Development of a Framework for the Sustainable Rivers Audit

A Report to the Murray Darling Basin Commission

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COOPERATIVE RESEARCH CENTRE FOR FRESHWATER ECOLOGY

Cooperative Research Centre for Freshwater Ecology

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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 (NO_x, NH_4, 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

(1 m). 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

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 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 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.

[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

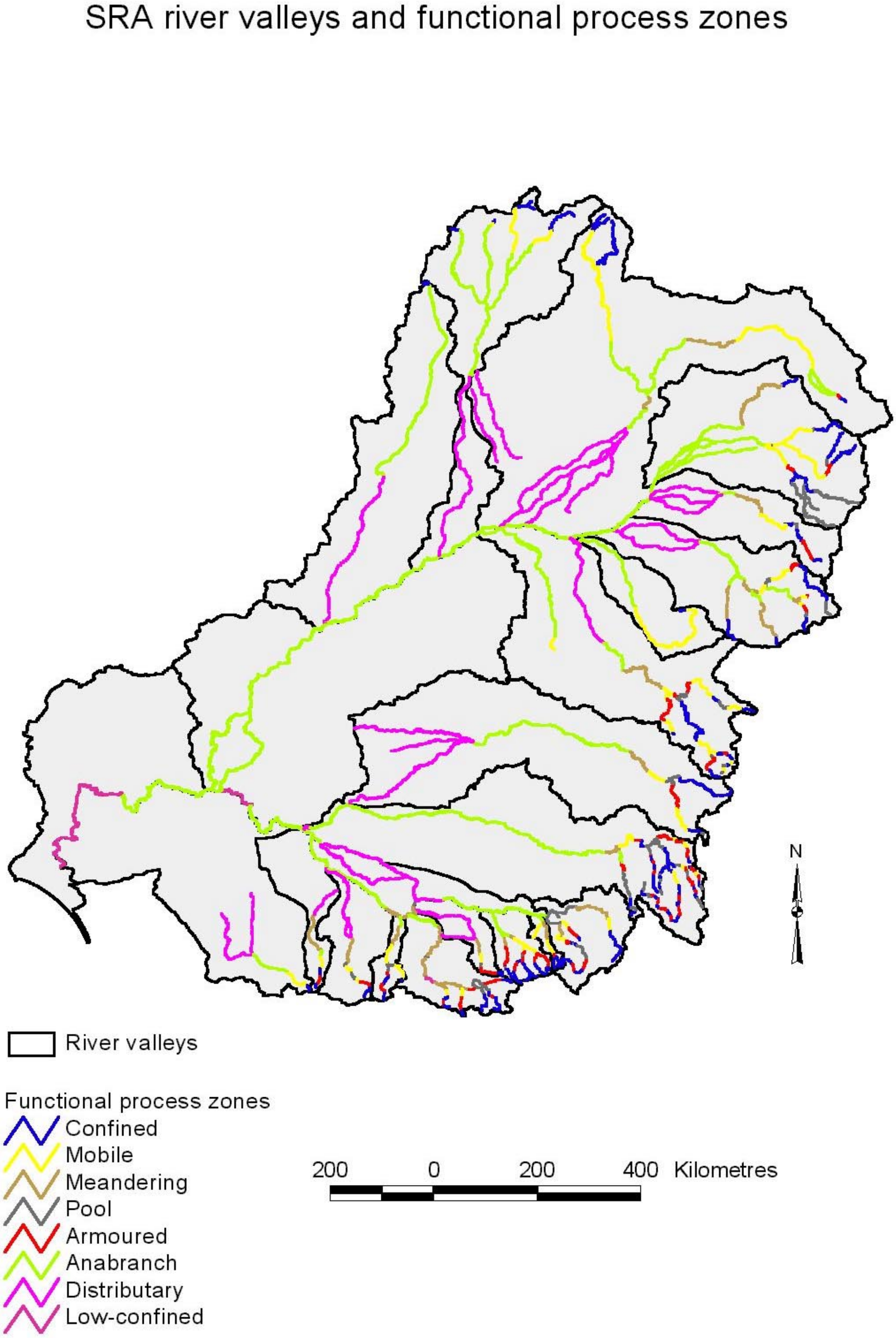

SRA river valleys and functional process zones
N
River valleys
Functional process zones
Confined
Mobile
Meandering
Pool
Armoured
Anabranch
Distributary
Low-confined
200 0 200 400 Kilometres

Figure 2

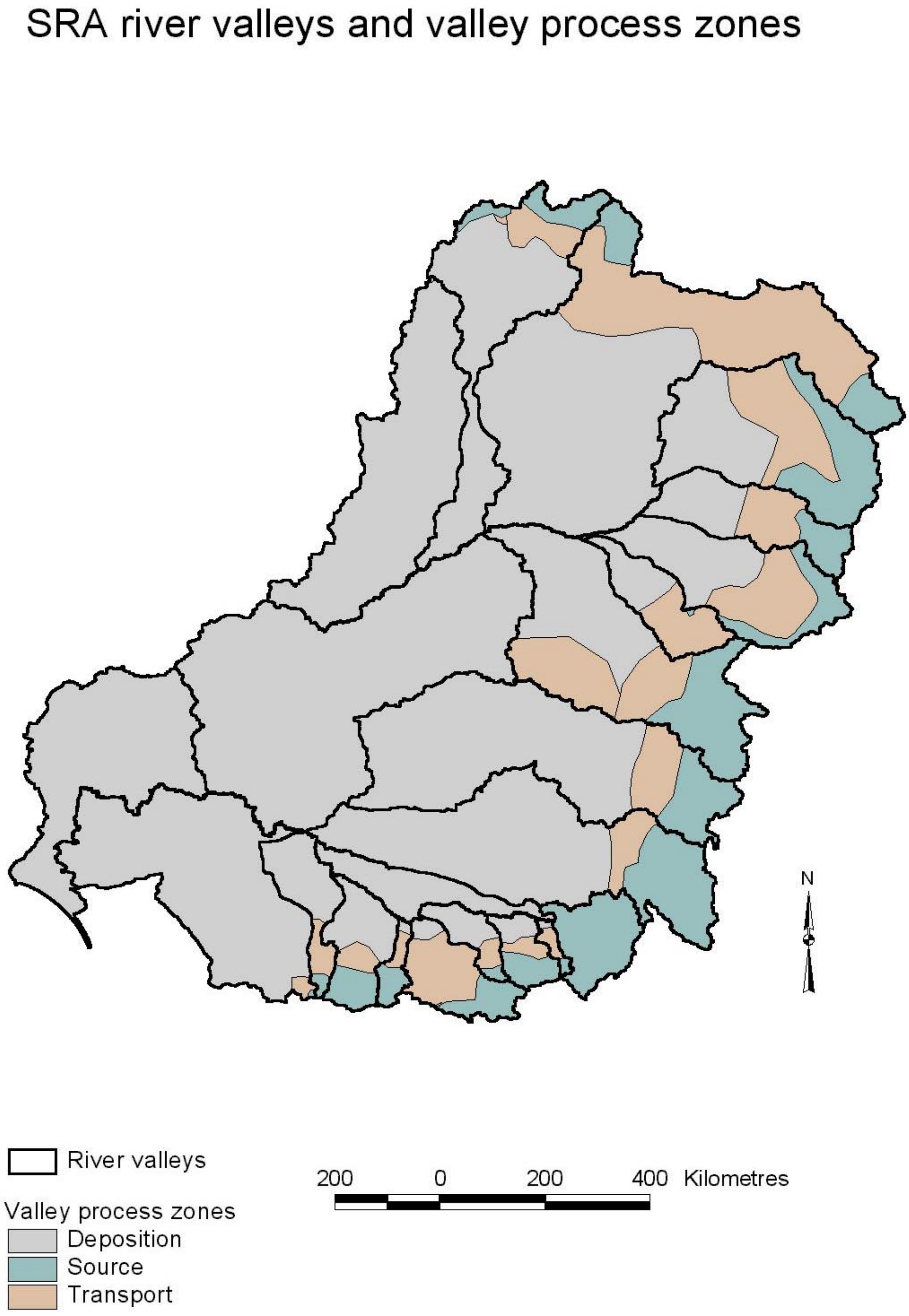

SRA river valleys and valley process zones
N
River valleys
Valley process zones
Deposition
Source
Transport
200
0
200
400
Kilometres

Figure 3

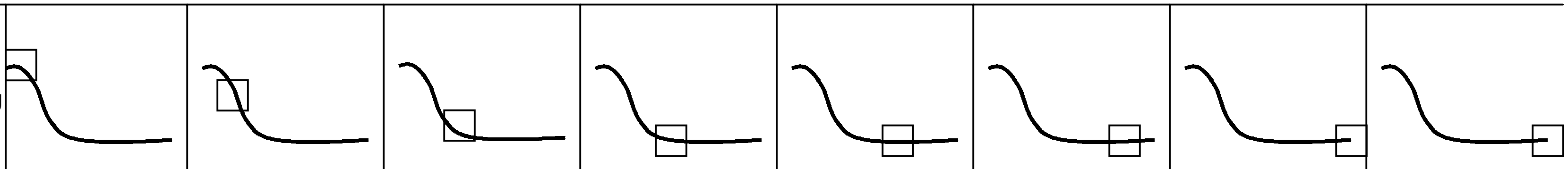
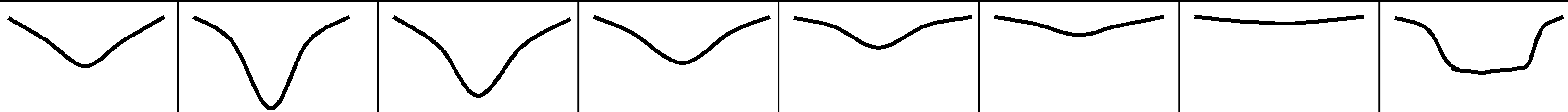
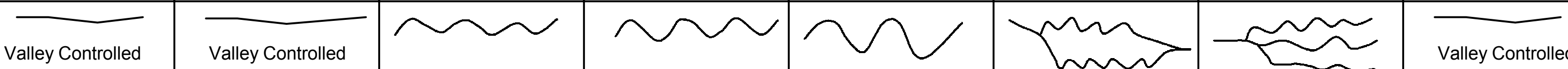
Geomorphological Units	Upland zones (sediment supply)			Mid-slope zones (sediment transfer)		Lowland zones (sediment deposition/storage)		
	Pool	**Upland Gorge**	**Armoured**	**Mobile**	**Meander**	**Anabranch**	**Distributary**	**Lowland gorge**
Valley gradient/ Long profile								
Valley profile								
Floodplain features	No floodplain	No floodplain	Minimal floodplain development. Some high level terraces.	Point and lateral bars, terraces, incised benches, former channels, avulsions, floodrunners	Point and lateral bars, terraces, incised and inset benches, former channels, avulsions, floodrunners	Low level floodrunners, anabranch channels, extensive floodplain	Distributary channels	Floodplain independent of main channel
Planform	 Valley Controlled Sinuosity = < 1.2	Valley Controlled Sinuosity = < 1.2	Sinuosity = 1.4	Sinuosity = 1.4 - 1.6	Sinuosity = 1.6 - 1.8	Sinuosity = > 1.8	Sinuosity = > 1.8	Valley Controlled Sinuosity = < 1.2?
Stream power	Low	Very high	High	Moderate	Moderate-Low	Low	Low	Moderate?
Dominant sediments	Bedrock, boulder	Bedrock, boulder, cobble	Cobble and gravel surface layer protecting poorly sorted finer sub-sediments	Bimodal distribution of gravel/pebble and finer particles	Sand	Sand, silt, clay	Silt and clay	?
Function (sediments, nutrients, organics)	Relatively immobile source area	Highly mobile source area	Mobile source area	Mobile transfer area	Highly mobile transfer area. Some deposition of finer particles	Deposition	Deposition distributary	Deposition
Key aquatic habitats	Pool, riffle chutes	Riffle and pool substratum	Riffle and pool substratum, high flow floodrunners, riparian vegetation, snags	Riffle and pool substratum, point and lateral bars, incised benches, floodrunners, woody debris (snags), macrophytes	Pool substratum, point and lateral bars, former channels, avulsions, incised and inset benches, woody debris (snags), macrophytes	Pools, anabranch channels, billabongs, woody debris, macrophtyes	Pool substratum, billabongs, woody debris (snags), macrophytes	Pools,wetlands adjacent to channel, macrophytes
Major components of carbon supply	Allochthonous inputs dominant: CPOM and FPOM, minor primary production: microalgae (diatoms), some submerged and emergent macrophytes	Allochthonous inputs dominant: CPOM and FPOM, minor primary production: microalgae	Allochthonous inputs dominant: CPOM, FPOM and logs, minor primary production: periphyton	Allochthonous inputs: CPOM, FPOM and logs equal primary production: emergent vegetation in pools, periphyton	Allochthonous inputs: CPOM, FPOM and logs equal primary production: submerged and emergent vegetation in pools	Primary production dominant: filamentous algae and phytoplankton, minor inputs of CPOM, FPOM and logs	Primary production dominant: filamentous algae and phytoplankton, minor inputs of CPOM, FPOM and logs	Primary production dominant: phytoplankton, minor inputs of CPOM, FPOM and logs
High flow	Pool depth increases, flushing flows, valley restricts lateral connection	Riparian vegetation inundated, scouring and flushing flows	Small floodrunners inundated increasing habitat, flushing and scouring flows	Floodrunners, inchannel benches and terrestrial environment inundated increasing habitat and food resources	Floodrunners, inchannel benches and anabranches inundated increasing habitat and food resources	Floodrunners, inchannel benches and anabranches inundated increasing habitat and food resources	Floodrunners, inchannel benches, anabranches and bifurcating channels inundated	Pool depth increases, valley restricts lateral connection
Low flow	Pool depth decreases, no major habitat loss	Habitat area decreases	Habitat area decreases	Riffles and deep pools, sandy point bars, emergent vegetation	No riffles, large pools, sandy point bars, emergent vegetation	Riffles, large pools, sandy point bars, habitat reduced to main channel	Deep pools and riffles,some point bars, habitat reduced to main channel	Water salinity increases from groundwater interception

Table 1. Criteria for mapping Valley Process Zones

Valley Process Zone	Functional Process Zones	Characteristic
Source zone	Pool, Upland gorge, Armoured	Sediment source *upland*
Transport zone	Mobile, Meander	Sediment transport *mid-slope*
Deposition zone	Anabranch, Distributary Lowland gorge	Sediment deposition *lowland*

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

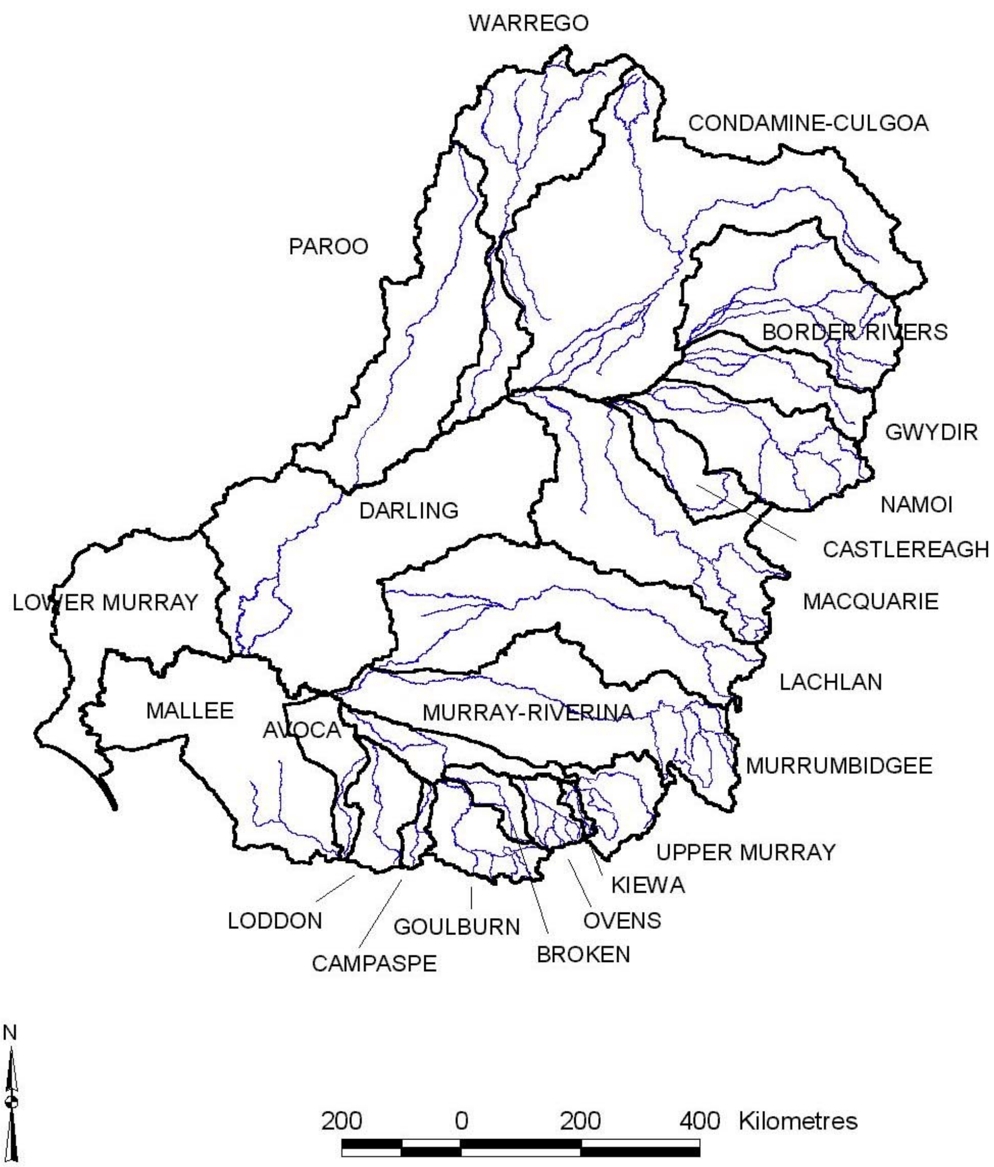


Table 2. River valleys and catchment areas identified for the Audit

River Valley	Area (km^2)
Avoca	21538
Border Rivers	81040
Broken	10935
Campaspe	6319
Castlereagh	23817
Condamine-Culgoa	207808
Darling	188233
Goulburn	26393
Gwydir	35355
Kiewa	2956
Lachlan	130868
Loddon	24216
Lower Murray	84098
Macquarie	103956
Mallee	108375
Murray-Riverina	22742
Murrumbidgee	121742
Namoi	56977
Ovens	12372
Paroo	97144
Upper Murray	23653
Warrego	79256

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).

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

*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.

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

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).

Table 5. Summary of observed variability and sample size requirements for measuring the AUSRIVAS OE50 Index during the FNARH. Shaded regions are the best available estimates of sample size requirements using the trial data and the traditional values of α = 0.05 and Power = 0.80. For example, 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.

				a = 0.10, b= 0.80			a = 0.10, b= 0.90			a = 0.05, b= 0.90			a = 0.05, b= 0.80		
				Size of diference to detect											
Reporting Scale	**Spatial Sampling Scale**	**Mean OE50**	**Standard Deviation**	**0.15**	**0.1**	**0.05**	**0.15**	**0.1**	**0.05**	**0.15**	**0.1**	**0.05**	**0.15**	**0.1**	**0.05**
River Valley	Ovens River Valley	0.933	0.166	11	19	68	12	22	76	12	23	83	11	21	75
	Murrumbidgee River Valley	0.779	0.196	13	26	93	15	29	105	16	31	114	15	28	103
	Condamine River Valley	0.785	0.194	13	25	91	14	28	102	16	31	112	14	28	101
VPZ	Ovens source	0.985	0.146	7	14	51	8	15	57	8	17	63	8	15	57
	Ovens transportational	1.015	0.105	4	8	27	5	9	31	5	10	34	5	9	30
	Ovens depositional	0.820	0.164	8	17	65	9	19	73	10	21	80	9	19	72
	Murrumbidgee source	0.716	0.218	14	29	112	15	33	126	17	36	138	15	32	125
	Murrumbidgee transportational	0.806	0.090	4	6	20	4	7	23	4	8	25	4	7	23
	Murrumbidgee depositional	0.797	0.198	12	24	93	13	27	105	14	30	115	13	27	103
	Condamine source	0.780	0.197	11	24	92	13	27	104	14	30	113	13	27	102
	Condamine transportational	0.779	0.210	13	27	104	14	30	117	16	33	128	14	30	116
	Condamine depositional	0.793	0.186	10	21	82	12	24	92	13	26	101	11	24	91
VPZ & River Valley	Ovens			21	41	145	24	45	163	25	50	179	24	45	161
	Murrumbidgee			32	61	227	34	69	256	37	76	280	34	68	253
	Condamine			36	74	280	41	83	315	45	91	344	40	83	311
FPZ	Mallee anabranch	0.94071	0.13252	6	12	42	7	13	48	7	14	52	7	13	47
	Murrumbidgee anabranch	0.77368	0.20563	12	26	100	14	29	113	15	32	124	14	29	111
	Ovens anabranch	0.79533	0.13494	6	12	44	7	13	49	7	15	54	7	13	49
	Goulburn armoured	1.116	0.10019	4	7	25	5	8	28	5	9	31	5	8	28
	Macquarie armoured	0.71479	0.26201	19	41	162	22	47	182	24	51	200	21	46	180
	Murrumbidgee armoured	0.81036	0.16141	8	17	62	9	19	70	10	20	77	9	18	69
	Ovens armoured	1.00094	0.13551	6	12	44	7	14	50	8	15	55	7	13	49
	Murrumbidgee confined	0.78783	0.17826	10	20	76	11	22	85	12	25	93	11	22	84
	Mallee distributary	0.87806	0.14957	7	14	54	8	16	60	9	18	66	8	16	60
	Mallee lowconfined	0.79816	0.30362	25	55	217	28	62	244	31	68	267	28	61	241
	Goulburn meandering	0.76458	0.18353	10	21	80	11	24	90	12	26	99	11	23	89
	Upper Murray meandering	0.86744	0.13777	6	12	46	7	14	51	8	15	56	7	14	51
	Lachlan mobile	0.9245	0.16894	9	18	68	10	20	77	11	22	84	10	20	76
	Macquarie mobile	0.7587	0.1201	5	10	35	6	11	39	6	12	43	6	11	39
	Murrumbidgee mobile	0.73933	0.1886	11	22	85	12	25	95	13	27	104	12	25	94
	Upper Murray mobile	0.88345	0.18313	10	21	80	11	24	90	12	26	98	11	23	88
	Border Rivers pool	0.86373	0.14509	7	14	51	8	15	57	8	17	62	8	15	56
	Murrumbidgee pool	0.8027	0.2003	12	25	95	13	28	107	14	31	117	13	28	106
FPZ & River Valley	Compositional			77	151	553	87	168	619	93	185	677	87	167	613

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.

River Valley	Deposition VPZ (area in km^2)	Source VPZ (area in km^2)	Transport VPZ (area in km^2)
Avoca	16300	1226	4012
Border Rivers	31788	25656	23596
Broken	7456	1114	2364
Campaspe	602	3831	1886
Castlereagh	10414	159	13244
Condamine-Culgoa	122641	14347	70820
Darling	188233		
Goulburn	2185	7984	16224
Gwydir	15785	7919	11651
Kiewa	469	712	1774
Lachlan	102762	15663	12442
Loddon	13955	6812	3449
Lower Murray	84098		
Macquarie	43615	27682	32658
Mallee	106777	188	1410
Murray-Riverina	22742		
Murrumbidgee	87363	26446	7934
Namoi	26226	11194	19557
Ovens	3951	5855	2567
Paroo	97063	81	
Upper Murray		23653	
Warrego	62961	8823	7472

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[2] provides a suitable

[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 km^2);
2 a link is that section of stream between tributaries (i.e. where each tributary link joins the stream a new l ink 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 25th and 75th 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

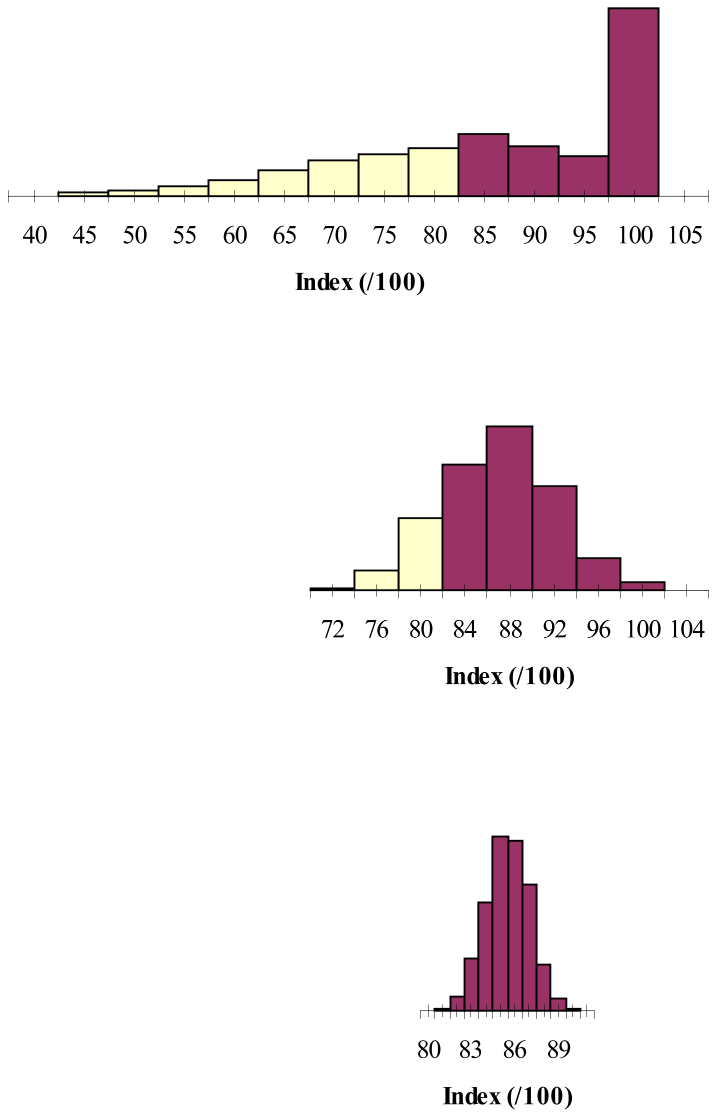


Figure 5. Three possible distributions for indices having the same mean (85/100). Note that the top graph has 34% of sites below 0.8 (which for this example may be considered as impaired), and the second graph has 18% of sites below 0.8, while the third has none. In the top figure the distribution is 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 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

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

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.

	Theme Score					Biological Score		Overall Score		
Site	Fish	Inverts	WQ	Hydro	Habitat	Mean	Worst			Number of impaired themes
Valley A Site 1	0.93	0.96	0.92	0.87	0.95	0.945	0.93			0
Valley A Site 2	0.75	0.79	0.87	0.81	0.54	0.77	0.75			3
Valley A Site 3	0.71	0.965	0.89	0.75	0.82	0.8375	0.71			2
Valley A Site 4	0.81	0.71	0.9	0.84	0.93	0.76	0.71			1
etc.										
etc.										
Valley A Site n	0.84	0.94	0.89	0.74	0.88	0.89	0.84			1
Valley A Score [Median]	0.81	0.94	0.89	0.81	0.88					
[1st Quartile]	0.74	0.77	0.885	0.7475	0.75					
[3rd Quartile]	0.8175	0.94625	0.8925	0.8175	0.8925	Proportion of sites impaired on at least one theme				
						1 theme	2 themes	3 themes	4 themes	5 themes
Proportion impaired sites on individual themes	0.16	0.18	0.075	0.33	0.21	0.56	0.21	0.08	0.03	0

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.

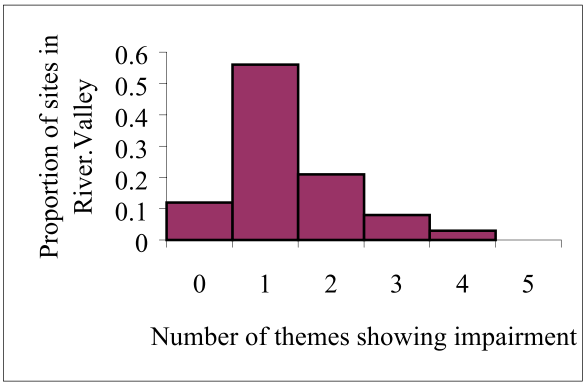


Figure 6. Summary of river health based on the proportion of river with impaired ecological themes using data from Table 8.

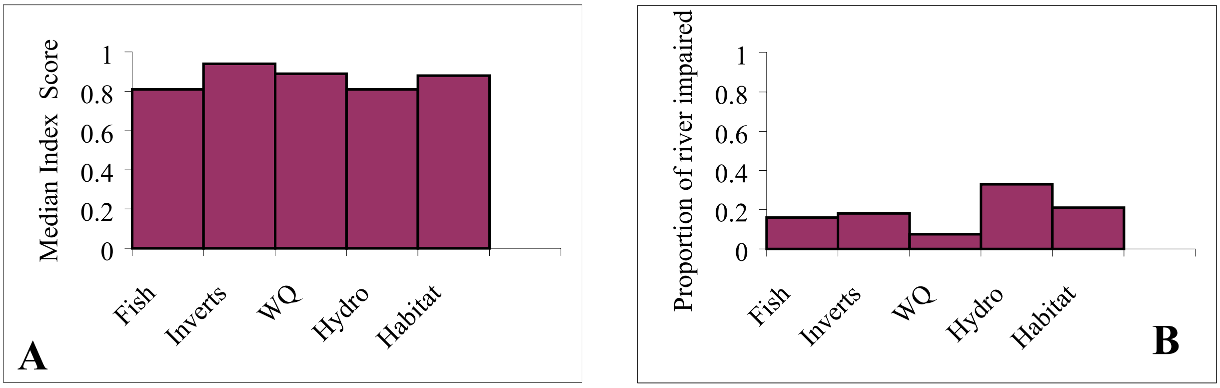


Figure 7. Summary of river health expressed as (a) Median Index Score and (b) proportion of river impaired for each environmental theme using data from Table 8.

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 (α) 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.

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

* 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.

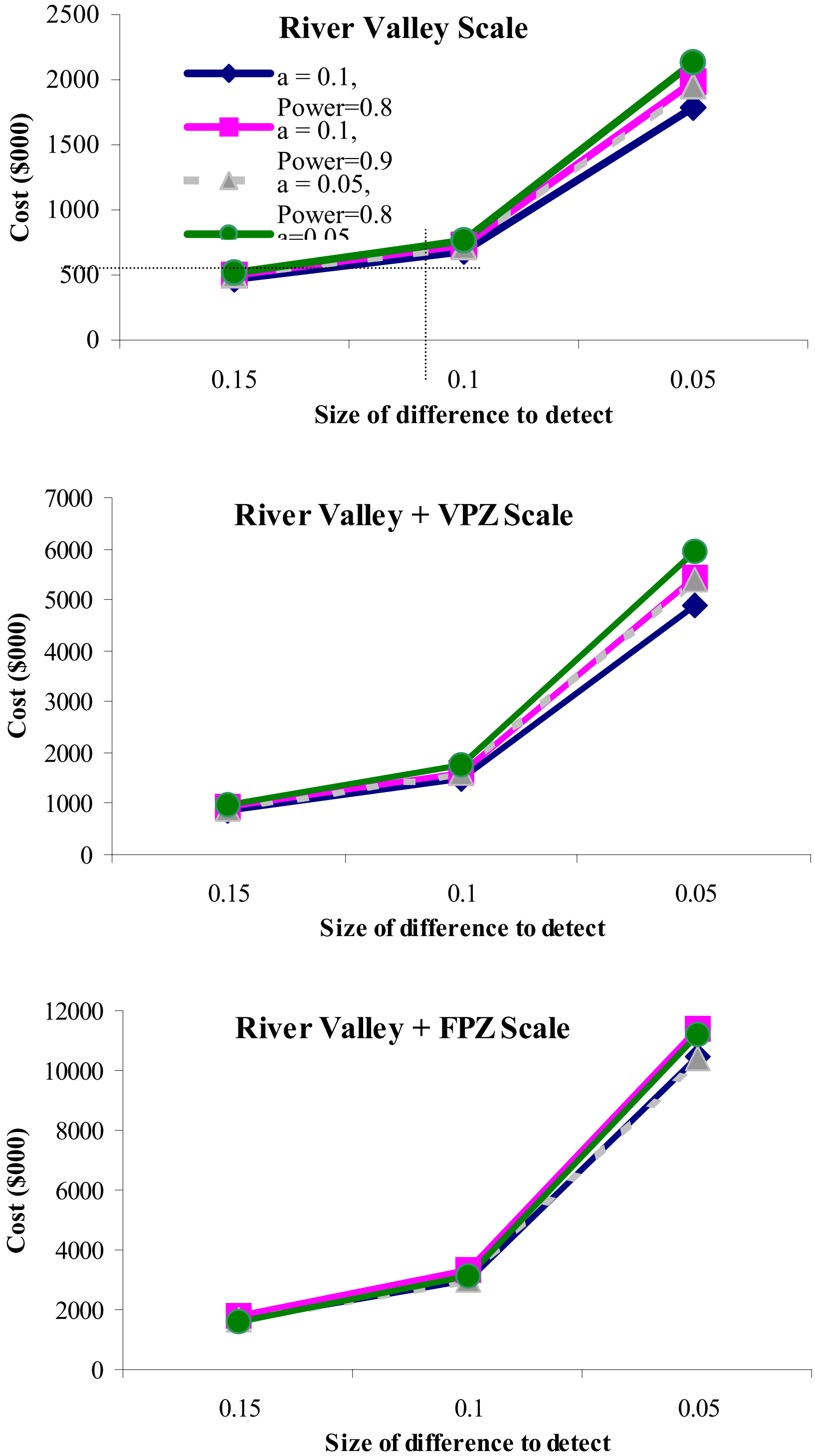


Figure 8. Trade-off between Total Basin Cost and Scale of reporting for the macroinvertebrate theme for the Audit. Note that the vertical axes are different for each figure. Dotted lines indicate recommended cost for first round sampling.

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

Valley	Reaches	Hydrology Index
Ovens		
valley	33	0.96
Source	15	0.95
Transport	11	0.97
Deposition	7	0.97
Murrumbidgee		
valley	399	0.52
Source	106	0.53
Transport	26	0.58
Deposition	267	0.51
Condamine-Balonne		
valley	610	0.81
Source	56	0.93
Transport	299	0.88
Deposition	255	0.71

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.

	Ovens	River Valley Murrumbidgee	Condamine-Balonne
Number of sites	42	60	56
Median Index Value	0.98	0.8	0.82
Number of Impaired sites	11	30	26
Proportion of Impaired sites	0.26	0.50	0.46
Number of severely Impaired sites	0	5	6

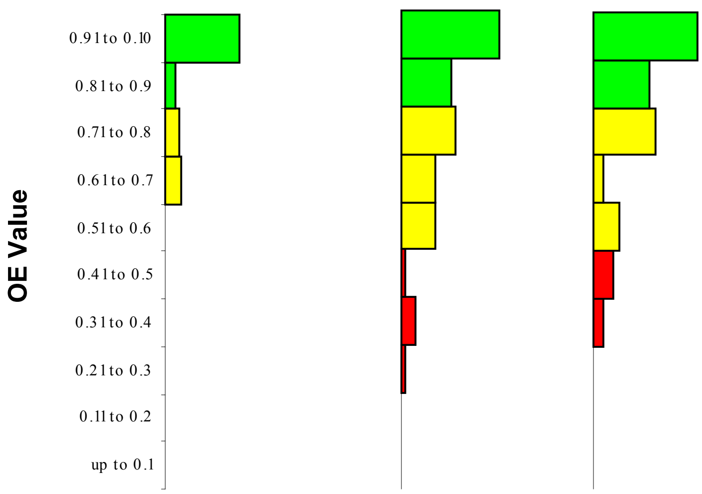


Figure 9. Relative frequency histograms for the Macroinvertebrate Indicator of river health, representing the number of sites in each impairment class. Green indicates good condition, yellow indicates moderate condition and red indicates severely impaired.

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.

River Valley		Ovens			Murrumbidgee			Condamine Balonne	
Valley Process Zone	Source	Transport	Deposition	Source	Transport	Deposition	Source	Transport	Deposition
Number of sites	17	10	18	14	6	40	13	21	22
Median Index value	1.05	1.04	0.83	0.74	0.78	0.81	0.77	0.81	0.84
Number of Impaired sites	3	1	7	9	3	18	7	10	9
Proportion of Impaired sites	0.18	0.10	0.39	0.64	0.50	0.45	0.54	0.48	0.41
Number of severely Impaired sites	0	0	0	2	0	3	1	2	3

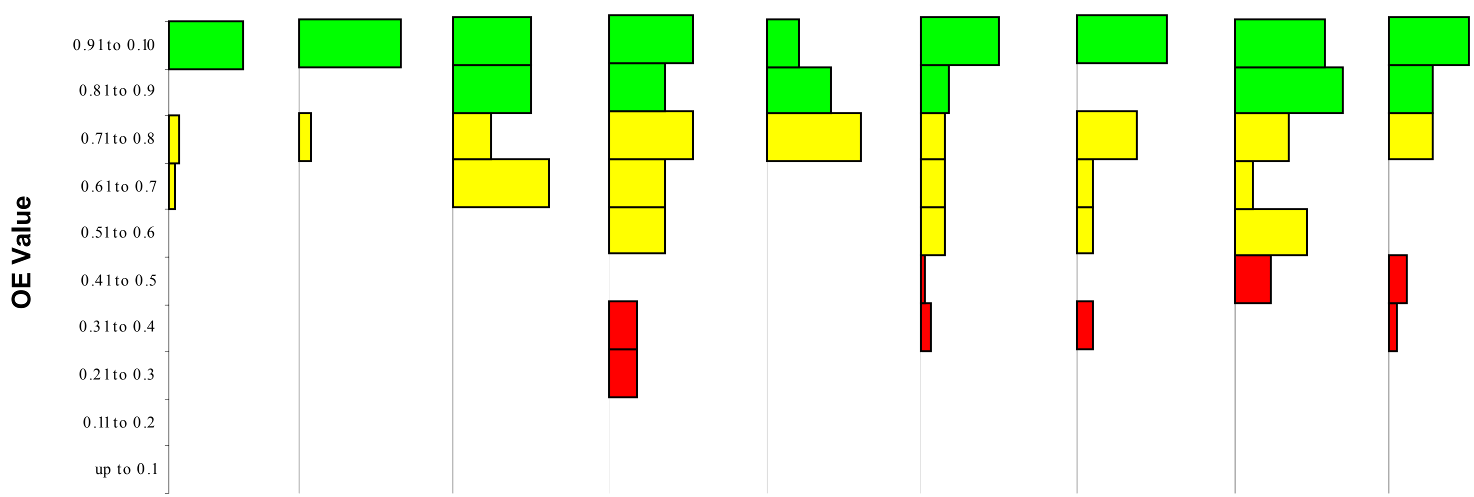


Figure 10. Relative frequency histograms for the Macroinvertebrate Indicator of river health, representing the number of sites in each impairment class. Green indicates good condition, yellow indicates moderate condition and red indicates severely impaired.

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

Term	Description
Aggregation	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.
Assessment tool	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.
Audit (see also SRA)	Sustainable Rivers Audit
AUSRIVAS	Australian River Assessment Scheme which is a tool for undertaking macroinvertebrate-based assessment of river condition
AWRC	Australian Water Resources Commission
CRCFE	Cooperative Research Centre for Freshwater Ecology
CSA	Comprehensive Sustainability Assessment proposed to be undertaken five-yearly
DOM	Dissolved organic matter
DRP	Dissolved reactive phosphorus
EC	Electrical conductivity — a measure of salinity
Environmental Index	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'.
Environmental Theme	Environmental themes are the broad process or structure elements of the environment for which an index is being developed.
FNARH	First National Assessment of River Health
FPOM	Fine particulate organic matter
FPZ	Functional Process Zone — lengths of river with similar discharge and sediment regimes
IAG	Independent Audit Group of the Murray-Darling Basin Ministerial Council
IBI	Index of Biotic Integrity — an international assessment method developed for NSW using fish
IMEF	Integrated Monitoring of Environmental Flows — a NSW-designed assessment for determining effectiveness of environmental flows in regulated rivers

Indicator	An indicator indicates the state or condition of an environmental parameter; for example, O/E, Signal, [N], DO, etc.
Integration	Integration denotes combining measures of different indicators at a given scale to generate an index, e.g. various measures of water quality.
ISC	Index of Stream Condition — used in river health assessment in Victoria to assess river management priorities
ISRAG	Independent Sustainable Rivers Audit Group
MDBC	Murray-Darling Basin Commission
MDBMC	Murray-Darling Basin Ministerial Council
NL&WRA	National Land and Water Audit, which has a waterway condition component
NRHP	National River Health Program
O/E score	Output of AUSRIVAS — the ratio of observed to expected macroinvertebrate taxa
PBH	Pressure–Biota–Habitat — a NSW-designed assessment for unregulated streams
River Health Index	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.
SRA (see also Audit)	Sustainable Rivers Audit proposed to be undertaken annually
SS	Suspended solids
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
VPZ	Valley Process Zone

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

Workshop	Participants
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)

Fish Index Workshop 11-12 April 2001	Peter Davies, Freshwater Systems, Tas David Moffatt, NRM QLD Peter Gherke, Fisheries NSW Ivor Growns, Fisheries NSW Tarmo Raadik, NRE VIC Mark Lintermans, Environment ACT Mark Kennard, CRCFE Paul Humphries, CRCFE Bruce Chessman, DLWC NSW John Harris, CRCFE Richard Norris, CRCFE Alison King, CRCFE Claire Petekin, DPI QLD Sean Sloan, SA Leon Barmuta, UTAS Brian Lawrence, MDBC Jim Barrett, MDBC John Whittington, CRCFE Julie Coysh, CRCFE
Water Quality Index Virtual Workshop	Ian Lawrence, CRCFE Klaus Koop, EPA NSW H. Daly, DLWC NSW Paul Wilson, NRE VIC Peter Goonan, DEH SA Neil Rovert, Environment ACT Jenny Edwards, DNR QLD Jean Chesson, EA Barry Hart, CRCFE Bill Maher, CRCFE
Hydrology Virtual Workshop	Tom Vanderbyl, NMR QLD Darren Barma, DLWC NSW Penny Knights, DLWC NSW Greg Keen, Environment ACT J. Barratt, DEH SA A. Herbert, DEH SA Paul Wilson, NRE VIC Brian Wilkinson, Environment ACT Dan Diaconu, Environment ACT Fiona Dyer, CRCFE Brian Lawrence, MDBC David Cresswell, SA Martin Thoms, CRCFE

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