wide assessment of the health of aquatic systems was conducted at approximately 6000 sites across Australia.
2.13 Stressed Rivers Assessment
Where used: NSW
Agency responsible: Department of Land and Water Conservation
When developed: 1997 to 1999
Principal focus: Assessment of hydrologic stress and conservation status
Principal documentation: No general description of methods is available. However, assessments compiled for individual river basins have followed a similar approach and include descriptions of methods.

The Stressed Rivers program arose from the NSW Government Water Reforms, with the intention of providing information on the environmental stress, particularly hydrologic, of unregulated rivers. High priority catchments were identified where demand for water exceeds supply, where the water environment is degraded or the catchments have high conservation value. This information was to be used to guide management priorities and policies. Stressed Rivers Assessment relies on information already collected on hydrology, land use, conservation issues etc, and does not involve field sampling.

2.14 Waterwatch
Where used: Australia
Agency responsible: Coordinated nationally by Environment Australia, with State and Territory Coordinators. On ground activities conducted by an extensive network of community groups.
When developed: 1995 to present
Principal focus: Community assessment of stream ecological and water quality status.
Principal documentation: No general description of methods is available. Individual Waterwatch groups, regional bodies and State/Territory bodies determine their own approaches and produce their own protocols and communication. Nevertheless efforts are made to coordinate between groups so that there is a degree of consistency in the type of data collected and the methods used. State/Territory manuals are available.

The Waterwatch program differs from others in this review in that, although funded to an extent by the Natural Heritage Trust program, it is conducted almost entirely by the community. The Waterwatch program was developed to provide community members interested in the status of their streams with techniques they could use to monitor stream condition. It is recognised that data collected under this program varies in quality and consistency depending on the expertise of the different Waterwatch groups. It is included here because it has been responsible for collection of a vast body of data across the Basin, and demonstrates the level of and location of community interest in stream condition in the Basin. As an indication of the level of sampling effort involved, in 1999 in NSW there were 15,138 people in the Waterwatch program and 981 sites were monitored.

2.15 Other State and Territory water quality, hydrology and fish monitoring programs
Where used: All States and Territories
Agency responsible: Various
When developed: Various
Principal focus: Monitoring of particular variables
Principal documentation: Commonly in-house documentation or undocumented

All States and Territories have monitoring programs directed at measuring particular variables that would contribute to a more comprehensive assessment of river health. In some States monitoring programs provide the information used in more comprehensive “river health” assessments and reports.

3 Cost

At this stage of the development of the Audit and CSA it is not useful to conduct a cost effectiveness assessment of different assessment programs undertaken throughout the Basin. It would also be very difficult to achieve and is likely to provide unreliable information due to issues such as cross-subsidy of indicator measurement in existing programs. The purpose of the development of an audit framework is to identify appropriate elements from different programs that together meet the Audit and CSA requirements. After development of detailed conceptual models, leading to recommendations on appropriate indicators, we may need to consider cost effectiveness of alternative approaches to measuring an indicator; for example, in the situation in which an indicator has not been measured in a particular State. It was not intended that an entire program would be recommended for adoption on the basis of its cost effectiveness.

4 Spatial classification of rivers

The Audit and CSA will be reporting at a “river valley” scale using data acquired at finer spatial scales within each river valley. For the purposes of this study, river valleys were taken to be the AWRC basins that occur in the MDB, slightly modified to remove anomalies such as catchments being divided by State boundaries, e.g. the Warrego. One of the responsibilities of the scoping project is to review and provide recommendations on the spatial distribution of sampling sites. It is important for the Audit and CSA that data collected within a river valley should provide reliable spatial measures of indicators within the valley and perhaps within functional zones in each valley. In consequence, an important component of this process will be identification of functional process zones throughout the Murray-Darling Basin.

In identifying an appropriate sampling framework it is useful to consider the assessing/reporting frameworks used by different programs. This should include consideration of any river classification adopted, and how sampling sites were located within “reaches” or “zones”.

In this section the term “reach” is used for the basic component of the river for which data is collected and an assessment made. For some methods of assessment the term “reach” is used for this component. In others, terms such as “segment”, “sub-section” or “geomorphic unit” are used, and the term “reach” may be used for a different purpose. Most programs classify rivers into reaches or equivalent for sampling purposes. Additionally, some programs classify rivers into broader categories to assist stratified sampling. Program details are summarised in Table 2.
4.1 ISC
Reaches are defined as sections of river typically 10-30 km long and relatively homogeneous in terms of their hydrology, physical form, streamside vegetation, and water quality or aquatic life.

Initially the ISC proposed that a “representative” measuring site be identified in each reach, and five transects be assessed at that site. Analysis of the representative nature of these assessments led to the evolution of a modified sub-sampling schema in which three measuring sites are randomly identified within each reach, and three transects assessed at each site. This schema was found to be the optimum balance between reliability of results and cost.

4.2 IMEF
The IMEF has an experimental focus with nine priority hypotheses being tested in one or more river valleys. Site selection procedures varied across the different studies, but generally followed stratified random designs. In some cases, sites were selected for strategic reasons (e.g., weir pools where cyanobacterial blooms have been reported). No overarching river classification schema was determined for use by the IMEF program.

4.3 PBH
PBH uses the geomorphic River Styles™ approach to identify reaches for stratified random site selection. The river styles approach is based on the critical role played by fluvial geomorphology, hydrology and vegetation in determining the physical template of rivers. It provides a technique for characterising rivers at three nested spatial scales; catchment, reach and geomorphic unit. The catchment is the largest scale and determines the boundary conditions within which a river operates. The reach is a length of channel within which there is a characteristic channel form. The geomorphic unit, the smallest scale, is the basic building block of a river system and within which basic processes operate to create the channel and floodplain morphology. The identification of the components of a river style requires detailed field mapping. This contrasts with many other approaches used to define sections of river.

4.4 State of Rivers
The State of the Rivers approach identifies units for reporting, called sub-sections, in a two stage process. The first stage is identification of homogeneous “sections” based on sub-catchment structure / stream order, natural and artificial barriers and obstructions, altitude, slope, stream gradient, geology, soils, catchment land use, climate, stream permanence, point sources, diversions and other major discontinuities. Sections could include several tributaries within a catchment. This stage is completed using maps and GIS tools.

The second stage involves identification of “sub-sections”, formed by the division of sections at each tributary junction or other discontinuity of land use, stream slope etc.

Once sub-sections have been determined, the river is reconnoitred using maps and on the ground to identify a site that is representative of the habitats and conditions within the sub-section. Initially one site is identified within each sub-section, but if the study design permits, more sites can be allocated.
4.5 MDBC WQ Monitoring program
Reaches are not explicitly defined under this program. Sites have been identified based on areas of particular interest or with perceived problems.

4.6 National SOE
Reaches are not explicitly defined under this program.

4.7 WAMP ecological assessment
Major rivers and streams in the study area are divided into relatively homogeneous river reaches on the basis of their natural characteristics, management regimes, and location of gauging stations in order to provide a spatial reference framework. Reaches appear to range in length from 10 to 80 km.

4.8 ARC
Reaches are defined as sections of river with relatively homogeneous geomorphology. Reach boundaries are determined from a digital elevation model at points where stream power, a major determinant of geomorphology, changes (usually increases) by more than a factor of two. Two other rules are followed; in the extreme part of a catchment a reach does not commence until it has a contributing catchment of at least 50 km², and the minimum length for reaches is 5 km.

For most ARC components, assessment is conducted for all 250 m sections of a reach, and aggregated to arrive at a reach assessment.

4.9 NSW River Survey
Reach selection was undertaken as staged process. For the MDB, rivers were firstly classified into one of four main types: unregulated lowland, regulated lowland, slopes (300-700 m altitude) and montane. River reaches were selected from within these river types. The definition of river reach varied between river type; in lowland rivers it was between 20 and 50 km length of river and all slopes and montane reaches were 10km long. Minimum catchment size criteria were set which required a catchment to be larger than 20 km² and have a stream order of 3 or greater.

A "constrained random" selection procedure was developed to select river reaches for sampling. To ensure a wide representation of river types, rivers were grouped in to large, medium and small rivers. A constraint on the random selection of reaches was that a maximum of three replicate reaches could be selected in total for each large river, two for each medium river and one for each small river. A second constraint was that a minimum of three reach lengths had to separate selected reaches, except for regulated reaches where a minimum of one reach length was required.

Within each randomly selected reach, a sampling site was chosen on practical reasons, usually access, provided the site appeared representative of that reach. Grossly degraded sites were excluded and another site chosen, however these excluded sites were recorded and assessed independently using a less intensive method.

4.10 Wild Rivers
In this program, each river or stream on the AUSLIG stream coverage is divided into "stream sections" comprising either a first order tributary, or a section of the mainstream
between tributary junctions. Each reach is partitioned into 280 m segments, an assessment is calculated for each segment and aggregated to give the reach assessment.

4.11 QLD EPA Guidelines for Waterway Conservation/Ecological Values
Waterways are classified under this approach using criteria that support the assessment of three of the ecological value criteria; rarity, representativeness and naturalness. Consequently waterway classification is based on biogeography, hydrology, habitat, and aquatic flora and fauna. The classification was trialled in the Burnett River catchment, assessing both intuitive and numerical classifications and adopting the latter.

4.12 NRHP
This program did not explicitly define reaches within which sampling sites should be located. Also, although a site sampled under this program is generally taken to be a measure of the condition of the reach some distance upstream and downstream of the site, the program did not seek to define the length of reach that a site condition represents.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Spatial reporting scale of river health approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Approach</strong></td>
<td><strong>Basic reporting unit</strong></td>
</tr>
<tr>
<td>ISC</td>
<td>No classification of catchment into broad zones. “Reaches” defined as relatively homogeneous river sections in terms of hydrology, physical form, streamside vegetation, and water quality or aquatic life.</td>
</tr>
<tr>
<td>IMEF</td>
<td>Fish monitoring, wetland replenishment, river organic matter and biofilm studies: Rivers divided into relatively homogeneous “segments” based on regulation, abstraction and geomorphology. Most other studies: Use key water quality sites; reaches not defined.</td>
</tr>
<tr>
<td>PBH</td>
<td>Uses River Styles™ approach and other information. Classifies sub-catchments into “zones” primarily on the basis of longitudinal changes in channel and planform geometry, topography, hydrology, land use and vegetation.</td>
</tr>
<tr>
<td>State of Rivers</td>
<td>No classification of catchment into broad zones. “Sub-sections” defined by tributary junctions or discontinuities of land use, stream slope, barriers, point sources, geology, soils etc.</td>
</tr>
<tr>
<td>MDBC WQ Monitoring program</td>
<td>Not defined</td>
</tr>
<tr>
<td>National SOE</td>
<td>Not defined</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>“Reaches” defined as relatively homogeneous sections in terms of their natural characteristics and management regimes.</td>
</tr>
<tr>
<td>ARC</td>
<td>No classification of catchment into broad zones. “Reaches” - Simple geomorphological approach adopted.</td>
</tr>
<tr>
<td>NSW River Survey</td>
<td>Catchments classified into four categories based on altitude (&lt;300, 300-700, &gt;700m) and whether they are regulated. Within the two lowland categories, reaches were determined based on river characteristics. The slopes and montane zones were divided up into 10 km reaches.</td>
</tr>
<tr>
<td>Wild Rivers</td>
<td>“Reaches” defined as sections between tributaries</td>
</tr>
</tbody>
</table>
4.13 Stressed Rivers Assessment
The scale at which this program produces assessments varies across the MDB. In the northern parts of the Basin assessments are produced for entire AWRC Basins, e.g. Paroo. In the southern parts of the Basin assessments are at a finer spatial scale, with AWRC Basins divided into sub-catchments on the basis of hydrology (primary), land use, government boundaries etc.

4.14 Waterwatch
Reaches are not explicitly defined under this program. Sites have been identified based on areas of particular interest or with perceived problems.

4.15 Other monitoring programs
Usually reaches are not defined under these programs. Sites are commonly located at problem areas or sites of interest.

5 Components measured by river health programs
One of the principles guiding development of the Audit and CSA that emerged from the scoping process was that the audit should build on what is being collected already in State and National programs. The following section describes the data used by different programs with an emphasis on measures identified for inclusion in the Audit and CSA. Until the detailed development of conceptual models is completed and the indicators finalised, it will not be possible to identify exactly what State, Territory and National data already available would form part of the audit.

5.1 ISC
The ISC comprises five sub-indices, each composed of a set of parameters or key indicators.

Hydrology:
- hydrologic deviation (Amended annual proportional flow deviation (AAPFD) – i.e. the sum of the monthly deviation of current from natural, divided by the average monthly flow,
- percentage of the catchment that is urbanised,
- presence of a hydroelectric dam in the catchment.
Physical form:
- Bank stability
- Bed condition
- Presence and influence of artificial barriers
- Instream physical habitat

Streamside zone:
- Width
- Longitudinal continuity of vegetation
- Structural intactness of vegetation
- Cover of exotic vegetation
- Condition of billabongs
- Regeneration of native species

Water quality:
- TP, NTU, EC, pH

Aquatic life:
- SIGNAL macroinvertebrate rating
- AUSRIVAS score

5.2 IMEF
The IMEF is based around a series of experimental studies. It is useful to describe the data collected for the main studies.

Bloom suppression and flushing
- Phytoplankton
- Water quality
- Light regime
- Stratification

Wetland replenishment
- Water quality
- Vegetation
- Macroinvertebrates, fish, frogs, birds

Conditioning Stony Beds
- Biofilm characteristics
- Macroinvertebrates
- Stable isotopes
- Water quality

Wetting of Terrestrial Organic Matter
- Organic carbon characteristics
- Microbial characteristics
- Zooplankton
- Macroinvertebrates

Rehabilitating fish communities
- Fish
- Physical habitat

All studies
- Water regime
5.3 PBH
Full details of this method are not yet available as the approach is still in the review phase. Interim components of the assessment include;

*Biota*
  - Diatoms, macrophytes, riparian vegetation, macroinvertebrates, fish

*Water quality measures*

*Water use data*

*Physical habitat and structure measures*

5.4 State of Rivers
The State of the Rivers approach has been applied to a number of catchments in both Queensland and NSW. The attributes measured in some catchments have differed slightly from those in the original manual (set out below) as regional authorities have adapted the technique to meet their management requirements.

*Reach environment condition*: Assessment of land adjacent to stream. Includes land use, vegetation, floodplain features, tenure. Also includes a measure of the water level.

*Channel habitat diversity*: This measure assesses the range of channel habitats such as waterfall, rapid, riffle, glide, run, pool, backwater, etc., in a reach.

*Bed, bank and bar condition*: Distribution of bars, stability of banks and bed, restriction to fish passage.

*Vegetation*: Aquatic and riparian vegetation recorded in terms of percentage cover, structure and presence of key species. The riparian zone is defined subjectively on site.

*Aquatic habitat*: This attribute is assessed in terms of the diversity of in-stream habitat types: logs, branches, leaves etc.

*Scenic, recreational and conservation values*: This measure includes an assessment of recreational opportunity, scenic quality and conservation status of the stream.

5.5 MDBC Water Quality Monitoring Program
This program has been in operation since 1978. During this time there have been significant changes in the program, e.g. inclusion of a macroinvertebrates measure. The components below are those currently monitored under the program.

- Physical and chemical variables (TP, EC, Turbidity, pH; nitrogen, major anions and cations, trace metals)
- Phytoplankton
- Macroinvertebrates (using an artificial substrate technique)

5.6 National SOE
The National SOE identifies a suite of indicators which meet its assessment requirements (listed below). The majority of the data which comprises the SOE is not collected by Environment Australia, the Commonwealth agency responsible for completion of the National SOE. Nor are the chosen indicators constrained by the existence of data; instead they comprise an ideal for which data may not have been collected.
• The proportion of each catchment under deep-rooted vegetation.
• The ratio of water use to catchment yield.
• The location and number of point source discharges into inland waters, including the type and load of materials discharged.
• Salinity levels in surface waters.
• Exceedences of ANZECC water quality guidelines for a suite of (unspecified) microbiological, bacterial and chemical parameters. (Note: exceedences are assessed against a range of uses, stock watering etc, not solely ecological integrity.)
• Incidence of freshwater algal blooms.
• Percentage of streamlength with riparian vegetation, its width and quality.
• Assemblages of macroinvertebrates as assessed by AUSRIVAS.
• Extent and condition of wetlands.
• Status of freshwater fishes and crustacean stocks.

5.7 WAMP ecological assessment
Although the actual approach taken for the ecological assessment has differed between basins, it is possible to identify elements generally common to WAMP ecological assessments.

**Geomorphological assessment:** Based on components such as channel morphology (size, shape, substrate), hydraulic habitat and sediment transport processes. A reference approach is used with reference condition being determined from historical photographs, site inspections, hydrological data and inference.

**Riparian and aquatic vegetation:** Vegetation was assessed on the basis of species richness, total abundance, and presence of weeds. Vegetation assessments were site-specific and were not necessarily applicable over the length of a reach.

**Aquatic macroinvertebrates:** Condition was determined from data collected as part of the NRHP program. Six indices have been used: taxonomic richness, sensitive (PET) taxa, SIGNAL index, AUSRIVAS scores, functional feeding groups, and flow velocity and substrate preference groups.

**Fish communities:** Condition was determined from a review of existing data. Criteria used in assessment included the total number of native species present within a reach, the ratio of the number of species observed versus the total number of species expected within a reach (as determined from historical information, comparisons with nearby streams and position in catchment), and proportion of the total number of individuals collected at a given site which are native species.

**Water quality:** Condition was assessed based on previous reports and existing data.

**Hydrological measures (for example):**
• Daily Flow
• Annual Flow
• Mean Annual Flow
• Median Annual Flow
• Coefficient of Variation of Mean Annual Flow
• Annual Proportional Flow Deviation (APFD).
• Annual Recurrence Interval (ARI) Flow Event Analysis - a measure of the change in size of floods of a given recurrence interval.
• Maximum Spell Duration - duration of the maximum dry spell
• High Flow Duration – percentage of days with flows above a certain threshold.
• Medium Flow Duration – percentage of days with flows above a certain threshold
• Low Flow Duration – percentage of days with flows above a certain threshold
• No Flow Duration – percentage of days with flows above a certain threshold

**Wetlands and Floodplains**
• Condition assessment
• Condition assessment under proposed water development scenarios

**Integrated Monitoring**
This program will look at different indicators, to be first trialled in the Condamine-Balonne Basin starting 2001, in relation to changes in flow regime while accounting for other influences such as land use.

### 5.8 ARC

*Biota assessment:*
  • Macroinvertebrates - AUSRIVAS score
  • Fish (not available in initial assessment)
  • Algae (not available in initial assessment)
  • Macrophytes (not available in initial assessment)

*Hydrological assessment:*
  • Mean Annual Flow
  • Deviation from mean annual flow
  • ARI Flow Event Analysis
  • Change in seasonal amplitude
  • Change in seasonal periodicity

*Water quality assessment:*
  • TP, TN, NTU, toxicants

*Physical habitat assessment:*
  • Riparian vegetation condition
  • Geomorphological condition
  • Connectivity of reaches

**Catchment disturbance index:**
  Measure of anthropogenic activities with the potential to impact on stream condition; principally land use and catchment infrastructure.

### 5.9 NSW River Survey

*Fish:*
  • All fish caught counted and identified to species
  • Catch or subsample measured for length to nearest mm
  • Each fish examined visually for disease, parasites and abnormalities

*Habitat Assessment:*
  • Water Quality - dissolved oxygen, pH, conductivity, turbidity and temperature
• Subjective grading system for flow, depth, width, substrate, vegetation cover, level and turbidity

5.10 Wild Rivers
*Catchment characteristics:*
• Land use
• Point sources
• Settlements (a measure of the extent of urbanisation of the catchment)
• Infrastructure
*In stream characteristics:*
• Impoundments
• Flow diversions
• Levees

5.11 QLD EPA Guidelines for Waterway Values
*Naturalness:* An assessment of the natural State of the river in terms of its biota, habitat, water quality, riparian zone, hydrology, catchment condition, and ecological processes.
*Representativeness:* An assessment of how representative the reach is in terms of its geomorphology, hydrology, riparian zone and biota.
*Diversity:* An assessment of the diversity of the river in terms of its biota, geomorphic and habitat components.
*Rarity:* Presence of rare or threatened biota, habitats or geomorphological features.
*SPECIAL FEATURES:* Special features that distinguish the river.

5.12 NRHP
*Biota:* AUSRIVAS score and SIGNAL score
*Habitat:* Varies between States and Territories
  - Queensland — Riparian vegetation, geomorphological condition
  - NSW — Not assessed
  - ACT — Riparian vegetation, geomorphological condition
  - Victoria — Riparian vegetation, geomorphological condition
  - SA — Riparian vegetation, geomorphological condition
*Water quality:* Range of variables including TP, TN, EC, NTU
*Hydrology:* Basic measures of flow, e.g. velocity

5.13 Stressed Rivers Assessment
Indicators common across the unregulated sections of the Basin (not including the Barwon Darling River) were:
*Proportion of water extracted*
*Band, bed, bar stability*
*Riparian and aquatic vegetation*
*Structures in the channel*
*Note:* this program was a desktop collation and interpretation of existing information.

5.14 Waterwatch
Parameters measured vary from region to region and with the expertise of the group. However, the following variables are measured in most programs:
• Habitat
5.15 Other monitoring programs

There are a number of other programs that measure water characteristics in streams across the Basin. They range in scale from samples collected at a few sites for a specific purpose, to multiple site monitoring programs that have been operating over a considerable period. The parameters measured also range enormously. In addition to this level of complexity, most water monitoring programs undergo more or less continual change in response to our understanding of processes, resources available, new analytical procedures and changes in agency responsibilities. Here we focus on three groups of measures identified as part of the Audit or CSA: water quality, fish, hydrology.

5.15.1 Water quality

Water quality measurements comprise one of the most complex suites of data in the Basin. The data presented here are intended to provide only an indication of the extent of water quality data across the Basin. There is a wide range of other data collected by State and Territory agencies across the Basin which may potentially be of use in the Audit or CSA. However, it is not useful to explore these extensive data coverages until we have a better idea of the water quality indicators that will be included.

The data presented here have been taken from the suite of water quality sites identified by the National Land and Water Audit as suitable for assessing water quality. In this process the Audit adopted stringent criteria to identify those water quality monitoring sites at which the data records were complete enough, and methods used robust enough to warrant inclusion in a national water quality database:

- There should be data for one or more of the parameters EC, pH, TP, TN, NTU or faecal coliforms.
- Standardised and recognised sampling, preservation and storage techniques were used.
- Laboratories undertaking the chemical analyses were NATA registered for that analysis (Waterwatch data was not included).
- Data was verified to ensure that transcription errors and database errors were removed before processing.
- A minimum of three years data with a monthly sampling interval is required.

The above requirements provide a rigorous though realistic filter with which to view the plethora of water quality data that has been collected in the Basin. We should not overlook the fact that it produces a subset of the highest quality data from a much larger data set.

5.15.2 Hydrology

Hydrological records have been kept by all States and the ACT at a number of gauging stations in the Basin. As with water quality monitoring, records for different stations are of different length and have been captured using different methods. This review uses the Bureau of Meteorology (BOM) database of Australian hydrological stations to provide an indication of the extent of hydrological data available for the Basin. The BOM database is compiled from information provided by the States and Territories and has been updated in 2000.
5.15.3 Fish

There has been considerable monitoring of fish populations in the Basin, but many surveys have focussed on particular species or groups of species; for example carp or major angling species. Such surveys are much less useful for an assessment of the ecological status of fish communities than the more comprehensive surveys in which all fish species are surveyed. The most comprehensive fish survey of this latter “biodiversity” type conducted in the Basin is the NSW River Survey, described separately, which is now being incorporated into the fish sampling that forms part of the IMEF program. In addition to this work there has been fish monitoring in Queensland, ACT, Victoria and South Australia.

In Queensland the Department of Primary Industries has only this year initiated a long-term fisheries monitoring program. Although the program will focus on species of particular interest to anglers, abundance data on all other species will be recorded. Sites will be re-sampled on a yearly interval. Only selected river catchments will be sampled, five in the north and five in the south of the State. The Condamine-Balonne is the only catchment in the Basin that will be sampled under this program. DNR also has a program looking at fish fauna in relation to fishways.

In the ACT fish populations have been monitored at a number of sites at irregular intervals. Originally the program focussed on larger fish species targeted by anglers, but since 1994 the program has been modified to include all fish species. A variety of sampling techniques are used, including electrofishing. The last survey was conducted in 1998 with six sites intended to continue to be monitored biennially.

In Victoria there is no State-wide survey program for fish biodiversity. There have been a series of fish monitoring programs extending back to the 1960s, but commonly these surveys were for particular fish species or groups and not fish biodiversity. Examples of the sort of programs for which there is data include the relatively intense sampling programs in the 1970s focussing on recreational fisheries, and the 600 sites surveyed for fish biodiversity for the RFA process. Only during the last ten years have data on full fish biodiversity been collected by the Arthur Rylah Institute, and these data have come from a range of programs, many of them single snapshots of a particular area. Data from the majority of these fish survey programs has been collated into a database managed by the Department of Natural Resources and Environment at the Arthur Rylah Institute and could be made available to the Audit project.

In South Australia catch and effort information has been collected for all commercial fishing in the State, extending back to the beginning of the 20th century. This information provides basic biological information on size structure of populations of commercial species. Currently there is a survey of recreational fishing which will provide a 'snap-shot' of the existing fishery. In addition, there have been a number of ad hoc surveys of native and exotic fish including work on threatened and endangered species.
6  Data documentation and level of expertise required

Programs differ in the extent to which the procedures used have been codified. They also differ in the degree of and ranges of expertise required to complete an assessment. These two elements are both important considerations if a particular technique were to be recommended for use in the Audit or CSA.

This comes as a clear message from other areas of monitoring, particularly water quality monitoring, with much data now regarded as virtually useless as a result of poor procedures or poor documentation of procedures. Clearly documented procedures are critical to ensure that data collected over time is consistent, and that it is comparable with the same indicator measured elsewhere in the State or in another State. The level of expertise required should be considered here, as ongoing monitoring as part of the Audit or CSA may need to be conducted by regional staff who have a range of other responsibilities. In this review the expertise required to conduct a program has been assigned to one of three classes: low = able to be conducted by staff with a minimum of experience in stream condition assessment, medium = requiring staff skilled in a range of techniques, high = requiring specialist skills.

6.1 ISC
The ISC program is well documented, including background to the development of indicators, management issues and a detailed users manual (yet to be finalised). Much of the data used in the ISC is sourced from other programs. That acquired during the ISC process requires a medium level of expertise.

6.2 IMEF
A Design Report (intended for publication in early 2001) sets out the rationale for and development of the IMEF approach. Seven Operations Manuals (one for each participating valley) and a Methods Manual (200 page set of field and laboratory procedures) are working documents for staff involved in the program. A Statistical Analysis Manual and initial Technical Report are in preparation. The IMEF program requires medium to high levels of expertise, depending on the study.

6.3 PBH
Documentation is unavailable for the PBH program as yet, as the report on the field trials (and a separate consultant report on desktop application of the framework) are currently in preparation. It is not possible to determine what expertise would be required for a routine PBH program until the approach is finalised; however, existing requirements are for a mix of general and specialised expertise (the latter mainly in fish and vegetation).

6.4 State of Rivers
The State of the Rivers approach was originally documented in the two reports referred to in Section 2.4. However since then the approach appears to have undergone undocumented refinement by both the originator of the approach and by agencies implementing the approach. The program was intentionally designed to be conducted by regional technical officers after a brief training period. Consequently it can be conducted by people with a low level of expertise.
6.5 MDBC WQ Monitoring program
Data for this program is collected by States and by private laboratories under contract. Prescription of measures and expertise required is detailed in those programs, but generally requires medium to high expertise.

6.6 National SOE
Data for this program is collected by States and Territories under a range of programs. Prescription of measures and expertise required is detailed in those programs.

6.7 WAMP ecological assessment
Techniques are not prescribed for the WAMP process in general. A Technical Advisory Panel (TAP) is set up for each basin, and this TAP determines how the environmental conditions within a basin will be assessed. Procedures adopted by each TAP to assess environmental conditions are set out in detail in the WAMP supporting documents. Despite the independence of the process there appears to be a good deal of consistency between basins in the indicators chosen and techniques adopted. A very high level of expertise in a range of disciplines is required, particularly in assessing the condition in relation to water resource development.

6.8 ARC
This is an approach used to provide a national snapshot of river health, and not a generic technique intended to be adopted for application elsewhere.

6.9 NSW River Survey
This fish survey program was designed by senior ecologists within NSW Fisheries and required sampling using five different gear types (boat electrofishing, backpack electrofishing, fyke nets, multimesh gill nets and small bait traps). During this survey all participants, NSW Fisheries scientific and technical staff, attended a three day sampling methods workshop to ensure a suitable level of consistency in the application of sampling methods. Medium to high level of expertise required.

6.10 Wild Rivers
Essentially, use of this technique only involves retrieval of existing river condition data using the established Wild Rivers approach. The technique does not involve processing newly collected data to recalculate a Wild Rivers measure. The procedure initially used to collect and process the data, and those required to access the data are described in detail. A high degree of expertise is required to access the Wild Rivers data.

6.11 QLD EPA Guidelines for Waterway Values
Techniques are not prescribed in detail in this Guideline document. The definition of ecological values and their measurement is deliberately left to the group involved. Consequently the level of expertise required may vary. This approach has been applied to only one catchment as a trial and so the comparability of results between areas assessed by different groups is not known.

6.12 NRHP
Strenuous attempts have been made in this program to standardise techniques for site selection, data collection, laboratory procedures and analysis so that results are
comparable between operators and regions. These procedures are well documented. A medium level of expertise is required.

6.13 Stressed Rivers Assessment
Techniques have not been formally prescribed, but enough detail of the approach is given in each report to enable a consistent application of the model. A medium level of expertise is required.

6.14 Waterwatch
This program is developing standard methods for use across regions and nationally. As a result of the different skill levels available, methods with different degrees of scientific rigour are used. Low to medium expertise required.

6.15 Other monitoring programs
Other monitoring programs, e.g. water quality and hydrological monitoring, are usually highly prescriptive. Generally they require a medium level of expertise in the field and a high level of expertise in the laboratory, and in the analysis and interpretation of the data.

7 Spatial and temporal variability
A natural characteristic of the measures used to assess river health is their variability over space and time. Spatial variability needs to be considered to assess the value of the data. The extent of variability within the basic spatial unit used in an assessment (reach, sub-catchment etc), will determine the representativeness of any individual measurement. If the intention of a sampling program is to provide a measure that represents the state of that reach or sub-catchment, knowledge of the spatial variability should inform the sampling design.

Common approaches taken to ensure that the data collected represent the status of the reach or sub-catchment of interest include:

- a stratified sampling approach, with sampling effort spread across regions.
- collection of data at scales appropriate to the data type, e.g. in-stream habitat data would be collected at a finer spatial scale than catchment land use data.

In a similar fashion, all river health measures vary over time, with time scales ranging from the geological to the very rapid. If measures are to be an accurate reflection of reach / sub-catchment condition such variability must be accommodated. Approaches taken include:

- using measures that integrate effects over time (e.g. fish)
- taking multiple samples over time (e.g. event based monitoring)
- modelling data based on a system understanding (e.g. hydrology)

The Audit and CSA should be capable of providing a reliable measure of river health. With the State and Territory programs comprising the building blocks of the audit, it is important to be aware of how these programs have dealt with spatial and temporal variability. The following section reviews how programs have dealt with spatial and temporal variability.
Another issue that needs to be addressed in tasks 3–7 is how data collected at non-randomly located sites, sampled at irregular or regular intervals, can be used to generate an unbiased estimate of river health in a catchment or river valley. Several of the assessment procedures discussed here provide a measure of river health for a catchment (e.g. ISC, ARC) by aggregating data from different sites and over time. If a sampling program were designed a priori to provide an accurate measure of the river condition in the catchment, sites could be chosen that were known to be representative of the river condition, or sampling locations could be chosen using a random or stratified random design. In addition repeat sampling should be conducted over timescales appropriate to the processes operating.

The approach most commonly adopted is to stratify the catchment into “homogeneous” units, and then conduct a comprehensive sampling of each or many of these units (e.g. ISC, State of the Rivers). Synthesis of these measurements into a single catchment measure is taken as an acceptable representation of the overall condition of the river within that catchment. In the course of synthesis the measurements may be weighted, e.g. on the length of “homogeneous” section from which they come, or not weighted at all. Weighting is based on the (often implicit) reasoning that an overall measure of condition should represent the status of a river wherever it is encountered in the catchment.

In this vein, an interesting component in the development of the ISC program was an investigation of how representative their overall measures of river condition were. This study led to a modified sampling design which improved the representativeness of their measures.

7.1 ISC
The ISC explicitly acknowledges the significance of natural spatial and temporal variability; indicators and sampling sites were chosen with this consideration in mind. As the ISC was planned to be a 5 yearly snapshot, the natural temporal variability of indicators was important when selecting measures that would provide a measure of trend. Spatial variability of indicators was accommodated both by choosing robust measures and by regionalisation to partition natural variability.

7.2 IMEF
Both spatial and temporal variability are considered in the different studies that comprise the IMEF. The approaches taken differ between studies. For example the wetland replenishment study uses spatially random sites, but with a sampling frequency and timing determined by the occurrence of unpredictable flow events. This enables species succession following flooding to be tracked. In contrast bloom flushing studies use a group of strategic sites sampled at fixed intervals dependent on the seasonal likelihood of blooms and the expected response time of phytoplankton populations.

7.3 PBH
PBH uses a stratified random approach to deal with spatial variability. The question of temporal variability has not been addressed at this stage of development (although time series data on many PBH variables are available from other studies).


7.4 State of Rivers
In order to accommodate spatial variability sampling sites are densely located, for example 48 sites were sampled in the Abercrombie River catchment (100km long). This strategy appears possible as a result of the relatively rapid techniques employed, but may still be extremely resource intensive.

Temporal variability is not explicitly addressed in the State of the Rivers approach as is intended to provide a snapshot of catchment condition. Even so, many of the measures chosen are relatively time invariant and so would provide a robust measure over time.

7.5 MDBC WQ Monitoring program
Spatial variability is explicitly addressed in this program which was designed to provide information at particular points along the river. The location of sampling sites was not originally designed to provide statistically reliable measures of water quality parameters for the river as a whole or for sections of the river.

This program was designed to detect temporal changes in the parameters measured. The sampling interval for different parameters was designed to be consistent with the time scales over which different parameters change. Sampling under this program has continued for a sufficient time to enable longer term trends to be elucidated.

7.6 National SOE
A review of indicators of the condition of inland waters for national SOE reporting acknowledges the importance of spatial variability, and recommends that ecologically based regionalisation be used to partition such variation (Fairweather and Napier 1998). Regions suggested are the AWRC drainage divisions and basins.

Temporal variability is not dealt with explicitly.

7.7 WAMP ecological assessment
Temporal variability of the different indices is considered a key factor in understanding ecosystem status and potential impacts. The difference in the response times of different ecosystem components (e.g. geomorphology, riparian vegetation) to flow is also recognised.

7.8 ARC
Spatial variability of stream condition is accommodated to an extent by using an approach based on remote sensed data that allows condition assessment at a fine spatial scale.

The ARC is a single snapshot and potentially temporal variability of data could reduce the accuracy of the assessment. Where possible, indicators were chosen that change slowly over time and with minimal seasonal variability.

7.9 NSW River Survey
A stratified random sampling approach was used to accommodate spatial variability in fish communities. Two ecoregions were identified within the MDB - the Darling Region and the Murray Region. Within each region four river types were identified. Comparisons were then made within river type and within ecoregion.
Temporal variation was addressed by sampling at standard times of the day relative to sunset and twice per year, in summer and winter. It was concluded that a single summer sampling was appropriate.

7.10  Wild Rivers
Spatial and temporal variability are not explicitly discussed in the Wild Rivers methods. Spatial variability, both natural and anthropogenic, would be accommodated to some extent by the remote sensing approach with its data coverage of the entire Australian continent at a fine spatial scale. A negative aspect of this approach may have been that key ecosystem data was not available at the national scale and so such factors would not have been used.

The Wild Rivers assessment is a single snapshot and temporal variability of data is not discussed. Nevertheless, the assessment would probably not be significantly compromised by temporal changes to data as most of the data upon which the assessment is based changes over time-scales of years.

7.11  QLD EPA Guidelines for Waterway Values
The Guidelines acknowledge the significance of natural spatial and temporal variability, and the importance of designing a sampling regime that will produce a reliable measure of ecological value in the face of such variability. They suggest a series of ways in which the problems of spatial and temporal variability can be addressed in indicator and sampling design. The Guidelines do not prescribe how a sampling program should be designed, intentionally leaving that to the group implementing the assessment.

7.12  NRHP
Spatial variability is not explicitly addressed. Sites were located on the basis of a range of factors including known problems, point sources and to represent different catchment land uses.

The NRHP program deliberately chose the aquatic macroinvertebrate fauna as a means of integrating the temporal variability of conditions in streams. This group was chosen because taxa have generation times long enough to span and react to episodic water quality changes, but no so long that the biotic response to changed conditions is too subtle to detect.

7.13  Stressed Rivers Assessment
A consideration of spatial and temporal variability is not directly applicable to this program which is focussed on stress, not condition.

7.14  Waterwatch
Spatial variability tends not to be addressed under this program with sites located in areas of interest or concern. Temporal variability is better accommodated, as community groups sometimes have the capacity to undertake very frequent sampling.

7.15  Other monitoring programs
Spatial variability is often not explicitly addressed. Temporal variability is a major consideration in collection of hydrological data and to a lesser extent water quality data. It is widely recognised that water quality programs based on sampling at regular intervals will
tend to underestimate annual loads as a large proportion of the load may be transmitted during short duration, intermittent flood events. Some programs attempt to address this issue though it does raise resourcing issues. For example the ISC water quality index is explicitly based on measurements of baseflow concentrations as it was determined that sampling of flood flows would be too difficult.

8 Sampling conducted in the MDB

Data that may be relevant to Audit and CSA has been collected in the MDB at a range of sites for different indicators over different periods and under an array of programs. This section details the broad sweep of such programs where they could be relevant to the Audit. There was no intention of providing a comprehensive review of all data collected in the MDB, an enormous task, particularly in the area of water quality monitoring programs. What is intended is that the data included in this review would be comprehensive for the completion of the project tasks that follow.

In this section data is ascribed to a program only if it is collected by the program. Where a program sources data from another program that data will only be reported against the latter program. For example, the ISC acquires habitat data but relies on other State programs for water quality and hydrology data.

8.1 ISC

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of reaches assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine-Balonne*</td>
<td>QLD</td>
<td>Channel physical form Streamside zone condition</td>
<td>16</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Kiewa</td>
<td>VIC</td>
<td>“</td>
<td>19</td>
<td>5 yearly</td>
</tr>
<tr>
<td>Ovens</td>
<td>VIC</td>
<td>“</td>
<td>47</td>
<td>“</td>
</tr>
<tr>
<td>Goulburn</td>
<td>VIC</td>
<td>“</td>
<td>75</td>
<td>“</td>
</tr>
<tr>
<td>Broken</td>
<td>VIC</td>
<td>“</td>
<td>35</td>
<td>“</td>
</tr>
<tr>
<td>Campaspe</td>
<td>VIC</td>
<td>“</td>
<td>24</td>
<td>“</td>
</tr>
<tr>
<td>Loddon</td>
<td>VIC</td>
<td>“</td>
<td>47</td>
<td>“</td>
</tr>
<tr>
<td>Avoca</td>
<td>VIC</td>
<td>“</td>
<td>20</td>
<td>“</td>
</tr>
<tr>
<td>Wimmera</td>
<td>VIC</td>
<td>“</td>
<td>72</td>
<td>“</td>
</tr>
<tr>
<td>Murray – Above Hume Dam</td>
<td>VIC section</td>
<td>“</td>
<td>44</td>
<td>“</td>
</tr>
</tbody>
</table>

* modified form of ISC (water quality parameters vary slightly)
8.2 IMEF

Table 4 River valleys for which there is IMEF data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of sites assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Border Rivers/ Moonie</td>
<td>NSW</td>
<td>Fish</td>
<td>2</td>
<td>2 occasions</td>
</tr>
<tr>
<td></td>
<td>section</td>
<td>Wetland flora and fauna</td>
<td>16</td>
<td>2 occasions Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Event driven</td>
</tr>
<tr>
<td>Gwydir</td>
<td>NSW</td>
<td>Fish</td>
<td>7</td>
<td>2 occasions Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland flora and fauna</td>
<td>5</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic carbon processing</td>
<td>3</td>
<td>Weekly to monthly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phytoplankton</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Namoi</td>
<td>NSW</td>
<td>Fish</td>
<td>8</td>
<td>2 occasions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland flora and fauna</td>
<td>12</td>
<td>Event driven</td>
</tr>
<tr>
<td>Macquarie</td>
<td>NSW</td>
<td>Fish</td>
<td>10</td>
<td>2 occasions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland flora and fauna</td>
<td>12</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phytoplankton</td>
<td>4</td>
<td>Weekly to monthly</td>
</tr>
<tr>
<td>Lachlan</td>
<td>NSW</td>
<td>Fish</td>
<td>9</td>
<td>2 occasions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland flora and fauna</td>
<td>18</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macroinvertebrates/ biofilm</td>
<td>8</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phytoplankton</td>
<td>4</td>
<td>Fortnightly</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>NSW</td>
<td>Fish</td>
<td>9</td>
<td>2 occasions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wetland flora and fauna</td>
<td>18</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macroinvertebrates/ biofilm</td>
<td>8</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phytoplankton</td>
<td>4</td>
<td>Fortnightly</td>
</tr>
<tr>
<td>The Barwon/Upper</td>
<td>NSW</td>
<td>Fish</td>
<td>9</td>
<td>2 occasions</td>
</tr>
<tr>
<td>Darling</td>
<td></td>
<td>Phytoplankton</td>
<td>13</td>
<td>Weekly to monthly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-flow habitat</td>
<td>4+</td>
<td></td>
</tr>
</tbody>
</table>

NA = Not available

8.3 PBH

Murrumbidgee - approximately 70 sites sampled
Lachlan - 20 sites sampled. This program is currently under review as to whether and in what form it will/can be applied more widely to unregulated rivers in NSW.

8.4 State of Rivers

Table 5 River valleys for which there is State of the Rivers data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Type of assessment and components measured</th>
<th>Number of sites assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine/Balonne/ Culgoa</td>
<td>QLD</td>
<td>Channel habitat diversity Riparian and aquatic vegetation Bank, bed and bar stability Aquatic habitats</td>
<td>750</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Border Rivers / Moonie</td>
<td>QLD</td>
<td>As above</td>
<td>367</td>
<td>“</td>
</tr>
<tr>
<td>Macquarie</td>
<td>NSW</td>
<td>As above</td>
<td>NA</td>
<td>“</td>
</tr>
<tr>
<td>Lachlan</td>
<td>NSW</td>
<td>As above</td>
<td>550</td>
<td>“</td>
</tr>
</tbody>
</table>

NA = Not available
8.5 MDBC WQ Monitoring program
Total number of sites: 35
Number of sites on the Murray: 19
With the exception of the macroinvertebrate sampling, data for this program was collected by NSW, Victorian and SA State agencies on behalf of the MDBC, and will be listed with other State agency water quality monitoring. The macroinvertebrate sampling was conducted twice yearly at two sites on the Murray; above Hume Reservoir and downstream of Lock 5 in SA.

8.6 National SOE
No primary data collected under this program

8.7 WAMP ecological assessment

Table 6 River valleys for which there is WAMP data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of reaches assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine/Balonne/</td>
<td>QLD section</td>
<td>Streamside zone (as per ISC)</td>
<td>16</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Culgoa</td>
<td></td>
<td>Physical form (as per ISC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macroinvertebrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Border Rivers</td>
<td>QLD section</td>
<td>&quot;</td>
<td>NA</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Warrego</td>
<td>QLD section</td>
<td>&quot;</td>
<td>NA</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Paroo</td>
<td>QLD section</td>
<td>&quot;</td>
<td>NA</td>
<td>Snapshot</td>
</tr>
</tbody>
</table>

NA = Not available

8.8 ARC

Table 7 River valleys for which there is ARC data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of reaches assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>All river valleys</td>
<td>QLD, NSW, ACT, VIC, SA</td>
<td>Macroinvertebrate condition</td>
<td>Approx. 5000 in MDB</td>
<td>Snapshot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrological condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nutrient status</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical habitat status</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Catchment disturbance measure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 1 Review of Existing Programs
Final Report for Project R2004
Appendix 1 Review of Existing Programs
Final Report for Project R2004

8.9 NSW Rivers Survey
The Survey assessed fish communities at a number of sites across the Basin (Table 8). Sites were surveyed four times over two years. There is no commitment for on-going sampling.

Table 8 River valleys for which there is NSW Rivers Survey data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of sites assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gwydir*</td>
<td>NSW</td>
<td>Fish abundance and community structure</td>
<td>3</td>
<td>4 occasions over 2 years</td>
</tr>
<tr>
<td>Namoi*</td>
<td>NSW</td>
<td></td>
<td>3</td>
<td>&quot;</td>
</tr>
<tr>
<td>Macquarie*</td>
<td>NSW</td>
<td></td>
<td>10</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lachlan*</td>
<td>NSW</td>
<td></td>
<td>5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murrumbidgee*</td>
<td>NSW</td>
<td></td>
<td>8</td>
<td>&quot;</td>
</tr>
<tr>
<td>The Barwon/Upper Darling*</td>
<td>NSW</td>
<td></td>
<td>1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Hume Dam to Tocumwal</td>
<td>NSW</td>
<td></td>
<td>1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Tocumwal to Murrumbidgee catchment</td>
<td>NSW</td>
<td>&quot;</td>
<td>1</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

* Currently part of IMEF.

8.10 Wild Rivers

Table 9 River valleys for which there is Wild Rivers data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of reaches assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>All river valleys</td>
<td>QLD, NSW, ACT, VIC, SA</td>
<td>Catchment disturbance index</td>
<td>NA</td>
<td>Snapshot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flow regime disturbance index</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>River disturbance index</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.11 QLD EPA Guidelines for Waterway Values
Not yet applied to any catchments in the Murray-Darling Basin.
8.12 NRHP

Table 10 River valleys for which there is NRHP data relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of sites assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine/Balonne</td>
<td>NSW / QLD</td>
<td>AUSRIVAS score SIGNAL score Riparian condition (some States) Geomorphological condition (some States)</td>
<td>20 + 56¹</td>
<td>Snapshot involving 2 or more samples</td>
</tr>
<tr>
<td>Border Rivers/ Moonie</td>
<td>NSW / QLD</td>
<td>&quot;</td>
<td>40 + 18</td>
<td>&quot;</td>
</tr>
<tr>
<td>Warrego River</td>
<td>NSW / QLD</td>
<td>&quot;</td>
<td>6 + 8</td>
<td>&quot;</td>
</tr>
<tr>
<td>Paroo</td>
<td>NSW / QLD</td>
<td>&quot;</td>
<td>6 + 4</td>
<td>&quot;</td>
</tr>
<tr>
<td>Gwydyr</td>
<td>NSW</td>
<td>&quot;</td>
<td>27</td>
<td>&quot;</td>
</tr>
<tr>
<td>Namoi</td>
<td>NSW</td>
<td>&quot;</td>
<td>26</td>
<td>&quot;</td>
</tr>
<tr>
<td>Macquarie</td>
<td>NSW</td>
<td>&quot;</td>
<td>59</td>
<td>&quot;</td>
</tr>
<tr>
<td>Castlereagh</td>
<td>NSW</td>
<td>&quot;</td>
<td>9</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lachlan</td>
<td>NSW</td>
<td>&quot;</td>
<td>59</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>NSW / ACT</td>
<td>&quot;</td>
<td>75 + 287</td>
<td>&quot;</td>
</tr>
<tr>
<td>The Barwon/Upper Darling</td>
<td>NSW</td>
<td>&quot;</td>
<td>19</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lower Darling: Menindee to Wentworth</td>
<td>NSW</td>
<td>&quot;</td>
<td>5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Kiewa</td>
<td>VIC</td>
<td>&quot;</td>
<td>21</td>
<td>&quot;</td>
</tr>
<tr>
<td>Ovens</td>
<td>VIC</td>
<td>&quot;</td>
<td>58</td>
<td>&quot;</td>
</tr>
<tr>
<td>Goulburn</td>
<td>VIC</td>
<td>&quot;</td>
<td>74</td>
<td>&quot;</td>
</tr>
<tr>
<td>Broken</td>
<td>VIC</td>
<td>&quot;</td>
<td>23</td>
<td>&quot;</td>
</tr>
<tr>
<td>Campaspe</td>
<td>VIC</td>
<td>&quot;</td>
<td>18</td>
<td>&quot;</td>
</tr>
<tr>
<td>Loddon</td>
<td>VIC</td>
<td>&quot;</td>
<td>26</td>
<td>&quot;</td>
</tr>
<tr>
<td>Avoca</td>
<td>VIC</td>
<td>&quot;</td>
<td>20</td>
<td>&quot;</td>
</tr>
<tr>
<td>Wimmera</td>
<td>VIC</td>
<td>&quot;</td>
<td>44</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Above Hume Dam</td>
<td>NSW / VIC</td>
<td>&quot;</td>
<td>33 + 6</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Hume Dam to Tocumwal</td>
<td>NSW</td>
<td>&quot;</td>
<td>4</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Tocumwal to Murrumbidgee catchment</td>
<td>NSW</td>
<td>&quot;</td>
<td>27</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Murrumbidgee catchment to Wentworth</td>
<td>NSW</td>
<td>&quot;</td>
<td>3</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray – Wentworth to Wellington</td>
<td>NSW / SA</td>
<td>&quot;</td>
<td>1 + NYA</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Note 1: Represents 20 NSW and 56 QLD sites.
NYA = Not yet available
### 8.13 Stressed Rivers Assessment

Table 11: River valleys for which there is Stressed Rivers data relevant to the Audit or CSA (note: unregulated river sections only)

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Data collected</th>
<th>No. of sites assessed</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine/Balonne</td>
<td>NSW section</td>
<td>Proportion of water extracted Band, bed, bar stability Riparian and aquatic vegetation Structures in the channel</td>
<td>2</td>
<td>Snapshot</td>
</tr>
<tr>
<td>Border Rivers/ Moonie</td>
<td>NSW</td>
<td>&quot;</td>
<td>22</td>
<td>&quot;</td>
</tr>
<tr>
<td>Warrego River</td>
<td>NSW / QLD</td>
<td>&quot;</td>
<td>1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Paroo</td>
<td>NSW / QLD</td>
<td>&quot;</td>
<td>1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Gwydir</td>
<td>NSW</td>
<td>&quot;</td>
<td>32</td>
<td>&quot;</td>
</tr>
<tr>
<td>Namoi</td>
<td>NSW</td>
<td>&quot;</td>
<td>40</td>
<td>&quot;</td>
</tr>
<tr>
<td>Macquarie / Castlereagh</td>
<td>NSW</td>
<td>&quot;</td>
<td>37</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lachlan</td>
<td>NSW</td>
<td>&quot;</td>
<td>24</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>NSW / ACT</td>
<td>&quot;</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>Murray</td>
<td>NSW</td>
<td>&quot;</td>
<td>19</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

### 8.14 Waterwatch

A breakdown on the Waterwatch data across the Basin is not available at this stage.

### 8.15 Other monitoring programs

Table 12: River valleys for which there is data from other monitoring programs relevant to the Audit or CSA

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Components measured / agency</th>
<th>Number of sites</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine/Balonne/ Culgoa</td>
<td>NSW / QLD</td>
<td>Hydrology – DNR, DLWC Water quality – DNR, DLWC Fish – DPI, NSW Fisheries</td>
<td>14 + 86</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 + 13</td>
<td>See Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>QLD - NA NSW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Border Rivers/ Moonie</td>
<td>NSW / QLD</td>
<td>Hydrology – DNR, DLWC Water quality – DNR, DLWC Fish – DPI, NSW Fisheries</td>
<td>64 + 50</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 + 3</td>
<td>See Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>QLD: 0</td>
<td></td>
</tr>
<tr>
<td>Warrego River</td>
<td>NSW / QLD</td>
<td>Hydrology – DNR, DLWC Water quality – DNR, DLWC Fish – DPI, NSW Fisheries</td>
<td>2 + 5</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 + 0</td>
<td>See Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>QLD: 0</td>
<td></td>
</tr>
<tr>
<td>Paroo</td>
<td>NSW / QLD</td>
<td>Hydrology – DNR, DLWC Water quality – DNR, DLWC Fish – DPI, NSW Fisheries</td>
<td>3 + 2</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 + 0</td>
<td>See Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>QLD: 0</td>
<td></td>
</tr>
<tr>
<td>Gwydir</td>
<td>NSW</td>
<td>Hydrology – DLWC Water quality – DLWC Fish – NSW Fisheries</td>
<td>80</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>See Note 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Namoi</td>
<td>NSW</td>
<td>Hydrology – DLWC Water quality – DLWC Fish – NSW Fisheries</td>
<td>92</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>See Note 2</td>
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<td></td>
<td></td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Macquarie</td>
<td>NSW</td>
<td>Hydrology – DLWC Water quality – DLWC Fish – NSW Fisheries</td>
<td>169</td>
<td>See Note 1</td>
</tr>
<tr>
<td></td>
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<td>6</td>
<td>See Note 2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Catchment</td>
<td>State/Region</td>
<td>Hydrology</td>
<td>Water quality</td>
<td>Fish</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>--------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Castlereagh</td>
<td>NSW</td>
<td>Hydrology – DLWC</td>
<td>Water quality – DLWC</td>
<td>Fish – NSW Fisheries</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Lachlan</td>
<td>NSW</td>
<td>Hydrology – DLWC</td>
<td>Water quality – DLWC</td>
<td>Fish – NSW Fisheries</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murrumbidgee</td>
<td>NSW/ACT</td>
<td>Hydrology – DLWC, ACTEW</td>
<td>Water quality – DLWC, EA</td>
<td>Fish – NSW Fisheries, EA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Barwon/Upper Darling (Menindee to Border R. junction)</td>
<td>NSW</td>
<td>Hydrology – DLWC</td>
<td>Water quality – DLWC</td>
<td>Fish – NSW Fisheries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Darling: Menindee Lakes to the Wentworth Weir Pool</td>
<td>NSW</td>
<td>Hydrology – DLWC</td>
<td>Water quality – DLWC</td>
<td>Fish – NSW Fisheries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kiewa</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovens</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Goulburn</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campaspe</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loddon</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avoca</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wimmera</td>
<td>VIC</td>
<td>Hydrology – NRE</td>
<td>Water quality – NRE</td>
<td>Fish – NRE</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray – Above Hume Dam</td>
<td>NSW/VIC</td>
<td>Hydrology – DLWC, NRE</td>
<td>Water quality – DLWC, NRE</td>
<td>Fish – NSW Fisheries, NRE</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray – Hume Dam to Tocumwal (main stem + NSW catchment)</td>
<td>NSW</td>
<td>Hydrology – DLWC</td>
<td>Water quality – DLWC</td>
<td>Fish – NSW Fisheries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray – Tocumwal to Murrumbidgee catchment (main stem + NSW catchment)</td>
<td>NSW</td>
<td>Hydrology</td>
<td>Water quality</td>
<td>Fish</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray – Murrumbidgee catchment to Wentworth (main stem only)</td>
<td>NSW</td>
<td>Hydrology</td>
<td>Water quality</td>
<td>Fish</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray – Wentworth to Wellington</td>
<td>NSW/SA</td>
<td>Hydrology – DWR</td>
<td>Water quality – SA Water</td>
<td>Fish - PIRSA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not yet available, DNR = Department of Natural Resources, CBWC = Condamine Balonne Water Committee, DPI = Department of Primary Industries, DLWC = Department of Land and Water Conservation, ACTEW = ACT Electricity and Water, EA = Environment ACT, NRE = Department of
Natural Resources and Environment, DWR = Department of Water Resources, PIRSA = Department of Primary Industries and Resources SA, EPA = Environment Protection Agency
Note 1: Most sites sampled continuously, some discontinuous regular or irregular. Hydrology sites include all gauging stations within the river valley, not just those on the main stem of the river.
Note 2: Sampled at least monthly (DLWC program under review).
Note 3: NSW fish survey information described in sections on NSW River Survey and IMEF.
Note 4: Fish data for individual Victorian and South Australian river valleys not available at this stage.

9 Reference Condition

The principles outlined in the scoping document for the Audit and CSA identified the importance of indicators clearly establishing the condition of rivers. Stream condition is most commonly established by comparing the condition in a stream with a set of generic reference conditions, e.g. ANZECC water quality guidelines, or by comparison with conditions at a reference site. Where ecological integrity is the criterion for river health, reference conditions are usually defined as the presumed natural state of a site, determined by comparison with similar undisturbed sites. Typically, it is impossible to find completely undisturbed sites with which to compare test sites, in which case minimally disturbed or best available sites are often used to define reference conditions (Wright et al. 1983, Simpson et al. 1996, Reynoldson et al. 1997). Finding pristine reference sites in the lower parts of the Basin is particularly difficult.

Here this review looks at the approaches adopted by different programs to determining condition with particular reference to the choice of reference condition.

9.1 ISC
The ISC is designed to provide a measure of condition compared with natural or ideal condition. It consists of a number of key indicators amalgamated to produce five sub-indices, and these in turn are amalgamated through an inverse ranking or weighting to produce an overall score, the ISC.

9.2 IMEF
The IMEF program has established hypotheses concerning ecological processes in rivers and is in the process of collecting data to test these hypotheses. It does not attempt to measure condition, but unregulated sites are used as a reference for some studies.

9.3 PBH
At the present stage of development, PBH is a comparative assessment (against the average of the assessed sub-catchments). It is intended that reference levels (thresholds of significance and thresholds of concern) will be incorporated at a later stage.

9.4 State of Rivers
Conditions are assessed relative to natural or near natural, though there is not a formalised process to identify natural conditions. Overall condition of a reach is assessed by first standardising the seven components used so that they each contribute equally. Sites are then forced into one of 7 groups using cluster analysis and conditions assigned to each of the clusters (very good to highly degraded). Later documentation suggests that this approach may have been modified to one in which overall rating is a simple average of the component ratings.
Weighting is applied when combining the sub-components of bank condition and riparian vegetation, but is not applied when spatially aggregating data to create an index for a sub-catchment.

### 9.5 MDBC WQ Monitoring program

There is no formalised reporting procedure for the data acquired under this program. Data is made available on request and is used for a variety of research and community purposes. Where the MDBC uses this data to provide a measure of condition, data is generally assessed by comparison with ANZECC water quality guidelines or in house benchmarks.

### 9.6 National SOE

Data in the initial National SOE (1996) were provided as a mixture of raw data and as a measure of condition; generally assessed by comparison with ANZECC water quality guidelines. The 2001 SOE includes more habitat and biotic elements which do not have an ANZECC guideline value. It is anticipated that some indicators used, e.g. AUSRIVAS scores, will use a reference site approach.

### 9.7 WAMP ecological assessment

Conditions are assessed relative to natural or near natural conditions.

### 9.8 ARC

Conditions are assessed relative to natural or near natural conditions. For most of the indices in the ARC, e.g. hydrology, pristine conditions are used as the reference condition. Other indices, notably the biota index, accept modified natural conditions as a reference point due to the difficulty of identifying pristine conditions in some of our heavily modified landscapes.

### 9.9 NSW River Survey

The NSW River Survey incorporates four independent sources of data, as well as other non-independent sources. Twelve metrics are calculated from the fish catch data with the scores for each metric summed to give an overall score at each site. Condition (poor – best) is assessed from individual scores by reference to the best examples from the data set. Therefore, reference condition represents the best condition for that metric for the rivers sampled. This means that the IBI score is not an absolute measure of river condition. Rather it is a score relative to other rivers in the sample data set.

### 9.10 Wild Rivers

The Wild Rivers Index produces a measure of a river’s “wildness” with pre-1750 conditions as the benchmark. A series of metrics are calculated:

- Sub-catchment disturbance index (calculated for just the catchment local to the reach)
- Sub-catchment flow regime disturbance index
- Catchment disturbance index (calculated for the entire catchment of a reach)
- Flow regime disturbance index
- River disturbance index (overall measure of river condition)

A complex series of weightings is applied during the calculation of these indices.
9.11 QLD EPA Guidelines for Waterway Values
An assessment using these Guidelines is designed to produce a measure of river condition relative to a range of benchmarks. Complete details are not provided on the benchmarks used to allow catchment authorities the opportunity to establish locally relevant approaches. As a guide, reference conditions are used for some of the criteria, e.g. naturalness and representativeness, and absolute benchmarks may be used for others, e.g. rarity.

9.12 NRHP
This program uses a reference condition approach to produce an assessment of river health. Condition of a test site is assessed by comparing the biota that are found at the site with those expected at the site with no or minimal disturbance. To assess a test site there needs to be a group of reference sites with similar basic characteristics but without the catchment or in-stream disturbance that the test site is subject to. Consequently, pristine reference sites are difficult to find in lowland rivers and the minimally modified reference sites are used.

9.13 Stressed Rivers Assessment
The Stressed Rivers reports do not include an explicit discussion of the reference conditions used to assess environmental stress. Advice from DLWC is that thresholds for individual indicators falling into Low, Medium or High classification were set by consensus of expert opinion, and that natural conditions (low level or no stressors) were used as a benchmark.

9.14 Waterwatch
The Waterwatch program focusses on measurement of water quality variables and the macroinvertebrate community. Water quality condition is measured with the ANZECC water quality guidelines as reference points, and the macroinvertebrate community is compared to the AUSRIVAS reference of natural or near natural sites.

10 Programs monitoring specific Audit components
This section draws together the information from different programs to provide an integrated picture of the potential sources of data for the nominated Audit and CSA components. Indicators of habitat condition nominated for inclusion in the Audit were macroinvertebrates, fish, hydrology and water quality. Indicators nominated for inclusion in the CSA were connectivity, riparian condition, woody debris in streams, geomorphic condition and wetlands.
### Table 13  Macroinvertebrate monitoring

<table>
<thead>
<tr>
<th>Approach</th>
<th>Monitoring procedure</th>
<th>Where applied in Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>SIGNAL rating</td>
<td>Entire Victorian section of Basin</td>
</tr>
<tr>
<td></td>
<td>AUSRIVAS score</td>
<td></td>
</tr>
<tr>
<td>IMEF</td>
<td>Wetland replenishment study: sweep-net sampling; species level identification</td>
<td>Gwydir, Macquarie, Lachlan, Murrumbidgee</td>
</tr>
<tr>
<td></td>
<td>Conditioning stony beds: sampling of individual stones; genus level identification</td>
<td>Barwon-Darling</td>
</tr>
<tr>
<td></td>
<td>Wetting of Terr. Org. matter: sampling of inundated leaf litter; species level</td>
<td>Namoi</td>
</tr>
<tr>
<td></td>
<td>identification</td>
<td></td>
</tr>
<tr>
<td>PBH</td>
<td>Sweep and kick net sampling of riffle or similar, edge-alcove and dominant habitat;</td>
<td>Murrumbidgee, Lachlan; Castlereagh</td>
</tr>
<tr>
<td></td>
<td>family richness and SIGNAL</td>
<td></td>
</tr>
<tr>
<td>State of Rivers</td>
<td>Not measured</td>
<td></td>
</tr>
<tr>
<td>MDBC WQ Monitoring program</td>
<td>Artificial substrate</td>
<td>Murray: Above Hume reservoir and below Wellington</td>
</tr>
<tr>
<td>National SOE</td>
<td>AUSRIVAS score</td>
<td>Sourced from NRHP and State programs</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>Taxonomic richness, PET taxa, SIGNAL index, AUSRIVAS score</td>
<td>QLD section of Condamine/ Balonne/ Culgoa, Border Rivers, Warrego and Paroo</td>
</tr>
<tr>
<td></td>
<td>Functional feeding groups, Flow velocity and substrate preference groups</td>
<td></td>
</tr>
<tr>
<td>ARC</td>
<td>AUSRIVAS score</td>
<td>Entire Basin</td>
</tr>
<tr>
<td>NSW River Survey</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>Wild Rivers</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>QLD EPA Guidelines for Waterway Values</td>
<td>Not specified</td>
<td>Not applied yet</td>
</tr>
<tr>
<td>NRHP</td>
<td>SIGNAL score</td>
<td>Entire Basin</td>
</tr>
<tr>
<td></td>
<td>AUSRIVAS score</td>
<td></td>
</tr>
<tr>
<td>Waterwatch</td>
<td>SIGNAL score</td>
<td>Sites throughout Basin</td>
</tr>
<tr>
<td></td>
<td>AUSRIVAS score</td>
<td></td>
</tr>
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</table>

### Table 14  Fish monitoring

<table>
<thead>
<tr>
<th>Approach</th>
<th>Monitoring procedure</th>
<th>Where applied in Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>IMEF (now includes NSW Fish Survey)</td>
<td>Electrofishing</td>
<td>Border Rivers, Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee, Barwon/Darling</td>
</tr>
<tr>
<td>PBH</td>
<td>Electrofishing</td>
<td>Murrumbidgee; Lachlan; Castlereagh</td>
</tr>
<tr>
<td>State of Rivers</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>MDBC WQ Monitoring program</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>National SOE</td>
<td>Uses data from State programs</td>
<td>See State programs</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>Uses data from other State programs</td>
<td>Condamine-Balonne, Border Rivers, Warrego, Paroo</td>
</tr>
<tr>
<td>ARC</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>NSW River Survey (original survey)</td>
<td>Range of techniques used</td>
<td>Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee, Barwon/Darling, Murray</td>
</tr>
</tbody>
</table>
Wild Rivers | Not measured | -
QLD EPA Guidelines for Waterway Values | Not specified | Not yet applied in Basin
NRHP | Not measured | -
Waterwatch | netting | Toowoomba area of Condamine-Balonne

<table>
<thead>
<tr>
<th>Table 15 Hydrological measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Approach</strong></td>
</tr>
</tbody>
</table>
| ISC | • Amended annual proportional flow deviation  
• Percentage of catchment urbanised  
• Presence of hydroelectric dams |
| IMEF | Various, depending on study |
| PBH | As for Stressed River program; also hydraulic diversity, depth, width, discharge |
| State of Rivers | • modification of natural flow regime  
• high flow events  
• low flow events  
• changes to seasonal pattern |
| MDBC WQ Monitoring program | Not measured |
| National SOE | The ratio of water use compared to catchment yield. |
| WAMP ecological assessment | • Daily Flow  
• Annual Flow  
• Mean Annual Flow  
• Median Annual Flow  
• CV of Mean Annual Flow  
• APFD  
• ARI Flow Event Analysis  
• Maximum dry spell  
• High Flow Duration  
• Medium Flow Duration  
• Low Flow Duration  
• No Flow Duration |
| ARC | • Mean Annual Flow  
• Deviation from mean annual flow  
• ARI Flow Event Analysis  
• Change in seasonal amplitude  
• Change in seasonal periodicity |
| NSW River Survey | Subjective grading of flow |
| Wild Rivers | • Presence of impoundments  
• Occurrence of flow diversions  
• Presence of levees |
| QLD EPA Guidelines for Waterway Values | Not specified |
| NRHP | Varies between States and ACT, and over time |
| Waterwatch | Not measured |

CV = Coefficient of Variation, APFD = Annual Proportional Flow Deviation, ARI = Annual Recurrence Interval
Table 16  Water quality

<table>
<thead>
<tr>
<th>Approach</th>
<th>Nominated Audit water quality variables measured (TP, EC, NTU and pH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>Sourced from other State programs</td>
</tr>
<tr>
<td>IMEF</td>
<td>Measured in some studies</td>
</tr>
<tr>
<td>PBH</td>
<td>Temperature, EC, turbidity, DO, pH, filterable NOx, NHx &amp; P</td>
</tr>
<tr>
<td>State of Rivers</td>
<td>No</td>
</tr>
<tr>
<td>MDBC WQ Monitoring program</td>
<td>Yes</td>
</tr>
<tr>
<td>National SOE</td>
<td>Not specified</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>Yes</td>
</tr>
<tr>
<td>ARC</td>
<td>TP only</td>
</tr>
<tr>
<td>NSW River Survey</td>
<td>EC, NTU, pH</td>
</tr>
<tr>
<td>Wild Rivers</td>
<td>No</td>
</tr>
<tr>
<td>QLD EPA Guidelines for Waterway Values</td>
<td>Not specified</td>
</tr>
<tr>
<td>NRHP</td>
<td>Yes</td>
</tr>
<tr>
<td>Waterwatch</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 17  CSA components currently assessed in the Murray-Darling Basin

<table>
<thead>
<tr>
<th>River valley</th>
<th>State</th>
<th>Type of assessment and components measured</th>
<th>Number of sites</th>
<th>Sampling interval</th>
</tr>
</thead>
</table>
| Condamine/ Balonne/ Culgoa| QLD section | SOR: See Note 1  
ARC: See Note 2  
NRHP: See Note 3  
Wild Rivers: See Note 4 | 750  
51 | Snapshot |
|                           | NSW section | Wild Rivers:  
ARC: | All reaches | Snapshot |
|                           |             | NRHP: | All reaches | Snapshot |
|                           |             | ARC: | All reaches | Snapshot |
|                           |             | Wild Rivers: | All reaches | Snapshot |
| Border Rivers / Moonie    | QLD section | SOR:  
ARC:  
Wild Rivers: | 367  
18 | Snapshot |
|                           | NSW section | NRHP:  
ARC: | All reaches | Snapshot |
|                           |             | Wild Rivers: | All reaches | Snapshot |
|                           |             | NRHP: | All reaches | Snapshot |
|                           |             | ARC: | All reaches | Snapshot |
| Warrego River             | QLD section | NRHP:  
ARC:  
Wild Rivers: | 8  
6 | Snapshot |
|                           | NSW section | Wild Rivers: | All reaches | Snapshot |
|                           |             | NRHP: | All reaches | Snapshot |
|                           |             | ARC: | All reaches | Snapshot |
| Paroo                     | QLD section | NRHP:  
ARC:  
Wild Rivers: | 4  
6 | Snapshot |
|                           | NSW section | Wild Rivers: | All reaches | Snapshot |
|                           |             | NRHP: | All reaches | Snapshot |
|                           |             | ARC: | All reaches | Snapshot |
| Gwydir                    | NSW | IMEF: Wetland condition  
ARC: | 5  
27 | 1-3 months |
|                           |             | Wild Rivers: | All reaches | Snapshot |
| Namoi                     | NSW | IMEF: Wetland condition, phytoplankton  
ARC: | 5, 8  
26 | 1-3 months, 0.25-1 month |
<p>|                           |             | Wild Rivers: | All reaches | Snapshot |</p>
<table>
<thead>
<tr>
<th>Location</th>
<th>State</th>
<th>Methodology</th>
<th>Surveys</th>
<th>Monitoring Frequency</th>
<th>Reporting Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macquarie</td>
<td>NSW</td>
<td>IMEF: Wetland condition, SOR:</td>
<td>12</td>
<td>Not available</td>
<td>1-3 months</td>
</tr>
<tr>
<td></td>
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<td>NRHP:</td>
<td></td>
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<td>ARC:</td>
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<tr>
<td>Castlereag</td>
<td>NSW</td>
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<td>9</td>
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<td>All reaches</td>
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<td>Wild Rivers:</td>
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<td>All reaches</td>
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<td>Lachlan</td>
<td>NSW</td>
<td>IMEF: Wetland condition, phytoplankton, SOR:</td>
<td>12, 4</td>
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<td>NRHP:</td>
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<td>1-3 months, 0.25-1 month</td>
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<tr>
<td>Murrumbidgee</td>
<td>NSW</td>
<td>IMEF: Wetland condition, phytoplankton, National Register of Heritage Places (NRHP):</td>
<td>18, 4</td>
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<tr>
<td>ACT section</td>
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<td>ARC:</td>
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<td>1-3 months, 2 weeks</td>
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</tr>
<tr>
<td>The Barwon/Upper Darling (Menindee to Border R. junction)</td>
<td>NSW</td>
<td>IMEF: Phytoplankton, low-flow habitat, NRHP:</td>
<td>13, 4+</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>ARC:</td>
<td></td>
<td>19</td>
<td>Snapshot</td>
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<tr>
<td>Lower Darling: Menindee Lakes to the Wentworth Weir Pool</td>
<td>NSW</td>
<td>NRHP:</td>
<td>5</td>
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<tr>
<td></td>
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<td>ARC:</td>
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<td>Wild Rivers:</td>
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<td>ARC:</td>
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<td>Wild Rivers:</td>
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<td>5 yearly</td>
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<td>Wild Rivers:</td>
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<td>Loddon</td>
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</tr>
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<td>26</td>
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</tr>
<tr>
<td>Avoca</td>
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<td>5 yearly</td>
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</tbody>
</table>
## 11 Summary of approaches

This section provides a brief overview of each of the river health programs reviewed. It covers such aspects as the purpose for which the program was designed, what sort of data has been collected and where sampling has occurred in the Murray-Darling Basin. Where appropriate it also touches on the spatial reporting scale, how reporting units (reaches) have been defined and the reference condition used.

### 11.1 ISC

The ISC was developed as a measure of river health that could be used by managers and the community to benchmark river condition, assess the effectiveness of rehabilitation and to set priorities for management action. It takes an ecological focus on river health and went through an extensive development phase to identify appropriate indicators. The ISC is reported at a reach scale, with reaches defined as sections of river typically 10-30 km long and relatively homogeneous in terms of their hydrology, physical form, streamside vegetation, and water quality or aquatic life.
Within each reach three measuring sites are randomly identified, with three transects assessed at each site. The ISC indicators have many elements in common with the components identified for inclusion in the Audit and CSA: hydrological, physical form, streamside zone, water quality and aquatic life measures. All river valleys within the Victorian part of the Basin have had reaches defined and all components of the ISC assessed. It should be noted that for some reaches data on aquatic life and water quality were not available and have been assessed on a pro rata basis from other sub-indices in the reach.

11.2 IMEF
The IMEF is a part of a State approach to assess ecological responses to improved flows. It relies on a hypothesis driven approach, with ecological responses to environmental flows being assessed in spatially and temporally replicated studies and through the construction and testing of predictive models. Nine priority hypotheses have been generated for different biota and processes, and are being tested in one or more valleys. The intended outcomes of the project are an understanding of the existing state and trends over time in hydrology, morphology and ecology in the major river systems, and evaluation of the likely contributions of environmental flows to these changes.

Site selection procedures differed between the studies that make up the IMEF program. As the program relies on data from other sampling programs in some instances, sites from those primary sampling programs were used. In other studies sites were randomly located to provide a spatially unbiased estimate of the indicators used, or placed at sites of specific concern. As a result of the different natures of the studies that IMEF program comprises, no overarching river classification schema was applied.

The different studies in the program have specific data requirements, and are applied to specific catchments. Consequently, the data collected under the IMEF program varies considerably between catchments. This is to be expected in a program the primary intention of which is system understanding not monitoring. Some of the data used in the studies are derived from other NSW monitoring programs, e.g. water quality and hydrological data. Data collected in the studies of particular relevance to the Audit will be data on biota (phytoplankton, fish, macroinvertebrates and birds, etc.) and on habitat (wetland condition, river biofilms). In addition to the data that is already available from the IMEF program, the system understanding from this approach will be valuable for future refinement of Audit and CSA indicators.

11.3 PBH
The PBH approach is a general framework for integrated conservation and stress assessment, which is being tested via a desktop review and via a multi-faceted, rapid procedure for small and medium size streams. The PBH approach uses three kinds of variables; human generated pressure on rivers, components of the biota, and aspects of bio-physical habitat. These variables are used to generate indicators of richness, rarity, native abundance, alien biota, sensitivity, physical structure, water extraction and water quality. These indicators are wrapped up into indices of conservation significance, biological stress (or condition) and stressors. It is explicitly designed to provide information for management prioritisation, for strategic river management by describing the properties of river systems and identifying key issues, and for general performance monitoring/environmental auditing. The PBH approach has been trialled by DLWC and the trial results will be reviewed in early 2001.
In the initial trials of the PBH approach, sampling sites were selected randomly within River Styles™. The PBH approach has been applied to two sub-catchments in the Murray-Darling Basin, with application to another 3 sub-catchments in the basin partly completed. Data from the first two trials in the basin are currently being compiled with other data into a draft report.

11.4 State of Rivers
The State of the Rivers assessment procedure was originally developed in Queensland as a way of assessing the physical and environmental health of rivers and streams. It has subsequently been adapted and used in NSW.

Reporting units, called sub-sections, are identified in a two stage process. Firstly homogeneous “sections” are identified based on a series of map based characteristics. Secondly sub-sections are identified by the division of sections at each tributary junction or other discontinuity. Each sub-section is sampled at least once, leading to an extremely dense array of sites. The State of the Rivers approach focusses on habitat assessment; catchment condition, channel habitat diversity, bank, bed and bar condition, vegetation and aquatic habitat. It does not measure water quality, biota or flow as these components were assessed as too technically difficult or required specialised equipment. Data is collected largely by field survey.

A manual for the State of the Rivers approach was produced in 1993 as part of the methods development process. Since that time the approach has been applied to a number of catchments in Queensland and at least two in NSW. It appears that during this period the methods used have been refined, both by the original developer of the method, and by regional agencies implementing the approach. If this method or components from it were to be used in the Audit or CSA it would be important that a standardised method be applied to ensure data from different regions were compatible.

11.5 MDBC WQ Monitoring program
The MDBC established a monitoring program in 1978 to monitor the water quality of the River Murray and of tributaries close to their confluence with the Murray. There is no explicit identification of river regions or reaches under this program.

Three types of data are collected; physico-chemical (35 sites), phytoplankton (12 sites) and macroinvertebrate data (7 sites). Actual monitoring is conducted by NSW Department of Land and Water Conservation, SA Water, Australian Water Technologies Victoria and Murray-Darling Freshwater Research Centre.

11.6 National SOE
National SOE reporting is undertaken to provide information on the environment as a foundation for ecologically sustainable development. It allows regular reports on indicators of changes in environmental condition and provides a means of monitoring the performance of government policies against actual outcomes. National SOE reporting is conducted approximately every five years, with the first assessment conducted in 1996, and the second report is planned for completion in 2001.

Reports are largely compiled from data collected by other State and Federal agencies and consequently any regionalisation, reach definition or site location in the Murray-Darling
Basin reported on in the National SOE will arise from other programs. The Commonwealth has undertaken an extensive investigation of the most appropriate indicators for the SOE. For the section of the SOE dealing with river health the nominated indicators include exceedences of ANZECC water quality guidelines, algal blooms, riparian vegetation, wetland condition and macroinvertebrates. The SOE program does not collect data, it uses data collected by State and Territory programs. So this suite of indicators represents an ideal for which data may not have been collected.

11.7 WAMP ecological assessment

The WAMP process is intended to provide an ecological baseline, for a catchment, of the effects of flow abstractions or diversions as an input to catchment and water allocation planning. Within a catchment the WAMP process tends to focus on the main river, though not to the exclusion of other streams. The assessment is made primarily on the existing data and information, although some supplementary surveys may be made in the field. Thus the analytical procedures are not prescribed for the entire WAMP process and assessments may differ from catchment to catchment.

Major rivers and streams in the catchment being assessed are divided into relatively homogeneous river reaches on the basis of their natural characteristics, management regimes, and locations of gauging stations. This results in a considerable variation in reach length, from 10 km to more than 100 km.

As techniques are not prescribed in the WAMP process the components measured differ between catchments. However, it is possible to identify elements generally common to WAMP ecological assessments. They include a geomorphological assessment, riparian vegetation, macroinvertebrates, fish, water quality and hydrology. Most of these measures consist of a number of sub-measures. Much of the data used in the WAMP process is sourced from other programs and the WAMP process is used to draw together a comprehensive picture of river health in relation to flow.

11.8 ARC

The ARC project is intended to provide an overarching view of the quality of rivers across Australia as input to National and State policy development, and as management input. It takes the assessment of ecological integrity as its principal measure of river health. It is intended to be used as both a measure of river condition and as a tool to identify management options for rivers. The reporting scale for this project is the river reach, defined as sections of river with relatively homogeneous geomorphology. Reach boundaries have been determined objectively using a national digital elevation model and a protocol for determining reaches based on river and catchment geomorphology.

The ARC project is developing a set of five indices to report on river health in each reach. Biota (initially using macroinvertebrate data) will be the primary measure of river health. The ARC will also report on the status of four indices measuring driving processes: hydrology, water quality, physical habitat and catchment disturbance. For many ARC components the data used is remote sensed data with an Australia wide coverage. An assessment is conducted for the entire length of each reach, or the entire area of a catchment. The ARC project will provide only a snapshot of river health, like many programs, and would need to be repeated to reveal trends.
11.9 NSW River Survey
The NSW Rivers Survey had a series of objectives including assessing the distribution and abundance of native fish of NSW rivers, developing an understanding of the ecological effects of river regulation, and establishing standardised fish survey methods for use in other studies. The survey approach classified rivers into four main types: unregulated lowland, regulated lowland, slopes (300-700m altitude) and montane. River reaches were selected from within these river types and samples taken at a number of reaches based on a random selection process.

Fish were sampled at selected reaches using a range of techniques to ensure that all species were sampled. Habitat measures were also taken. A series of metrics based on the Index of Biological Integrity were calculated from the fish data to generate a series of condition indices. The NSW River Survey was a snapshot of fish community status and has not been repeated. Note this has now been incorporated into IMEF.

11.10 Wild Rivers
The Wild Rivers project arose from a commitment by the Commonwealth to assist State and Territory agencies to identify rivers in near pristine condition and to encourage protection and proper management of their catchments. The approach uses data on human disturbances within a catchment and to the river’s channel directly, to assess the potential of a river to be a “wild river”. Elements chosen for inclusion include both those important to ecosystem functioning, and others of a more visual landscape basis. Although the focus of the project was originally on near pristine rivers, the approach is applicable to rivers across the entire spectrum of degraded to pristine.

The Wild Rivers spatial framework is a set of reaches determined on the stream network at a relatively fine scale across the Murray-Darling Basin. Each reach is assessed. However, there are details in this approach which detract from its usefulness as a sampling template for the Audit and CSA, and as a source of data. The reach delineation method uses the morphology of the stream network. It is not a geomorphologically defined approach and consequently changes in ecological functioning that reflect the geomorphological template may not be well represented. Also, the AUSLIG streamline database has been used to define streams. Stream density on this database varies geographically depending on the scale of maps available, and in consequence the density of Wild Rivers reaches varies geographically.

The indicators used in Wild Rivers were largely intended to measure “wildness” and reflected scenic or landscape quality to a large extent. Additionally, as Wild Rivers was a desktop study assessing much of the continent, indicators chosen were constrained to existing data sets with national coverage. In summary, the Wild Rivers data will be of limited use in the Audit and CSA process.

11.11 QLD EPA Guidelines for Waterway Conservation/Ecological Values
The purpose of the Conservation/Ecological Value Guidelines is to provide a systematic, comprehensive and flexible method to describe the ecological values of waterways and floodplains. The Guideline is designed to support both conservation planning and development assessment. The framework is centred around five categories of information deemed necessary for assessing the ecological values of streams. The Guidelines intentionally do not specify in detail how these five components should be assessed, how reaches should be determined, or how the information should be compiled and presented.
The intention of the Guidelines appears to be to provide a flexible framework so that a group assessing a particular basin can tailor the approach to their individual information needs and expertise. A negative aspect of this flexibility is that it could result in assessments that differed markedly in methodology between catchments, potentially producing assessments that would not be comparable.

11.12 NRHP
The National River Health Program was developed in a joint State–Commonwealth partnership to support the environmental component of the COAG Water Reform Framework. It has progressed through a development and trialling phase to a snapshot of river health. The objectives of the program are to:

- Provide a sound information base on which to establish environmental flows
- Undertake a comprehensive assessment of the health of inland waters
- Consolidate and apply techniques for improving the health of inland waters.

As part of this program the first Australia wide assessment of the health of aquatic systems based on macroinvertebrates as indicators was conducted at approximately 6000 sites across Australia. Sites sampled during this program were often places of interest to a management authority or places with potential problems. They were not chosen to provide an unbiased estimate of the status of the macroinvertebrate community in a catchment.

In conjunction with the macroinvertebrate data sampled with this program, a wide range of water quality and habitat variables were also measured at most sites. At present there is no commitment from the Commonwealth to continue the monitoring component of the program, though many States and Territories have adopted this procedure as part of their monitoring program.

11.13 Stressed Rivers Assessment
The Stressed Rivers program was developed by the NSW DLWC to provide information on the environmental stress, particularly hydrologic, of unregulated rivers. It was a desktop type study, drawing on data from previous studies and from in-house expertise.

The program produced a series of reports on catchments in the Murray-Darling Basin and elsewhere in NSW in which high priority catchments were identified where there was a high level of water extraction during low flow periods (80th percentile flow), during the driest month of high irrigation demand, or catchments with high conservation value. This information was to be used to guide management priorities and policies for interim water management rules.

The scale at which this program produced assessments varied across the MDB. In the northern parts of the Basin assessments were produced for entire AWRC Basins, e.g. Paroo. In the southern parts of the Basin assessments are at a finer spatial scale, with AWRC Basins divided into sub-catchments on the basis of land use, government boundaries etc, and an assessment produced for each sub-catchment. Assessments have been completed for all river valleys in the Basin.

11.14 Waterwatch
The Waterwatch program is a community based river health monitoring program developed to provide community members interested in the status of their streams with techniques they could use to monitor stream condition. It has developed a considerable groundswell of active involvement, with the number of people and groups participating
across Australia numbering in the tens of thousands and hundreds respectively. Sites sampled tend to be in those areas in which the group has a particular interest, rather than part of a more representative sampling network.

The data collected under this program varies in quality and consistency depending on the expertise of the different Waterwatch groups. Despite this shortcoming, it is worth consideration in development of the Audit and CSA because it comprises a large body of data across the Basin, and demonstrates the level of and location of community interest in stream condition in the Basin. However the issues of standardised methods and data quality need to be addressed.

12 References


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### State contacts for Tasks 1, 3–7

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**Appendix 1 Review of Existing Programs**

**Final Report for Project R2004**
Conceptual models of river function have been developed for each of the eight Functional Process Zones (FPZs) in the Murray-Darling Basin identified by Thoms (1998), Thoms et al. (2000), Thoms et al. (in press) and this study. These models should be interpreted in conjunction with the description of the FPZs, summarising the key geomorphic features of each model, and how they relate spatially to one another.
Table of Contents

Functional Process Zone Characteristics of the Murray-Darling Basin .............117
Headwater Pool Zone ..............................................................................................117
Confined zone ........................................................................................................118
Armoured zone ........................................................................................................118
Mobile zone ............................................................................................................119
Meandering zone .....................................................................................................120
Anabranching zone .................................................................................................121
Distributary zone ....................................................................................................122
Lowland Confined zone ..........................................................................................123
References ................................................................................................................125
Long pools form upstream of short channel constrictions formed by bedrock bars or local gravel deposits that act as riffle areas. Riffle areas are areas of relatively high energy which transport fine sediment and other material from upstream or from pool areas. Fine sediment overlying a bedrock/cobble base in pools may be scoured at bankfull flows, however discharges greater than 50 m/s are required to move coarser material in this zone. The pool zone is a sediment supply area to downstream zones, with most sediment entering the channel from upstream. Lateral connection to the floodplain (usually less than 30m wide) is restricted by the valley morphology. Detritus and nutrients are added to the stream by the surrounding catchment, most of which are transported downstream. The contribution that runoff makes to the stream is small because of good vegetation cover.

Riparian vegetation shades the edges of the stream, keeping the water temperature and P:R ratios down. Riparian and catchment inputs of large debris and CPOM provide important habitat and food resources for invertebrates, fish, frogs. Fine sediment (silt/clay) is deposited from upstream into pool areas in low flow. Primary production (another important food source) is dominated by microalgae (diatoms) with some submerged and emergent macrophytes, which provide habitat. Elevated flow increases pool depth and may result in flushing of detritus, nutrients and fine sediment from pools, but lateral connection is restricted by the valley shape.
Upland Gorge Zone (Constrained Zone)

1. Sediments are added directly to the channel from adjacent valley slopes and from upstream. 2. The in-channel environment consists of bedrock, large boulder/cobble accumulations and scour pools. This substrate is important habitat for riparian vegetation, invertebrates, fish and frogs. While boulder accumulations are very stable, cobble accumulations are highly mobile during flood flows. 3. A lack of sediment deposition areas in this zone makes it a sediment source area for downstream zones. 4. Vegetation commonly extends all the way down the valley to the river banks, so inputs of detritus and wood from the riparian zone can also form an important component of the habitat. However, this habitat is regularly scoured away in elevated flows, so retention time of nutrients and organic matter is short. 5. Lateral floodplain connections are again restricted by valley shape.
The armoured zone is characterised by a series of floodplains of different ages, inset into high level terraces. The channel meanders though the valley, constrained to some extent, but exhibiting some development, such as low level flood runners. The channel has riffle and pool sections, with a gravel substrate heavily armoured by a layer of cobbles. Pools may act as refuges for biota in times of high flow. The armoured zone is a sediment source area, with sediment derived from old floodplains, cutting the channel deeper, and from upstream sources. Nutrients and detritus are stored on floodplain surfaces, and may be washed into the channel in times of high flow. Debris dams may form in riffle areas from fallen timber, trapping organic matter and providing important habitat for fish, invertebrates and frogs. Habitat in the substrate is restricted for some organisms by the armour layer.
Mobile Zone

In the mobile zone high and low flow channel features are very distinctive. The low flow channel is characterised by large sandy point bars, riffles and large, deep pool sections. In low flow, habitat is provided by cobble/gravel accumulations and riparian vegetation in riffle sections, fallen trees, detritus and emergent vegetation in pool areas. The high flow channel is characterised by in-channel benches, flood runners and complex floodplain features. In high flow, flooding of the terrestrial environment, in channel benches and floodrunners provide habitat in the form of fallen and inundated vegetation and detritus. At high flow detritus, sediments and nutrients are flushed from the channel and the floodplain, which may temporarily increase turbidity and reduce light penetration. Benches are important areas for storage of organic matter, nutrients and sediments and play an important role in in-stream processes. Fallen timber may create debris dams, trapping organic matter of various sizes, also providing food and habitat for invertebrates, fish and frogs.

The mobile zone has a large valley floor, enabling development of floodplain features such as floodrunners, cutoffs and levees. In high flows, lateral connections to the floodplain are established and nutrients, detritus, etc may be flushed into the main channel from the floodplain and in-channel benches, creating habitat and food resources for invertebrates, fish and frogs. High flows also provide cues for fish migration, spawning and dispersal. The primary function of the mobile zone is transport of sediment and other material, with large storage areas such as point bars in the channel. Detritus may also be stored in debris dams that can form in riffle areas from fallen timber.
The meander zone has a large valley floor, enabling development of floodplain features such as floodrunners, former channels, cutoffs and minor anabranching. The in-channel environment is characterised by bars, benches and pools. In high flows, lateral connections to the floodplain are established and nutrients, detritus, etc may be flushed into the main channel from the floodplain and in-channel benches, creating habitat and food resources for invertebrates, fish and frogs. High flows also provide cues for fish migration, spawning and dispersal. The meander zone is also a sediment transport zone, with large storage areas such as point bars in the channel. Sediment is finer in the meander zone than the mobile zone, with banks steeper and more cohesive (mostly fine sands, silts and clays). As well as benches, detritus may again be stored in debris dams that can form in riffle areas from fallen timber.

Like the mobile zone, the high and low flow channel features of the meander zone are very distinctive. The low flow channel is characterised by sandy point bars, large riffles and large, deep pool sections. In low flow, habitat is provided in riffle areas by gravel/sand accumulations and riparian vegetation in riffle sections, fallen trees and detritus. Pool areas are characteristically sandy/silty with emergent vegetation and wood/detritus providing habitat. The high flow channel is characterised by in-channel benches, diverse flood runners and an extensive floodplain. Flooding of the terrestrial environment, in-channel benches and floodrunners provide habitat in the form of fallen and inundated vegetation and detritus. Inundation of anabranches, floodrunners, in-channel benches and the floodplain also flushes detritus, sediments and nutrients into the main channel. Fallen timber may create debris dams, trapping organic matter of various sizes, also providing food and habitat for invertebrates, fish and frogs. Banks are steeper and more cohesive than in the mobile zone.
Anabranch Zone

1. At low flow the channel is simple, with most habitat diversity occurring at high flows. The low flow channel has no riffle sections, characterised by large pools and sandy point bars. Substrate is limited to sandy bars, silt/clay areas, with fallen vegetation and emergent macrophytes the only main habitats.

2. The high flow channel is characterised by in-channel benches, diverse flood runners, large anabranches and an extensive floodplain. Woody debris is again the main habitat, with the inundated terrestrial environment also providing habitat at extremely high flow.

3. Anabranch channels are isolated at low flow but may begin to flow at one third to half bankfull discharges.

4. Sediment, nutrients and organics are deposited and stored in the anabranch zone.

5. Invertebrates, fish and frogs rely on riparian vegetation inputs to provide the main habitat. Benches can also be important areas for storage of organic matter, nutrients and sediments.

6. Vegetation in this zone is sparse and mainly restricted to the river banks.
Appendix 2 Functional Process Zone Conceptual Models of River Function
Final Report for Project R2004

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The distributary zone is defined by its bifurcating channels (channels that take off from each other). Although secondary channels exist relatively independently of the main channel, flow in the smaller distributary channels is directly related to flow in the main channel. Therefore many distributary channels may have zero flow for long periods. In all channels there is a rapid decrease downstream in bankfull cross sectional area because of evaporation and flood attenuation. Most channels are narrow and featureless, with sandy bars and the occasional deep hole the main features. In the high flow section of the main channel, in-channel benches occur, important for organic matter, nutrient and sediment storage and in-stream processes. At high flows inundation of terrestrial vegetation may form habitat, but the main habitat again is fallen woody debris such as snags and associated finer organic material, as the channel substrate is comprised of sand, silt and clay. The distributary zone is also a sediment storage area, with sediment, nutrients and organics retained in bars, on the floodplain and in smaller channels. Vegetation in this zone is again sparse and mainly restricted to the river banks.
The valley of this zone is constrained, with the channel also constrained within the gorge zone. Wetlands may form on tributary streams adjacent to the channel but are independent of channel flows. Riparian vegetation supplies debris and nutrients to the channel and adjacent wetlands, important habitat and food for invertebrates, fish and frogs. The incised river channel intercepts groundwater flow, therefore in low flow conditions salinity of water increases. Organisms have evolved in varying salinity conditions, with a higher presence of molluscs compared to insects. Higher turbidity may also inhibit phytoplankton, which would normally consume nitrogen, phosphorus and silica nutrients (used by molluscs).

Lowland Gorge Zone

The valley of this zone is constrained, with the channel also constrained within the gorge zone. Wetlands may form on tributary streams adjacent to the channel but are independent of channel flows. Riparian vegetation supplies debris and nutrients to the channel and adjacent wetlands, important habitat and food for invertebrates, fish and frogs. Small amounts of sediment may be supplied to the channel from upstream.
Functional Process Zone Characteristics of the Murray-Darling Basin

Headwater Pool Zone

Headwater Pool Zones (Figures 3.1, 3.2) are generally characterised by long pools separated by short channel constrictions. The pools are the dominant morphological feature and form upstream of these channel constrictions. Channel constrictions are often associated with major bedrock bars or substantial localised gravel deposits that extend across the channel and act as riffles. Local river bed slopes increase significantly at these constrictions, representing small areas of relatively high energy, in contrast to the relatively low bed slopes and energies of the pool environment. Overall, bed slopes in the pool zones can be in the order of 0.0001 with corresponding stream powers of 1.5 \( \omega \text{m}^{-2} \). Stream power is the rate of work (ie. sediment movement) or the energy that is expended in a stream or river.

The river channel planform or configuration of this zone is controlled by valley morphology. The river channel may have a small flanking floodplain (up to 30 m) but this is dependent on the size and configuration of the valley floor trough; as such the size of the valley floor limits floodplain development. Bankfull channel dimensions can be up to 30 m in width, 3 to 4 m deep, with width/depth ratios of 10. Bankfull channel capacities do not generally exceed 30 m\(^3\)s\(^{-1}\).

The channel-bed sediment or substratum in these reaches consists of fine silt/clay material overlying a bedrock/cobble base in the pools. However, gravel/cobble or bedrock dominate the short constricted riffle areas. Bankfull flows generally have the competence to entrain the finer bed substratum, but discharges in excess of bankfull capacities are required to initiate motion of coarser material. The river bed in these pool zones may be characterised as being stable with a Relative Bed Stability (RBS) index of between 1 and 2.3 (Jowett 1997).  

Habitats of this zone  

The major habitats of this zone are:

Functional set: the Headwater Pool Zone of each river system

Functional unit: the main Functional units in the Headwater Pool Zone of each river system are the riffle/chute areas and the large pool areas. Riffle/chutes provide areas of relatively fast flowing, shallow, turbulent water compared with deeper, slower flowing pool regions.

Mesohabitats: The major mesohabitats in the riffle and chute areas relate to the different substratum composition with areas of cobble/gravel and regions of sand. In the pool, mesohabitats appear to be somewhat more diverse with comparable regions.
of substratum, combined with emergent and possible submerged aquatic vegetation.

Confined Zone (Constrained)

This is a relatively high energy zone dominated by steep bed slopes S > 0.010 with bankfull channel stream powers in excess of 400 $\omega$ m$^{-2}$ (Figures 3.3, 3.4). Generally bedrock chutes, large boulder/cobble accumulations and scour pools dominate the in-channel environment. Boulder materials are relatively immobile, but cobble accumulations are highly mobile during flood flows producing well sorted deposits. Variations on this theme can occur in confined zones where the supply of sediment is finer. For example, the dominant geology in a catchment may consist mainly of sandstones, hence these confined valley sections will be dominated by sand as opposed to boulder/cobble. Because of the ‘confined’ nature of the valley floor, floodplain development is restricted and may not occur at all. Hence, in these zones sediments are added directly to the channel from adjacent valley slopes. There is a lack of any major sedimentary deposits, and this, together with the high-energy environment, suggests these areas are important sediment source zones for the downstream river system. The river bed is relatively unstable with Relative Bed Stability index of 0.46. Channel planforms are controlled by the structure of the valley.

Habitats of this zone

The major habitats of this zone are:

Functional set: the Confined Zone of a river system

Functional unit: there are few functional units in the Confined Zone of the river system. The main channel itself is the dominant unit with perhaps some differentiation of riffle areas and pool areas within the channel, although not as distinct as in the Pool Zone. Dominant within the channel are large boulder/cobble accumulations some of which provide habitat for riparian vegetation.

Mesohabitats: within the channel unit the major mesohabitats relate to substratum composition with variable accumulations of cobble/gravel providing a complex array of habitat types. The stands of riparian vegetation also provide habitat, both themselves and their associated fallen timber.

Armoured Zone

This is also a high energy zone with high bed slopes of (0.01 to 0.002) and corresponding bankfull stream powers up to 400 $\omega$ m$^{-2}$. A feature of this zone is that the bed sediments are highly armoured. Armouring of bed sediments refers to the development of a surface layer which is coarser than the sediment beneath it. This coarse layer protects the finer materials underneath which are not mobilised until the armour layer is removed. The Armoured Zone is also characterised by a series of floodplains of different ages, inset into high level terraces.
This zone is a sediment source area as evidenced by terrace formations and active lowering of the bed of the modern channel (Figures 3.5, 3.6). The river channel is partially constrained and is mainly controlled by the valley, but there are usually some floodplain formations present. The river channel exhibits a meandering pattern that is superimposed on a larger valley pattern. It is characteristic of a bed load/mixed load channel (Schumm 1988) with high bed slopes, low sinuosities, and large meander arcs and wavelengths. The in-channel environment is dominated by cobble and gravel-size sediments that are extensively armoured and relatively stable (RBS =0.38 to 1.05).

Habitats of this zone

The major habitats of this zone are:

Functional set: the Armoured Zone of a river system

Functional unit: the Armoured Zone marks the beginning of where Functional units begin to be divided into those occurring in the low-flow channel and those within a high-flow channel. Within the low-flow section of the Armoured Zone Functional units are riffle and pool areas within the main channel. Some of the riffle sections are large and support well established stands of riparian vegetation. Pool regions are also large and deep and would provide a substantial refuge area during floods. In the Armoured Zone the high-flow channel is present but not well developed. Functional units in this region of the channel include flat surfaces within the incised channel and the small flood runners.

Mesohabitats: within the low-flow channel the major mesohabitats relate to substratum composition with accumulations of cobble/gravel within the riffles providing a complex array of habitats. The stands of riparian vegetation also provide complex habitat, both themselves and their associated fallen timber, some of which can create large debris dams rich in organic matter of a range of sizes. Within the pool unit of the low-flow channel, mesohabitats include emergent and submerged vegetation. Woody debris can also be present within pools. The high-flow channel generally contains sparse mesohabitats, the most dominant being submerged terrestrial vegetation in times of flood.

Mobile Zone

The Mobile Zone (Figures 3.7, 3.8) is an area characterised by relatively mobile river-bed sediment, large sediment storage areas within the channel and a relatively active channel. The presence of well developed inset floodplain features such as benches, point bar systems, cut offs and levees testify to the relatively active and unrestricted nature of this river-floodplain environment. Valley floor widths of up to 10 km enable floodplain development.

The river channel is freely meandering with an irregular planform; sinuosities up to 1.95. Characteristics of the Mobile Zone are increases in meander wavelengths and meander arcs in comparison to the armoured reach. Stream powers can be up to 20 $\text{Wm}^{-2}$.
The morphology of the in-channel environment is extremely variable with the presence of bars (point and lateral), benches (at various levels) and riffle/pool sequences. These in-channel storage features reflect high rates of sediment transport. River bed sediments typically have a bimodal distribution (median grain size of 64 to 100 mm) and are highly mobile (RBS < 1) with a range of sediment sorting.

In this Functional Process Zone, short lengths of river (<50m), such as large riffles may have armoured bed sediments. This can occur where the valley floor may 'pinch' in or where flow is obstructed by an artificial structure, such as a bridge or road crossing.

**Habitats of this zone**

The major habitats of this zone are:

**Functional set:** the Mobile Zone of a river system

**Functional unit:** the Mobile Zone is probably the most complex reach in terms of functional unit development, with distinct and diverse low- and high-flow channels. Within the low-flow section of the Mobile Zone functional units are again the riffle and pool areas within the main channel. In this reach the riffle sections are large and support well established stands of riparian vegetation. Pool regions are also large and deep. The low-flow channel is also characterised by large sandy point bars. In the Mobile Zone the high-flow channel can be well developed with in-channel benches, diverse flood runners and an extensive floodplain. Functional units in the high-flow channel also include the flat bench surfaces, the small flood runners and complex features of the floodplain itself.

**Mesohabitats:** Within the low-flow channel the major mesohabitats relate to substratum composition with varying accumulations of cobble/gravel within the riffles providing complex substrate habitats. The stands of riparian vegetation also provide complex habitat, both themselves and their associated fallen timber which, as in the Armoured Zone, create large debris dams. Within the pool functional unit of the low-flow channel, microhabitats include emergent and submergent vegetation. Woody debris can also be present within pools. Mesohabitats within the high-flow channel relate to the terrestrial environment inundated during floods, but snags and fallen woody debris also form a major mesohabitat in this region of the channel.

**Meandering Zone**

A distinguishing feature of the Meandering Zone is the significant increase in the width of the valley floor (> 5 to 15 km) and the presence of large, well developed floodplain surfaces. The river channel is relatively active and displays a typically meandering style. Sinuosities may range from 1.8 to 2.35 with meander wavelengths up to 700 m. The presence of well developed floodplain features such as flood channels, former channels, avulsions, cut offs and minor anabranching testify to the relatively active and unrestricted nature of the river-floodplain environment in this reach. The river in this zone is typical of a mixed to wash-load channel (Schumm 1988).
The morphology of the in-channel environment is variable with the presence of bars (point and lateral), benches (at various levels) and riffle/pool sequences (Figures 3.9, 3.10). These in-channel sediment storage features reflect the relatively high rates of sediment transport. The river bed sediments typically have a bimodal distribution like those found in the Mobile Zone but are smaller in size (median grain size of < 1 to 64 mm). The appreciable fining of the bed sediment and/or well developed floodplain features are clear characteristics distinguishing between the Meander and Mobile Zones. The bank sediment is also very fine, mostly fine sands, silts and clays. The cohesive nature of the bank sediment contribute to relatively steeper banks in this zone compared to upstream zones. The bankfull channel widths can vary between 40 and 70 m and depths between 4 and 6 m.

Habits of this zone

The major habitats of this zone are:

Functional set: the Meandering Zone of a river system

Functional unit: the Meandering Zone contains a complex array of functional units with distinct and low- and high-flow channel units. Within the low-flow section of the Meandering Zone, Functional units are the riffle and pool areas within the main channel. In this zone, riffles can be large and support well established stands of riparian vegetation. Pool regions are also large and deep. The low-flow channel is also characterised by large sandy bar systems, both point and lateral bars. In this zone high-flow functional units are developed with in-channel benches, diverse flood runners and an extensive floodplain. Functional units include the flat bench surfaces, the small flood runners and complex features of the floodplain itself.

Mesohabitats: within the low-flow channel the major mesohabitats relate to the substratum composition with accumulations of gravel/sand within the riffles providing complex substrate habitats. The stands of riparian vegetation also provide complex habitat, both themselves and their associated fallen timber which, as in the Armoured and Mobile Zones, can create large debris dams. Within the pool functional unit of the low-flow channel, mesohabitats include the sand/silt-size sediment, emergent vegetation and possibly submerged vegetation. Woody debris can also be present within pools. Mesohabitats within the high-flow channel also relate to the terrestrial environment inundated during floods, but snags and fallen woody debris form a major mesohabitat in this region of the channel.

Anabranching Zone

This Functional Process Zone is characterised by multiple channels, which can be both anabranching or anastomosing, which dissect a generally extensive and well developed floodplain surface (Figures 3.11, 3.12). Anabranch channels break out from the main or ‘parent’ channel, flow across the floodplain to rejoin the main channel at a distance downstream. These anabranch channels begin to flow at approximately one third to half bankfull discharges. Anastomosing channels, rather than breaking out from a main channel, consist of multiple channels all of which are ‘active’ to the same degree during periods of flow. The individual channels are characteristic of a wash-load system.
(Schumm 1988), with low bed slopes (<0.00001), high sinuosities (>2.0), low bankfull stream power (<5 $\omega m^{-2}$) and highly cohesive river bank materials (percent weight of silt/clay >25%). The contemporary channel can have sinuosities up to 2.10, and is often contained within a older channel system that has a much larger meander wavelengths (>13 km) and channel dimensions (widths > 800m). The active channel generally has bankfull characteristics of low width/depth ratios, widths of between 30 and 50 m, and depths of 10 to 15 m. The river bed is normally stable with a RBS of 0.98 to 4.85. The effect of multiple channels means that bankfull capacities in this zone are lower in comparison to other zones (50 m$^3$s$^{-1}$).

**Habitats of this zone**

The major habitats of this zone are:

**Functional set:** the Anabranching Zone of a river system.

**Functional unit:** the Anabranching Zone is typical of many inland lowland rivers in Australia. In this zone the low-flow channel is relatively simple with most of the habitat diversity occurring at higher-flow levels. Within the low-flow section of the Anabranching Zone, riffles do not exist and the main functional units are the large pools within the main channel. Sections of the low-flow channel may also be characterised by large bar systems, principally point bars. In the Anabranching Zone the high-flow channel is also well developed with in-channel benches occurring at different levels within the channel, diverse flood runners and large anabranches leaving the main channel at different flow heights and an extensive floodplain. Functional units in the high-flow channel include flat bench surfaces, flood runners and anabranches and complex features of the floodplain itself.

**Mesohabitats:** within the low-flow channel the major mesohabitats relate to substrate composition, but diversity is limited to sandy bars, regions of silt/clay and small areas of bedrock. Woody debris from fallen riparian vegetation is the other major microhabitat of the low-flow channel. Mesohabitats within the high-flow channel are similar to those within the low-flow channel with woody debris dominating. At extremely high flows mesohabitats relate to the terrestrial environment inundated, but snags and fallen woody debris again form a major microhabitat in this region of the channel.

**Distributary Zone**

The basic feature that defines a Distributary Zone is that it has bifurcating channels — channels that off take from each other (Figures 3.13, 3.14). These secondary channels persist relatively independently of the main channel, the channel from which they off take, for some length far in excess of their width. These distributary channels may or may not rejoin the main channel. Distributary channels that do not rejoin other channels often terminate in lakes or terminate dispersed across floodplains. Daily flows of 1–50 m$^3$s$^{-1}$ do occur in these channels but for the majority of the channels long periods of zero flow are common. Flow in the smaller distributary channels is related to high flows in the main channel.
In all channels there is a rapid downstream decrease in bankfull cross sectional area. This is attributed to loss of water by evaporation and flood attenuation. The sediment within all channels is comprised of very fine sands, silts and clays. Indeed, the percentage weight of silts and clays can be up to 40%. Most of the channels are relatively narrow and featureless with occasional deep holes scattered along their length.

Habitats of this zone

The major habitats of this zone are:

Functional set: the Distributary Zone of a river system.

Functional unit: In the Distributary Zone the low-flow channel is relatively simple with most of the habitat diversity occurring within the higher flow channels. Within the low-flow section of the distributary Zone deep pools are common functional units. Sections of the low-flow channel may also have point bars. In the high-flow section of the main channel in-channel benches occur at different levels and these are considered to be important for the in-stream ecological processes. The secondary channels and the extensive floodplain surface through which they flow are the dominant functional unit in this zone. The high-flow channels also contain flat bench surfaces, flood runners and anabranches and a complex array of floodplain features.

Mesohabitats: Within the low-flow channel the major mesohabitats relate to substrate composition, but diversity is limited to sandy bars and regions of silt/clay. Woody debris from fallen riparian vegetation is the other major microhabitat of the low-flow channel. Mesohabitats within the high-flow channel are similar to those within the low-flow channel with woody debris dominating. At high flows mesohabitats relate to the secondary channels and inundated terrestrial environments, but snags and fallen woody debris again form a major mesohabitat in this region of the channel.

Lowland Confined

This Functional Process Zone contains many features similar to the Meandering Zone, but the main channel is confined, hence lateral movement is limited. A distinguishing feature of Lowland Confined Zones is a relatively narrow width of the valley floor (2 to 3 km) and associated floodplain surface (Figures 3.15, 3.16). These sections of river are generally confined within geological structures or paleo-channels. Floodplain features such as minor anabranching and flood channels dominate this zone. The river bed and bank sediments are typically fine sands, silts and clays. The appreciable fining of the bed sediment and/or well developed relatively stable floodplain features are also notable in this zone. The river channel in this zone is predominately a wash load channel (Schumm 1988).

The morphology of the in-channel environment is variable with the presence of large bars (point and lateral) and benches (at various levels); hence large amounts of sediments are stored in this zone. The cohesive nature of the bank sediment contributes to relatively steeper banks in this zone compared to upstream zones. The bankfull channel has widths between 40 and 70 m and depths between 4 and 6 m.
Habitats of this zone

The major habitats of this zone are:

Functional set: the Lowland Confined Zone of a river system

Functional unit: the Lowland Confined Zone contains an array of functional units with distinct low- and high-flow channel units, which include floodplain surfaces. Within the low-flow section of the Lowland Confined Zone, Functional units are deep pool areas within the main channel. These pools can be large and support well established stands of riparian vegetation. In this zone high-flow functional units are developed with diverse bars and in-channel benches and limited floodplain surfaces. Floodplain features include; levees, flood runners and older channels. Functional units include the flat bench surfaces, the small flood runners and features of the floodplain itself.

Mesohabitats: within the low-flow channel the major mesohabitats relate to the substratum composition with accumulations of fine sand, silt and clay within the pools providing relatively homogeneous substrate habitats. Present within the pool functional unit of the low-flow channel are emergent vegetation and possibly submerged vegetation. Woody debris can also be present within pools. Mesohabitats within the high-flow channel also relate to the terrestrial environment inundated during floods, but snags and fallen woody debris form a major mesohabitat in this region of the channel.
References


Appendix 3
Macroinvertebrates

Review and Development of Aquatic Macroinvertebrate Protocols

Julie Coysh
Richard Norris
Wayne Robinson

This report on the macroinvertebrate theme component of the Sustainable Rivers Audit is presented in two sections. Part A is a review of existing macroinvertebrate programs in each jurisdiction, and presents discussion outcomes from the workshop that was attended by representatives from all jurisdictions in the Basin. Part B develops the indicators and the framework in which the macroinvertebrate theme will be reported. Recommendations from Part B are summarised in the summary at the beginning of this document.
# Table of Contents

Summary ........................................................................................................................................ 130

**PART A** .................................................................................................................................. 132
Review of existing programs and recommendations................................................................. 132
Section A1.................................................................................................................................... 133
Review of existing macroinvertebrate programs in the Basin .................................................. 133
  A1.1 Review of existing programs ............................................................................................. 133
  A1.2 Index of Stream Condition (ISC) .................................................................................. 134
  A1.3 Integrated Monitoring of Environmental Flows (IMEF) ............................................... 135
  A1.4 Pressure - Biota - Habitat (PBH) .................................................................................. 135
  A1.5 MDBC water quality monitoring program ................................................................. 136
  A1.6 National River Health Program ................................................................................... 136
  A1.7 Waterwatch .................................................................................................................. 137
  A1.8 Other Indicators .......................................................................................................... 137

Section A2.................................................................................................................................... 137
Selection of assessment tools and indicators ............................................................................. 137
  A2.1 Potential macroinvertebrate indicators ......................................................................... 137
  A2.1.1 Indices and Metrics .................................................................................................. 138
  A2.1.2 Predictive Models .................................................................................................... 141
  A2.2 Criteria for selecting assessment tools and indicators ................................................ 141
  A2.3 How the potential indicators meet the criteria for a useful indicator ......................... 142
  A2.4 Summary .................................................................................................................... 147

Section A3.................................................................................................................................... 148
Development of indicators for the Murray Darling Basin ....................................................... 148
  A3.1 How the assessment tool and indicators address each FPZ ........................................ 148
  A3.2 Jurisdictional Review of existing AUSRIVAS models ............................................... 149
  A3.3 Development of models for the MDB versus using existing State/Territory models .... 155
  A3.4 Sample season and habitat .......................................................................................... 156
  A3.5 Sampling design, precision and reporting scale options .......................................... 157
  A3.6 Reference condition .................................................................................................... 158
  A3.7 Interpretation of indicators .......................................................................................... 160
  A3.8 Frequency of assessment ............................................................................................ 161

Section A4  Summary and Recommendations ........................................................................... 162

**PART B** .................................................................................................................................. 165
Development of Methods and Indicators .................................................................................. 165
Section B1.................................................................................................................................... 166
Indicators ..................................................................................................................................... 166
Section B2.................................................................................................................................... 167
Methods ...................................................................................................................................... 167
  B2.1 Sampling Methods ....................................................................................................... 167
  B2.2 Spatial coverage of AUSRIVAS models .................................................................... 167
  B2.3 Frequency and season of assessment ......................................................................... 170
  B2.4 Sample habitat ............................................................................................................ 172
  B2.5 Taxonomic resolution .................................................................................................. 172

Section B3.................................................................................................................................... 172
Analysis ...................................................................................................................................... 172
  B3.1 Reference condition and possible adjustment ............................................................ 172
  B3.2 Integration and aggregation of scores to produce an assessment .............................. 175

Section B4.................................................................................................................................... 176
Sampling design ....................................................................................................................... 176
  B4.1 Precision and number of sampling sites ..................................................................... 176
  B4.2 Reporting scale .......................................................................................................... 181

Appendix 3 Review and development of aquatic macroinvertebrate protocols .......................... 128
Final Report for Project R2004
Summary

1. Two indicators of condition for the macroinvertebrate theme are proposed, AUSRIVAS O/E taxa and a form of SIGNAL score. O/E SIGNAL and raw SIGNAL as currently calculated have been demonstrated to be insensitive to impacts and consistently overestimate condition. Therefore it is recommended that the AUSRIVAS O/E taxa score is used as the macroinvertebrate indicator for the first year of the Audit. It is proposed a more robust form of SIGNAL is developed in the first year of the Audit by testing regionalised raw SIGNAL scores and calculating O/E SIGNAL using all taxa.

2. It is recommended that existing AUSRIVAS models and associated sampling and processing protocols should be used for assessment in the first year. Existing regional models should be used in preference to statewide models where available and appropriate. Concurrently, existing models should be evaluated using a stepwise process to ascertain whether the existing model is the most appropriate model in each case. Development of regional models for the Basin where appropriate is proposed for the first year of the Audit.

3. The frequency of assessment should maximise the power of the sampling design to detect spatial and long-term temporal trends. Single season models are therefore recommended where taxa numbers are high enough, as sampling density can be increased for the same cost. In Western regions, however, combined season models are recommended to provide an adequate taxon list.

4. Existing Victorian data and models will be used to test the effect of increased taxonomic resolution on taxon richness in lowland zones. The accuracy of assessments can be analysed with existing Victorian models by examining the change in reference sites over time. After testing, genus or species models may be adopted where appropriate.

5. Analysis of both AUSRIVAS O/E taxa and SIGNAL will use comparison to a reference condition. The macroinvertebrate theme should incorporate a measure of departure from reference, and a measure of departure of reference from natural to account for the varying definition of reference condition currently used. Options proposed to measure the departure of reference from natural include using the River Disturbance Index, conceptual models of river function or a narrative description. To measure the departure of a site from reference condition, scoring against reference criteria and measuring the departure of the O/E value from 1 were proposed. These measures would then be turned into alternative health indicators and tested for sensitivity to known disturbances, allowing existing reference sites and models to be used, and providing comparability between different standards of reference.

6. Caution should be used in integrating indicator scores to produce a single score. Preferably, indicators should be reported separately, as they represent different information about the health of a stream. Where a single score is required, reporting of the indicator score that is the further away from reference is recommended. Only the O/E taxa indicator will be reported in the first year. Aggregation will follow the general principles outlined for reporting of theme condition, using the median score for a river valley.
7. Valleys and Valley Process Zones have been proposed as reporting scales. A number of options for sampling design and precision have been proposed, on which a decision is required by the Audit taskforce. The recommended level of change detectable at the river-valley scale for an AUSRIVAS O/E score is 10% and for a SIGNAL score 5%. These are considered appropriate and meaningful levels at which a change should be detectable. A commitment in the order of $714,500 per annum across the Basin would be required to achieve this level of precision at the valley scale. Reporting at the valley scale and the VPZ scale requires considerably more sites, with costs estimated in the order of $1,620,000 per annum.
PART A
Review of existing programs and recommendations
Section A1

Review of existing macroinvertebrate programs in the Basin

The outcomes of this review were discussed at a workshop held at the University of Canberra on 20th March, attended by representatives from each jurisdiction in the Murray-Darling Basin (MDB), the Commission and the CRCFE (see below). Discussion points and changes have been added where necessary in italics. Thus, this document represents the view of all jurisdictions with regard to macroinvertebrate indicators and assessment tools.

<table>
<thead>
<tr>
<th>State Representatives</th>
<th>Organisation</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eren Turak</td>
<td>EPA</td>
<td>NSW</td>
</tr>
<tr>
<td>Natasha Waddell</td>
<td>EPA</td>
<td>NSW</td>
</tr>
<tr>
<td>Bruce Chessman</td>
<td>DLWC</td>
<td>NSW</td>
</tr>
<tr>
<td>Greg Keen</td>
<td>Environment ACT</td>
<td>ACT</td>
</tr>
<tr>
<td>Brian Wilkinson</td>
<td>Environment ACT</td>
<td>ACT</td>
</tr>
<tr>
<td>Satish Choy</td>
<td>DNR</td>
<td>QLD</td>
</tr>
<tr>
<td>Peter Goonan</td>
<td>EPA</td>
<td>SA</td>
</tr>
<tr>
<td>Leon Metzeling</td>
<td>EPA</td>
<td>VIC</td>
</tr>
</tbody>
</table>

Other Representatives

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sue Grau</td>
<td>MDBC</td>
</tr>
<tr>
<td>Brian Lawrence</td>
<td>MDBC</td>
</tr>
<tr>
<td>John Whittington</td>
<td>CRCFE</td>
</tr>
<tr>
<td>Peter Liston</td>
<td>CRCFE</td>
</tr>
<tr>
<td>Julie Coysh</td>
<td>CRCFE</td>
</tr>
<tr>
<td>Richard Norris</td>
<td>CRCFE</td>
</tr>
</tbody>
</table>

A1.1 Review of existing programs

The review of existing programs undertaken in Task 1 of the Audit indicated that the following major sampling programs in the MDB incorporate macroinvertebrate indices:

- Index of Stream Condition (ISC)
- Integrated Monitoring of Environmental Flows (IMEF)
- Pressure - Biota - Habitat (PBH)
- MDBC water quality monitoring program
- National River Health Program (NRHP)
- Waterwatch

A number of other programs report macroinvertebrate data (below), but these data are sourced from one of the above programs:

- National State of the Environment Reporting (SOE)
- Water Allocation Management Planning (WAMP) ecological assessment
- Assessment of River Condition (ARC)
Table A1 Macroinvertebrate monitoring programs in the Basin (from Task 1 Report: Review of Existing Programs).

<table>
<thead>
<tr>
<th>Approach</th>
<th>Monitoring procedure</th>
<th>Where applied in Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>AUSRIVAS sampling, AUSRIVAS score, probability weighted/raw SIGNAL score</td>
<td>Entire Victorian section of Basin</td>
</tr>
<tr>
<td>PBH</td>
<td>SIGNAL, number of families</td>
<td>Castlereagh, Lachlan, Murrumbidgee</td>
</tr>
<tr>
<td>State of Rivers</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>MDBC WQ Monitoring program</td>
<td>Artificial substrate</td>
<td>Murray: Above Hume reservoir and below Wellington</td>
</tr>
<tr>
<td>National SOE</td>
<td>AUSRIVAS score sourced from NRHP and State programs</td>
<td>Entire Basin</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>AUSRIVAS sampling plus additional analyses on data collected as follows: Taxonomic richness PET taxa SIGNAL index, AUSRIVAS score Functional feeding groups Flow velocity and substrate preference groups</td>
<td>QLD section of Condamine/ Balonne/Culgoa</td>
</tr>
<tr>
<td>ARC</td>
<td>AUSRIVAS score sourced from NRHP and State programs</td>
<td>Entire Basin</td>
</tr>
<tr>
<td>NSW River Survey</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>Wild Rivers</td>
<td>Not measured</td>
<td>-</td>
</tr>
<tr>
<td>QLD EPA Guidelines for Waterway Values</td>
<td>Not specified</td>
<td>Not applied yet</td>
</tr>
<tr>
<td>NRHP</td>
<td>AUSRIVAS sampling, AUSRIVAS score and probability weighted SIGNAL score</td>
<td>Entire Basin</td>
</tr>
<tr>
<td>Waterwatch</td>
<td>AUSRIVAS sampling, AUSRIVAS score, probability weighted/raw SIGNAL score</td>
<td>Sites throughout Basin</td>
</tr>
</tbody>
</table>

The major sampling programs that undertake assessments using macroinvertebrates (ISC, IMEF, PBH, MDBC WQ Monitoring Program, NRHP and Waterwatch) in the MDB are summarised below.

A1.2 Index of Stream Condition (ISC)

The ISC was developed as a holistic measure of river health to be used by natural resource managers and CMAs for benchmarking river health, monitoring rehabilitation efforts, and to set priorities for management action. The ISC provides measures of the health of the
aquatic biota and the drivers that may impact on the health of the biota. The ISC incorporates the following 5 indices, that are formed from sub-indices:

- Hydrology
- Physical form
- Streamside Zone
- Water Quality
- Aquatic Life

Macroinvertebrates were selected for the Aquatic Life Index because:
- their ubiquitous and sedentary nature indicates local conditions,
- they integrate the effects of impacts over time, from weeks to years,
- they have a wide range of tolerance to environmental conditions,
- they are well studied, have relatively simple taxonomy and sampling procedures.

Macroinvertebrates were collected according to the sampling protocols of the National River Health Program, which aim to provide a representative sample of the macroinvertebrates at a site. The Aquatic life index is comprised of two sub-indices, the AUSRIVAS O/E score and SIGNAL [O/E] score. The AUSRIVAS O/E score and the SIGNAL score are changed into ratings between 0 and 4, weighted equally and summed to give the Aquatic Life Index. Because of the lower sensitivities that would be expected of macroinvertebrate taxa in more lowland river sections, separate SIGNAL scoring systems have been derived for upland and lowland reaches (Table A2).

<table>
<thead>
<tr>
<th>SIGNAL value (upland reaches)</th>
<th>SIGNAL value (lowland reaches)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;7</td>
<td>&gt;6</td>
<td>4</td>
</tr>
<tr>
<td>6-7</td>
<td>5-6</td>
<td>3</td>
</tr>
<tr>
<td>5-6</td>
<td>4-5</td>
<td>2</td>
</tr>
<tr>
<td>4-5</td>
<td>3-4</td>
<td>1</td>
</tr>
<tr>
<td>&lt;4</td>
<td>&lt;3</td>
<td>0</td>
</tr>
</tbody>
</table>

A1.3 Integrated Monitoring of Environmental Flows (IMEF)

This program was designed to evaluate ecological responses to environmental flows in regulated rivers. IMEF tests a series of hypotheses associated with water management approaches. Hypotheses may include analysis of macroinvertebrates, as well as other biota. IMEF is focused on understanding the impacts of water management rather than providing a condition assessment of a river. Because different studies in the program are testing different hypotheses, the type of data collected and the analyses vary between rivers.

A1.4 Pressure - Biota - Habitat (PBH)

The PBH program is designed to be a rapid, multi-faceted procedure for assessing ecosystem stress and conservation value in small to medium size streams. PBH has been
Cooperative Research Centre for Freshwater Ecology

Appendix 3 Review and development of aquatic macroinvertebrate protocols

136

Final Report for Project R2004

trialled in 12 NSW sub-catchments. Indicators are grouped under 8 categories; richness, rarity, native abundance, physical structure, water quality, alien biota, sensitivity and hydrological stress. Field trials produced 4 scores; conservation significance, sensitivity, general stress and hydrological stress.

Several components of the biota are measured, including macroinvertebrates. Macroinvertebrates are sampled from 3 habitats using a handnet and live-picked for 30 minutes with the aim of maximising the number of taxa collected. Two macroinvertebrate indicators are incorporated in the components of the biota: richness (number of macroinvertebrate families) and a modification of the SIGNAL score weighted by abundance, the Macroinvertebrate Family Index (MFI). These indices are combined with other biotic indices to produce an average score for components of the biota (Chessman 2001). While these particular assessment tools and indicators were used in the trial of PBH, the program is proposed as a flexible framework in which a range of macroinvertebrate assessment tools and indicators could be used.

A1.5 MDBC water quality monitoring program

The MDBC Water Quality Program is designed to monitor the water quality in the River Murray and several major tributaries by measuring water quality, phytoplankton and macroinvertebrates. Macroinvertebrates are sampled using artificial substrate samplers (ASS) made of plastic mesh, with sampling twice a year. A major limitation of the ASS is that substrates have to be left in the river for at least 30 days for colonisation. During this time the samplers are susceptible to loss and damage because of river level changes and vandalism (MDBC report 1985). A number of indices are reported, including community similarity indices, functional feeding groups (FFGs), species composition and abundance and macroinvertebrate biomass (Bennison et al. 1989).

A1.6 National River Health Program

The National River Health Program (NRHP) was designed to assess the ecological status of streams nationwide using macroinvertebrate fauna. As part of the program the First National Assessment of River Health (FNARH) was conducted, with approximately 6000 sites across Australia sampled. Samples are taken with a handnet from either one or two habitats in autumn and/or spring. Macroinvertebrate samples are either lab-sorted or live-picked in the field, (depending on the State/Territory), with the aim of obtaining a representative sample of the invertebrate community at a site to provide an accurate assessment of river health (as opposed to maximising the list of taxa collected). The Australian River Assessment System (AUSRIVAS) is a predictive modelling system that was developed as part of the NRHP to provide an assessment of condition for the nations rivers. AUSRIVAS predicts an expected macroinvertebrate family composition for a site in minimally disturbed condition, based on physical and chemical characteristics, to which the observed macroinvertebrate families are compared. This is reported as a ratio, the AUSRIVAS Observed/Expected (O/E) score. Similarly, an expected and observed SIGNAL score are calculated as part of AUSRIVAS producing an O/E SIGNAL score, providing two indicators of river condition (Simpson and Norris 2000).
A1.7 Waterwatch

Waterwatch is a community-based program for river health assessment. It provides local communities interested in river health with simple, rapid and inexpensive techniques to monitor stream condition including macroinvertebrate protocols. However, not all Waterwatch programs collect information on macroinvertebrates. Macroinvertebrates collected are processed in several ways, depending on the level of expertise and resources available. Sites have been sampled across the Basin, but data and analysis vary in quality and consistency.

A1.8 Other Indicators

While not existing, the development of State Environment Protection Policies (SEPPs) in Victoria were discussed at the workshop, as the indicators to be used are relevant to the Audit. SEPPs will use existing data and new data collected according to the rapid sampling protocols used for AUSRIVAS models. Five macroinvertebrate indicators will be reported for SEPPs:

- a measure of diversity — number of families
- biotic indices — SIGNAL and EPT indices
- measures of community structure — numbers of key families and AUSRIVAS predictive models.

The rationale behind using multiple indicators is that greater confidence can be placed on the outcome if the indicators are in accord; and where a discrepancy occurs, this can be used to indicate a potential impact.

Section A2

Selection of assessment tools and indicators

A2.1 Potential macroinvertebrate indicators

To review potential assessment tools and indicators for macroinvertebrates, it is important to distinguish between the programs that use data derived from macroinvertebrate sampling, the assessment tools used to collect the data and the indicators used to analyse the macroinvertebrate data. To assess macroinvertebrate data there are two main methods of analysis, these are:

- indices and metrics
- predictive models

Indices and metrics refer to standalone measures of river health that are usually interpreted against guidelines or predetermined thresholds. Most indices do not have well defined site specific standards against which they can be compared to determine an effect. Predictive models do provide site-specific assessments by comparing the observed community to a predicted community for a site. This requires a large set of reference sites for comparison. Indices or metrics can also be probability weighted and made site specific using the
predictive models. The different assessment tools, indicators and methods of analysis are outlined in Table A3 for each of the programs with a macroinvertebrate component reviewed in Task 1.

**Table A3** Assessment tools and indicators used by existing programs with a macroinvertebrate component in the MDB.

<table>
<thead>
<tr>
<th>Program</th>
<th>Assessment tool</th>
<th>Indicator</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISC</td>
<td>AUSRIVAS sampling</td>
<td>AUSRIVAS O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIGNAL score</td>
<td>Index/metric</td>
</tr>
<tr>
<td>IMEF</td>
<td>Experimental (varying)</td>
<td>Varies depending on experiment</td>
<td></td>
</tr>
<tr>
<td>PBH</td>
<td>Handnet sampling (3 habitats)</td>
<td>Richness</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macroinvertebrate Family Index</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(SIGNAL weighted by abundance)</td>
<td></td>
</tr>
<tr>
<td>MDBC WQ monitoring program</td>
<td>Artificial Substrate Sampling (ASS)</td>
<td>Community similarity indices</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Functional feeding groups</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Species composition and abundance</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biomass</td>
<td>Index/metric</td>
</tr>
<tr>
<td>National SOE</td>
<td>AUSRIVAS sampling</td>
<td>AUSRIVAS O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td>WAMP ecological assessment</td>
<td>AUSRIVAS sampling</td>
<td>Taxonomic richness</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EPT taxa</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Functional Feeding Groups</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flow velocity and substrate preference groups</td>
<td>Index/metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIGNAL O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AUSRIVAS O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td>ARC</td>
<td>AUSRIVAS sampling</td>
<td>AUSRIVAS O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td>NRHP</td>
<td>AUSRIVAS sampling</td>
<td>AUSRIVAS O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIGNAL O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td>Waterwatch</td>
<td>Varies, some use AUSRIVAS sampling</td>
<td>Varies, some use O/E score</td>
<td>Modelled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Varies, some use SIGNAL O/E score</td>
<td>Modelled</td>
</tr>
</tbody>
</table>

**A2.1.1 Indices and Metrics**

**Richness Indices**

- **Number of EPT taxa**

The number of EPT taxa is the number of macroinvertebrates collected in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Taxa in these orders are considered sensitive, and a decline in the number of EPT taxa can indicate a potential impact.

MDB programs: Only used in Queensland in the WAMP ecological assessment process.

**Biotic Indices**

Biotic indices indicate the sensitivity of the biota present to impacts. If sensitive taxa are missing, then the ecosystem is likely to be stressed.
• **SIGNAL**

SIGNAL provides an assessment of the sensitivities of the taxa that were collected at a site to various human-caused stressors such as stream salinisation and organic pollution. A SIGNAL score for a site is calculated by summing the SIGNAL sensitivity grades for all taxa present at a site and dividing by the number of taxa at a site to give an average SIGNAL sensitivity score, ranging from 1 to 10.

MDB programs: Used in Victoria for the ISC, Waterwatch and PBH. Probability weighted scores are used as part of AUSRIVAS assessments.

• **Macroinvertebrate Family Index (MFI)**

The MFI is a modification of the SIGNAL index, weighted by abundance. SIGNAL grades for each family are multiplied by the square root of the total abundance of each family and summed for all taxa present at a site. This figure is then divided by the square root of the abundance of all taxa at a site to give an average score between 1 and 10.

MDB programs: The MFI is only used in a subset of NSW sub-catchments by PBH.

**Composition Indices**

• **Community similarity indices**

Generally provide a measure of the similarity or dissimilarity of communities, based on taxa common or absent from communities or the mathematical distance between the community composition at pairs of samples/sites. Can be used to compare condition between sites or over time. Examples are Sorensen's Index, Czekanowski's Index, Sokal's Measure of Distance, Canberra Metric Dissimilarity Measure, Jaccard Similarity Index.

MDB programs: Only used in the MDBC WQ monitoring program for the River Murray and major tributaries.

• **Species composition and abundance**

The species in the community, their relative proportions and abundance can provide information about the health of the stream. Knowledge of life history and ecology of invertebrates can be used to infer information about the health of a site.

MDB programs: Used in the MDBC WQ monitoring program. Richness also used in NSW for the PBH program and in Queensland for WAMP ecological assessments.

**Feeding**

• **Functional Feeding Groups (FFGs)**

Categorisation of invertebrates into functional feeding groups should indicate process-level aquatic ecosystem attributes, based on changes in macroinvertebrate food sources and types that occur with distance downstream. Therefore, the macroinvertebrate community present should provide an indication of the food types available or missing and hence some indication of the health of the stream. These groups are generally reported as numbers or percentages (Table A4).
Table A4 Functional Feeding groups

<table>
<thead>
<tr>
<th>FFG</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>% shredders</td>
<td>Percent of the macrobenthos that &quot;shred&quot; leaf litter</td>
</tr>
<tr>
<td>% collectors/gatherers</td>
<td>Percent of the macrobenthos that &quot;gather&quot;</td>
</tr>
<tr>
<td>% filterers</td>
<td>Percent of the macrobenthos that filter FPOM from either the water column or sediment</td>
</tr>
<tr>
<td>% grazers and scrapers</td>
<td>Percent of the macrobenthos that scrape or graze upon periphyton</td>
</tr>
<tr>
<td>% predators</td>
<td>Percent of the predator functional feeding group. Can be made restrictive to exclude omnivores</td>
</tr>
<tr>
<td>% scavengers/generalists</td>
<td>Percent of generalists in feeding strategies</td>
</tr>
</tbody>
</table>

MDB programs: Only used in Queensland for WAMP ecological assessments

Discussion of the use of FFG in Australian streams highlighted a number of potential problems:

- High variability among species in each family to assign FFG to a family.
- Based on Northern Hemisphere FFG assignments.
- FFG are highly variable across regions.
- Taxa may use a number of different strategies at different stages — this is particularly so in Australian streams as many taxa are generalists.

If FFG were to be recommended for the Basin, further research would be required and FFG assignments would need to be improved.

Tolerance

- Flow velocity and substrate preference groups

These categories give an indication of the preferred environmental conditions of macroinvertebrate taxa in regard to flow conditions and substrates. Substrate preference groups of macroinvertebrates were identified by Queensland DNR and related to flow statistics, resulting in determination of a number of flow preference groups: high, low and no preference. Information about river health may be inferred by the presence or absence of taxa when related to the tolerance groups.

MDB programs: Only used in Queensland for WAMP ecological assessments

Other

- Biomass

Biomass is the weight of invertebrates, which may give an indication of density and abundance. Generally in a site in best available condition the abundance of sensitive taxa would be high, but seasonal factors may make abundance and hence biomass an unreliable measure.

MDB programs: Only used in the MDBC WQ monitoring program for the River Murray and major tributaries.
A2.1.2 Predictive Models

• **AUSRIVAS O/E score**

AUSRIVAS is a predictive modelling system, based on the British River InVertebrate Prediction And Classification Scheme (RIVPACS), which predicts an expected taxonomic composition for a site in minimally disturbed condition, based on physical and chemical characteristics, to which the observed community is compared. This is reported as a ratio, the AUSRIVAS Observed/Expected (O/E) score. The probability of occurrence of a macroinvertebrate family at a new test site is calculated in the model by comparison to reference sites in the model. The sum of the probabilities of families predicted at the site gives the number of taxa expected at the site. The observed number of taxa, based on the presence or absence of macroinvertebrate families at the site, is compared to the number expected, providing an observed/expected score. The AUSRIVAS O/E score provides an assessment of river health by comparing the diversity of the community against what would be expected in a minimally disturbed stream with a similar location and physical characteristics, independent of human activities. The AUSRIVAS program also provides a list of expected taxa that are missing, that can be used to infer potential impacts.

MDB programs: Used by all States and Territories in the MDB for NRHP, ARC, National SOE, ISC, WAMP ecological assessments, Waterwatch.

• **SIGNAL O/E score**

The SIGNAL score is also incorporated in the AUSRIVAS program as a second measure of river health, to be interpreted alongside the AUSRIVAS O/E score. In AUSRIVAS, the SIGNAL score is calculated in the same way as it is as an index; however, observed and expected SIGNAL scores are calculated and converted to an observed/expected ratio, giving an assessment in terms of reference condition rather than comparison to predetermined thresholds. Because the SIGNAL score is calculated in the AUSRIVAS framework, the observed and expected scores are site specific. The SIGNAL O/E score provides an assessment of river health by providing information on the sensitivities of taxa collected and also those missing, useful for identifying potential impacts and site condition.

MDB programs: Used by all States and Territories in the Basin for NRHP, ISC, WAMP ecological assessments, Waterwatch.

A2.2 Criteria for selecting assessment tools and indicators

A number of criteria have been proposed for the selection of indicators for each environmental theme in the Audit. Indicators should:

• *build upon existing programs and data as much as possible*

• *be consistent with the conceptual models of river function developed for the Functional Process Zones*

• *be responsive to disturbance*

• *be characterised by measurement and analysis that are rapid (analysis is built into reporting of the indicator)*
• have standardised methods available and be technically appropriate for State agencies to undertake
• have output that can be interpreted relatively unambiguously
• have meaning to the wider Basin community.

The first criterion is also an Audit project objective. Assessment of all the potential indicators against these criteria highlighted two indicators for detailed consideration: the AUSRIVAS O/E score and the SIGNAL O/E score.

A2.3 How the potential indicators meet the criteria for a useful indicator

• Consistent with the conceptual models of river function developed for the Functional Process Zones

The conceptual models of river function developed for the Audit represent the physical, chemical and biological entities and processes that occur in each Functional Process Zone (FPZ) in pristine/minimally disturbed condition. The AUSRIVAS score gives an assessment of the diversity of the community against what would be expected in a minimally disturbed (reference) stream with similar location and physical characteristics (independent of human activities) and provides a list of those taxa expected that are missing. The SIGNAL score provides information on the sensitivities of taxa collected and also those missing. Thus, a departure of AUSRIVAS and SIGNAL O/E values from reference condition indicates a likely impact. By examining the list of taxa that were expected but not collected and the sensitivities of these taxa, potential impacts can be identified, providing a focus for further investigation.

It has been suggested in the development of indicators that some environmental themes may be more or less relevant for different Functional Process Zones. With regard to the macroinvertebrate theme, there are no Functional Process Zones in which the use of macroinvertebrates to assess river health is inappropriate. Although macroinvertebrates vary in composition in different zones, as long as the conditions with which they are compared are also varied accordingly, the indicators will remain relevant throughout the zones. AUSRIVAS varies the condition to which a site is compared by using sets of 'reference' sites to which a new 'test' site is assigned a probability of belonging, based on physical and locational catchment variables. A chi squared test of the distance of a new site from each of the reference site groups is used to ensure the new site is similar enough to reference sites comprising the model to be assessed. If the site is too far away from any group the site is allocated "outside the experience of the model" and no assessment is produced.

Some discussion was had at the workshop as to whether structural measures were the most appropriate measures in each zone and whether functional measures may be more appropriate for some zones, for example, lowland zones. It was concluded that a change in function without a change in structure is unlikely, and therefore measures of structure represent functional change anyway.

SIGNAL was originally developed for use in perennially flowing upland streams in Eastern Australia; however, national SIGNAL grades were developed by the NRHP and were applied to a wide range of stream types. The use of SIGNAL in ephemeral streams
and large lowland rivers has not been thoroughly assessed. The ISC program developed separate criteria for defining a healthy system in lowland and upland reaches based on SIGNAL scores because of the lower sensitivities of taxa that occur in lowland zones. The use of SIGNAL within the AUSRIVAS program ensures appropriate comparisons, assuming there are an adequate number of lowland reference sites, by generating expected SIGNAL scores that are site specific using a large number of reference sites for comparison. The SIGNAL score used independently of AUSRIVAS does not have this site specificity. However, the sensitivity of SIGNAL may be affected by its use in AUSRIVAS. AUSRIVAS only considers taxa with a 0.5 or greater chance of occurrence, whereas SIGNAL was designed to rate the sensitivity of all taxa present. The workshop agreed that O/E SIGNAL as it is currently calculated is insensitive and some modified form would have to be developed to be useful for the Audit.

- **Responsive to disturbance**

AUSRIVAS O/E scores have been used to demonstrate environmental harm in several recent pollution investigation cases in a number of States and Territories in the MDB. For example, Table A5 shows the use of AUSRIVAS in pollution investigations by the NSW EPA from January to June 2000. Impacts detected by AUSRIVAS scores have been assessed for sites along a known trace metal pollution gradient by Sloane and Norris (submitted). This study showed that AUSRIVAS is a sensitive assessment tool and the AUSRIVAS O/E score is a sensitive indicator for detecting mining impacts. AUSRIVAS was also used in the assessment of the impact of an uncontrolled sewage discharge into Perisher Creek from the Perisher Resort in July 2000. AUSRIVAS detected the impacts of the sewage spill above the normal impact of increased resort use at that time.

**Table A5** The use of AUSRIVAS for pollution investigations by the NSW EPA January – June 2000 (Source: Turak *et al.* 2000 report).

<table>
<thead>
<tr>
<th>Issue investigated</th>
<th>Sites Sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avgas spill into a creek on the Central Coast</td>
<td>2</td>
</tr>
<tr>
<td>Subsidence of rubbish from an illegal tip into a creek in Northwest Sydney</td>
<td>3</td>
</tr>
<tr>
<td>Sedimentation of creeks in the Sydney Catchment area caused by construction activities</td>
<td>4</td>
</tr>
<tr>
<td>Bentonite release into a river in the Sydney Catchment area during construction activities</td>
<td>2</td>
</tr>
<tr>
<td>Overflow of water from tailings dam and mismanagement of runoff from a Bauxite mine in Northern NSW</td>
<td>5</td>
</tr>
</tbody>
</table>

The use of SIGNAL has been validated for the assessment of stream salinisation and organic pollution from sewage treatment plants (Chessman 1995). However, its usefulness for assessing toxic pollution and other types of disturbance is uncertain. Because AUSRIVAS and SIGNAL scores may be sensitive to a different range of impacts (Ladson and White 1999), it is recommended that both indices, AUSRIVAS O/E and SIGNAL O/E, should be used and interpreted together, to ensure the most accurate assessment.

**NSW EPA presented an analysis of the robustness of AUSRIVAS and SIGNAL scores as demonstrated by the assessment of NSW sites. Findings showed that in the assessment of reference sites, O/E taxa and O/E SIGNAL produced stable assessments, with a central tendency around one, whereas number of taxa and raw SIGNAL produced very variable**
assessments for reference sites (Figure A1, Table A6). Little variation was shown in O/E taxa and SIGNAL scores among regions for reference sites, but significant variation was shown in the number of taxa and raw SIGNAL scores for reference sites among regions (Figure A1, Table A6).

Both AUSRIVAS O/E and raw SIGNAL scores were regressed against a pH gradient related to a mine site (Figure A2). AUSRIVAS O/E scores showed a good correlation with pH, but raw SIGNAL scores showed no change with changing pH. Thus SIGNAL is insensitive to some mining impacts. NSW DLWC presented scatterplots of raw SIGNAL and O/E taxa against EC, but these were not corrected for confounding factors and thus interpretation of trends was difficult (Figure A3).

![Figure A1 Assessments at reference sites across natural regions (Source: NSW EPA).](image-url)
Table A6  Pairwise comparisons of assessments at reference sites across natural regions (Source: NSW EPA).

<table>
<thead>
<tr>
<th>Index</th>
<th>Probability</th>
<th>Significant pairwise differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/E taxa</td>
<td>0.0827</td>
<td>0</td>
</tr>
<tr>
<td>O/E SIGNAL</td>
<td>0.0324</td>
<td>1</td>
</tr>
<tr>
<td>Number of taxa</td>
<td>&lt;0.0001</td>
<td>9</td>
</tr>
<tr>
<td>SIGNAL</td>
<td>&lt;0.0001</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure A2  a) pH vs O/E taxa, and b) pH vs SIGNAL (Source: NSW EPA).

Figure A3  Example scatterplots of a) O/E taxa and b) O/E SIGNAL against EC for edgewater habitats (Source: NSW DLWC).

- Measurement and analysis are rapid (analysis is built into reporting of the indicator)

AUSRIVAS sampling protocols are designed to be rapid, with sampling macroinvertebrates involving a single sweep (edge) or kick (riffle, bed) of 10m of habitat with a handnet. Samples are then sorted in the field by live sort (Victoria, NSW, Queensland) or in the laboratory (ACT/Murrumbidgee catchment upstream of Burrinjuck.
storage and South Australia). In addition, several habitat and locational variables are measured and recorded on site as predictor variables but extensive habitat assessments may also be collected. For lab sample processing, sites can be sampled within 1-2 hours and the results reported back within a week, depending on the lab. For live-pick sampling, site time is approximately 2–3 hours with an even shorter turn around time of results.

Analysis of macroinvertebrate data is rapid. AUSRIVAS is downloaded from the internet and run locally on the users machine. Users simply input their invertebrate data using the national coding system and the required list of phys/chem data using the AUSRIVAS predictor variable names into the appropriate spreadsheets. The correct model for the region, season and habitat is then selected and run, with outputs displayed immediately. The user may then save these outputs to a local directory. Both AUSRIVAS O/E and SIGNAL O/E scores can be divided into bands of impairment for reporting, from richer than reference to impoverished.

- **Standardised methods are available and are technically appropriate for State agencies to undertake**

A strength of AUSRIVAS is that the techniques for site selection, data collection, laboratory procedures and analysis have been standardised, which means that results are comparable between operators and regions. AUSRIVAS has been used by each jurisdiction in the Basin, and all jurisdictions have staff trained in AUSRIVAS sampling protocols.

- **Output can be interpreted relatively unambiguously**

The AUSRIVAS program has been tailored to suit a variety of users, including resource managers, scientists and community groups. To suit different users, a number of outputs are produced that range in complexity. Outputs include:

- probability of a site's membership to each site group
- probabilities of all taxa at every site
- number of taxa predicted, expected and observed at a site
- observed and expected SIGNAL scores for a site
- O/E taxa and O/E SIGNAL scores for a site
- a list of taxa collected but not used in the model
- a banding for a site (X, A, B, C, D).

Outputs from AUSRIVAS are relatively easy to interpret. Guidance on interpreting AUSRIVAS outputs is provided in the form of a web-based manual located at http://ausrivas.canberra.edu.au.

- **Indicator has meaning to the wider Basin community**

The AUSRIVAS O/E scores provide a meaningful assessment of condition that can be easily understood by the wider Basin community. For example, an AUSRIVAS Observed/Expected (O/E) score of 0.5 would mean that 50% of the macroinvertebrate taxa expected at a particular site, if it were in 'best available' condition, are missing. Similarly, an O/E SIGNAL score of 0.5 would mean that the sensitivity of the macroinvertebrate community on average at a particular site is 50% lower than if it were in 'best available' condition. While sensitive taxa may still be present in the community, the diversity of
sensitive taxa has been reduced. In their simplest form, AUSRIVAS O/E scores can be converted to bands, providing a broad assessment of stream condition in comparison to reference that has very obvious meaning about the condition of a stream (Table A7). A similar banding can be produced for SIGNAL O/E scores. The labels and interpretation put on the bands may be varied as appropriate, according to the values of the Basin community.

**Table A7 AUSRIVAS bands of impairment**

<table>
<thead>
<tr>
<th>Band</th>
<th>Label</th>
<th>Potential Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Richer than reference</td>
<td>More families found than expected. Mild organic enrichment. Continuous irrigation flow in a normally intermittent stream</td>
</tr>
<tr>
<td>A</td>
<td>Equivalent to reference</td>
<td>Expected number of families within the range found at 80% of the reference sites</td>
</tr>
<tr>
<td>B</td>
<td>Below reference</td>
<td>Fewer families than expected. Potential impact either on water and/or habitat quality resulting in a loss of families</td>
</tr>
<tr>
<td>C</td>
<td>Well below reference</td>
<td>Many fewer families than expected. Loss of families from substantial impairment of expected biota caused by water and/or habitat quality</td>
</tr>
<tr>
<td>D</td>
<td>Impoverished</td>
<td>Few of the expected families remain. Severe impairment</td>
</tr>
</tbody>
</table>

### A2.4 Summary

The AUSRIVAS sampling and assessment approach builds on existing State and Territory programs, expertise, methods and data. The SIGNAL scoring system is already incorporated into AUSRIVAS and therefore, it is possible to use existing models and data to generate both AUSRIVAS and SIGNAL scores, with no development of new indicators required. AUSRIVAS assessments have already been undertaken by all States/Territories in the MDB and each jurisdiction has staff trained in AUSRIVAS sampling and analysis protocols. Good site coverage of the Basin exists through the NRHP. The NRHP can be used as a database for identifying areas of poor site coverage for the Audit. Thus, it is recommended that the standardised sampling protocols of AUSRIVAS be adopted as the assessment tool of the Audit for the macroinvertebrate theme. As the AUSRIVAS O/E score and the SIGNAL O/E score meet all the criteria proposed for selection of indicators, it is recommended that they be used as indicators for this environmental theme.

*The workshop agreed to the use of the AUSRIVAS O/E score as one indicator of condition and some form of SIGNAL as another, but not SIGNAL O/E as it is currently calculated, as it is too insensitive. Either some revision of the calculation of SIGNAL in AUSRIVAS or regionalisation of the raw SIGNAL score would be required. SIGNAL varies naturally over the Basin, therefore different rating systems for different regions would be required if the raw SIGNAL score is used.*
Section A3

Development of indicators for the Murray Darling Basin

A3.1 How the assessment tool and indicators address each FPZ

Ideally, indicators for the Murray Darling Basin should be appropriate for all the major Functional Process Zones and stream types in the MDB. Consistency in the use of indicators across the Basin will reduce complexity in reporting and ensure comparability across the MDB. Appropriateness of using the proposed indicators in each Functional Process Zone and potential limitations of the indicators are considered in Table A8.
Table 8 How AUSRIVAS addresses each FPZ

<table>
<thead>
<tr>
<th>Amalgamated Zones</th>
<th>Upland Zones</th>
<th>Mid-slope Zones</th>
<th>Lowland Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pool</td>
<td>Upland Gorge</td>
<td>Armoured</td>
</tr>
<tr>
<td>Functional Process Zone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference site coverage of zone by existing models</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Main macroinvertebrate habitats</td>
<td>Pool/Riffle</td>
<td>Pool/Riffle</td>
<td>Pool/Riffle</td>
</tr>
<tr>
<td>Sampling area recommended</td>
<td>Main Channel / Edge</td>
<td>Main Channel / Edge</td>
<td>Main Channel / Edge</td>
</tr>
<tr>
<td>Taxa numbers</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Comments</td>
<td>Separate main channel/edge model for these zones</td>
<td>Separate edge/snag model for these zones</td>
<td>More reference sites needed for these zones. Separate edge/snag model for these zones accounting for lower taxa numbers. Combined seasons model.</td>
</tr>
</tbody>
</table>
A3.2 Jurisdictional Review of existing AUSRIVAS models

AUSRIVAS models have been produced for each of the States/Territories in the Basin for a range of stream types. It has been suggested that AUSRIVAS may not be sensitive in lowland Functional Process Zones, and the sensitivity of AUSRIVAS in lowland streams remains largely untested. In initial AUSRIVAS sampling, lowland areas lacked adequate coverage of reference sites. This led to sites being unable to be assessed from these zones because they fell outside the experience of the models produced. Subsequent sampling rounds recognised this problem and sampled more sites from these zones. Not all States/Territories have incorporated these additional reference sites into their models (see Table A9). Thus, if one or more MDB models were to be built, it could include these sites not in existing models.

The major problems with the assessment of lowland zones in each jurisdiction highlighted by Table A9 are:

• poor existing reference site coverage
• low taxa richness

To address the first point, conditions acceptable for reference can be redefined as the 'best available' in areas with insufficient reference sites, and additional reference sites already sampled but not yet included in models can be added. To address the second point, the list of taxa can be maximised by using combined season models. Another option is to lower the taxonomic resolution to species rather than family level. However, this would require re-identification of all samples already collected to enable use of existing data. While this would entail a significant cost, it would be much less than having to revisit and sample all sites anew.

The question was raised at the workshop; how predictable is the macroinvertebrate fauna in lowland rivers? While insufficient reference sites are considered the main limitation for prediction in lowland streams, it is possible that precision may also be a problem. Climatic influences such as flood/drought cycles are likely to be major drivers of ecosystem function in lowland streams and therefore existing predictor variables may be inappropriate. It was proposed that replication of sampling is required to detect the precision of existing sampling protocols. Other questions raised included: what is the appropriate scale for assessment? Is 10 m of edge habitat enough to provide an indication of river health in each FPZ?

A study on area sampled and replication in Thredbo River (Nichols and Norris submitted) found that for replicated 5, 10 and 20 m rapid collections using a D-net that the number of taxa recovered was not significantly different, using lab-sorting. Total abundance was most variable in the 20 m collections, attributed to possible net clogging and backwash. However, all sampling areas were found to be precise, producing the same site assessment using AUSRIVAS.

A similar study has been done in Victoria by Metzeling and Miller (in press), sampling 4 major habitats (riffle, edge, macrophytes and pool rocks), with sampling replicated for 3, 5, 10 and 20 m using live-picking. An increase in species was detected with sample size,
however this was not significant except for riffles. It was found that 10 m was sufficient sampling area for all the habitats sampled.

When the reporting scale of the river valley was considered, it was suggested that replication at the scale of within a site may be unnecessary. However, it was concluded at the workshop that some form of replicated sampling at test sites in each zone would be useful to obtain an estimate of the error in existing collection methods in each main habitat.

The possibility of using species level models was considered at the meeting. Results from Victorian species models were presented. Species level models had narrower bands and seem to be more sensitive, i.e. more sites were failed. However, it is equally likely that species level data introduces more noise and the models are just more variable. It was concluded that there was a need to check how reference site assessments changed through time using all models to determine the most accurate models. It was proposed that existing species and genus models could be assessed using Western Victorian data to determine whether changing the taxonomic resolution is effective in increasing taxa richness and improving accuracy of assessments.
Table A9 Jurisdictional review of existing experiences with AUSRIVAS models.

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Reference site coverage of lowland rivers</th>
<th>Model performance and assessment of sites</th>
<th>Model development status of State/Territory</th>
<th>Other issues particular to States</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Queensland</strong></td>
<td>-Number of lowland reference sites in existing models is low, extra reference sites have now been sampled since these models were created</td>
<td>-Models appear to be working well for upland and mid river reaches -Uncertain of accuracy of model assessments in lowland reaches. Models assess most sites as poor, which is consistent with expectations of sites. However, these rivers have naturally low numbers of taxa, so may be being assessed as worse than they are. Alternatively, relevant reference sites may be significantly altered and thus provide conservative assessments</td>
<td>-QLD have two out of 7 final versions of models. Funding for the other 5 models has recently been approved and development of these models would be expected in the next 6 months. -Existing versions of the models have high misclassification errors and poor group discrimination. The inclusion of microcrustacea in sampling and models may be responsible for poor predictions as more sensitive taxa are not collected.</td>
<td>-Large lowland rivers in QLD may not be able to be compared to large rivers elsewhere because of differences in water quality, for example, conductivity can be naturally high. -It was suggested that regional models within Queensland would be an improvement on existing State models.</td>
</tr>
<tr>
<td><strong>NSW</strong></td>
<td>-Additional reference sites have been added to new models and a separate western region model developed. -The western model is built for lowland rivers (less than 200m altitude) to account for the naturally low numbers of taxa in this area. -Reference sites chosen for the western model were of poorer quality than reference sites in other models.</td>
<td>-Test sites known to be in poor condition from other knowledge of the site are being assessed as poor and reference sites run though the models are coming out as reference, therefore the models appear to be working well -NSW EPA have used AUSRIVAS assessments in a number of pollution cases.</td>
<td>-NSW have all seven statewide models completed. NSW EPA have considerably refined models from earlier versions, with group discrimination and predictor variables improved from earlier versions.</td>
<td>-To obtain sufficient reference sites for models, reference sites were divided into classes of reference: pristine, slightly modified and moderately disturbed -Development of the western lowland model was limited to edge habitat. Taxa lists from two seasons were combined to maximise numbers of taxa</td>
</tr>
</tbody>
</table>
### ACT

**Existing state-wide family models:**
- Autumn edge
- Autumn riffle
- Spring edge
- Spring riffle
- Combined season edge
- Combined season riffle

-A lack of suitable reference sites for assessment of the Murrumbidgee river has been a problem with existing models. Repeat sampling of existing sites is being used to expand the reference data-set, however, these sites have not been incorporated into the models as yet.

-Test sites assessed by AUSRIVAS along a known gradient of impairment were assessed as impaired by the models.

-Reference sites assessed by the models are generally assessed as in reference condition, with the exception of reference sites affected by drought conditions.

-All six models for the ACT have been developed to final versions.

-In periods of drought, riffle habitat may disappear in ACT, thus edge sampling is relied upon for an assessment.

### Victoria

**Existing state-wide family models:**
- Autumn edge
- Autumn riffle
- Spring edge
- Spring riffle
- Combined season edge
- Combined season riffle

-7 regional family models, edge and riffle
- 3 genus models
- 2 species models
- 2 urban models, family and species

-No models have been specifically built for lowland areas, but 7 regional models have been developed for the State, in addition to the statewide models, which cover lowland areas.

-Both state-wide and regional models appear to be providing similar and accurate assessments.

-Victoria is one of the few States that has used transformed predictor variables, which seems to be improving predictions.

-In addition to developing final versions of regional models, final versions of all state-wide models exist. Preliminary results indicate that regional and state-wide models provide very similar assessments. Where results differ, the regional assessment is taken, as group discrimination appears better.

-Victoria have also developed some genus and species models to investigate the effect of increased taxonomic resolution on model predictions but analysis of these models has not yet been undertaken.
### South Australia

**Existing state-wide family models:**
- Autumn edge
- Autumn riffle
- Spring edge
- Spring riffle
- Combined edge
- Combined riffle

- Sites in the lowland constrained zone of the Murray have naturally high salinity and fall outside the experience of existing models because of insufficient reference sites.
- Site assessments for other rivers and zones in South Australia appear to be accurate.
- SA EPA have used AUSRIVAS assessments in a number of pollution cases.
- 6 existing models for the State are currently used for assessments.
- The models are to be rebuilt in March 2001 to include enough naturally salty Murray sites to form a classification group in the models.
- Because lowland sites have naturally lower numbers of taxa, band widths of models may increase and other test sites may be assessed as better than they are. Thus O/E values should be interpreted in preference to bands.
A3.3 Development of models for the MDB versus using existing State/Territory models

Potential modelling options:

1. Use existing State models

A set of predictive models already exists for each State/Territory and could be used for the Audit for the assessment of new or existing test sites. Most States/Territories have a main channel and edge model already developed (Table A9). Thus, it would be possible to use existing models and existing data to generate both AUSRIVAS and SIGNAL scores, with no development of new models required. However, potential problems are insufficient reference sites for the assessment of some lowland zones, as reference sites for existing models are generally defined as 'minimally disturbed', not 'best available' as agreed on for the Audit. Some existing models also have predictor variables that may be inappropriate for lowland streams. Lowland systems are quite different in nature to upland systems, for example in their substrate composition. There are naturally more fines in lowland systems but this can also be an impact. Available habitat in channels and run/riffle/pool ratios is lower in lowland systems and riparian vegetation may be naturally low in lowland systems but scores as disturbed. Although AUSRIVAS models are ideally comparable across the nation, differences in macroinvertebrate sample processing protocols between States and Territories may also have some influence on the comparability of models across the Basin. In the MDB, Queensland, NSW and Victoria all use the live-pick processing protocols, whereas ACT and South Australia use lab-sort processing protocols. However, this should not be a problem provided the methods appropriate to each of the models are followed.

2. Development of a MDB model.

Development of one model for the whole MDB would resolve the differences that currently exist with a range of State/Territory models. However, a potential problem with this option is the large scale the model would have to account for. Modelling experiences to date indicate smaller regional models produce better predictions than large-scale models. At the large scale, locational variables discriminate best between the biota, whereas at smaller scales more specific habitat features become important. Predictor variables would most likely be restricted to locational variables, such as latitude, longitude, altitude, stream order etc. Predictor variables would be restricted to variables common to all State and Territory data-sets (and measured in the same way). Combining macroinvertebrate data from different States and Territories is likely to introduce some bias because of differing sample processing methods, as even data collected using the same sample processing method may have slight collection differences between States and Territories. This issue is relevant to all the modelling options and all the methods considered in this review. One solution to this issue of combining data is to assume that all the methods are basically measuring the same things; thus the result can be turned into a dimensionless score and be comparable.

3. Develop several regional (subcatchment models) within the Basin.

Development of several regional models would reduce the scale of model coverage from the MDB to a subset of Basins. Obviously these splits would make more ecological sense than jurisdictional boundaries on which existing models are based. This option has the
same issues regarding combining of physical/chemical and biological data across the Basin as discussed above.

4. Development of models for each Functional Process Zone or Valley Process Zone.

- Because AUSRIVAS matches sites independently for comparison using physical and chemical measures, models for each FPZ are not necessary for choosing reference conditions. However, because different habitats are more appropriate to sample in each Functional Process Zone, different models will be required for each habitat. This may also enable selection of more appropriate predictor variables for upland and lowland sections. Alternatively, models could be created for each Valley Process Zone (upland, mid-slope and lowland). Some regionalisation may be required with this option, as Queensland rivers for example would not necessarily be comparable with Victorian rivers.

The workshop decided unanimously that a single model for the whole Basin would be on too big a scale to provide good predictions. It would also require combining different sampling methods and habitats, possibly requiring resampling of all sites. Regionalisation of models in Victoria and NSW has demonstrated the utility of regional models, with outputs more accurate and robust. It was proposed that regional models be recommended to be developed and tested. A stepwise process to assess the best model option in each case should be used, for example, existing models may be available in some areas that are robust and no new models are required. In other regions new models are needed and considerations include the scale of the region, the taxonomic resolution of the model and the possibility of combining data-sets across State boundaries. It was proposed that one model for the western parts of Victoria, NSW and Queensland may be appropriate, or a further division into FPZs in this area. Initially, combining of data for these States seems possible. All though slightly different protocols are used, all three States use the live-picking method for sample processing. It was proposed that comparability of State models could be assessed by comparing assessments of sites in overlapping regions, for example, assessment of NSW sites in Queensland models and vice-versa.

A3.4 Sample season and habitat

The original scoping study document recommended that edge models be used if existing models are used. However, after consideration of the appropriateness of models for each FPZ (Table A8), it is recommended that main channel or edge models be used for amalgamated upland zones, and edge or snag models for other zones, whether existing or new models are used. Climatic changes may affect the availability of both main channel and edge habitats to macroinvertebrates, with changing wetting and drying regimes. However, these are temporary extremes in climate and the sampling seasons autumn and spring generally avoid the severest of these extremes. Combined model data have been shown to provide the most robust assessment for all zones at the scale of a site, because the taxa list is maximised and seasonal biases are less influential. Using combined data means that new assessments would be delayed until both a spring and autumn sample had been collected from a site. However, existing test site data sampled in two seasons could be assessed immediately. If rapid assessments for new sites were required, existing single season models could be used for this purpose.
Sampling of snags was discussed by the workshop, and it was concluded that the fauna collected on snags are not predictable enough to be modelled. The number of taxa collected is very variable, and taxa numbers found in this habitat are often low. NSW DLWC suggested that existing edgewater models are insensitive to some disturbances. However, NSW EPA presented results from the Western combined edge model that demonstrated the model was working well. Both riffle and edge models for the eastern part of NSW were able to detect impacts of pH related to a mine and have been used to demonstrate a range of impacts in the past.

There was some concern about the recommendation to use combined season models, as the time gap between assessments may mean important changes are missed. As two seasons have to be sampled anyway to produce a combined season assessment, the workshop agreed that single season assessments should also be done where taxa numbers are high enough to enable a robust single season model. It was also recommended that more assessment of single season vs combined models was required. Replication of assessments within a season was proposed as another way of maximising the list of taxa collected.

A3.5 Sampling design, precision and reporting scale options

The workshop was asked to make a recommendation based on best scientific judgement of what would be an acceptable level of precision for indicators. The acceptable amount of change that could confidently be detected was recommended as 0.1 or 10% change in an AUSRIVAS O/E score. As the true mean of a river valley should equal one, this represents a 10% change (i.e. a change in O/E50 of 0.1). To obtain this level of precision, confidence limits of ± 0.05 around the mean for a river valley would be required. For any form of SIGNAL it was suggested that 5% change in the range of variation would be acceptable, which would require confidence limits of ± 0.025 to obtain this level of precision.

Reporting scale options include:

- reporting at the river-valley scale only
- reporting at the Functional Process Zone scale, which allows the option of aggregating to the river-valley scale as well
- reporting at the scale of Valley Process Zones (upland, mid-slopes, lowland), which allows reporting at the valley scale
- reporting assessments at the river-valley scale, with extra sites in areas of specific interest enabling reporting also at the FPZ scale for these catchments or at sites of specific interest or concern.

While a State or regional model may be used to assess sites, the reporting scale of results can still be at the scale of Valley Process Zones or the river valley, providing the reporting scale is determined prior to the sampling design, to ensure sufficient site coverage and statistical power for robust results.
A3.6 Reference condition

The definition of river health that has been adopted by the Audit emphasises comparison relative to natural habitats within a region: "the degree to which aquatic ecosystems support and maintain processes and a community of organisms and habitats with a species composition, diversity, and functional organisation relative to that of natural habitats within a region". Existing AUSRIVAS models use the definition of 'minimally disturbed' for reference condition. This may be a limitation to assessing sites using existing State models with insufficient 'minimally disturbed' lowland sites are available for comparison. Generally, the majority of reference sites in AUSRIVAS models are from smaller stream orders, with fewer reference sites from large lowland rivers. However, test sites from large rivers must be compared to reference sites also from large rivers for a relevant comparison, because lowland large rivers have naturally lower numbers of taxa in comparison to smaller upland streams. The reference condition that has been accepted for the Audit is 'best available' natural habitats (progress report). Thus, development of any new models for the MDB should use this definition. 'Best available' reference for upland sites may be minimally disturbed in many cases. However, 'best available' for lowland streams is likely to be those sites with good management practices for example, considering that for many lowland sites, minimally disturbed conditions are not likely to be encountered.

Therefore, existing reference sites will require redefining to meet the definition of 'best available' and extra reference sites will need to be included in models, whether new or existing models are used. Several approaches are proposed for defining reference condition for macroinvertebrate indicators.

1) Use existing data. Most reference sites for AUSRIVAS predictive models use the definition of minimally disturbed that is equivalent to 'best available'. In areas with insufficient reference sites, for example, lowland zones, define 'best available' reference in conjunction with State agencies (this would require rebuilding of predictive models if additional reference sites were to be added to the models).

2) Another way of defining best available for each river type is to use a reference hierarchy. For example, the NSW EPA divided their reference sites into three classes, A, B and C. The classes A and B indicate near pristine and slightly modified reference sites respectively, with C indicating moderately disturbed sites. Moderately disturbed sites were nominated as the 'best available' reference sites where more appropriate reference sites were not available for that type of river.

3) Use of specific criteria to define 'best available'. The following criteria are an example, they were used to redefine reference sites for the Queensland WAMP process (Table A10). Sites were considered to be in reference condition if they passed all criteria (P), or failed only one criterion (PC - conditional pass) as long as it was not the one relating to upstream dams and weirs. All sites failing this criterion were failed as were those failing a total of two or more criteria (F).

Considerable discussion was had at the workshop and in previous meetings about reference condition. It was concluded that the move away from minimally disturbed as the reference condition was inevitable, and indeed, all States agreed that in existing AUSRIVAS models not all reference sites are minimally disturbed. The management implications of setting reference were considered (downward and upward spirals of
condition) and the importance of recognising we are setting a condition for comparison, we are not setting targets. The changing definition of reference over time was also a concern. If an upward spiral model of condition is used where the comparison condition improves over time for example, how will trends be detected over time? It was suggested that all data could be run through new models as they became available and past condition assessments possibly revised. It was accepted that more information would always be revealed over time. The use of Alternative 3 (below) would enable a static point from which to measure change over time.

NSW DLWC proposed a number of options for dealing with the fact that not all reference sites are near pristine or minimally disturbed.

Alternative 1: Use SIGNAL with a rating system to adjust for natural variation (e.g. rainfall).

Alternative 2: Modify Audit definition of healthy to mean "minimally disturbed" where such rivers exist and "well managed" where they don't.

Alternative 3: Use an assessment method that incorporates both departure from "reference" and departure of "reference" from "natural". To do this;

- Agree on criteria for “less disturbed” or “better managed” sites
- Develop measures of departure of fauna from reference (O/E-taxa and others)
- Develop measures of departure of environment from natural (e.g. current vs modelled natural flow regime)
- Combine these measures into alternative “health” indicators
- Test these alternative indicators for sensitivity to known disturbances

It was agreed that Alternative 3 would be good solution to the problem of "natural" in the existing definition of river health and a good way to measure how far away we have moved from "natural". It was proposed initially that State models could be used and reference assessed relative to natural using a disturbance index such as RDI or perhaps the Queensland method of scoring each of the criteria used for reference site selection (above). Other methods may also be considered, such as using the conceptual models of river function. This approach would be immediately applicable.

In lowland areas where no appropriate conditions for comparison are available, the notion of a hypothetical natural was considered, possibly using the conceptual models of river function. While it is inevitable that reference is likely to be defined differently for different themes, reference condition for each indicator needs to be the same to ensure comparability. The use of a measure of departure of "reference" from "natural" ensures comparability, even if the "reference" is variable across a region.
Table A10 Criteria used for selecting reference sites in Queensland for WAMP Ecological Assessments.

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference Condition Selection Criteria</th>
</tr>
</thead>
</table>
| 1   | No intensive agriculture within 20 km upstream.  
      Intensive agriculture is that which involves irrigation, widespread soil disturbance, use of agrochemicals and pine plantations. Dry-land grazing does not fall into this category. |
| 2   | No major extractive industry (existing or historical) within 20 km upstream.  
      This includes mines, quarries and sand/gravel extraction. |
| 3   | No major urban area (> 5000 population) within 20 km upstream  
      If the urban area is small and the river large, this criterion can be relaxed. |
| 4   | No significant point source waste water discharge within 20 km upstream.  
      Exceptions can again be made for small discharges into large rivers. |
| 5   | No dam or major weir within 20 km upstream.  
      Sites within the ponded area of impoundments also fail. Sites failing this criterion automatically fail the overall assessment. |
| 6   | Seasonal flow regime not greatly altered.  
      This may be by abstraction or regulation further upstream than 20 km. Includes either an increase or decrease in seasonal flow. |
| 7   | Riparian Zone of natural appearance.  
      Riparian vegetation should be intact and dominated by native species. |
| 8   | Riparian Zone and banks not excessively eroded beyond natural levels or significantly damaged by stock.  
      Stock damage to the stream bed may be included in this category. |
| 9   | Stream Channel not affected by major geomorphological change.  
      Geomorphological change includes bank slumping, shallowing, braiding and unnatural aggradation or degradation. |
| 10  | Instream conditions and habitats not altered.  
      This may be altered by excessive algal and macrophyte growth, by sedimentation and siltation, by reduction in habitat diversity by drowning or drying out of habitats (e.g. riffles), by direct access of stock into the river. |

A3.7 Interpretation of indicators

The AUSRIVAS O/E score and the SIGNAL O/E score have been proposed as the main indicators for the macroinvertebrate theme. However, AUSRIVAS as an assessment tool provides a range of other outputs that could be used for interpretation to improve the understanding of a system. Important ecological information is available by examining the list of taxa collected at a site, and also those expected at a site that weren't collected. Knowledge of the sensitivities of macroinvertebrates to various impacts and their functional roles in an ecosystem is significant and could aid in the interpretation of condition. While O/E scores are proposed as the primary indicators of condition, there is value in having another level of detail underneath these indicators at the interpretation stage, providing understanding of the processes that are occurring in a stream relative to those described in the conceptual models of river function.

A study on the Lithgow mine site by NSW EPA demonstrated the usefulness of other AUSRIVAS model outputs, such as the list of predicted taxa, for interpreting model assessments. They proposed that assignment of taxa to sensitivity categories could be used to detect specific impacts using the known tolerances of specific families/species.
SEPPs in Victoria use a list of key invertebrate families derived for each region, similar to a list of expected families predicted by AUSRIVAS. The list of key families provides an indication of habitat availability as well as water quality. A separate list for each region is necessary to account for differences in altitude, topography, stream size, flow, temperature, etc. The list of key families is based on a range of habitats, stream sizes and stream types within a region; therefore it is unlikely that a site would have all key families present. A percentile of the distribution of reference sites (10th, 30th) is used to set objectives for the indicator.

Key invertebrate families are determined for SEPPs as:

- typically found in the types of stream in that region
- representative of a particular habitat type
- representing reasonable to good water quality, tending to disappear as conditions deteriorate
- are commonly collected when present (50% or greater chance of occurrence), using the recommended method to sample edges and riffles

A similar list of key families could be derived for each FPZ or region using the predicted list of taxa for reference sites in a FPZ or region. These taxa lists could be added to the conceptual models of river function and used to provide information about the habitat availability and water quality at a site.

A3.8 Frequency of assessment

The workshop was asked to comment on what they thought would be an appropriate timeframe for assessment. A number of options were proposed but there was little agreement. Options included:

- A fixed set of sites sampled once every five years
- Sampling fewer sites more times (may be more statistically effective)
- A mixed sampling design, some sites fixed, some sites only every five years

It was recommended that the sampling design and frequency be determined by the statistical power required to maximise detection of trends for the reporting scale/s decided on by the taskforce.
Section A4  Summary and Recommendations

Section A1.

- A number of programs exist in the MDB which sample macroinvertebrate data. Of these programs only the NRHP and Waterwatch have a Basin-wide coverage.

Section A2.

- The assessment tool most common to the macroinvertebrate sampling programs is AUSRIVAS. The indicators most common to all the programs are the AUSRIVAS O/E score and the SIGNAL O/E score. This assessment tool and indicators build the most effectively on existing data, which is a Audit project objective, and meet all the other criteria proposed by the CRCFE for selection of indicators. Therefore, it is proposed that AUSRIVAS be used as the macroinvertebrate assessment tool for the Audit and the AUSRIVAS and SIGNAL O/E scores be used as indicators for the macroinvertebrate theme.

There was unanimous agreement on the recommendation to use the AUSRIVAS O/E taxa score as an indicator. Further consideration of the options for SIGNAL was recommended as O/E SIGNAL as it is currently calculated is too insensitive.

Section A3.

- It was proposed that one approach for sampling, analysis and reporting would be to use upland, mid-slope and lowland sections (VPZs) for the macroinvertebrate theme.

- Potential problems identified with existing AUSRIVAS models in each jurisdiction were the potential poor reference site coverage of lowland zones by some models and the lower taxa richness of lowland zones. As reference sites in existing models are defined as minimally disturbed, using the definition of best available and including additional sites sampled but not in the models would substantially increase the reference site coverage of models. Splitting the models into broad zones, using combined season models, and lowering the taxonomic resolution to species level, were proposed to address the lower numbers of taxa in lowland zones.

The merits of using genus/species data will be assessed using Western Victorian data.

- As reference condition for the Audit is defined as 'best available' and existing sites may need to be redefined to meet this definition, a number of approaches were proposed. As well as redefining reference sites, extra reference sites not included in existing models also need to be added. Therefore, redevelopment of existing State models seems necessary if they are to be used for the Audit. Redevelopment of existing models or creation of MDB models does not require collection of new data, therefore these options build effectively on existing data.

It was accepted to use "reference" as currently defined but to use departure from ‘reference’ and departure of ‘reference’ from ‘natural’ as a way of benchmarking condition to ‘natural’.
One option proposed for development of new models was to create a model for the VPZs in each State, incorporating new reference site data not included in existing models. This would enable appropriate habitat models relevant to zones, while using existing data. Reference sites and predictor variables appropriate to zones could then be used in the models.

Potential Basin models include:

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland</td>
<td>Upland, Mid-slope, Lowland</td>
</tr>
<tr>
<td>NSW</td>
<td>Upland, Mid-slope, Lowland (NSW already has a western edge combined season models that could be used here)</td>
</tr>
<tr>
<td>ACT</td>
<td>Upland</td>
</tr>
<tr>
<td>Victoria</td>
<td>Upland, Mid-slope, Lowland</td>
</tr>
<tr>
<td>South Australia</td>
<td>Lowland</td>
</tr>
</tbody>
</table>

This would give a total of 11 models for the MDB.

Regionalisation was recommended as the preferred approach to be explored, possibly in combination with existing models, dependent on the ability to combine data across State boundaries. Existing models should be used initially while development issues for regional models are investigated, e.g. taxonomic resolution, sample habitat, season, data compatibility.

- It was proposed that habitat models be developed that are appropriate to the Functional Process Zones and the conceptual models of river function. Thus, for the amalgamated upland zones, main channel or edge was proposed as the sampling habitat. In the mid-slope and lowland zones, the edge was proposed as the sampling habitat.

Snags were not recommended as a suitable sampling habitat for predictive modelling.

- Combined season models are recommended for all lowland zones to obtain the largest possible taxa list and average the effect of seasonal influences, providing the most robust assessment.

It was recommended that combined season models should not represent the only assessment in upland and mid-slope zones where taxa numbers were higher and that single season models should be used in preference to combined season models if only one assessment was done.

The frequency of assessment should be determined by the statistical requirements; the aim being to maximise the power to detect trends.

- The existing NRHP data-set is proposed as a baseline data-set for which gaps in test site coverage may be identified and further sampling recommended.
- Four options for the sampling and reporting scale were proposed:
  - reporting at the river-valley scale only
  - reporting at the Functional Process Zone scale, which allows the option of aggregating to the river-valley scale as well
- reporting at the scale of Valley Process Zones (upland, mid-slopes, lowland), which also allows the option of aggregating to the river-valley scale
- reporting assessments at the river-valley scale, with extra sites in areas of specific interest enabling reporting also at the FPZ scale for these catchments.

The decision on reporting scale should be determined by the taskforce prior to sampling, informed by the level of precision and number of sampling sites required. The ability to detect a change of 10% was considered the maximum acceptable for an AUSRIVAS O/E score and 5% for a SIGNAL score.

- Additional AUSRIVAS outputs not proposed as indicators were suggested as valuable aids for the interpretation of stream condition and ecosystem functioning, in conjunction with the conceptual models of river function.

The conceptual models of river function should be used in interpretation as well as AUSRIVAS outputs additional to those used as indicators. Key families should be identified for each FPZ or region and added to the conceptual models of river function.
PART B
Development of Methods and Indicators
Section B1
Indicators

To assess condition for the macroinvertebrate theme, measures of structure and sensitivity were chosen. Two indicators have been proposed, the AUSRIVAS O/E taxa score and a version of the SIGNAL score.

O/E SIGNAL as it is calculated currently in AUSRIVAS has been demonstrated to be insensitive in some cases, as has the raw SIGNAL score (see section 2.3 of review and Figures B1, B2 below). However, the SIGNAL index can give valuable information in many cases about the sensitivity of taxa to impacts and is worthwhile including as an indicator. Raw SIGNAL was used in the Index of Stream Condition (ISC), with threshold scores regionalised to resolve differences between SIGNAL scores for upland and lowland sites and different types of rivers. Use of SIGNAL in AUSRIVAS has the advantage of giving a site specific expected SIGNAL score for a site, taking into account other influences such as location and season in the expected score. However, AUSRIVAS only uses those taxa that are predicted with a 50% or greater chance of occurrence in the calculation of a SIGNAL score. It is considered that including all taxa collected may improve the sensitivity of SIGNAL in AUSRIVAS. Thus, development and testing of alternative calculation of O/E SIGNAL scores and regionalisation of scores is recommended for the first year of the Audit. As the SIGNAL O/E value as currently calculated is insensitive and the raw SIGNAL score is not regionalised, use of SIGNAL in either of its existing forms would be inaccurate. For example, Figures B1 and B2 show that SIGNAL O/E as it is currently calculated is insensitive to impairment and consistently over-estimates site condition. Therefore, the first year of reporting should only include the AUSRIVAS indicator while the robustness of the SIGNAL indicator is improved.

**Figure B1** The same NSW AUSRIVAS test sites assessed using a) O/E taxa and b) O/E SIGNAL. The skewed distribution of O/E SIGNAL demonstrates the insensitivity of O/E SIGNAL as it is currently calculated to impacts.
Section B2
Methods

B2.1 Sampling Methods

The sampling methods will follow the rapid sampling protocols currently used for AUSRIVAS models. This requires collection of macroinvertebrates from 10 m of a single habitat using a sweep/kick net. Samples are then processed by "live-picking" in the field or "lab-sorting" in a laboratory. Sample collection and processing methods are particular to jurisdictions and in some cases, models. Sample collection, processing and quality control procedures used by each jurisdiction are detailed in manuals available on the AUSRIVAS website (http://ausrivas.canberra.edu.au).

B2.2 Spatial coverage of AUSRIVAS models

The same spatial scale should be used for both AUSRIVAS and SIGNAL indicators, whether AUSRIVAS models or stand-alone indices are used to calculate SIGNAL scores. Scales proposed for consideration for models/indicators were statewide, Basin wide, regional and Valley Process Zones. Regionalisation was recommended by the review as
the preferred option for testing and development. However, it is proposed that existing models be used initially for the first year of assessment while development issues for other models are investigated. A stepwise process is suggested for the selection of the most appropriate models for each region to be developed. Existing models should be evaluated and possible options for new models considered. A decision tree for selecting models is proposed in Figure B3. A similar decision tree may be used for determining the most appropriate SIGNAL scoring system across the Basin, e.g. are existing SIGNAL scores available?; are they appropriate for each FPZ?: yes— use existing; no— develop regional signal scores/references appropriate to each model/region.
Figure B3 Decision tree for model selection
Table B1 Proposed modelling options for the Murray Darling Basin

<table>
<thead>
<tr>
<th>Assessment for 1st year of Audit</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Use existing State models (Queensland, NSW, South Australia, ACT)</td>
<td>-can be used immediately</td>
<td>-not appropriate for all FPZs (problems with low taxa nos, ref sites, etc.)</td>
</tr>
<tr>
<td>-Use existing regional models for remaining parts of Victoria and western regional model for western NSW</td>
<td>-already developed and tested, improvement on State models, able to be used immediately</td>
<td></td>
</tr>
</tbody>
</table>

Concurrently in 1st year of Audit

- Evaluate existing models and explore development of regional model for western Queensland (possibly combine with NSW and Victoria western region models to form a western Basin model)
  - increased taxa list and reference sites, more appropriate predictor variables, comparing rivers with low taxa numbers
  - Victorian and NSW western models already exist
  - existing data must be able to be combined if one large western model was adopted

- Develop regional models for remaining parts of NSW and Queensland, South Australia
  - improvement on existing State models
  - new models required

B2.3 Frequency and season of assessment

The frequency of assessment and the sampling design should reflect the most statistically effective way to maximise the power of the design to detect both spatial and temporal trends. Two main options are available, to sample more intensively and less frequently and to sample less intensively but more frequently.

To sample more intensively and less frequently suggests more interest in quantifying the nature of the long-term trend in the data (Figure B4a). To sample less intensively and more frequently suggests more interest in quantifying the long-term trend and the seasonal fluctuations in the data (Figure B4b). Subsequently, it is likely that the best sampling strategy is dependent on the index being used but ultimately it may be a compromise between two conflicting needs. If quantification of the long-term trend is the priority then increased power is available by reducing variability in the model by sampling only in one season.
Thus, the consequences of each sampling option are as follows:

1) **sampling twice a year (combined season model or two single season assessments)**
   - more frequent, less intensive; also estimates long term trend but partitions out the effect of seasonal fluctuations
   - sampling twice a year required (cost implications)
   - the number of taxa collected is maximised, but an averaged assessment of condition from two seasons is provided

2) **sampling once a year (single season model)**
   - less frequent, less intensive, more extensive — enables a greater number of sites to be sampled
   - one sample per site per year, more cost effective
   - single snapshot measurement of site provided

While seasonal influences have been shown to be an important factor in the analysis of macroinvertebrate data, use of an O/E score takes into account seasonal influences in the expected value. Therefore, if O/E indicators are used it is not necessary to sample more frequently and account for seasonal variation. Thus, of the options proposed, a single season model is likely to be the most effective for detecting long term trends at the valley scale where the numbers of taxa are high enough to provide robust predictions, because sampling density can be increased for the same cost. However, in western regions, combined season models may be required to provide an adequate taxon list. Thus, a cost effective option may be to use single season models in upland areas, possibly sampling the full range of sites in different seasons to even out costs and workload, and using combined season models in lowland areas. However, if individual State agencies see the need for seasonal site assessments they may decide to sample all sites in both seasons and have the opportunity for both individual and combined season assessments. Inevitably, this will reduce the overall number of sites that can be assessed in the available budget. Ultimately the number of sites that can be sampled will be determined by the reporting scale chosen.
B2.4 Sample habitat

It was recommended by the review, that the most appropriate sampling habitat for each FPZ/VPZ should be used. In most cases an appropriate habitat is already being used for assessments, but where this is not the case new models may have to be developed.

B2.5 Taxonomic resolution

It was proposed by the review that species and genus models already developed for Western Victoria should be used to test whether changing the taxonomic resolution is likely to be effective in increasing taxa richness in lowland zones. A main concern is that models are more sensitive, not just more variable, when compared to existing AUSRIVAS models. Accuracy of assessments will be tested by analysing how Western Victorian reference site assessments change over time, assuming that little overall change in assessment would be expected in a reference site that has not been impaired. After testing, models with altered taxonomic resolution should be developed where appropriate.

Section B3

Analysis

Analysis of both indicators, O/E taxa and O/E SIGNAL, will be against a reference condition. Analysis using AUSRIVAS calculates what is expected in terms of reference condition for a particular site and compares this to what is observed (O/E ratio). This indicator generally ranges from 0 to 1, although it is possible to exceed one in some circumstances. Both AUSRIVAS O/E taxa and O/E SIGNAL scores are calculated in this way, giving a score of condition for a site in terms of an appropriate reference. Use of a regionalised raw version of SIGNAL uses a predetermined reference threshold that is not site specific.

B3.1 Reference condition and possible adjustment

It was recommended by the review that assessment methods for the macroinvertebrate theme should incorporate a measure of departure from reference and departure of reference from natural, to account for the varying definition of reference condition currently used. To do this, reference sites can be scored against criteria; for example, the criteria used for selecting reference sites for Queensland in the WAMP process (Table B2), The River Disturbance Index, the conceptual models of river function for each FPZ or even against a narrative description.
Table B2 Selection criteria for reference sites used in the Queensland WAMP process.

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference Condition Selection Criteria</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No intensive agriculture within 20 km upstream. Intensive agriculture is that which involves irrigation, widespread soil disturbance, use of agrochemicals and pine plantations. Dry-land grazing does not fall into this category.</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>No major extractive industry (existing or historical) within 20 km upstream. This includes mines, quarries and sand/gravel extraction.</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>No major urban area (&gt; 5000 population) within 20 km upstream. If the urban area is small and the river large, this criterion can be relaxed.</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>No significant point source waste water discharge within 20 km upstream. Exceptions can again be made for small discharges into large rivers.</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>No dam or major weir within 20 km upstream. Sites within the ponded area of impoundments also fail. Sites failing this criterion automatically fail the overall assessment.</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Seasonal flow regime not greatly altered. This may be by abstraction or regulation further upstream than 20 km. Includes either an increase or decrease in seasonal flow.</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Riparian Zone of natural appearance. Riparian vegetation should be intact and dominated by native species.</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Riparian Zone and banks not excessively eroded beyond natural levels or significantly damaged by stock. Stock damage to the stream bed may be included in this category.</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Stream Channel not affected by major geomorphological change. Geomorphological change includes bank slumping, shallowing, braiding and unnatural aggradation or degradation.</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Instream conditions and habitats not altered. This may be altered by excessive algal and macrophyte growth, by sedimentation and siltation, by reduction in habitat diversity by drowning or drying out of habitats (e.g. riffles), by direct access of stock into the river</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>SUM                                                                                                   /30</td>
<td></td>
</tr>
</tbody>
</table>

For example, this scoring method was used for the WAMP process: each criterion is assessed as a ‘pass’ or ‘fail’. A ‘pass’ is automatically assigned a value of ‘3’; a ‘fail’ is then allocated a numerical value according to the level of impact:

1. greatest impact
2. moderate impact
3. no/little impact.

Scores are summed and reference condition assigned to sites where total is >26 (except where Criterion 5 scores a ‘1’ or ‘2’, in which case the site records a ‘fail’). For the Audit, scores could be used to provide a measure of departure from reference. e.g. if reference is considered a score of 26, a site with a score of 17 would have moved away from reference by 35% (-0.35).

Steps proposed are:

- Agree on criteria for “less disturbed” or “better managed” sites.
• Develop measures of departure of fauna from reference (O/E taxa reference=1) and site from reference (scoring against reference criteria or other).

• Develop measures of departure of environment from natural (e.g. existing vs modelled natural flow regime, River Disturbance Index (RDI), conceptual model or narrative description).

• Combine these measures into alternative “health” indicators that can be aggregated to the valley scale.

• Test these alternative indicators for sensitivity to known disturbances.

A decision hierarchy (Figure B5) can aid selection of the most appropriate reference sites. This decision tree has already been used informally for reference site selection for existing AUSRIVAS models by most jurisdictions. However, measures of departure from reference and natural have not been used. Therefore, in most cases, more appropriate reference sites are not likely to be available and existing models will be used. Where additional sites are added, the AUSRIVAS models will have to be rebuilt.

**Figure B5** Reference condition decision tree
B3.2 Integration and aggregation of scores to produce an assessment

No integration of indicators will be done in the first year of the Audit to produce a macroinvertebrate assessment, as SIGNAL in its existing forms has been shown to be insensitive in a number of cases. Thus, only the AUSRIVAS score should be reported in the first year while the sensitivity of the SIGNAL score is improved. After the first year, integration of a new version/calculation of SIGNAL indicator with the AUSRIVAS O/E indicator should follow the procedure reported by Barmuta et al. (1996) below, to produce a single score if required. However, caution should be used in reporting a single number and where possible indicators should be reported separately, as they represent different information about the health of a stream. The AUSRIVAS O/E taxa score reports on structural features of the community, whereas the SIGNAL score informs on sensitivity of macroinvertebrate taxa. Rather than combine indicators, Barmuta et al. (1996) recommend reporting of the indicator score that is the further away from reference, to be conservative.

Barmuta et al. (1996) state

‘Both O/E FAMILIES and O/E SIGNAL can vary from 0 to greater than 1 (the observed values of both indices are set to zero if no expected families are present). However, simply averaging the two indices is a poor method of combining them, this is because O/E SIGNAL is less variable amongst reference sites than O/E FAMILIES, and so the two indices are not strictly commensurate. Accordingly, a set of rules based on banding the two indices separately is most appropriate. There are many different ways that indices could be combined (Institute of Freshwater Ecology 1991), and several options were canvassed in the regional workshops and discussed by the expect panel. For the time being the most precautionary approach was favoured by the potential end users so that test sites were allocated to the band that was farthest from reference conditions based on the values of either index. In some cases this may mean that "borderline" sites may be banded lower than they should be. However, there seemed to be general consensus that this risk was justifiable on three grounds. Firstly, the procedure is a rapid bioassessment procedure and is, therefore, less sensitive than more time consuming and expensive quantitative procedures. Secondly, the margin of error or confidence intervals for the indices cannot be estimated yet, so the most precautionary approach was also the most defensible. Thirdly, adopting the "worst case" was the simplest rule and the most publicly accountable.’

Aggregation of scores to the river-valley scale/VPZ scale will follow the general principles of aggregation that will be used for each theme, reporting theme condition for a river-valley as a median river-valley score (see Final Report).
Section B4

Sampling design

B4.1 Precision and number of sampling sites

Detection of a 10% change (a change of 0.1 in an O/E score) has been recommended as appropriate for the AUSRIVAS O/E score and 5% change for the SIGNAL score. For a valley assessment, this means that one macroinvertebrate taxon lost out of 10 macroinvertebrate taxa present would be able to be detected. This is considered a significant level of change that should be detectable. However, because the SIGNAL scoring system is less variable, smaller changes of 5% need to be able to be detected in the index (Figures A3, A4). Detection of 10% change in an AUSRIVAS O/E taxa score and 5% in an O/E SIGNAL score on average represents approximately half a band change in each indicator, respectively. Hence, these precision levels are considered the most appropriate and biologically sensitive levels for each indicator. An analysis of the sample size required to achieve this level of precision was performed for the AUSRIVAS O/E score to identify if such levels of precision were realistic. No sample size analysis was performed for the SIGNAL indicator as the version of SIGNAL that will be used has not yet been determined and reporting of this indicator is not required in the first year of the audit.

The number of samples required (sites/reaches assessed) for the Audit depends on the:

- spatial reporting scale of the assessment
- variability of the indicator
- initial condition score of the indicator
- aggregation and reporting statistics used
- desired level of change to detect
- confidence in detecting that change.

The Audit framework attempts to explicitly identify the implications and tradeoffs associated with these sample design issues.

To measure the condition of rivers in the Murray Darling Basin the spatial scale of inference for a measure could be determined and the number of those spatial units that fitted into the largest spatial unit for reporting calculated. For example, if an AUSRIVAS OE50 score is determined to be representative of a 10 km section of river and there are 77358.2 km of river in the MDB, then to sample the MDB precisely would take at least 7736 sites. Obviously this is an unrealistic number of sites and so a sampling regime must be determined that allows inferences to be made at a broad scale (e.g. river-valley), but still allows measurements to be made at the small scale (e.g. site). The sample unit size needs to be known to determine the number of samples required, which is related to the reporting scale and how variable the measure is at the broad scale. For example one could wish to make inference about a measurement at the catchment, river-valley, process zone, reach or site scale and subsequently design a sampling unit size that is different at each scale but the statistical distribution of the measurement (which will affect the number of collections needed) may also differ scale-dependently.
In other words imagine the impairment in river condition is at the Valley Process Zone (VPZ) level. A river valley may have good quality source and transport zones, but the depositional zone may be impaired from say agricultural practices. A good sampling strategy designed for reporting at the VPZ scale obviously should quantify the health in each VPZ and locate the impairment in the depositional zone. A sampling strategy designed for reporting only at the river-valley scale, however, will not necessarily give conclusive evidence as to which VPZ is impaired and in fact may say that on average the river valley is in good condition. Another way of depicting this is to imagine a river valley has a number of impaired reaches randomly distributed across VPZs. If the strategy is to sample sites randomly across the river valley as a whole, or even each VPZ as a whole, the variability of the measure will be a lot greater than if measuring within each reach.

To design an effective sampling strategy, knowledge is required of the distribution of the index at each of the site, reach, process zone and river-valley zone scales. The sample sizes required for each environmental theme are based on an analysis of existing data-sets where they are available. The most comprehensive data-set for this style of analysis is the macroinvertebrate data collected for the First National Assessment of River Health (FNARH). The following discussion refers specifically to this data-set as well as a simulated data-set, (described below), but the principles apply for each environmental theme.

A pseudo data-set of OE50 values for a fictitious river valley was created that consisted of 3 VPZs, 75 reaches (25/VPZ) and 600 sites (8/reach). In each site a normal distribution of 100 possible OE50 scores that could be sampled was generated (mean of 1 and standard deviation of 0.1). For use as the baseline condition and confirmation of the procedure, the following scale dependent sampling strategies were performed on the data-set:

- 20 OE50s randomly from across all 60,000 possible values for the river valley,
- 20 OE50s randomly within the 20,000 possible values within each of the three VPZs
- 20 OE50s randomly within the 800 possible values within each of the 25 reaches within each of the three VPZs
- 20 OE50s randomly within the 100 possible values within each site within each of the 25 reaches within each of the three VPZs.

The sample size of 20 has no bearing whatsoever on the final estimates of sample size for the Audit. It was simply a computationally convenient size and expected to return a reliable estimate of the standard deviation at each sampling scale.

As expected, the samples always returned comparable values for the true mean and standard deviation regardless of sampling scale (Table B3).

The sample sizes required to detect changes in the average OE50 for each scale were then calculated using the iterative formula described in Zar (1984). As the Audit has proposed a stratified random sampling strategy using VPZs \( n = 3 \) for stratification, a further two degrees of freedom were added to each sample size (Table B3).

Naturally the sample sizes calculated on the 'reference' data show that the same sample size is required at each scale of measurement. For example if the precision is required at the river-valley scale then a sample size of \( n \) will be enough to detect a change in the mean.
OE50 of 0.1. If the same precision is required at the VPZ then a sample of size \( n \) is required within each VPZ, and so on (Table B3).

It is assumed more likely, however, that impairments could occur in individual sites, individual reaches, across VPZs, or combinations of these scales. Therefore, in a series of subsequent models, sites were manually impaired sites using the following methods:

- **VPZ Minor**: Sites in one Valley Process Zone were impaired by subtracting 0.4 of a randomly selected uniformly distributed variate (ranging from 0 to 1) from each OE50 in that VPZ; impaired sites in another valley were created by subtracting 0.2 of a uniformly distributed variate from each OE50; the other Valley Process Zone was left as reference.

- **VPZ Major**: Sites in one Valley Process Zone were impaired by subtracting 0.4 of a randomly selected uniformly distributed variate (ranging from 0 to 1) from each OE50 in that VPZ; impaired sites in another valley were created by subtracting 0.8 of a uniformly distributed variate from each OE50; the other Valley Process Zone was left as reference.

- **Random Reaches Minor**: 25% of reaches were randomly selected and impaired by subtracting 0.8 of a uniformly distributed variate from each OE50 within an impaired reach; the other reaches were left as reference.

- **Random Reaches Major**: 50% of reaches were randomly selected and impaired by subtracting 0.8 of a uniformly distributed variate from each OE50 within an impaired reach; the other reaches were left as reference.

- **Sites Minor**: 25% of sites were randomly selected and impaired across the whole catchment by randomly subtracting between 0 and 0.8 (uniformly distributed) from the OE50 values.

- **Sites Major**: 50% of sites were randomly selected and impaired across the whole catchment by randomly subtracting between 0 and 0.8 (uniformly distributed) from the OE50 values.

- **Random**: All sites were randomly impaired across the whole catchment by randomly subtracting between 0 and 0.8 (uniformly distributed) from the OE50 values.

Finally the actual between-site variation in the OE50 was investigated using existing data from the Ovens, Murrumbidgee and Condamine river valleys. These data allowed estimates of sample sizes required for making inference at the river-valley and Valley Process Zone levels, but not at finer resolutions. The advantage of using the real data is that it allows estimation of the actual sample sizes (i.e. how many sites to sample) in each of the Valley Process Zones, whereas with the artificial data the VPZs would be assumed to be equal for computational simplicity. This procedure allows exact sample size estimates for these three particular river valleys at the river-valley, the VPZ or the river-valley + VPZ scales of reporting. The disadvantage, however, is that it is unknown how much of the observed variability in OE50s is from within-site variation. It is worth noting that the three trial river valleys displayed different types of impairment, with the Ovens showing considerable between-VPZ variation and the other two having relatively even proportions of impaired sites between VPZs. Overall between 0.26 and 0.50 of all sites in each river valley were impaired in the trial data, suggesting that in the final analysis the sampling strategy may have to be determined individually for each river valley. Therefore, the sampling strategy will require review after the first round of sampling, when individual river-valley variability is better understood.
The major finding of the sample size calculations is that considerable variability in sample size can be encountered, particularly within and between river valleys. Looking at the common use values of \( \alpha = 0.05 \), Power (1-\( \beta \)) = 0.80 and requiring to detect a change in the OE50 of 0.1, the artificial data-set required between 10 and 70 sites to be sampled for each River Valley. For example, if the river valley had about 25% of raches impaired and was randomly positioned among the Valley Process Zones (Reach Minor), then to detect a change of 0.15 in the average OE50 whilst sampling and reporting at the river-valley scale with (a) \( \alpha = 0.10 \) (Type I error = probability of concluding there is a difference when in reality there is not) and (b) Power (1-\( \beta \)) = 0.80 (\( \beta \) = Type II error = probability of concluding there is no difference when in fact there is) there would need to be 14 sites sampled (Boxed). If sampling and reporting were required at the Valley Process Zone level, there would need to be 12 sites sampled per process zone; at the reach level, there would need to be 7 sites per reach, etc. The shaded regions are the best available estimates using the trial data and the traditional values of \( \alpha = 0.05 \) and Power = 0.80; that is, to report at the river-valley level in the Ovens River would require 21 sites. To report in the Ovens River at the river-valley and the Valley Process Zone level would require 45 sites.

Table B3. Summary of observed variability and sample size requirements for measuring the AUSRIVAS OE50 index at four spatial scales of measurement from an artificial dataset and from the Audit trial data in three river valleys. For example, if the river valley had about 25% of raches impaired and was randomly positioned among Valley Process Zones (Reach Minor), then to detect a change of 0.15 in the average OE50 whilst sampling and reporting at the river-valley scale with (a) \( \alpha = 0.10 \) (Type I error = probability of concluding there is a difference when in reality there is not) and (b) Power (1-\( \beta \)) = 0.80 (\( \beta \) = Type II error = probability of concluding there is no difference when in fact there is) there would need to be 14 sites sampled (Boxed). If sampling and reporting were required at the Valley Process Zone level, there would need to be 12 sites sampled per process zone; at the reach level, there would need to be 7 sites per reach, etc. The shaded regions are the best available estimates using the trial data and the traditional values of \( \alpha = 0.05 \) and Power = 0.80; that is, to report at the river-valley level in the Ovens River would require 21 sites. To report in the Ovens River at the river-valley and the Valley Process Zone level would require 45 sites.
at the river-valley scale in the Ovens River, and 28 sites for the other two river valleys. If reporting was also required at each Valley Process Zone the sample sizes were 45, 68 and 83 per river valley (Table B3).

As all the river valleys have different lengths and different proportions of each Functional and Valley Process Zone, a concern regarding the sampling design is that the variability of the index may be influenced by spatial scale. This issue was investigated using the trial data, and results showed the variability of the index was influenced by the type of process zone, regardless of its length.

**Summary**

The exact sample sizes required to detect changes in the AUSRIVAS OE50 score cannot be precisely calculated in advance of a pilot study because:

- the true within site variability of the OE50 score is unknown
- the samples sizes required at the proposed sampling/reporting scale (river-valley) vary considerably depending on different types and levels of impairment
- the finer the scale of impairment, the more variable the indicator at higher reporting scales
- the samples sizes required at the proposed sampling/reporting scale (river-valley) will certainly be different for each river valley but, based on existing data, 30 sites per river valley would achieve an acceptable level of precision.

All these issues can be addressed after the first round of sampling.

**Recommendations**

We may possibly speculate that the three trial data-sets are representative of the expected variability in the 29 river valleys to be sampled. This is reasonable because the Ovens is a smaller river valley (1000 km of river) and has a relatively high proportion of Source process zone (Percentage of catchment area that is Source:Transitional:Deposition = 48:21:32), the Condamine is one of the largest river valleys (11000 km) with a relatively large proportion of Depositional process zone (7:34:59) and the Murrumbidgee is in between (6500 km) but has a relatively small proportion of transitional process zone (22:6:72).

Without considering the cost–benefit aspect it is therefore recommend that the ideal sample size for the first round of sampling is 30 sites per river valley. This includes the 28 as determined in the sample size analysis of the trial data and includes 2 extra sites to compensate for rounding in the stratification process and to ensure that a minimum of three sites are positioned in any given VPZ. The MDBC can then be 95% confident of obtaining the true average AUSRIVAS OE50 score for each river valley, knowing that future sampling rounds will also be able to detect changes in river condition at the river-valley scale.
B4.2 Reporting scale

While reporting the mean index score is required at the river-valley scale, models used don't need to be at this scale, because sampling sites form replicates from which results can be amalgamated to provide a valley score.

As well as reporting at the river-valley scale, the options of reporting at the Valley Process Zone scale or the Functional Process Zone scale were also proposed by the review. The sample size analysis indicates that considerably more sites are required to report accurately at these scales. The cost implications of reporting at the valley scale, the VPZ scale and the FPZ scale are estimated in the next section.

Section B5

Approximate costing

B5.1 Reporting at the valley scale

Costs will vary with proximity of sites, condition of river valleys and whether habitat and water quality sampling overlaps with variables required for AUSRIVAS models. Based on the average cost of $750 per site, the approximate cost for sampling and analysis of a river valley for the macroinvertebrate theme is likely to be around $22500 (Table B4). With a fixed cost of $60000 for the 80 additional reference sites needed across the Basin, the approximate cost for sampling the Basin is $714500 for a sampling round.

Table B4 Approximate costing for reporting the macro invertebrate index at the River-valley scale using the Significance level of 0.05 and Power of 0.8.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroinvertebrate sampling, processing, identification, analysis</td>
<td>$ 450 per site</td>
</tr>
<tr>
<td>Physical/chemical water quality measures required for models</td>
<td>$ 300 per site</td>
</tr>
<tr>
<td>Cost per Site</td>
<td>$ 750 per site</td>
</tr>
<tr>
<td>Cost per River Valley using recommended 30 sites</td>
<td>$ 22500 per river valley</td>
</tr>
<tr>
<td>Added second sample season in lowland zones</td>
<td>$ 7250 per river valley</td>
</tr>
<tr>
<td>Basin Wide cost for test site sampling across 22 River Valleys</td>
<td>$654500 for Basin</td>
</tr>
<tr>
<td>80 additional Reference sites across entire Basin @$750 each</td>
<td>$ 60000 for Basin</td>
</tr>
<tr>
<td>Total Basin Costs</td>
<td>$ 714500</td>
</tr>
</tbody>
</table>

B5.2 Alternative costing and benefits

The major trade off in costing occurs when reporting at finer scales or when detecting small changes in the OE50 score. The differences between using type I error rates of 0.05 or 0.1, or type II error rates of 0.1 or 0.2 are small relative to the difference in reporting scales (Figure B6). As an example, to report with the same levels of type I and type II error and level of detection as above, but at the river-valley and Valley Process Zone level
results in a Basin-wide cost of $1.62M whilst the river-valley and Functional Process Zone level reporting is projected to cost $3.01M (Figure B6).

**Figure B6:** Trade off between total Basin cost and scale of reporting for macroinvertebrate theme for Audit. Note the vertical axes are different for each figure. Dotted lines indicate recommended cost for first round sampling.
References


Nichols SJ and Norris RH (Submitted) Bioassessment precision using macroinvertebrates: effects of area sampled and replication. *Freshwater Biology*.

Sloane PIW and Norris RH (Submitted) Bioassessment: Are predictive model outputs related to a pollution gradient? *Freshwater Biology*.


Final Report
Project R2004
Development of a Framework for the Sustainable Rivers Audit

Appendix 4
Fish

Review and Development of Fish Assessment Protocols

Peter Davies
# Table of Contents

1. Summary...................................................................................................................... 187
2. Introduction/Context..................................................................................................... 189
3. Existing programs/methods ........................................................................................ 192
   3.1 Sampling methods..................................................................................................... 192
   3.2 Sampling design ....................................................................................................... 193
   3.3 Variables measured................................................................................................... 195
   3.4 Analytical Frameworks and Approaches.................................................................... 195
      3.4.1 Multimetric analysis ....................................................................................... 195
      3.4.2 Multivariate predictive modelling .................................................................. 200
      3.4.3 Analytical framework — summary ................................................................. 207
4. Proposed Program and Methods for the Audit .......................................................... 208
   4.1 Method development and data collection, in parallel ............................................ 208
   4.2 Proposed schedule .................................................................................................. 208
      1. Phase 1: 2001–2002............................................................................................ 208
   4.3 Sampling methodology ............................................................................................ 210
      4.4 Timing and frequency of sampling.................................................................... 210
      4.5 Variables to be measured.................................................................................. 211
      4.6 Reference condition........................................................................................... 211
      4.7 Sampling design & precision............................................................................. 212
      4.8 Protocols for assessment .................................................................................. 212
      4.9 Analysis ............................................................................................................. 212
      4.10 Aggregation of individual indicators to form theme assessment ...................... 212
5. Approximate Costings .................................................................................................. 214
References ....................................................................................................................... 215
Attendees and Agenda for Audit Fish Bioassessment Workshop ............................. 217
1. Summary

This report recommends a program of work to be conducted within the Sustainable Rivers Audit (Audit) aimed at:

- finalising a standard methodology for fish bioassessment across the MDB;
- conducting the first Basin-wide assessment of river health using fish data.

A specialist workshop, focused on fish-based bioassessment for the Audit, was attended by key personnel from the relevant Murray-Darling Basin agencies (MDBAs) in April 2001. Key issues discussed at the workshop were:

- the absence of and the need for standardised sampling methods across the Murray-Darling Basin (MDB);
- the need for a standard set of variables and derived measures (‘metrics’) which describe fish communities at a range of levels of organisation from the individual to the community level;
- the difficulty in defining reference conditions for fish within the MDB;
- the need for a single analytical method (‘framework’) for making comparisons of metrics against expectations or reference conditions;
- the need for outputs from the assessment which are readily understood and communicable to river managers in the MDB.

All the issues were discussed and agreement reached on a program of activities and surveys to be conducted in the first five-year Audit period in order to implement fish-based bioassessment within the Audit.

All fishery agencies within the MDB use a suite of active and passive fishing gear with survey programs involving varying combinations of electrofishing, nets and traps, with the exception of South Australia which relies only on collection of recreational and commercial fishery data. There was little agreement between MDBA representatives at the workshop on a single sampling methodology, with technical constraints potentially limiting the application of all methods across the diverse range of river types within the MDB. It was agreed that two sampling approaches should be jointly trialled and evaluated in a preliminary phase of the Audit survey — electrofishing (boat and backpack) and passive gear (fyke and gill nets and baited light traps). Formal comparison of catches from the ‘electrofishing only’ and ‘all gear’ (electrofishing plus passive gear) options at the end of the ‘first round’ (2001–2002) of sampling was recommended, with one of the two options to be selected for further sampling rounds within the first five-year term of the Audit. This will allow all data from the first round to be compatible with ensuing sampling rounds.

Sampling for all surveys will be conducted once at each site in the low flow summer–autumn periods. Site lengths will be consistent with the NSW Rivers Survey, but will also be evaluated following the first sampling round. Insufficient data was available to the workshop participants and for this study to allow a detailed evaluation of the number of sites required to be sampled within each river valley for the Audit. A ‘design’ project is therefore recommended to collate all existing and new fish survey data from major MDBA programs, and to conduct power analyses relevant to agreed ‘effect sizes’. This project will recommend final numbers of sites for each river valley which will allow detection of
changes in fish assemblage measures with a known sensitivity. The project must be completed in the 2001/2002 financial year.

A suite of fish and environmental variables was recommended to be measured on each sampling occasion. The fish data will be used to derive values for a total of 29 ‘metrics’ chosen to quantify the state of fish assemblage condition at community, population and individual levels including measures of abundance; biomass; native fish biodiversity; aliens; representation of habitat guilds, trophic, reproductive and migratory guilds; tolerances; abnormalities; and size distribution.

Two analytical frameworks were identified as being potentially suitable for fish-based bioassessment in the Audit — multimetric analysis and multi/univariate predictive modelling. Both frameworks have recently been applied to stream fish assemblages in or adjacent to the Basin. Two methods have been developed within each of the two frameworks:

- **multimetric**: the Index of Biological Integrity, and two fish metrics developed under the NSW DLWC MARA program; and
- **multivariate predictive**: AUSRIVAS/RIVPACS (multivariate), and the regression tree approach (univariate).

None has been fully evaluated and all are still in active development. It was recommended that a project be funded to conduct a comparative assessment of the methods, using Audit fish survey data, whose primary aim will be to develop a final ‘unified’ framework and methodology. The methodology and the form of final outputs will be subject to peer review prior to adoption. The project should also be tasked with analysing the data from the first three Audit fish survey rounds using the final recommended method.

Intrinsic to both analytical frameworks is the concept of reference condition and the need to quantitatively define it in terms of metrics and variable values that are regionally based and representative of an ‘undisturbed’ or ‘least disturbed’ condition. It was recommended that two approaches be used — a ‘best available’ approach using data from the best reference sites/reaches within the MDB following screening for human impacts; and a ‘historical’ approach using expert knowledge and historical sources to define lists of species known to occur in each river valley prior to agricultural development in the MDB. A small review and workshop project is recommended to define the reference condition for fish within the Basin.

Overall, it was concluded that:

- fish bioassessment can readily be developed as an integral part of the Audit;
- much of the background work required to develop a standardised methodology has been done;
- several aspects still require completion and evaluation, under dedicated funding, and preferably with ongoing coordination during the first five-year term;
- this can be done in parallel with the first ‘rounds’ of sampling within the first five year phase of the Audit.
2. Introduction/Context

The purpose of the Sustainable Rivers Audit (Audit) scoping project conducted by the CRC for Freshwater Ecology was to:

- identify and/or develop appropriate cost effective and scientifically robust indicators of river health for the proposed Sustainable Rivers Audit, building on existing knowledge and monitoring arrangements;
- develop a process by which the respective indicators may be measured and interpreted, at recommended temporal and spatial intervals, for each major river within the Basin and reported to Commission;
- provide indicative costs for undertaking the measurement component of the recommended program; and
- with information provided by the SRA Taskforce and in partnership with State and Territory agencies and the Commission, to undertake a trial assessment that tests the feasibility of the proposed measurement and reporting process.

The Audit will be based on two broad themes with five sub-themes:

<table>
<thead>
<tr>
<th>Biotic Themes</th>
<th>Physical Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Macroinvertebrates</td>
<td>• Water Quality</td>
</tr>
<tr>
<td>• Fish</td>
<td>• Hydrology</td>
</tr>
<tr>
<td></td>
<td>• Physical Habitat</td>
</tr>
</tbody>
</table>

This project focusses on fish, and the need to develop a standardised approach to fish-based assessment of ‘river health’. The primary aim for the fish project was to develop fish-community based assessment for the Audit, with the following specific task description:

“Conduct a specialist workshop of State representatives on fish assessments, along with others skilled in survey design, to determine the sampling procedures and approach to sampling and reporting fish community information. This workshop is to advise on sampling effort as well as reporting protocols.”

Specialists in riverine fish biology and assessment, including representatives from each of the MDB agencies (MDBAs) attended a 1.5 day workshop in Canberra on 11–12 April 2001. Agreement was sought on the issues of sampling methodology and design, core variables, analytical framework for fish-based bioassessment in the Audit. The list of attendees and agenda for the workshop are at the end of this appendix.

Fish values in the Murray-Darling

Fish are key ecological components of MDB river systems, interacting with and influencing a range of stream ecosystem components and processes (e.g. as in Figure 1).
Incised floodplains of different ages formed by channel scouring become inundated at high flow, with submerged terrestrial vegetation and organic litter then available as food and habitat. Fallen timber may create debris dams, trapping organic matter of various sizes, also providing food and habitat for invertebrates, fish and frogs. Armoured cobbles and gravels provide a restricted invertebrate habitat within the substratum and trap detritus, however fish spawning is prevented by the armour layer to low flow areas under logs. Sediment, detritus and nutrients are exported downstream when flow is high enough to move the bed surface and/or scour terraces. Small floodrunners are inundated at high flows, increasing available habitat area.

Figure 1. Conceptual model of armoured functional process zone (FPZ) as used in scoping for the Audit. Fish are envisaged as a top predator with close interactions with in-stream cover substrate and production, as well as habitats available at high flow. Fish are also top-down predators, influencing community and population dynamics of macroinvertebrates and occasionally causing ‘trophic cascades’, with resulting changes in primary production or algal standing crops.

Fish are also seen as of significant social, recreational and economic value, through recreational and commercial fishing for riverine species. Considerable efforts have been made and continue to be made to maintain and/or rehabilitate river fisheries in the Basin via stocking and habitat management programs. Native fish are seen as having major intrinsic value in themselves, and as indicators of the ‘naturalness’ of MDB rivers. A number of programs focus on the restoration of native fish populations, again through stocking and habitat rehabilitation. Introduced or ‘alien’ fish species, especially carp, redfin perch, gambusia and trout, are seen as significant threats to the integrity of MDB river fish populations and ecosystem functioning.

As indicated above, fish communities in the MDB tend to be low in diversity. They are frequently also dominated by alien species, particularly carp in the lowlands and trout in the uplands. The historical changes in MDB fish communities over the last 200 years are believed to be profound (Lake 1982, Gehrke1997, Schiller et al. 1997).

Numbers of species recorded in the NSW River Survey (NSWRS, Harris and Gehrke 1997) were low, with 20 freshwater fish species in total across both the Murray and Darling basins (with nine native fish species not observed, but expected). Many native fish species have suffered substantial declines in abundance and in range within the NSW sections of the Basin.

Fish bioassessment
Methods for sampling fish populations are well established. However, there has been little standardisation of sampling methods in previous surveys across the Basin (Faragher and Rodgers 1997).

In addition to a lack of standardisation in sampling methods, there has been little development of a standardised manner of either reporting or analysis of fish population and community data across the Basin. A formal analytical framework was entirely lacking until the advent of the IBI approach as used in the NSW Rivers Survey (NSWRS; Harris 1995, Harris and Silveira 1999). There has been no review or assessment of the strengths and weaknesses of the various analytical frameworks or approaches available for fish bioassessment data in the MDB rivers to date.

A problem specific to bioassessment using fish data in the MDB is the low species diversity at basin, river valley and site scales, as indicated above. An analytical framework which relies strongly on patterns of species occurrence, or on species data alone, is likely to generate outputs which are highly vulnerable to changes in sampling efficiency and which are relatively insensitive to environmental change. It is therefore desirable to use a framework which captures data at a range of ‘organisational levels’ in order to maximise the information gained from fish survey data (see Adams and Ryon 1994, Adams et al. 1996). These can include measures of individual fish health (physiological and/or biochemical measures), growth, condition and energetic status (length–weight and organ–fat–somatic ratios), population size and recruitment, community composition by species and trophic guilds. Together such measures provide an ‘integrated’ assessment of the condition of fish assemblages, as well as providing key indicators of the effects of a range of human impacts on fish ecology.

Another major problem for any analytical approach to assessing river health using fish data in the MDB is the lack of existing ‘reference’ or undisturbed fish communities against which to measure changes. Much of the MDB is heavily disturbed at a local scale through physical in-stream and riparian habitat alteration, flow regime change, water quality changes from point and diffuse source pollution. However, major disturbance to key processes in fish populations also operate at reach and valley level scales, particularly through the influence of barriers and storages on fish passage, water quality and thermal regimes. This is particularly relevant to fish species with life histories dependent on migration over substantial distances. In addition, the invasion of substantial portions of the MDB drainage network by alien fish species is seen as a significant impact on native fish assemblages and values. Thus, there are few reaches within the Basin which contain a true undisturbed reference fish assemblage, and none in the predominant lowland regions.

Choice and quantification of a reference condition is a major issue for fish-based bioassessment across the Basin.
3. Existing programs/methods

This section briefly discusses the key issues which were examined at the Audit Fish Bioassessment Scoping workshop held in April 2001.

3.1 Sampling methods

A wide range of sampling techniques are used and have been used for riverine fish surveys by the agencies involved in fish monitoring and assessment in the MDB (hereafter the “MDBAs”), with two major distinctions:
- passive sampling (nets, traps, etc.); and
- active sampling (electrofishing, seining, angling, etc.).

Some evaluation of the relative efficacy and cost effectiveness of these approaches has been done. Considerable thought was put into sampling methodologies for the NSW Rivers Survey (Harris and Gehrke 1997), and attempts were made to standardise catch-effort and equipment across a range of river sizes and types. Subsequent comparative investigations have concluded (e.g. Faragher and Rodgers 1997, Pusey et al. 1998) that electrofishing, by boat in large river habitats, and backpack in smaller headwater shallow sections, is the most cost-effective approach for sampling a range of fish metrics, possibly combined with seining in smaller snag-free rivers, and can be reasonably standardised between river/reach/habitat types. Electrofishing is not only cost-effective, but also most effective by other yardsticks, such as assessment of abundance, species representation, representation of rare species, representation of various habitat guilds.

Intensive discussion on sampling approaches at the Audit Fish Bioassessment workshop revealed that several agencies were not convinced that these comparative assessments had unequivocally shown that passive gear sampling was not required when sampling across a wide range of river types in the MDB. Concerns were raised about relative efficiency of electrofishing in highly turbid sites and sites with extremes of conductivity, as well as in relation to accessibility of sample sites with electrofishing boats. The discussion concluded that further work was required to confirm the cost-effectiveness and representativeness of electrofishing alone vs combining electrofishing with passive sampling (“all gear”) across a range of site types before adopting a single method for the Audit.

Two other issues were relevant to this discussion — the need for high sampling efficiency in river reaches with low species diversity, and the greatly increased resources (in field time, personnel, and hence funding) for sampling program which includes deployment of passive gear.

The efficiency and representativeness of sampling at a site are key issues. For example, the efficiency of electrofishing is dependent on a number of factors (e.g. Davies 1989, Faragher and Rodgers 1997, Pusey et al. 1998), most notably fish size and behaviour; conductivity; visibility (water colour, turbidity); habitat type (complexity, depth).

Overall estimates of population size, number of species and size distribution within populations derived from electrofishing are strongly dependent on the number of
electrofishing passes through a sample site. Pusey *et al.* (1989) evaluated this for Queensland streams and recommended a minimum of 3–4 passes (accompanied by seine netting where possible). While multiple passes, especially within stop-netted sites, will maximise accuracy and precision of fish-community estimates at the site level, a trade-off is needed between a high commitment of effort at smaller sites and the need for greater site coverage to reduce the variance of overall estimates at a valley scale.

### 3.2 Sampling design

#### Size of sites

While sampling efficiency within a site can be controlled by use of multiple passes and standardised effort and ‘search strategies’, two things determine how well a sample from a fish population represents the situation at reach/VPZ/river-valley scale:

- spatial variability in species/life stage occurrence at the site scale or the reach/valley scale;
- temporal variability (e.g. with season).

The site-scale issue can be addressed by sampling a length of stream adequate to represent the range of habitat types, and hence return a cumulative species/age class/size class number close to an ‘asymptotic’ value for the reach. Angermeir and Smogor (1995) and Lyons (1992) identified relationships between number of species recovered and length of stream/number of habitat types sampled in larger US rivers. They concluded that sampling needed to cover a site length equivalent to 22–67 and 35 stream widths, respectively, to provide an adequate recovery of species, with the latter figure resulting in sampling of some three complete riffle-pool sequences.

The NSWRS sampled sites varying in length but typically with sampling occurring through a 400 m reach in montane areas, and 1000 m in slopes and lowland river types. These site lengths are comparable with the above studies for slope and upland streams, but somewhat shorter for lowland sites, and some evaluation of the adequacy of these site lengths is needed for lowland situations.

#### Number and location of sites

Some preliminary analysis will be required to estimate the number of sites required to be sampled within a ‘reach’ or Valley Process Zone (as defined under the proposed Audit conceptual framework). This will need to address the issues of:

- the number of sites required to produce an assessment that is ‘representative’ of the reach/VPZ, and
- the ‘effect size’ which the Audit is required to detect using fish-based bioassessment.

There was insufficient data available for conducting this type of analysis at the VPZ or river valley scale when this report was prepared. Only 20 sites had been sampled in the NSWRS in each of the Murray and Darling basins, and the availability of data for Queensland and Victorian MDB rivers collected with comparable gear was limited. New data is rapidly becoming available from further sampling being conducted in both Queensland and NSW (e.g. in the DLWC IMEF program). The Audit Fish Bioassessment workshop recommended that existing and new data-sets be collated in the first year of the Audit and that a series of analyses (power analyses and accretion curves) be conducted to
evaluate the number of sampling sites required in each river valley and VPZ in order to
detect specific effect sizes for the agreed variables. This should then be used to refine the
sampling program, taking into account the cost implications of the outcomes of the
sampling methodology assessment.

I conducted several preliminary power analyses on NSWRS data for three variables:
number of species, IBI score and % fish with abnormalities. The results (Table 1) indicate
the great variability in the number of sites required to detect ecologically significant
changes in fish variables at the river valley/VPZ scale, depending on the metric chosen.
For example, the detection of the complete loss (or gain) or a fish species at the river
valley scale will require around 20–40 sites per valley (at an alpha level of 0.05, and
power of 0.8). This has major implications for the cost of the fish component of the Audit.
A review of acceptable effect sizes required to be detected by the Audit fish component
must be conducted following completion of a detailed power analysis using a data-set
collated from programs across the Basin.

Most sampling programs to date have focused on in-stream fish assemblages, with little
emphasis on routine sampling of floodplain/billabong habitats. Existing data-sets on
floodplain/billabong fish should be collated and analysed as part of the proposed
data/design review, and stratification of sampling site by habitat type considered.

Table 1. Results of preliminary power analyses aimed at determining the minimum number of
river sites needed to detect changes in fish variables of specified magnitudes (‘effect sizes’) at the
river valley or VPZ scale: alpha = 0.05, beta = 0.8.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Valley/VPZ</th>
<th>Effect size</th>
<th>No. sites needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fish species</td>
<td>Darling River, reaches with &gt;12,500 km² catchment area (slopes/lowlands)</td>
<td>Loss of 1 species (from site mean of 8.9)</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of 2 species (from site mean of 8.9)</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>River Murray, reaches with &gt;11,000 km² catchment area (slopes/lowlands)</td>
<td>Loss of 1 species (from site mean of 7)</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of 2 species (from site mean of 7)</td>
<td>7</td>
</tr>
<tr>
<td>IBI score</td>
<td>Montane (Murray and Darling)</td>
<td>Decline of 6 IBI units – i.e. decline by one band e.g. from poor to below poor</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Slopes/Unregulated lowlands (Murray and Darling)</td>
<td>As above</td>
<td>7</td>
</tr>
<tr>
<td>% fish with abnormalities</td>
<td>Darling, montane (most variable values between sites)</td>
<td>Doubling (from 5% to 10%)</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trebling (from 5% to 15%)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Darling, regulated lowland (least variable values between sites)</td>
<td>Doubling (from 5% to 10%)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trebling (from 5% to 15%)</td>
<td>3</td>
</tr>
</tbody>
</table>
3.3 Variables measured

No two MDBA fish survey programs have generated data in the same form. Most current programs provide estimates of the total number of species, the numbers of native and alien species and biomass. Fish length, or size/maturity class is often recorded. Fish weight is not always recorded due to the additional field effort involved.

There is little consistency in derived variables (e.g. fish condition, proportions of trophic groups etc.) reported between MDBA fish survey programs, due in part to differences in aims of the various surveys.

3.4 Analytical Frameworks and Approaches

There are two major approaches to fish-based bioassessment which have been trialled in Australian rivers. They are:

- **multimetric analysis** — IBI and MARA (FSI) approaches
- **multivariate ‘predictive’ modelling** — AUSRIVAS/RIVPACS, and Regression tree approaches

Neither of these frameworks have been used with large fish data-sets or thoroughly evaluated and tested with independent fish and/or environmental data.

Both approaches use a ‘reference’ condition as a basis for assessing change (see discussion in Reynoldson *et al.* 1997), although this may not be as obvious or explicit in the metric approaches (e.g. in the case of the FSI).

3.4.1 Multimetric analysis

*Basis:*
The IBI (Index of Biotic Integrity) approach was developed by Karr (1981, 1987, 1991) and Fausch *et al.* (1986) for rivers in the USA. The IBI uses a series of ‘metrics’ (univariate descriptors) of aquatic biological communities to provide an overall score for a site. A metric is defined as:

“a calculated term or enumeration representing some aspect of biological assemblage structure, function or other measurable characteristic that changes in a predictable way with increased human influence.” (Barbour and Yoder 2000)

A large suite of metrics is available in the IBI approach, with suites for fish and macroinvertebrates derived by Karr (see Fausch *et al.* 1986), and modified by Barbour and others (Barbour *et al.* 1995). A large set of metrics was adopted by the USEPA within its set of Rapid Bioassessment Protocols (Barbour *et al.* 1999) and have been used by a number of other US Federal and state agencies for aquatic bioassessment since the mid 1980s. Metrics are chosen to be:

- ecologically relevant to the assemblage under study and to the program objectives;
- sensitive to stressors;
- responsive in a way that can be discriminated from natural variation.
More than 15 individual metrics are available for fish alone. The choice of individual metrics is largely left to the user, with agencies adopting, and modifying their own particular suite for routine use. Fish metrics include measures of species richness and community composition, trophic structure, abundance and individual fish ‘health’. Assessment using measures at a range of levels of organisation is a feature of the IBI approach. The ability to select metrics from a ‘shopping list’ is regarded by some as adding flexibility to the assessment process, and by others as leading to non-standardisation.

Metrics are derived from standardised sampling of the fish community, combined with internal standardisation against the highest values obtained for each variable for the relevant catchment area. This is done by plotting values against catchment area and fitting lines by eye close to the maximum values (i.e. which lie above 95% of the sites surveyed). This line is referred to as the ‘maximum species richness line’ or MSRL by Fausch et al. (1984), see Figure 2. Once metric values are derived, they are then transformed to standardised scores, and these scores are then added to form a composite score called the IBI. The IBI is then compared to thresholds (‘biocriteria’), derived by the user (though often taken directly from the USEPA guidelines). In the US, these are frequently incorporated into state agency regulatory programs.

![Figure 2](image-url). Example of the MSRL technique for defining the upper bounds and scores for the number of native fish species metric at different catchment areas within the Darling Basin (unpub. data from the NSW DLWC MARA, IMEF programs and the NSWRS).

Test sites are selected on a regional basis, and grouped within ‘stream classes’ (or ‘bioregions’) based on broad aquatic biological characteristics. While it is sometimes claimed that this classification is based on aquatic reference sites (Barbour and Yoder 2000), in fact this is rarely the case in practice, and many users simply use elevation or some other measure of position in the drainage network as a template for classification and stratification of site selection. A suite of test sites are then selected within each region.

The word predictive is used within some of the IBI literature, but the technique does not comply with strict definitions of a method which results in predictions of a site’s condition based on biological–environmental relationships. Thus, while it does not make a
‘prediction’, the IBI and metric scores are rated in comparison to threshold values derived from data from sites with the highest metric values. These are equivalent to the use of reference data based on the ‘best available’ sites in the region.

Analysis of the data is generally restricted to comparison of final IBI scores with threshold values. It is often accompanied by examination of spatial trends of individual metrics, and occasionally by correlation with physical/chemical variables. Validation of fish IBI results by such approaches has produced equivocal results (e.g. Shields et al. 1995, Frenzel and Swanson 1996, Karr and Chu 1997, Harris and Silveira 1999).

Weaknesses of the IBI approach claimed in the literature include:
- the prevalence of assumptions about the ecological meaning and relevance of metrics, especially when transferred from one region to another;
- the untested validity of standardising metrics for fish using catchment area relationships;
- the semi-arbitrary (i.e. non-statistical) nature of dividing the area under the catchment area curve into three bands of equal area to provide value ranges for standardising metric values;
- the loss of information, potential for summing errors, and the risk of overweighting attribute values (through metric redundancy) when simply summing standardised metrics to form an overall score;
- the uncertain nature of the responses of some individual metrics to human disturbance.

Strengths of the IBI approach claimed in the literature include:
- ready use of IBI and metric scores in new situations without the need for complex model building and/or analysis;
- flexibility in choice of metrics and final IBI score thresholds;
- metrics based on ecologically relevant concepts.

Other strengths include:
- the capacity to apply a broad range of knowledge about fish responses to disturbance assessment, in addition to simple species-richness changes;
- the capacity to make comparisons across diverse sites and regions;
- the capacity to refine the approach by measuring the performance of metrics and enhancing the data used in MSRLs.

The second metric-based approach is a univariate metric method using two fish-based metrics, under development by NSW DLWC (Chessman pers. comm.). The first is a fish equivalent of the Australian macroinvertebrate SIGNAL index, called the FSI (fish species index). It assigns ‘disturbance tolerance grades’ ranging from 1 (tolerant) to 10 (intolerant) to fish species then calculates an abundance-weighted average grade for those species present. There are three versions in development, with one each for assessing water quality, migration and general conditions. The initial grading has been developed based on Harris and Gehrke’s (1997) list of intolerant species. New grades are being derived by more standardised procedures (as in Chessman et al. 1997).
The second metric being developed by NSW DLWC is the mean rarity score (MRS). Each native species is assigned a rarity grade according to the number of individuals encountered in the NSWRS, ranging from 1 (most common) to 100 (most rare or not recorded). The rarity grades are then averaged for species at a survey site.

Use in Australia:
NSW Fisheries assessed the IBI (Harris 1995, Harris and Silveira 1999) using results of the NSWRS (Harris and Gehrke 1997) at 80 sites in NSW, including 40 sites in the MDB (20 in each of the Murray and Darling drainages, of which 5 were in the montane regions and 5 were in slopes regions in each of the two drainages). A suite of 12 metrics were adopted from Fausch et al. (1990), shown in Table 2. One of these metrics (metric 8) was subsequently shown to perform poorly, and Harris and Silveira (1999) recommend the use of only the remaining 11 metrics in future assessments. An IBI sampling and analysis manual is currently being produced (Harris in prep.) for use in south-eastern Australian rivers.

It is unclear to what extent the ‘reference’ condition was adequately identified and sampled in the 40 MDB sites sampled in the NSWRS. There is scope for better defining the relationship between the fish-community attribute values and catchment area in order to provide improved IBI assessments, as illustrated in Figure 2 where new data considerably improves definition of one MSRL.

The use of IBI in the NSWRS was deemed successful (Harris and Silveira 1999) due to:
• a broad match of IBI scores with perceived levels of disturbance and biological impairment;
• a statistically significant correlation between IBI scores and scores of the ‘RDI’ (River Disturbance Index – a measure of physical habitat disturbance as used in the Wild Rivers project, Stein et al. 1998), though with low described variance ($r^2 = 0.10$);
• the ease of use of the approach;
• the consistency in scores between the two annual summer sampling events (interannual correlation in scores with $r^2 = 0.564$).

Both the FSI and MRS metrics are being developed and used within the NSW DLWC ‘Multi-Attribute Reach Assessment’ (MARA) program, in four NSW catchments (upper Castlereagh, Wollombi, Adelong and on the southern coast). Neither methodology has been fully developed or trialled to date, and data made available for discussion at the Audit Fish workshop was preliminary.
Table 2. Fish assemblage metrics used to calculate the IBI for the NSW Rivers Survey (Harris and Silveira 1999).

<table>
<thead>
<tr>
<th>Category</th>
<th>Metric</th>
<th>Scores and Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species richness and composition</td>
<td>1. Total number of native species</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2. Number of riffle-dwelling benthic species</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3. Number of pool-dwelling benthic species</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4. Number of pelagic pool species</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Number of intolerant* species</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Percent native fish individuals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Percent tentative species</td>
<td></td>
</tr>
<tr>
<td>Trophic composition</td>
<td>8. Proportion of individuals as microphagic omnivores</td>
<td>&lt; 33%</td>
</tr>
<tr>
<td></td>
<td>9. Proportion as microphagic carnivores</td>
<td>33 – 67%</td>
</tr>
<tr>
<td></td>
<td>10. Proportion as macrophagic carnivores</td>
<td>&gt; 67%</td>
</tr>
<tr>
<td>Fish abundance and condition</td>
<td>11. Number of individuals in sample</td>
<td>0 – 2%</td>
</tr>
<tr>
<td></td>
<td>12. Proportion of individuals with disease, parasites and abnormalities</td>
<td>2 – 5%</td>
</tr>
</tbody>
</table>

* intolerance to factors including poor water quality and barriers to migration.
3.4.2 Multivariate predictive modelling

Basis:

These two methods (AUSRIVAS/RIVPACS and regression trees) are based on:

- predictive modelling — that is, predictions of assemblage characteristics based on environmental relationships in reference (‘least impacted’) site data-sets; coupled with
- statistical comparison of observed values at test sites with model (reference) predictions, and
- calculating measures of deviation from the reference site values as indicators of ecological health or intensity of disturbance.

Both methods are highly complementary in data requirements, with the regression tree method focused on univariate descriptions of fish assemblages, and AUSRIVAS/RIVPACS focused on multivariate descriptors (species lists).

RIVPACS (River Invertebrate Prediction and Classification Scheme, Wright 1995) is a multivariate predictive approach, originally developed for macroinvertebrate bioassessment, now incorporated within AUSRIVAS (the Australian River Assessment Scheme, Schofield and Davies 1996, Davies 2000), which can also be used to predict fish assemblage structure (presence/absence of species, life stage). This approach is based on the concept of making bioassessment evaluations, using community compositional data, for a test site relative to an undisturbed community composition ‘predicted’ by models derived from a data-set collected at a set of reference sites. Development of the predictive model is a separate process from the use of it in assessment, and involves several analytical steps (classification, group designation, discriminant analysis, reference group and taxon probability estimation). The use of the reference condition is explicit within the analytical methodology for RIVPACS, and the appropriate choice of reference sites is a core requirement for its success.

Data from a set of reference sites is classified to define natural biological groupings based on community composition (typically species presence/absence). These groupings are then used to derive the probability of membership of each species in each group.

In addition, ‘discriminant functions’ are developed (by discriminant function analysis, or DFA) to discriminate the biological groupings using environmental variables which are uninfluenced by human disturbance (‘predictor variables’, e.g. altitude, distance from source, width). These functions are then used to calculate the probability of membership of a new ‘test’ site in each reference site group.

The two probabilities are then combined to estimate the probability of a species occurring at the new test site as if the site were in reference (‘least impacted’) condition. Thus, a list of species can be derived for the test site which are predicted to occur there, each at a given level of probability. The sum of the probabilities is then generated to provide a total number of expected species expected to occur at the test site if it were least impacted.

A count is then made of the number of predicted species actually observed at the test site (using the same sampling methodology). The ratio of the observed number to the expected number (the ‘O/E ratio’) is then calculated. This ratio spans from 0 (with no expected
species present at the test site) to around 1 (with all expected species present). This ratio is the primary output of the RIVPACS approach, and forms the basis of reporting for macroinvertebrate bioassessment under AUSRIVAS. Error bands, incorporating both sampling error and prediction error would provide a basis for objective judgement of the strength of the assessment. Analytical approaches for calculating these are being developed within AUSRIVAS in time for use in the Audit.

The modes of AUSRIVAS/RIVPACS model development and use are quite distinct, and are illustrated in Figures 3 and 4.

The range of O/E values is divided into ‘bands’ for reporting purposes (Figure 5). A band falling between the 10th and 90th percentile values of O/E for the reference sites is derived as the ‘A’ or ‘equivalent to reference’ band. Two bands are then delineated below this band with widths equivalent to the A band — the ‘B’ or significantly impacted, and ‘C’ or ‘severely impacted’ bands. A final ‘D’ band then falls between the lower bound of the C band and 0.

Criticisms of the RIVPACS/AUSRIVAS approach in Australia have included:
• the need to find suitable reference conditions (sites) for model development;
• the need for intensive stages of model development prior to using the technique;
• problems with incorporating temporal variability within the modelling component;
• problems with low species diversity;
• the complexity of the model development stage which requires expert involvement;
• the need for further ‘diagnostic’ analysis as an aid in interpretation;
• the need for an intensive data collection from reference sites before assessments can be made.

Other criticisms tend to focus on issues of quality control in sampling and site selection, and pertain more to the history of development of macroinvertebrate-based assessment within AUSRIVAS rather than the RIVPACS approach per se.

Key advantages claimed for the RIVPACS/AUSRIVAS approach include:
• the explicit use of a reference framework as a basis for comparative assessment;
• use of regional data in model development and assessment;
• the ease of interpretability of the O/E score as a measure of departure from reference condition;
• the standardisation in sampling and analytical approaches required by the method;
• the standardisation in O/E score outputs and the opportunity to standardise the basis for delineating thresholds (ranges or ‘bands’ of impairment).

The regression tree approach also uses a data-set from reference sites to derive ‘predicted’ values of single variables describing the fish community. Regression trees can be developed for a number of univariate descriptors of fish assemblage structure, such as number of native fish species, % microphagic carnivores, total biomass etc., and could also be developed for variables describing life history and fish health characteristics. Sites in the reference data-set are classified using regressions of environmental variables to discriminate values of a single variable (Figure 6). This provides both a classification
structure based on value of the environmental variables (e.g. altitude, width etc.), and a statistical distribution for the variable within each reference site classification group.

Test sites are first classified using critical values of the environmental variables into a single reference site group. Values of the fish variable are then compared with the statistical distribution derived from the reference site group data (Figures 6 and 7). Kennard proposes that values outside the 20th and 80th percentile values for the reference site group be identified as in ‘poor condition’, while those sites falling inside the 20–80 percentile range are in ‘good condition’. There is scope for further refining this comparison and providing impairment bands as in RIVPACS.
I. Developing RIVPACS

Select **REFERENCE** sites

Measure site **environmental** variables

Standardised sampling for **fish**

Species data

Site classification using UPGMA and Bray Curtis Similarities

**Biological Site Groups**

**Discriminant Analysis:**
Select predictor variables; develop discriminant functions

Site and taxon Probability calculations

**Final Model**

**Presence/absence data and/or Abundance categories (as ‘pseudo-species’)**
II. Using RIVPACS

Figure 4. Process of using RIVPACS (AUSRIVAS) models for bioassessment.
Figure 5. Banding scheme for AUSRIVAS/RIVPACS O/E values.

Figure 6. Example of regression tree derived for number of native fish species occurring at reference river sites in SW Queensland (Kennard pers. comm.). Total $r^2 = 0.62$. Box plots show distribution of number of species in each site group.
Figure 7. Method for calculating indicator values at new sites in the regression tree approach, as % of reference condition, with a reference or ‘good condition’ band set at 20th and 80th percentile of reference site values.

Uses in Australia:

AUSRIVAS/RIVPACS models have been developed for fish community data in Queensland (Kennard et al. unpub. report, Kennard pers. comm.) as well as for New Zealand rivers (Joy and Death 2000). The New Zealand model was highly successful at predicting species occurrence, but was focussed on relatively species rich coastal streams, relatively small catchments, a very strong altitude gradient, and a speciose fauna dominated by migratory fish that are highly responsive to altitude and distance from the sea. The Queensland (Brisbane River) model successfully predicted fish species presence/absence, but the authors noted problems with low species richness. In addition, the ability to incorporate other variables (fish abundance, trophic levels etc.) has not been evaluated with this approach to date, although it is technically feasible.

The regression-tree approach has been used and evaluated as part of the Design and Implementation of Baseline Monitoring project # 3 (South East Queensland Regional Water Quality Management Strategy) by Kennard (unpub. data). Regression tree models were successfully developed using up to eight ‘predictor’ environmental variables for 6 fish variables, with cross-validated $r^2$ values ranging from 0.4 to 0.62. The inability to develop valid regression trees and hence make valid predictions, due in part to the inability to discriminate fish variables using the independent environmental variables, is an issue with this approach, and good predictive models could not be developed for four variables including total fish biomass and abundance.

Kennard also developed AUSRIVAS (RIVPACS) style models using the same data as for the regression tree models. The models were successfully validated using independent data, and were based on DFAs with acceptable reclassification errors. O/E values for test sites were related to environmental disturbance indicators by General Linear Modelling. Kennard has concluded that:
Evidence to date therefore indicates that both the AUSRIVAS/RIVPACS and the regression tree predictive modelling approaches are suitable as analytical frameworks for fish bioassessment in MDB rivers.

3.4.3 Analytical framework — summary

In summary, there is no single analytical framework that has been universally adopted for fish-based bioassessment in Australian rivers, or within the Basin. None of the methods described above has been used on large spatial data-sets to date, and there has been little external validation (i.e. by use of independent fish and/or environmental data), or formal peer review. The assessments conducted to date for IBI, AUSRIVAS/RIVPACS and the regression tree approach are all encouraging, and no single approach ‘stands out’ to date. Low species diversity, strong temporal variability and the absence of undisturbed reference conditions within the MDB pose problems for all three methods. There is considerable commonality between the approaches, and there are strong grounds for a comparative analysis of a large common data-set to evaluate and refine them. Several criteria for fish-based bioassessment framework within the MDB Audit are desirable. No single method satisfies all of them (Table 3), and some further development is needed in all cases.

Table 3. The ability of the three methods to satisfy key criteria for fish-based bioassessment within the Audit.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IBI</th>
<th>RIVPACS/ AUSRIVAS</th>
<th>Regression tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The need to incorporate a reference site/condition as basis for relative assessment of river ‘health’.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>The need for measures at several levels of biological organisation including the community, population and individual levels.</td>
<td>Yes</td>
<td>No, but possible</td>
<td>Yes</td>
</tr>
<tr>
<td>The desirability of a predictive approach which accounts for natural regional differences in fish assemblage structure and the spatial scale relevant to dynamics of individual species populations (e.g. migratory species).</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>The need to incorporate a temporal aspect into the assessment which accounts for key events which influence processes such as recruitment and mortality.</td>
<td>No, but possible</td>
<td>No, but possible</td>
<td>No, but possible</td>
</tr>
<tr>
<td>Outputs that are interpretable and can be related to variables describing the intensity of human impacts.</td>
<td>Yes, but only for individual metrics</td>
<td>Yes, but requires development</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Cooperative Research Centre for Freshwater Ecology

Appendix 4 Review and development of fish assessment protocols
Final Report for Project R2004
4. Proposed Program and Methods for the Audit

4.1 Method development and data collection, in parallel

Because of the need to achieve a better consensus with regard to sampling and analytical methods for fish-based bioassessment, the Audit Fish Bioassessment workshop recommended a two phase program for the first five-year term of the Audit. The first phase will involve a ‘first round’ of sampling on a subset of sites, but will also include a design review project which will finalise the ongoing sampling strategy (number and layout of sites) and make a final recommendation on sampling methods, based on analysing results from the first round. It will also include a small project to provide interim historical and expert-opinion reference species lists and a spatial reference site list. The second phase will be the commencement of the agreed ongoing program, with a full set of sampling sites sampled prior to the first five-year review over a two-year period. It will also include a project to apply the three possible analytical approaches to the Audit data, review their performance and develop and recommend a final analytical framework and methodology for the Audit Fish component. The project will also conduct the first full analysis of the first Audit fish assessment data in time for the first five-year review.

4.2 Proposed schedule

Thus, the proposed schedule is as follows:

1. Phase 1: 2001–2002

**Project 1: Data collation, power analyses and sampling design review**

This project, commencing in mid 2001, will collate existing data on fish assemblages within the MDB from all partner agencies. Data of sufficient quality will be incorporated into a series of analyses designed to assess the number of sites and their spatial ‘layout’ (e.g. stratification by reach type/FPZ) required to provide a representative sampling regime which is able to detect specified differences (‘effect sizes’) in key fish variables. The project will require a small workshop to agree on effect sizes once the initial power analyses have been conducted, and to agree on the ‘trade-off’ between program resources, effect size detection (and/or power) and the number of sites in each river valley. This workshop will also review the issue of reference sites (see project below) and how they are to be incorporated as a ‘stratum’ within the sampling design.

The project will also analyse data from the first sampling round and use it, along with previous data from the NSWRS, to formally assess the cost–benefits of the two sampling options (electrofishing only vs ‘all gear’ ie electrofishing plus passive gear).

The project will, by September 2002, report on:

- a final agreed spatial sampling design;
- a final agreed sampling methodology.

**Project 2: Reference condition project**

A small project, commencing in late 2001, will conduct a preliminary assessment of the spatial and historical reference condition for the MDB. The project will collate all available historical data and lists of fish species for the river valleys in the MDB, and
conduct a workshop to discuss and agree on a series of historical reference lists of species for each river valley (or major valley section), with the MDBAs and invited experts.

In addition, the project will develop an initial classification of reference reaches/sub-catchments in the MDB, based on a set of reference site criteria agreed to by the MDBC and MDBAs. This will be used as the basis for developing a preliminary set of reference reaches or sites, finalised at the above workshop, to be used in the design of the first full rounds (rounds 2 and 3) of the Audit fish survey. The agreed list of sites will be provided to the design phase project team to incorporate within the design analysis.

The project will, by mid 2002:
- provide historical and expert-opinion reference lists of fish species for each river valley and major habitat stratum in the MDB;
- provide an accompanying report citing sources and justification and the process and outcomes of the workshop;
- provide a list of initial/interim reference sites/reaches/sub-catchments for use in the Design review project and in the final, stage 2 Analysis project (see below).

**Survey: Round 1.**
A subset of sites sampled once within all MDB States/Territories in summer–autumn 2001/2 covering a range of site conditions (VPZ, salinity, turbidity etc.) in a stratified design. The intention is not only to conduct sampling that can be incorporated within the first five-year Audit analysis, but also to collect data to allow comparison of the electrofishing vs electrofishing plus set gear method options (see below).

**2. Phase 2: 2002–2004**

**Survey: Rounds 2 and 3.**
The first full survey of all sites will be conducted over a two-year sampling period (in two separate sampling rounds), with a single sampling of each site conducted in summer–autumn of 2002/3 and 2003/4. The spatial design and sampling methodology recommended from Phase 1 Design project will be used throughout by all agencies.

**Project 3: Data analysis review project**
This project, commencing in late 2003, will:
- Collate, and screen for quality, all data from sampling rounds 1–3;
- Conduct analyses on the combined MDB Audit fish data-set using three methods:
  - IBI — multimetric analysis — using the revised IBI methodology (Harris in prep.);
  - AUSRIVAS/RIVPACS (and/or the related e-ball) — multivariate predictive modelling — using a range of variables including the metrics from the IBI approach;
  - the regression tree approach — univariate predictive modelling — using a range of univariate measures and/or metrics (including those from the IBI approach).

The project should evaluate the three approaches against a set of performance criteria (to be agreed with the MDBC and the MDBAs). The potential for adopting components of each approach within one analytical framework should be actively explored. A final analytical framework and methodology is to be recommended, and the first 3 rounds of the Audit fish data analysed using it.
This project will, therefore, by late 2004, produce:

- a report detailing a final analytical framework and methodology for fish bioassessment within the Audit;
- reports to the MDBAs and MDBC on the results from the first five-year stage of the Audit fish survey data, analysed using the final methodology;
- a report detailing the methods and results of the comparative analysis.

### 4.3 Sampling methodology

The following sampling methodology will commence in Phase 1, with two components:

1. **Electrofishing**
   - Boat electrofishing in large rivers. 15 x 2 minute ‘shots’, stratified in proportion to the dominant habitats within the site. A minimum of 2 minutes between each shot.
   - Backpack electrofishing of 2 x 50 m of pool-edge habitat and 2 x 50 m of riffle-run habitat in smaller systems. 5 x 2 minute passes of edge/snag habitats on each bank, in larger systems in addition to boat-shocking.

2. **Passive gear**
   - Fyke nets in all rivers. 4 nets each with 15 mm stretched mesh. Cod-end out to eliminate platypus mortality.
   - Three multipanel gill nets (slow water only).
   - Baited light traps, all rivers.

One night set for all gear only. Nets to be pulled and re-set through the night to reduce fish mortality.

All fish to be identified and processed in a manner consistent with that used in the NSWRS, and including measuring fork lengths to the nearest mm. Details of all data and of each sampling visit are to be recorded on standard field sheets. All catches are to be recorded separately by gear type.

Following the proposed review of the results of Phase 1 round 1 sampling, i.e. from 2002 onwards, a decision will be made as to whether sampling is reduced to electrofishing only. All subsequent sampling will be conducted in a manner consistent with the outcomes of this review.

A suite of habitat variables will be measured at each site and sampling occasion, consistent with habitat variables required for AUSRIVAS sampling in NSW in addition to on-site measurement of dissolved oxygen, pH, conductivity, turbidity and temperature.

### 4.4 Timing and frequency of sampling

All sampling is to be done during lower flows in summer–autumn period (December–April inclusive). All sites will be assessed (surveyed) once. Due to the intensity of resources required to conduct fish surveys in the MDB rivers, each full survey of all sites will be conducted over a two-year period, with half the sites being assessed in year 1 and the other half in year 2. It is intended that at least one full survey (each of two, annual sampling rounds), and possibly two (depending on the final number of sites specified for each river valley) could be completed prior to each five-yearly Audit review.
4.5 Variables to be measured

The Audit Fish Bioassessment workshop reviewed the variables that are required to be measured, while being conscious of the practicalities and limitations of fish sampling in MDB rivers. The following variables are to be derived from data recorded for each sampling occasion in the Audit fish component:

- number of species caught;
- abundance of each species in the catch;
- size distribution, as lengths;
- biomass, to be derived from ‘standard’ length–weight relationships for each species combined with the above length data;
- % of external lesions, abnormalities and parasites;
- variables which influence capture efficiency — EC, temperature, turbidity, fast/slow flow conditions;
- stocking/fishing history of study reach (where applicable).

4.6 Reference condition

The reference concept is particularly problematic for organisms like fish which respond to environmental cues and disturbances at relatively large spatial and temporal scales. Indeed, it is arguable that for some large-scale-migratory fish species, rivers of the scale of the Murray and Darling are required to identify reference conditions. In the absence of lowland river reaches that fit the criteria of a reference condition, assessments must be made relative to the ‘best available’ conditions. This principle is embedded within the Audit, and within a number of competing/complementary analytical approaches to river health assessment. However it must be recognised that true reference communities are absent within almost all of the Basin, due to the large-scale impacts of barriers, water-quality and habitat changes and interactions with alien species. In addition, considerable care must be taken in identifying issues relating to absence or reduced recruitment of migratory fish upstream and downstream of barriers when selecting candidate reference sites within sub-catchments.

The RFA Fish Bioassessment workshop recommended that two methods for defining the reference condition be used:

- data from ‘best available’ sites, which are screened against specific criteria (usually indicators of disturbance);
- lists of species believed to have occurred in each river valley/section, derived from expert knowledge and historical records.

The first type of reference ‘set’ is that used in the current NSW fish IBI and AUSRIVAS/RIVPACS macroinvertebrate bioassessment approaches. However, there was agreement that a historical list is also required to provide a broader conservation context to fish assessment in the Basin. This approach was also taken in the NSWRS (Harris and Gehrke 1997), and while the workshop recognised the problems with bias and fallibility of historical records, it considered that this is still a valid approach to defining a reference condition for fish species presence/absence and diversity, combined with expert-opinion assessment.
4.7 Sampling design & precision
Sampling design and precision will be explored as part of the recommended Design and Analysis projects. The spatial scale at which the indicators are to be reported is consistent with that for the other indicators in the Audit, i.e. the Valley Process Zone and river-valley scales. The analytical methods used for fish will allow aggregation of site assessments to these two scales in a manner consistent with the other indicators/themes.

4.8 Protocols for assessment
For the purpose of the Audit, river health is considered synonymous with the term ecological integrity. For the purposes of the Audit, river health will be measured as:

- the degree to which aquatic ecosystems support and maintain processes and a community of organisms and habitats relative to the species composition, diversity, and functional organisation of natural habitats within a region.

A suite of derived variables or ‘metrics’ was recommended by the Audit Fish Bioassessment workshop (Table 4) in order to provide data that could be analysed in a manner consistent with the above definition. These metrics are to be derived from the variables to be recorded for each survey sample (see list above).

4.9 Analysis
The final analytical framework has yet to be decided. It must:

- incorporate a reference site/condition as basis for relative assessment of river ‘health’;
- use measures at several levels of biological organisation (community, population and individual levels) i.e. all the recommended metrics listed above;
- use a predictive approach which accounts for natural regional differences in fish assemblage structure;
- incorporate a temporal aspect into the assessment which accounts for key large-scale events which influence processes such as recruitment and mortality;
- produce outputs that are interpretable and can be related to variables describing the intensity of human impacts.

4.10 Aggregation of individual indicators to form theme assessment
The aggregation method for fish indicators within VPZs or river valleys will be consistent with the methods used for macroinvertebrates.
Table 4. Derived variables or metrics to be used in analysis of Audit fish bioassessment data.

<table>
<thead>
<tr>
<th>Concept/Class</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>Total abundance per unit effort</td>
</tr>
<tr>
<td>Biomass</td>
<td>Total biomass per unit effort</td>
</tr>
</tbody>
</table>
| Native fish biodiversity | Number of native species  
|                | Evenness of native species |
| Aliens        | Biomass  
|                | Abundance  
|                | Biomass as proportion of all fish  
|                | Abundance as proportion of all fish |
| Habitat guilds | Number of species (including aliens) that are:  
|                | Benthic  
|                | Pelagic  
|                | Riffle dwelling  
|                | Floodplain dwelling |
| Trophic guilds | Number of species (including aliens) that are:  
|                | Macrophagic carnivores  
|                | Microphagic carnivores  
|                | Omnivores |
| Reproductive guilds | Number of species (including aliens) that are in reproductive strategy 1,2, 3a or 3b |
| Migratory guilds | Number of species (including aliens) that migrate at:  
|                 | basin scale  
|                 | Audit river valley scale  
|                 | local (reach) scale |
| Tolerances     | Average scores across all species for:  
|                | FSI (water quality)  
|                | FSI (migration)  
|                | FSI (general) sensu Chessman (in prep.) |
| Abnormalities  | Number of individuals (including aliens) that have:  
|                | visible abnormalities  
|                | parasites |
| Size distribution | Number of individuals (list aliens separately) that are adult or subadult. |
5. Approximate Costings

The following are indicative costings only for the main elements of phases 1 and 2 of the first five years for the Audit fish component. Detailed costings will need to be provided to support budgetary allocations and decisions.

Support for a part-time coordinator is recommended at approx. $12k per annum during the first five years of this component, in order to coordinate MDB agency input, data provision, workshops and ongoing development of the design and analytical components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Indicative cost*</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collation, power analyses and sampling design review</td>
<td>$50,000</td>
<td>External sub-contractor. MDB agencies to provide data for analysis and attend workshop.</td>
</tr>
<tr>
<td>Reference condition project</td>
<td>$25,000</td>
<td>External sub-contractor, MDB agency staff, and experts to attend workshop.</td>
</tr>
<tr>
<td>Survey, round 1. Approx. 50 sites</td>
<td>$200,000</td>
<td>Vic, Qld, NSW MDB agencies only.</td>
</tr>
<tr>
<td>Survey, rounds 2 and 3. Approx. 200 sites</td>
<td>$400,000</td>
<td>All MDB agencies.</td>
</tr>
<tr>
<td>Data analysis review project</td>
<td>$75,000</td>
<td>External sub-contractor.</td>
</tr>
<tr>
<td>Program coordination</td>
<td>$60,000</td>
<td>External sub-contractor.</td>
</tr>
</tbody>
</table>
References


Frenzel SA and Swanson RB (1996) Relations of fish community composition to environmental variables in streams of central Nebraska, USA. *Environmental Management* 20, 689–705.


Attendees and Agenda for Audit Fish Bioassessment Workshop

Venue: University of Canberra Room 3B7, University of Canberra.
Dates: 1330 Wednesday April 11 – 1600 Thursday April 12.

Attendees: David Moffatt, Paul Humphries, Mark Kennard, Alison King, John Harris, Mark Lintermans, Tarmo Raadik, Sean Sloan, Peter Gehrke, John Whittington, Richard Norris, Leon Barmuta, Bruce Chessman, Ivor Growns, Julie Coysh, Claire Petekin.

Workshop facilitator: Peter Davies

Wednesday April 11th, 1330–1800
1330  - Gather in CRCFE front office, and walk to venue.
1400  - Welcome and workshop agenda (PD)
1410  - Introduction to the Audit (JW, PD)
1420  - Introduction to Audit Fish bioassessment scoping project (PD)
        - Incorporating fish bioassessment into the Audit
        - Key questions from the starter document (discussion)
1500  - the reference concept and Basin fish bioassessment.
1530  - afternoon tea
1550  - the reference concept continued.
1630  - Sampling methods used by MDB state agencies (discussion)
1700  - Sampling strategy (discussion)
1800  - Session close

April 12th, 0830–1600
0830  - John Harris – the IBI method
0900  - Richard Norris - RIVPACS style predictive modelling
0930  - Bruce Chessman – the PBH and MARA projects.
1000  - Mark Kennard - SW Queensland DIBM fish component
1030  - morning tea.
1100  - Discussion on core criteria for Audit fish bioassessment, and how each
       approach fits those criteria.
1300  - Lunch
1340  - Discussion and resolution on best overall approach for the Audit:
       - analytical framework and methods;
       - sampling.
1500  - afternoon tea
1520  - Final discussion and wrap up.
1600  - Close
Appendix 5
Water Quality

Review and Development of Physico-Chemical Indicators

Ian Lawrence
Table of Contents

Summary..........................................................................................................................221
Introduction: Theme context.........................................................................................222
What is being assessed: Health assessment focus.......................................................223
Conceptual Models.......................................................................................................223
Selection of indicators..................................................................................................224
  Ecological process outcome (physico-chemical) indicators......................................225
  Potential modifiers of ecological process indicators.................................................227
Development of index..................................................................................................229
  Upland VPZ..............................................................................................................230
  Mid slope and lowland VPZs..................................................................................230
Reference System Selection Basis................................................................................233
Sampling Design.........................................................................................................234
  Overview of existing programs.................................................................................234
  Selection of test sites.............................................................................................234
  Design of number of sites and sampling frequency................................................235
Protocols for assessment.............................................................................................235
Costing.........................................................................................................................236
References....................................................................................................................241
Summary

The selection of physico-chemical indicators is based on the capacity of streams to transform catchment inputs into food forms sustaining higher trophic levels in the stream, and to recycle the in-stream generated detritus.

The indicators reflect the key ecological processes (primary and secondary production & the mineralisation of organic material), and the potential modifiers of these processes (temperature, light or nutrient limitation or stimulation, salinity).

Except in cases of sampling sites established to monitor point source discharges, monitoring sites are predominantly ‘mixed zone’ (riffles, reaches) based.

In addition, given the low frequency of significant flow events, the routine nature of sampling for monitoring purposes means that data is predominantly for low to medium flow conditions. The proposed Audit approach builds on this existing monitoring approach, with data interpreted as reflecting outcomes on in-stream processes.

The adoption of a ‘reference’ based Index (O/E) to assessment of values for the test sites is proposed. In the case of the lowland Valley Process Zones (VPZs), it is generally not possible to identify pristine reference conditions. It is proposed in this case to use process based models to simulate ‘pre-development’ physico-chemical reference conditions.

This appendix elaborates the specific indicators to be measured, the structure of the physico-chemical sustainability index on a VPZ basis, the required number of sites and frequency of sampling, and the estimated annual cost of monitoring across the Basin.
Introduction: Theme context

This appendix addresses the selection of water quality related indicators of stream health, and the development of a physico-chemical index of health.

The Sustainable Rivers Audit has agreed on the development of an assessment framework, as a means of ensuring consistency in approach to the assessment across the Basin, and of guiding the selection of appropriate indicators and integration across themes.

The framework is also seen as an important means of communicating the selection of methods and indicators across a range of stakeholders.

The Audit framework comprises:

- reporting at the river-valley and Valley Process Zone (VPZ) scales;
- the adoption of river valleys, and a three major Functional Process Zones within the valleys, as a basis for stratifying rivers of the Basin into reasonably consistent functional groups for comparison purposes, and for stratification of monitoring sites;
- the development of a narrative (conceptual models) summarising our best understanding of key bio-geochemical processes determining in-stream physical, chemical and biological state responses to catchment inflows;
- the identification of principles guiding the selection of reference systems appropriate to each Functional Process Zone;
- the application of process based models to generate reference conditions where suitable ‘pristine’ or ‘slightly modified’ reference conditions are unavailable.

The framework identifies three types of process zones (VPZs) in the river valleys:

- upland zones (sediment supply);
- mid-slope zones (sediment transfer);
- lowland zones (sediment deposition or storage).

In approaching the task of selection of appropriate physico-chemical indicators, the primary focus has been on the assessment of river health (outcomes of ecological processes), in association with an assessment of potential physico-chemical modifiers of ecological processes.

Basic steps in undertaking the water quality assessment comprise:

- selection of water quality indicators of key ecological processes or modifiers of processes;
- selection of water quality monitoring (test) sites on a Valley-Process-Zone-basis and catchment-area-basis;
- selection of reference systems for each Valley Process Zone and region (or river-valley) category;
- generation of ‘reference values’ where ‘pristine’ or ‘slightly modified’ reference conditions are not available;
• assessment of available water quality data for designated test and reference sites across Basin, and computation of ‘health index’ values for each;
• comparison of test’ and ‘reference’ health indices on a river-valley and Functional Process Zone basis.

What is being assessed: Health assessment focus

The Audit project defined River Health as:

i) the degree to which aquatic ecosystems support and maintain processes and a community of organisms and habitats relative to the species composition, diversity, and functional organisation of natural habitats within a region;

ii) the degree to which biological processes incorporate similar amounts of material into the food web as reference systems (productivity); and maintain a food web of similar complexity to that of reference systems (ecological processes) (Gawne 2001).

The second of these definitions provides a rationale and framework for stratifying rivers on the basis of similar functional processes, and similar indicators of structure and ecological processes. This has been adopted as the basis of the development of the physico-chemical assessment of health approach.

The definition also highlights the importance of the stream capacity to transform inputs to the stream into food forms (primary & secondary production) sustaining higher trophic levels in the stream. Productivity of a stream is a function of the organic material and nutrient inputs from its catchment, the in-stream transformation of these materials and recycling rates, temperature and availability of light.

There is also a range of potential modifiers of these processes, either limiting levels of production, or over stimulating production in the case of wastewater discharges high in bio-available nutrients.

In approaching the task of selection of appropriate physico-chemical indicators, the primary focus is on the assessment of river health (outcomes of ecological processes), in association with an assessment of potential physico-chemical modifiers of ecological processes.

Conceptual models

Generally, we observe longitudinal gradients along streams not only in their elevation, but also in their streambed particle size, suspended particle size, size and complexity of organic material, composition of nutrients, and total dissolved solids, to mention a few constituents.

The River continuum concept (RCC) builds on this principle in terms of its description of organic composition and the range of functional feeding groups present in each functional zone. However, the concept needs to be modified in terms of the overlay of riparian and lateral inputs (Riverine productivity model), important during periods of low flow. In addition, within each functional zone, the flow phase plays an important role in
determining the dominant functional processes (Flood pulse concept). At the biota level, ‘flow disturbance’ also plays an important role in driving diversity.

In the case of lowland VPZs, the longitudinal processes are further complicated by the changing connectivity structure of the system with changes in flow (water height) rates. The drainage from backwaters or overbank return flows on the falling arm of a flood hydrograph may represent significant lateral inputs of organic material and nutrients to the main channel(s).

For medium to low flow conditions, the physico-chemical water quality at a point in a stream will be a reflection of in-stream bio-geochemical processing of upstream inputs from the catchment (primarily during high rainfall–catchment discharge conditions), together with local inputs from stream corridor and riparian vegetation.

In cases of point source discharges (wastewater or groundwater discharge), stream reaches immediately downstream may exhibit unutilised nutrients or organic material, due to the lag in growth of primary or secondary biomass, lack of suitable substrate, light or nutrient limitations, low temperature or insufficient detention time.

Consequently, the physico-chemical quality at the sampling point reflects the outcome of upstream ecological processes and the potential modifiers.

It is important to note that this approach sets aside the more traditional ‘driver’ approach to water quality monitoring, on the basis that:

- the lack of intensive monitoring of flow events, or surveys of the composition of sediments, prevent any systematic ‘driver’ based assessment of streams;
- the routine monitoring of mid-slope and lowland VPZs represents predominantly medium to low flow conditions, during which in-stream processing of recycled nutrients and organic material is dominant. viz: the physico-chemical water quality reflects outcomes of in-stream ecological processes;
- the stream health focus is more about the state of the system than driver–ecological impairment descriptions.

The proposal to undertake a Pilot Run provides an important means of further developing and testing the approach. The approach is entirely consistent with the conceptual models, risk assessment and reference condition basis of the revised Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000).

**Selection of indicators**

Two approaches are proposed to the selection of physico-chemical indicators and the development of an index:

- build on the ‘narrative of dominant ecological processes’ developed as part of the overall Audit framework, in identifying key physico-chemical indicators of in-stream bio-geochemical processes;
- build on the methods documented in the Guidelines for Fresh & Marine Water Quality (ANZECC & ARMCANZ 2000) in identifying possible modifiers of ecological processes, and in selecting appropriate indicators of stressors or modifying agents.
Ecological process outcome (physico-chemical) indicators

From a physico-chemical assessment perspective, there are three components:

- **primary drivers of in-stream ecological processes**: the nutrients, organic material discharged to streams during catchment rainfall events, and in point source and groundwater discharges;

- **modifiers of ecological processes**: the availability of nutrients & light, temperature (rate of growth), physical mixing, salinity (impact on cell physiology), pH & alkalinity modifiers (impact on chemical equilibrium);

- **in-stream ecological (primary & secondary production) response processes and associated physico-chemical outcomes** (indicators).

As noted above, the primary focus of a ‘stream health’ assessment is on the physico-chemical water quality ‘outcomes’ of in-stream ecological processes, and on potential modifiers of these in-stream ecological processes, rather than on an assessment of drivers.

In view of the predominant non-point source nature of stream inputs, point source discharges may be treated as ‘modifiers’ of in-stream ecological processes.

A further important assumption underpinning the approach is that under the low flow conditions, water quality and biological uptakes at the point of sampling are close to equilibrium in relation to the rates of bio-availability of nutrient and carbon sources.

Drawing on the best available understanding of bio-geochemical processes characteristic of a range of Valley Process Zones, a map of the key bio-geochemical processes as a function of stream flow phase and functional zone has been developed.

Tables 4 A & B describe the dominant bio-geochemical processes specific to each River Valley Zone and flow condition. The process descriptions have been used to identify the key physico-chemical outcomes (indicators) of ecological processes, across the range of Valley Process Zones. They also provide a framework for interpretation of the condition being measured and what the data tells us about stream health.

**Summary of indicators of physico-chemical outcomes of ecological processes:**

**Upland VPZs**
- nutrient levels & level of mineralisation, level of FPOM & DOM and proportion of total organic material;

**Mid-slope VPZs**
- DO level & diurnal variation, pH level & diurnal variation, nutrient levels & composition, level of FPOM & DOM and proportion of total organic material;

**Lowland VPZs**
- DO level & diurnal variation, pH level & diurnal variation, chlorophyll ‘a’, nutrient levels & composition, level of FPOM & DOM and proportion of total organic material.
How do indicators meet the criteria for indicator selection:

**Consistency with conceptual models of river function:**
The indicators have been built directly on the functional processes models described in Appendix 2. It is proposed that the conceptual models be expanded upon in the first pilot year of the Audit to provide more detailed information on the physico-chemical aspects as described in this paper.

**Responsiveness to disturbance:**
All the outcome indicators are highly responsive to changes in trophic levels and processes, as well as having distinctly different characteristics across different zones.

**Measurement and analysis are rapid:**
Field probe or sensor (conductivity, DO, pH, NH4, NOx) based measurements in a number of cases, combustion loss or non-filterable residue (TOC, SS), chemical colorimetric or titrimetric or oxidation (DRP, TKN, DOC, alkalinity) methods.

**Standardised methods are available:**
Analysis for all indicators is covered by standard methods.

**Output can be interpreted relatively unambiguously:**
Measurement of major potential modifiers of processes is included to assist the interpretation of the indicator values.

**Indicator has meaning to the wider Basin community:**
Indicator and O/E values are common across FPZs for VPZs.

A number of the indicators are well established as sensitive measures of net primary production (diurnal DO change, pH change), secondary production & mineralisation (NH4/NOx, NOx/TN), and the processing of organic material & mineralisation ((FPOM+DOM)/TOC, NOx/TN) in the case of upland Process Zones. Lawrence *et al.* (2000) demonstrated the sensitivity of the NH4/NOx ratio as an indication of reducing levels in the case of reservoirs. While similar patterns have been observed in relation to wastewater discharge zones in streams, there has not been extensive application of this indicator to streams at this stage. Further explanation regarding the application of these indicators is required in the Report.

For non-point source based river systems, runoff derived from elevated rainfall events constitutes the major driver of inputs of suspended solids, nutrients and organic material to streams. Research reported by Hart, Grace & Beckett indicates that particulate material rapidly adsorbs nutrients and toxicants, and develops biological coatings of organic material. The particulates with their coating of nutrients, organic material and toxicants, settle to the sediments under less turbulent flow conditions in deeper pools or on the falling arm of the flow event hydrograph.

There has been extensive laboratory and reservoir and lake based demonstration of P release from sediments under low redox conditions. Laboratory based sediment core experiments (Armitage 1995) demonstrated the capacity for a range of carbon sources to reduce sediments, with significant remobilisation of N and P. The research demonstrated
the potential for nutrient limitation of the microbial growth, slowing or limiting the sediment reduction and transformation and release of nutrients.

Hart et al. 2000 reported that benthic chamber analysis of stream sediment fluxes indicates that monitored P releases do not necessarily increase even when sediments turn anoxic.

Field observations of river sediment release of P are confounded by the heterogeneity of sediments, limited duration (limited redox development) of benthic chamber experiments, lack of redox measurement, limited labile C to drive redox conditions down, and the rapid uptake of a component of released P by bacteria.

The application of sediment diagenesis models, linked to redox conditions, indicates rapid to slow release of P from sediments, depending on the depth of Fe(OH)₃ layers and redox conditions (Harper 2001).

There is extensive published material reporting on in-stream N release rates from sediments. De-nitrification occurs at low levels of DO and moderate redox level conditions, and an order higher level of N than P.

Analysis of a range of organic materials indicates algae and some grasses have a labile carbon content some 20 times that of eucalyptus-derived litter. The analysis also highlighted the slow rate of bio-degradation of a range of native vegetation-derived carbon materials, in excess of 100 days in some cases, and the nutrient limitation as a significant factor in determining slow decomposition rate for some materials (Esslemont 2000).

There is substantial similarity between the State of the Environment and Audit water quality indicators (turbidity or suspended solids, salinity, pH, DO, temperature, nutrients). TOC has been added to the Audit indicators, as an important indicator of organic material recycling efficiency, while toxicants have been excluded on the basis of monitoring being beyond the capability of the Audit at this stage.

The selection of indicators was also cognisant of resource constraints faced by monitoring agencies in terms of funds, staff and technical capacity in relation to non-traditional measures, and requiring more complex laboratory analysis. This meant that in a number of cases, the available indicators were sub-optimal.

**Potential modifiers of ecological processes indicators**

The Guidelines for Fresh & Marine Water Quality (ANZECC & ARMCANZ 2000) identifies the nine major threats (management issues) to aquatic ecosystem functioning and biota, and related indicators of stressors and potential modifiers (Table 1).
### Table 1. Summary of threats to aquatic biota and related indicators

<table>
<thead>
<tr>
<th>Management issue</th>
<th>Condition indicator</th>
<th>Stressor indicator</th>
<th>Potential modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>nuisance plant growth</td>
<td>Chlorophyll ‘a’, change of pH, DO, algal composition</td>
<td>TP, TN, TOC loads (indirect)</td>
<td>Detention time (flow), turbidity, SS (nutrient sorption), pH, temperature, substrate</td>
</tr>
<tr>
<td>oxygen depletion</td>
<td>change of DO</td>
<td>TOC or BOD load, NH₄</td>
<td>Mixing (flow), re-aeration (flow), temperature, photosynthesis</td>
</tr>
<tr>
<td>elevated suspended solids</td>
<td>turbidity, algal composition, SS concentration</td>
<td>SS load</td>
<td>Flow</td>
</tr>
<tr>
<td>salinity changes</td>
<td>EC</td>
<td>Salt load, evaporation losses</td>
<td>Flow</td>
</tr>
<tr>
<td>temperature change</td>
<td>change of temperature</td>
<td>temperature of inflows</td>
<td>Flow</td>
</tr>
<tr>
<td>pH modification (direct &amp; indirect)</td>
<td>change of pH</td>
<td>acids, bases, photosynthesis, respiration</td>
<td>Alkalinity</td>
</tr>
<tr>
<td>changes in optical properties</td>
<td>change of turbidity</td>
<td>SS, nutrient loads (direct), TOC loads (indirect)</td>
<td>TDS, flow</td>
</tr>
<tr>
<td>changes in flow regime</td>
<td>seasonal flow regimes</td>
<td>change of seasonal flow duration</td>
<td></td>
</tr>
<tr>
<td>toxicants metals</td>
<td>biological effects</td>
<td>Cd, Cu, Pb, Zn NH₄</td>
<td>TDS, DO, SS, DOM, temperature, hardness, pH</td>
</tr>
<tr>
<td>non-metal inorganics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Proposed physico-chemical indicators of potential modifiers of ecological processes for the Audit:
— flow, temperature, TDS or EC, turbidity, SS, pH, alkalinity, DO or %saturation, NH₄.

The retention of the monitoring of the modifiers is important:
• to provide a basis for interpretation of observed shifts in the physico-chemical index values;
• to ‘normalise’ reference and test site measurements in the case of available reference sites; and
• to estimate reference conditions appropriate for the test site conditions in the case of the modelled reference conditions.

Development of Index

There is a range of existing water quality indices, including the Saprobien system of organic pollution measurement, and the trophic system of nutrient enrichment measurement. The indices provide a measure of the cumulative effects of a selected stressor (organic material, nutrients) on the abundance & composition of selected phyla. These indices relate to specific management issues and focus on biological effects.

In view of the major focus of the Sustainable Rivers Audit on the health of the stream, it is important that the physico-chemical index provides a measure of the primary and secondary productivity of the stream, and of potential modifiers to these systems. It is intended that the measures for the test site be compared to the same measures for the reference site, to provide an Observed/Expected ratio.

The physico-chemical indicators of ecological process outcomes, and of potential modifiers to the ecological processes, were identified in the ‘Selection of indicators’ Section above. The map of the ‘key bio-geochemical processes as a function of stream flow phase and functional zone’ (Tables 4A, 4B) highlights the central role of primary and secondary production in recycling key elements of life — organic carbon and nutrients.

The productivity of the stream, and the in-stream utilisation of organic material and nutrients discharged from their catchments, are a function of the efficiency of these recycling processes. The measurement of the efficiency of recycling therefore provides a powerful index of stream health, or conversely, departure from expected recycling levels is indicative of either the absence of drivers, or the presence of modifiers potentially impairing the recycling processes. The primary & secondary production is the base of the food web, while the modifiers also relate to the health of the higher trophic levels.

For example, in the case of elevated nutrients, the resultant algal stimulation will result in marked shifts in the DO, pH and NH₄/NOx ratios. Conversely, elevated suspended solids will result in the suppression of biota (smothering, nutrient adsorption & burial, light limitation), and diminution of ranges in DO and pH, and in-stream nutrient residuals.
Similarly, elevated levels of organic material will stimulate secondary production, with depressed levels of DO and pH, and increased levels in the NH\textsubscript{4}/NOx ratio and FRP occurring.

In the case of elevated total dissolved salts, shifts will occur in the composition and potentially, in the productivity of biota. Consequently, TDS is being treated as a modifier of ecological processes/health of the stream.

The modifier indicators provide a basis for:
- explanation of observed shifts in indicator values;
- normalisation of monitored and reference sites where ‘naturally based’ differences occur in flow and temperature;
- calculation of diurnal DO or pH ranges where a single day-time sample only is available.

Impairment due to toxicants will be read in terms of reduced metabolic rates and shifts in fauna composition, e.g. situation of depressed primary production levels in presence of DRP & NOx residuals, and free of light, temperature or retention time constraints.

Given that the wash-off of toxicants will occur during rainfall events (elevated flows), the ‘low flow’ based monitoring approach would exclude sampling of these discharge conditions. There are also difficulties in relation to the wide range of potential toxicants. It may be that a generic toxicant such as endosulfans could be assessed as representative of a range of crop related pesticides. The possibility of incorporating some background water quality indicators as part of the monitoring program (including toxicants) could be explored as part of the Pilot Project.

The description of key bio-geochemical processes in Tables 4A & B also highlights some important differences between the upland, and the mid-slope and lowland VPZs ecological processes. Building on this approach, the following index measures & structures are proposed:

**Upland VPZ**

Organic material recycling processes: transformation of CPOM to FPOM & DOM and further uptake by secondary production and higher trophic levels:

i)  efficiency measures: (FPOM + DOM)/TOC;

ii) potential modifiers of processes: flow level, temperature, elevated SS.

Nutrient recycling processes: mineralisation of organic forms of nutrients to inorganic forms & further uptake by primary production:

i)  efficiency measure: NOx/TN;

ii) potential modifiers of processes: flow level, temperature, elevated SS, elevated nutrients (point source).

**Mid slope & Lowland VPZs**

Organic material recycling processes: utilisation of FPOM & DOM in secondary production and direct uptake by filter feeders & grazers:
Appendix 5 Review and development of physico-chemical indicators

Cooperative Research Centre for Freshwater Ecology

i) efficiency measures: TOC, \((FPOM+DOM)/TOC\), NH₄/NOx, diurnal range of DO or pH;

ii) potential modifiers of processes: flow level, temperature, elevated SS, elevated organic material (point source).

Nutrient recycling processes: mineralisation of organic forms of nutrients to inorganic forms & further uptake by primary production:

i) efficiency measures: level of primary production (diurnal range of DO or pH), chlorophyll ‘a’ levels, residual inorganic nutrients (NOx, NH₄, DRP), level of mineralisation (NOx/TN);

ii) potential modifiers of processes: flow level, temperature, elevated SS, elevated nutrients (point source), elevated TDS.

The Index structure is summarised in Figure 1. Outline of Index structure. Note that this approach is significantly different from the current fashion of multi-variate analysis. It provides a much more transparent representation of the in-stream functioning of primary and secondary processes.

**Table 2. Calculation of Index**

<table>
<thead>
<tr>
<th>Valley Zone</th>
<th>Indicator</th>
<th>Range of levels</th>
<th>Calculation of Index relative to Reference values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland</td>
<td>TOC</td>
<td>TOC &gt; Ref, TOC &lt; Ref</td>
<td>inverse ratio, direct ratio</td>
</tr>
<tr>
<td></td>
<td>(FPOM+DOM)/TOC</td>
<td>low (extensive processing) to high (limited processing)</td>
<td>inverse ratio</td>
</tr>
<tr>
<td></td>
<td>NOx/TN</td>
<td>high (extensive mineralisation) to low (limited mineralisation)</td>
<td>direct ratio</td>
</tr>
<tr>
<td>Mid-slope &amp; lowland</td>
<td>diurnal DO</td>
<td>DO &gt; 100%saturation net production DO &lt; 100% saturation net reduction</td>
<td>inverse ratio, direct ratio</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>pH &gt; Ref net production, pH &lt; Ref net reduction</td>
<td>inverse ratio, direct ratio</td>
</tr>
<tr>
<td></td>
<td>TOC</td>
<td>TOC &gt; Ref, TOC &lt; Ref</td>
<td>inverse ratio, direct ratio</td>
</tr>
<tr>
<td></td>
<td>Chlorophyll ‘a’</td>
<td>Chlor a &gt; Ref, Chlor a &lt; Ref</td>
<td>inverse ratio, direct ratio</td>
</tr>
<tr>
<td></td>
<td>(FPOM+DOM)/TOC</td>
<td>low (extensive processing) to high (limited processing)</td>
<td>inverse ratio</td>
</tr>
<tr>
<td></td>
<td>NH₄/NOx</td>
<td>low (well oxidised) to high (severe reducing)</td>
<td>inverse ratio</td>
</tr>
<tr>
<td></td>
<td>DRP</td>
<td>limiting levels — effic growth higher levels — impair growth</td>
<td>inverse ratio</td>
</tr>
<tr>
<td></td>
<td>NOx/TN</td>
<td>high (extensive mineralisation) to low (limited mineralisation)</td>
<td>direct ratio</td>
</tr>
</tbody>
</table>

Notes: A number of the indicators are flow and/or temperature dependent, and so require normalisation in relation to differences between monitored site and Reference site ‘natural’ background factors (based on flow–indicator regression curves for the Reference site).
Composite Water Quality Index calculation:
(sum of the individual indicator indices) ÷ (the number of the indices for the VPZ).

The ‘20% change values’ is a judgement, guided by the ANZECC Water Quality Guidelines 1992 ‘limits to acceptable change’ in relation to the potential for impairment of biota. It is intended as the identification of an ‘increment’ of change that is likely to be significant in ecological terms, without any overlay of acceptable or unacceptable bands at this stage. The proposed Pilot Project will be invaluable in further testing and developing this aspect of the approach.

**Figure 1.** Outline of Index structure

Calculation of Water Quality Index:

i) Normalise Reference site ecological indicator values for flows equivalent (percentile) to monitored site flows.

ii) Calculate the O/E Index for each ecological Indicator, based on Table 2.

iii) Calculate the cumulative Water Quality Index for the site, based on the sum of the individual indicator indices, divided by the number of the indices for the Valley Process Zone.
Reference system selection basis

The revised Guidelines (ANZECC & ARMCANZ 2000) require selection of reference sites on the basis of similar bio-geographic & climatic regions, geo-morphological, pedological & topographical characteristics, similar range of habitats and equivalent riparian and aquatic plant communities. In the case of the Audit approach, the framework provides a systematic basis for stratification of river valleys and Functional Process Zones, guiding the selection of reference systems appropriate to the test site.

The selection of reference sites for water quality sampling needs to reflect the Valley, Valley Process Zone and Functional Process Zone of each monitored site Valley Process Zone & Functional Process Zone category, on a valley by valley basis.

In tabulating the list of possible reference sites meeting these criteria, there is a need to exclude non-representative sites such as sites immediately downstream of river junctions or point-source discharges (problem of transverse stratification of flows). A random selection of reference sites is then made from the tabulation of possible sites.

In the case of lowland Process Zones, there are few unmodified streams available for reference purposes. In these cases, it is proposed to generate the best available estimate of reference conditions, drawing on data from modified streams, and estimates provided by the application of an interactive transport, sedimentation, sediment redox & biofilm uptake process based model (daily time step).

The process-based models will be built-up from the conceptual (narrative) models, utilising established physical, chemical & biological (primary & secondary production) relationships. The models will be based on daily time steps and ‘train of channel morphological components’ representative of the Functional Process Zone. The CRCFE has established process-based river models, integrating transport, sedimentation, re-suspension, sediment redox (secondary production), nutrient release, algal uptake (primary production) for mid-slope and lowland rivers. The models are Excel based, with simple input of daily inflows and composition.

A key component of the models will be the temporal changes in physical structure (secondary channel and floodplain connectivity) and processes as a function of flow.

In the case of physico-chemical assessment, indicator values are significantly influenced by flow. Where differences occur between the test site flow and the reference system flow, the test and reference sites are no longer comparable.

Limiting ‘acceptable data’ to baseflow conditions (20 to 80 percentile range), for which a ‘comparable’ reference value is available, does not appear to be a viable solution to this problem, in view of the 20 to 80 percentile flow ratios of 30, 10 & 5 times for upland, mid-slope & lowland streams respectively.

It is proposed that the reference condition should be based on the flow duration condition comparable to that prevailing at the test site at the time of sampling.
This will require the establishment of flow duration curves for both reference and test sites, and the development of a correlation of physico-chemical values with flow in the case of the reference sites.

In this case, a flow–concentration regression curve will need to be developed for each indicator, based on multiple sites and samples for the VPZ. Analysis of the O/E for the test site is then based on the monitored test site value over the regression curve value for the reference VPZ for the equivalent flow condition. Flow condition in this context is the equivalent flow duration probability.

**Sampling design**

**Overview of existing programs & methods**

Routine physico-chemical monitoring programs typically are based on sampling from well mixed (riffle or stream reach) zones, and reflect predominantly medium to low flow conditions (flows prevailing for some 97–99% of the time for mid-slope & lowland River Valley Zones).

There is little to no event based monitoring or sediment surveys currently undertaken, against which systematic assessment of drivers of processes could be made: viz. physico-chemical based assessment is limited to assessment of in-stream bio-geochemical process outcomes.

There is an extensive network of water quality monitoring sites for the northern and western slope streams, but limited sites for the western plains streams.

**Selection of test sites**

There is a choice of two approaches to the selection of test sites:

- a ‘random’ based selection of sites from available monitoring sites for the river valley and Functional Process Zone; or
- a ‘stratified’-based selection, reflecting a standard set of drainage areas.

There is a substantial body of literature describing the inverse relationship between sediment, nutrient, organic loads per km² and basin drainage area, reflecting in part the greater proportion of lowland river zones (reduction in transport energy) associated with large lowland areas in the case of the larger basins. While the Functional Process Zones-based stratification approach will go some way towards removing this dependence, it is expected that rivers having extensive lowland reaches, such as the Darling, will show significant differences between the upper and lower reaches of the lowland river functional zone.

It is proposed that a ‘basin drainage area’ based selection of monitoring sites should be adopted as a further ‘stratification overlay’ in these cases.

In the case of the water quality indicators, the site comprises a riffle or well-mixed zone in the case of upland and mid-slope Process Zones, and a channel (pool) reach in the case of lowland Process Zones. Sampling needs to be taken clear of edge effects in each case, in order to reflect channel water quality. In the case of the lowland Process Zones, under low
flow conditions, the ‘channel’ water quality will of course reflect local transverse inputs and bio-geochemical processes.

At this point, it is proposed that the only criteria to be used to define sites are the Valley Process Zone and Functional Process Zone categories, and the requirement for sites to be capable of providing a representative (mixed) sample. The framework proposes a random selection of sites from the sites meeting these three criteria, on a valley by valley basis.

**Design of number of sites & sampling frequency**

The required confidence level in estimates is differences of 20% in the averaged O/E ratio to be detectable at the 10% level.

Number of sites required — confidence levels in respect to differences:

- 6 test sites per River Valley Zone per river valley;
- 3 reference sites per River Valley Zone per river valley.

Timing & frequency of sampling:

- 2 or 3 monthly based samplings across the year (= 4–6 samples/year).

**Protocols for assessment**

From the CRCFE and other research into in-stream bio-geochemical processes, there is now an appreciation that in-stream physico-chemical data is sometimes a measure of drivers of biological processes, and at other times a measure of the outcome of biological processes. In the unlikely event that a sample reflects a high flow event condition, it is proposed that this data should be excluded on the basis that it does not represent in-stream ecological process outcomes.

Proposal for resolving this issue: Undertake assessment of the water quality data in relation to flow conditions at the time of sampling, and classification of water quality data into drivers or outcomes on the basis of flow levels greater than or less than:

- 15 percentile flows for lowland VPZs;
- 25 percentile flows for mid-slope VPZs;
- 35 percentile flows for upland VPZs.

In the case of the water quality indicators, the site comprises a riffle or well-mixed zone in the case of upland and mid-slope Process Zones, and a channel (pool) reach in the case of lowland Process Zones. Sampling needs to be taken clear of edge effects in each case, in order to reflect channel water quality. In the case of the lowland Process Zones, under low flow conditions, the ‘channel’ water quality will of course reflect local transverse inputs and bio-geochemical processes.

In order to assess the monitored indicator values, in some cases, information is required on a range of associated potential modifiers of bio-geochemical processes. For example, ideally, monitoring is required of the diurnal pattern of in-stream DO and pH, in order to
assess primary or secondary production and respiration balance and rates. As a requirement for 24 hours monitoring at each site would be resource intensive, it is proposed to compare a daylight based sample with calculated equilibrium for the prevailing flow, temperature and alkalinity conditions, to assess production & respiration rates.

In the case of the limited depth of the riffle zone based sampling sites for the upland and mid-slope Process Zones, this will not be an issue. In the case of the deeper channel (pool) reaches for the lowland Process Zones, it is proposed that an integrated sampler (tube) be used to integrate variation in indicator values across the depth of the pool.

For each River Valley index, aggregate the VPZs’ indices on the basis of the mean value of individual VPZ indices.

Costing

Based on preliminary analysis of water quality variability and the required detectable difference and confidence level, the required number of samples is 6 samples per site (9) per river-valley zone per river valley.

Typically, the water quality index site selection requirements are consistent with the macroinvertebrate site selection requirements. Consequently, water quality sampling could be taken at the same site and time as the macroinvertebrate surveys. Additional water quality samples will be required in order to meet the statistical significance probability criteria.

It is assumed that based on the existing gauging network, and the application of hydraulic models, estimates of flows of sufficient accuracy for the purposes of the Audit can generally be generated without the need for additional gauging stations. Where gauging stations are required, it may be sufficient that staff gauges are installed at sampling sites (officers collecting water quality samples to note level), rather than incurring the high cost of establishing fully automated stations. Costing has included the cost of establishing and calibrating additional staff gauges across 20% of the sites.

Based on the schedule of variables to be analysed, the University of Canberra Ecochemistry Laboratory analysis rates, and an estimate of travel and sampling technicians cost, the annual cost of the physico-chemical sampling and analysis is estimated at $830,000 (see Table 3).
Table 3. Cost of one year’s sampling for water quality index.

Table: Cost of one year’s sampling for water quality index.

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Mid slope Valley Process Zone

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Lowland Valley Process Zone

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<th>Avg Valley Total</th>
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Notes:
Based on 6 test sites & 3 reference sites per Valley Process Zone, and 6 samples/site/yr
Based on the numbers of valley process zones identified for the 22 river valleys
Based on an average travel distance of 500 km/sampling run/Valley Process Zone x 50 c/km
Based on 2 technicians x 1 day x $200/day per sampling run per Valley Process Zone
Analysis costs based on University of Canberra EcoChemistry Laboratory rates 6 July 1999
Table 4A. Map of key bio-geochemical processes as a function of flow phase and functional zone: Upland River Valley Zone

<table>
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<tr>
<th>Functional zone</th>
<th>Flow events</th>
<th>Flow phase</th>
<th>Post event period</th>
<th>Sustained low flow</th>
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<td>Dominant processes:</td>
<td>Flow rates, duration of event, elevated sediment loads</td>
<td>Flow rates, low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n/FPOM), consumption of epilithon by periphyton &amp; contribution to detrital pool.</td>
<td>Low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n/FPOM), consumption of epilithon by periphyton &amp; contribution to detrital pool.</td>
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<tr>
<td>Potential modifiers of processes:</td>
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<tr>
<td>Dominant processes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential modifiers of processes:</td>
<td>Flow rates, elevated sediment load, disturbance of cobbles/gravel.</td>
<td>Flow rates, low temperature (suppress biological rates), elevated SS (light limitation), nutrient point source discharge (elevated primary prod’n/FPOM), consumption of epilithon by periphyton &amp; contribution to detrital pool.</td>
<td>Low temperature (suppress biological rates), elevated SS (light limitation), nutrient point source discharge (elevated primary prod’n/FPOM), consumption of epilithon by periphyton &amp; contribution to detrital pool.</td>
<td></td>
</tr>
<tr>
<td>Physico-chemical outcomes of bio-geochemical processes (riffle zones)</td>
<td>Sediment &amp; SS levels, organic mat’l levels, nutrient (adsorbed) levels</td>
<td>Mineralisation of organic mat’l. Breakdown of CPOM to FPOM &amp; DOM. SS, residual nutrients &amp; composition, residual FPOM &amp; DOM.</td>
<td>Mineralisation of organic mat’l. Breakdown of CPOM to FPOM &amp; DOM. SS, residual nutrients &amp; composition, residual FPOM &amp; DOM.</td>
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</tbody>
</table>
### Table 4B (i). Map of key bio-geochemical processes as a function of flow phase and functional zone: Mid-slope & Lowland River Valley Zones

<table>
<thead>
<tr>
<th>Functional zone</th>
<th>Flow events</th>
<th>Post event period</th>
<th>Sustained low flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pools</td>
<td>Major catchment discharge of water, SS, adsorbed nutrients, organic mat’l. Transport of sediment &amp; SS. Re-suspension of organic mat’l previously deposited or built-up in reaches &amp; riffles post the previous event. Deposition of sediment, SS, adsorbed nutrients &amp; organic mat’l in large pools.</td>
<td>Decomposition of sedimented organic mat’l (secondary production), with potential release of mineralised nutrients, or adsorption/burial in sediments, or loss to atmosphere. Uptake of released nutrient by benthic biofilm, attached algae, plankton.</td>
<td>Run-down in leakage of nutrients from previous event. Direct recycling of nutrients. Riparian vegetation inputs locally. Biofilm uptake of FPOM &amp; DOM from detrital sources &amp; decomposition of riparian mat’l.</td>
</tr>
<tr>
<td>Dominant processes:</td>
<td>Flow rates, duration of event, elevated sediment loads, elevated SS levels, over-bank flows &amp; returns (dispersion of SS/adsorbed nutrients, elevated CPOM &amp; FPOM returns)</td>
<td>Time since event, pH (chemical equilibrium), elevated TDS (flocculation SS, toxicity), low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n), consumption organic prod’n by grazers &amp; collectors.</td>
<td></td>
</tr>
<tr>
<td>Potential modifiers of processes:</td>
<td>High organic mat’l loads (de-oxygenation, redox), high SS levels (nutrient adsorption/limitation, light limitation), pH modification (chemical equilibrium), elevated TDS (flocculation SS, toxicity), low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n), consumption organic prod’n by grazers &amp; collectors.</td>
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</table>

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Appendix 5 Review and development of physico-chemical indicators
Final Report for Project R2004

239
### Table 4B (ii). Map of key bio-geochemical processes as a function of flow phase and functional zone: Mid-slope & Lowland River Valley Zones

<table>
<thead>
<tr>
<th>Functional zone</th>
<th>Flow events</th>
<th>Post event period</th>
<th>Flow phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riffles/reaches</td>
<td>Re-suspension or sloughing of organic mat’l built-up post the previous event &amp; transport downstream.</td>
<td>Uptake of nutrient &amp; FPOM released from upstream pools by biofilm, benthic algae, attached algae &amp; plankton.</td>
<td>Direct recycling of nutrients. Riparian vegetation inputs locally. Biofilm uptake of FPOM &amp; DOM from detrital sources &amp; decomposition of riparian mat’l.</td>
</tr>
<tr>
<td>Dominant processes:</td>
<td>Flow rates, elevated sediment loads (aggrading/degrading), bank erosion (additional sediment, nutrient &amp; organic mat’l load)</td>
<td>Flow rates, high SS levels (nutrient adsorption/limitation, light limitation), pH (chemical equilibrium), elevated TDS (flocculation SS, toxicity), low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n), consumption organic prod’n by grazers &amp; collectors.</td>
<td>Time since event, flow rates, pH (chemical equilibrium), elevated TDS (flocculation SS, toxicity), low temperature (suppress biological rates), nutrient point source discharge (elevated primary prod’n), consumption organic prod’n by grazers &amp; collectors.</td>
</tr>
<tr>
<td>Potential modifiers of processes:</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Physico-chemical outcomes of bio-geochemical processes (riffle zones or reaches)</td>
<td>Sediment &amp; SS levels, organic mat’l levels, nutrient (adsorbed) levels</td>
<td>SS, DO, pH, residual nutrients &amp; composition, residual FPOM &amp; DOM</td>
<td>SS, DO, pH, residual nutrients &amp; composition, residual FPOM &amp; DOM</td>
</tr>
</tbody>
</table>
References


Appendix 6
Hydrology

Review and Development of Hydrological Indicators

Martin Thoms
Fiona Dyer
Table of Contents

Preamble.......................................................................................................................... 246
Introduction .................................................................................................................... 246
Flow regime .................................................................................................................... 247
Flow history ..................................................................................................................... 247
Flood pulse ...................................................................................................................... 247
Flow Hydraulics ............................................................................................................. 248
Existing programs/methods .......................................................................................... 250
General methods ............................................................................................................. 250
Index of Stream Condition — Hydrological deviation .................................................... 251
Hydrology sub-index ......................................................................................................... 252
New South Wales — Stressed Rivers Program .............................................................. 253
Hydrological stress .......................................................................................................... 254
Queensland Water Allocation Management Plan (WAMP) ........................................... 254
Important Features of the Selected Key flow statistics .................................................... 255
Proportion of Median Annual Flow ............................................................................... 255
Annual Proportional Flow Deviation (APFD) ................................................................ 256
Proportion of Natural Monthly Flow Variability ............................................................ 257
Proportion of Natural “High Flow” and “Medium Flow” Event Frequency .................... 257
Proportion of Natural “Low Flow” and “No Flow” Duration .......................................... 257
Summary ......................................................................................................................... 257
Flow models .................................................................................................................... 258
Integrated Quantity Quality Model (IQQM) — New South Wales and Queensland ... 258
RESOURCE ALLOCATION MODEL — Victoria .............................................................. 260
System Specification ....................................................................................................... 260
Inputs ................................................................................................................................. 260
Outputs ............................................................................................................................... 260
BigMod — Murray-Darling Basin Commission Flow Model ......................................... 260
Flow Routing ................................................................................................................... 261
Summary ......................................................................................................................... 262
Methods for the Audit Hydrology Index ........................................................................ 262
Data required .................................................................................................................... 263
1.  Mean Annual Flow (A) .............................................................................................. 263
   Comments..................................................................................................................... 263
2.  Flow Duration Curve Difference (M) ....................................................................... 263
   Comments..................................................................................................................... 264
3.  Seasonal differences ................................................................................................. 264
   • Seasonal Amplitude (SA) ...................................................................................... 265
   • Seasonal Period (SP) ............................................................................................. 265
Determining the hydrological index for a river valley .................................................... 266
Principles for the calculation of the hydrology index where data are unavailable ........ 266
Case 1. Zones on unregulated streams .......................................................................... 266
Case 2. Zones on regulated streams ............................................................................... 266
Case 3. Zones on regulated streams, upstream of dams ............................................... 266
Case 4. Zones on regulated streams, downstream of a dam, upstream of a zone with data suitable for calculating the index with unregulated tributaries joining the main stem ...................................................................................................................... 267
Case 5. Zones on a regulated stream downstream of a zone with data suitable for
calculating the index with unregulated tributaries joining the main stem..............268

Testing the Hydrology Index ..................................................................................269
  Background ............................................................................................................269
  Data .......................................................................................................................269
  Component Testing ...............................................................................................270
    Test Aims ..............................................................................................................270
  Mean Annual Flow ...............................................................................................270
    Test results ..........................................................................................................270
  Flow Duration Curve Difference (M) ....................................................................271
    Test results ..........................................................................................................274
  Seasonal differences .............................................................................................275
  Seasonal Amplitude ...............................................................................................277
    Test results ..........................................................................................................277
  Seasonal Period .....................................................................................................277
    Test results ..........................................................................................................278

Overall Hydrology Index .........................................................................................278
  Conclusions ............................................................................................................279

References ...............................................................................................................279
Preamble

The aim of the Sustainable Rivers Audit (Audit) is to provide on-going assessment of river health in the Murray-Darling Basin. However, river health has never been systematically assessed across the Basin. This means that it is not possible to conduct informed discussion on river health and the factors affecting it, or to determine the effectiveness of current river management initiatives. To address this deficiency, a framework is being established in order to conduct an effective Basin wide assessment of river health (see Scope of the Sustainable Rivers Audit, June 2000).

The index of river health being derived for the Murray-Darling Basin integrates indices for five environmental themes (fish, hydrology, macroinvertebrates, physical habitat and water quality) and reports condition at a river-valley scale. This report outlines the development of a hydrological index for incorporation within the broader River Health Index.

Introduction

Flow is the maestro that orchestrates pattern and process in river systems (Walker et al. 1995). The literature is replete with examples suggesting that flow is one of the most important elements in determining the physical, chemical and biological processes occurring within any river system. A river’s flow regime shapes the river channel and determines the nature and distribution of riverine sediments. These features, in association with flow and water chemistry, control the distribution, physiology and abundance of organisms, as well as the dynamics of riverine communities.

Australian rivers like those of the Murray-Darling system have some of the most variable flow regimes in the world (Finlayson and McMahon 1988). From a human perspective, they are unreliable water resources and have required extensive flow modification. Large floods that breach the river banks and cover vast tracts of land are a feature of the rivers of the Murray-Darling Basin, as are periodic droughts. These events can result in large costs to rural communities. However, the animals and plants inhabiting these systems are well adapted to the variability. In fact the ecological integrity of these rivers, particularly in the lowland areas, depends upon periodic lateral movements of water onto the floodplain as well as substantial drying out periods.

A number of key aspects of flow have been identified as having particular ecological significance. Their ecological importance can be assigned to one of four operational time scales: flow regime, flow history, flow pulse and flow hydraulics. The detail and relevance of each is provided below and shown schematically in Figure 1.
Flow regime
A long-term, statistical generalisation of flow behaviour. It describes influences that extend over hundreds of years, such as the flood and drought cycles determined by atmospheric conditions like ENSO. Aspects of flow that operate at the 'flow regime' scale include:

- **Flow variability**: the natural range of flow levels, and their timing; and,
- **Measures of central tendency**: Mean, median and skew of the long term flow record.

Flow history
The sequence of floods or droughts, including the antecedent conditions of flow pulses before any point in time. The flow history describes influences that operate over scales of between 1 and 100 years. Aspects of flow that are evident at the 'flow history' scale include:

- **Frequency**: the frequency of events in a range of flow sizes;
- **Antecedent conditions**: the time elapsed since the last event of a given magnitude;
- **Seasonality**: the time of year when a flow of given magnitude occurs; and
- **No flow (dry) periods**: the duration and nature of dry periods.

Flood pulse
A single flood event (Figure 2), generally defined as a rise and fall in discharge. Flood pulses generally extend for less than one year. Aspects of flow that are evident at the scale of a ‘flood pulse’ include:

- **Magnitude**: the size of a flow event;
- **Duration of event**: the duration of a flow event; and
- **Rate of fall in hydrograph**: the rate at which flood waters recede.
Figure 2. Features of a flood pulse that may have ecological significance.

Flow Hydraulics

The hydraulics of flow relate to the detailed motion of the flow. Its velocity, depth, stress and turbulence. Aspects of flow at this scale are:

- **Velocity**: the motion of the flow — this can be measured at the bed or other flow depths;
- **Depth**;
- **Stress**: the time of year when a flow of given magnitude occurs; and
- **Turbulence**:

Thus rivers can be described as nested hierarchical systems and hydrological change through water resource and or catchment development may influence all or some of the various hierarchies. For example, studies on the Murray and Barwon-Darling have shown that water resource development has had a marked but variable impact on all hydrological scales (Thoms and Sheldon 2000). In the Barwon Darling River flows are highly modified through the presence of 9 headwater dams, 15 main channel weirs and 267 licensed water extractors. Median annual runoff has been reduced by 42% over a 60 year period. Small flood events (e.g. Average Recurrence Interval of <1.2 years) have suffered the greatest impact with reductions in magnitude of between 35 and 70%. At a number of stations the seasonality of flows has also been affected with a distinct shift in seasonal flow peaks relating to irrigation diversions. Overall, flows show a marked increase in predictability and consistency (*sensu* Colwell 1974). There has also been a change in the shape of the hydrograph. Both long and short-term hydrological changes in the Barwon-Darling.
associated with water resource development, may prove to be critical for the ecological health of the system.

The flow of a river at any one point is an integration of all upstream conditions. Hence, to assess the hydrological behaviour of a river system in a spatial context, data (usually one gauging station) are required for stretches of river between major tributary inputs or river losses. Similarly, a continuous daily data series of at least 30 years is required in order to assess its temporal behaviour.

The influence of scale has been recognised in many ecosystem studies. Investigations at a catchment or river-valley scale requires that processes that operate over longer time periods (tens of years and greater) are considered rather than those over periods of days and years (Figure 3).

![Figure 3. Temporal and spatial scales over which various fluvial processes operate (after Schumm 1988).](image-url)
The hydrology of many of the rivers in the Murray-Darling Basin has been altered or regulated in some fashion, as noted above. There are many definitions of a ‘regulated river’. In order to provide a definition of a regulated river for the Audit one must separate out legal and administrative definitions from those that pertain to the functioning of riverine ecosystems. The Audit is concerned with the development of a framework with which to assess the condition of rivers throughout the Murray-Darling Basin. Hence an ecosystem perspective should be used in defining a regulated river. Thus, for the purposes of the Audit a regulated river is any river or section of river that has a structure (e.g. dam, weir or barrage) on it or is subject to anthropogenic additions or withdrawals of water.

**Existing programs/methods**

Methods of assessing alterations to the hydrological regime because of catchment and water resource development are well documented within the scientific literature (Richter *et al.* 1996, Gehrke *et al.* 1995, Ladson *et al.* 1999). All rely upon the comparison of pre- and post-impact hydrological regimes at a variety of scales. Within the Murray-Darling Basin, a variety of different procedures have been employed, and there is currently no consistent method of assessment across the Basin. The following sections outline some of the methods from the scientific literature as well as the approaches used by the various agencies within the Basin. It has been through an assessment of the benefits and problems associated with these that the hydrology index has been developed for the Audit.

**General methods**

The most recent and comprehensive method of hydrological assessment is that proposed by Richter *et al.* (1996). This calculates 32 ecologically relevant hydrological parameters that are placed in five groups of Indicators of Hydrological Alteration (IHA) (Table 1).

<table>
<thead>
<tr>
<th>IHA statistics group</th>
<th>Regime character</th>
<th>Hydrological parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude of monthly water conditions</td>
<td>Magnitude Timing</td>
<td>Mean value for each calendar month</td>
</tr>
<tr>
<td><strong>Group 2:</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Magnitude and duration of annual extreme water conditions | Magnitude Duration | Annual minima 1-day means  
Annual maxima 1-day means  
Annual minima 3-day means  
Annual maxima 3-day means  
Annual minima 7-day means  
Annual maxima 7-day means  
Annual minima 30-day means  
Annual maxima 30-day means  
Annual minima 90-day means  
Annual maxima 90-day means |
| **Group 3:**        |                  |                        |
| Timing of annual extreme water conditions | Timing | Julian date of each annual 1 day maximum  
Julian date of each annual 1 day minimum |
Appendix 6 Review and development of hydrological indicators

The general approach for this hydrological assessment has four steps:

1. Define the data series for pre- and post impact periods in the river system of interest.
2. Calculate values of each hydrological variable. This is done for each year of the data series, i.e. one set for the pre- and post-impact series.
3. Compare inter-annual statistics. Measures of central tendency and dispersion for the individual parameters are calculated. This produces 64 inter-annual statistics for each data series.
4. Calculate values of the IHA. The 64 inter-annual statistics between the pre- and post-impact data series are compared and each result is presented as a percentage deviation of one time period (the post-impact condition).

This approach relies upon a reasonable length (at least 30 years) of pre-impact flow data. In Australia, we generally do not possess such hydrological data series. Water resource development, particularly in the Murray-Darling began in the early 1900s. Although the records for some gauging stations in the Murray-Darling Basin span almost 100 years, a rapid rate of water resource development combined with the naturally variable flow makes it difficult to evaluate the impact of development on the hydrological regime using only historical data. Thus any assessment of the hydrology of the Murray-Darling system will rely on simulated data.

Index of Stream Condition — Hydrological deviation

The Index of Stream Condition (ISC) was developed to assist with the overall management of rivers in Victoria. This assessment of stream condition is fundamental to the setting of priorities and the allocation of resources to various strategies by State and regional managers. The ISC can also be used to measure the effectiveness of the integrated management effort and provide information with which to set benchmarks for stream condition throughout the State. The ISC is available for on-going assessment where information is collated, processed and used by waterway management agencies, and provides direct input to management decisions.

The guiding principle behind ISC is that of assigning a score based on a comparison with ‘naturalness’; that is, the score is based on a comparison between existing stream condition and that thought to have existed before European settlement in Australia. It has been neither possible nor desirable to rigorously reconstruct historical stream condition. Rather than rigorously reconstructing historical stream condition, this principle has been
applied pragmatically by the specialist group to develop a rating system for chosen indicators. In this way, reference conditions are established on the basis of best professional judgement, avoiding the need for comparisons with particular control sites (Reynoldson et al. 1997).

The index is predominantly a qualitative assessment of various aspects of stream condition, and the sum of the ratings of each of these components provides an indication of change from natural to ideal conditions. Five components are included in the ISC:

- hydrology (an assessment of flow);
- physical form (condition of the channel and physical habitat);
- streamside zone (measurement of quantity and quality of streamside vegetation and wetlands);
- water quality; and
- aquatic life (macroinvertebrate populations).

Hydrology sub-index

The hydrology sub-index is based on changes to the volume and seasonality of flow, by using a combination of simulated and actual data. A value, termed the hydrologic deviation, is calculated by summing the absolute values of the differences between the simulated undeveloped monthly flow and the simulated existing flow over a year. The total is then divided by the annual undeveloped flow. The formula for this sub-index is:

$$\sum_{j=1922}^{1995} \sum_{i=1}^{12} \frac{MN_{ij} - ME_{ij}}{AN_j}$$

where:
- $MN_{ij}$ (monthly natural) = simulated undeveloped monthly flow
- $ME_{ij}$ (monthly existing) = simulated existing monthly flow
- $AN_j$ (annual natural) = annual undeveloped flow
- $i =$ Month: Jan, Feb, ..., Dec ; $j =$ Year: 1922, 1923, ..., 1995.

The rating of the sub-index is given in Table 2.

The hydrologic deviation in the ISC highlights reaches with the greatest departures from natural hydrologic conditions. The hydrologic deviation is similar to the Annual Proportional Flow Deviation parameter developed by Gehrke et al. (1995), which has been shown to be related to ecological impacts. Additionally, the hydrologic deviation is reduced if there are hydroelectric schemes or if urban areas constitute more than 20% of the catchment area of a river reach.

<table>
<thead>
<tr>
<th>Hydrologic deviation</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20%</td>
<td>4</td>
</tr>
<tr>
<td>20% to &lt;35%</td>
<td>3</td>
</tr>
<tr>
<td>35% to &lt;50%</td>
<td>2</td>
</tr>
<tr>
<td>50% to &lt;65%</td>
<td>1</td>
</tr>
<tr>
<td>&gt;65%</td>
<td>0</td>
</tr>
</tbody>
</table>
This approach has the benefit of being quantitative and, with the assigning of a rating, is comparable across basins. However, it is a single value which encapsulates both changes to flow volumes and seasonality and consequently it is not possible to determine which of these aspects of the flow history is causing the greatest hydrological deviation. Furthermore, it only provides an assessment of flow history rather than flow regime (see section 1).

New South Wales — Stressed Rivers Program

The ‘Stressed Rivers Program’, introduced in New South Wales in 1997 classifies rivers according to their assessed level of environmental stress and conservation value. This classification is used to guide both management priorities and policies. The scheme is based at a sub-catchment level and places these into one of nine categories (stressed and unstressed) see Table 3. These are based upon estimates of existing water use and assessments of environmental health.

Table 3. The classifications are based upon estimates of current water use (hydrological stress) and assessments of environmental health (from professional judgement).

<table>
<thead>
<tr>
<th>High proportion of water extracted</th>
<th>Low environmental stress</th>
<th>Medium environmental stress</th>
<th>High environmental stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category U1</td>
<td>Despite high levels of water extraction the river seems reasonably healthy. However, more detailed evaluation should be undertaken to confirm. It is also likely that conflict between users may be occurring during critical periods.</td>
<td>Category S3 Water extraction is likely to be contributing to environmental stress.</td>
<td>Category S1 Water extraction is likely to be contributing to environmental stress.</td>
</tr>
<tr>
<td>Category U2</td>
<td>There is no indication of a problem and therefore such rivers would be a low priority for management action.</td>
<td>Category S4 Water extraction may be contributing to environmental stress.</td>
<td>Category S2 Water extraction may be contributing to environmental stress.</td>
</tr>
<tr>
<td>Category U4</td>
<td>There is no indication of a problem and therefore such rivers would be a low priority for management action.</td>
<td>Category U3 Environmental stress is likely to be due to factors other than water extraction and as stress is not high these rivers would be a lower priority for management action.</td>
<td>Category S5 While environmental stress is likely to be due to factors other than water extraction the high level of environmental stress means it is important to ensure extraction is not exacerbating the problem.</td>
</tr>
</tbody>
</table>
Hydrological stress

The hydrological stress of a sub catchment is calculated as the estimated proportion of daily flow that has been made available for extraction under existing licenses. This requires estimation of stream flow and water use. The index of hydrological stress is derived for each sub catchment as the proportion of estimated water extraction relative to the estimated stream flow. The water use is taken as the peak monthly water extractions as lodged by the licensed water extractors, and stream flow is taken as the 80th percentile for the month of maximum demand. Each sub catchment is then classified as being of low (0–33% extraction of flow), medium (34–66%) or high (67–100%) hydrologic stress.

While this approach has the advantage of being applicable to rivers which do not have major regulating structures, it relies on accurate and up to date extraction data which can be difficult to obtain. It also assumes that hydrological stress is primarily a function of water extraction and does not provide any indication of changes in seasonal flow patterns. Furthermore, in the absence of flow and extraction data, assessment of hydrological stress is subjectively made.

Queensland Water Allocation Management Plan (WAMP)

The determination of flow changes and how these relate to the ecological condition of a river system is a key part of the WAMP. The choice of individual flow statistics differs between WAMPs and this is dependent upon the Technical Advisory Panel (TAP). For the Condamine-Balonne WAMP nine key flow statistics were selected (Table 4). These statistics were assumed to focus on the principal ecological requirements of the Condamine-Balonne river system in terms of the quantity of flow, as well as the frequency and duration of flow events of differing magnitude including periods of no flow.

In practical terms, there were two main points that affected how the key flow statistics were expressed. These were that:

1. the ecological condition of a river can only be ideal if the flow regime is unaltered from the natural state and the key flow statistics should reflect this important concept; and

2. while it was preferred that values be standardised across the key flow statistics, it is more practical to calculate the frequency of high magnitude flow events and the duration of low magnitude flow events due to differences in isolating individual flow events.

To reflect the relationship between ecological impacts and changes in the natural flow regime, relevant key flow statistics were expressed as the proportional change from natural flow conditions. For example, for the proportion of natural “high flow” events, the frequency of “high flow” events under the modelled water resources development scenario (the developed condition) was divided by the frequency of these flow events under modelled natural flow conditions.

This simple calculation yields a proportion that theoretically ranges from zero to infinity. In terms of proportion of natural “high flow” event frequency, values of zero indicate that “high flow” events no longer occur, while a value of one indicates that the frequency of “high flow” events is unchanged from the natural flow regime. Values greater than one indicate “high flow” events occur more frequently than would naturally have occurred.
Table 4. Key flow statistics selected to describe the ecological water requirements of the Condamine-Balonne river system, including associated floodplain, riparian and wetland habitats

<table>
<thead>
<tr>
<th>Key statistic</th>
<th>Primary features of importance</th>
</tr>
</thead>
</table>
| Proportion of natural median annual flow           | • Annual discharge  
                                           • Sediment transport  
                                           • Availability of aquatic habitat |
| Annual Proportional Flow Deviation (APFD)          | • Overall modification of the flow regime  
                                           • Reproduction of native fish and water birds  
                                           • Abundance of alien fish species, e.g. carp |
| Proportion of natural monthly flow variability    | • Daily variation in flow, and seasonal patterns of flow variability  
                                           • Natural disturbance |
| Proportion of natural “high flow” event frequency | • Flooding, and near bank-full flow events  
                                           • Floodplain inundation  
                                           • Natural disturbance  
                                           • Movement of native fish over weirs |
| Proportion of natural “medium flow” event frequency | • Within-channel flow events  
                                           • Maintenance of channel complexity  
                                           • Inundation of channel benches |
| Proportion of natural “low flow” duration         | • Connectivity of riverine pools  
                                           • Movement of native fish  
                                           • Maintenance of riffle habitat |
| Proportion of natural “no flow” duration          | • Drying of the in-stream environment  
                                           • Natural disturbance  
                                           • Maintenance of in-stream vegetation  
                                           • Oxidation of nutrients |
| Proportion of river inundated by dams and weirs   | • Loss of natural riverine habitat |

Important Features of the Selected Key flow statistics

Several of the key flow statistics selected by the Condamine-Balonne TAP were intentionally defined in qualitative terms. Descriptors such as “low”, “medium” and “high” were chosen to describe the ecological function each category of flow event was intended to perform. These terms require quantitative description, and a basic understanding of the ecological significance of each of the key flow statistics is required to appreciate their full importance.

Proportion of Median Annual Flow

The median, like the more widely known ‘mean’, provides an indication of the centre of a set of numbers (sample). Median annual flow is calculated as the middle value of a time-series of annual river flow ordered by magnitude.

The median is equal to the arithmetic mean when there is equal probability of occurrence of any value within the observed range of numbers. However, annual flow data for the Condamine-Balonne river system tends to be strongly “right-skewed”, since years of
lesser flow are much more common than “wet” years. The median rather than the mean tends to be a better indicator of the flow most likely to be experienced in any year, although neither of these statistics is ideal.

**Annual Proportional Flow Deviation (APFD)**

APFD was formulated in 1994–95 by a team of scientists from NSW Fisheries to summarise changes in natural flow regimes associated with water resource development. APFD was originally used in an examination of the ecology of rivers affected by varying degrees of river regulation. However, it is equally applicable to river systems such as the Condamine-Balonne where the bulk of consumptive water use occurs via the harvesting of natural flow events.

APFD has four particularly important characteristics. It is:

- scaled so that it is comparable across locations/rivers of differing flow volume
- sensitive to changes in flow volume occurring in any given month
- sensitive to changes in the overall seasonality of flow
- sensitive to changes in the shape of the seasonal pattern of flow

APFD, as used by the Condamine-Balonne TAP$^1$, is defined in mathematical notation as:

$$APFD = \sum_{j=1}^{p} \sqrt{\frac{1}{p} \sum_{i=1}^{12} \left( \frac{c_{ij} - n_{ij}}{n_i} \right)^2}$$

where: $p$ = number of years in the simulation period, $c_{ij}$ = modelled existing flow for month $i$ in year $j$, $n_{ij}$ = modelled natural flow for month $i$ in year $j$, $n_i$ = mean natural flow for month $i$ across $p$ years.

APFD values used by the TAP were calculated from simulated flow data produced using the Condamine-Balonne IQQM. Referring to the modelled development scenario as “existing” conditions, APFD is based on the difference between existing and natural flow (expressed as a proportion of the corresponding average natural flow) for each month. The resulting values (one for each month) are squared to make each positive, then added, and the square root of the answer is found, to remove the effect of previously squaring values. In this way a single value is calculated for each year of simulated data and APFD is then calculated simply as the average of yearly values.

A particularly important aspect of the calculation of APFD is that changes in monthly flow are expressed as a proportion of the expected natural flow for each month. For this reason this statistic is called the Annual *Proportional* Flow Deviation.
Proportion of Natural Monthly Flow Variability

The monthly flow variability described by this statistic was calculated as the Coefficient of Variation (CV) of the sum of monthly flows across years.

Proportion of Natural “High Flow” and “Medium Flow” Event Frequency

“High flow” and “medium flow” events were defined as events occurring at an average interval of 12–18 months and 4–6 months, respectively. The event frequencies under each water resource development scenario (natural and various extraction scenarios) were averaged to provide a single value.

Proportion of Natural “Low Flow” and “No Flow” Duration

Both “low flow” and “no flow” events were expressed as flow duration percentiles, which indicate the proportion of time that flow was equal to, or exceeded, a specific rate of flow. This proportion was calculated as the number of days per annum.

The benefits of the WAMP approach to hydrological assessment are that the parameters chosen are basin specific and thus directly relevant to the ecological issues within a particular basin. While this is useful for the purposes of management within the basin, it doesn’t facilitate the interbasin comparisons that allow higher level policy decisions to be made. It would also be a time consuming and expensive process to conduct for the whole of the Murray-Darling Basin.

The WAMP hydrological assessment also has the advantage of a quantitative approach which, once established, will enable monitoring of changes due to management activities. The range of hydrological measures used encapsulates changes to flow volume, flow regime and flood pulses.

Summary

- There are a variety of procedures used to estimate changes in the hydrology of river systems within the Murray-Darling Basin.
- Many use hydrological models that can generate flow data for 'natural' and 'developed' scenarios.
- There is no consistent method used in the Basin.

For the Audit:

- A quantitative approach has the greatest advantage.
- The measures need to encapsulate changes to flow regime and seasonality.
- The measures need to use data which are readily available.
- The approach needs to be applicable to streams without major regulation (the use of simulated data allows this).
- The approach needs to be consistent across the Basin (enabling interbasin comparisons).
Flow models

Given that flow models are utilised by many State agencies as water resource management tools the following section outlines those commonly used. Three models are outlined briefly: The Integrated Quantity Quality Model (IQQM), which is used by NSW Dept of Land and Water Conservation and the Queensland Dept of Natural Resources; The REsource ALlocation Model (REALM) used in Victoria; and, the Murray-Darling Basin Commission’s Monthly Simulation Model.

Integrated Quantity Quality Model (IQQM) — New South Wales and Queensland

IQQM was developed as a generic, hydrologic, river system simulation package for investigating new water resources management policy options and refinements to existing policies. The model is a strategic planning tool designed for investigating water sharing issues at the river basin, inter-state or international level, and between competing groups of users including the environment.

IQQM simulates river system behaviour at a daily time step with an option to use smaller time steps for some processes. It is able to simulate water quality behaviour and water quantity behaviour in an integrated manner, and is capable of application to both regulated and unregulated streams. IQQM was designed specifically to be effective in investigating issues where short term changes in flows or other parameters are important, such as environmental flows and event sharing. Because it operates on a daily time step, it can provide a much more detailed representation of short term variations in all factors relevant to any river system than is possible with a monthly model. IQQM is therefore a substantial advance in technology over the monthly models in use up to now.

IQQM is structured as a modelling shell with component modules linking together to form an integrated package. This shell has been designed to facilitate the incorporation of additional component modules as required. The main components of IQQM are:

- user interface shell,
- in-stream water quantity,
- in-stream water quality,
- rainfall-runoff,
- pollutant washoff and export,
- groundwater quantity and quality,
- statistical tools, and
- climate data generation tools.

IQQM uses two basic units for representing river systems:

(i) nodes: which represent points on a river system having certain operational or physical processes associated with them;

(ii) links: which represent river reaches between nodes.
To apply IQQM to a river system, it is necessary to configure the model to represent the physical features and the water management system. Configuring for the physical system includes defining locations of storages, demand centres, tributary inflows, effluent outflows and returns, floodplain detention storages and limits of flow routing reaches. Configuring for the management system includes defining system operating rules such as flow thresholds for unregulated flow licences.

IQQM implementation involves calibration and validation of the in-stream water quantity component in a two stage process. Stage 1 calibration requires deriving values of flow routing coefficients, effluent flow and transmission loss relationships, and relationships describing floodplain storage behaviour. In Stage 1, the model is run with recorded values of water diversions at each irrigation node. In Stage 2 of the calibration, values of parameters relating to irrigation demands are derived and results compared with available data.

When interpreting the results obtained from a model such as IQQM, due recognition needs to be given to the purpose of the model, the limitations of the data used to calibrate and validate the model and the limitations of the model itself. In particular it needs to be recognised that:

IQQM is a planning tool. It is intended to provide information on long-term future system performance and behaviour under given scenarios of management rules and physical constraints. It can provide a great deal of valuable information on a daily, monthly, seasonal, annual or longer basis, but in a statistical sense. As it is a planning tool, IQQM cannot be used to hindcast, say, the flows that would have occurred on a specific date in the past under a given scenario. For example the model may not reproduce the timing of a flood precisely although it may simulate the hydrograph volume and shape correctly; this does not matter in a planning model but it may be critical in other applications such as flood forecasting.

In current modelling practice, the prediction of long term future performance using models such as IQQM is based on historical hydrologic data (rainfall, streamflow, evaporation). A major limitation of this approach is that it basically assumes that the future will be a repeat of the past, which is clearly unlikely. An interpretation commonly used is that model results show what would have happened in the past had the scenario being modelled been in place then. On this basis the model could be used to hindcast past system performance, but only in a statistical sense and not in terms of comparing modelled and actual behaviour on given dates.

There are limitations in the accuracy of the input data. In the case of streamflow data the accuracy in the mid-flow range is usually 20% at best. At low flows and high flows the accuracy is generally very much worse and can frequently be no better than +100%/-50%. Accuracy is affected by channel bed stability at low flows and by erratic overland flow behaviour at high flows, both of which are problems in many rivers in the Basin. There are limitations in the accuracy of other data used in model calibration, such as water use data, which is incomplete or contains anomalies as discussed earlier. Metering will largely overcome errors in water use data.

There are uncertainties in calibration which are directly related to uncertainties in available data. Great care is taken during calibration to minimise data uncertainties and impacts on subsequent study results, but there will still be data-related uncertainties in model results.
RESOURCE ALLOCATION MODEL — Victoria

REsource ALlocation Model (REALM) is a PC-based water allocation simulation computer package. It uses the network linear programming algorithm to solve a water supply system represented by a connected system of arcs and nodes. Nodes represent storage reservoirs, diversion structures, demand centres and stream channel or pipe junctions. Arcs represent natural water carriers such as rivers and tributary streams or artificial water carriers such as lined or unlined channels or closed conduits. The model can be run on any specified time step such as annual, seasonal (bi-monthly, tri-monthly, etc.), monthly, weekly or daily.

System Specification

The package provides for analysing both urban and irrigation water supply systems. A graphical editor provides for setting up new water supply systems and specifying the system characteristics including storage capacity, carriers’ fixed or variable maximum capacities and minimum flows, carrier transmission losses, operating rules, supply restriction rules, storage distribution targets, etc. The graphical editor can also be used to modify or expand existing system files for analysing various planning or operational scenarios.

Inputs

The external inputs to the configured water supply network constitute streamflows time series at various intake points specified on the network and the unrestricted demand time series for specified demand centres in the network. Both these time series would be at the specified time step for simulation. Stochastic data generation algorithms used to generate daily series of rainfall and evaporation data can be used as input into REALM. The package of system specification, inflows, demands and outputs is specified through a WINDOWS™ based input facility.

Outputs

The model puts out files containing various system performance parameters such as storage volumes, flows, demands, supplies, losses, etc. at each simulation time step. The choice of output parameters can be specified through the WINDOWS based input facility. The output files can be examined via a graphical plotting package provided in the REALM package. Other utilities such as plotting system network configuration, system listing, data manipulation, etc., are also available within the REALM package suite of programs.

BigMod — Murray-Darling Basin Commission Flow Model

BigMod is a computer program used for modelling flow and solute transport in rivers. It operates on a time-step of one day and was developed by the Murray-Darling Basin Commission for three main roles:

- making short term flow and salinity forecasts;
- routing flow and salt in planning studies that test the performance of different options for river management against historical climatic conditions; and
• analysing historical data to calculate the solute loads entering the reaches of the river between water quality measurement stations.

The features of this model are:
• its ability to be calibrated accurately;
• its numerical stability; and
• its ability to model river reaches and branches that cease to flow.

Flow Routing

Bigmod routes flow using a hydrologic technique. The river is divided into reaches and sub-reaches. For each sub-reach the downstream flow is calculated as:

\[ \text{Downstream flow} = \text{Upstream flow} - \text{Storage change} - \text{Diversions} - \text{Losses} \]

The storage in any sub-reach is a function of the upstream flow. The relationship between storage and flow is defined in the model input parameters and is specified for each reach. It is specified in a table that relates flow to the travel time of the flow wave. Travel time, which defines the slope of the storage/flow relationship, is a parameter that is easy to determine during the calibration of the model by comparing the inflow and outflow hydrographs.

The method of routing is numerically stable provided that sub-reaches are small enough. The model automatically subdivides reaches into sub-reaches that ensure that the maximum flow travel time in any sub-reach is less than half a day. Dividing the reaches into smaller sub-reaches than this does not significantly change the model accuracy. The use of a tabulated relationship enables complicated storage functions to be specified which are especially useful when modelling the changes in flow travel time that occur at the transition between inbank and overbank flow.

The loss function has three components.
• an evaporation component which is based on an input value of net evaporation and a tabulated relationship between flow and surface area;
• a monthly loss component which enables constant losses or losses that vary on a seasonal pattern (such as unmetered diversions) to be included;
• a tabulated function between flow and loss (or gain) which enables losses on the flood plain (or systematic errors in flow measurement) to be modelled.

The inclusion of other features, including weirs, lakes connected to the river, branches, junctions, point diversions and point inflows have enabled the model to be applied to the whole River Murray from Hume Dam to the sea with considerable success.
Summary

The effect of catchment and water resource development on the hydrological regime of a river can be assessed with data generated from the above models. These models can provide:

- a ‘natural’ output, for which data are simulated as if there were no flow-regulating structures, abstractions of water or catchment development, using long-term mean climatic conditions;
- a ‘present’ development output, for which the water and catchment development conditions at a particular point in time are chosen from actual records and combined with long-term mean climatic conditions to provide an estimate of the resulting hydrological conditions; and
- data that can be accessed at any designated node along a river system.

Methods for the Audit Hydrology Index

The hydrology index being developed for the Audit needs to provide the following:

- a measure of the change in the flow regime caused by human activities;
- comparison of this change with respect to a reference condition. Because there is a lack of adequate flow data before catchment and water development and given the inherent flow variability of rivers in the Basin there will be a reliance on modelled data — in this case modelled 'natural'.
- a report of this change at a river-valley scale. At this scale appropriate flow indices must be reported at the flow regime and history scale because of the relationship between spatial and temporal scales in riverine ecosystem functioning. Moreover, data will be required at least for each valley zone or more preferably for each Functional Process Zone.

Currently, there is no standard hydrology index in terms of approach and indices used for rivers in the Murray-Darling Basin. Hence the following provides the development of a standard set of flow indices and an approach with which to assess hydrological change. There are two sections to this; the first derives several relatively simple components that measure hydrological deviation from a ‘natural’ flow. These components provide a measure of changes in both volume and pattern and are applicable across all the main river valleys in the Basin.

The Hydrology Index (HI) is defined in terms of four sub-indices:

- Mean Annual Flow Index (A);
- Flow Duration Curve Difference Index (M);
- Seasonal Amplitude Index (SA); and
- Seasonal Period (SP).
HI is defined as the ‘Euclidean Distance’ between an unimpacted hydrology condition and the condition defined by four sub-indices in a four-dimensional space (Equation 1). This could be the same approach as used to combine all five indices into the Audit. The hydrology sub-indices are all defined on the range 0–1, where 1 represents ‘unimpacted’, and 0 represents ‘maximum impact’. This index is similar to that being developed by the CRC for Freshwater Ecology and CSIRO Land and Water for the National Land and Water Audit.

$$HI = 1 - \frac{\sqrt{(1 - A)^2 + (1 - M)^2 + (1 - SA)^2 + (1 - SP)^2}}{\sqrt{4}}$$

Equation 1

The second section outlines the aggregation from s site(s) to the Functional Process Zone or valley zone.

Data required

Modelled flow data for rivers (under existing and unregulated and ‘natural’ conditions) will be required in each of the identified Functional Process Zones. The modelled ‘natural’ conditions should reflect historic changes in rainfall and catchment conditions. Note: some modelled data have been collected from each of the States for the National Land and Water Audit. NSW and Queensland have provided modelled daily data whilst the majority of the Victorian data and data provided by the MDBC for the River Murray are monthly. Preliminary analyses of these data have been undertaken, highlighting the successful application of the hydrology index (see section 5).

1. Mean Annual Flow (A)

This provides a measure of the difference in flow volume between current and natural conditions. It is given by the statistic $A$ as defined in Equation 2 where the mean annual flow under current (i.e. existing) and natural conditions is given by $Q_c$ and $Q_n$ respectively.

$$\text{if } Q_c > Q_n \text{ then } A = \frac{Q_c}{Q_n}, \text{ else } A = \frac{Q_n}{Q_c}. \quad \text{Equation 2}$$

Comments

This statistic is constrained to a maximum of 1, representing no change in mean annual flow, and 0, representing the most modified mean annual flow conditions. This statistic assumes that a doubling of mean annual flow is equally as ‘bad’ as a halving of mean annual flow.

2. Flow Duration Curve Difference (M)

The flow duration curve difference (see Figure 4) provides a measure of the overall difference between current and natural flow duration curves. This precursor to this statistic was developed to assess the overall hydrological deviation of an option from the...
transparent flow option (Young et al. 2001). It has subsequently been modified to ensure that values returned are between 0 and 1.

\[ M = \begin{cases} \frac{1}{n} \sum_{i=1}^{p} c, & \text{if } n > c \\ \frac{1}{p} \sum_{i=1}^{n} c, & \text{else} \end{cases} \]  

Equation 3

Comments

This approach weights all percentile flows equally and this may result in an undue bias toward changes in flow in the interquartile range whereas small changes in the >90% or <10% which may be more significant to river condition will have less of an impact. An alternative is to weight high and low flows more heavily — or to only include high and low flows. However, some justification for this and the choice of percentile flows would be required. One way of handling this is to determine \( M \) for a series of scenarios and see if the result is intuitive in terms of river condition.

3. Seasonal differences

Seasonal changes can occur as changes in amplitude (the difference between the highest and lowest monthly flows) or period (the months in which the flow is conveyed) (Figure 5). Two separate statistics are therefore proposed to assess seasonal change.
Figure 5. Types of seasonal change: a) represents a change in amplitude, b) represents a change in period

• Seasonal Amplitude (SA)

The statistic $SA$ is given in Equation 4, where $h$ is the highest mean monthly flow and $l$ is the lowest mean monthly flow for current (subscript $c$) and natural (subscript $n$) conditions. The denominator is always the larger value of $h_c$ and $h_n$ or $l_c$ and $l_n$.

$$SA = \frac{\left[\frac{h}{h_n} + \frac{l}{l_n}\right]}{2}$$  \hspace{1cm} \text{Equation 4}

• Seasonal Period (SP)

The statistic $SP$ (Equation 5) is defined as the difference from 1 of the sum of the differences between the numerical values of the months with the highest mean monthly flow ($H$) and the numerical values of the months with the lowest mean monthly flow ($L$) for current and natural conditions (subscript $c$ and $n$ respectively), divided by 12.

$$SP = 1 - \frac{1}{12} \left( \text{if } |H_c - H_n| \leq 6 \text{ then } H_c - H_n \text{, else lookuptable } + \text{ if } |L_c - L_n| \leq 6 \text{ then } L_c - L_n \text{, else lookuptable} \right)$$  \hspace{1cm} \text{Equation 5}

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<tr>
<th>lookuptable: if then =</th>
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</table>

Example: Natural conditions: highest mean monthly flow — August (month 8) lowest mean monthly flow — February (month 2) Current conditions: highest mean monthly flow — March (month 3) lowest mean monthly flow — September (month 9)
Determining the hydrological index for a river valley

Once the hydrological index has been calculated for each site within a Functional Process Zone a simple process of aggregation can occur in order to report the index at a valley zone or river-valley scale. It is suggested that a weighted catchment area approach be adopted where the weightings are simply the catchment area upstream of the individual Functional Process Zones relative to the total catchment area. This is to ensure that the correct weightings of the various Functional Process Zones are recognised. For example, Australian watercourses have recently been mapped at a 1:250,000 scale by Stein et al. (1998). Using these data Thoms and Sheldon (2000) have calculated that there are approximately 3127 million kilometres of lowland rivers in Australia. This represents 97% of the total length of Australian rivers. Of this, the majority, 83%, are inland systems (Pickup 1986) and have semi arid to arid (dryland) climatic regimes and many cease to flow for periods of time.

Principles for the calculation of the hydrology index where data are unavailable

There may be situations for which hydrological data suitable for calculating the hydrological index\(^2\) are not available — thus calculating the hydrological index (and its components) is not possible. The following are a set of suggested principles for use in determining the index in circumstances where suitable data are not available.

Case 1. Zones on unregulated streams

Hydrology index set to 1.

While we recognise that land use change may alter the hydrology of a stream, the literature on this does not indicate that the change is consistent or predictable.

Case 2. Zones on regulated streams

Hydrology index set to non-assessed.

Case 3. Zones on regulated streams, upstream of dams

Hydrology index set to 1.

These are effectively unregulated reaches. This assumes that where there are major abstractions, modelled data are generally available. Where there are minor abstractions,

\[ SP = 1 - \frac{1}{12} \left( |3 - 8| + |9 - 2| \right) = 1 - \frac{1}{12} (5 + 5) = 1 - \frac{10}{12} = \frac{2}{12} . \]

\(^2\) Suitable data are the following paired data sets:
1. modelled natural and modelled existing flows;
2. modelled natural and observed flows; and
3. observed flows pre- and post-regulation.
the components of the index are unlikely to deviate significantly from 1 as they are fairly insensitive to small changes in flow regime.

Case 4. Zones on regulated streams, downstream of a dam, upstream of a zone with data suitable for calculating the index with unregulated tributaries joining the main stem

E.g. See Figure 6. Data are not available for reaches R1, R2 & R3, and data are available for reach R4. T1, T2 & T3 represent the unregulated tributaries joining the main stem.

![Figure 6](image)

Under these circumstances the components of the index are apportioned according to mean annual flow in the reaches upstream of the “known” reach:

Thus for R3

\[
Q_{R4}M_{R4} \equiv (M_{R3}Q_{R3} + M_{T3}Q_{T3})
\]

or

\[
M_{R3} \equiv \frac{(M_{R4}Q_{R4} - Q_{T3})}{Q_{R3}} \text{ since } M_{T3}=1.
\]

Similarly for R2 & R1:

\[
M_{R2} \equiv \frac{(M_{R2}Q_{R2} - Q_{T2})}{Q_{R2}} \qquad M_{R1} \equiv \frac{(M_{R1}Q_{R1} - Q_{T1})}{Q_{R1}}
\]

where: $M_{R#}$ = the component of the index for mainstem reaches R1–R4,

$M_{T#}$ = the component of the index in the unregulated tributaries (which by nature of our index components equals 1),

$Q_{R#}$ = mean annual flow in the mainstem reaches,

$Q_{T#}$ = mean annual flow in the unregulated tributaries.
Then if for example, the downstream reach (R4) had $M_{R4} = 0.5$, and the upstream regulated reach (R3) contributed 70% of the total (regulated) flow, then $M_{R3}$ for the regulated upstream reach would be $(0.5 - 0.3)/0.7 = 0.29$, thus showing that the addition of the unregulated tributary had reduced the degree of regulation in proportion to the flow added.

This relies on
1. Having information about the mean annual flow for the unregulated tributaries. This could be supplied from standard regionalisation procedures.
2. Being able to automate the calculation.

Case 5. Zones on a regulated stream downstream of a zone with data suitable for calculating the index with unregulated tributaries joining the main stem

E.g. See Figure 7. Data are available for R1, but not R2-R4. T1, T2 & T3 are unregulated tributaries.

Figure 7

If there are major diversions in reaches R2–R4, then these should be set to non-assessed. This assumes that we do not have data on diversion volumes — where we do have diversion data, we also have modelled data and the index can be calculated.

If there are no major diversions in reaches R2–R4, the indices are again apportioned according to mean annual flow in the reaches.

Thus for R2

$$M_{R2} \equiv \frac{(M_{R1}Q_{R1} - Q_{T1})}{Q_{R2}}$$

since $M_{T1} = 1$.

Similarly for R3 & R4:

$$M_{R3} \equiv \frac{(M_{R2}Q_{R2} - Q_{T2})}{Q_{R3}}$$

$$M_{R4} \equiv \frac{(M_{R3}Q_{R3} - Q_{T3})}{Q_{R4}}$$

where: $M_{R\#} =$ the component of the index for mainstem reaches R1–R4,
MT# = the component of the index in the unregulated tributaries (which by nature of our index components equals 1),

\[ Q_{R#} = \text{mean annual flow in the mainstem reaches}, \]

\[ Q_{T#} = \text{mean annual flow in the unregulated tributaries}. \]

Again this relies on the conditions for case 4 and 5, that we have mean annual flow data for the reaches and tributaries and that we can automate the calculation.

## Testing the Hydrology Index

### Background

The four simple measures of change in riverine flow regime outlined above have been tested using flow data from the River Murray at Dartmouth and Hume Dams, as well as data from the Upper Murrumbidgee system, and the result of the testing is outlined below.

### Data

The modelling group from the Murray-Darling Basin Commission (MDBC) supplied the following data to enable testing of the hydrology indices:

- Daily inflows and releases from Dartmouth Dam: Jan 1980–Jan 2000
- Monthly inflows and releases from Dartmouth Dam: Jan 1980–April 2000

Inflows are modelled ‘natural’ (unregulated) flows and releases are ‘current’ (regulated) flows. Strictly speaking, statistics summarise the impact of dams on flow regime, and ‘natural’ flow means flow not impacted by a dam, rather than the flow regime in an undisturbed catchment.

Modelled data (output from IQQM) was also supplied by NSW DLWC for the Upper Murrumbidgee system at Tumut, Burrinjuck, Gundagai and Wagga:

- Monthly modelled ‘natural’ and existing flow data for the Tumut River at Tumut: 1890–1997
- Monthly modelled ‘natural’ and existing flow data for the Murrumbidgee River at Gundagai: 1890–1997
- Monthly modelled ‘natural’ and existing flow data for the Murrumbidgee River at Wagga: 1890–1997
Component Testing

Test Aims

- To determine if each of the components returns a value between 0 and 1, where 0 is highly modified and 1 is equivalent to natural.

- To determine if there is a difference in the components calculated using daily or monthly data.

- To determine if the statistics proposed are robust — i.e. they ‘work’ at a range of sites — and if the components produce ‘realistic’ numbers given what we know about the systems for which we have data.

Mean Annual Flow

\[
\begin{align*}
\text{if } & Q_c > Q_n \text{ then } A = \frac{Q_n}{Q_c}, \text{ else } A = \frac{Q_c}{Q_n} \quad \text{— provides a measure of the difference in flow volume between existing and natural conditions.}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Location</th>
<th>(Q_c) (ML)</th>
<th>(Q_n) (ML)</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Murray at Dartmouth</td>
<td>855 000</td>
<td>883 000</td>
<td>0.97</td>
</tr>
<tr>
<td>River Murray at Hume</td>
<td>4 967 000</td>
<td>4 667 000</td>
<td>0.94</td>
</tr>
<tr>
<td>Tumut River at Tumut</td>
<td>1 993 000</td>
<td>1 277 000</td>
<td>0.64</td>
</tr>
<tr>
<td>Murrumbidgee River at Burrianjuck</td>
<td>1 379 000</td>
<td>1 485 000</td>
<td>0.93</td>
</tr>
<tr>
<td>Murrumbidgee River at Gundagai</td>
<td>3 940 000</td>
<td>3 372 000</td>
<td>0.86</td>
</tr>
<tr>
<td>Murrumbidgee River at Wagga</td>
<td>4 400 000</td>
<td>3 754 000</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Test results

1. The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system. *Note:* doubling of flows will return a value of 0.5 which is equivalent to a halving of flows.

2. Not tested — there should be no difference in this statistic calculated using daily or monthly data (provided the models producing the data are in agreement!).

3. The statistic appears to work for all sets of data.
   - The difference in average annual flows between ‘natural’ and ‘current’ conditions at both sites on the River Murray is small and Hume Dam modifies average annual flows in the River Murray more than does Dartmouth Dam. The derived statistic reflects both of these factors at 0.97 and 0.94 for Dartmouth and Hume.
respectively. Hume current is greater than Hume natural due to transfers from the Snowy system.

- Inter-basin transfers from the Snowy scheme and transfers within the Upper Murrumbidgee system mean that flows at Tumut, Gundagai and Wagga have increased compared with natural flows. This is most pronounced for the Tumut River and is reflected in the derived statistic. Flows at Burrinjuck are reduced compared with natural due to transfers from Tantangara.

**Flow Duration Curve Difference (M)**

If $n > c$ then

$$M = \frac{1}{p} \sum_{i=1}^{p} \frac{c}{n}$$

else

$$M = \frac{1}{p} \sum_{i=1}^{p} \frac{n}{c}$$

— provides a measure of the overall difference between current (existing) and natural flow duration curves.

**River Murray at Dartmouth:**

*Daily Data:*

![Daily flow duration curve: River Murray at Dartmouth](image)

$M = 0.59$
Monthly Data:

Monthly flow duration curve: River Murray at Dartmouth, 1980-2000

\[ M = 0.46 \]

River Murray at Hume

Monthly Data:

Monthly flow duration curve: River Murray at Hume, 1969-2000

\[ M = 0.36 \]
Appendix 6 Review and development of hydrological indicators
Final Report for Project R2004

Tumut River at Tumut

Monthly flow duration curves under natural and current conditions: Tumut 1890-1999

$M = 0.49$

Murrumbidgee River at Burrinjuck

Monthly flow duration curves under current and natural conditions: Burrinjuck

$M = 0.86$
Murrumbidgee River at Gundagai

![Monthly flow duration curves under current and natural conditions: Gundagai](image)

\[ M = 0.60 \]

Murrumbidgee River at Wagga

![Monthly flow duration curve under current and natural conditions: Wagga](image)

\[ M = 0.58 \]

Test results

1. The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system.

2. There is some difference between the statistics generated using daily and monthly data. Curiously daily data returns a value of 0.59 at Dartmouth and monthly data returns a value of 0.46 which indicates that the daily flow duration curve has been modified less extensively than the monthly flow duration curve — which is counter intuitive.

3. The statistic appears to work for all sets of data. Relative differences in the flow duration curves are reflected in the magnitude of the statistic M — e.g. the flow duration curves at Tumut are markedly different and the value of M at this site is 0.49 whereas the flow duration curves at Burrinjuck are only slightly different producing a value of M of 0.86.
Seasonal differences

Seasonal changes can occur as changes in amplitude (the difference between the highest and lowest monthly flows) or period (the months in which the flow is conveyed). Two separate statistics are therefore proposed to assess seasonal change.

![Average monthly flows: River Murray at Dartmouth, 1980-2000](image1)

![Average Monthly Flows: River Murray at Hume, 1969-2000](image2)

![Average monthly flows: Tumut River at Tumut, 1890-1997](image3)
Average monthly flows: Murrumbidgee River at Burrinjuck: 1890-1997

Average monthly flows: Murrumbidgee River at Gundagai: 1890-1997

Average monthly flows: Murrumbidgee River at Wagga: 1890-1997
Seasonal Amplitude

$$SA = \frac{\left(\frac{h_c}{h_n} + \frac{l_c}{l_n}\right)}{2},$$

where the denominator is always the larger value of $h_c$ and $h_n$ or $l_c$ and $l_n$.

<table>
<thead>
<tr>
<th>Location</th>
<th>$h_c$ (ML)</th>
<th>$h_n$ (ML)</th>
<th>$l_c$ (ML)</th>
<th>$l_n$ (ML)</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Murray at Dartmouth</td>
<td>104 000</td>
<td>152 000</td>
<td>10 000</td>
<td>13 000</td>
<td>0.72</td>
</tr>
<tr>
<td>River Murray at Hume</td>
<td>694 000</td>
<td>826 000</td>
<td>54 000</td>
<td>108 000</td>
<td>0.67</td>
</tr>
<tr>
<td>Tumut River at Tumut</td>
<td>239 000</td>
<td>220 000</td>
<td>79 000</td>
<td>25 000</td>
<td>0.61</td>
</tr>
<tr>
<td>Murrumbidgee River at Burrinjuck</td>
<td>161 000</td>
<td>212 000</td>
<td>60 000</td>
<td>50 000</td>
<td>0.79</td>
</tr>
<tr>
<td>Murrumbidgee River at Gundagai</td>
<td>424 000</td>
<td>507 000</td>
<td>209 000</td>
<td>92 000</td>
<td>0.63</td>
</tr>
<tr>
<td>Murrumbidgee River at Wagga</td>
<td>464 000</td>
<td>585 000</td>
<td>230 000</td>
<td>95 000</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Test results

1. The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system.
2. Not tested — only monthly data used.
3. This option appears to work with all sets of data. This option reflects actual changes in the mean maximum and the mean minimum monthly flows and is therefore not a direct measure of the change in amplitude (the difference between the maximum and minimum flows). However, it is a more relevant measure — in the situations above, minimum monthly flows at Hume have halved and maximum monthly flows have dropped by 25% — yet the amplitude change is only small.

Seasonal Period

$$SP = 1 - \frac{1}{12} (\text{if } |H_c - H_n| \leq 6 \text{ then } |H_c - H_n|, \text{ else lookuptable} + \text{if } |L_c - L_n| \leq 6 \text{ then } |L_c - L_n|, \text{ else lookuptable})$$

lookuptable:

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<td>10</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>
Test results

1. The statistic produces a value of 1 where existing conditions are equivalent to natural and 0 for a highly modified system.
2. Not tested — uses only monthly flows.
3. The statistic appears to work for all sets of data. The results returned appear realistic.

Overall Hydrology Index

The four statistics outlined above are combined to produce the overall hydrology index according to the following equation.

$$HI = \left(1 - \frac{\sqrt{(1 - A)^2 + (1 - M)^2 + (1 - SA)^2 + (1 - SP)^2}}{4}\right)$$

Equation 6

<table>
<thead>
<tr>
<th>Location</th>
<th>$H_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Murray at Dartmouth</td>
<td>0.67/0.63*</td>
</tr>
<tr>
<td>River Murray at Hume</td>
<td>0.60</td>
</tr>
<tr>
<td>Cotter River at Kiosk</td>
<td>0.63</td>
</tr>
<tr>
<td>Tumut River at Tumut</td>
<td>0.53</td>
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<tr>
<td>Murrumbidgee River at Burrinjuck</td>
<td>0.60</td>
</tr>
<tr>
<td>Murrumbidgee River at Gundagai</td>
<td>0.56</td>
</tr>
<tr>
<td>Murrumbidgee River at Wagga</td>
<td>0.63</td>
</tr>
</tbody>
</table>

* Daily/Monthly
Conclusions

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Conclusion</th>
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<tbody>
<tr>
<td>A</td>
<td>Good — but there is an issue with doubling of flows being considered equivalent to a halving of flows</td>
</tr>
<tr>
<td>M</td>
<td>Good — although why is the daily flow duration curve less variable than the monthly flow duration curve?</td>
</tr>
<tr>
<td>SA</td>
<td>Good — although not truly representing an amplitude change</td>
</tr>
<tr>
<td>SP</td>
<td>Good</td>
</tr>
</tbody>
</table>

References


Appendix 7
Physical Habitat

Review and Development of Physical Habitat Assessment Protocols

Ben Gawne
# Table of Contents

Table of Contents.................................................................................................................. 282  
Summary................................................................................................................................ 284  
Objectives ............................................................................................................................... 285  
Definition of Habitat ............................................................................................................... 286  
Tasks ....................................................................................................................................... 286  
Conceptual Model .................................................................................................................. 287  
Habitats .................................................................................................................................... 288  
Floodplain ............................................................................................................................... 288  
Channel Features ................................................................................................................... 288  
Hydraulic ................................................................................................................................. 289  
Physical Features ................................................................................................................... 289  
In-channel Patches .................................................................................................................. 290  
Reference Approach ................................................................................................................ 292  
Additional Problems with Referential Approach when assessing physical habitat ................. 295  
Review of Habitat Assessment ............................................................................................... 296  
AUSRIVAS — National .......................................................................................................... 296  
Index of Stream Condition — Victoria .................................................................................. 297  
River Styles — NSW .............................................................................................................. 298  
Pressure—Biota—Habitat — NSW .......................................................................................... 299  
State of the Rivers — Queensland ........................................................................................ 299  
Other assessment approaches ............................................................................................... 300  
Analysing Data from the Habitat Assessment ...................................................................... 300  
Index Scores .......................................................................................................................... 301  
ANOVA comparisons ............................................................................................................ 301  
Ordination ............................................................................................................................... 301  
Canonical Analysis ................................................................................................................ 301  
O/E values ............................................................................................................................... 301  
Proposed Assessment Protocol ............................................................................................. 303  
Floodplain ............................................................................................................................... 304  
Channel Features ................................................................................................................... 305  
Banks ..................................................................................................................................... 305  
Riparian Vegetation ............................................................................................................... 305  
Species richness and diversity .............................................................................................. 306  
Relative abundance ............................................................................................................... 307  
Riparian Width ....................................................................................................................... 308  
Habitat Fragmentation .......................................................................................................... 308  
Riparian Canopy Complexity ............................................................................................... 309  
Riparian Demography ........................................................................................................... 310  
Standing Litter ....................................................................................................................... 310  
Vegetation Overhang ............................................................................................................ 311  
Vegetation Vigour ................................................................................................................ 311  
Emergent macrophytes ....................................................................................................... 312  
Species richness and diversity .............................................................................................. 312  
Macrophyte area & relative abundance .............................................................................. 313  
Channel form ........................................................................................................................ 314  
Channel features (riffles, pools, islands, rock bars, sand bars, backwaters, benches, point bars) ................................................................................................................................. 314  
Pools ..................................................................................................................................... 314  
Snags ..................................................................................................................................... 315  
Recommendations for monitoring/assessment ..................................................................... 316  
Low-level high-resolution aerial photography .................................................................... 316  
Position in water column ..................................................................................................... 316  
Visual assessment ............................................................................................................... 317  
Preferred method .................................................................................................................. 317  
In-Channel patches ............................................................................................................... 317  
Proportion of clay, silt, sand, gravel, cobble, boulders, bedrock, detritus ......................... 317  
Embeddedness ....................................................................................................................... 318  
Proportion of each patch covered in algae/periphyton/biofilm ........................................ 318  

Appendix 7 Review and development of physical habitat assessment protocols
Final Report for Project R2004
Appendix 7 Review and development of physical habitat assessment protocols

Cooperative Research Centre for Freshwater Ecology

Process Measures........................................................................................................................................ 318
Riparian Regeneration ............................................................................................................................ 318
Potential input of Large Woody Debris .................................................................................................. 319
Connectivity ............................................................................................................................................. 319
Sediment Regime .................................................................................................................................... 320
Costing .................................................................................................................................................... 321
Reporting ............................................................................................................................................... 323
Priority Tasks .......................................................................................................................................... 323
References ............................................................................................................................................... 329
Summary

It is recommended that physical habitat be assessed at three spatial scales: floodplain (km), channel feature (100 m) and in-channel patches (1 m). The assessment protocol uses a combination of remote sensing and field data collection. Each river valley assessment will be undertaken once in each five-year period as most of the variables change over relatively long time periods.

Within each spatial scale there is an assessment of the type, area and diversity of physical habitat. The major habitat categories include the vegetation, geomorphological, and hydraulic characteristics of each habitat type (see Table 4 at the end of this appendix). The selection of indicators was based on an explicit conceptual model with consideration given to the cost of data collection, our limited understanding of the important characteristics of physical habitat, and ecological rigour. The protocol includes a separate assessment of processes that either maintain or degrade physical habitat such as erosion or isolation.

An O/E score will be generated for each spatial scale using the E-Ball technique. This will allow separate determination of floodplain and stream feature components. The score for each scale should be reported individually. The lowest of the three spatial scale assessment scores should be used to derive a single physical habitat score.
Objectives

Habitat, along with flow and water quality, is a major determinant of biological outcomes in rivers. Yet it is equally valid to consider that physical habitat is, to some extent, the product of biological processes. A further complication is that many of the indices of physical habitat (e.g. riparian vegetation, macrophytes) would be included in assessments of riverine biodiversity. This component of the Sustainable Rivers Audit describes a protocol for the assessment of physical habitat in rivers of the Murray-Darling Basin. The objectives of the Sustainable Rivers Audit are to:

- develop a common reporting framework for river condition using comparable information, through time and across catchments;
- report the assessment of River Condition against a consistent and scientifically robust set of river health indicators;
- trigger further investigation or action in response to evidence of deteriorating river health;
- inform the development of targets for river health, and monitor progress towards achieving those targets.

The outputs of the Sustainable Rivers Audit are:

- identification of effective indicators of river health, monitoring protocols, interpretive methodologies and appropriate reporting intervals for those indicators;
- a reporting framework/matrix by which these indicators and management activities will be regularly reported.

The specific objectives of the assessment of the physical habitat component are to:

- develop a common reporting framework for the assessment of physical habitat and reporting of habitat condition at the river-valley scale, and at the Valley Process Zone Scale;
- build on the knowledge and experience of existing monitoring programs;
- develop a series of indicators that will enable the cost-effective assessment of the existing condition of riverine habitat in the Basin and thence its subsequent improvement or decline.

The assessment of physical habitat is a complex task made all the more difficult by our limited understanding of many organisms’ use of habitat and the extreme variability of habitat within lowland river ecosystems. Because of this the assessment protocol should collect data in a manner that anticipates future knowledge requirements. This will ensure that future generations can accurately determine the direction and rate of change of river condition in the Murray-Darling Basin. This can be achieved by collecting quantitative spatially explicit data on a wide variety of parameters. In recognition of the need to collect a diverse array of information the Physical Habitat task group recommends that the Audit assessment include five elements, reflecting:

- connectivity (including weirs and levees that block the movement of water and organisms among habitats);
- riparian condition;
• woody debris (e.g. snags);
• geomorphic characteristics;
• wetland and floodplain elements.

These components are packaged in a scale-explicit, ecologically robust manner that clearly shows the relationships among the indicators being assessed.

Definition of Habitat

Before describing the protocol for habitat assessment, it is important to define the term “habitat”. The following three definitions were obtained from biological dictionaries:

1. Habitat = The natural home or dwelling place of an organism (Steen 1971)
2. Habitat = The living place of an organism or community, characterised by its physical or biotic properties (Allaby 1991)
3. Habitat = Place or environment in which specified organisms live (Thain and Hickman 1994).

These definitions reveal that there are two components to defining habitat:

1. the species that is being considered;
2. the characteristics of a patch defined in terms of its physical or biotic properties.

As a consequence, “habitat” without reference to a taxa or group of organisms renders the term meaningless. This is because, at least on Planet Earth, everywhere is habitat for something, whether it be the space station Mir (rogue fungi), deep sea vents (worms and bacteria) or several kilometres down in the earth’s crust (bacteria).

One of the major issues arising from this definition is that habitat is scale-dependent, with both the scale at which organisms respond to their environment and the hierarchy of biotic and abiotic processes that shape the habitat patchwork at a given scale being important.

Tasks

Development of a method of physical habitat assessment is best undertaken as a series of tasks that will result in the formulation of a robust and cost effective protocol. The major tasks are:

1. develop a conceptual model of physical habitat,
2. define the habitats to be assessed,
3. define/describe reference condition against which assessments will be compared,
4. describe a protocol to assess habitat,
5. describe a protocol to assess whether the processes required to maintain habitat are operating,
6. describe a method to enable comparison between test site data and the reference condition,
7. deliver assessment of condition.
Conceptual Model

The existing Australian physical habitat assessment protocols tend not to explicitly specify conceptual models upon which they are built, although there are exceptions (e.g. NSW IMEF). An evaluation of the indices measured by existing programs indicates three common elements:

1. The Flood Pulse Concept, or at least the idea that lateral exchanges between the riparian and floodplain zones and the main channel are important in determining the condition of rivers, is implicit in most programs.

2. Assessment protocols are based on the hypothesis that there is a relationship between habitat diversity and biotic diversity. This hypothesis is linked to the hypothesis that diversity is correlated with “health”.

3. Most of the habitat descriptions are couched in terms of fish or arthropod invertebrates suggesting a hypothesis that fish and arthropod invertebrates are either keystone taxa in river ecosystems or that they are indicators of the condition of other taxa and ecological processes.

While there are varying degrees of evidence to support these models or hypotheses, it would appear unlikely that riverine ecosystems are actually either this simple or homogeneous. As a result we have developed a more complex conceptual model that better describes the riverine environment.

Habitat within lowland rivers is structured in the first instance by the interaction of flow regime and the geology of the catchment. At a large scale, water moving over the landscape produces a mosaic of channels and depressions filled with sediment of different types. At a smaller scale, flow produces a variety of hydraulic environments that impose shear, lift and drag forces on organisms.

At the larger scale the sediment type and the flow regime at a given point will determine the fundamental habitat potential of a site. This potential can then be modified by the action of the biota. Examples include the growth of riparian vegetation, macrophytes or construction of hydropsychid nets that modify the existing habitat and potentially create new habitat for other organisms.

The interaction of flow and geology create the fundamental template and so any assessment of physical habitat must be undertaken in conjunction with an analysis of flow regime. The importance of this point can be illustrated by consideration of snags. Snags are regarded as a significant physical habitat element in lowland rivers, providing shelter and food for fish and a stable substrate that supports a biofilm which provides food for invertebrates and an attachment point for filtering invertebrates. While this hypothesis is true in a general sense, the value of snags to fish and invertebrates depends on the flow regime. If flows are too high, the snag may not provide protection, if flows are too low, the snag may not have any impact on current speeds and/or the holes created by snags may become filled with sediment. The value of snags to filter and biofilm feeders will also vary in response to flow as the delivery of food and the nature and palatability of the biofilm on the snag depend on the flow regime and current speeds over the snag.

Hypothesis 1: Habitat is determined by the interaction of flow regime and geology.
While the characteristics of habitat can be defined in terms of the flow, substrate characteristics and modifications by the biota, this is only part of the relationship between habitat and the associated organisms. There are a number of other considerations about both the quality, quantity and spatial arrangement of habitat that will affect the composition of the biotic community and the rate of ecological processes. These relationships can be summarised in the following hypotheses.

Hypothesis 2: There is a correlation between habitat diversity and species diversity.

Hypothesis 3: Habitat abundance or area affects the rate of ecological processes and species population size.

Hypothesis 4: For ephemeral habitats, there is a relationship between the temporal characteristics of the habitat and the abundance of a species in the ecosystem.

Hypothesis 5: For species that move among habitat patches, the spatial and temporal arrangement of habitat patches will affect a species abundance in the ecosystem and the rates of ecological processes.

Hypothesis 6: For species that require different habitats for different life stages (larval, pupal, adult) or different activities (feeding, breeding or sheltering) the spatial and temporal arrangement of habitat patches will affect the population size and persistence of species in the ecosystem.

Hypothesis 7: Species that use multiple habitat patches or types, or species that require a resource delivered from a different habitat (e.g. allochthonous organic matter) the nature, duration and timing of connection among habitats will affect the flow of material, the persistence of species and the community structure in the river ecosystem.

These seven hypotheses constitute a summary of our understanding of the relationship between physical habitats and as such encapsulate our conceptual model.

Habitats

Before physical habitat can be assessed, the broad habitat types need to be described. Because habitat definition requires a description of the scale being considered, the organisms being considered and physical characteristics important to those organisms, we consider physical habitat at three spatial scales, namely floodplain, channel feature and “in-channel” patches.

Floodplain

- Floodplain: Important habitat for a diverse and unique botanical community that supports a diverse and productive faunal community. From an aquatic perspective, it is among the most ephemerals of habitats. Used by invertebrates, fish and birds for feeding and some micro-invertebrates for reproduction.
- Anabranches: A dynamic habitat, which undergoes transitions from flowing channel to pool to terrestrial environment. As a consequence, its use as habitat by any given
species tends to be patchy in time. Anabranches provide habitat for macrophytes and have the potential to provide habitat for fish, invertebrates, reptiles and birds as feeding habitat, and for by some invertebrates and possibly amphibians and fish for reproduction.

- Flood-runners: Another ephemeral habitat that undergoes frequent transitions between terrestrial and aquatic phases. Flood-runners are important habitat for macrophytes and may be used by fish, invertebrates, reptiles and birds as feeding habitat and by some invertebrates and possibly amphibians and fish for reproduction.

- Wetlands: A diverse category of habitats ranging from wet meadows to deep permanent bodies of standing water. Among the most diverse of habitats in lowland river ecosystems, supporting communities of trees, grasses, annuals, macrophytes, macroinvertebrates, zooplankton, fish, birds, reptiles, amphibians and mammals. The diverse biotic community is structured by water, nutrient and sediment regime and the characteristics of its connection to other wetlands and the river.

## Channel Features

### Hydraulic

- Pool: areas of low flow and deep water that provide habitat for invertebrates, submerged and emergent macrophytes and large fish.
- Run: areas of faster flowing water with standing waves, but white water is absent or rare.
- Riffle: areas of high slope and fast flowing water with standing waves and broken water.

### Physical Features

- Banks: a heterogeneous collection of habitats from gently sloping vegetated banks to steep cliffs. They can form an important ecotone between aquatic and terrestrial areas and may provide habitat for birds, mammals, crustaceans and other terrestrial, aquatic and amphibious invertebrates.
- Riparian vegetation: important to the adult stages of some aquatic insects, arboreal and terrestrial invertebrates, birds and, during periods of inundation, fish, invertebrates, algae, fungi and bacteria.
- Riparian groundcover: the ground associated with river banks provides habitat for a range of invertebrates, amphibians, reptiles, mammals and birds. The quality of this habitat has been found to depend on the extent of cover provided by living and dead plant material.
- Overhanging vegetation: Overhanging vegetation is correlated with abundance and distribution patterns for a range of aquatic fauna. For macroinvertebrates, habitat heterogeneity (including habitat patches created by overhanging vegetation) plays a crucial role in the distribution and abundances of different functional groups. Crayfish...
show shade-seeking behaviour and their presence has been correlated with the proportion of channel overhung by plant canopy. Many fish show habitat preferences for areas with overhead cover including that provided by overhanging vegetation, which reduces predation risk by obstructing visual detection. Platypus and water rat burrows tend to be located in association with overhanging vegetation, and usage by other organisms relates to the provision of roosting, perching and calling sites (waterbirds, reptiles, frogs).

- Emergent macrophytes: support a diverse and productive biofilm community; provide habitat and food for invertebrates, fish, reptiles, amphibians, birds and mammals.
- Benches: may provide areas of slow flowing, shallow water which are important for some species of bird. Their organic matter retention properties make them important habitat for macroinvertebrates.
- Pools: provide important refuges during periods of drought for all permanently aquatic species. During base flow conditions, pools provide refuge for fish.
- Snags are often the dominant hard substrate in lowland rivers. As such they can support a biofilm that provides food or habitat for macroinvertebrates. Snags also provide a point of attachment for filtering insects allowing access to preferred hydraulic conditions. Snags also have an impact on the hydraulic environment around the snag. This effect can increase hydraulic heterogeneity and provide habitat for fish seeking refuge from the current and predators.
- Riffles are not common in Australian lowland rivers. Riffles offer relatively stable substrate and a diverse hydraulic environment that provides habitat for a diverse community of algae, bacteria and macroinvertebrates.
- Rock bars: do not make a significant contribution to habitat in lowland rivers in terms of surface area. They do however offer habitats similar to snags with regard to stable substrate and hydraulic heterogeneity.
- Sand bars are large and often conspicuous components of lowland rivers that actually provide a variety of environmental conditions from erosional faces, to shallow areas of very low flow to slightly deeper depositional zones on the trailing edge. As a consequence, sand bars provide habitat for episammic algae, fungi and bacteria associated with deposits of organic matter, and mobile invertebrates capable of dealing with the unstable nature of the substrate.
- Water column: Often ignored as a specific habitat, but can be significant for algae, bacteria, fish and birds. Habitat suitability is defined by parameters such as depth, current speed and flow patterns.
- Back waters: a habitat that can be difficult to define due to their dependence on flow conditions, they are important areas of organic matter deposition. Sand bars can also be important areas of zooplankton accumulation and may be important in the survival of fish larvae.

**In-channel Patches**

Small-scale habitat is described primarily by sediment or vegetation type and the hydraulic environment. The hydraulic environment is often assessed by measurement of current
speed. Little is known about the hydraulic characteristics of habitat, but broad generalisations can be made.

- Areas of high current speed provide habitat for some filter-feeders and benthic invertebrates who prefer clean, scoured substrate.
- Areas of moderate current provide a supply of food and well oxygenated water without the associated metabolic costs of resisting displacement. These areas provide habitat for fish and invertebrates such as crayfish.
- Areas of slow current allow deposition of organic matter, providing habitat for fungi, detritivorous macroinvertebrates, planktonic species of invertebrate and fish larvae.

The major sediment or vegetation patches include:

- Submerged Macrophytes — support a diverse and productive biofilm community; provide structural habitat and food for invertebrates and fish.
- Macroalgae — provide habitat for macro and micro-invertebrates.
- Silt/mud — organically rich, easily disturbed and prone to becoming oxygen depleted; provide habitat for algae, bacteria, fungi and invertebrates, especially oligochaetes, nematodes and chironomids.
- Sand — highly mobile and prone to disturbance with lower concentrations of organic matter; regarded as poor habitat for macroinvertebrates, but can support algal and bacterial communities that may have a significant impact on water quality as flows move through the sub-surface region. Patches of sand may also support populations of highly mobile invertebrate such as shrimp.
- Clay — stable and can be rich in organic matter, but tends to be a relatively simple habitat; provides habitat for biofilm and invertebrates.
- Gravel — less mobile than sand with larger interstices. The greater stability tends to allow development of more extensive biofilm and this may attract collecting macroinvertebrates.
- Cobble — a far more stable substrate found in higher currents. The stability allows for the development of biofilms, while the shape and packing of the cobbles creates a diverse hydraulic environment. The spaces between cobbles also allow for the storage of organic matter and may provide refuge for some invertebrates. These attributes mean that cobbles support an abundant and diverse invertebrate community. Cobble beds are maintained by periodic high flows and are prone to being degraded by an excessive supply of fine particulate material.
- Boulders — provide many similar attributes to cobbles, but will have lower rates of tumbling disturbance. The less frequent disturbances means that boulders are suitable habitat for mosses, lichens, macro-algae and sedentary filter feeding invertebrates. The final community composition will depend on the flow regime and water quality.

The role of many of the identifiable riverine features as habitat is not well understood. As an example, floodplains are an obvious feature of lowland river ecosystems and yet the data we have for some relatively well known taxa (e.g. yabbies and fish) does not currently allow us to determine the importance of the floodplain as habitat. Other habitat types currently appear to be relatively insignificant in terms of diversity or abundance of animals (e.g. sand bars) and yet their loss or modification would probably affect species or
habitats in ways that are currently difficult to predict. An example is that invertebrate abundance appears to be highest at the margins of lowland rivers, but management aimed at simply increasing the extent of the river margins at the expense of other features is unlikely to produce the desired outcome of improved riverine health.

The corollary to this is that we don’t know much about the habitat requirements of many taxa and so we are forced to use broad generalisations. The consequence of this is that we tend to define habitats in terms of features at spatial and temporal scales that are obvious to us. Our limited knowledge and scale of perception helps explain the heavy emphasis placed on the habitat requirements of fish and macroinvertebrates. There are other taxonomic groups about which we have very little knowledge of either their habitat requirements or their role in determining river condition. Examples at the microscale include Zooplankton, Fungi, Micro-metazoa, Bacteria and at much larger scales, Turtles, Birds and Mammals.

Our ignorance of these and other groups of organisms may not be a major problem. The point of raising this issue is that we need to be cognisant of the fact that our habitat list and our assessment of habitats will be affected by our limited understanding of riverine ecology. This framework will, therefore, be based on the following assumptions:

1. Assessment of habitat at the three nominated scales will provide a good indication of habitat at other spatial scales.
2. Assessment of habitat for the taxa that we are familiar with will provide a good indication of the abundance and diversity of habitat for other lesser-known organisms.

Reference Approach

An Audit objective is to develop a common reporting framework for river condition assessment using comparable information, through time and across catchments. To do this the Audit has adopted a referential approach to enable all sites to be compared to a standard benchmark. The benchmark that has been adopted is “natural” condition. While not entirely free from confusion, the term natural is defined as the condition that existed prior to European development.

Natural condition is related to a river reach’s geomorphology, flow and climate. In order to ensure that an appropriate benchmark is set for each river valley, it is important to choose an appropriate reference condition for each test site. One way of facilitating the process is to classify rivers according to their geomorphology. The classification system used by the Audit is the Functional Process Zone (FPZ) system.

Once the appropriate FPZ has been selected for a site, the assessment has to derive the data that describes that reference condition. There are a number of challenges associated with this, including these two:

- If examined in enough detail, every lowland river is unique and so differences between a test site and a nearby reference river may be due to differences in the natural condition of both rivers. This becomes a far more intractable problem for rivers in the west of the Murray-Darling Basin such as the Darling and Murray where there are no easily identified reference rivers.
Many of Australia’s lowland rivers are highly degraded and there is often very little information available from which to construct a description of a reference condition.

There are two broad approaches to describing the reference condition. The first is to use a similar river reach as a reference site and assess its condition in the same way that you assess the test site. This approach is seldom used in broad-scale monitoring programs, but is used in the assessment of particular activities, such as mining or urban development.

The second approach is to synthesise a reference condition. The way in which the synthesis is undertaken depends on the question being asked, the data available and the resources available to undertake the assessment.

One synthesis approach is to have an implicit reference system in which the reference condition is never defined, but remains as a pseudo-cognate model of a “healthy” river. The assessment can then be undertaken by scoring the test site against the assessors’ concept of the “healthy” or “natural” condition. There are two problems with this approach. The first is that because the reference condition is not explicitly defined, there is considerable scope for subjectivity in the assessment. The second problem is that the reference condition is applied uniformly across all the rivers assessed. This is obviously inappropriate for an assessment that will be applied across the entire Murray-Darling Basin. Of course individual operators will modify their assessment of a particular reach depending on their understanding of what rivers in a region ought to look like. Unfortunately, this will only exacerbate the subjectivity of the assessment as different operators may have different views of what constitutes “healthy” or “natural”.

A second synthesis approach is to use a number of reference sites to construct a model that enables prediction of the characteristics of a test site. In the case of physical habitat the models use large-scale variables that are not disturbed by natural resource development to predict test site characteristics. This approach reduces the problems associated with the unique character of rivers and has the potential to incorporate the extent of natural variation that we would expect into the reference description. An advantage of this is that it is possible to determine whether the test site falls within the range of natural variation observed at reference sites or whether the test site is significantly different. Unfortunately the approach suffers from the need for a number of sites that can act as “natural” reference condition from which to construct the model. As discussed earlier, this may present problems in a number of valleys, particularly in the west of the MDB.

A third approach would be to use the modelling approach described above, but either modify the data from the reference sites or alter the model predictions to compensate for the estimated anthropogenic impacts at the reference sites. This approach has not been employed up to this point, but it would address the issues of lack of disturbed sites and the unique character of rivers. The problem with the approach is that it introduces a level of subjectivity associated with the assessment of the degree of anthropogenic influence and subsequent manipulation of the data. An example of the sort of modification that is possible would be to choose reference sites and then assess the extent of their departure from natural through an evaluation of the flow regime and catchment management. This modification would allow the assessment of a test site to be corrected for the degradation present at the reference site by, for instance, reducing the O/E score by an agreed value. The problem with this approach is that a test site may, over time, come to resemble the reference site. This may mean that the site is improving in condition, or it may mean that
the two sites share a type of degradation. In other words this method does not allow determination of whether a test site is recovering toward natural.

The final approach would be to use all the data available (e.g. ecological, historical, anecdotal, paleolimnological) to synthesise a quantitative description of the natural reference condition. While theoretically possible, there are a number of issues associated with the lack of historical data on many attributes of rivers. We do not currently believe that this approach is possible, but believe that ultimately this approach is the most desirable and therefore some effort should be invested in developing a transparent, repeatable process of synthesising a reference description from a diverse array of data.

**Recommendation**

We recommend that descriptions of reference condition be synthesised from models developed from reference site surveys and the application of E-Ball technique (Linke 2000). The models would be generated from large-scale variables that are not affected by natural resource development. Variables would include river order, Functional Process Zone, climate and geology. Where possible, the reference site description would incorporate historical data so that the model reference condition is as close as possible to the natural condition. We also strongly recommend that considerable effort be invested in developing techniques for integrating disparate data to enable a better description of the “natural” condition of river reaches.

In many Valley Process Zones, the reference sites and the test sites will be on the same river due to the lack of suitable reference rivers. This situation is less than desirable given the broad scale at which many stresses occur throughout the Murray-Darling Basin. In these cases, we recommend the following criteria be used in the selection of reference sites (modified from Coysh and Norris, this volume).

1. Sites within the lowest 10% of agricultural development as assessed by the examination of floodplain transects. This will minimise the impacts of agricultural development on floodplain connectivity, habitat heterogeneity, groundwater movement, nutrient dynamics and drainage to the river.
2. Sites within the lowest 10% grazing pressure as assessed by the examination of floodplain transects. This will minimise the impacts of grazing and trampling on riparian vegetation, floodplain litter cover and bank erosion.
3. Sites within the lowest 10% of catchment disturbance as assessed by the examination of floodplain transects. To minimise the impacts of mining, clearing and towns.
4. No major urban area within 50 km upstream. This will help minimise the impact of pavement area, storm-water run-off, recreational impacts and sewage treatment plants.
5. Sites without any significant point-source wastewater discharge
6. No dam or major weir within 50 km upstream, nor should the site fall within the upstream influence of any regulatory structures.
7. Flow regime in the 10th percentile of least affected flow regimes in a Valley Process Zone. In some Valley Process Zones this parameter will be become a subjective assessment of which type of flow modification is the least damaging to the river.
These sites need to be surveyed using the indices described below and the data used to generate models of reference condition from which descriptions of reference condition can be derived.

Additional Problems with Referential Approach when assessing physical habitat

One of the largest problems associated with physical habitat assessment is the extent of temporal variation experienced by rivers and streams. In many cases variation in flow and the delivery or erosion of sediment is essential in determining the type, extent and availability of habitat. Physical habitat assessment is undertaken at discrete times that may not provide a good indication of the habitat at other times. Monitoring agencies are faced with a trade-off between the spatial extent and the level of detail of their monitoring programs. This trade-off would mean that determining the extent of temporal variation would lead to the significant loss of sites from the monitoring program. Unfortunately, this does not resolve the issue that any assessment based on a limited number of assessments at a given site may be compromised due to the lack of information about changes through time.

One apparent solution to this dilemma would appear to be the collection of data in a spatially explicit form. This would enable the synthesis of physical habitat and hydrological data to model the temporal characteristics of physical habitat at a site. While this sort of analysis has not yet been undertaken, there are a number of researchers who currently have techniques that could be bent to this task. These techniques include:

- models of the relationship between channel morphology and hydraulic conditions, being developed by Mike Stewardson at CRC for Catchment Hydrology (Melbourne University).
- spell analysis to determine the impacts of water resource development, being developed by Martin Thoms at the CRCFE.
- GIS flood-inundation models developed for the Riverland by SARDI and the MDBC.

Our conceptual model states that physical habitat is the result of the interaction of flow and geology. This implies that habitats are created and maintained by dynamic processes within the river. The consequence of this is that any audit of physical habitat will provide only a snap-shot of the physical habitat present during the sampling. In order to be able to predict whether that habitat will persist requires some assessment of the processes required to maintain that habitat in that condition. Examples of the sorts of processes that can be important follow.

**Riparian regeneration:**

If the riparian vegetation is not actively recruiting, then at some point in the future the vegetation will be lost as old trees die.

**Sediment transport:**
Riffle habitats are created by the erosion of fine sediments from amongst the cobble matrix. If the dynamics of sediment transport change, then the result may be an increase in sediment deposition and the loss of riffle habitats.

**Erosion:**

Many lowland rivers are in dynamic equilibrium with their floodplains. The erosion of banks and re-deposition of sediments is an important process in the creation of billabongs, in-channel benches, pools and sand bars. Both excessive and inadequate rates of erosion can lead to the loss of habitat.

A number of the existing monitoring programs include some assessment of these processes, which are incorporated into their assessment of river condition. While the importance of these measures cannot be underestimated, it is important that they be carried out in the same manner as other indices. In the case of the Audit this will mean adopting a referential approach and comparing rates of erosion or riparian regeneration to those observed at reference sites rather than assigning scores which, given our limited understanding of these processes, tend to be value laden.

**Recommendation:**

That considerable effort be invested in improving our ability to describe the reference condition in terms of both its physical and chemical characteristics and its spatial and temporal variability. A number of techniques are currently being developed that will significantly improve our ability to undertake this task and therefore we anticipate rapid progress.

**Review of Habitat Assessment**

As with any investigation, the sampling design is determined by the question and the resources available. We have addressed the issue of what questions ought to be asked in the “Conceptual Model” section. In this section we discuss the issue of the allocation of limited resources to the assessment of stream condition. In general, the existing programs have focussed on developing rapid, cost-effective techniques that require minimal technical expertise. For the agencies, these have the advantage of minimising the costs associated with training personnel, and then collecting, processing and analysing data. The following is a review of the major existing programs.

**AUSRIVAS — National**

AUSRIVAS was initially based on the RIVPACS approach and subsequently standardised under the NRHP methods (Davies et al. 2000). The AUSRIVAS method is directed towards the assessment of invertebrate health in riffle and edge zones. As such, in-stream habitat characteristics are noted, rather than the characteristics of pool habitats. Characteristics relevant to in-stream habitat recorded by the AUSRIVAS method are presented in Table 1.
Table 1. Instream habitat variables measured as part of the AUSRIVAS protocol (source: Davies et al. 2000)

<table>
<thead>
<tr>
<th>Local scale habitat features</th>
<th>Reach, riffle and edge specific characteristics</th>
<th>Habitat assessment variables&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream width (m)</td>
<td>% bedrock</td>
<td>Substrate (categories 0-20)</td>
</tr>
<tr>
<td>Bank width (m)</td>
<td>% cobble</td>
<td>Embeddedness (categories 0-20)</td>
</tr>
<tr>
<td>Bank height (m)</td>
<td>% pebble</td>
<td>Channel alteration (categories 0-15)</td>
</tr>
<tr>
<td>% riffle area</td>
<td>% gravel</td>
<td>Scouring (categories 0-15)</td>
</tr>
<tr>
<td>Riffle depth (cm)</td>
<td>% sand</td>
<td>Pool/riffle run/bend ratio (categories 0-15)</td>
</tr>
<tr>
<td>Riffle flow (ms&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>% macrophytes</td>
<td>Bank stability (categories 0-10)</td>
</tr>
<tr>
<td>% edge area</td>
<td>% detritus (sticks, wood, CPOM)</td>
<td>Vegetation stability (categories 0-10)</td>
</tr>
<tr>
<td>Edge depth (cm)</td>
<td>% muck/mud</td>
<td>Vegetation cover (categories 0-10)</td>
</tr>
<tr>
<td>Edge flow (ms&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>% of habitat covered by periphyton, muss, filamentous algae, macrophytes</td>
<td>Habitat score (total of habitat assessment variables)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Categories are based on a visual assessment of poor to excellent. Descriptions of what to expect for each score are provided as part of the assessment procedure.

In addition, Davies et al. (2000) have measured a range of catchment-scale variables and developed a model that predicts local stream habitat based on the measured catchment-scale variables. This model has been used to compare observed versus expected habitat at reference and test sites in a way similar to the AUSRIVAS model for predicting invertebrate observed versus expected scores.

The habitat characterisation and assessment method used by AUSRIVAS is comprehensive, although as indicated above it does not consider pool habitats. Also, the AUSRIVAS habitat assessment is basically a characterisation process. It provides an indication of habitat diversity based on patch areas, but no links are made to in-stream processes that may be important for ecosystem health. The complexity and location of in-channel habitat, e.g. snags and islands, are not considered, nor is the shape of features such as sand bars, benches and banks.

Recently, a review of physical habitat assessment methods related to the AUSRIVAS program has been conducted (Parsons et al. 2000) and a new physical assessment protocol for AUSRIVAS recommended (Parsons et al. 2001). This protocol is compatible with the AUSRIVAS biological protocol and is designed to provide a predictive capability to habitat assessment based on the work of Davies et al. (2000).

**Index of Stream Condition — Victoria**

The Index of Stream Condition (ISC) is a technique developed in Victoria for benchmarking the condition of streams, to assess the long term effectiveness of management intervention and to aid in objective-setting by waterway managers (NRE 1997). Specifically, the ISC process involves the calculation of a condition rating for a range of components or sub-indices, namely:

- Hydrology,
- Physical form,
- Streamside zone,
- Water quality,
• Aquatic life.

The sub-indices are totalled to provide an overall condition rating relative to natural or ideal condition for that particular stream type.

The development of the Physical form sub-index involved an assessment of a range of possible indicators and settled on four indicators:

• Bank stability,
• Bed condition,
• Influence of artificial barriers, and
• Density and origin of large woody debris.

Several indicators were assessed for their suitability including bed composition, embeddedness, sedimentation and proportion of pools and riffles, but were dismissed as it was concluded that they were difficult to measure on a statewide basis because of the large natural variation on these indicators (NRE 1997).

While the Physical form sub-index of the ISC method provides a general assessment of in-stream condition and may be suitable for assessing changes based on future management intervention, indicators are subjective and based on visual assessment (except for artificial barriers) and its focus could be considered narrow. Assessment against natural or ideal condition is implicit based on the rating system with low values implying poor condition and high values excellent condition.

River Styles — NSW

The River Styles™ approach classifies the zones as good (close to natural), moderate (degraded but with potential to be rehabilitated) and poor (heavily degraded with little prospect for rehabilitation). Currently, approximately one third of NSW MDB has been mapped using this approach with the remaining two-thirds expected to be completed 2003–2004. The approach examines geomorphic characteristics, riparian vegetation, river behaviour and the capacity for river adjustment. The indices assessed include:

• channel geometry,
• channel planform,
• bed/bank composition,
• flow diversity and volume of sand/gravel bedload,
• channel geomorphology including descriptions of pools, riffles benches and banks,
• floodplain geomorphology including presence and descriptions of floodplain habitats,
• riparian vegetation coverage,
• river behaviour including a description of the sediment regime and erosion,
• channel slope,
• catchment area.

The river styles approach is designed to provide guidance to managers to enable determination of rehabilitation priorities.
Pressure–Biota–Habitat — NSW

The Pressure–Biota–Habitat (PBH) assessment approach is under development in New South Wales. The method is currently being trialled in 12 NSW sub-catchments. PBH generates three indices related to human pressure, the biota and physical habitat. Included within the Physical Habitat Index are a range of flow, structural and process indicators that are measured and related to invertebrate biodiversity. Indicators include:

- substratum size,
- channel depths,
- bank alteration,
- bank stability,
- bed stability,
- riparian vegetation,
- overhanging vegetation,
- aquatic vegetation,
- overhanging banks,
- large woody debris.

State of the Rivers — Queensland

The Queensland DPI State of the Rivers is a comprehensive assessment of a range of indicators including reach scale, riparian and in-stream vegetation and in-stream channel form and habitat types. The program is based around a series of detailed data collection sheets that reduce the need for technical expertise among the field operatives. Specific in-stream indicators include:

- channel habitat (% depth, length and width of channel type, e.g. waterfall, cascade, rapid, riffle, glide, run, pool, backwater);
- cross section (bank slope, height and width, channel depth cross sections and flow profiles, sediment classification, e.g. percentage fines, sand, gravel, cobble, boulder, rock, detritus);
- aquatic habitat (percentage cover of individual logs, log jams, individual branches, branch piles, tree roots, leaves and twigs, macrophytes, periphyton, bank overhangs, overhanging vegetation, canopy cover);
- bed and bar conditions (bar types, shapes and angularity, bed compaction, factors affecting bed stability, degree of passage for aquatic biota);
- bank condition (location and type of erosion on upper and lower banks, bank shape, presence of levee banks).

The State of the Rivers approach is based on a proportional assessment of habitat features, similar to but more comprehensive than the AUSRIVAS approach. Using this technique, reaches are characterised based on their habitat features. An assessment of condition
would need to be made based on a comparison to a reference condition based on a geomorphic classification.

Other assessment approaches

There are a range of other assessment techniques where in-stream habitat is measured (e.g. CSIRO, Border Rivers IMEF). These techniques are based on categorical qualitative assessment or proportional assessment of habitat patches similar to the methods already described above.

The Audit is committed to a referential approach and as such we believe that the reference condition will be described quantitatively. This implies that the assessment of the test site will also be quantitative. The issue then becomes how the necessary data could be collected as cheaply as possible. The best solution is offered through a mix of remote sensing and ground truthing. The trade-off with remote sensing is that it is an emerging field and that desktop analysis reduces the knowledge gained by field workers as they survey the sites. While we acknowledge this trade-off, remote imagery will provide a valuable information resource that will both complement and add value to the knowledge retained by agency field operatives.

A further characteristic of the assessment protocol is that the reason that a particular metric is being measured should be explicit. In a number of the existing agency monitoring programs there is no clear conceptual model, and so habitat assessments are mixed with measures of biodiversity and process measures that make sense to the designers of the program, but add little to the transparency of the assessment. We therefore recommend that habitats be defined in terms of their physical/chemical characteristics, the organisms that use the habitat or the process being measured, and the reason for its measurement.

The trade-off between cost and information has an impact on the sorts of variables measured. Spatially explicit data is the most information rich and expensive to collect and analyse. Our conceptual model indicates that the spatial arrangement of habitat within the river-floodplain system may be important and therefore the collection of this type of data is desirable, although our knowledge of the relationship between habitat structure and riverine ecology is currently poor. Because it is the highest resolution data, it can be easily reduced to less information-rich data formats such as abundance, areas, % contributions, ranks or presence–absence data. Where we see no cost penalty for the collection of spatially explicit data we have recommended its collection in this form. This emphasis will be assisted by the use of remote sensing, as the images will ensure a data record that could be reinterrogated as techniques improve and the need arises.

Analysing Data from the Habitat Assessment

Once the habitat assessment is completed it is then necessary to compare the target site to the reference condition. Reviews of analysis of assessment data have been undertaken by a number of authors, and so we will only briefly examine the approaches available. Selection of a data comparison technique depends on both the question being asked of the data and the type of data collected.
Index Scores

If the assessment generates a score, then the score represents the result of a comparison with an implicit reference condition and a determination of the significance of that difference. As a consequence, there is no need to undertake any statistical data comparison. It is interesting to note that several of the scoring systems have four or five bands, implying that agencies currently regard a 20 to 25% departure from reference as significant.

A variation of this technique is the IBI approach in which a number of indicators are combined to produce a score for the site which is compared to the score of a reference condition which is the combination of the maximum score for each indicator.

ANOVA comparisons

These techniques are based on the collection as if the impact on the target site were a treatment in an experiment. This immediately causes a problem because, in most cases, managers are interested in assessing the condition of a single site and not a suite of replicate sites. A partial solution to this is to assess multiple reference sites, but this results in an unbalanced design, and even under the best conditions limited power to detect differences.

Ordination

A variety of ordination techniques can be used to compare target and reference data. These techniques provide a means of quantifying the difference between sites, which are then expressed as scores that can be plotted. There are two problems associated with the application of most ordination techniques to assessment data. The first is that the ordination process involves the loss of information. The second is that the analysis is unique to the data being analysed and so it is not possible to standardise the differences between target and reference sites across the Murray-Darling Basin. This means that this type of analysis would fail one of the requirements of the Audit.

Canonical Analysis

A form of multivariate analysis that examines correlations among the differences of two data sets. This technique could be used to examine the differences between sites in terms of large scale factors such as catchment area, slope stream order and then compare these to differences between the physical habitat measurements. The conclusion from the analysis would be that differences not correlated with the large scale variables would be due to disturbance at the test site.

O/E values

The Observed over Expected methodology employed by RIVPACS and AUSRIVAS uses multivariate techniques to describe the reference condition. The technique generates a model of community structure, which then predicts which taxa have a 50% probability of occurring at a site and then compares this value to the number of taxa observed. Making predictions about the number of taxa found at the reference sites validates the model and this validation is used to generate a distribution of O/E ratios against which assessments...
An O/E below the 10th percentile indicates a significant departure from the reference condition. The method is designed to assess the loss of diversity usually associated with anthropogenic stress. The technique has been modified for use with physical habitat assessment through the conversion of habitat variables to categorical variables (REF), such that, for example, 0–10% bedrock might be considered one category while 11–25% bedrock might be considered a separate category. This approach has the advantage that it provides a single value for the condition of the site and a list of the parameters that are different from the reference condition. The authors regard the possibility that replacement of one habitat category by a “better” habitat category may lead to an erroneous assessment. As discussed earlier, we do not believe that this is a valid concern as it is not currently possible to describe habitats as good or bad, merely as different from the reference, which, when the reference is “natural”, is regarded as undesirable.

The problem with this approach is that, like any technique developed for one purpose and subsequently modified for another, compromises have been made. In this case, the AUSRIVAS technique is based around the presence of taxa with macroinvertebrate community diversity expected to decline in response to disturbance. Thus the question addressed is “has the number of taxa declined significantly?” In the case of physical habitat assessment the question is “has the amount, type and availability of habitat changed significantly and if so, by how much?” AUSRIVAS use of categories and the exclusion of species with less than 50% probability of occurrence at a site will lead to the loss of information and seem inappropriate for the measurements obtained when assessing physical habitat.

An alternative technique is the E-ball methodology (Linke, 2000), which uses raw data rather than categorical data to describe the reference condition. E-Ball differs from AUSRIVAS because it avoids the classification step, and rather than simply predicting presence/absence of taxa E-Ball allows the prediction of continuous variables such as those in habitat data-sets. Rather than make predictions based on linear models like the Discriminant Function Analysis used in AUSRIVAS, E-Ball actually compares test sites to a number of reference sites. However only reference sites that are most like the test site based on large scale variables (such as Geology, Latitude, Functional Process Zone) are used in each comparison. Simplified, the steps in the E-Ball analysis are:

- Ordinate the reference sites in large-scale variable space
- Position the test site in the above ordination space
- Calculate the Euclidean distance of the test site from the reference sites according to the large-scale variables
- Select the reference sites that are most similar to the test site according to the large-scale variables
- Predict the value of the small-scale variables expected at the test site (these are weighted averages according to the Euclidean distance from the reference sites)
- Compare each of the observed small scale variables at the test site to those predicted
- Combine the Observed to Predicted values in an O/E index for the site.
This overcomes a number of the AUSRIVAS limitations, but it still requires multiple reference sites to generate a predicted reference condition. The E-ball technique also allows assessment of numerical data although this has not yet been undertaken in any assessment program. Varying statistical distributions are accounted for by range and variance standardisation in the calculation of Euclidean distance from the test to the reference sites. The variables used to calculate the expected values are always measured at a higher scale than the variables being predicted. Despite the novelty of this approach it appears, at the present time, to be the most appropriate analytical tool available.

Recommendation:

We recommend E-ball analysis (Linke 2000) be used to compare test site observed data to the expected data generated by the E-Ball models.

Proposed Assessment Protocol

The proposed assessment protocol uses a combination of remote sensing and field data collection that will allow an assessment of physical habitat at three spatial scales. The data collected will allow a rapid assessment of the amount and type of habitat available, but our objective is to collect data in such a way that more detailed analysis of the temporal characteristics and spatial arrangement of habitat will also be possible as appropriate techniques are developed.

The assessment will be undertaken once every five years, as most of the recommended variables change over relatively long time periods. Some of the small-scale variables do change over shorter time-periods. We recommend that field staff undertaking assessment of other components of the Audit be provided with photographs of the site and summary information to enable a rapid visual assessment of any changes that may have occurred. This information will enable determination of the rates of change of variables and a better understanding of temporal variation in physical habitat. This information would be included in measures of temporal variation as they are developed.

At each site the assessment will be based on four replicates of three types of transects (floodplain, riparian and channel; Figure 1) across the river and its associated floodplain. Transects should cover the geomorphic variation present in a river reach (e.g. inside curve, outside curve, straight section, pool). As a consequence a site may vary from a few hundred metres of river to several kilometres depending on meander length. A similar approach has been adopted by the Victorian ISC.
The first step in the assessment will be to obtain orthophoto imagery of each site. As many indicators as possible will be assessed from this imagery. The site image will then be printed out and associated with with a data sheet, similar to those developed for the Queensland State of the Rivers Program. Field operatives will ground truth the remote analysis and assess those indicators that cannot be measured remotely using the images and data sheet. The benefits of this approach are that:

1) the imagery represents a valuable source of data that can be reanalysed in the future as our understanding of physical habitat improves;

2) the use of remote sensing will save considerable time and labour while allowing quantification of variables that would not otherwise be possible given the limited resources;

3) the imagery will provide an invaluable aid to field personnel, much as the photographs currently taken for the Victorian ISC represent an invaluable aid to their field operatives;

4) for a number of indicators, this approach will ensure a level of quality assurance with indices being cross checked by two sets of personnel and two techniques.

Floodplain

Assessment of the floodplain could be carried out to a similar level of detail as the river itself, but the costs would be excessive and the level of knowledge required is not available throughout the MDB. We therefore recommend an approach that will primarily assess the diversity and relative abundance of the major habitat types found on floodplains.
The assessment will involve identifying a 100 m wide transect through the river using the remote imagery. The transect length will vary depending on the width of the floodplain and the FPZ, but should extend to the 1 in 100 year flood extent. Cost savings could be achieved through the selection of the 1 in 50 year limit. The 1 in 100 is currently mapped in most valleys. The proportion of the transect occupied by the major habitat types will be determined. This is a relatively straightforward procedure in GIS packages such as ArcView. The major habitat types expected to occur would include:

- floodplain vegetation types,
- grazed pasture,
- irrigated horticulture,
- natural flood-runner,
- billabong,
- wet meadow (<1 m depth),
- shallow wetland (1–2 m deep),
- lake (>2 m deep).

The exact habitat categories will depend on the FPZ and the reference condition. Once this assessment is complete, the characterisation would be printed out for confirmation on the ground. Once the various habitat types had been confirmed, the assessment would compare the diversity of habitat types and their areal contributions to those found in the reference condition.

While this form of assessment is much more detailed than the existing programs, once imagery is obtained, a relatively simple analysis will provide considerable information.

Channel Features

Banks

Bank slope is determined by survey techniques. The bank is divided into high and low bank and an assessment of bank shape can also be made, e.g. undercut, convex, stepped etc. Assessment of bank slope and shape should be made at least at the 4 points where the floodplain transects cross the river. This will ensure that the range of geomorphic locations within a reach (e.g. point bars, inside bends) are sampled. Banks can also be assessed for erosion type and extent, slumping, lateral scour, local scour and aggradation. This assessment should be applied to upper and lower banks and based on the proportion of bank impacted. The Queensland State of the Rivers Bank Condition Sheet 7 provides a suitable approach to measuring the above bank condition indicators.

Riparian Vegetation

Riparian vegetation is one of the most important plant communities forming the structural and functional framework for riverine ecosystems in Australia. Vegetation in this zone performs a range of ecosystem services which affect the functioning of other ecosystem
components and the quality of in-stream habitat, including primary production, provision of detritus, filtering, sediment stabilisation, water and nutrient cycling and groundwater recharge mediation. Interactions between these plant communities and other aspects of physical habitat (e.g. geomorphology, physico-chemical environment, flow patterns) form feedback loops which continually reshape the dynamic physical characteristics of rivers. Additionally, riparian vegetation represents a major contributor of habitat for both terrestrial and aquatic fauna, including aquatic macroinvertebrates, fish, crayfish, insects, platypuses, water rats, birds, frogs and reptiles.

Aspects of physical habitat that affect its value to associated fauna are the quantity, quality and heterogeneity of habitat elements available. Abundance, patch size and connectivity, and the importance of gaps in relation to the area of existing vegetation are important to faunal population sizes, diversity, movement, foraging and persistence. The proportions of native and introduced species comprising the riparian vegetation at a site are correlated with faunal diversity. Habitat complexity including niche diversity and temporal & spatial variability of connectivity have a profound influence on the nature and interactions of associated faunal assemblages. Heterogeneity is supplied by variations in vegetation biodiversity, density, canopy complexity, demographics of live and dead biomass, vegetation overhang and the interactions of these elements. Usage of different habitat patches can vary over a range of temporal and spatial scales, demonstrating the importance of habitat heterogeneity to aquatic systems.

Development of riverine areas and increased demand for water has led to modifications to channel morphology, water quality and flow. These indirect effects have combined with direct manipulation of habitat components such as riparian vegetation, snags and channel features such as sand and gravel bars, resulting in significant impacts on the physical habitat of our riverine ecosystems. These pressures necessitate the development of improved methods for assessing impacts on physical habitat, which attempt to describe the quantity and quality (including heterogeneity) of habitat present at a site. Current models of river ecosystem condition assessment measure only a limited number of components of community structure. These methods tend to overlook the importance of having the processes, which maintain this structure in place and working efficiently. More in-depth and meaningful structural analysis is required, as is a better understanding of habitat maintenance processes, potentially threatening processes and future trends. The hypotheses proposed relating habitat diversity & abundance with species diversity, abundance & persistence require data on the abundance, integrity, connectivity, temporal and spatial variability and projected persistence of different habitat types. The indicators of habitat condition selected to assess riparian vegetation meet these requirements and are outlined below.

Species richness and diversity

Habitat heterogeneity is generally associated with higher levels of faunal diversity — one aspect of heterogeneity in river ecosystems is riparian vegetation biodiversity. The proportions of native and introduced species comprising the vegetation diversity at a site have implications for native terrestrial fauna (due to differences in food availability, habitat and nesting sites) and for the timing, quantity and quality of inputs to the channel (leaf litter and large woody debris). Interactions between different species create feedback loops affecting species richness and diversity, with competition by introduced species reducing native diversity through shading, allelopathic exudates and excessive growth.
Determination of this indicator involves the assessment of the number of species present standardised by abundance. A range of commonly used indices exist for assessing species richness and diversity, and are generally interpreted as indicators of the community's stability and capacity to respond to disturbance. Calculating these indices is often considered labour intensive due to the need to identify and count all species. This can be overcome by sampling and assessing large (primarily woody species) and common (those that comprise more than 5% of canopy cover) vegetation only within 10–30 m quadrats, limiting the taxonomic expertise required and allowing rapid assessment of large areas. Difficulties arise when attempting to make direct comparisons of absolute index values across sites because some ecosystems naturally have low richness or diversity and are not necessarily less resilient or stable. The implications of richness and diversity for ecosystem health assessments rely on comparison with an appropriate reference condition.

Measurement of this indicator will be undertaken by determining the dominant (defined as those species that comprise more than 75% of canopy cover) tree and shrub species present in a reach using on-site assessments along 4 transects. The length of the transects will depend on the width of the riparian vegetation zone, unless the riparian zone is greater than 100 m in which case the transect will be limited to 100 m. These assessments would follow the technique employed by AUSRIVAS and Queensland State of the Rivers program for macrophytes, where field operatives are provided with a checklist of the major species expected at a site, and they record presence and percentage cover. On-site differentiation requires some skills at plant identification, and would be facilitated by assessment during the early summer growth flush. As transects will be continuations of those used for channel mapping, selected on channel sinuosity rather than specifically as being representative of the reach vegetation, verification of species abundance and distribution along the transects to the reach scale will be required. This would utilise high-resolution multi-spectral digital aerial photography. Different proportions of water, lignin and chemical constituents in leaves, and leaf shape and texture produce variations in spectral reflectance from canopies of different species. These differences in spectral reflectance can be detected by comparisons of different wavelengths of remote digital imagery, which produce the most reliable data if performed during the peak vegetation period (early summer). Comparisons using remote sensing could also be made based on deciduous or evergreen habitat, requiring assessment in early winter. Verification of transect assessments would involve referencing the distribution of species recorded during fieldwork to the digital imagery by determining the location of each transect in the image and comparing the spectral reflectance of the canopy at this location to the rest of the reach. Data reported would be number of species, % native species, richness and diversity indices (calculated using relative abundance data), and a species list (divided into native and introduced) for each reach.

Relative abundance

Relative abundance is estimated by a set of measurements contributing to the assessment of habitat quantity and quality (based on species’ preferences for different vegetation densities) provided by riparian vegetation. Additionally, performance of certain ecosystem functions such as nutrient filtering and reduction of sediment run-off are related to vegetation density. As with the measures of diversity, absolute abundance values are meaningless for assessing habitat condition without comparison to an appropriate reference condition, or through monitoring over time. Significant changes over time may indicate increasing impacts on the ecosystem, and can have an effect on the habitat value
of the vegetation. The relative proportion of native and introduced species comprising the vegetation biomass at a site has impacts on the native fauna present. Changes in the area of native vegetation per biogeographic region are correlated with faunal diversity — clearing or replacement of native vegetation with exotic species causes reductions in faunal diversity.

Relative abundance data would be obtained from low labour on-site assessments using 3 replicate quadrats per transect and Bitterlich assessment of basal area. Quadrat size will depend on vegetation density with smaller quadrats (10 m radius) used in dense vegetation and larger quadrats (30 m radius) used in sparsely vegetated regions. Basal area and stem density of the dominant riparian species should be assessed during the peak vegetation period in early summer, noting proportions of native and introduced species. These methods are established practice and are commonly used by forestry staff and ecologists. They are simple and rapid, requiring minimal technical expertise. Data would be reported as basal area and stem density (noting % native) for quadrats, scaled to the whole reach on an aerial basis.

Riparian Width

Patch size has been shown to be a particularly significant factor determining habitat quality of native vegetation to terrestrial fauna. In riparian communities, width of vegetation is the important dimension affecting the zone's value as habitat. The performance of certain ecosystem services which impact on the quality of in-stream habitat is also affected by the width of riparian vegetation (such as filtering nutrients and sediments, affecting groundwater depth & recharge, impacting on local water cycling, retaining banks and reducing erosion). Riparian width is measured as the distance from the edge of the channel to cleared or developed land. It should be reported in relation to channel width for comparison to a reference condition. For sites with an obvious floodplain greater than 30m wide, this indicator should extend to encompass assessment of floodplain vegetation. An adaptation of the method used in the Queensland/NSW Border Rivers Flow Management program would involve measurement of the average width of the floodplain along a reach and the density of floodplain vegetation.

Riparian and floodplain width and % coverage of the floodplain with woody vegetation can be measured from aerial photography. This method is rapid, reliable and requires no ground-truthing or technical expertise. Average riparian and floodplain widths for each reach should be reported in raw distance units and as a proportion of channel width, while floodplain vegetation data is reported as % coverage of the floodplain with vegetation.

Habitat Fragmentation

This indicator combines "Longitudinal Continuity" of the Victorian ISC program and the concept of patch size based on the ratio of edge to area for vegetation patches. The indicator provides information on riparian vegetation patch size and connectivity, and the importance of gaps in relation to the area of existing vegetation, which are important to the diversity, movement, foraging and persistence of terrestrial fauna. The occurrence of vegetation directly adjacent to the river channel is an important aspect of habitat quality. Continuity of streamside woody vegetation is also important to ensure the ecosystem services provided by width are performed along a significant proportion of the stream length. The indicator is comprised of 4 components:
• the vegetated stream-length (length of bank with vegetation (trees and shrubs) greater than 5 m wide),
• the number of significant discontinuities (gaps greater than 10 m long and with a width of at least 0.5 x the average width of the vegetation),
• the average patch size (ratio of edges to area of vegetation patches), and
• connectivity between vegetation patches (average length of significant discontinuities).

Measurement of lengths and widths of riparian vegetation and gaps, and calculation of edge to area ratios of vegetation patches can be obtained from aerial photos preferably imaged during the middle of the day in early summer. Data should be reported as raw counts and distance measurements for both banks, with vegetated stream length also calculated as a percentage of reach length, and connectivity also expressed as a percentage of vegetated stream length. This is a simple, rapid method requiring no field validation.

**Riparian Canopy Complexity**

Habitat complexity and connectivity have significant effects on the structure and interactions of associated faunal assemblages. Variation in the proportions of different canopy layers provides a source of heterogeneity in riparian habitat quantity and quality, with connectivity between the different elements and proportions of native canopy also important. The proportions of the riparian zone covered with deep or shallow rooted vegetation vs bare ground is important for catchment water cycling and groundwater depth and recharge, with an increase in shallow rooted vegetation or bare ground generally having a detrimental impact on catchment hydrology. Information on these aspects can be inferred from assessment of canopy complexity, as canopy type is correlated with root penetration depth. This indicator provides an assessment of the different canopy levels present at a site, by comparing the percentage cover of the following canopy categories (adapted from the Victorian ISC program):

• trees (woody plants over 5 m tall, usually with a single stem, e.g. eucalypts, banksias, acacias, willows),
• shrubs (woody plants less than 5 m tall, frequently with many stems arising at or near the base, e.g. Melaleuca, Leptospermum, tree ferns, blackberries),
• understorey (non-woody plants up to 1.5 m tall, e.g. sedges, reeds, saltbush),
• herbs & groundcovers (non-woody low-growing plants, e.g. grasses, Persicaria, Ranunculus).

Determination of the appropriateness of current canopy complexity for the site is based on comparison of the different proportions of each storey to a reference condition. The indicator may also reveal areas potentially at risk from waterlogging or salinisation through groundwater changes.

While the majority of data for this indicator would be obtained through on-site visual assessment of the four riparian transects, remote sensing can provide information on percent cover of the uppermost canopy levels (detection of lower canopy cover may be possible in areas of low density vegetation). On-site assessment of percent cover of each canopy layer would be performed along the four riparian transects. Similar methods have been used by the Victorian ISC program and researchers developing rapid vegetation assessment methods.
appraisal techniques. No technical expertise is required — the method is based on a simple classification of percent cover data into well-defined vegetation growth form categories, reporting native and introduced cover for each canopy layer. Areas potentially at risk from waterlogging and salinisation due to impacts on catchment groundwater should be noted for targeting in future assessments. Assessment of this indicator would be performed concurrently with on-site measurements of relative abundance.

Riparian Demography

Variation in demographics of the riparian vegetation at a site is another source of habitat heterogeneity within the streamside zone. The presence of a range of age-classes of vegetation, including standing and fallen dead, is important for faunal diversity and persistence. Targeting of specific age-classes of vegetation in different life stages means that a diverse demography is essential for the completion of these life cycles. The spatial and temporal arrangement of different elements can also impact on the success of life stage transitions — the habitat type required for the next stage must be available and within a distance compatible with the organism's dispersive abilities for the transition to be successful. Representation of a range of age-classes amongst dead biomass is just as important as among the living — there is a range of different sizes and arrangements of twigs, holes and hollows, different densities of wood and ratios of bark to core in different aged vegetation. Fallen dead are important to a range of ground-dwelling fauna while standing dead are used by flying or climbing species. As with many of the other indicators assessing the habitat value of vegetation, the usefulness of this indicator relies on comparison to a reference condition before comparisons between sites can be made.

Measurement would involve on-site assessment of abundance of different age-classes (including standing and fallen dead) of major riparian plants along the four riparian transects. Definition of age-class categories for each of the major riparian species would be necessary. The dominant species may be operationally defined as those species that comprise greater than 75% of cover. No technical expertise is required — the method involves classification of relative abundance data into age-class categories. Assessment of this indicator would be performed concurrently with on-site measurements of relative abundance and riparian canopy complexity.

Standing Litter

Floodplain litter represents an important habitat niche for many terrestrial ground-dwelling fauna such as insects, reptiles, frogs, birds and small mammals. It also forms important ephemeral foraging habitat when floodplain inundation occurs. Abundance and composition of standing litter is a good indicator of anthropogenic impacts and has been shown to be a major discriminant of site condition when used in a rapid appraisal method for assessing ecological condition of riparian areas (Jansen & Robertson 2001).

Measurement of this indicator involves on-site assessment of the quantity of riparian leaf litter. Percentage cover of standing litter is estimated and then the depth of litter is measured at 10 replicate points along the riparian transects. This is a rapid and reliable method requiring no technical expertise or specialised equipment.
Vegetation Overhang

Overhanging vegetation provides a type of in-stream habitat patch, has implications for potential snag input and shades the water column, affecting water temperature and light availability. Overhanging vegetation is correlated with abundance and distribution patterns for a range of aquatic fauna. For macroinvertebrates, habitat heterogeneity (including habitat patches created by overhanging vegetation) plays a crucial role in the distribution and abundances of different functional groups. Crayfish show shade-seeking behaviour and their presence has been correlated with the proportion of channel overhung by plant canopy. Many fish show habitat preferences for areas with overhead cover including that provided by overhanging vegetation, which reduces predation risk by obstructing visual detection. Platypus and water rat burrows tend to be located in association with overhanging vegetation, and usage by other organisms relates to the provision of roosting, perching and calling sites (waterbirds, reptiles, frogs). Usage of different habitat patches often varies over a diel cycle and with life stage, demonstrating the importance of habitat heterogeneity to aquatic systems. Shading has implications for macrophyte and algal growth and can effectively ameliorate temperature extremes. The ratio of shade width to channel width has been used previously as an indicator of stream condition. Vegetation overhang or distance of canopy from the channel also has implications for the input of leaf litter and large woody debris to the channel.

Direct measurements of overhang (positive value) or distance from canopy to the channel (negative value) can be obtained from geo-referenced digital aerial photography. Reach averages for these parameters would be based on measurements at eight randomly selected positions along the channel edge. The area of canopy overhang can be determined from the aerial photographs, standardised by the average reach canopy cover (from the canopy complexity index) and reported in relation to the surface area of the reach (proportion of surface area shaded by overhanging vegetation). The method would require validation of remotely sensed canopy overhang and canopy cover measurements in the field. Limited technical expertise is required.

Vegetation Vigour

The vigour of the riparian vegetation community affects its current habitat quality and ability to provide future value as habitat. A range of methods can be used to assess the physiological condition of these plants, including assessments of sap flow, photosynthetic rates & efficiency, and analysis of pigment ratios and other tissue constituents. However, the majority of these techniques are time-consuming, require expert technical skills and expensive equipment and are generally targeted towards assessment of individual plants or small-scale monitoring. Remotely sensed spectral vegetation indices (SVIs) such as the Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Chlorophyll Absorption in Reflectance Index (MCARI) are commonly used indicators of vegetation vigour, and are regularly applied to large-scale assessments of condition in a range of vegetation communities.

Each index provides information on different aspects of the physiological status of the plant community and so a combination of indices, selected to complement each other, is most useful for assessing vegetation vigour and comparing different plant communities. NDVI is the most widely used SVI, and has proven especially useful for assessing dense
canopies and estimating canopy absorption of photosynthetically active radiation (PAR), % green cover, transpiration and water use efficiency. SAVI is a modification of the NDVI with correction for background noise due to soil influences. It is more sensitive to structural canopy parameters such as leaf area index, biomass and leaf morphology, and is useful for assessment in areas with incomplete canopies. MCARI measures the depth of chlorophyll absorption of PAR, providing an indication of the photosynthetic efficiency of the canopy. The ability of these indices to detect small-scale responses associated with sublethal stress effects provides a short-term predictive capacity as to vegetation vigour and persistence.

Measurement of these indices is based on comparisons of different wavelength bands reflected by vegetation in multi-spectral digital imagery. This is a rapid method of assessment providing important data on vegetation condition, which are directly comparable across sites and to a large range of vegetation communities worldwide. The use of high resolution imagery for assessing these indices would require pixel averaging functions to be applied before analyses can be performed, necessitating high levels of technical expertise for this step. SVI analysis requires familiarity with imaging software, and could potentially be performed by the photogrammetry supplier during image processing. It is recommended that these indices be re-assessed no less frequently than every 5 years. Average values for each index for a reach should be reported, providing a broad assessment of the condition of riparian vegetation for that reach. Any areas determined to be in high-risk categories for vegetation persistence can be targeted for particular attention during future monitoring.

**Emergent macrophytes**

Macrophytes are important structural and functional components of riverine ecosystems, being highly productive, providing a source of detritus to the aquatic foodweb, and being involved in baffling, filtering, nutrient and water cycling, sediment stabilisation and water column gas exchange. These plant communities also represent a major source of stable substrate for epilithic production and habitat for aquatic fauna. Macrophyte beds are used by fish, macroinvertebrates, insects, waterbirds, frogs and reptiles as roosting, nesting, foraging, refuge, resting and mating habitat. Macrophytes receive poor coverage by most programs monitoring ecosystem condition in aquatic systems, with assessments based on presence/absence or aerial coverage only. We would recommend applying greater attention to assessing macrophyte communities, to collect meaningful data on the role of these plants in providing complex, high quality habitat, and, as they are good indicators of impacts on aquatic systems, responding relatively quickly to changes in river geomorphology, flow and water quality. The indicators selected to assess the habitat value of macrophytes cover aspects of the provision of habitat quantity, quality and complexity.

**Species richness and diversity**

The species richness and diversity in the vegetation community at a site provides information on habitat quality and heterogeneity, which are generally associated with faunal diversity. Macrophyte species richness and diversity have implications for fauna with respect to the provision of food, habitat and nesting sites, and on the timing, quantity and quality of inputs to the channel. Determination of these indicators involves the assessment of the number of species present standardised by the abundance of each species, with data reported by incorporation into calculations of various indices. Higher
index values are generally considered to represent communities with higher stability and capacity to respond to disturbance. Calculating these indices is often considered labour intensive due to the need to identify and count all species. This can be overcome by assessing large and common vegetation only along transects, limiting the taxonomic expertise required and allowing rapid assessment of large areas. The assessment would be against a check-list of expected species. The implications of richness and diversity for ecosystem health assessments rely on comparison to an appropriate reference condition.

Measurement of this indicator involves determination of the dominant macrophyte species present in a reach using on-site assessments along the riparian and in-stream transects. Remote sensing methods may not be suitable for differentiating macrophyte species due to limited differences in spectral reflection of these plants. On-site differentiation requires some taxonomic skill, and would be facilitated by assessment during the early summer growth flush. Assessment of this indicator in autumn or winter should be avoided as the seasonal growth patterns of many macrophytes result in a paucity of above-ground material during these seasons, making identification difficult or causing underestimation in species counts.

Data reported would be number of species, % native species, richness and diversity indices (calculated using relative abundance data), and a species list (divided into native and introduced) for each reach.

**Macrophyte area & relative abundance**

Emergent and submerged macrophytes are an important component of in-stream habitat for fish, macroinvertebrates, aquatic insects, waterbirds, reptiles and amphibians, as well as providing stable substrate for epilithic production and performing a range of ecosystem services critical to the maintenance of water quality and ecosystem functioning. These indicators assess the quantity and quality of habitat provided by macrophytes within a reach. The habitat value of macrophyte communities to different faunal species varies with availability, biomass and plant density. Significant changes over time with respect to areal extent, percent cover or biomass may indicate increasing impacts on the ecosystem (e.g. increased macrophytes due to pooling, silting and increased nutrients), and can have an effect on the habitat value of the vegetation. As with the measures of diversity, differences in absolute values at different sites do not in themselves provide an indication of condition at the sites — only through comparisons with a natural reference do the values become meaningful as indicators of ecosystem health.

Areas and percent cover of aquatic macrophytes in a reach can be calculated from high-resolution digital aerial photographs, using manipulation of wavelengths in the imagery to detect submerged and emergent vegetation. Initial validation in the field would be required, assessing the extent of vegetation at locations determined from aerial photos. Measurements of stem density provide data required for calculating indexes of species richness and diversity. However, direct on-site assessment can be time-consuming, especially if numerous species are present. Initial on-site validation of percent cover assessments from aerial photos can encompass stem density and standing biomass measurements (replicated quadrats (0.04 m² for high density patches to 1 m² for low density patches) and representative area harvests). Data on relative abundance for each reach can then be extrapolated from measurements of percent cover from aerial photos. These indicators should be assessed during the peak vegetation period in early summer,
noting proportions of live and dead material if possible. Assessments during late autumn to early winter are not recommended, as seasonal dieback of macrophytes in the majority of the Murray-Darling Basin during cooler months would potentially under-represent this important component of physical habitat. Total area and averages for percent cover, biomass and stem density should be reported for each reach. Division of reporting into values for different species would be useful where differentiation is possible.

## Channel form

The assessment of channel form will be based on four transects of the bank-full channel as described in the introduction to this section. The objective of this index is primarily to assess habitat diversity within the channel. The primary hypothesis is that increasing channel complexity will lead to increased habitat diversity. To assess channel complexity the shape of the channel is compared to a simple ‘U’ shape. The greater the extent of deviation from the ‘U’ shape, the more complex the channel. The software is called The Channel Program and is available from the University of Canberra.

Transect mapping can be carried out under a variety of flow conditions, although low flow periods probably provide less challenging conditions. When flows are low, surveying can be undertaken with a variety of equipment, but theodolite survey techniques are relatively cost effective. Such surveys are often required for discharge monitoring.

When conducting transect measurements the location of large woody debris and macrophytes in the water column and on benches and sand bars should be noted, as should the amount of organic material and sediment type (e.g. Queensland DPI Sheet 6).

### Channel features (riffles, pools, islands, rock bars, sand bars, backwaters, benches, point bars)

The overall channel form and the dimensions of various channel features within a reach should be measured and the proportion of each type determined. Large channel features can be assessed using low-level aerial photography (see snag assessment). Aerial photography would need to validated during the site visit.

A problem with this approach is that it does not necessarily provide an indication of the amount of various habitats available under different discharges. It is hoped that further development of hydrological analysis in conjunction with the channel surveys will enable modelling of the temporal distribution and availability of channel features.

### Pools

Pools provide important habitat in lowland rivers, particularly as refuge from low flows (e.g. Boulton 1989). The residual pool volume is an important indicator for assessing habitat availability and the ability of aquatic organisms to survive in drought prone and ephemeral streams. Cross sectional surveys provide an indication of depth but not longitudinal extent of pools. Pool width and length should also be measured, particularly in those streams prone to low flow conditions where pools become important refugia for aquatic species during low flow. Pool depth or extent relative to different flow levels or
hydrological bands would provide a useful indicator of the extent of available pool habitat and degree of connectivity between pool habitats during low flow.

Pool depths can only be measured directly in the field, but it may be possible to measure pool width and length from low-level aerial photography (see snag assessment) depending on water level and clarity.

Snags

Snags provide one of the only hard stable substrates for colonisation by biofilm and invertebrates in lowland rivers. There are several quantitative techniques available for measuring snag density, surface area or volume. The line intersect method (Gippel et al. 1996, Marsh et al. 1999, Wallace and Benke 1984) can be used to measure snag surface area and volume expressed as a proportion of streambed area. However, it is time consuming and requires at least 10–20 transects per site due to the patchy distribution of snags in lowland rivers. A complete census of snags in a reach can also be conducted but again this is time consuming. The benefits of the line intersect and census methods are that location within the water column can also be determined so that the amount of available snag habitat at different river depths and flow regimes can be determined. However, the turbidity and depth of many lowland rivers may make it difficult to accurately count and measure snags deep in the water column.

Marsh et al. (1999) suggests a rapid assessment technique were the numbers of snags over 30 cm diameter are counted and related to a predetermined relationship between snag number and volume. However, this method still requires a more detailed census to establish an initial relationship between snag number and volume for a particular river type. Counting snags over 30 cm diameter however, can provide a rapid census technique for comparison between sites and sampling times without determining absolute density.

More recently, Koehn et al. (2001) have used low-level high-resolution aerial photography to count snag numbers, size and distribution in a reach of the Murray River. Low-level aerial photography was conducted during low flow and high water clarity conditions. From the photographs it was possible to measure snag type, distribution, aggregations and geometry within the river channel. Field assessment using echo sounding and visual counts was used to further assess snag numbers and distribution and to test the effectiveness of aerial photography at identifying all snags present. Ground-truthing revealed a 77% error in the ability of aerial photography to detect all snags. However, the authors concluded that low-level aerial photography is a useful tool for measuring snag density and distribution over large areas provided ground-truthing is conducted and that error rates are consistent across sites. It is also essential that photographs are taken during low flow and clear water conditions. They recommend strong consideration should be given to opportunistically commissioning low-level high-resolution aerial photography of rivers when they are in suitable condition (low flow, high clarity) for future assessment.

The simplest technique for assessing snag habitat is a visual assessment of loadings based on a percentage of stream bed covered (e.g. Queensland DPI) or some predetermined categorical condition (e.g. ISC). This method is very subjective as snags are often patchily distributed and many snags are located in accumulations making an assessment of the proportion of streambed covered difficult. Also, this technique does not provide for the
three-dimensional distribution of snags or give an indication of snag complexity, e.g. number of branches etc.

The type of snag is also an important consideration when assessing habitat condition. Introduced species may not provide the appropriate habitat for native invertebrates and fish. For example, willows do not produce the hollow branches shown to be favoured by many native fish species, and willows quickly decompose and don’t provide the stability and longevity of native wood species.

An assessment of the delivery mechanism and source of recruitment of snags is important for determining the future supply of snag material to the river. Some streams may have suitable in-stream snag loadings but because of riparian clearing, the potential for recruitment has been reduced. Identifying these situations is important in providing a general assessment of river condition and an understanding of future problems.

Recommendations for monitoring/assessment

Due to the complexity of snag habitat and the time consuming nature of direct census and line-intersect techniques for measuring snag abundance a range of methods for assessing snag habitat are recommended.

Low-level high-resolution aerial photography

Low-level high-resolution aerial photography is recommended as a suitable method for gaining a general assessment of snag type, distribution, complexity and geometry within the channel. Techniques for analysing aerial photographs are described by Koehn et al. (2001). Briefly, a grid with known dimensions is overlaid on the photograph and in each cell the number of snags, their length, distance from bank, number of contacts with other snags, orientation and type are recorded. Orientation is categorised according to angle from bank of the main axis of the snag. The direction, upstream or downstream, is recorded based on the location of the root wad. Snag type is recorded as full tree, branch, root mass, trunk or tree head. The position of snags relative to channel features is also recorded.

Ground-truthing is required to determine error rates, but ground-truthing techniques do not require exhaustive census techniques. In lowland rivers, most snags are located close to the bank since stream power is generally insufficient to move snags large distances into the centre of the channel. Ground-truthing can be carried out by visual assessment of snag numbers in specified reaches and from echo sounder traces conducted along transects parallel to but 15 m from each bank (Koehn et al. 2001).

Low-level high-resolution aerial photography needs to be conducted when river flow is very low and water clarity is high. Given the stability of snags in lowland rivers aerial photography for snag assessment may only need to be conducted every 5 or 10 years.

Position in water column

Snag position in the water column can be assessed using a number of techniques. Echo sounding can provide an indication of snag numbers and their position in the water.
column. This can be conducted in conjunction with ground-truthing for aerial photography.

Position in water column can also be determined from cross sectional profiles. When channel cross sections are surveyed, the location of snags relative to the distance from the bank and depth in the channel and snag diameter should also be recorded. A minimum of five cross sections in a reach would provide a qualitative indication of snag location in the water column; snag surface area and volume can also be calculated using the formulas for the line-intersect technique (Wallace and Benke 1984). However, 10 to 20 transect are generally considered the minimum required when using the line-intersect technique.

Visual assessment

Qualitative visual assessment of snag habitat across a reach can also be made. Techniques based on an assessment of the relative proportion of different snag types, e.g. large logs, branches, individual pieces accumulations, tree roots etc, similar to the process used by the Queensland DPI (State of the Rivers Sheet 10 Aquatic Habitat) are appropriate for gaining an overall appreciation of available snag habitat. The assessment technique used for ranking density and origin of coarse woody debris by the Victorian ISC can provide a rapid indication overall condition.

Additional categories should include a visual assessment of snag surfaces to indicate if surfaces are covered in filamentous or diatomaceous algal biofilm or inorganic sediment. This provides an indication of the potential for those surfaces to contribute to carbon processes in the river and act as a food resource for in-stream organisms.

Preferred method

The preferred methods for characterising snag habitat incorporate a combination of the above techniques. It is recommended that aerial photography and ground-truthing be conducted every 5 to 10 years when suitable conditions exist. Water column position and snag diameter should be recorded whenever cross sectional profiles of reaches are made. Visual assessments based on the Queensland DPI technique and overall assessment of condition should be conducted annually.

In-Channel patches

Proportion of clay, silt, sand, gravel, cobble, boulders, bedrock, detritus

Four transects of the channel shape will be undertaken as described above. For the wetted channel additional information will be gathered using a protocol similar to that undertaken by AUSRIVAS. Within the wetted channel water depth and current velocity should be measured at 15 evenly spaced points. While transects are being performed the operators will take note of the sediment type and presence of macrophytes, filamentous algae, periphyton and detritus. Transect data will be used to derive the coefficient of variation for depth and current velocity.
Once transects have been completed the bed material, macrophytes, filamentous algae and detritus should be characterised based on a visual assessment of percentage.

**Embeddedness**

The embeddedness or degree of infilling of interstitial spaces provides information on the capacity of sediments to support aquatic life. High embeddedness can reduce habitat availability, but low embeddedness can result in significant bed movement which may also reduce habitat suitability. Embeddedness can be measured using sediment cores. However, this is likely to be expensive and time consuming. A visual assessment similar to that used by Queensland DPI (Sheet 8 Bed and Bar Condition) is the preferred rapid assessment method. Embeddedness can change rapidly with changing land use and catchment management activities, and should be measured annually.

**Proportion of each patch covered in algae/periphyton/biofilm**

Benthic surfaces are important for providing habitat for colonisation by biofilms. Biofilms contribute to carbon supply to rivers and provide a food source for many organisms. The extent of biofilm can also provide an indication of the nutrient status of a waterway. For example, excessive filamentous algal growth may indicate nutrient enrichment and reduced scouring flows; heavy layers of inorganic sediment on benthic surfaces (snags and cobbles) can indicate excessive erosion and sediment delivery as a result of catchment activities.

The amount and composition of biofilm on benthic surfaces, including wood and bed materials should be visually assessed. The proportion of surfaces covered by algae or fine silt should be noted as well as the type of biofilm (e.g. filamentous, diatomaceous, inorganic) and the thickness (e.g. thick >5 mm, medium 2–5 mm, thin <2 mm).

**Process Measures**

**Riparian Regeneration**

Regeneration of riparian vegetation is an important component to monitor as a process maintaining the quantity and quality of habitat provided by the vegetation. It is also important as a predictor of invasions by introduced species. Due to difficulties with monitoring regeneration of all the vegetation in this zone, we recommend focusing on the large and common species only (e.g. river red gum, willows). There are problems associated with monitoring regeneration given the sporadic nature of germination and recruitment of many native riparian species such as river red gum, which require flooding during specific seasons for successful regeneration — random quadrats may miss hotspots of regeneration. However, for a given length of stream side to have appropriate riparian cover in the future, it is essential that some representation of younger generations of plants occurs in the present. Assessment would involve incorporation of riparian demography data from on-site transects into equations based on survivorship curves for the dominant species, producing an estimate of expected population demography for the future based on current vegetation status.
Potential input of Large Woody Debris

The abundance and composition of snags in the river channel, which are important components of in-stream habitat, are dependent on recruitment of large woody debris from riparian vegetation. Width of vegetation overhang and distance from the canopy to the channel have major implications for potential snag input. If all the trees are further from the channel than 1 x tree height, snag recruitment won't occur until regeneration of riparian vegetation adjacent to the channel occurs, or the channel moves. An indication of the quantity and composition of large woody debris available for potential input into the channel can be obtained through combining measurements of a range of vegetation, geomorphology and flow parameters. Vegetation overhang/distance to channel, tree height, species composition & demography, average basal area, vegetation vigour, bank stability and rate of water level decrease all contribute to snag recruitment for a given area of stream bank, which can then be scaled using vegetated stream-length and tree density.

Connectivity

The River Murray Expert Panel identified connectivity among habitats as an essential element in protecting the health of rivers. One of the impacts of water resource development has been the dramatic reduction in connectivity, both longitudinally along the river and laterally with the floodplain. The loss of connectivity can be regarded as a threatening process and should be assessed as part of the physical habitat assessment because it has an impact on habitat availability. AUSRIVAS and the Queensland State of the Rivers program both categorise longitudinal connectivity based on the shape of the wetted channel. This technique is flawed as the ability of fish to move along the channel will vary in response to flow. The issue that becomes important is not whether the fish can move at the time of assessment but whether the timing and duration of suitable conditions for fish migration are similar to those found at the reference condition. This is a further example where integration of channel morphology and hydrological analyses will yield a more thorough understanding of the condition of a river.

Levees although not always effective, are designed to “protect” floodplains from floods. In the short term this allows the uninterrupted exploitation of the floodplain’s natural resources, but in the long term they lead to the decline of both river and floodplain condition. It is proposed that a floodplain connectivity index (CI) could be determined for each site with the use of remote sensed images and aerial photographs.

The floodplain connectivity index (CI) is a measure of the degree of floodplain isolation caused by levees at a site. The technique involves generating a plot of floodplain area inundated under natural conditions and also in the presence of levees. These curves can be generated by two methods. The first would utilise a series of aerial photographs or remotely sensed images taken at different periods of over bank in order to derive a relationship between flow and area of floodplain inundated both with and without levees. The second approach would utilise a Digital Elevation Model (DEM) of the floodplain surface. Once this was acquired the area inundated with various flows could be calculated and levees then included onto the DEM.

Calculating the difference among the two relationships between flow – floodplain area inundated, then derives the floodplain connectivity index (CI). This is derived from any number of percentile points along the curve. The statistic CI is shown in Equation 1, where
n is the natural (without levees) floodplain inundated area value for percentile point i, p is the number of percentile points and c is the floodplain inundated area with levees value for percentile point i. The statistic CI gives equal weighting for floodplain area inundated, from the lowest area to the highest area.

Equation 1

If $n > c$ then \[ M = \frac{1}{p} \sum_{i=1}^{p} \frac{c}{n} \] else \[ M = \frac{1}{p} \sum_{i=1}^{p} \frac{n}{c} \] Equation 1

In-stream barriers such as weirs and dams have a number of detrimental effects on both physical habitat and organisms’ ability to access that habitat. Barriers prevent fish migration, denying native species access to spawning sites. Barriers also alter the movement of sediment and organic matter downstream, creating sedimentation problems within the weir pool and erosion problems downstream. The distance to the nearest weir is recorded as part of the AUSRIVAS program, and we believe should be included in the Audit. A survey of barriers should have already been conducted for each state in the MDBC. This information can be used to determine whether test reaches are affected by barriers. Flow related channel morphology will also provide information on the connectivity of pools, backwaters and floodplains during different flow levels.

Sediment Regime

There are two important elements to the sediment regime in rivers. The first is the input of sediment to the river through erosion. The second is the movement of sediment within the channel.

It is generally thought that the input of sediment to rivers has increased due to vegetation clearing and grazing. The extent of vegetation cover will be assessed as described in the section above. We also recommend that an assessment of grazing be incorporated into the Audit. This would involve surveying the appropriate land holders to determine stock density, whether stock have unlimited access to riparian areas and whether they are provided with watering points.

Direct assessment of erosion is currently undertaken by a visual assessment of river banks. This form of assessment is particularly limited due to the fact that lowland rivers naturally experience erosion as the channel moves across the floodplain. It is, therefore, difficult to assess whether the rates of apparent erosion lie within those that would be expected in a healthy river.

The measurement of erosion can be simply undertaken using aerial photography. This technique is regularly used to determine bank erosion and channel migration at a reach scale. Aerial photographs taken at different time periods for the same reach of river are simply compared to determine channel migration, loss of vegetation and expansion of gullies. Once established, rates of bank erosion can be compared among test and reference reaches.

The sediment regime within the river is also important in creating and maintaining habitat. In addition to erosion, the sediment regime within rivers has been affected by water resource development. An assessment of sediment dynamics can be carried out by determining the sediment load carried under different flow levels, and integrating this information with the natural and existing flow regime. If this were to be undertaken at
each site, it would involve an increase in sampling effort, but if suspended solid sampling were undertaken in conjunction with existing nutrient and water quality monitoring programs the additional cost would be minimal. Sediment data need only be collected once with subsequent analysis performed by comparison with the hydrograph for the latest sampling interval.

Costing

It will be apparent that the proposed protocol will involve a greater investment than most existing programs. The major and most significant difference in effort is in the area of remote sensing. We believe that the information generated by this form of analysis represents a major advance in the power of physical habitat assessment and enables the cost-effective collection of information that would be vastly more expensive if collected by conventional techniques. The costs of imagery currently appear significant in terms of cash, but in terms of information gained the technique is comparable to field techniques. In addition we anticipate that image costs will decrease while resolution increases. We believe, therefore that this type of analysis represents a sound investment in knowledge acquisition.

We recommend the use of aerial photography until equivalent satellite imagery becomes available which will probably be in the second 5-year cycle. The aerial photography will allow the evaluation of all the indices proposed in most circumstances. The major exception to this will occur where the floodplain is very large. In these cases, we would suggest that additional low resolution LandSat 7 imagery be used for the floodplain scale analysis. This additional imagery will not significantly increase the costs of assessment.

We cannot currently provide accurate estimates for the total costs associated with remote sensing because the cost depends on the number of sites and the distribution of those sites in the Basin. There are cheaper sources of imagery available, but the trade-off is that the resolution tends to decline. There are currently two types of satellite imagery available, LandSat 7 and the French Spot Satellite (Table 2). While some of the indices could be determined using this imagery there would be a loss of accuracy, and in some of the smaller rivers the resolution would prevent collection of the information. The consequence of this is that field workers would have a greater work load. We do not anticipate that this will prevent the information being gathered, but the cost of assessing these sites may be marginally more expensive.

The majority of the ground truthing techniques are currently undertaken by one of the existing programs (Table 3) and appear to be relatively cost effective. The difference between the methods recommended and those of the existing programs is our emphasis on quantitative, spatially explicit data rather than categorical data. We believe that this type of data will provide a much better foundation for monitoring change at sites and for allowing the integration of habitat data with water quality and hydrological data.
### Table 2. Costs of various methods of obtaining data

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<th>LandSat 7</th>
<th>Spot</th>
<th>Spot 2 5</th>
<th>Aerial Photo</th>
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<td>10 m (20m for shortwave IR reqd for SVTs)</td>
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X – not possible, ✓ — possible, L – low resolution, M – medium resolution

### Tasks

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<tr>
<td>Imagery</td>
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<tr>
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<td>1.5 h</td>
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<tr>
<td>Overhang</td>
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<td>Riparian Demography</td>
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<td>30 min</td>
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<tr>
<td>Transects, sediment characterisation, flow measurement, snag assessment</td>
<td>5 h</td>
<td>$400</td>
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<td>$40</td>
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<td>Weirs</td>
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<tr>
<td>TOTAL (per site)</td>
<td>15.5 h</td>
<td>$1,940</td>
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<tr>
<td>TOTAL (20 sites per valley* 22 valleys)</td>
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<td>$853,600</td>
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<tr>
<td><strong>5 year TOTAL</strong></td>
<td></td>
<td><strong>$903,600</strong></td>
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</table>
Reporting

As described above, we anticipate that the physical habitat assessment will be undertaken once every five years. The data may need to be collected over a period of 18 months to allow the analysis of aerial photography to precede the site visits. We recommend that an O/E score be generated for the three spatial scales (floodplain, feature and patch). This would allow separate determination of the condition of the floodplain and stream feature components, both of which are heavily influenced by the vegetation community.

There are several ways to provide a single score for physical habitat. The assessment of physical habitat reported in the Audit could be the lowest score of the three scales. This would represent the most conservative measure of physical habitat. Alternatively, scores for the three scales can be integrated to form an average physical condition score. This approach may hide significant degradation at one spatial scale that might otherwise act as an indication of future degradation at the other spatial scales. This can be overcome by always providing reports at the three scales as well as the average score.

Priority Tasks

To undertake the assessment the agencies will need to undertake a number of tasks. These include:

1. accepting the recommended protocol,
2. selecting both test and reference sites,
3. developing the assessment data sheets (see AUSRIVAS data sheets),
4. purchasing imagery,
5. undertaking image analysis,
6. surveying reference sites,
7. synthesising reference condition for test sites using E-ball,
8. surveying test sites,
9. undertaking assessment,
10. reviewing assessment sampling regime.

It is also recommended that the Commission undertake a number of tasks that will assist with the development of a better assessment of physical habitat. These tasks include:

1. undertaking investigations of the natural state of rivers in the basin using a variety of data sources,
2. developing methods for integrating disparate data into a description of reference condition,
3. developing indicators and protocols for assessing changes in the spatial arrangement of habitat,
4. developing indicators and protocols for assessing changes in the temporal characteristics of habitat.
### Table 3. Indices measured in current programs and proposed for the Audit

<table>
<thead>
<tr>
<th>Index</th>
<th>AUSRIVAS</th>
<th>Border Rivers</th>
<th>Queensland DPI</th>
<th>Victorian ISC</th>
<th>River Styles</th>
<th>NSW PBH</th>
<th>Audit proposal</th>
</tr>
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<tbody>
<tr>
<td>Floodplain Diversity*</td>
<td>✓</td>
<td>C</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>% contribution of habitats*</td>
<td>C</td>
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<td>✓</td>
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<tr>
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<td>✓</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>% Native Species*</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
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<tr>
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<tr>
<td>Riparian width*</td>
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<td></td>
</tr>
<tr>
<td>% Cover of Floodplain*</td>
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<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Vegetated Streamlength*</td>
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<td>Average Patch Size*</td>
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<tr>
<td>Riparian Connectivity*</td>
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<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>% cover trees &gt; 5m*</td>
<td>✓</td>
<td>C</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>% cover shrubs &lt; 5m</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
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<td>% cover understorey</td>
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<td>✓</td>
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<tr>
<td>% Macrophyte Cover within patches</td>
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<td>% pool, riffle, run etc*</td>
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<td>C</td>
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<td>Snag distribution*</td>
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<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

- * Indicates measurements that can be, at least partially undertaken by remote sensing.
- ✓ indicates this information is currently collected by the program
- C indicates that this information is collected as a category or rating.
- I indicates that this information is included in an index within the program.
Table 4. Audit habitat assessment

<table>
<thead>
<tr>
<th>Component</th>
<th>Measurement units</th>
<th>Number of units per site</th>
<th>Measurement variables</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Floodplain</td>
<td>100 m wide transect extending to 1 in 100 year flood level</td>
<td>4 non-random (different channel forms)</td>
<td>• Proportions of major habitat types</td>
<td>Orthophoto imagery / GIS / ground truth</td>
</tr>
<tr>
<td>2. Bank</td>
<td>High bank Low bank</td>
<td>4 non-random channel transects (different channel forms)</td>
<td>• Bank slope • Bank shape • Erosion type • Erosion extent (proportion of bank) • Slumping (proportion of bank) • Lateral scour (proportion of bank) • Local scour (proportion of bank) • Aggradation (proportion of bank)</td>
<td>On-ground visual estimation</td>
</tr>
<tr>
<td>3. Riparian vegetation species</td>
<td>Transects up to 100 m long</td>
<td>4 non-random riparian transects</td>
<td>• Dominant tree and shrub species</td>
<td>On-ground presence/absence and percent cover of species on checklist of expected species at a site</td>
</tr>
<tr>
<td>4. Riparian vegetation cover</td>
<td>Reach defined by meander wavelength</td>
<td>1</td>
<td>• Relative cover of dominant species</td>
<td>High-resolution multi-spectral digital aerial photography</td>
</tr>
<tr>
<td>5. Riparian vegetation density</td>
<td>10 m to 30 m radius quadrat</td>
<td>12 quadrats</td>
<td>• Bitterlich basal area of dominant species • Stem density of dominant species</td>
<td>‘Established forestry practice’</td>
</tr>
</tbody>
</table>
| 6. Riparian vegetation width | Transects up to 100 m long | 4 non-random riparian transects | • Distance from edge of channel to cleared or developed land  
• Channel width  
• Width of floodplain  
• Density of floodplain ‘vegetation’ | Adaptation of Queensland/NSW Border Rivers Flow Management program (aerial photography) |
|-----------------------------|---------------------------|-------------------------------|--------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| 7. Riparian habitat fragmentation | Reach scale | Reach | • Length of bank with ‘vegetation’ >5 m wide  
• Number of gaps  
• Patch size  
• Length of gaps | Aerial photography |
| 8. Riparian canopy complexity | Riparian transects | 4 non-random riparian transects | • Percent cover of trees  
• Percent cover of shrubs  
• Percent cover of understorey  
• Percent cover of ground vegetation | On-ground visual assessment (plus aerial photography for tree layer) |
| 9. Riparian demography | Riparian transects | 4 non-random riparian transects | • Proportion of individuals of each species of ‘major riparian plants’ (trees only?) in each age class | On-ground visual assessment. Method for age class determination unspecified |
| 10. Standing litter | Points along riparian transects | 40 | • Depth and percentage cover of litter in quadrats | Depth measurement and visual assessment |
| 11. Vegetation overhang | Randomly selected positions along channel edge | 8 | • Distance of canopy from channel  
• Distance from canopy to channel | Aerial photography |
| 12. Vegetation vigour | Reach scale | Reach | • Spectral vegetation indices | Multi-spectral digital imagery |
| 13. Emergent aquatic macrophyte species richness and diversity | Quadrats or transects | 4 channel transects. 15 points within wetted channel. 4 replicate quadrats (size variable) | • List of species  
• Relative abundance of each species | On-ground visual assessment |
|---------------|----------------------|------------------------------------------------|-------------------------------|----------------------------------|
| 14. Emergent aquatic macrophyte area and relative abundance | Reach assessment for remote sensing  
Quadrats (size and location unspecified) for on-ground assessment | 0.04–1 m² depending on density | • Cover of aquatic macrophytes  
• Biomass of aquatic macrophytes  
• Stem density of aquatic macrophytes | High-resolution digital aerial photographs  
On-ground visual assessment |
| 15. Channel form | Transect of bank-full channel | 4 non-random channel transects | • Deviation from U-shape  
• Location of large woody debris  
• Location of macrophytes  
• Amount of organic matter  
• Sediment type | Theodolite survey.  
Visual assessment |
| 16. Pools | Pool | Depth via transects width and length from remote imagery | • Pool length  
• Pool width  
• Pool depth | Cross sectional surveys  
Low level aerial photography |
| 17. Snags | Surface area per m² river bed | 20 transects | • Snag number  
• Snag type  
• Snag diameter  
• Snag water column position | Aerial photography  
(with ground truthing)  
Cross-sectional profiles  
Visual assessment |
<p>| 18. Proportion of clay, silt, sand, gravel, cobble, boulders, bedrock, detritus | Wetted channel transects | 4 non-random channel transects | • Proportion of bed material | Visual assessment |
| 19. Embeddedness | Wetted channel transects | 4 non-random channel transects | • Embeddedness category | Visual assessment (Qld DPI sheet 8) |</p>
<table>
<thead>
<tr>
<th>Section</th>
<th>Methodology</th>
<th>Parameters</th>
<th>Data Collection Method</th>
</tr>
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<tbody>
<tr>
<td>20. Cover of algae/periphyton/biofilm</td>
<td>Wetted channel transects</td>
<td>4 non-random channel transects</td>
<td>Visual assessment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Proportion of surface covered by algal categories</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Proportion of surface covered by fine silt</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• Type of biofilm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Thickness of biofilm</td>
<td></td>
</tr>
<tr>
<td>21. Riparian regeneration</td>
<td>Riparian transects</td>
<td>4 non-random riparian transects</td>
<td>Survivorship curves applied to demography</td>
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<td></td>
<td></td>
<td>• Expected future proportion of individuals of ‘large and common species’ in each age class</td>
<td>data from 9 above</td>
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<tr>
<td>22. Potential input of large woody debris</td>
<td>Riparian transects</td>
<td>4 non-random riparian transects</td>
<td>Aerial photography, DEM, connectivity index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Snag recruitment per unit area of bank</td>
<td>Visual assessment</td>
</tr>
<tr>
<td>23. Connectivity</td>
<td>Reach scale</td>
<td>Reach</td>
<td>Aerial photography, DEM, connectivity index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Presence of levees</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distance to the nearest weir</td>
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</tr>
<tr>
<td>24. Sediment regime (and grazing)</td>
<td>Transect lines (dimensions unspecified)</td>
<td>Unspecified</td>
<td>Landholder survey</td>
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<tr>
<td></td>
<td></td>
<td>• Stock density</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stock access to riparian areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stock watering points</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Channel movement, area of gullying</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ‘Sediment load’</td>
<td></td>
</tr>
</tbody>
</table>
References


Final Report
Project R2004
Development of a Framework for the Sustainable Rivers Audit

Appendix 8
Response to SRA Taskforce questions on Draft Report
## SRA Taskforce Questions on Draft Audit Report

<table>
<thead>
<tr>
<th>General Questions</th>
<th>CRCFE Project Team Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Would it be possible to include the sequence of steps involved in implementing the full monitoring framework, indicating which steps this report covers. NSW provided a draft 34 step process used for the implementation of IMEF as guide (attached within NSW's comments).</td>
<td>Implementing a full monitoring program at the Basin-scale is a complex undertaking. The task can be broken down into discrete steps. These steps include articulating the objectives of the program and then designing a study to meet these objectives that includes issues of sampling, analysis and reporting. DLWC (NSW) supplied a list of possible steps to be undertaken in designing and implementing a river health sampling program (See Attachment 1). This list is comprehensive and has a strong focus on implementation. A number of steps appear out of order, for example we would consider that issues such as data storage and management (Step 19), selection of sampling points (Step 21) and development of communication and reporting strategies be included in the design stage (Step 1). Since the list of steps provided by DLWC has not been evaluated for effectiveness, we would caution against their adoption until this had occurred. In the meantime, they provide a guide to the issues that need to be addressed in developing a monitoring program. Clearly, most of the steps on the NSW list are beyond the scope of the CRCFE’s brief (e.g. steps 2,3,5,9–34 and parts of the remaining points). The Tasks addressed by the Framework and the outstanding Tasks are covered in the Final Report.</td>
</tr>
<tr>
<td>2. Could you bring forward to the Executive Summary more discussion on the frequency of reporting, its costs and which indicators should be reported annually?</td>
<td>Information on the frequency of reporting, its costs and which indicators should be reported annually was reported in the Draft Executive Summary. This discussion has been enhanced in both the Executive Summary and the text of the Final Report.</td>
</tr>
<tr>
<td>3. Would it be possible to design the Pilot to provide better evidence of the benefits (vs costs) of the Audit?</td>
<td>After receipt of the Draft Framework for the Development of the Sustainable Rivers Audit, the Taskforce recommended that a Pilot Audit be undertaken prior to commencement of a Basin-wide Audit. There is considerable merit in undertaking an appropriately scaled and resourced Pilot Audit. The benefits of this are outlined in the Final Report. Briefly, the Pilot will allow further development of methods and a trial of all indicators before full implementation. Analysis of the Pilot data will provide considerable guidance in indicator refinement, site selection and number of samples required. This is because much of the Audit framework is new and consequently little is currently known of the behaviour of the proposed indicators.</td>
</tr>
<tr>
<td>Question</td>
<td>Response</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4 Given the demand for the Audit to be used Regionally, could you provide costs for increased sensitivity (e.g. down to FPZs or reaches which are more relevant management units)?</td>
<td>The draft final report provided indicative costs associated with data collection and analysis based on reporting at the river-valley scale. These cost estimates were based on current commercial rates for sampling. The number of sample sites is dictated by the desired sensitivity and power of the assessment. If there is an intention to report at the Functional Process Zone scale a much greater number of monitoring sites would be required than for the reporting at the river-valley scale. At the FPZ scale there are several monitoring strategies that could be of interest; reporting on the condition of each FPZ in each river valley, or reporting on the condition of a one FPZ (e.g. armoured) in a particular river valley. There are a total of 291 discrete FPZs across the MDB. Providing an assessment of individual condition would require measuring each of the indices at a set of spatially random sites within each FPZ. The number of sites would be determined by the yet unknown spatial variability of each index within each FPZ. Although it is likely that the spatial variability within an FPZ would be less than that within a river valley, so requiring fewer sites, reporting at the FPZ scale could require approximately ten times the number of sites required to report at the river-valley scale. It would seem more likely that a management agency would be more interested in the condition of a particular FPZ in a river valley of concern. Assessing the condition of a single FPZ would require monitoring a spatially random set of sites within the FPZ. Again, because it is likely that the spatial variability within an FPZ would be less than that within a river valley, fewer sites would be required than for assessing a single river valley.</td>
</tr>
<tr>
<td>5 Could you emphasise the fact that the referential approach does not equate with an objective of returning to natural? (see also AFFA’s comments).</td>
<td>This was discussed at length in the draft report on pages 11–13. This point has been further emphasised in that section and further comments to this effect have been included in the Executive Summary.</td>
</tr>
<tr>
<td>6 Could you provide additional information/justification on the approach to defining reference condition (i.e. WQ sites, physical habitat)?</td>
<td>Water Quality: The selection of water quality sampling sites is traditionally based on ‘well mixed’ sites, capable of providing a ‘representative’ sample. Typically, these sites are riffle FPZs in the case of upland and mid-slope Valley Process Zones, and channel (pool) reach FPZs in the case of lowland valley process zones. This is also the basis of selection of sampling sites adopted in the Audit framework. The selection of reference sites for water quality sampling needs to reflect the Valley, Valley Process Zone (VPZ) and FPZ of each monitored site VPZ &amp; FPZ category, on a valley by valley basis.</td>
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</table>
In tabulating the list of possible reference sites meeting these criteria, there is a need to exclude non-representative sites such as sites immediately downstream of river junctions or point-source discharges (problem of transverse stratification of flows). A random selection of reference sites is then made from the tabulation of possible sites.

In the case of lowland Process Zones, there are few unmodified streams available for reference purposes. In these cases, it is proposed to generate the best available estimate of reference conditions, drawing on data from modified streams, and estimates provided by the application of an interactive transport, sedimentation, sediment redox & biofilm uptake process based model (daily time step).

Fish: There will be two approaches for fish. ‘Sampling best available sites’: a set of reach and site based criteria will be used, similar to those for macroinvertebrates (with the addition of a criterion in relation to proximity to dams), as originally described by Davies (1994) for the AUSRIVAS program to screen site suitability.

‘Historical species list’: a ‘historical’ list of fish species, derived by a group of fish biologists for each valley/reach, will act as a secondary reference for direct comparison with site data. No specific reference site sampling will be needed for this approach.

Macroinvertebrates: For defining reference sites for the assessment of invertebrates it is recommended that criteria similar to those used for the QLD WAMP process are adopted. (Refer to Appendix 3 Table A10.)

Could you update ISC sampling procedure with most recent version?

Paul Wilson (Victoria DNRE) has informed the Project Team that the “Index of Stream Condition — Reference Manual (1999)” contains the most recent description of the ISC sampling procedures and method for calculation of the ISC score.

The details on the ISC given in the Draft Final Report reflect this information. In particular, details on the recent changes to the sampling protocol (to 3 transects sampled at 3 sites) are given on page 9, and details of the revised method for calculation of the ISC score (using inverse ranking) are given on page 35.

Could you accommodate a 'movement from current condition' as a short term alternative to 'distance from reference’?'

The use of ‘natural’ condition as reference condition has several advantages. These are discussed in the Final Report.

There are several major problems with using ‘current condition’ as a reference. Using current condition as reference does not allow current condition to be interpreted. Is current condition good, bad or otherwise? Following from this, changes in condition measured over time cannot be interpreted. Is a change a good change or a bad one? How do you know how far it has changed?
<table>
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<th>Does the report need to reiterate the basis for selecting the five indicators, or to acknowledge other indicators? Might stressor/threat indicators have more success in preventing decline?</th>
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</table>
| 9 | The Project Brief for the Development of a Framework for the Audit clearly states that indicators to be developed by the CRCFE for the framework were: Macroinvertebrates, Fish, Water Quality, Hydrology and Habitat. The final report has been amended to make this point clear. These indicators were recommended in a scoping study (Cullen et al. 2000) undertaken prior to this project. The scope document used the following criteria to identify suitable indicators:  
  • they built upon existing programs and data as much as possible  
  • were consistent with the conceptual models of river function developed for the Functional Process Zones  
  • responsive to disturbance  
  • measurement and analysis are rapid (analysis is built into reporting of the indicator)  
  • standardised methods are available and are technically appropriate for State agencies to undertake  
  • output can be interpreted relatively unambiguously  
  • indicator has meaning to the wider Basin community |
| 10 | Could you include a summary table of the tasks, time, resources and costs of the steps required to implement the framework, to assist in cost-benefit analysis? Could you include the tasks for the staged development of indicators in that table?  
It is beyond the Scope of this project to fully cost the implementation of the Audit. This project provides cost estimates for undertaking the recommended sampling and analysis (see Final Report, “Indicative Costing”, pp. 39–42). Costs associated with the ISRAG, project management by the Commission and jurisdictions, communication activities and data archiving have not been calculated. |
| 11 | Could you include comment on how reporting arrangements might provide access to the source data i.e. to help overcome the problem of masking?  
ISRAG will have to ensure that they have adequate access to the source data to ensure that they can effectively audit the jurisdictional reports. How ISRAG manages this process is a matter for ISRAG and the jurisdictions to determine.  
A danger to the integrity of the Audit is using data to report at scales other than those for which the Audit has been designed. Unfettered access to the source data will need to be managed to minimise the chance of this occurring. The Framework is designed to report river health at the scale at which the sampling regime has been developed e.g. the river-valley scale or valley process zone scale. For example, reporting reach condition on the basis of one sampling location would be unreplicated therefore there is no estimate of the variability at that scale. |
| 12 | Can you include comment on the integration with existing monitoring programs? For example the new paradigm inherent in the water quality theme is quite different to existing arrangements. Explain why we can not use existing programs as much as some would hope. | Appendix 1 “Review of existing programs that measure and report river health in the Murray-Darling Basin” describes in detail existing river health programs and what they purport to measure. The outcomes of the review presented in Appendix 1 are discussed in the Final report. In summary, the review concluded that current programs undertaken by partner governments and the Commission do not fully satisfy the information and reporting requirements of the Audit for several reasons. Therefore, the Final Report argued that the Audit could not be built directly upon ongoing programs and data sources. Rather, elements of various programs may provide data to the Audit, where appropriate. The ‘new paradigm inherent in the water quality theme’ reflects the objectives of the Audit. Fundamental to the Audit is the assessment of river health and therefore the water quality indicators are developed to assess river health (e.g. indicators reflect outcomes of primary and secondary production and the mineralisation of organic material). In the past, water quality monitoring programs have not been developed to assess river health. Consequently, it should not come as a surprise that a new paradigm will require a different approach to water quality sampling. |
| 13 | Can you elaborate on how the Audit will inform target setting or revision within catchments? | An accurate picture of river condition is a critical element in the process of setting targets for river health. By reporting at the river-valley scale and potentially at other within valley scales the Sustainable Rivers Audit will provide a Basin-wide assessment of river condition. Ongoing monitoring of river health is critical in knowing whether actions are moving river health towards the desired targets. The Audit will also provide information on the likely drivers of river health, e.g. habitat, hydrology, etc. This information will help in determining appropriate management actions to reach river health targets. It is not the role or function of the Audit to set targets for river health. Targets for river health are being developed for the Murray-Darling Basin as part of the ICM in the Murray-Darling Basin 2001–2010 — delivering a sustainable future (MDBMC 2001) pp. 8–10. |
| 14 | Could you elaborate on how the conceptual models in Appendix 2 influence the selection of indicators and the locations and parameters to be sampled? Options to reduce costs might exist in tailoring where/what to monitor. | The selection of the water quality health indicators has built directly on the conceptual models and Functional Process Zones, as outlined in Appendices 2 and 5. The selection of water quality indicators has been based on the assessment of river health, in terms of the physical and chemical outcomes of in-stream biological processes. As the dominant biological processes vary according to VPZs & FPZs, it has been necessary to set the upland and mid-slope Process Zones indicators different to those for the lowland Process Zones. |
In order to assess the monitored indicator values, in some cases, information is required on a range of associated potential modifiers of bio-geochemical processes.

For example, ideally, monitoring is required of the diurnal pattern of instream DO and pH, in order to assess primary or secondary production and respiration balance and rates. As a requirement for 24 hours monitoring at each site would be resource intensive, it is proposed to compare a daylight based sample with calculated equilibrium for the prevailing flow, temperature and alkalinity conditions, to assess production & respiration rates.

Fish — fish are central to all conceptual models. Sampling to focus on instream communities.

Invertebrate composition is an integral part of ecosystem structure and processes, as shown by the conceptual models (Appendix 2). Invertebrate indicators were chosen to measure composition and sensitivity compared to what should be at a site (Appendix 3 section A2). Loss of community components will affect the structure and processes described in the conceptual models. Specific habitats of importance for invertebrates, indicated by the conceptual models, are proposed for sampling. To reduce costs, sampling should address only the key parameters required to adequately represent the biological community and influential environmental variables at a site. Conceptual models can be used to infer potential effects and causes if key indicators are monitored.

**15** Could you review the criteria for reference site selection and suggest more detailed criteria? How should weir pools be dealt with?

The current Audit framework excludes standing water bodies such as weir pools and reservoirs. The approach could be expanded to include these ‘Functional Process Zones’. A distinctly different set of indicators would be required to reflect the ecological health of these systems.

More detailed criteria for reference site selection can be developed for regions as appropriate. Weir pools are unlikely to be sampled for invertebrates as they are a limited habitat and sampling sites must be representative of the whole valley.

**16** Could you elaborate on the criteria for stratifying rivers for sample site selection? Are major human impacts (e.g. structures) an important layer for stratifying?

The criteria for stratifying rivers is detailed in the Final Report.

The Final report recommends two scales for stratification, valley process zones and Functional Process Zones — see Final Report for descriptions of these. The choice of scale will depend on the desired reporting scale.

These zones are based on regions of relatively homogeneous geomorphology. VPZs are defined by their sediment transport characteristics and are built up from FPZs, which are defined by a combination of geomorphology and hydrology.

The number of sites within a zone is allocated by proportion of total catchment (by area) in each zone. If a zone represents 30% of the catchment area then 30% of the sites will be allocated to that zone. Stratification ensures representation of all river types in the final assessment of river health.
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<th>Question</th>
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<tr>
<td>What physical dimensions define a ‘site’?</td>
<td>The zones are defined by the geomorphic and hydrological conditions that occurred prior to regulation. Consequently major dams and other human impacts are not considered in the stratification process. The rationale for this is that the primary objective of the Audit is to provide an assessment of river health at the valley scale. Stratification based on major geomorphic zones ensures appropriate representation of the major geographic regions of the river valleys which may not occur if stratified by zones defined by river management or other structures.</td>
</tr>
</tbody>
</table>
| Could you better explain the $8.2M — what it covers and over what period. | Water Quality: In the case of the water quality indicators, the site comprises a riffle or well mixed zone in the case of upland and mid-slope Process Zones, and a channel (pool) reach in the case of lowland Process Zones. Sampling needs to be taken clear of edge effects in each case, in order to reflect channel water quality. In the case of the lowland Process Zones, under low flow conditions, the ‘channel’ water quality will of course reflect local transverse inputs and bio-geochemical processes. 

In summary, a site comprises a randomly selected river reach having a pre-defined Functional Process Zone characteristic, and a sampling location in respect to the distance from the steam edge. 

In the case of the deeper lowland Valley Zone channel (pool) reach sites, some vertical stratification in indicator values is possible. In these cases, sampling should be based on integrated (tube) sampler rather than a jar sampler. 

Fish — a site will consist of at least one meander wavelength, and will fall between 20 and 40 times the river width. Approx.4–500 m in source-transport zones and 1–3 km in deposition zones. 

Macroinvertebrates - The standard AUSRIVAS protocol is to use 10 times the bankfull width to define the site. |

How the cost estimate of $8.2M for the Audit was determined is described in the Final Report and in the various Appendices for each theme. 

The Final Report clearly states that the exact cost of undertaking the Audit cannot be calculated at this stage of its development because several key decisions about the Audit model have not yet been resolved, e.g. the reporting scale. 

The indicative cost of $8.2M represents the cost of sampling the sites required for a river-valley scale assessment. These costs were calculated based on standard commercial rates obtained from several laboratories in SE Australia. The estimated cost also includes costs associated with development of several models and analysis tools required to undertake the project. The indicative costs do not include the costs of abstracting the hydrology data from existing models and databases. 

The indicative costs does not include provision for costs associated with project management (either within the Commission or within the jurisdictions), with reporting or with the ISRAG. These costs
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<tbody>
<tr>
<td>19</td>
<td>Could you include the objectives and purpose of the Audit as approved by Council?</td>
<td>The objectives and purpose of the Audit, as agreed by the Ministerial Council, have been included in the Final Report.</td>
</tr>
<tr>
<td>20</td>
<td>How might an adaptability capacity be established in the Framework?</td>
<td>The science underpinning ecological assessment will continue to improve through research projects and experience with assessment programs. As new knowledge becomes available the Audit requires the flexibility to respond to this. Tempering this is the need to acquire comparable data over long periods so that changes in river condition can be assessed. Any changes made to the indicators will need to be undertaken cautiously so as not to compromise the ability of the Audit to monitor long term trends in condition. Balancing the need for adaptability with the constancy required to detect long term changes is a complex task and one that should be the responsibility of ISRAG. The Pilot Audit provides an excellent opportunity to review the indicators and to undertake various analyses to determine if they are optimised. The 5 yearly CSA is also an appropriate time to review the performance of the indices.</td>
</tr>
<tr>
<td>21</td>
<td>Use of sustainable/sustainability — Phrases such as ‘assurance that water is being managed sustainably’ (page 3) and ‘the ecological sustainability of current management’ (page 11) should either be replaced with words such as ‘managed according to the principles of ecologically sustainable development’ or defined explicitly. At the moment they are open to wide interpretation.</td>
<td>It is agreed that the use of the concept ‘sustainable’ in the Report needs to be clearly defined. There is no commonly agreed definition of the term sustainability. It is frequently argued (e.g. Garcia and Staples 2000) that sustainability is not a stable property of a system that can be defined but rather it is a journey — is what we are doing now driving us in a direction that is sustainable? The National Strategy for ESD (Commonwealth of Australia 1992) defines ecological sustainable development as ‘using, conserving and enhancing the community’s resources so that the ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased. ESD refers not only to the quality of the ecological system but also to the quality of life of the community. The Audit is focussed only on assessing the condition of the ecological system and so does not measure ‘sustainability’ in the broader context. The text of the Final Report has been amended as suggested.</td>
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<td>22</td>
<td>Table 5. It is unclear what a change of, for example, 10% means. Is it a percentage of the proportion or a change from .6 to .7?</td>
<td>This section has been significantly revised. See Final Report.</td>
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<tr>
<td>No.</td>
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<td>Response</td>
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<td>23</td>
<td>Comment on the use of sensitivity analysis on the Pilot data — to see if indices can be rationalised</td>
<td>Sensitivity analysis should be performed on the Pilot Audit data to see if indices can be rationalised.</td>
</tr>
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</table>
| 24  | Provide a Section on the value of a Pilot to the Audit? — e.g. what sort of valleys should be chosen. | The Audit Taskforce has proposed that there be a Pilot of the Audit that reports in 2003. During the Pilot, all indicators will be developed and be trialled, probably in four river valleys across the Basin.  
  • The Pilot is a logical step in implementing the full Audit. Data from the Pilot can be used to determine how to improve the efficiency of the indicators — does everything that is being measured need to be measured?  
  • The number of samples required and the frequency of sampling are driven by a number of factors including the magnitude of the desired detectable change, the confidence in detecting that change, the initial condition score, the variability in the indicator and the reporting scale. While the sample size estimates presented in the report are based on best information available to the Project Team, a number of assumptions about the behaviour of the indicators have been made. Better estimates of sample size can be made once the behaviour of the indices is better known through the Pilot processes.  
  • The Pilot provides an opportunity to assemble and train the technicians required to undertake the monitoring to a an appropriate standard.  
  • It will enable the analysis and reporting of the assessment to be trialled; these are often monitoring elements that are overlooked  
  • It could enable a more accurate assessment of the costs of a full implementation.  |
  There is substantial similarity between the SoE and Audit water quality indicators (turbidity or suspended solids, salinity, pH, DO, temperature, nutrients). TOC has been added to the Audit indicators, as an important indicator of organic material recycling efficiency, while toxicants have been excluded on the basis of monitoring being beyond the capability of the Audit at this stage.  
  The revised Water Quality Guidelines (2000) have moved away from the guideline levels identified against each of the indicators, on the basis of inappropriateness of a single set of numbers to cover all ecosystems for all geographic regions of the continent, and the inappropriateness of absolute (magic) numbers to highly variable and multi-stressor based systems. |

General comments across Indices

The revised Water Quality Guidelines (2000) have moved away from the guideline levels identified against each of the indicators, on the basis of inappropriateness of a single set of numbers to cover all ecosystems for all geographic regions of the continent, and the inappropriateness of absolute (magic) numbers to highly variable and multi-stressor based systems.
### Response to questions

The approach adopted in the revised Water Quality Guidelines (2000) and proposed in the Audit framework is levels based on reference systems.

AUSRIVAS is a core indicator for SOE reporting on inland water quality, thus use of AUSRIVAS in the Audit will ensure consistency.

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<th>26</th>
<th>Could you discuss further the integration and relationships between indicators?</th>
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<td></td>
<td>The indices developed for the five environmental themes can be broadly classified into driver and outcome indices. Driver indices describe the state of the physical environment and provide a diagnostic function for the condition reported by the biotic and biological process (outcome) indicators. The combination of indicators developed will assess the ecological condition of the rivers and will provide information of the likely causes of that condition. This will allow targeted studies to focus on problem areas.</td>
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<td></td>
<td>The Final Report does not recommend using a mathematical function to integrate scores for the five themes to produce a single river health score. The rationale for this is given in the Final Report.</td>
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<td>The report proposes that each of the five environmental themes be reported independently. If a single score for river health is required (e.g. for the river valley). It is recommended that one of the two biotic theme scores (for fish or macroinvertebrates) be used to represent river health. This approach assumes that the biota integrate the combined effects of alterations in the biotic and abiotic environment. Ideally, the scores for both biotic themes will be reported. If however, a single score is required the Final Report recommends that the lower of the two biotic indices (fish or macroinvertebrates) be reported.</td>
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<th>27</th>
<th>Can the concept of FPZ be further discussed in relation to index development</th>
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<td>As outlined in Appendix 5, the water quality index is based on the capacity of streams to transform inputs to streams into food forms (primary &amp; secondary production) sustaining higher trophic levels, and maintain a food web of similar complexity to that of the reference system.</td>
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<td>The water quality index has drawn on a range of indicators reflecting the physico-chemical outcomes of instream primary and secondary production processes. The dominant bio-geochemical processes for each Functional Process Zone are described in Tables 1A &amp; 1B of Appendix 5. The Water Quality Index is the sum of the individual ratios of monitored to reference site indicator values.</td>
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<td>Riffles have been adopted as the basis of sampling in the case of the upland and mid-slope Process Zones, on the basis that their water quality is representative of outcomes of the epilithon or biofilm (assuming equilibrium conditions along the riffle reach).</td>
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<td>Channel (pool) reaches have been adopted as the basis of sampling in the case of lowland Process Zones, on the basis that their water quality is representative of outcomes of the microbial</td>
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<tr>
<td>28 How are the VPZ indices aggregated into a River Valley Index?</td>
<td>The scores for each index are aggregated to the reporting scale from site scores for each index. The aggregation protocol from sites to reporting scale is the same for each reporting scale. The aggregation protocol is described in the Final Report.</td>
</tr>
<tr>
<td>29 Could you include reference lists for Appendices 5, 6 and 7 and any further case studies of the experimental or trial use of these indicators?</td>
<td>Water Quality: The proposed Audit approach to water quality indicators of health represents a significant shift from previous approaches. The proposal to undertake a Pilot Run therefore provides an important means of further developing and testing the approach. The approach is entirely consistent with the conceptual models, risk assessment and reference condition basis of the revised ANZECC Guidelines for Fresh and Marine Water Quality 2000. A number of the indicators are well established as sensitive measures of net primary production (diurnal DO change, pH change), secondary production &amp; mineralisation (NH₄/NOx, NOx/TN), and the processing of organic material &amp; mineralisation ((FPOM+DOM)/(TOC, NOx/TN)) in the case of upland Process Zones. Lawrence et al. (2000) demonstrated the sensitivity of the NH₄/NOx ratio as an indication of reducing levels. For non-point source based river systems, runoff derived from elevated rainfall events constitutes the major driver of inputs of suspended solids, nutrients and organic material to streams. Research reported by Hart, Grace &amp; Beckett indicate that particulate material rapidly adsorbs nutrients and toxicants, and develops biological coating of organic material. The particulates with their coating of nutrients, organic material and toxicants, settle to the sediments under less turbulent flow conditions in deeper pools or on the falling arm of the flow event hydrograph. There has been extensive laboratory and reservoir and lake based demonstration of P release from sediments under low redox conditions. Laboratory based sediment core experiments (Armitage 1995) demonstrated the capacity for a range of carbon sources to reduce sediments, with significant remobilisation of N and P. The research demonstrated the potential for nutrient limitation of the microbial growth, slowing or limiting the sediment reduction and transformation and release of nutrients. Field observations of river sediment release of P are confounded by...</td>
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the heterogeneity of sediments, limited duration (limited redox development) of benthic chamber experiments, lack of redox measurement, limited labile C to drive redox conditions down, and the rapid uptake of a component of released P by bacteria.

Hart et al. 2000 reported that benthic chamber analysis of stream sediment fluxes indicates that monitored P releases do not necessarily increase even when sediments turned anoxic.

The application of sediment diagenesis models, linked to redox conditions, indicates rapid to slow release of P from sediments, depending on the depth of Fe(OH)₃ layers and redox conditions (Harper 2001).

There is extensive published material reporting on instream N release rates from sediments. De-nitrification at low levels of DO and moderate redox level conditions, and an order higher level of N than P.

Analysis of a range of organic materials indicates algae and some grasses have a labile carbon content some 20 times that of eucalyptus derived litter. The analysis also highlighted the slow rate of bio-degradation of a range of native vegetation derived carbon materials, in excess of 100 days in some cases, and the nutrient limitation as a significant factor in determining slow decomposition rate for some materials (Esslemont 2000).

### 30 Could you include a table of the status of development and trialling of each of the indicators, including any validation of sensitivity against known stressors, and including where current State programs are spatially and temporarily adequate?

A table that has the status of development and trialling of indicators is presented in the Final Report.

Validation of macroinvertebrate indices against some environmental stressors is described for the macroinvertebrate indicators in Appendix 3. It is not appropriate to validate the fish, water quality, habitat or hydrology indicators against known stressors as these have not yet been trialled.

The Final Report argues that current programs of the partner governments do not meet all the requirements of the Audit. However, there may be specific examples where appropriate information is collected by the State agencies. This will need to be assessed on a site by site basis. Issues that will need consideration include detailed description of site location, the motivation for choosing that location, the time of the year that those sites are sampled and the exact methods used. This is a matter for the jurisdictions to address in the site selection process.

### 31 Could you include more detail on how the numbers of sites for sampling per indicator was arrived at, for example was it based on empirical studies of natural variation, or other analyses?

See Final Report.
<table>
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| 32 Can you include for each indicator an analysis of how they meet the criteria for indicator selection (as done for macroinvertebrates)? | A number of criteria have been proposed for the selection of indicators for each environmental theme in the Audit:  
  - builds upon existing programs and data as much as possible  
  - consistent with the conceptual models of river function developed for the Functional Process Zones  
  - responsive to disturbance  
  - measurement and analysis are rapid (analysis is built into reporting of the indicator)  
  - standardised methods are available and are technically appropriate for State agencies to undertake  
  - output can be interpreted relatively unambiguously  
  - indicator has meaning to the wider Basin community                                                                                        |
| 33 Could you include comment on acceptable levels of change and is there any technical basis for it? e.g. terms such as impairment need to be carefully defined. | It is not the role of the Audit to comment on acceptable levels of change. Acceptability of change is a decision that needs to be made by the broader community. The role of the Audit is to inform the debate on levels of change. The Audit has chosen to do this as change from a natural condition.  
In the case of the AUSRIVAS O/E indicator, which is scaled between 0 and 1+, each 0.1 change reflects the absence of 10% of the predicted biota at a site. The Audit will determine the level of the indicator (e.g. 0.6). Whether the community accepts a loss of 40% of the predicted macroinvertebrate taxa is for them to decide. |
| 34 How is natural variability allowed for in the power analysis and hence the required sampling numbers? |                                                                                                                                                                                                          |
| 35 How does lack of consistency between the States, in things like site selection, sampling and modelling, affect the framework? | One of the primary motivations for the development of the Audit is the lack of consistency between the States in the way river health is assessed and reported.  
It is for this reason that the Final Report has recommended a new framework which defines the study design including; site selection, methods and models. |
| 36 What are the State by State totals for numbers of sites? | See Final Report.                                                                                                                                                                                         |
| Could you clarify the geographic coverage of the indicators, e.g. Lower Lakes? | The Audit framework was developed to assess the condition of the Basin's rivers. The Framework, as it stands is not appropriate for assessing the ecological condition of the Lower Lakes (e.g. Lake Alexandrina).  
While some of the indices developed for the framework may be readily adapted to assess the condition of the Lower Lakes the indices have not been tested in these environments.  
It is recommended that a separate project be undertaken to develop a framework for assessing condition of the Lower Lakes, if this is an objective of the Audit. |
<table>
<thead>
<tr>
<th>WQ Index</th>
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<tr>
<td>37 Does the approach consider opportunities to rationalise sample sites?</td>
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<tr>
<td>38 Is it the case that this index is comparatively less developed than the Fish index and requires a development plan similar to that proposed for the Fish index?</td>
</tr>
<tr>
<td>39 Can you elaborate on how the index will be calculated, interpreted and then used as a trigger? Are the two separate components given any weighting? Is a 20% change an adequate basis for sample design?</td>
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</table>
|   |   | Details on the individual Index calculation basis for each Indicator have been included in Appendix 5.  
|   |   | The 20% change values is a judgement on my part, guided by ANZECC Water Quality Guidelines 1992 ‘limits to acceptable change’ in relation to potential for impairment of biota. It is intended as the identification of an ‘increment’ of change that is likely to be significant in ecological terms, without any overlay of acceptable or unacceptable bands at this stage. The proposed Pilot Project will be invaluable in further testing and developing this aspect of the approach. |
|   |   | **40** Could you review Victoria’s analysis of power vs practicality (to be provided by Jane Doolan)? |
|   |   | In the case of the upland Process Zone, the dominant process is one of breakdown of organic detritus material by mechanical, leaching and microbial processes. Robertson *et al*. 1999 notes that the input of carbon to streams is the major energy source driving microbial food webs.  
|   |   | In the case of the mid-slope and lowland Process Zones, it is the input of carbon to streams that is the major energy source driving microbial food webs, and driving the remobilisation of nutrients from the sediments to sustain biofilm and algal growth.  
|   |   | The instream fixing of carbon in Australian streams is typically nutrient limited, as a result of soils and native vegetation low in nutrients, and adsorption of nutrients on particulates and their sedimentation (removal from the water column) and burial in the sediments. The larger macro-plants are able to access the sedimanted nutrients through their root systems. They recycle the nutrients via leaf fall and decomposition of stem material.  
|   |   | External inputs of organic material are important drivers of benthic microbial processes, mineralisation of organic material (release of constituent nutrients), and driving down redox conditions such that nutrients in sediments are remobilised.  
|   |   | The composition of organic material provides an indicator of the breakdown and mineralisation of coarse particulate organic material by biofilm, microbial processes, or macroinvertebrate grazing and any divergence to expected conditions.  
|   |   | **41** Could you further describe and include references and justification for the sampling of organic carbon? |
|   |   | The current Audit framework excludes standing water bodies such as weir pools, lakes and reservoirs. The approach could be expanded to include these ‘Functional Process Zones’. A distinctly different set of indicators would be required to reflect the ecological health of these systems. |
|   |   | **43** Having further This is a matter for individual States and Territories. The advances |

Appendix 8  Response to questions  
Final Report for Project R2004
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>developed this indicator, could you now include a review the relevant State WQ programs in Appendix 1?</td>
<td>made in our application of new knowledge to interpretation of data, as represented by the Audit framework, will inevitably influence approaches to river health assessment nationally.</td>
</tr>
<tr>
<td>Will the exclusion of high flow events from sampling adequately cater for unregulated event-based rivers?</td>
<td>In the case of upland (unregulated) streams, the proposed cut-off in flows, beyond which sampling should be excluded, is the 30 percentile duration flow. As explained in the Map of dominant bio-geochemical processes Tables 1A &amp; B, under the event flow conditions, the physical processes of flow and sediment transport, sedimentation and re-suspension dominate, rather than the instream biological processes. As noted in Appendix 5, the focus of the stream health assessment is on the water quality indicators of instream ecological processes (instream responses following a flow event). The Appendix also notes that as the few grab samples are totally inadequate in terms of characterising the event flow conditions, this data is of limited value.</td>
</tr>
<tr>
<td>Should cost of flow gauging be incorporated into this — what level of flow gauging is required?</td>
<td>The initial costing did not include stream gauging. It was assumed that based on the existing gauging network, and the application of hydraulic models, estimates of flows of sufficient accuracy for the purposes of the Audit could be generated without the need for additional gauging stations. Where gauging stations are required, it may be sufficient that staff gauges are installed at sampling sites (officers collecting water quality samples to note level), rather than incurring the high cost of establishing fully automated stations.</td>
</tr>
<tr>
<td>Could you provide greater explanation of where in the water column Organic C is to be sampled.</td>
<td>In the case of the limited depth of the riffle zone based sampling sites for the upland and mid-slope Process Zones, this will not be an issue. In the case of the deeper channel (pool) reaches for the lowland Process Zones, it is proposed that an integrated sampler (tube) be used to integrated variation in indicator values across the depth of the pool.</td>
</tr>
<tr>
<td>Physical Habitat</td>
<td>The table provided by Bruce Chessman has been completed to provide more detailed description of the protocols recommended. It is now located at the end of Appendix 7 (Table 4).</td>
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Physical Habitat

A table provided by NSW (attached) lists information that allows costings in the physical habitat sampling - can you provide a similar breakdown of attributes that would allow more detailed costings?
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>48 Could you review the recommendations to ensure their consistency with the discussion e.g. aerial techniques, what can be picked up from orthophotos and what cannot. ?</td>
<td>We have reviewed the document and endeavoured to make the recommendations consistent. To facilitate this we have also included a summary table of the indices and the technique to be employed (see Table 4 in Appendix 7).</td>
</tr>
<tr>
<td>49 Is it possible to refine or reduce variables to better match existing programs? (The large number of variables mean either high cost or low replication and need prioritising)</td>
<td>This question needs to be answered in two parts. For most of the remotely sensed indices the statement about replication and cost is not applicable or is trivial. Second, the vast majority (31 of 37) of indices are already measured by existing programs and we therefore believe there is a reasonable match between our recommendations and existing programs. Where we recommend a different technique it is because we believe that our recommendation will lead to a dramatic improvement in the quality of the data collected without adding significantly to the cost of the assessment. Finally, it is possible to delete any of the measurements we recommend, from the Audit. We believe that any deletion will, however, result in a loss of information that we have endeavoured to make explicit in the appendix. We strongly recommend that all the proposed indices be assessed during the Pilot. Once the Pilot is complete it would be appropriate to undertake a sensitivity analysis to determine whether some measures could be omitted from the Audit without any loss of information.</td>
</tr>
<tr>
<td>50 How will FPZs inform sample site design for the VPZs? At what scale is the lowest 10% of disturbance interpreted — Basin, valley, VPZ or FPZ and what are the implications of this?</td>
<td>It is unclear to which measurement this question is directed. In general, however, 10m grain size would be too large to adequately assess macrophytes, snags or sediment types.</td>
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<td>51 What is the assumed travel distance for field trips (p.41) and the</td>
<td>We assumed a travel time of 8 hours per site. It was not possible to provide a more accurate estimate until sites are selected and determination of which agency staff will undertake the monitoring</td>
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<td>52 Can you provide more detail on the process models and E-ball technique? How will O/E be generated for each spatial scale? How will E-ball deal with attributes of varying type, scale and statistical distribution, and with variables for which the expected natural value is infinity?</td>
<td>More detail of E-Ball has been incorporated into the Appendix. The O/E is always calculated at the site scale. Aggregation to higher spatial scales can be made using averages as per the invertebrate O/E measure. No variables with an expected natural value of infinity will be used in the habitat index. Varying statistical distributions are accounted for by range and variance standardisation in the calculation of Euclidean distance from the test to the reference sites. The variables used to calculate the expected values are always measured at a higher scale than the variables being predicted.</td>
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<td>53 How do you establish a natural erosion rate using pins, given the stochastic nature of change?</td>
<td>The question encouraged the team to re-examine the proposed protocol. Erosion pin data would be highly variable which we had envisaged would be dealt with by having a large number of replicates. The cost of replication has led the team to change its recommendation such that we now suggest the use of aerial photography to assess channel movement and erosion.</td>
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<td>54 What criteria should be used to define a site? Can you address issues of downstream extent of impact (dams, towns), 'significance' of source discharge, impoundment of site, criteria for alien species, relationship to past or present activities?</td>
<td>Issues of site selection are detailed in the Final Report, “Site Selection”, p. 33. We have changed the Appendix text to make it more explicit. Site selection is governed by the sites selected for other components. Issues of dams, towns, discharges, impoundment, past and present activities are not part of the assessment of condition. We believe that they are stressors or drivers of condition and therefore lie outside the scope of the Audit. At this point, it is proposed that the only criteria to be used to define sites are the Valley Process Zone and Functional Process Zone categories, and the requirement for sites capable of providing a representative (mixed) sample. The framework proposes a random selection of sites from the sites meeting these three criteria, on a valley by valley basis.</td>
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<tr>
<td>55 Can you suggest alternatives to the spatial sample design of 100m transects? Can other techniques such as systematic sampling, two-stage sampling or stratified random sampling been considered?</td>
<td>The imperative for the Audit was to develop a cost effective means of assessing physical habitat. While other sampling designs could be employed we believe that they would involve greater cost, or would be more difficult to apply across all rivers in the Basin.</td>
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<tr>
<td>56 For floodplain habitats, can you comment on: - the scale of the habitat types relative to the size of the transect and the need to increase transect size - the potential for</td>
<td>The scale of the habitats is only marginally related to the size of the transect. We do not believe that increasing the size of the transect above 100 m will have any impact on the results. There is considerable scope for remote sensing, which is why all the metrics recorded from the 100 m transects will be remotely sensed. As stated in the Appendix, it is hoped that in the future there will be integration between physical habitat and hydrology metrics that will allow assessment of wetting and drying regimes in floodplain wetlands. Any on-ground assessment of this would require a</td>
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remote imaging - the attributes to be assessed (for example in billabongs - wetting and drying?) | dramatic increase in sampling frequency which we believe would add significant costs.

| 57 | For riparian vegetation, given the importance of rigour and repeatability in assessing species diversity and richness. have you considered other techniques such as systematic sampling, two-stage sampling or stratified random sampling? | See answer to Q 55 |

| 58 | Should habitat fragmentation be measured on a site scale or over a larger scale using aerial photography? | We recommend that habitat fragmentation be measured using aerial photography. We believe that the floodplain and riparian definitions we use represent an appropriate scale, but believe that the proposed Pilot will give us an opportunity to evaluate whether issues of scale need to be revised. |

| 59 | Should the sampling techniques for riparian demography be refined? | Most of the techniques we recommend should be refined. We believe that the Pilot will provide an opportunity to refine all the indices where appropriate. |

| 60 | For emergent macrophytes, can you explain: • how a measure of grazing pressure might be incorporated • how the extent and abundance of submerged macrophytes might be assessed in turbid conditions • what 'spot sampling' is • what sample units are used, over what length of river. | We have amended the description of the techniques to make our intent clearer. We have not incorporated any measure of grazing pressure as we regard it as a stressor and therefore outside the scope of the Audit. |

| 61 | For snags, have you considered a series of line transects at different elevations? Could snags be measured with a random selection from the first 100 encountered? | For each transect, the height of the snag in the channel is recorded, this can be referenced to base flow or some stage level. By doing this you can build a profile of snag surface area/volume at different river heights. Snags could be measured with a random selection from the first 100, or 1000 sampled, but all that would tell you was the average size of a piece of wood based on a sub-sample of some population. To get the most value, the measurement needs to be referenced to a reach length or bed area. The random sample method would only be useful if all you wanted to say were that the snags in one river are big, longer, heavier, etc., than the snags in
### Appendix 8  Response to questions

Final Report for Project R2004

<table>
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<tr>
<th>Question</th>
<th>Response</th>
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| 62 | For levees, can you include comment on:  
• how the data will guide management  
• how their impacts on connectivity will be quantified  
• how position and alignment will vary their influence on connectivity  
• how a more comprehensive inventory of levees might aid floodplain management.  

The Audit is designed to guide management. We do not believe that each measure should be justified or described in terms of management guidance.  
• We have altered this component to quantify the effects of levees on connectivity, although there will be a one-off cost associated with this determination.  
• The last dot-point is outside the scope of the current project. |
| 63 | Can you include the missing section on transects (p.54)?  

We have included this component. |
| 64 | How feasible is the aerial photography in discriminating between species, between structural variations and for snags, depth and macrophytes?  

The snag and macrophyte techniques have been trialled and the results published in refereed journals. The techniques proposed do not require remote imagery to distinguish among species, merely among species groups, such as willow, acacia and eucalypt. |
| **Hydrology** |  
**65** | Could you include a definition of regulated and unregulated, and is the assumption that unregulated streams are unimpacted valid?  

In order to answer this question one must separate out legal and administrative definitions and those which pertain to the functioning of riverine ecosystems. The Sustainable Rivers Audit is concerned with the development of a framework with which to assess the condition of rivers through out the Murray-Darling Basin. Hence an ecosystem perspective should be used in defining a regulated river. Thus, for the purposes of the Audit a regulated river is *any river or section of river that has a structure (e.g. dam, weir or barrage) on it or is subject to anthropogenic additions or withdrawals of water*. An extra paragraph has been added to the Appendix that provides this definition. |
<p>| <strong>66</strong> | Could you overcome the dampening effect of averaging deviations over the FDC by using current vs natural and return time over time for specific percentile ranges? Given dampening, should the | There is no dampening effect of averaging deviations. The Flow Duration Curve Difference parameter provides a measure of the overall difference between current and natural flow duration curves. In the absence of ‘rigorous scientific’ evidence to the contrary, all flows are considered to be of equal importance to the ecological functioning of the river. Consequently, this approach weights all percentile flows equally. Moreover, given that river channels are governed by the full range of flows it would appear not to be sensible to choose specific flows. |</p>
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<tr>
<td>four indicators be averaged or not?</td>
<td>No — see above</td>
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<td>Given the above, is weighting an option?</td>
<td>No. The Mean Annual Flow parameter is designed to indicate the total volume of water extracted from or added to the river. Use of medians would not encapsulate this information. Differences in the monthly flows are represented by the Flow Duration Curve parameter.</td>
</tr>
<tr>
<td>Will the use of means rather than medians and annual rather than monthly/daily bias the extent of departure from natural?</td>
<td>No. The Mean Annual Flow parameter is designed to indicate the total volume of water extracted from or added to the river. Use of medians would not encapsulate this information. Differences in the monthly flows are represented by the Flow Duration Curve parameter.</td>
</tr>
<tr>
<td>Will the use of monthly flows (for the year rather than a period) limit the seasonal amplitude index and also lead to high flow biasing?</td>
<td>No</td>
</tr>
<tr>
<td>68 Could you include comment on:</td>
<td>• THE USE OF FREQUENCY INDICATORS FOR SPECIAL EVENTS (RETURN FREQUENCY)</td>
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<td>The aim of Sustainable Rivers Audit (Audit) is to provide on-going assessment of river health in the Murray-Darling Basin and as such it has assembled a group of hydrological indicators suitable to apply to all the rivers in the Basin. Each river will have a set of frequency indicators that is relevant to its structure and function. For example, many use the Frequency of an event with a recurrence interval of 2.33 years (annual series) and assume this to be the frequency of bankfull events. This has proven to be unsuitable for many rivers in the Basin (see Woodyer 1968). Therefore, the physical, chemical and biological character of a river is a reflection of all flows not just specific flows of certain frequencies (Pickup and Reiger 1979). The hydrological parameters used in the Audit are measures of the entire flow regime of the river.</td>
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<td>• RELATING FLOW TO OTHER INDICES</td>
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<td>The Audit has developed a series of hydrological indices that measure the health of biological processes and complementary indices that measure the condition of the physical and chemical processes that may impact on the biota within a river. In doing this we recognise that it is difficult to deconvolve the effects of individual physical and chemical processes on biota. It is therefore not possible to state, for example, that a 50% reduction in flow will result in a 50% reduction in macroinvertebrates. Instead, physical and chemical indices should be used in conjunction with the biological indices to indicate either possible reasons for biological impairment or the potential for future biological impairment.</td>
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<td>• SENSITIVITY TO CHANGE, COMPARED TO THE COMPONENT INDICES</td>
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<td>Analysis of sensitivity requires additional model runs for both existing and natural flows. While it is possible to perform sensitivity analysis, the data requirements are substantial and the State agencies have not been in a position to supply the data for this.</td>
</tr>
</tbody>
</table>
• **SENSITIVITY TO “ANTICIPATED” ENVIRONMENTAL FLOW RELEASES**
  Require modelling runs do this — none provided — see above comment

• **ACCURACY OF THE IQQM MODEL**
The hydrology index has been designed to make use of modelled data from the State agencies. IQQM is the standard hydrologic model used by NSW DLWC and QLD DNRM and the use of IQQM as a water resource management tool has been documented in the literature (see Black et al. 1997) It is not within the scope of the Audit to comment further.

• **THE TIME SCALES THAT THE INDICATORS REFLECT**
The Sustainable Rivers Audit was required to report the condition of rivers in Basin at a reach scale. Relationships between spatial and temporal scales are well documented in the literature (Frissell 1986, Schumm 1988, Thoms 2001) hence setting of a reach as the reporting scale sets the temporal scale in which one must view the hydrology of a river in terms of auditing. The parameters used fit within the scale set for the Audit.

69 Comment on the question “Having calculated Hydrology Index in year 1, is it necessary to ever do it again, unless this is triggered by a major change in operation rules?”

It is recommended that calculation of the hydrology index will take place if there is a change in operation rules and/or with the improvement or refinement of the various hydrological models that are in use within the Basin.

**Macroinvertebrates**

70 Are you aware that the lowland Murray valley is rated by AUSRIVAS as good by the NLWRA theme 7 assessment and should you include comment on that discrepancy with other literature, on other habitat types that may need to be monitored and on the sensitivity of AUSRIVAS and SIGNAL scores in stressed conditions.

It is unclear which literature is being referred to here and what the discrepancy is. It may be related to the definition of 'good' or an assumption of poor valley condition that has not been thoroughly tested. It is also possible that AUSRIVAS scores may be conservative for the river valley and could overestimate condition in some cases. However, it is proposed that scores should be adjusted based on agreed departure of reference condition from pristine (see Appendix 3, section A3.6).

71 Does the sensitivity of Regional models need to be addressed? - 3 in Vic but 1 in NSW and 1 in

Regardless of the model, the final outputs (including O/E values) should be comparable. However, it is proposed that this assumption should be tested using Victorian data, for which a large number of models are available.
| 72 | Can you include costings for identifying to species level? | The initial costing was provided in the scoping document at $208,000. |
| 73 | Is one 10 m dab net sweep adequate? | This issue has been researched extensively and it has been found that one 10 m sweep is adequate to represent the health of a site (see Appendix 3, section A3.2). |
| 74 | Will the main channel, edge habitats and wetlands be treated as discrete habitats? | Yes, these are all discrete habitats, representative of the river valley. Habitats will be sampled separately to provide an overall measure of health for a valley. |
| 75 | What happens in SA where there are no riffles in the Murray? | The main habitat in each case should be sampled. In the case of the Murray in SA another habitat such as main channel, edge or macrophytes should be sampled. The final O/E score for the valley should be representative, regardless of which habitat has been sampled. |

**Fish**

| 76 | Would historical literature and expert opinion be the best way to establish reference condition for this indicator? | Not the best way (there is no best way), but it will be used as one of two reference approaches, in combination. It is recognised that it will be biased (toward ‘big’ fish and specific valleys/reaches) and patchy, but will be critically reviewed prior to use. |
| 77 | Can you include further detail on selection of sites to allow calculation of costs. | Not without a preliminary round of data collection followed by gear comparison, and power analysis. |
| 78 | Can South Australia be included in the Pilot, and explain how habitats other than the main channel will be included? | Yes, but this will require the agency to change approach. Currently only commercial fishery data are collected. A survey can target stratified selection of off-channel habitats. |
| 79 | Can the pilot fish index development be rescheduled to fit with the pilot Audit? | Yes, they should be one and the same. |
| 80 | Can fyke nets be set at dawn and dusk, not left out overnight. | Possibly; we need agency input on this prior to Pilot. |
References


