Final Report
Project R2004
Development of a Framework for the Sustainable Rivers Audit

Appendix 6
Hydrology

Review and Development of Hydrological Indicators

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Preamble

The aim of the Sustainable Rivers Audit (Audit) is to provide on-going assessment of river health in the Murray-Darling Basin. However, river health has never been systematically assessed across the Basin. This means that it is not possible to conduct informed discussion on river health and the factors affecting it, or to determine the effectiveness of current river management initiatives. To address this deficiency, a framework is being established in order to conduct an effective Basin wide assessment of river health (see *Scope of the Sustainable Rivers Audit*, June 2000).

The index of river health being derived for the Murray-Darling Basin integrates indices for five environmental themes (fish, hydrology, macroinvertebrates, physical habitat and water quality) and reports condition at a river-valley scale. This report outlines the development of a hydrological index for incorporation within the broader River Health Index.

Introduction

Flow is the *maestro* that orchestrates pattern and process in river systems (Walker *et al.* 1995). The literature is replete with examples suggesting that flow is one of the most important elements in determining the physical, chemical and biological processes occurring within any river system. A river’s flow regime shapes the river channel and determines the nature and distribution of riverine sediments. These features, in association with flow and water chemistry, control the distribution, physiology and abundance of organisms, as well as the dynamics of riverine communities.

Australian rivers like those of the Murray-Darling system have some of the most variable flow regimes in the world (Finlayson and McMahon 1988). From a human perspective, they are unreliable water resources and have required extensive flow modification. Large floods that breach the river banks and cover vast tracts of land are a feature of the rivers of the Murray-Darling Basin, as are periodic droughts. These events can result in large costs to rural communities. However, the animals and plants inhabiting these systems are well adapted to the variability. In fact the ecological integrity of these rivers, particularly in the lowland areas, depends upon periodic lateral movements of water onto the floodplain as well as substantial drying out periods.

A number of key aspects of flow have been identified as having particular ecological significance. Their ecological importance can be assigned to one of four operational time scales: *flow regime*, *flow history*, *flow pulse* and *flow hydraulics*. The detail and relevance of each is provided below and shown schematically in Figure 1.

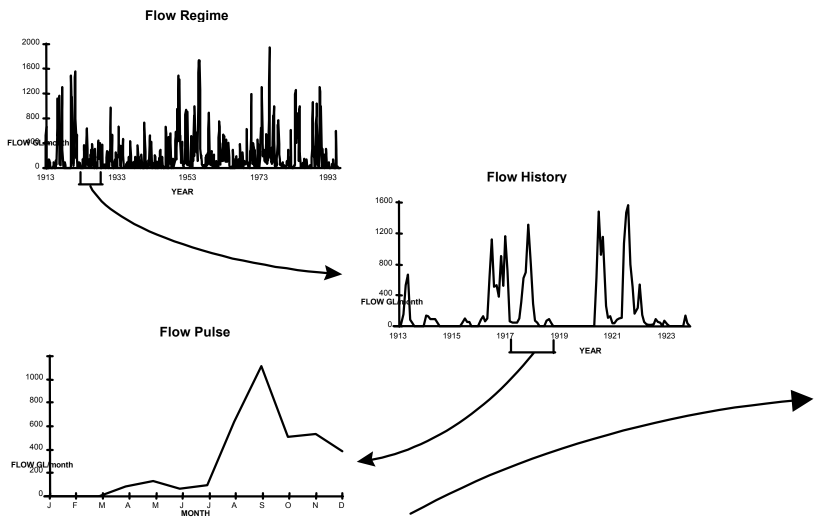


Figure 1. A heirarchical view of aspects of flow

Flow regime

A long-term, statistical generalisation of flow behaviour. It describes influences that extend over hundreds of years, such as the flood and drought cycles determined by atmospheric conditions like ENSO. Aspects of flow that operate at the 'flow regime' scale include:

- **Flow variability**: the natural range of flow levels, and their timing; and,
- **Measures of central tendency:** Mean, median and skew of the long term flow record.

Flow history

The sequence of floods or droughts, including the antecedent conditions of flow pulses before any point in time. The flow history describes influences that operate over scales of between 1 and 100 years. Aspects of flow that are evident at the 'flow history' scale include:

- **Frequency**: the frequency of events in a range of flow sizes;
- **Antecedent conditions**: the time elapsed since the last event of a given magnitude;
- **Seasonality**: the time of year when a flow of given magnitude occurs; and
- **No flow (dry) periods**: the duration and nature of dry periods.

Flood pulse

A single flood event (Figure 2), generally defined as a rise and fall in discharge. Flood pulses generally extend for less than one year. Aspects of flow that are evident at the scale of a ‘flood pulse’ include:

- **Magnitude**: the size of a flow event;
- **Duration of event**: the duration of a flow event; and
- **Rate of fall in hydrograph**: the rate at which flood waters recede.

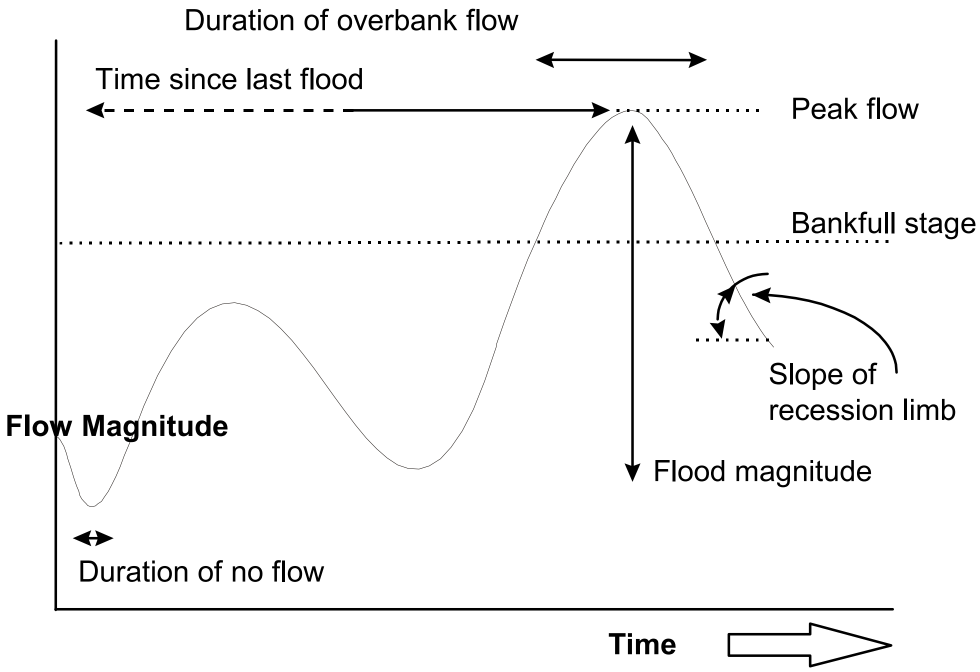


Figure 2 . Features of a flood pulse that may have ecological significance.

Flow Hydraulics

The hydraulics of flow relate to the detailed motion of the flow. Its velocity, depth, stress and turbulence. Aspects of flow at this scale are:

- **Velocity**: the motion of the flow — this can be measured at the bed or other flow depths;
- **Depth**;
- **Stress**: the time of year when a flow of given magnitude occurs; and
- **Turbulence**:

Thus rivers can be described as nested hierarchical systems and hydrological change through water resource and or catchment development may influence all or some of the various hierarchies. For example, studies on the Murray and Barwon-Darling have shown that water resource development has had a marked but variable impact on all hydrological scales (Thoms and Sheldon 2000). In the Barwon Darling River flows are highly modified through the presence of 9 headwater dams, 15 main channel weirs and 267 licensed water extractors. Median annual runoff has been reduced by 42% over a 60 year period. Small flood events (e.g. Average Recurrence Interval of <1.2 years) have suffered the greatest impact with reductions in magnitude of between 35 and 70%. At a number of stations the seasonality of flows has also been affected with a distinct shift in seasonal flow peaks relating to irrigation diversions. Overall, flows show a marked increase in predictability and consistency (*sensu* Colwell 1974). There has also been a change in the shape of the hydrograph. Both long and short-term hydrological changes in the Barwon-Darling, associated with water resource development, may prove to be critical for the ecological health of the system.

The flow of a river at any one point is an integration of all upstream conditions. Hence, to assess the hydrological behaviour of a river system in a spatial context, data (usually one gauging station) are required for stretches of river between major tributary inputs or river losses. Similarly, a continuous daily data series of at least 30 years is required in order to assess its temporal behaviour.

The influence of scale has been recognised in many ecosystem studies. Investigations at a catchment or river-valley scale requires that processes that operate over longer time periods (tens of years and greater) are considered rather than those over periods of days and years (Figure 3).

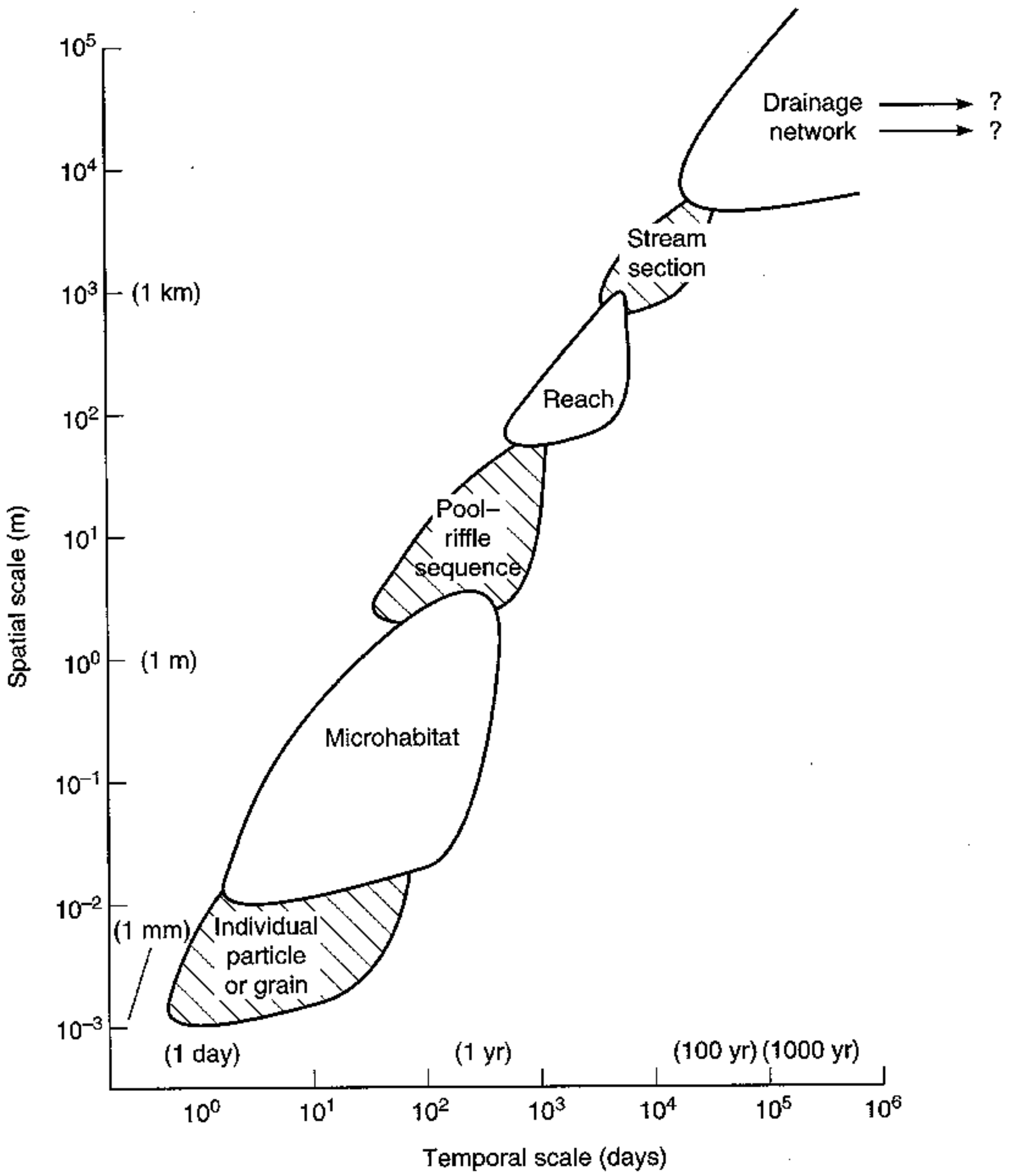


Figure 3. Temporal and spatial scales over which various fluvial processes operate (after Schumm 1988).

The hydrology of many of the rivers in the Murray-Darling Basin has been altered or regulated in some fashion, as noted above. There are many definitions of a 'regulated river'. In order to provide a definition of a regulated river for the Audit one must separate out legal and administrative definitions from those that pertain to the functioning of riverine ecosystems. The Audit is concerned with the development of a framework with which to assess the condition of rivers throughout the Murray-Darling Basin. Hence an ecosystem perspective should be used in defining a regulated river. Thus, for the purposes of the Audit a regulated river is *any river or section of river that has a structure (e.g. dam, weir or barrage) on it or is subject to anthropogenic additions or withdrawals of water*.

Existing programs/methods

Methods of assessing alterations to the hydrological regime because of catchment and water resource development are well documented within the scientific literature (Richter *et al.* 1996, Gehrke *et al.* 1995, Ladson *et al.* 1999). All rely upon the comparison of pre- and post-impact hydrological regimes at a variety of scales. Within the Murray-Darling Basin, a variety of different procedures have been employed, and there is currently no consistent method of assessment across the Basin. The following sections outline some of the methods from the scientific literature as well as the approaches used by the various agencies within the Basin. It has been through an assessment of the benefits and problems associated with these that the hydrology index has been developed for the Audit.

General methods

The most recent and comprehensive method of hydrological assessment is that proposed by Richter *et al.* (1996). This calculates 32 ecologically relevant hydrological parameters that are placed in five groups of Indicators of Hydrological Alteration (IHA) (Table 1).

Table 1. Summary of hydrologic parameters used in the Indicators of Hydrologic Alteration and their characteristic (from Richter *et al.* 1996).

IHA statistics group	**Regime character**	**Hydrological parameter**
Group 1: Magnitude of monthly water conditions	Magnitude Timing	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude Duration	Annual minima 1-day means Annual maxima 1-day means Annual minima 3-day means Annual maxima 3-day means Annual minima 7-day means Annual maxima 7-day means Annual minima 30-day means Annual maxima 30-day means Annual minima 90-day means Annual maxima 90-day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1 day maximum Julian date of each annual 1 day minimum

Group 4: Frequency and duration of high and low pulses	Magnitude Frequency Duration	No. of high pulses each year No. of low pulses each year Mean duration of high pulses within each year Mean duration of low pulses within each year
Group 5: Rate and frequency of water condition changes	Frequency Rate of change	Means of all positive differences between consecutive daily means Means of all negative differences between consecutive daily means No. of rises No. of falls

The general approach for this hydrological assessment has four steps:

1. Define the data series for pre- and post impact periods in the river system of interest.
2. Calculate values of each hydrological variable. This is done for each year of the data series, i.e. one set for the pre- and post-impact series.
3. Compare inter-annual statistics. Measures of central tendency and dispersion for the individual parameters are calculated. This produces 64 inter-annual statistics for each data series.
4. Calculate values of the IHA. The 64 inter-annual statistics between the pre - and post-impact data series are compared and reach result is presented as a percentage deviation of one time period (the post-impact condition).

This approach relies upon a reasonable length (at least 30 years) of pre-impact flow data. In Australia, we generally do not possess such hydrological data series. Water resource development, particularly in the Murray-Darling began in the early 1900s. Although the records for some gauging stations in the Murray-Darling Basin span almost 100 years, a rapid rate of water resource development combined with the naturally variable flow makes it difficult to evaluate the impact of development on the hydrological regime using only historical data. Thus any assessment of the hydrology of the Murray-Darling system will rely on simulated data.

Index of Stream Condition — Hydrological deviation

The Index of Stream Condition (ISC) was developed to assist with the overall management of rivers in Victoria. This assessment of stream condition is fundamental to the setting of priorities and the allocation of resources to various strategies by State and regional managers. The ISC can also be used to measure the effectiveness of the integrated management effort and provide information with which to set benchmarks for stream condition throughout the State. The ISC is available for on-going assessment where information is collated, processed and used by waterway management agencies, and provides direct input to management decisions.

The guiding principle behind ISC is that of assigning a score based on a comparison with ‘naturalness’; that is, the score is based on a comparison between existing stream condition and that thought to have existed before European settlement in Australia. It has been neither possible nor desirable to rigorously reconstruct historical stream condition. Rather than rigorously reconstructing historical stream condition, this principle has been applied pragmatically by the specialist group to develop a rating system for chosen indicators. In this way, reference conditions are established on the basis of best professional judgement, avoiding the need for comparisons with particular control sites (Reynoldson *et al.* 1997).

The index is predominantly a qualitative assessment of various aspects of stream condition, and the sum of the ratings of each of these components provides an indication of change from natural to ideal conditions. Five components are included in the ISC:

- hydrology (an assessment of flow);
- physical form (condition of the channel and physical habitat);
- streamside zone (measurement of quantity and quality of streamside vegetation and wetlands);
- water quality; and
- aquatic life (macroinvertebrate populations).

Hydrology sub-index

The hydrology sub-index is based on changes to the volume and seasonality of flow, by using a combination of simulated and actual data. A value, termed the hydrologic deviation, is calculated by summing the absolute values of the differences between the simulated undeveloped monthly flow and the simulated existing flow over a year. The total is then divided by the annual undeveloped flow. The formula for this sub-index is:

$$\sum_{j=1922}^{1995} \frac{\sum_{i=1}^{12} MN_{ij} - ME_{ij}}{AN_j}$$

where: *MN* (monthly natural) = simulated undeveloped monthly flow
ME (monthly existing) = simulated existing monthly flow
AN (annual natural) = annual undeveloped flow
i = Month: Jan, Feb, …, Dec ; *j* = Year: 1922, 1923, …, 1995.

The rating of the sub-index is given in Table 2.

The hydrologic deviation in the ISC highlights reaches with the greatest departures from natural hydrologic conditions. The hydrologic deviation is similar to the Annual Proportional Flow Deviation parameter developed by Gehrke *et al.* (1995), which has been shown to be related to ecological impacts. Additionally, the hydrologic deviation is reduced if there are hydroelectric schemes or if urban areas constitute more than 20% of the catchment area of a river reach.

Table 2 Rating the hydrologic deviation

Hydrologic deviation	Rating
<20%	4
20% to <35%	3
35% to <50%	2
50% to <65%	1
>65%	0

This approach has the benefit of being quantitative and, with the assigning of a rating, is comparable across basins. However, it is a single value which encapsulates both changes to flow volumes and seasonality and consequently it is not possible to determine which of these aspects of the flow history is causing the greatest hydrological deviation. Furthermore, it only provides an assessment of flow history rather than flow regime (see section 1).

New South Wales — Stressed Rivers Program

The 'Stressed Rivers Program', introduced in New South Wales in 1997 classifies rivers according to their assessed level of environmental stress and conservation value. This classification is used to guide both management priorities and policies. The scheme is based at a sub-catchment level and places these into one of nine categories (stressed and unstressed) see Table 3. These are based upon estimates of existing water use and assessments of environmental health.

Table 3. The classifications are based upon estimates of current water use (hydrological stress) and assessments of environmental health (from professional judgement).

	Low environmental stress	**Medium environmental stress**	**High environmental stress**
High proportion of water extracted	Category U1 Despite high levels of water extraction the river seems reasonably healthy. However, more detailed evaluation should be undertaken to confirm. It is also likely that conflict between users may be occurring during critical periods.	Category S3 Water extraction is likely to be contributing to environmental stress.	Category S1 Water extraction is likely to be contributing to environmental stress.
Medium proportion of water extracted	Category U2 There is no indication of a problem and therefore such rivers would be a low priority for management action.	Category S4 Water extraction may be contributing to environmental stress.	Category S2 Water extraction may be contributing to environmental stress.
Low proportion of water extracted	Category U4 There is no indication of a problem and therefore such rivers would be a low priority for management action.	Category U3 Environmental stress is likely to be due to factors other than water extraction and as stress is not high these rivers would be a lower priority for management action.	Category S5 While environmental stress is likely to be due to factors other than water extraction the high level of environmental stress means it is important to ensure extraction is not exacerbating the problem.

Hydrological stress

The hydrological stress of a sub catchment is calculated as the estimated proportion of daily flow that has been made available for extraction under existing licenses. This requires estimation of stream flow and water use. The index of hydrological stress is derived for each sub catchment as the proportion of estimated water extraction relative to the estimated stream flow. The water use is taken as the peak monthly water extractions as lodged by the licensed water extractors, and stream flow is taken as the 80th percentile for the month of maximum demand. Each sub catchment is then classified as being of low (0–33% extraction of flow), medium (34–66%) or high (67–100%) hydrologic stress.

While this approach has the advantage of being applicable to rivers which do not have major regulating structures, it relies on accurate and up to date extraction data which can be difficult to obtain. It also assumes that hydrological stress is primarily a function of water extraction and does not provide any indication of changes in seasonal flow patterns. Furthermore, in the absence of flow and extraction data, assessment of hydrological stress is subjectively made.

Queensland Water Allocation Management Plan (WAMP)

The determination of flow changes and how these relate to the ecological condition of a river system is a key part of the WAMP. The choice of individual flow statistics differs between WAMPs and this is dependent upon the Technical Advisory Panel (TAP). For the Condamine-Balonne WAMP nine key flow statistics were selected (Table 4). These statistics were assumed to focus on the principal ecological requirements of the Condamine-Balonne river system in terms of the quantity of flow, as well as the frequency and duration of flow events of differing magnitude including periods of no flow.

In practical terms, there were two main points that affected how the key flow statistics were expressed. These were that:

1. the ecological condition of a river can only be ideal if the flow regime is unaltered from the natural state and the key flow statistics should reflect this important concept; and
2. while it was preferred that values be standardised across the key flow statistics, it is more practical to calculate the *frequency* of high magnitude flow events and the *duration* of low magnitude flow events due to differences in isolating individual flow events

To reflect the relationship between ecological impacts and changes in the natural flow regime, relevant key flow statistics were expressed as the proportional change from natural flow conditions. For example, for the *proportion of natural "high flow" events*, the frequency of "high flow" events under the modelled water resources development scenario (the developed condition) was divided by the frequency of these flow events under modelled natural flow conditions.

This simple calculation yields a proportion that theoretically ranges from zero to infinity. In terms of *proportion of natural "high flow" event frequency*, values of zero indicate that "high flow" events no longer occur, while a value of one indicates that the frequency of "high flow" events is unchanged from the natural flow regime. Values greater than one indicate "high flow" events occur more frequently than would naturally have occurred.

Table 4. Key flow statistics selected to describe the ecological water requirements of the Condamine-Balonne river system, including associated floodplain, riparian and wetland habitats

Key statistic	Primary features of importance
Proportion of natural median annual flow	• Annual discharge • Sediment transport • Availability of aquatic habitat
Annual Proportional Flow Deviation (APFD)	• Overall modification of the flow regime • Reproduction of native fish and water birds • Abundance of alien fish species, e.g. carp
Proportion of natural monthly flow variability	• Daily variation in flow, and seasonal patterns of flow variability • Natural disturbance
Proportion of natural "high flow" event frequency	• Flooding, and near bank-full flow events • Floodplain inundation • Natural disturbance • Movement of native fish over weirs
Proportion of natural "medium flow" event frequency	• Within-channel flow events • Maintenance of channel complexity • Inundation of channel benches
Proportion of natural "low flow" duration	• Connectivity of riverine pools • Movement of native fish • Maintenance of riffle habitat
Proportion of natural "no flow" duration	• Drying of the in-stream environment • Natural disturbance • Maintenance of in-stream vegetation • Oxidation of nutrients
Proportion of river inundated by dams and weirs	• Loss of natural riverine habitat

Important Features of the Selected Key flow statistics

Several of the key flow statistics selected by the Condamine-Balonne TAP were intentionally defined in qualitative terms. Descriptors such as "low", "medium" and "high" were chosen to describe the ecological function each category of flow event was intended to perform. These terms require quantitative description, and a basic understanding of the ecological significance of each of the key flow statistics is required to appreciate their full importance.

Proportion of Median Annual Flow

The median, like the more widely known 'mean', provides an indication of the centre of a set of numbers (sample). Median annual flow is calculated as the middle value of a time-series of annual river flow ordered by magnitude.

The median is equal to the arithmetic mean when there is equal probability of occurrence of any value within the observed range of numbers. However, annual flow data for the Condamine-Balonne river system tends to be strongly "right-skewed", since years of lesser flow are much more common than "wet" years. The median rather than the mean tends to be a better indicator of the flow most likely to be experienced in any year, although neither of these statistics is ideal.

Annual Proportional Flow Deviation (APFD)

APFD was formulated in 1994–95 by a team of scientists from NSW Fisheries to summarise changes in natural flow regimes associated with water resource development. APFD was originally used in an examination of the ecology of rivers affected by varying degrees of river regulation. However, it is equally applicable to river systems such as the Condamine-Balonne where the bulk of consumptive water use occurs via the harvesting of natural flow events.

APFD has four particularly important characteristics. It is:

- scaled so that it is comparable across locations/rivers of differing flow volume
- sensitive to changes in flow volume occurring in any given month
- sensitive to changes in the overall seasonality of flow
- sensitive to changes in the shape of the seasonal pattern of flow

APFD, as used by the Condamine-Balonne TAP[1], is defined in mathematical notation as:

$$APFD = \sum_{j=1}^{p} \frac{\sqrt{\sum_{i=1}^{12} \left(\frac{c_{ij} - n_{ij}}{\bar{n}_i} \right)^2}}{p}$$

where: p = number of years in the simulation period,
c_{ij} = modelled existing flow for month i in year j,
n_{ij} = modelled natural flow for month i in year j,
$\bar{n}_i$ = mean natural flow for month i across p years.

APFD values used by the TAP were calculated from simulated flow data produced using the Condamine-Balonne IQQM. Referring to the modelled development scenario as "existing" conditions, APFD is based on the difference between existing and natural flow (expressed as a proportion of the corresponding average natural flow) for each month. The resulting values (one for each month) are squared to make each positive, then added, and the square root of the answer is found, to remove the effect of previously squaring values. In this way a single value is calculated for each year of simulated data and APFD is then calculated simply as the average of yearly values.

A particularly important aspect of the calculation of APFD is that changes in monthly flow are expressed as a *proportion* of the expected natural flow for each month. For this reason this statistic is called the Annual *Proportional* Flow Deviation.

Proportion of Natural Monthly Flow Variability

The monthly flow variability described by this statistic was calculated as the Coefficient of Variation (CV) of the sum of monthly flows across years.

Proportion of Natural “High Flow” and “Medium Flow” Event Frequency

“High flow” and “medium flow” events were defined as events occurring at an average interval of 12–18 months and 4–6 months, respectively. The event frequencies under each water resource development scenario (natural and various extraction scenarios) were averaged to provide a single value.

Proportion of Natural “Low Flow” and “No Flow” Duration

Both “low flow” and “no flow” events were expressed as flow duration percentiles, which indicate the proportion of *time* that flow was equal to, or exceeded, a specific rate of flow This proportion was calculated as the number of days per annum.

The benefits of the WAMP approach to hydrological assessment are that the parameters chosen are basin specific and thus directly relevant to the ecological issues within a particular basin. While this is useful for the purposes of management within the basin, it doesn’t facilitate the interbasin comparisons that allow higher level policy decisions to be made. It would also be a time consuming and expensive process to conduct for the whole of the Murray-Darling Basin.

The WAMP hydrological assessment also has the advantage of a quantitative approach which, once established, will enable monitoring of changes due to management activities. The range of hydrological measures used encapsulates changes to flow volume, flow regime and flood pulses.

Summary

- There are a variety of procedures used to estimate changes in the hydrology of river systems within the Murray-Darling Basin.
- Many use hydrological models that can generate flow data for 'natural' and 'developed' scenarios.
- There is no consistent method used in the Basin

For the Audit:

- A quantitative approach has the greatest advantage.
- The measures need to encapsulate changes to flow regime and seasonality.
- The measures need to use data which are readily available.
- The approach needs to be applicable to streams without major regulation (the use of simulated data allows this).
- The approach needs to be consistent across the Basin (enabling interbasin comparisons).

Flow models

Given that flow models are utilised by many State agencies as water resource management tools the following section outlines those commonly used. Three models are outlined briefly: The Integrated Quantity Quality Model (IQQM), which is used by NSW Dept of Land and Water Conservation and the Queensland Dept of Natural Resources; The **RE**source **AL**location **M**odel (REALM) used in Victoria; and, the Murray-Darling Basin Commission's Monthly Simulation Model.

Integrated Quantity Quality Model (IQQM) — New South Wales and Queensland

IQQM was developed as a generic, hydrologic, river system simulation package for investigating new water resources management policy options and refinements to existing policies. The model is a strategic planning tool designed for investigating water sharing issues at the river basin, inter-state or international level, and between competing groups of users including the environment.

IQQM simulates river system behaviour at a daily time step with an option to use smaller time steps for some processes. It is able to simulate water quality behaviour and water quantity behaviour in an integrated manner, and is capable of application to both regulated and unregulated streams. IQQM was designed specifically to be effective in investigating issues where short term changes in flows or other parameters are important, such as environmental flows and event sharing. Because it operates on a daily time step, it can provide a much more detailed representation of short term variations in all factors relevant to any river system than is possible with a monthly model. IQQM is therefore a substantial advance in technology over the monthly models in use up to now.

IQQM is structured as a modelling shell with component modules linking together to form an integrated package. This shell has been designed to facilitate the incorporation of additional component modules as required. The main components of IQQM are:

- user interface shell,
- in-stream water quantity,
- in-stream water quality,
- rainfall-runoff,
- pollutant washoff and export,
- groundwater quantity and quality,
- statistical tools, and
- climate data generation tools.

IQQM uses two basic units for representing river systems:

(i) nodes: which represent points on a river system having certain operational or physical processes associated with them;

(ii) links: which represent river reaches between nodes.

To apply IQQM to a river system, it is necessary to configure the model to represent the physical features and the water management system. Configuring for the physical system includes defining locations of storages, demand centres, tributary inflows, effluent outflows and returns, floodplain detention storages and limits of flow routing reaches. Configuring for the management system includes defining system operating rules such as flow thresholds for unregulated flow licences.

IQQM implementation involves calibration and validation of the in-stream water quantity component in a two stage process. Stage 1 calibration requires deriving values of flow routing coefficients, effluent flow and transmission loss relationships, and relationships describing floodplain storage behaviour. In Stage 1, the model is run with recorded values of water diversions at each irrigation node. In Stage 2 of the calibration, values of parameters relating to irrigation demands are derived and results compared with available data.

When interpreting the results obtained from a model such as IQQM, due recognition needs to be given to the purpose of the model, the limitations of the data used to calibrate and validate the model and the limitations of the model itself. In particular it needs to be recognised that:

IQQM is a planning tool. It is intended to provide information on long-term future system performance and behaviour under given scenarios of management rules and physical constraints. It can provide a great deal of valuable information on a daily, monthly, seasonal, annual or longer basis, but in a statistical sense. As it is a planning tool, IQQM cannot be used to hindcast, say, the flows that would have occurred on a specific date in the past under a given scenario. For example the model may not reproduce the timing of a flood precisely although it may simulate the hydrograph volume and shape correctly; this does not matter in a planning model but it may be critical in other applications such as flood forecasting.

In current modelling practice, the prediction of long term future performance using models such as IQQM is based on historical hydrologic data (rainfall, streamflow, evaporation). A major limitation of this approach is that it basically assumes that the future will be a repeat of the past, which is clearly unlikely. An interpretation commonly used is that model results show what would have happened in the past had the scenario being modelled been in place then. On this basis the model could be used to hindcast past system performance, but only in a statistical sense and not in terms of comparing modelled and actual behaviour on given dates.

There are limitations in the accuracy of the input data. In the case of streamflow data the accuracy in the mid-flow range is usually 20% at best. At low flows and high flows the accuracy is generally very much worse and can frequently be no better than +100%/-50%. Accuracy is affected by channel bed stability at low flows and by erratic overland flow behaviour at high flows, both of which are problems in many rivers in the Basin. There are limitations in the accuracy of other data used in model calibration, such as water use data, which is incomplete or contains anomalies as discussed earlier. Metering will largely overcome errors in water use data.

There are uncertainties in calibration which are directly related to uncertainties in available data. Great care is taken during calibration to minimise data uncertainties and impacts on subsequent study results, but there will still be data-related uncertainties in model results.

RESOURCE ALLOCATION MODEL — Victoria

REsource **AL**location **M**odel (REALM) is a PC-based water allocation simulation computer package. It uses the network linear programming algorithm to solve a water supply system represented by a connected system of arcs and nodes. Nodes represent storage reservoirs, diversion structures, demand centres and stream channel or pipe junctions. Arcs represent natural water carriers such as rivers and tributary streams or artificial water carriers such as lined or unlined channels or closed conduits. The model can be run on any specified time step such as annual, seasonal (bi-monthly, tri-monthly, etc.), monthly, weekly or daily.

System Specification

The package provides for analysing both urban and irrigation water supply systems. A graphical editor provides for setting up new water supply systems and specifying the system characteristics including storage capacity, carriers' fixed or variable maximum capacities and minimum flows, carrier transmission losses, operating rules, supply restriction rules, storage distribution targets, etc. The graphical editor can also be used to modify or expand existing system files for analysing various planning or operational scenarios.

Inputs

The external inputs to the configured water supply network constitute streamflows time series at various intake points specified on the network and the unrestricted demand time series for specified demand centres in the network. Both these time series would be at the specified time step for simulation. Stochastic data generation algorithms used to generate daily series of rainfall and evaporation data can be used as input into REALM. The package of system specification, inflows, demands and outputs is specified through a WINDOWS™ based input facility.

Outputs

The model puts out files containing various system performance parameters such as storage volumes, flows, demands, supplies, losses, etc. at each simulation time step. The choice of output parameters can be specified through the WINDOWS based input facility. The output files can be examined via a graphical plotting package provided in the REALM package. Other utilities such as plotting system network configuration, system listing, data manipulation, etc., are also available within the REALM package suite of programs.

BigMod — Murray-Darling Basin Commission Flow Model

Bigmod is a computer program used for modelling flow and solute transport in rivers. It operates on a time-step of one day and was developed by the Murray-Darling Basin Commission for three main roles:

- making short term flow and salinity forecasts;
- routing flow and salt in planning studies that test the performance of different options for river management against historical climatic conditions; and

- analysing historical data to calculate the solute loads entering the reaches of the river between water quality measurement stations.

The features of this model are:

- its ability to be calibrated accurately;
- its numerical stability; and
- its ability to model river reaches and branches that cease to flow.

Flow Routing

Bigmod routes flow using a hydrologic technique. The river is divided into reaches and sub-reaches. For each sub-reach the downstream flow is calculated as:

Downstream flow = Upstream flow – Storage change – Diversions – Losses

The storage in any sub-reach is a function of the upstream flow. The relationship between storage and flow is defined in the model input parameters and is specified for each reach. It is specified in a table that relates flow to the travel time of the flow wave. Travel time, which defines the slope of the storage/flow relationship, is a parameter that is easy to determine during the calibration of the model by comparing the inflow and outflow hydrographs.

The method of routing is numerically stable provided that sub-reaches are small enough. The model automatically subdivides reaches into sub-reaches that ensure that the maximum flow travel time in any sub-reach is less than half a day. Dividing the reaches into smaller sub-reaches than this does not significantly change the model accuracy. The use of a tabulated relationship enables complicated storage functions to be specified which are especially useful when modelling the changes in flow travel time that occur at the transition between inbank and overbank flow.

The loss function has three components.

- an evaporation component which is based on an input value of net evaporation and a tabulated relationship between flow and surface area;
- a monthly loss component which enables constant losses or losses that vary on a seasonal pattern (such as unmetered diversions) to be included;
- a tabulated function between flow and loss (or gain) which enables losses on the flood plain (or systematic errors in flow measurement) to be modelled.

The inclusion of other features, including weirs, lakes connected to the river, branches, junctions, point diversions and point inflows have enabled the model to be applied to the whole River Murray from Hume Dam to the sea with considerable success.

Summary

The effect of catchment and water resource development on the hydrological regime of a river can be assessed with data generated from the above models. These models can provide:

- a 'natural' output, for which data are simulated as if there were no flow-regulating structures, abstractions of water or catchment development, using long-term mean climatic conditions;
- a 'present' development output, for which the water and catchment development conditions at a particular point in time are chosen from actual records and combined with long-term mean climatic conditions to provide an estimate of the resulting hydrological conditions; and
- data that can be accessed at any designated node along a river system.

Methods for the Audit Hydrology Index

The hydrology index being developed for the Audit needs to provide the following:

- a measure of the change in the flow regime caused by human activities;
- comparison of this change with respect to a reference condition. Because there is a lack of adequate flow data before catchment and water development and given the inherent flow variability of rivers in the Basin there will be a reliance on modelled data — in this case modelled 'natural'.
- a report of this change at a river-valley scale. At this scale appropriate flow indices must be reported at the flow regime and history scale because of the relationship between spatial and temporal scales in riverine ecosystem functioning. Moreover, data will be required at least for each valley zone or more preferably for each Functional Process Zone.

Currently, there is no standard hydrology index in terms of approach and indices used for rivers in the Murray-Darling Basin. Hence the following provides the development of a standard set of flow indices and an approach with which to assess hydrological change. There are two sections to this; the first derives several relatively simple components that measure hdyrological deviation from a 'natural' flow. These components provide a measure of changes in both volume and pattern and are applicable across all the main river valleys in the Basin.

The Hydrology Index (**HI**) is defined in terms of four sub-indices:

- Mean Annual Flow Index (A);
- Flow Duration Curve Difference Index (M);
- Seasonal Amplitude Index (SA); and
- Seasonal Period (SP).

HI is defined as the 'Euclidean Distance' between an unimpacted hydrology condition and the condition defined by four sub-indices in a four-dimensional space (Equation 1). This could be the same approach as used to combine all five indices into the Audit. The hydrology sub-indices are all defined on the range 0–1, where 1 represents 'unimpacted', and 0 represents 'maximum impact'. This index is similar to that being developed by the CRC for Freshwater Ecology and CSIRO Land and Water for the National Land and Water Audit.

$$HI = \left(1 - \frac{\sqrt{(1-A)^2 + (1-M)^2 + (1-SA)^2 + (1-SP)^2}}{\sqrt{4^2}} \right) \qquad \text{Equation 1}$$

The second section outlines the aggregation from *s* site(s) to the Functional Process Zone or valley zone.

Data required

Modelled flow data for rivers (under existing and unregulated and 'natural' conditions) will be required in each of the identified Functional Process Zones. The modelled 'natural' conditions should reflect historic changes in rainfall and catchment conditions. *Note*: some modelled data have been collected from each of the States for the National Land and Water Audit. NSW and Queensland have provided modelled daily data whilst the majority of the Victorian data and data provided by the MDBC for the River Murray are monthly. Preliminary analyses of these data have been undertaken, highlighting the successful application of the hydrology index (see section 5).

1. Mean Annual Flow (A)

This provides a measure of the difference in flow volume between current and natural conditions. It is given by the statistic *A* as defined in Equation 2 where the mean annual flow under current (i.e. existing) and natural conditions is given by Q_c and Q_n respectively.

$$\text{if } \overline{Q}_c > \overline{Q}_n \text{ then } A = \frac{\overline{Q}_n}{\overline{Q}_c} \text{ , else } A = \frac{\overline{Q}_c}{\overline{Q}_n} \text{ .} \qquad \text{Equation 2}$$

Comments

This statistic is constrained to a maximum of 1, representing no change in mean annual flow, and 0, representing the most modified mean annual flow conditions. This statistic assumes that a *doubling* of mean annual flow is equally as 'bad' as a *halving* of mean annual flow.

2. Flow Duration Curve Difference (M)

The flow duration curve difference (see Figure 4) provides a measure of the overall difference between current and natural flow duration curves. This precursor to this statistic was developed to assess the overall hydrological deviation of an option from the transparent flow option (Young *et al.* 2001). It has subsequently been modified to ensure that values returned are between 0 and 1.

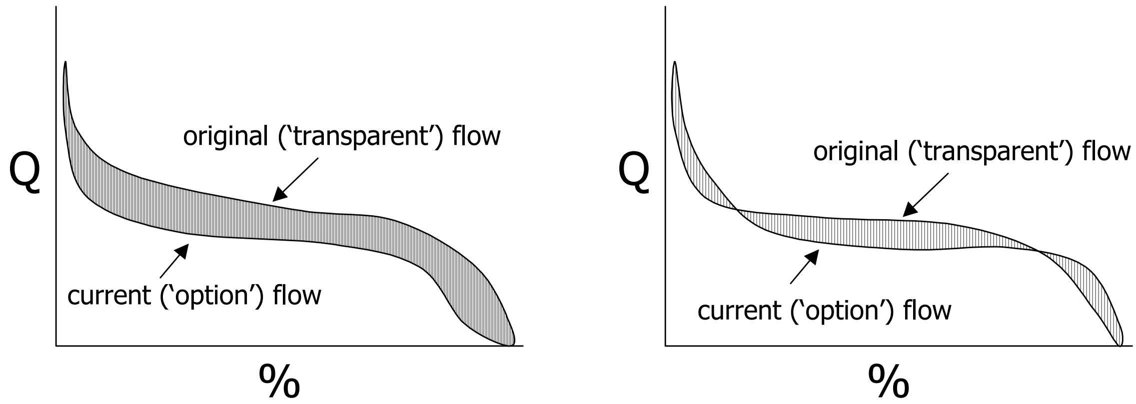


Figure 4. Flow duration curve differences for two flow modifications — the M statistic can be derived from any number of percentile points along the curve.

The statistic *M* is shown in Equation 3, where *n* is the natural flow value for percentile point *i, p* is the number of daily flow percentile points and *c* is the current (i.e. existing) flow value for percentile point *i*. The statistic *M* gives equal weighting to each percentile flow, from the lowest flow to the highest flow.

$$\text{If } n > c \text{ then } M = \frac{1}{p}\sum_{i=1}^{p}\frac{c}{n}, \quad \text{else } M = \frac{1}{p}\sum_{i=1}^{p}\frac{n}{c} \;. \qquad \text{Equation 3}$$

Comments

This approach weights all percentile flows equally and this may result in an undue bias toward changes in flow in the interquartile range whereas small changes in the >90% or <10% which ***may*** be more significant to river condition will have less of an impact. An alternative is to weight high and low flows more heavily — or to only include high and low flows. However, some justification for this and the choice of percentile flows would be required. One way of handling this is to determine *M* for a series of scenarios and see if the result is intuitive in terms of river condition.

3. Seasonal differences

Seasonal changes can occur as changes in amplitude (the difference between the highest and lowest monthly flows) or period (the months in which the flow is conveyed) (Figure 5). Two separate statistics are therefore proposed to assess seasonal change.

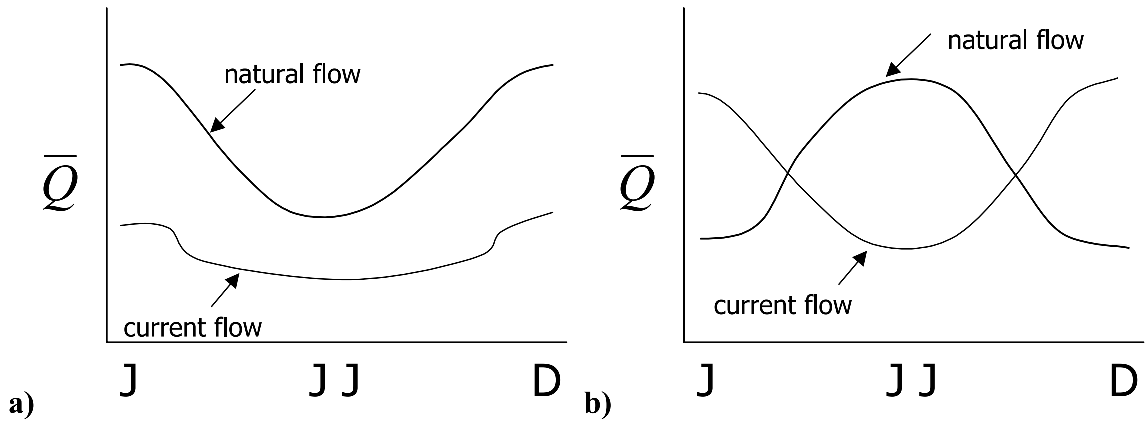


Figure 5. Types of seasonal change: a) represents a change in amplitude, b) represents a change in period

- Seasonal Amplitude (SA)

The statistic *SA* is given in Equation 4, where h is the highest mean monthly flow and l is the lowest mean monthly flow for current (subscript c) and natural (subscript n) conditions. The denominator is always the larger value of h_c and h_n or l_c and l_n.

$$SA = \frac{\left[{}^{h_c}\!/_{h_n} + {}^{l_c}\!/_{l_n} \right]}{2} \qquad \text{Equation 4}$$

- Seasonal Period (SP)

The statistic *SP* (Equation 5) is defined as the difference from 1 of the sum of the differences between the numerical values of the months with the highest mean monthly flow (H) and the numerical values of the months with the lowest mean monthly flow (L) for current and natural conditions (subscript c and n respectively), divided by 12.

$$SP = 1 - \frac{1}{12}\left(\text{if } |H_c - H_n| \le 6 \text{ then } |H_c - H_n|, \text{ else lookuptable } + \text{if } |L_c - L_n| \le 6 \text{ then } |L_c - L_n|, \text{ else lookuptable}\right)$$

Equation 5

lookuptable:

if	**then =**
7	5
8	4
9	3
10	2
11	1

Example: Natural conditions: highest mean monthly flow — August (month 8)
lowest mean monthly flow — February (month 2)
Current conditions: highest mean monthly flow — March (month 3)
lowest mean monthly flow — September (month 9)

$$SP = 1 - \frac{1}{12}\left(\left|3-8\right| + \left|9-2\right|\right) = 1 - \frac{1}{12}\left(5+5\right) = 1 - \frac{10}{12} = \frac{2}{12} \; .$$

Determining the hydrological index for a river valley

Once the hydrological index has been calculated for each site within a Functional Process Zone a simple process of aggregation can occur in order to report the index at a valley zone or river-valley scale. It is suggested that a weighted catchment area approach be adopted where the weightings are simply the catchment area upstream of the individual Functional Process Zones relative to the total catchment area. This is to ensure that the correct weightings of the various Functional Process Zones are recognised. For example, Australian watercourses have recently been mapped at a 1:250,000 scale by Stein *et al.* (1998). Using these data Thoms and Sheldon (2000) have calculated that there are approximately 3127 million kilometres of lowland rivers in Australia. This represents 97% of the total length of Australian rivers. Of this, the majority, 83 %, are inland systems (Pickup 1986) and have semi arid to arid (dryland) climatic regimes and many cease to flow for periods of time.

Principles for the calculation of the hydrology index where data are unavailable

There may be situations for which hydrological data suitable for calculating the hydrological index[2] are not available — thus calculating the hydrological index (and its components) is not possible. The following are a set of suggested principles for use in determining the index in circumstances where suitable data are not available.

Case 1. Zones on unregulated streams

Hydrology index set to 1.

While we recognise that land use change may alter the hydrology of a stream, the literature on this does not indicate that the change is consistent or predictable.

Case 2. Zones on regulated streams

Hydrology index set to non-assessed.

Case 3. Zones on regulated streams, upstream of dams

Hydrology index set to 1.

These are effectively unregulated reaches. This assumes that where there are major abstractions, modelled data are generally available. Where there are minor abstractions,

[2] Suitable data are the following paired data sets:
1. modelled natural and modelled existing flows;
2. modelled natural and observed flows; and
3. observed flows pre- and post-regulation

the components of the index are unlikely to deviate significantly from 1 as they are fairly insensitive to small changes in flow regime.

Case 4. Zones on regulated streams, downstream of a dam, upstream of a zone with data suitable for calculating the index with unregulated tributaries joining the main stem

E.g. See Figure 6. Data are not available for reaches R1, R2 & R3, and data are available for reach R4. T1, T2 &T3 represent the unregulated tributaries joining the main stem.

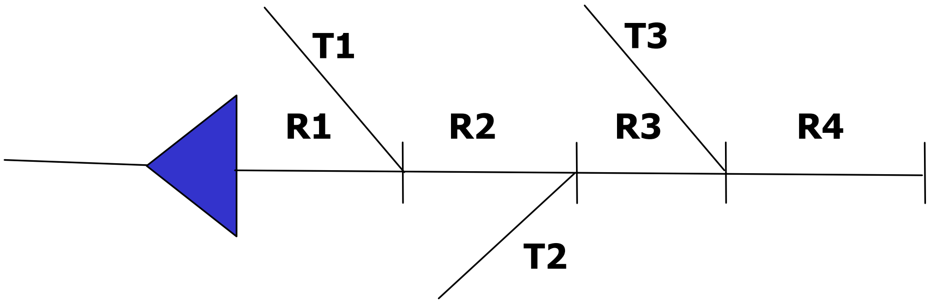


Figure 6

Under these circumstances the components of the index are apportioned according to mean annual flow in the reaches upstream of the "known" reach:

Thus for R3

$$Q_{R4}M_{R4} \cong (M_{R3}Q_{R3} + M_{T3}Q_{T3})$$

or

$$M_{R3} \cong \frac{(M_{R4}Q_{R4} - Q_{T3})}{Q_{R3}} \text{ since } M_{T3}=1 \text{ .}$$

Similarly for R2 & R1:

$$M_{R2} \cong \frac{(M_{R3}Q_{R3} - Q_{T2})}{Q_{R2}} \qquad M_{R1} \cong \frac{(M_{R2}Q_{R2} - Q_{T1})}{Q_{R1}}$$

where: $M_{R\#}$ = the component of the index for mainstem reaches R1–R4,

$M_{T\#}$ = the component of the index in the unregulated tributaries (which by nature of our index components equals 1),

$Q_{R\#}$ = mean annual flow in the mainstem reaches,

$Q_{T\#}$ = mean annual flow in the unregulated tributaries.

Then if for example, the downstream reach (R4) had $M_{R4} = 0.5$, and the upstream regulated reach (R3) contributed 70% of the total (regulated) flow, then M_{R3} for the regulated upstream reach would be = (0.5 – 0.3)/0.7 = 0.29, thus showing that the addition of the unregulated tributary had reduced the degree of regulation in proportion to the flow added.

This relies on

1. Having information about the mean annual flow for the unregulated tributaries. This could be supplied from standard regionalisation procedures.
2. Being able to automate the calculation.

Case 5. Zones on a regulated stream downstream of a zone with data suitable for calculating the index with unregulated tributaries joining the main stem

E.g. See Figure 7. Data are available for R1, but not R2-R4. T1, T2 & T3 are unregulated tributaries.

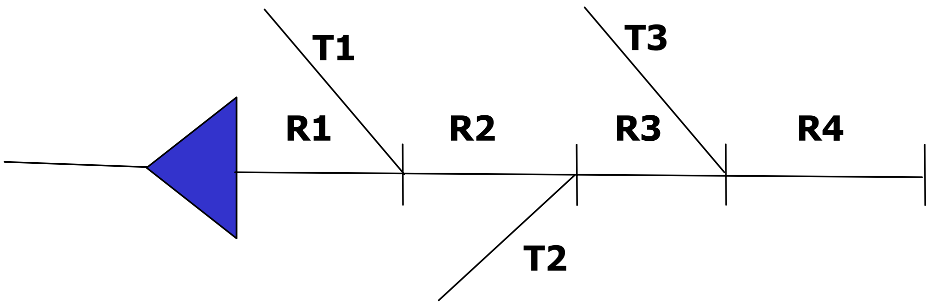


Figure 7

If there are major diversions in reaches R2–R4, then these should be set to non-assessed. This assumes that we do not have data on diversion volumes — where we do have diversion data, we also have modelled data and the index can be calculated.

If there are no major diversions in reaches R2–R4, the indices are again apportioned according to mean annual flow in the reaches.

Thus for R2

$$M_{R2} \cong \frac{(M_{R1}Q_{R1} - Q_{T1})}{Q_{R2}} \text{ since } M_{T1}=1 .$$

Similarly for R3 & R4:

$$M_{R3} \cong \frac{(M_{R2}Q_{R2} - Q_{T2})}{Q_{R3}} \qquad M_{R4} \cong \frac{(M_{R3}Q_{R3} - Q_{T3})}{Q_{R4}}$$

where: $M_{R\#}$ = the component of the index for mainstem reaches R1–R4,

$M_{T\#}$ = the component of the index in the unregulated tributaries (which by nature of our index components equals 1),

$Q_{R\#}$ = mean annual flow in the mainstem reaches,

$Q_{T\#}$ = mean annual flow in the unregulated tributaries.

Again this relies on the conditions for case 4 and 5, that we have mean annual flow data for the reaches and tributaries and that we can automate the calculation.

Testing the Hydrology Index

Background

The four simple measures of change in riverine flow regime outlined above have been tested using flow data from the River Murray at Dartmouth and Hume Dams, as well as data from the Upper Murrumbidgee system, and the result of the testing is outlined below.

Data

The modelling group from the Murray-Darling Basin Commission (MDBC) supplied the following data to enable testing of the hydrology indices:

- Daily inflows and releases from Dartmouth Dam: Jan 1980–Jan 2000
- Monthly inflows and releases from Dartmouth Dam: Jan 1980–April 2000
- Monthly inflows and releases from Hume Dam: Jan 1969–April 2000.

Inflows are modelled ‘natural’ (unregulated) flows and releases are ‘current’ (regulated) flows. Strictly speaking, statistics summarise the impact of dams on flow regime, and ‘natural’ flow means flow not impacted by a dam, rather than the flow regime in an undisturbed catchment.

Modelled data (output from IQQM) was also supplied by NSW DLWC for the Upper Murrumbidgee system at Tumut, Burrinjuck, Gundagai and Wagga:

- Monthly modelled ‘natural’ and existing flow data for the Tumut River at Tumut: 1890–1997
- Monthly modelled ‘natural’ and existing flow data for the Murrumbidgee River at Burrinjuck: 1890–1997
- Monthly modelled ‘natural’ and existing flow data for the Murrumbidgee River at Gundagai: 1890–1997
- Monthly modelled ‘natural’ and existing flow data for the Murrumbidgee River at Wagga: 1890–1997

Component Testing

Test Aims

- To determine if each of the components returns a value between 0 and 1, where 0 is highly modified and 1 is equivalent to natural.
- To determine if there is a difference in the components calculated using daily or monthly data.
- To determine if the statistics proposed are robust — i.e. they 'work' at a range of sites — and if the components produce 'realistic' numbers given what we know about the systems for which we have data.

Mean Annual Flow

if $\overline{Q}_c > \overline{Q}_n$ then $A = \frac{\overline{Q}_n}{\overline{Q}_c}$ else $A = \frac{\overline{Q}_c}{\overline{Q}_n}$ — provides a measure of the difference in flow volume between existing and natural conditions.

Location	Q_c (ML)	Q_n (ML)	A
River Murray at Dartmouth	855 000	883 000	0.97
River Murray at Hume	4 967 000	4 667 000	0.94
Tumut River at Tumut	1 993 000	1 277 000	0.64
Murrumbidgee River at Burrinjuck	1 379 000	1 485 000	0.93
Murrumbidgee River at Gundagai	3 940 000	3 372 000	0.86
Murrumbidgee River at Wagga	4 400 000	3 754 000	0.85

Test results

1. The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system. *Note*: doubling of flows will return a value of 0.5 which is equivalent to a halving of flows.
2. Not tested — there should be no difference in this statistic calculated using daily or monthly data (provided the models producing the data are in agreement!).
3. The statistic appears to work for all sets of data.
    - The difference in average annual flows between 'natural' and 'current' conditions at both sites on the River Murray is small and Hume Dam modifies average annual flows in the River Murray more than does Dartmouth Dam. The derived statistic reflects both of these factors at 0.97 and 0.94 for Dartmouth and Hume

respectively. Hume current is greater than Hume natural due to transfers from the Snowy system.

- Inter-basin transfers from the Snowy scheme and transfers within the Upper Murrumbidgee system mean that flows at Tumut, Gundagai and Wagga have increased compared with natural flows. This is most pronounced for the Tumut River and is reflected in the derived statistic. Flows at Burrinjuck are reduced compared with natural due to transfers from Tantangara.

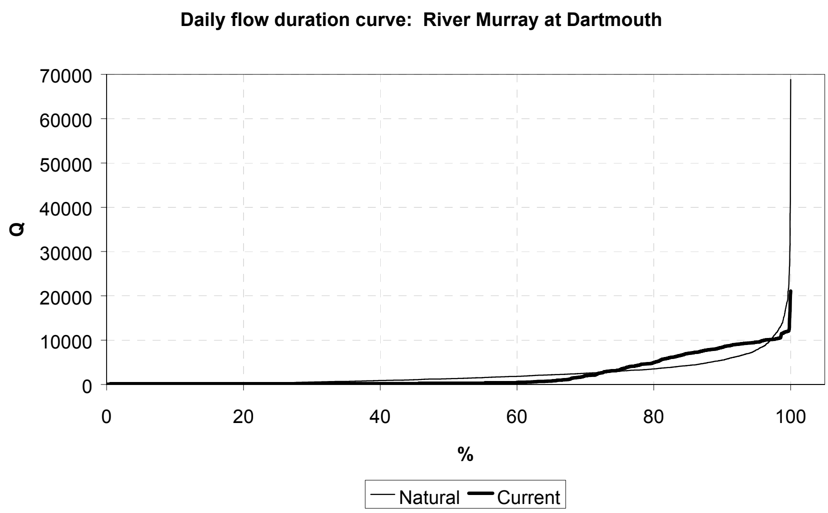
Flow Duration Curve Difference (M)

If $n > c$ then $M = \frac{1}{p}\sum_{i=1}^{p}\frac{c}{n}$ else $M = \frac{1}{p}\sum_{i=1}^{p}\frac{n}{c}$

— provides a measure of the overall difference between current (existing) and natural flow duration curves.

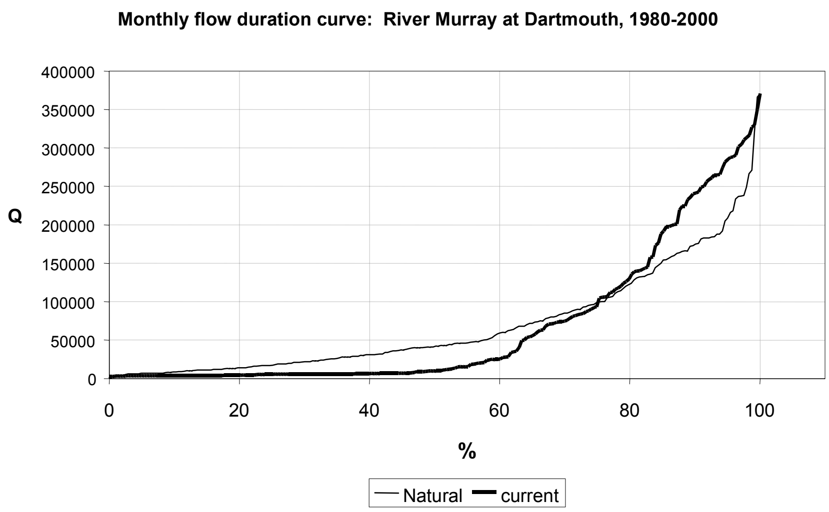
River Murray at Dartmouth:

Daily Data:



$M = 0.59$

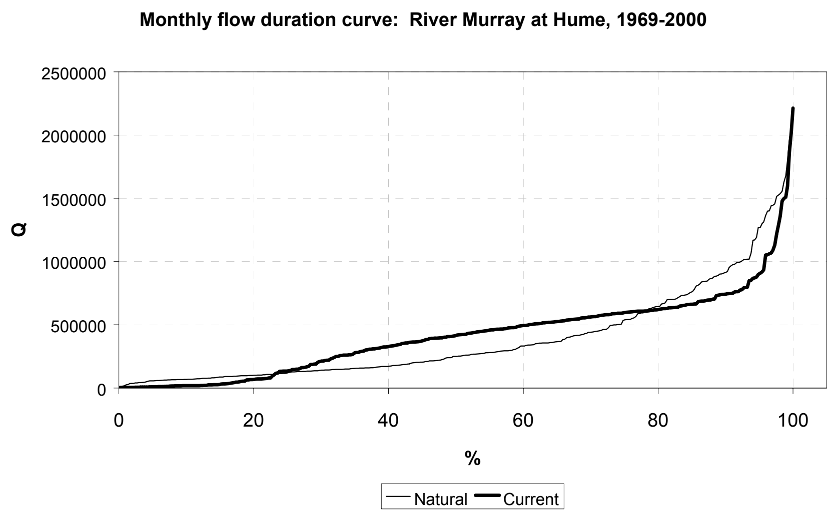
Monthly Data:



$M = 0.46$

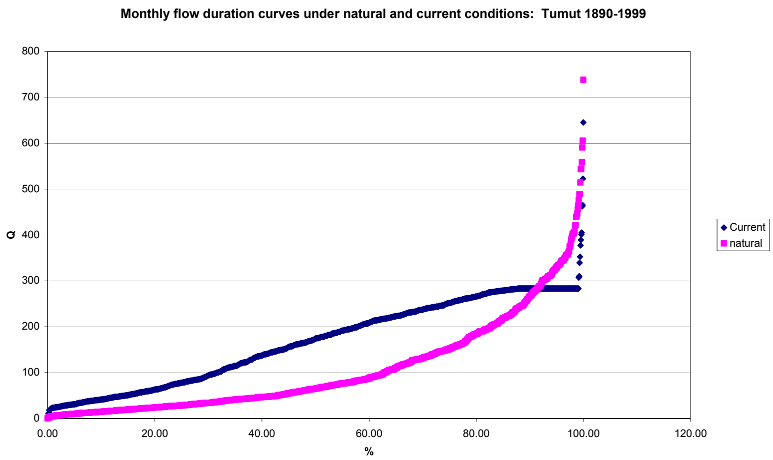
River Murray at Hume

Monthly Data:



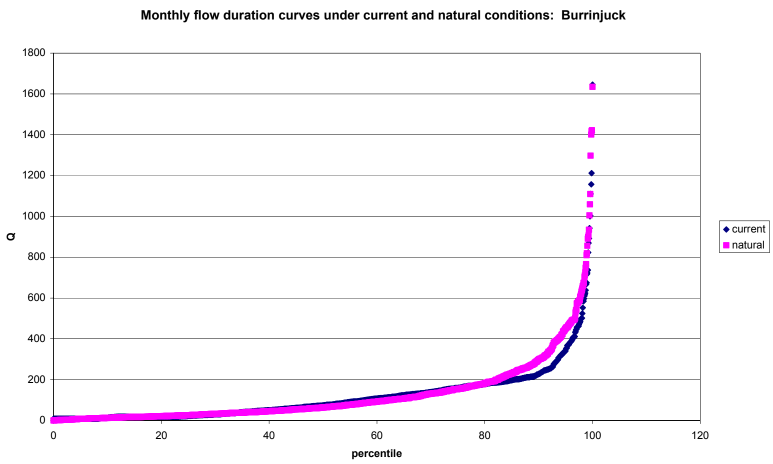
$M = 0.36$

Tumut River at Tumut



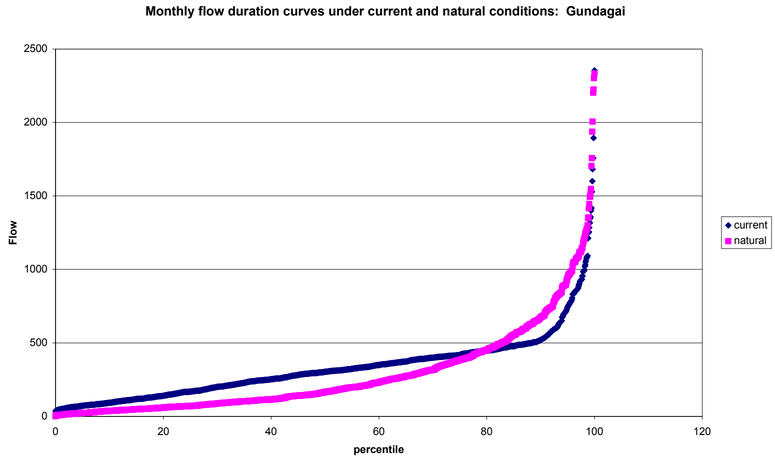
$M = 0.49$

Murrumbidgee River at Burrinjuck



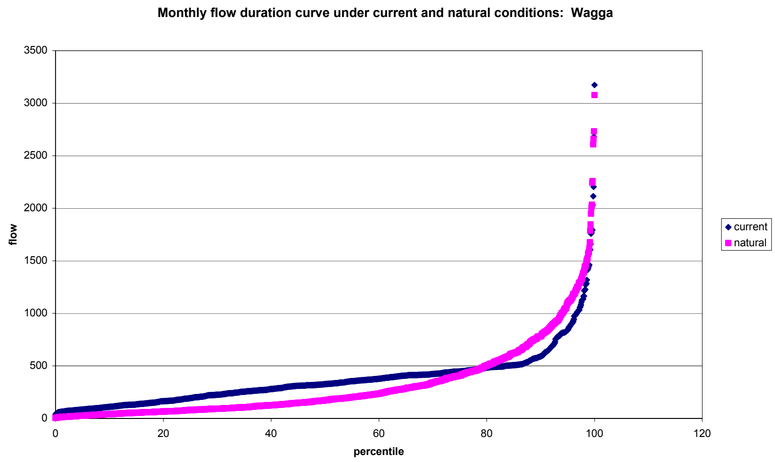
$M = 0.86$

Murrumbidgee River at Gundagai



$M = 0.60$

Murrumbidgee River at Wagga



$M = 0.58$

Test results

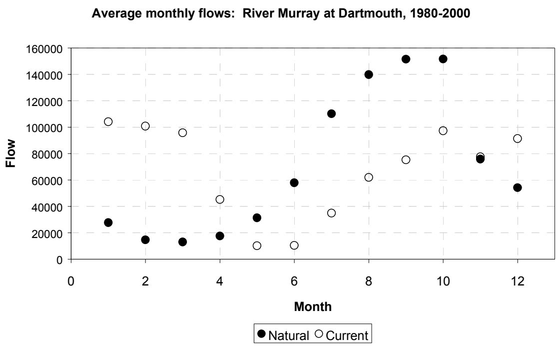
1 The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system.

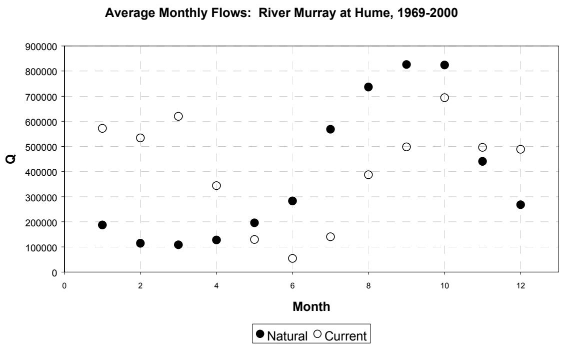
2 There is some difference between the statistics generated using daily and monthly data. Curiously daily data returns a value of 0.59 at Dartmouth and monthly data returns a value of 0.46 which indicates that the daily flow duration curve has been modified less extensively than the monthly flow duration curve — which is counter intuitive.

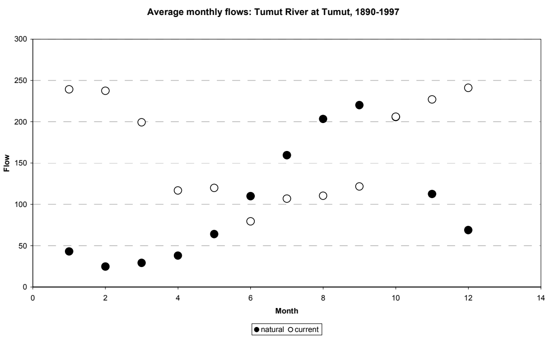
3. The statistic appears to work for all sets of data. Relative differences in the flow duration curves are reflected in the magnitude of the statistic M — e.g. the flow duration curves at Tumut are markedly different and the value of M at this site is 0.49 whereas the flow duration curves at Burrinjuck are only slightly different producing a value of M of 0.86.

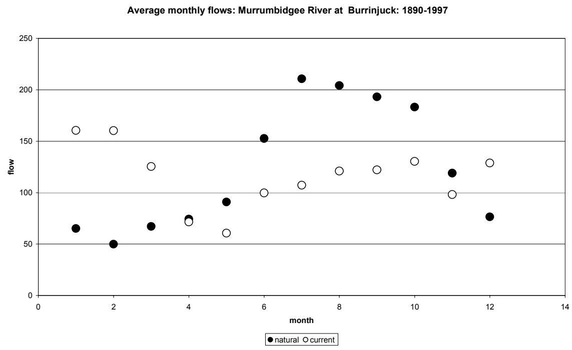
Seasonal differences

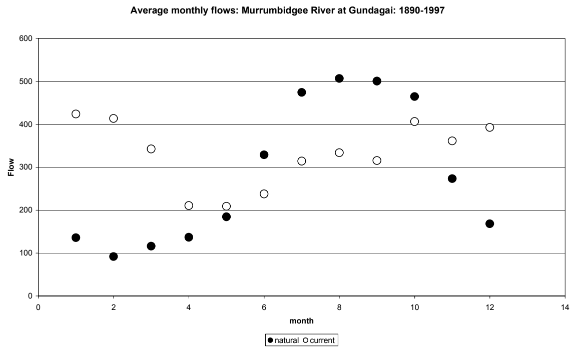
Seasonal changes can occur as changes in amplitude (the difference between the highest and lowest monthly flows) or period (the months in which the flow is conveyed). Two separate statistics are therefore proposed to assess seasonal change.

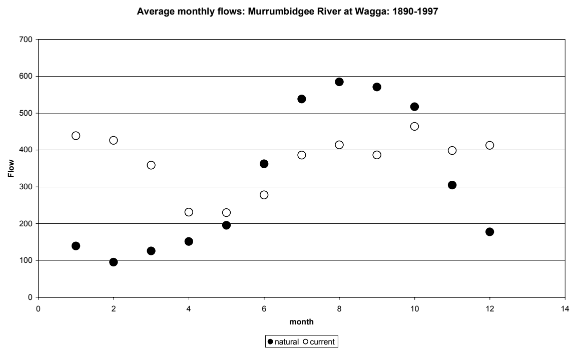







Average monthly flows: Murrumbidgee River at Burrinjuck: 1890-1997
flow
month
natural
current


Average monthly flows: Murrumbidgee River at Gundagai: 1890-1997
Flow
month
natural
current


Average monthly flows: Murrumbidgee River at Wagga: 1890-1997
Flow
month
natural
current

Seasonal Amplitude

$$SA = \frac{\left[h_c/h_n + l_c/l_n \right]}{2},$$

where the denominator is always the larger value of h_c and h_n or l_c and l_n.

Location	h_c (ML)	h_n (ML)	l_c (ML)	l_n (ML)	SA
River Murray at Dartmouth	104 000	152 000	10 000	13 000	0.72
River Murray at Hume	694 000	826 000	54 000	108 000	0.67
Tumut River at Tumut	239 000	220 000	79 000	25 000	0.61
Murrumbidgee River at Burrinjuck	161 000	212 000	60 000	50 000	0.79
Murrumbidgee River at Gundagai	424 000	507 000	209 000	92 000	0.63
Murrumbidgee River at Wagga	464 000	585 000	230 000	95 000	0.58

Test results

1. The statistic produces a value of 1 where current conditions are equivalent to natural and 0 for a highly modified system.
2. Not tested — only monthly data used.
3. This option appears to work with all sets of data. This option reflects actual changes in the mean maximum and the mean minimum monthly flows and is therefore not a direct measure of the change in amplitude (the difference *between* the maximum and minimum flows). However, it is a more relevant measure — in the situations above, minimum monthly flows at Hume have halved and maximum monthly flows have dropped by 25% — yet the amplitude change is only small.

Seasonal Period

$$SP = 1 - \frac{1}{12}\left(\text{if } |H_c - H_n| \le 6 \text{ then } |H_c - H_n|, \text{ else lookuptable } + \text{if } |L_c - L_n| \le 6 \text{ then } |L_c - L_n|, \text{ else lookuptable}\right)$$

lookuptable:

if	then =
7	5
8	4
9	3
10	2
11	1

Location	H_c	H_n	L_c	L_n	SP
River Murray at Dartmouth	1	10	5	3	0.58
River Murray at Hume	10	9	6	3	0.67
Tumut River at Tumut	1	9	6	2	0.42
Murrumbidgee River at Burrinjuck	1	7	5	2	0.25
Murrumbidgee River at Gundagai	1	8	5	2	0.33
Murrumbidgee River at Wagga	10	8	5	2	0.58

Test results

1. The statistic produces a value of 1 where existing conditions are equivalent to natural and 0 for a highly modified system.
2. Not tested — uses only monthly flows.
3. The statistic appears to work for all sets of data. The results returned appear realistic.

Overall Hydrology Index

The four statistics outlined above are combined to produce the overall hydrology index according to the following equation.

$$HI = \left(1 - \frac{\sqrt{(1-A)^2 + (1-M)^2 + (1-SA)^2 + (1-SP)^2}}{\sqrt{4^2}}\right) \qquad \text{Equation 6}$$

Location	*HI*
River Murray at Dartmouth	0.67/0.63*
River Murray at Hume	0.60
Cotter River at Kiosk	0.63
Tumut River at Tumut	0.53
Murrumbidgee River at Burrinjuck	0.60
Murrumbidgee River at Gundagai	0.56
Murrumbidgee River at Wagga	0.63

* Daily/Monthly

Conclusions

Statistic	Conclusion
A	Good — but there is an issue with doubling of flows being considered equivalent to a halving of flows
M	Good — although why is the daily flow duration curve less variable than the monthly flow duration curve?
SA	Good — although not truly representing an amplitude change
SP	Good

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Final Report
Project R2004
Development of a Framework for the Sustainable Rivers Audit

Appendix 7
Physical Habitat

Review and Development of Physical Habitat Assessment Protocols

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Summary

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

Within each spatial scale there is an assessment of the type, area and diversity of physical habitat. The major habitat categories include the vegetation, geomorphological, and hydraulic characteristics of each habitat type (see Table 4 at the end of this appendix). The selection of indicators was based on an explicit conceptual model with consideration given to the cost of data collection, our limited understanding of the important characteristics of physical habitat, and ecological rigour. The protocol includes a separate assessment of processes that either maintain or degrade physical habitat such as erosion or isolation.

An O/E score will be generated for each spatial scale using the E-Ball technique. This will allow separate determination of floodplain and stream feature components. The score for each scale should be reported individually. The lowest of the three spatial scale assessment scores should be used to derive a single physical habitat score.

Objectives

Habitat, along with flow and water quality, is a major determinant of biological outcomes in rivers. Yet it is equally valid to consider that physical habitat is, to some extent, the product of biological processes. A further complication is that many of the indices of physical habitat (e.g. riparian vegetation, macrophytes) would be included in assessments of riverine biodiversity. This component of the Sustainable Rivers Audit describes a protocol for the assessment of physical habitat in rivers of the Murray-Darling Basin. The objectives of the Sustainable Rivers Audit are to:

- develop a common reporting framework for river condition using comparable information, through time and across catchments;
- report the assessment of River Condition against a consistent and scientifically robust set of river health indicators;
- trigger further investigation or action in response to evidence of deteriorating river health;
- inform the development of targets for river health, and monitor progress towards achieving those targets.

The outputs of the Sustainable Rivers Audit are:

- identification of effective indicators of river health, monitoring protocols, interpretive methodologies and appropriate reporting intervals for those indicators;
- a reporting framework/matrix by which these indicators and management activities will be regularly reported.

The specific objectives of the assessment of the physical habitat component are to:

- develop a common reporting framework for the assessment of physical habitat and reporting of habitat condition at the river-valley scale, and at the Valley Process Zone Scale;
- build on the knowledge and experience of existing monitoring programs;
- develop a series of indicators that will enable the cost-effective assessment of the existing condition of riverine habitat in the Basin and thence its subsequent improvement or decline.

The assessment of physical habitat is a complex task made all the more difficult by our limited understanding of many organisms' use of habitat and the extreme variability of habitat within lowland river ecosystems. Because of this the assessment protocol should collect data in a manner that anticipates future knowledge requirements. This will ensure that future generations can accurately determine the direction and rate of change of river condition in the Murray-Darling Basin. This can be achieved by collecting quantitative spatially explicit data on a wide variety of parameters. In recognition of the need to collect a diverse array of information the Physical Habitat task group recommends that the Audit assessment include five elements, reflecting:

- connectivity (including weirs and levees that block the movement of water and organisms among habitats);
- riparian condition;

- woody debris (e.g. snags);
- geomorphic characteristics;
- wetland and floodplain elements.

These components are packaged in a scale-explicit, ecologically robust manner that clearly shows the relationships among the indicators being assessed.

Definition of Habitat

Before describing the protocol for habitat assessment, it is important to define the term "habitat". The following three definitions were obtained from biological dictionaries:

1. Habitat = The natural home or dwelling place of an organism (Steen 1971)
2. Habitat = The living place of an organism or community, characterised by its physical or biotic properties (Allaby 1991)
3. Habitat = Place or environment in which specified organisms live (Thain and Hickman 1994).

These definitions reveal that there are two components to defining habitat:

1. the species that is being considered;
2. the characteristics of a patch defined in terms of its physical or biotic properties.

As a consequence, "habitat" without reference to a taxa or group of organisms renders the term meaningless. This is because, at least on Planet Earth, everywhere is habitat for something, whether it be the space station Mir (rogue fungi), deep sea vents (worms and bacteria) or several kilometres down in the earth's crust (bacteria).

One of the major issues arising from this definition is that habitat is scale-dependent, with both the scale at which organisms respond to their environment and the hierarchy of biotic and abiotic processes that shape the habitat patchwork at a given scale being important.

Tasks

Development of a method of physical habitat assessment is best undertaken as a series of tasks that will result in the formulation of a robust and cost effective protocol. The major tasks are:

1. develop a conceptual model of physical habitat,
2. define the habitats to be assessed,
3. define/describe reference condition against which assessments will be compared,
4. describe a protocol to assess habitat,
5. describe a protocol to assess whether the processes required to maintain habitat are operating,
6. describe a method to enable comparison between test site data and the reference condition,
7. deliver assessment of condition.

Conceptual Model

The existing Australian physical habitat assessment protocols tend not to explicitly specify conceptual models upon which they are built, although there are exceptions (e.g. NSW IMEF). An evaluation of the indices measured by existing programs indicates three common elements:

1. The Flood Pulse Concept, or at least the idea that lateral exchanges between the riparian and floodplain zones and the main channel are important in determining the condition of rivers, is implicit in most programs.
2. Assessment protocols are based on the hypothesis that there is a relationship between habitat diversity and biotic diversity. This hypothesis is linked to the hypothesis that diversity is correlated with "health".
3. Most of the habitat descriptions are couched in terms of fish or arthropod invertebrates suggesting a hypothesis that fish and arthropod invertebrates are either keystone taxa in river ecosystems or that they are indicators of the condition of other taxa and ecological processes.

While there are varying degrees of evidence to support these models or hypotheses, it would appear unlikely that riverine ecosystems are actually either this simple or homogeneous. As a result we have developed a more complex conceptual model that better describes the riverine environment.

Habitat within lowland rivers is structured in the first instance by the interaction of flow regime and the geology of the catchment. At a large scale, water moving over the landscape produces a mosaic of channels and depressions filled with sediment of different types. At a smaller scale, flow produces a variety of hydraulic environments that impose sheer, lift and drag forces on organisms.

At the larger scale the sediment type and the flow regime at a given point will determine the fundamental habitat potential of a site. This potential can then be modified by the action of the biota. Examples include the growth of riparian vegetation, macrophytes or construction of hydropsychid nets that modify the existing habitat and potentially create new habitat for other organisms.

The interaction of flow and geology create the fundamental template and so any assessment of physical habitat must be undertaken in conjunction with an analysis of flow regime. The importance of this point can be illustrated by consideration of snags. Snags are regarded as a significant physical habitat element in lowland rivers, providing shelter and food for fish and a stable substrate that supports a biofilm which provides food for invertebrates and an attachment point for filtering invertebrates. While this hypothesis is true in a general sense, the value of snags to fish and invertebrates depends on the flow regime. If flows are too high, the snag may not provide protection, if flows are too low, the snag may not have any impact on current speeds and/or the holes created by snags may become filled with sediment. The value of snags to filter and biofilm feeders will also vary in response to flow as the delivery of food and the nature and palatability of the biofilm on the snag depend on the flow regime and current speeds over the snag.

Hypothesis 1: Habitat is determined by the interaction of flow regime and geology.

While the characteristics of habitat can be defined in terms of the flow, substrate characteristics and modifications by the biota, this is only part of the relationship between habitat and the associated organisms. There are a number of other considerations about both the quality, quantity and spatial arrangement of habitat that will affect the composition of the biotic community and the rate of ecological processes. These relationships can be summarised in the following hypotheses.

Hypothesis 2: There is a correlation between habitat diversity and species diversity.

Hypothesis 3: Habitat abundance or area affects the rate of ecological processes and species population size.

Hypothesis 4: For ephemeral habitats, there is a relationship between the temporal characteristics of the habitat and the abundance of a species in the ecosystem.

Hypothesis 5: For species that move among habitat patches, the spatial and temporal arrangement of habitat patches will affect a species abundance in the ecosystem and the rates of ecological processes.

Hypothesis 6: For species that require different habitats for different life stages (larval, pupal, adult) or different activities (feeding, breeding or sheltering) the spatial and temporal arrangement of habitat patches will affect the population size and persistence of species in the ecosystem.

Hypothesis 7: Species that use multiple habitat patches or types, or species that require a resource delivered from a different habitat (e.g. allochthonous organic matter) the nature, duration and timing of connection among habitats will affect the flow of material, the persistence of species and the community structure in the river ecosystem.

These seven hypotheses constitute a summary of our understanding of the relationship between physical habitats and as such encapsulate our conceptual model.

Habitats

Before physical habitat can be assessed, the broad habitat types need to be described. Because habitat definition requires a description of the scale being considered, the organisms being considered and physical characteristics important to those organisms, we consider physical habitat at three spatial scales, namely floodplain, channel feature and "in-channel" patches.

Floodplain

- Floodplain: Important habitat for a diverse and unique botanical community that supports a diverse and productive faunal community. From an aquatic perspective, it is among the most ephemerals of habitats. Used by invertebrates, fish and birds for feeding and some micro-invertebrates for reproduction.
- Anabranches: A dynamic habitat, which undergoes transitions from flowing channel to pool to terrestrial environment. As a consequence, its use as habitat by any given

species tends to be patchy in time. Anabranches provide habitat for macrophytes and have the potential to provide habitat for fish, invertebrates, reptiles and birds as feeding habitat, and for by some invertebrates and possibly amphibians and fish for reproduction.

- Flood-runners: Another ephemeral habitat that undergoes frequent transitions between terrestrial and aquatic phases. Flood-runnersare important habitat for macrophytes and may be used by fish, invertebrates, reptiles and birds as feeding habitat and by some invertebrates and possibly amphibians and fish for reproduction.
- Wetlands: A diverse category of habitats ranging from wet meadows to deep permanent bodies of standing water. Among the most diverse of habitats in lowland river ecosystems, supporting communities of trees, grasses, annuals, macrophytes, macroinvertebrates, zooplankton, fish, birds, reptiles, amphibians and mammals. The diverse biotic community is structured by water, nutrient and sediment regime and the characteristics of its connection to other wetlands and the river.

Channel Features

Hydraulic

- Pool: areas of low flow and deep water that provide habitat for invertebrates, submerged and emergent macrophytes and large fish.
- Run: areas of faster flowing water with standing waves, but white water is absent or rare.
- Riffle: areas of high slope and fast flowing water with standing waves and broken water.

Physical Features

- Banks: a heterogeneous collection of habitats from gently sloping vegetated banks to steep cliffs. They can form an important ecotone between aquatic and terrestrial areas and may provide habitat for birds, mammals, crustaceans and other terrestrial, aquatic and amphibious invertebrates.
- Riparian vegetation: important to the adult stages of some aquatic insects, arboreal and terrestrial invertebrates, birds and, during periods of inundation, fish, invertebrates, algae, fungi and bacteria.
- Riparian groundcover: the ground associated with river banks provides habitat for a range of invertebrates, amphibians, reptiles, mammals and birds. The quality of this habitat has been found to depend on the extent of cover provided by living and dead plant material.
- Overhanging vegetation: Overhanging vegetation is correlated with abundance and distribution patterns for a range of aquatic fauna. For macroinvertebrates, habitat heterogeneity (including habitat patches created by overhanging vegetation) plays a crucial role in the distribution and abundances of different functional groups. Crayfish

show shade-seeking behaviour and their presence has been correlated with the proportion of channel overhung by plant canopy. Many fish show habitat preferences for areas with overhead cover including that provided by overhanging vegetation, which reduces predation risk by obstructing visual detection. Platypus and water rat burrows tend to be located in association with overhanging vegetation, and usage by other organisms relates to the provision of roosting, perching and calling sites (waterbirds, reptiles, frogs).

- Emergent macrophytes: support a diverse and productive biofilm community; provide habitat and food for invertebrates, fish, reptiles, amphibians, birds and mammals.
- Benches: may provide areas of slow flowing, shallow water which are important for some species of bird. Their organic matter retention properties make them important habitat for macroinvertebrates.
- Pools: provide important refuges during periods of drought for all permanently aquatic species. During base flow conditions, pools provide refuge for fish.
- Snags are often the dominant hard substrate in lowland rivers. As such they can support a biofilm that provides food or habitat for macroinvertebrates. Snags also provide a point of attachment for filtering insects allowing access to preferred hydraulic conditions. Snags also have an impact on the hydraulic environment around the snag. This effect can increase hydraulic heterogeneity and provide habitat for fish seeking refuge from the current and predators.
- Riffles are not common in Australian lowland rivers. Riffles offer relatively stable substrate and a diverse hydraulic environment that provides habitat for a diverse community of algae, bacteria and macroinvertebrates.
- Rock bars: do not make a significant contribution to habitat in lowland rivers in terms of surface area. They do however offer habitats similar to snags with regard to stable substrate and hydraulic heterogeneity.
- Sand bars are large and often conspicuous components of lowland rivers that actually provide a variety of environmental conditions from erosional faces, to shallow areas of very low flow to slightly deeper depositional zones on the trailing edge. As a consequence, sand bars provide habitat for episammic algae, fungi and bacteria associated with deposits of organic matter, and mobile invertebrates capable of dealing with the unstable nature of the substrate.
- Water column: Often ignored as a specific habitat, but can be significant for algae, bacteria, fish and birds. Habitat suitability is defined by parameters such as depth, current speed and flow patterns.
- Back waters: a habitat that can be difficult to define due to their dependence on flow conditions, they are important areas of organic matter deposition. Sand bars can also be important areas of zooplankton accumulation and may be important in the survival of fish larvae.

In-channel Patches

Small-scale habitat is described primarily by sediment or vegetation type and the hydraulic environment. The hydraulic environment is often assessed by measurement of current speed. Little is known about the hydraulic characteristics of habitat, but broad generalisations can be made.

- Areas of high current speed provide habitat for some filter-feeders and benthic invertebrates who prefer clean, scoured substrate.
- Areas of moderate current provide a supply of food and well oxygenated water without the associated metabolic costs of resisting displacement. These areas provide habitat for fish and invertebrates such as crayfish.
- Areas of slow current allow deposition of organic matter, providing habitat for fungi, detritivorous macroinvertebrates, planktonic species of invertebrate and fish larvae.

The major sediment or vegetation patches include:

- Submerged Macrophytes — support a diverse and productive biofilm community; provide structural habitat and food for invertebrates and fish.
- Macroalgae — provide habitat for macro and micro-invertebrates.
- Silt/mud — organically rich, easily disturbed and prone to becoming oxygen depleted; provide habitat for algae, bacteria, fungi and invertebrates, especially oligochaetes, nematodes and chironomids.
- Sand — highly mobile and prone to disturbance with lower concentrations of organic matter; regarded as poor habitat for macroinvertebrates, but can support algal and bacterial communities that may have a significant impact on water quality as flows move through the sub-surface region. Patches of sand may also support populations of highly mobile invertebrate such as shrimp.
- Clay — stable and can be rich in organic matter, but tends to be a relatively simple habitat; provides habitat for biofilm and invertebrates.
- Gravel — less mobile than sand with larger interstices. The greater stability tends to allow development of more extensive biofilm and this may attract collecting macroinvertebrates.
- Cobble — a far more stable substrate found in higher currents. The stability allows for the development of biofilms, while the shape and packing of the cobbles creates a diverse hydraulic environment. The spaces between cobbles also allow for the storage of organic matter and may provide refuge for some invertebrates. These attributes mean that cobbles support an abundant and diverse invertebrate community. Cobble beds are maintained by periodic high flows and are prone to being degraded by an excessive supply of fine particulate material.
- Boulders — provide many similar attributes to cobbles, but will have lower rates of tumbling disturbance. The less frequent disturbances means that boulders are suitable habitat for mosses, lichens, macro-algae and sedentary filter feeding invertebrates. The final community composition will depend on the flow regime and water quality.

The role of many of the identifiable riverine features as habitat is not well understood. As an example, floodplains are an obvious feature of lowland river ecosystems and yet the data we have for some relatively well known taxa (e.g. yabbies and fish) does not currently allow us to determine the importance of the floodplain as habitat. Other habitat types currently appear to be relatively insignificant in terms of diversity or abundance of animals (e.g. sand bars) and yet their loss or modification would probably affect species or habitats in ways that are currently difficult to predict. An example is that invertebrate abundance appears to be highest at the margins of lowland rivers, but management aimed at simply increasing the extent of the river margins at the expense of other features is unlikely to produce the desired outcome of improved riverine health.

The corollary to this is that we don't know much about the habitat requirements of many taxa and so we are forced to use broad generalisations. The consequence of this is that we tend to define habitats in terms of features at spatial and temporal scales that are obvious to us. Our limited knowledge and scale of perception helps explain the heavy emphasis placed on the habitat requirements of fish and macroinvertebrates. There are other taxonomic groups about which we have very little knowledge of either their habitat requirements or their role in determining river condition. Examples at the microscale include Zooplankton, Fungi, Micro-metazoa, Bacteria and at much larger scales, Turtles, Birds and Mammals.

Our ignorance of these and other groups of organisms may not be a major problem. The point of raising this issue is that we need to be cognisant of the fact that our habitat list and our assessment of habitats will be affected by our limited understanding of riverine ecology. This framework will, therefore, be based on the following assumptions:

1. Assessment of habitat at the three nominated scales will provide a good indication of habitat at other spatial scales.
2. Assessment of habitat for the taxa that we are familiar with will provide a good indication of the abundance and diversity of habitat for other lesser-known organisms.

Reference Approach

An Audit objective is to develop a common reporting framework for river condition assessment using comparable information, through time and across catchments. To do this the Audit has adopted a referential approach to enable all sites to be compared to a standard benchmark. The benchmark that has been adopted is "natural" condition. While not entirely free from confusion, the term natural is defined as the condition that existed prior to European development.

Natural condition is related to a river reach's geomorphology, flow and climate. In order to ensure that an appropriate benchmark is set for each river valley, it is important to choose an appropriate reference condition for each test site. One way of facilitating the process is to classify rivers according to their geomorphology. The classification system used by the Audit is the Functional Process Zone (FPZ) system.

Once the appropriate FPZ has been selected for a site, the assessment has to derive the data that describes that reference condition. There are a number of challenges associated with this, including these two:

- If examined in enough detail, every lowland river is unique and so differences between a test site and a nearby reference river may be due to differences in the natural condition of both rivers. This becomes a far more intractable problem for rivers in the west of the Murray-Darling Basin such as the Darling and Murray where there are no easily identified reference rivers.

- Many of Australia's lowland rivers are highly degraded and there is often very little information available from which to construct a description of a reference condition.

There are two broad approaches to describing the reference condition. The first is to use a similar river reach as a reference site and assess its condition in the same way that you assess the test site. This approach is seldom used in broad-scale monitoring programs, but is used in the assessment of particular activities, such as mining or urban development.

The second approach is to synthesise a reference condition. The way in which the synthesis is undertaken depends on the question being asked, the data available and the resources available to undertake the assessment.

One synthesis approach is to have an implicit reference system in which the reference condition is never defined, but remains as a pseudo-cognate model of a "healthy" river. The assessment can then be undertaken by scoring the test site against the assessors' concept of the "healthy" or "natural" condition. There are two problems with this approach. The first is that because the reference condition is not explicitly defined, there is considerable scope for subjectivity in the assessment. The second problem is that the reference condition is applied uniformly across all the rivers assessed. This is obviously inappropriate for an assessment that will be applied across the entire Murray-Darling Basin. Of course individual operators will modify their assessment of a particular reach depending on their understanding of what rivers in a region ought to look like. Unfortunately, this will only exacerbate the subjectivity of the assessment as different operators may have different views of what constitutes "healthy" or "natural".

A second synthesis approach is to use a number of reference sites to construct a model that enables prediction of the characteristics of a test site. In the case of physical habitat the models use large-scale variables that are not disturbed by natural resource development to predict test site characteristics. This approach reduces the problems associated with the unique character of rivers and has the potential to incorporate the extent of natural variation that we would expect into the reference description. An advantage of this is that it is possible to determine whether the test site falls within the range of natural variation observed at reference sites or whether the test site is significantly different. Unfortunately the approach suffers from the need for a number of sites that can act as "natural" reference condition from which to construct the model. As discussed earlier, this may present problems in a number of valleys, particularly in the west of the MDB.

A third approach would be to use the modelling approach described above, but either modify the data from the reference sites or alter the model predictions to compensate for the estimated anthropogenic impacts at the reference sites. This approach has not been employed up to this point, but it would address the issues of lack of disturbed sites and the unique character of rivers. The problem with the approach is that it introduces a level of subjectivity associated with the assessment of the degree of anthropogenic influence and subsequent manipulation of the data. An example of the sort of modification that is possible would be to choose reference sites and then assess the extent of their departure from natural through an evaluation of the flow regime and catchment management. This modification would allow the assessment of a test site to be corrected for the degradation present at the reference site by, for instance, reducing the O/E score by an agreed value. The problem with this approach is that a test site may, over time, come to resemble the reference site. This may mean that the site is improving in condition, or it may mean that the two sites share a type of degradation. In other words this method does not allow determination of whether a test site is recovering toward natural.

The final approach would be to use all the data available (e.g. ecological, historical, anecdotal, paleolimnological) to synthesise a quantitative description of the natural reference condition. While theoretically possible, there are a number of issues associated with the lack of historical data on many attributes of rivers. We do not currently believe that this approach is possible, but believe that ultimately this approach is the most desirable and therefore some effort should be invested in developing a transparent, repeatable process of synthesising a reference description from a diverse array of data.

Recommendation

We recommend that descriptions of reference condition be synthesised from models developed from reference site surveys and the application of E-Ball technique (Linke 2000). The models would be generated from large-scale variables that are not affected by natural resource development. Variables would include river order, Functional Process Zone, climate and geology. Where possible, the reference site description would incorporate historical data so that the model reference condition is as close as possible to the natural condition. We also strongly recommend that considerable effort be invested in developing techniques for integrating disparate data to enable a better description of the "natural" condition of river reaches.

In many Valley Process Zones, the reference sites and the test sites will be on the same river due to the lack of suitable reference rivers. This situation is less than desirable given the broad scale at which many stresses occur throughout the Murray-Darling Basin. In these cases, we recommend the following criteria be used in the selection of reference sites (modified from Coysh and Norris, this volume).

1. Sites within the lowest 10% of agricultural development as assessed by the examination of floodplain transects. This will minimise the impacts of agricultural development on floodplain connectivity, habitat heterogeneity, groundwater movement, nutrient dynamics and drainage to the river.
2. Sites within the lowest 10% grazing pressure as assessed by the examination of floodplain transects. This will minimise the impacts of grazing and trampling on riparian vegetation, floodplain litter cover and bank erosion.
3. Sites within the lowest 10% of catchment disturbance as assessed by the examination of floodplain transects. To minimise the impacts of mining, clearing and towns.
4. No major urban area within 50 km upstream. This will help minimise the impact of pavement area, storm-water run-off, recreational impacts and sewage treatment plants.
5. Sites without any significant point-source wastewater discharge
6. No dam or major weir within 50 km upstream, nor should the site fall within the upstream influence of any regulatory structures.
7. Flow regime in the 10th percentile of least affected flow regimes in a Valley Process Zone. In some Valley Process Zones this parameter will be become a subjective assessment of which type of flow modification is the least damaging to the river.

These sites need to be surveyed using the indices described below and the data used to generate models of reference condition from which descriptions of reference condition can be derived.

Additional Problems with Referential Approach when assessing physical habitat

One of the largest problems associated with physical habitat assessment is the extent of temporal variation experienced by rivers and streams. In many cases variation in flow and the delivery or erosion of sediment is essential in determining the type, extent and availability of habitat. Physical habitat assessment is undertaken at discrete times that may not provide a good indication of the habitat at other times. Monitoring agencies are faced with a trade-off between the spatial extent and the level of detail of their monitoring programs. This trade-off would mean that determining the extent of temporal variation would lead to the significant loss of sites from the monitoring program. Unfortunately, this does not resolve the issue that any assessment based on a limited number of assessments at a given site may be compromised due to the lack of information about changes through time.

One apparent solution to this dilemma would appear to be the collection of data in a spatially explicit form. This would enable the synthesis of physical habitat and hydrological data to model the temporal characteristics of physical habitat at a site. While this sort of analysis has not yet been undertaken, there are a number of researchers who currently have techniques that could be bent to this task. These techniques include:

- models of the relationship between channel morphology and hydraulic conditions, being developed by Mike Stewardson at CRC for Catchment Hydrology (Melbourne University).
- spell analysis to determine the impacts of water resource development, being developed by Martin Thoms at the CRCFE.
- GIS flood-inundation models developed for the Riverland by SARDI and the MDBC.

Our conceptual model states that physical habitat is the result of the interaction of flow and geology. This implies that habitats are created and maintained by dynamic processes within the river. The consequence of this is that any audit of physical habitat will provide only a snap-shot of the physical habitat present during the sampling. In order to be able to predict whether that habitat will persist requires some assessment of the processes required to maintain that habitat in that condition. Examples of the sorts of processes that can be important follow.

Riparian regeneration:

If the riparian vegetation is not actively recruiting, then at some point in the future the vegetation will be lost as old trees die.

Sediment transport:

Riffle habitats are created by the erosion of fine sediments from amongst the cobble matrix. If the dynamics of sediment transport change, then the result may be an increase in sediment deposition and the loss of riffle habitats.

Erosion:

Many lowland rivers are in dynamic equilibrium with their floodplains. The erosion of banks and re-deposition of sediments is an important process in the creation of billabongs, in-channel benches, pools and sand bars. Both excessive and inadequate rates of erosion can lead to the loss of habitat.

A number of the existing monitoring programs include some assessment of these processes, which are incorporated into their assessment of river condition. While the importance of these measures cannot be underestimated, it is important that they be carried out in the same manner as other indices. In the case of the Audit this will mean adopting a referential approach and comparing rates of erosion or riparian regeneration to those observed at reference sites rather than assigning scores which, given our limited understanding of these processes, tend to be value laden.

Recommendation:

That considerable effort be invested in improving our ability to describe the reference condition in terms of both its physical and chemical characteristics and its spatial and temporal variability. A number of techniques are currently being developed that will significantly improve our ability to undertake this task and therefore we anticipate rapid progress.

Review of Habitat Assessment

As with any investigation, the sampling design is determined by the question and the resources available. We have addressed the issue of what questions ought to be asked in the “Conceptual Model” section. In this section we discuss the issue of the allocation of limited resources to the assessment of stream condition. In general, the existing programs have focussed on developing rapid, cost-effective techniques that require minimal technical expertise. For the agencies, these have the advantage of minimising the costs associated with training personnel, and then collecting, processing and analysing data. The following is a review of the major existing programs.

AUSRIVAS — National

AUSRIVAS was initially based on the RIVPACS approach and subsequently standardised under the NRHP methods (Davies *et al.* 2000). The AUSRIVAS method is directed towards the assessment of invertebrate health in riffle and edge zones. As such, in-stream habitat characteristics are noted, rather than the characteristics of pool habitats. Characteristics relevant to in-stream habitat recorded by the AUSRIVAS method are presented in Table 1.

Table 1. Instream habitat variables measured as part of the AUSRIVAS protocol (source: Davies *et al.* 2000)

Local scale habitat features	Reach, riffle and edge specific characteristics	Habitat assessment variables[a]
Stream width (m)	% bedrock	Substrate (categories 0-20)
Bank width (m)	% cobble	Embeddedness (categories 0-20)
Bank height (m)	% pebble	Channel alteration (categories 0-15)
% riffle area	% gravel	Scouring (categories 0-15)
Riffle depth (cm)	% sand	Pool/riffle run/bend ratio (categories 0-15)
Riffle flow (ms^{-1})	% macrophytes	Bank stability (categories 0-10)
% edge area	% detritus (sticks, wood, CPOM)	Vegetation stability (categories 0-10)
Edge depth (cm)	% muck/mud	Vegetation cover (categories 0-10)
Edge flow (ms^{-1})	% of habitat covered by periphyton, moss, filamentous algae, macrophytes	Habitat score (total of habitat assessment variables)

[a] categories are based on a visual assessment of poor to excellent. Descriptions of what to expect for each score are provided as part of the assessment procedure.

In addition, Davies *et al.* (2000) have measured a range of catchment-scale variables and developed a model that predicts local stream habitat based on the measured catchment-scale variables. This model has been used to compare observed versus expected habitat at reference and test sites in a way similar to the AUSRIVAS model for predicting invertebrate observed versus expected scores.

The habitat characterisation and assessment method used by AUSRIVAS is comprehensive, although as indicated above it does not consider pool habitats. Also, the AUSRIVAS habitat assessment is basically a characterisation process. It provides an indication of habitat diversity based on patch areas, but no links are made to in-stream processes that may be important for ecosystem health. The complexity and location of in-channel habitat, e.g. snags and islands, are not considered, nor is the shape of features such as sand bars, benches and banks.

Recently, a review of physical habitat assessment methods related to the AUSRIVAS program has been conducted (Parsons *et al.* 2000) and a new physical assessment protocol for AUSRIVAS recommended (Parsons *et al.* 2001). This protocol is compatible with the AUSRIVAS biological protocol and is designed to provide a predictive capability to habitat assessment based on the work of Davies *et al.* (2000).

Index of Stream Condition — Victoria

The Index of Stream Condition (ISC) is a technique developed in Victoria for benchmarking the condition of streams, to assess the long term effectiveness of management intervention and to aid in objective-setting by waterway managers (NRE 1997). Specifically, the ISC process involves the calculation of a condition rating for a range of components or sub-indices, namely:

- Hydrology,
- Physical form,
- Streamside zone,
- Water quality,

- Aquatic life.

The sub-indices are totalled to provide an overall condition rating relative to natural or ideal condition for that particular stream type.

The development of the Physical form sub-index involved an assessment of a range of possible indicators and settled on four indicators:

- Bank stability,
- Bed condition,
- Influence of artificial barriers, and
- Density and origin of large woody debris.

Several indicators were assessed for their suitableness including bed composition, embeddedness, sedimentation and proportion of pools and riffles, but were dismissed as it was concluded that they were difficult to measure on a statewide basis because of the large natural variation on these indicators (NRE 1997).

While the Physical form sub-index of the ISC method provides a general assessment of in-stream condition and may be suitable for assessing changes based on future management intervention, indicators are subjective and based on visual assessment (except for artificial barriers) and its focus could be considered narrow. Assessment against natural or ideal condition is implicit based on the rating system with low values implying poor condition and high values excellent condition.

River Styles — NSW

The River Styles™ approach classifies the zones as good (close to natural), moderate (degraded but with potential to be rehabilitated) and poor (heavily degraded with little prospect for rehabilitation). Currently, approximately one third of NSW MDB has been mapped using this approach with the remaining two-thirds expected to be completed 2003–2004. The approach examines geomorphic characteristics, riparian vegetation, river behaviour and the capacity for river adjustment. The indices assessed include:

- channel geometry,
- channel planform,
- bed/bank composition,
- flow diversity and volume of sand/gravel bedload,
- channel geomorphology including descriptions of pools, riffles benches and banks,
- floodplain geomorphology including presence and descriptions of floodplain habitats,
- riparian vegetation coverage,
- river behaviour including a description of the sediment regime and erosion,
- channel slope,
- catchment area.

The river styles approach is designed to provide guidance to managers to enable determination of rehabilitation priorities.

Pressure–Biota–Habitat — NSW

The Pressure–Biota–Habitat (PBH) assessment approach is under development in New South Wales. The method is currently being trialled in 12 NSW sub-catchments. PBH generates three indices related to human pressure, the biota and physical habitat. Included within the Physical Habitat Index are a range of flow, structural and process indicators that are measured and related to invertebrate biodiversity. indicators include:

- substratum size,
- channel depths,
- bank alteration,
- bank stability,
- bed stability,
- riparian vegetation,
- overhanging vegetation,
- aquatic vegetation,
- overhanging banks,
- large woody debris.
-

State of the Rivers — Queensland

The Queensland DPI State of the Rivers is a comprehensive assessment of a range of indicators including reach scale, riparian and in-stream vegetation and in-stream channel form and habitat types. The program is based around a series of detailed data collection sheets that reduce the need for technical expertise among the field operatives. Specific in-stream indicators include:

- channel habitat (%, depth, length and width of channel type, e.g. waterfall, cascade, rapid, riffle, glide, run, pool, backwater);
- cross section (bank slope, height and width, channel depth cross sections and flow profiles, sediment classification, e.g. percentage fines, sand, gravel, cobble, boulder, rock, detritus);
- aquatic habitat (percentage cover of individual logs, log jams, individual branches, branch piles, tree roots, leaves and twigs, macrophytes, periphyton, bank overhangs, overhanging vegetation, canopy cover);
- bed and bar conditions (bar types, shapes and angularity, bed compaction, factors affecting bed stability, degree of passage for aquatic biota);
- bank condition (location and type of erosion on upper and lower banks, bank shape, presence of levee banks).

The State of the Rivers approach is based on a proportional assessment of habitat features, similar to but more comprehensive than the AUSRIVAS approach. Using this technique, reaches are characterised based on their habitat features. An assessment of condition would need to be made based on a comparison to a reference condition based on a geomorphic classification.

Other assessment approaches

There are a range of other assessment techniques where in-stream habitat is measured (e.g. CSIRO, Border Rivers IMEF). These techniques are based on categorical qualitative assessment or proportional assessment of habitat patches similar to the methods already described above.

The Audit is committed to a referential approach and as such we believe that the reference condition will be described quantitatively. This implies that the assessment of the test site will also be quantitative. The issue then becomes how the necessary data could be collected as cheaply as possible. The best solution is offered through a mix of remote sensing and ground truthing. The trade-off with remote sensing is that it is an emerging field and that desktop analysis reduces the knowledge gained by field workers as they survey the sites. While we acknowledge this trade-off, remote imagery will provide a valuable information resource that will both complement and add value to the knowledge retained by agency field operatives.

A further characteristic of the assessment protocol is that the reason that a particular metric is being measured should be explicit. In a number of the existing agency monitoring programs there is no clear conceptual model, and so habitat assessments are mixed with measures of biodiversity and process measures that make sense to the designers of the program, but add little to the transparency of the assessment. We therefore recommend that habitats be defined in terms of their physical/chemical characteristics, the organisms that use the habitat or the process being measured, and the reason for its measurement.

The trade-off between cost and information has an impact on the sorts of variables measured. Spatially explicit data is the most information rich and expensive to collect and analyse. Our conceptual model indicates that the spatial arrangement of habitat within the river-floodplain system may be important and therefore the collection of this type of data is desirable, although our knowledge of the relationship between habitat structure and riverine ecology is currently poor. Because it is the highest resolution data, it can be easily reduced to less information-rich data formats such as abundance, areas, % contributions, ranks or presence–absence data. Where we see no cost penalty for the collection of spatially explicit data we have recommended its collection in this form. This emphasis will be assisted by the use of remote sensing, as the images will ensure a data record that could be reinterrogated as techniques improve and the need arises.

Analysing Data from the Habitat Assessment

Once the habitat assessment is completed it is then necessary to compare the target site to the reference condition. Reviews of analysis of assessment data have been undertaken by a number of authors, and so we will only briefly examine the approaches available. Selection of a data comparison technique depends on both the question being asked of the data and the type of data collected.

Index Scores

If the assessment generates a score, then the score represents the result of a comparison with an implicit reference condition and a determination of the significance of that difference. As a consequence, there is no need to undertake any statistical data comparison. It is interesting to note that several of the scoring systems have four or five bands, implying that agencies currently regard a 20 to 25% departure from reference as significant.

A variation of this technique is the IBI approach in which a number of indicators are combined to produce a score for the site which is compared to the score of a reference condition which is the combination of the maximum score for each indicator.

ANOVA comparisons

These techniques are based on the collection as if the impact on the target site were a treatment in an experiment. This immediately causes a problem because, in most cases, managers are interested in assessing the condition of a single site and not a suite of replicate sites. A partial solution to this is to assess multiple reference sites, but this results in an unbalanced design, and even under the best conditions limited power to detect differences.

Ordination

A variety of ordination techniques can be used to compare target and reference data. These techniques provide a means of quantifying the difference between sites, which are then expressed as scores that can be plotted. There are two problems associated with the application of most ordination techniques to assessment data. The first is that the ordination process involves the loss of information. The second is that the analysis is unique to the data being analysed and so it is not possible to standardise the differences between target and reference sites across the Murray-Darling Basin. This means that this type of analysis would fail one of the requirements of the Audit.

Canonical Analysis

A form of multivariate analysis that examines correlations among the differences of two data sets. This technique could be used to examine the differences between sites in terms of large scale factors such as catchment area, slope stream order and then compare these to differences between the physical habitat measurements. The conclusion from the analysis would be that differences not correlated with the large scale variables would be due to disturbance at the test site.

O/E values

The Observed over Expected methodology employed by RIVPACS and AUSRIVAS uses multivariate techniques to describe the reference condition. The technique generates a model of community structure, which then predicts which taxa have a 50% probability of occurring at a site and then compares this value to the number of taxa observed. Making predictions about the number of taxa found at the reference sites validates the model and this validation is used to generate a distribution of O/E ratios against which assessments can be made. An O/E below the 10th percentile indicates a significant departure from the reference condition. The method is designed to assess the loss of diversity usually associated with anthropogenic stress. The technique has been modified for use with physical habitat assessment through the conversion of habitat variables to categorical variables (REF), such that, for example, 0–10% bedrock might be considered one category while 11–25% bedrock might be considered a separate category. This approach has the advantage that it provides a single value for the condition of the site and a list of the parameters that are different from the reference condition. The authors regard the possibility that replacement of one habitat category by a "better" habitat category may lead to an erroneous assessment. As discussed earlier, we do not believe that this is a valid concern as it is not currently possible to describe habitats as good or bad, merely as different from the reference, which, when the reference is "natural", is regarded as undesirable.

The problem with this approach is that, like any technique developed for one purpose and subsequently modified for another, compromises have been made. In this case, the AUSRIVAS technique is based around the presence of taxa with macroinvertebrate community diversity expected to decline in response to disturbance. Thus the question addressed is "has the number of taxa declined significantly?" In the case of physical habitat assessment the question is "has the amount, type and availability of habitat changed significantly and if so, by how much?" AUSRIVAS use of categories and the exclusion of species with less than 50% probability of occurrence at a site will lead to the loss of information and seem inappropriate for the measurements obtained when assessing physical habitat.

An alternative technique is the E-ball methodology (Linke, 2000), which uses raw data rather than categorical data to describe the reference condition. E-Ball differs from AUSRIVAS because it avoids the classification step, and rather than simply predicting presence/absence of taxa E-Ball allows the prediction of continuous variables such as those in habitat data-sets. Rather than make predictions based on linear models like the Discriminant Function Analysis used in AUSRIVAS, E-Ball actually compares test sites to a number of reference sites. However only reference sites that are most like the test site based on large scale variables (such as Geology, Latitude, Functional Process Zone) are used in each comparison. Simplified, the steps in the E-Ball analysis are:

- ♦ Ordinate the reference sites in large-scale variable space
- ♦ Position the test site in the above ordination space
- ♦ Calculate the Euclidean distance of the test site from the reference sites according to the large-scale variables
- ♦ Select the reference sites that are most similar to the test site according to the large-scale variables
- ♦ Predict the value of the small-scale variables expected at the test site (these are weighted averages according to the Euclidean distance from the reference sites)
- ♦ Compare each of the observed small scale variables at the test site to those predicted
- ♦ Combine the Observed to Predicted values in an O/E index for the site.

This overcomes a number of the AUSRIVAS limitations, but it still requires multiple reference sites to generate a predicted reference condition. The E-ball technique also allows assessment of numerical data although this has not yet been undertaken in any assessment program. Varying statistical distributions are accounted for by range and variance standardisation in the calculation of Euclidean distance from the test to the reference sites. The variables used to calculate the expected values are always measured at a higher scale than the variables being predicted. Despite the novelty of this approach it appears, at the present time, to be the most appropriate analytical tool available.

Recommendation:

We recommend E-ball analysis (Linke 2000) be used to compare test site observed data to the expected data generated by the E-Ball models.

Proposed Assessment Protocol

The proposed assessment protocol uses a combination of remote sensing and field data collection that will allow an assessment of physical habitat at three spatial scales. The data collected will allow a rapid assessment of the amount and type of habitat available, but our objective is to collect data in such a way that more detailed analysis of the temporal characteristics and spatial arrangement of habitat will also be possible as appropriate techniques are developed.

The assessment will be undertaken once every five years, as most of the recommended variables change over relatively long time periods. Some of the small-scale variables do change over shorter time-periods. We recommend that field staff undertaking assessment of other components of the Audit be provided with photographs of the site and summary information to enable a rapid visual assessment of any changes that may have occurred. This information will enable determination of the rates of change of variables and a better understanding of temporal variation in physical habitat. This information would be included in measures of temporal variation as they are developed.

At each site the assessment will be based on four replicates of three types of transects (floodplain, riparian and channel; Figure 1) across the river and its associated floodplain. Transects should cover the geomorphic variation present in a river reach (e.g. inside curve, outside curve, straight section, pool). As a consequence a site may vary from a few hundred metres of river to several kilometres depending on meander length. A similar approach has been adopted by the Victorian ISC.

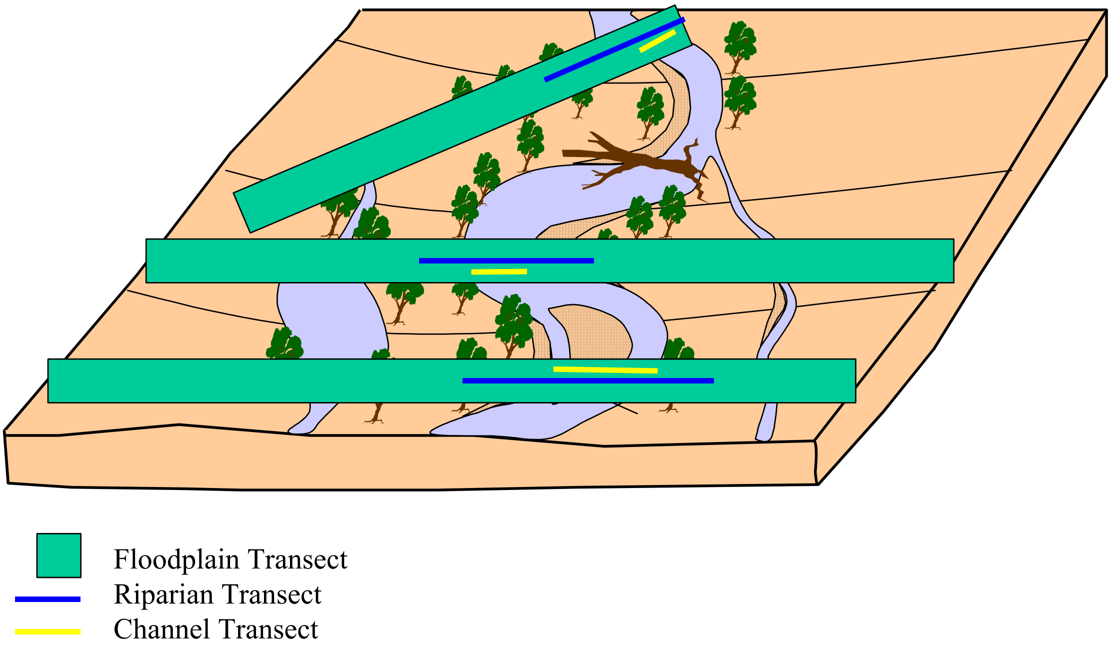

Figure 1. Illustration of types of transects

The first step in the assessment will be to obtain orthophoto imagery of each site. As many indicators as possible will be assessed from this imagery. The site image will then be printed out and associated with with a data sheet, similar to those developed for the Queensland State of the Rivers Program. Field operatives will ground truth the remote analysis and assess those indicators that cannot be measured remotely using the images and data sheet. The benefits of this approach are that:

1) the imagery represents a valuable source of data that can be reanalysed in the future as our understanding of physical habitat improves;
2) the use of remote sensing will save considerable time and labour while allowing quantification of variables that would not otherwise be possible given the limited resources;
3) the imagery will provide an invaluable aid to field personnel, much as the photographs currently taken for the Victorian ISC represent an invaluable aid to their field operatives;
4) for a number of indicators, this approach will ensure a level of quality assurance with indices being cross checked by two sets of personnel and two techniques.

Floodplain

Assessment of the floodplain could be carried out to a similar level of detail as the river itself, but the costs would be excessive and the level of knowledge required is not available throughout the MDB. We therefore recommend an approach that will primarily assess the diversity and relative abundance of the major habitat types found on floodplains.

The assessment will involve identifying a 100 m wide transect through the river using the remote imagery. The transect length will vary depending on the width of the floodplain and the FPZ, but should extend to the 1 in 100 year flood extent. Cost savings could be achieved through the selection of the 1 in 50 year limit. The 1 in 100 is currently mapped in most valleys. The proportion of the transect occupied by the major habitat types will be determined. This is a relatively straightforward procedure in GIS packages such as Arc-View. The major habitat types expected to occur would include:

- floodplain vegetation types,
- grazed pasture,
- irrigated horticulture,
- natural flood-runner,
- billabong,
- wet meadow (<1 m depth),
- shallow wetland (1–2 m deep),
- lake (>2 m deep).

The exact habitat categories will depend on the FPZ and the reference condition. Once this assessment is complete, the characterisation would be printed out for confirmation on the ground. Once the various habitat types had been confirmed, the assessment would compare the diversity of habitat types and their areal contributions to those found in the reference condition.

While this form of assessment is much more detailed than the existing programs, once imagery is obtained, a relatively simple analysis will provide considerable information.

Channel Features

Banks

Bank slope is determined by survey techniques. The bank is divided into high and low bank and an assessment of bank shape can also be made, e.g. undercut, convex, stepped etc. Assessment of bank slope and shape should be made at least at the 4 points where the floodplain transects cross the river. This will ensure that the range of geomorphic locations within a reach (e.g. point bars, inside bends) are sampled. Banks can also be assessed for erosion type and extent, slumping, lateral scour, local scour and aggradation. This assessment should be applied to upper and lower banks and based on the proportion of bank impacted. The Queensland State of the Rivers Bank Condition Sheet 7 provides a suitable approach to measuring the above bank condition indicators.

Riparian Vegetation

Riparian vegetation is one of the most important plant communities forming the structural and functional framework for riverine ecosystems in Australia. Vegetation in this zone performs a range of ecosystem services which affect the functioning of other ecosystem components and the quality of in-stream habitat, including primary production, provision of detritus, filtering, sediment stabilisation, water and nutrient cycling and groundwater recharge mediation. Interactions between these plant communities and other aspects of physical habitat (e.g. geomorphology, physico-chemical environment, flow patterns) form feedback loops which continually reshape the dynamic physical characteristics of rivers. Additionally, riparian vegetation represents a major contributor of habitat for both terrestrial and aquatic fauna, including aquatic macroinvertebrates, fish, crayfish, insects, platypuses, water rats, birds, frogs and reptiles.

Aspects of physical habitat that affect its value to associated fauna are the quantity, quality and heterogeneity of habitat elements available. Abundance, patch size and connectivity, and the importance of gaps in relation to the area of existing vegetation are important to faunal population sizes, diversity, movement, foraging and persistence. The proportions of native and introduced species comprising the riparian vegetation at a site are correlated with faunal diversity. Habitat complexity including niche diversity and temporal & spatial variability of connectivity have a profound influence on the nature and interactions of associated faunal assemblages. Heterogeneity is supplied by variations in vegetation biodiversity, density, canopy complexity, demographics of live and dead biomass, vegetation overhang and the interactions of these elements. Usage of different habitat patches can vary over a range of temporal and spatial scales, demonstrating the importance of habitat heterogeneity to aquatic systems.

Development of riverine areas and increased demand for water has led to modifications to channel morphology, water quality and flow. These indirect effects have combined with direct manipulation of habitat components such as riparian vegetation, snags and channel features such as sand and gravel bars, resulting in significant impacts on the physical habitat of our riverine ecosystems. These pressures necessitate the development of improved methods for assessing impacts on physical habitat, which attempt to describe the quantity and quality (including heterogeneity) of habitat present at a site. Current models of river ecosystem condition assessment measure only a limited number of components of community structure. These methods tend to overlook the importance of having the processes, which maintain this structure in place and working efficiently. More in-depth and meaningful structural analysis is required, as is a better understanding of habitat maintenance processes, potentially threatening processes and future trends. The hypotheses proposed relating habitat diversity & abundance with species diversity, abundance & persistence require data on the abundance, integrity, connectivity, temporal and spatial variability and projected persistence of different habitat types. The indicators of habitat condition selected to assess riparian vegetation meet these requirements and are outlined below.

Species richness and diversity

Habitat heterogeneity is generally associated with higher levels of faunal diversity — one aspect of heterogeneity in river ecosystems is riparian vegetation biodiversity. The proportions of native and introduced species comprising the vegetation diversity at a site have implications for native terrestrial fauna (due to differences in food availability, habitat and nesting sites) and for the timing, quantity and quality of inputs to the channel (leaf litter and large woody debris). Interactions between different species create feedback loops affecting species richness and diversity, with competition by introduced species reducing native diversity through shading, allelopathic exudates and excessive growth.

Determination of this indicator involves the assessment of the number of species present standardised by abundance. A range of commonly used indices exist for assessing species richness and diversity, and are generally interpreted as indicators of the community's stability and capacity to respond to disturbance. Calculating these indices is often considered labour intensive due to the need to identify and count all species. This can be overcome by sampling and assessing large (primarily woody species) and common (those that comprise more than 5% of canopy cover) vegetation only within 10–30 m quadrats, limiting the taxonomic expertise required and allowing rapid assessment of large areas. Difficulties arise when attempting to make direct comparisons of absolute index values across sites because some ecosystems naturally have low richness or diversity and are not necessarily less resilient or stable. The implications of richness and diversity for ecosystem health assessments rely on comparison with an appropriate reference condition.

Measurement of this indicator will be undertaken by determining the dominant (defined as those species that comprise more than 75% of canopy cover) tree and shrub species present in a reach using on-site assessments along 4 transects. The length of the transects will depend on the width of the riparian vegetation zone, unless the riparian zone is greater than 100 m in which case the transect will be limited to 100 m. These assessments would follow the technique employed by AUSRIVAS and Queensland State of the Rivers program for macrophytes, where field operatives are provided with a checklist of the major species expected at a site, and they record presence and percentage cover. On-site differentiation requires some skills at plant identification, and would be facilitated by assessment during the early summer growth flush. As transects will be continuations of those used for channel mapping, selected on channel sinuosity rather than specifically as being representative of the reach vegetation, verification of species abundance and distribution along the transects to the reach scale will be required. This would utilise high-resolution multi-spectral digital aerial photography. Different proportions of water, lignin and chemical constituents in leaves, and leaf shape and texture produce variations in spectral reflectance from canopies of different species. These differences in spectral reflectance can be detected by comparisons of different wavelengths of remote digital imagery, which produce the most reliable data if performed during the peak vegetation period (early summer). Comparisons using remote sensing could also be made based on deciduous or evergreen habitat, requiring assessment in early winter. Verification of transect assessments would involve referencing the distribution of species recorded during fieldwork to the digital imagery by determining the location of each transect in the image and comparing the spectral reflectance of the canopy at this location to the rest of the reach. Data reported would be number of species, % native species, richness and diversity indices (calculated using relative abundance data), and a species list (divided into native and introduced) for each reach.

Relative abundance

Relative abundance is estimated by a set of measurements contributing to the assessment of habitat quantity and quality (based on species' preferences for different vegetation densities) provided by riparian vegetation. Additionally, performance of certain ecosystem functions such as nutrient filtering and reduction of sediment run-off are related to vegetation density. As with the measures of diversity, absolute abundance values are meaningless for assessing habitat condition without comparison to an appropriate reference condition, or through monitoring over time. Significant changes over time may indicate increasing impacts on the ecosystem, and can have an effect on the habitat value of the vegetation. The relative proportion of native and introduced species comprising the vegetation biomass at a site has impacts on the native fauna present. Changes in the area of native vegetation per biogeographic region are correlated with faunal diversity — clearing or replacement of native vegetation with exotic species causes reductions in faunal diversity.

Relative abundance data would be obtained from low labour on-site assessments using 3 replicate quadrats per transect and Bitterlich assessment of basal area. Quadrat size will depend on vegetation density with smaller quadrats (10 m radius) used in dense vegetation and larger quadrats (30 m radius) used in sparsely vegetated regions. Basal area and stem density of the dominant riparian species should be assessed during the peak vegetation period in early summer, noting proportions of native and introduced species. These methods are established practice and are commonly used by forestry staff and ecologists. They are simple and rapid, requiring minimal technical expertise. Data would be reported as basal area and stem density (noting % native) for quadrats, scaled to the whole reach on an aerial basis.

Riparian Width

Patch size has been shown to be a particularly significant factor determining habitat quality of native vegetation to terrestrial fauna. In riparian communities, width of vegetation is the important dimension affecting the zone's value as habitat. The performance of certain ecosystem services which impact on the quality of in-stream habitat is also affected by the width of riparian vegetation (such as filtering nutrients and sediments, affecting groundwater depth & recharge, impacting on local water cycling, retaining banks and reducing erosion). Riparian width is measured as the distance from the edge of the channel to cleared or developed land. It should be reported in relation to channel width for comparison to a reference condition. For sites with an obvious floodplain greater than 30m wide, this indicator should extend to encompass assessment of floodplain vegetation. An adaptation of the method used in the Queensland/NSW Border Rivers Flow Management program would involve measurement of the average width of the floodplain along a reach and the density of floodplain vegetation.

Riparian and floodplain width and % coverage of the floodplain with woody vegetation can be measured from aerial photography. This method is rapid, reliable and requires no ground-truthing or technical expertise. Average riparian and floodplain widths for each reach should be reported in raw distance units and as a proportion of channel width, while floodplain vegetation data is reported as % coverage of the floodplain with vegetation.

Habitat Fragmentation

This indicator combines "Longitudinal Continuity" of the Victorian ISC program and the concept of patch size based on the ratio of edge to area for vegetation patches. The indicator provides information on riparian vegetation patch size and connectivity, and the importance of gaps in relation to the area of existing vegetation, which are important to the diversity, movement, foraging and persistence of terrestrial fauna. The occurrence of vegetation directly adjacent to the river channel is an important aspect of habitat quality. Continuity of streamside woody vegetation is also important to ensure the ecosystem services provided by width are performed along a significant proportion of the stream length. The indicator is comprised of 4 components:

- the vegetated stream-length (length of bank with vegetation (trees and shrubs) greater than 5 m wide),
- the number of significant discontinuities (gaps greater than 10 m long and with a width of at least 0.5 x the average width of the vegetation),
- the average patch size (ratio of edges to area of vegetation patches), and
- connectivity between vegetation patches (average length of significant discontinuities).

Measurement of lengths and widths of riparian vegetation and gaps, and calculation of edge to area ratios of vegetation patches can be obtained from aerial photos preferably imaged during the middle of the day in early summer. Data should be reported as raw counts and distance measurements for both banks, with vegetated stream length also calculated as a percentage of reach length, and connectivity also expressed as a percentage of vegetated stream length. This is a simple, rapid method requiring no field validation.

Riparian Canopy Complexity

Habitat complexity and connectivity have significant effects on the structure and interactions of associated faunal assemblages. Variation in the proportions of different canopy layers provides a source of heterogeneity in riparian habitat quantity and quality, with connectivity between the different elements and proportions of native canopy also important. The proportions of the riparian zone covered with deep or shallow rooted vegetation vs bare ground is important for catchment water cycling and groundwater depth and recharge, with an increase in shallow rooted vegetation or bare ground generally having a detrimental impact on catchment hydrology. Information on these aspects can be inferred from assessment of canopy complexity, as canopy type is correlated with root penetration depth. This indicator provides an assessment of the different canopy levels present at a site, by comparing the percentage cover of the following canopy categories (adapted from the Victorian ISC program):

- trees (woody plants over 5 m tall, usually with a single stem, e.g. eucalypts, banksias, acacias, willows),
- shrubs (woody plants less than 5 m tall, frequently with many stems arising at or near the base, e.g. Melaleuca, Leptospermum, tree ferns, blackberries),
- understorey (non-woody plants up to 1.5 m tall, e.g. sedges, reeds, saltbush),
- herbs & groundcovers (non-woody low-growing plants, e.g. grasses, Persicaria, Ranunculus).

Determination of the appropriateness of current canopy complexity for the site is based on comparison of the different proportions of each storey to a reference condition. The indicator may also reveal areas potentially at risk from waterlogging or salinisation through groundwater changes.

While the majority of data for this indicator would be obtained through on-site visual assessment of the four riparian transects, remote sensing can provide information on percent cover of the uppermost canopy levels (detection of lower canopy cover may be possible in areas of low density vegetation). On-site assessment of percent cover of each canopy layer would be performed along the four riparian transects. Similar methods have been used by the Victorian ISC program and researchers developing rapid vegetation appraisal techniques. No technical expertise is required — the method is based on a simple classification of percent cover data into well-defined vegetation growth form categories, reporting native and introduced cover for each canopy layer. Areas potentially at risk from waterlogging and salinisation due to impacts on catchment groundwater should be noted for targeting in future assessments. Assessment of this indicator would be performed concurrently with on-site measurements of relative abundance.

Riparian Demography

Variation in demographics of the riparian vegetation at a site is another source of habitat heterogeneity within the streamside zone. The presence of a range of age-classes of vegetation, including standing and fallen dead, is important for faunal diversity and persistence. Targeting of specific age-classes of vegetation in different life stages means that a diverse demography is essential for the completion of these life cycles. The spatial and temporal arrangement of different elements can also impact on the success of life stage transitions — the habitat type required for the next stage must be available and within a distance compatible with the organism's dispersive abilities for the transition to be successful. Representation of a range of age-classes amongst dead biomass is just as important as among the living — there is a range of different sizes and arrangements of twigs, holes and hollows, different densities of wood and ratios of bark to core in different aged vegetation. Fallen dead are important to a range of ground-dwelling fauna while standing dead are used by flying or climbing species. As with many of the other indicators assessing the habitat value of vegetation, the usefulness of this indicator relies on comparison to a reference condition before comparisons between sites can be made.

Measurement would involve on-site assessment of abundance of different age-classes (including standing and fallen dead) of major riparian plants along the four riparian transects. Definition of age-class categories for each of the major riparian species would be necessary. The dominant species may be operationally defined as those species that comprise greater than 75% of cover. No technical expertise is required — the method involves classification of relative abundance data into age-class categories. Assessment of this indicator would be performed concurrently with on-site measurements of relative abundance and riparian canopy complexity.

Standing Litter

Floodplain litter represents an important habitat niche for many terrestrial ground-dwelling fauna such as insects, reptiles, frogs, birds and small mammals. It also forms important ephemeral foraging habitat when floodplain inundation occurs. Abundance and composition of standing litter is a good indicator of anthropogenic impacts and has been shown to be a major discriminant of site condition when used in a rapid appraisal method for assessing ecological condition of riparian areas (Jansen & Robertson 2001).

Measurement of this indicator involves on-site assessment of the quantity of riparian leaf litter. Percentage cover of standing litter is estimated and then the depth of litter is measured at 10 replicate points along the riparian transects. This is a rapid and reliable method requiring no technical expertise or specialised equipment.

Vegetation Overhang

Overhanging vegetation provides a type of in-stream habitat patch, has implications for potential snag input and shades the water column, affecting water temperature and light availability. Overhanging vegetation is correlated with abundance and distribution patterns for a range of aquatic fauna. For macroinvertebrates, habitat heterogeneity (including habitat patches created by overhanging vegetation) plays a crucial role in the distribution and abundances of different functional groups. Crayfish show shade-seeking behaviour and their presence has been correlated with the proportion of channel overhung by plant canopy. Many fish show habitat preferences for areas with overhead cover including that provided by overhanging vegetation, which reduces predation risk by obstructing visual detection. Platypus and water rat burrows tend to be located in association with overhanging vegetation, and usage by other organisms relates to the provision of roosting, perching and calling sites (waterbirds, reptiles, frogs). Usage of different habitat patches often varies over a diel cycle and with life stage, demonstrating the importance of habitat heterogeneity to aquatic systems. Shading has implications for macrophyte and algal growth and can effectively ameliorate temperature extremes. The ratio of shade width to channel width has been used previously as an indicator of stream condition. Vegetation overhang or distance of canopy from the channel also has implications for the input of leaf litter and large woody debris to the channel.

Direct measurements of overhang (positive value) or distance from canopy to the channel (negative value) can be obtained from geo-referenced digital aerial photography. Reach averages for these parameters would be based on measurements at eight randomly selected positions along the channel edge. The area of canopy overhang can be determined from the aerial photographs, standardised by the average reach canopy cover (from the canopy complexity index) and reported in relation to the surface area of the reach (proportion of surface area shaded by overhanging vegetation). The method would require validation of remotely sensed canopy overhang and canopy cover measurements in the field. Limited technical expertise is required.

Vegetation Vigour

The vigour of the riparian vegetation community affects its current habitat quality and ability to provide future value as habitat. A range of methods can be used to assess the physiological condition of these plants, including assessments of sap flow, photosynthetic rates & efficiency, and analysis of pigment ratios and other tissue constituents. However, the majority of these techniques are time-consuming, require expert technical skills and expensive equipment and are generally targeted towards assessment of individual plants or small-scale monitoring. Remotely sensed spectral vegetation indices (SVIs) such as the Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Chlorophyll Absorption in Reflectance Index (MCARI) are commonly used indicators of vegetation vigour, and are regularly applied to large-scale assessments of condition in a range of vegetation communities.

Each index provides information on different aspects of the physiological status of the plant community and so a combination of indices, selected to complement each other, is most useful for assessing vegetation vigour and comparing different plant communities. NDVI is the most widely used SVI, and has proven especially useful for assessing dense canopies and estimating canopy absorption of photosynthetically active radiation (PAR), % green cover, transpiration and water use efficiency. SAVI is a modification of the NDVI with correction for background noise due to soil influences. It is more sensitive to structural canopy parameters such as leaf area index, biomass and leaf morphology, and is useful for assessment in areas with incomplete canopies. MCARI measures the depth of chlorophyll absorption of PAR, providing an indication of the photosynthetic efficiency of the canopy. The ability of these indices to detect small-scale responses associated with sublethal stress effects provides a short-term predictive capacity as to vegetation vigour and persistence.

Measurement of these indices is based on comparisons of different wavelength bands reflected by vegetation in multi-spectral digital imagery. This is a rapid method of assessment providing important data on vegetation condition, which are directly comparable across sites and to a large range of vegetation communities worldwide. The use of high resolution imagery for assessing these indices would require pixel averaging functions to be applied before analyses can be performed, necessitating high levels of technical expertise for this step. SVI analysis requires familiarity with imaging software, and could potentially be performed by the photogrammetry supplier during image processing. It is recommended that these indices be re-assessed no less frequently than every 5 years. Average values for each index for a reach should be reported, providing a broad assessment of the condition of riparian vegetation for that reach. Any areas determined to be in high-risk categories for vegetation persistence can be targeted for particular attention during future monitoring.

Emergent macrophytes

Macrophytes are important structural and functional components of riverine ecosystems, being highly productive, providing a source of detritus to the aquatic foodweb, and being involved in baffling, filtering, nutrient and water cycling, sediment stabilisation and water column gas exchange. These plant communities also represent a major source of stable substrate for epilithic production and habitat for aquatic fauna. Macrophyte beds are used by fish, macroinvertebrates, insects, waterbirds, frogs and reptiles as roosting, nesting, foraging, refuge, resting and mating habitat. Macrophytes receive poor coverage by most programs monitoring ecosystem condition in aquatic systems, with assessments based on presence/absence or aerial coverage only. We would recommend applying greater attention to assessing macrophyte communities, to collect meaningful data on the role of these plants in providing complex, high quality habitat, and, as they are good indicators of impacts on aquatic systems, responding relatively quickly to changes in river geomorphology, flow and water quality. The indicators selected to assess the habitat value of macrophytes cover aspects of the provision of habitat quantity, quality and complexity.

Species richness and diversity

The species richness and diversity in the vegetation community at a site provides information on habitat quality and heterogeneity, which are generally associated with faunal diversity. Macrophyte species richness and diversity have implications for fauna with respect to the provision of food, habitat and nesting sites, and on the timing, quantity and quality of inputs to the channel. Determination of these indicators involves the assessment of the number of species present standardised by the abundance of each species, with data reported by incorporation into calculations of various indices. Higher index values are generally considered to represent communities with higher stability and capacity to respond to disturbance. Calculating these indices is often considered labour intensive due to the need to identify and count all species. This can be overcome by assessing large and common vegetation only along transects, limiting the taxonomic expertise required and allowing rapid assessment of large areas. The assessment would be against a check-list of expected species. The implications of richness and diversity for ecosystem health assessments rely on comparison to an appropriate reference condition.

Measurement of this indicator involves determination of the dominant macrophyte species present in a reach using on-site assessments along the riparian and in-stream transects. Remote sensing methods may not be suitable for differentiating macrophyte species due to limited differences in spectral reflection of these plants. On-site differentiation requires some taxonomic skill, and would be facilitated by assessment during the early summer growth flush. Assessment of this indicator in autumn or winter should be avoided as the seasonal growth patterns of many macrophytes result in a paucity of above-ground material during these seasons, making identification difficult or causing underestimation in species counts.

Data reported would be number of species, % native species, richness and diversity indices (calculated using relative abundance data), and a species list (divided into native and introduced) for each reach.

Macrophyte area & relative abundance

Emergent and submerged macrophytes are an important component of in-stream habitat for fish, macroinvertebrates, aquatic insects, waterbirds, reptiles and amphibians, as well as providing stable substrate for epilithic production and performing a range of ecosystem services critical to the maintenance of water quality and ecosystem functioning. These indicators assess the quantity and quality of habitat provided by macrophytes within a reach. The habitat value of macrophyte communities to different faunal species varies with availability, biomass and plant density. Significant changes over time with respect to areal extent, percent cover or biomass may indicate increasing impacts on the ecosystem (e.g. increased macrophytes due to pooling, silting and increased nutrients), and can have an effect on the habitat value of the vegetation. As with the measures of diversity, differences in absolute values at different sites do not in themselves provide an indication of condition at the sites — only through comparisons with a natural reference do the values become meaningful as indicators of ecosystem health.

Areas and percent cover of aquatic macrophytes in a reach can be calculated from high-resolution digital aerial photographs, using manipulation of wavelengths in the imagery to detect submerged and emergent vegetation. Initial validation in the field would be required, assessing the extent of vegetation at locations determined from aerial photos. Measurements of stem density provide data required for calculating indexes of species richness and diversity. However, direct on-site assessment can be time-consuming, especially if numerous species are present. Initial on-site validation of percent cover assessments from aerial photos can encompass stem density and standing biomass measurements (replicated quadrats (0.04 m^2 for high density patches to 1 m^2 for low density patches) and representative area harvests). Data on relative abundance for each reach can then be extrapolated from measurements of percent cover from aerial photos. These indicators should be assessed during the peak vegetation period in early summer, noting proportions of live and dead material if possible. Assessments during late autumn to early winter are not recommended, as seasonal dieback of macrophytes in the majority of the Murray-Darling Basin during cooler months would potentially under-represent this important component of physical habitat. Total area and averages for percent cover, biomass and stem density should be reported for each reach. Division of reporting into values for different species would be useful where differentiation is possible.

Channel form

The assessment of channel form will be based on four transects of the bank-full channel as described in the introduction to this section. The objective of this index is primarily to assess habitat diversity within the channel. The primary hypothesis is that increasing channel complexity will lead to increased habitat diversity. To assess channel complexity the shape of the channel is compared to a simple ‘U’ shape. The greater the extent of deviation from the ‘U’ shape, the more complex the channel. The software is called The Channel Program and is available from the University of Canberra.

Transect mapping can be carried out under a variety of flow conditions, although low flow periods probably provide less challenging conditions. When flows are low, surveying can be undertaken with a variety of equipment, but theodolite survey techniques are relatively cost effective. Such surveys are often required for discharge monitoring.

When conducting transect measurements the location of large woody debris and macrophytes in the water column and on benches and sand bars should be noted, as should the amount of organic material and sediment type (e.g. Queensland DPI Sheet 6).

Channel features (riffles, pools, islands, rock bars, sand bars, backwaters, benches, point bars)

The overall channel form and the dimensions of various channel features within a reach should be measured and the proportion of each type determined. Large channel features can be assessed using low-level aerial photography (see snag assessment). Aerial photography would need to validated during the site visit.

A problem with this approach is that it does not necessarily provide an indication of the amount of various habitats available under different discharges. It is hoped that further development of hydrological analysis in conjunction with the channel surveys will enable modelling of the temporal distribution and availability of channel features.

Pools

Pools provide important habitat in lowland rivers, particularly as refuge from low flows (e.g. Boulton 1989). The residual pool volume is an important indicator for assessing habitat availability and the ability of aquatic organisms to survive in drought prone and ephemeral streams. Cross sectional surveys provide an indication of depth but not longitudinal extent of pools. Pool width and length should also be measured, particularly in those streams prone to low flow conditions where pools become important refugia for aquatic species during low flow. Pool depth or extent relative to different flow levels or hydrological bands would provide a useful indicator of the extent of available pool habitat and degree of connectivity between pool habitats during low flow.

Pool depths can only be measured directly in the field, but it may be possible to measure pool width and length from low-level aerial photography (see snag assessment) depending on water level and clarity.

Snags

Snags provide one of the only hard stable substrates for colonisation by biofilm and invertebrates in lowland rivers. There are several quantitative techniques available for measuring snag density, surface area or volume. The line intersect method (Gippel *et al.* 1996, Marsh *et al.* 1999, Wallace and Benke 1984) can be used to measure snag surface area and volume expressed as a proportion of streambed area. However, it is time consuming and requires at least 10–20 transects per site due to the patchy distribution of snags in lowland rivers. A complete census of snags in a reach can also be conducted but again this is time consuming. The benefits of the line intersect and census methods are that location within the water column can also be determined so that the amount of available snag habitat at different river depths and flow regimes can be determined. However, the turbidity and depth of many lowland rivers may make it difficult to accurately count and measure snags deep in the water column.

Marsh *et al.* (1999) suggests a rapid assessment technique were the numbers of snags over 30 cm diameter are counted and related to a predetermined relationship between snag number and volume. However, this method still requires a more detailed census to establish an initial relationship between snag number and volume for a particular river type. Counting snags over 30 cm diameter however, can provide a rapid census technique for comparison between sites and sampling times without determining absolute density.

More recently, Koehn *et al.* (2001) have used low-level high-resolution aerial photography to count snag numbers, size and distribution in a reach of the Murray River. Low-level aerial photography was conducted during low flow and high water clarity conditions. From the photographs it was possible to measure snag type, distribution, aggregations and geometry within the river channel. Field assessment using echo sounding and visual counts was used to further assess snag numbers and distribution and to test the effectiveness of aerial photography at identifying all snags present. Ground-truthing revealed a 77% error in the ability of aerial photography to detect all snags. However, the authors concluded that low-level aerial photography is a useful tool for measuring snag density and distribution over large areas provided ground-truthing is conducted and that error rates are consistent across sites. It is also essential that photographs are taken during low flow and clear water conditions. They recommend strong consideration should be given to opportunistically commissioning low-level high-resolution aerial photography of rivers when they are in suitable condition (low flow, high clarity) for future assessment.

The simplest technique for assessing snag habitat is a visual assessment of loadings based on a percentage of stream bed covered (e.g. Queensland DPI) or some predetermined categorical condition (e.g. ISC). This method is very subjective as snags are often patchily distributed and many snags are located in accumulations making an assessment of the proportion of streambed covered difficult. Also, this technique does not provide for the three-dimensional distribution of snags or give an indication of snag complexity, e.g. number of branches etc.

The type of snag is also an important consideration when assessing habitat condition. Introduced species may not provide the appropriate habitat for native invertebrates and fish. For example, willows do not produce the hollow branches shown to be favoured by many native fish species, and willows quickly decompose and don't provide the stability and longevity of native wood species.

An assessment of the delivery mechanism and source of recruitment of snags is important for determining the future supply of snag material to the river. Some streams may have suitable in-stream snag loadings but because of riparian clearing, the potential for recruitment has been reduced. Identifying these situations is important in providing a general assessment of river condition and an understanding of future problems.

Recommendations for monitoring/assessment

Due to the complexity of snag habitat and the time consuming nature of direct census and line-intersect techniques for measuring snag abundance a range of methods for assessing snag habitat are recommended.

Low-level high-resolution aerial photography

Low-level high-resolution aerial photography is recommended as a suitable method for gaining a general assessment of snag type, distribution, complexity and geometry within the channel. Techniques for analysing aerial photographs are described by Koehn *et al.* (2001). Briefly, a grid with known dimensions is overlaid on the photograph and in each cell the number of snags, their length, distance from bank, number of contacts with other snags, orientation and type are recorded. Orientation is categorised according to angle from bank of the main axis of the snag. The direction, upstream or downstream, is recorded based on the location of the root wad. Snag type is recorded as full tree, branch, root mass, trunk or tree head. The position of snags relative to channel features is also recorded

Ground-truthing is required to determine error rates, but ground-truthing techniques do not require exhaustive census techniques. In lowland rivers, most snags are located close to the bank since stream power is generally insufficient to move snags large distances into the centre of the channel. Ground-truthing can be carried out by visual assessment of snag numbers in specified reaches and from echo sounder traces conducted along transects parallel to but 15 m from each bank (Koehn *et al.* 2001).

Low-level high-resolution aerial photography needs to be conducted when river flow is very low and water clarity is high. Given the stability of snags in lowland rivers aerial photography for snag assessment may only need to be conducted every 5 or 10 years.

Position in water column

Snag position in the water column can be assessed using a number of techniques. Echo sounding can provide an indication of snag numbers and their position in the water column. This can be conducted in conjunction with ground-truthing for aerial photography.

Position in water column can also be determined from cross sectional profiles. When channel cross sections are surveyed, the location of snags relative to the distance from the bank and depth in the channel and snag diameter should also be recorded. A minimum of five cross sections in a reach would provide a qualitative indication of snag location in the water column; snag surface area and volume can also be calculated using the formulas for the line-intersect technique (Wallace and Benke 1984). However, 10 to 20 transect are generally considered the minimum required when using the line-intersect technique.

Visual assessment

Qualitative visual assessment of snag habitat across a reach can also be made. Techniques based on an assessment of the relative proportion of different snag types, e.g. large logs, branches, individual pieces accumulations, tree roots etc, similar to the process used by the Queensland DPI (State of the Rivers Sheet 10 Aquatic Habitat) are appropriate for gaining an overall appreciation of available snag habitat. The assessment technique used for ranking density and origin of coarse woody debris by the Victorian ISC can provide a rapid indication overall condition.

Additional categories should include a visual assessment of snag surfaces to indicate if surfaces are covered in filamentous or diatomaceous algal biofilm or inorganic sediment. This provides an indication of the potential for those surfaces to contribute to carbon processes in the river and act as a food resource for in-stream organisms.

Preferred method

The preferred methods for characterising snag habitat incorporate a combination of the above techniques. It is recommended that aerial photography and ground-truthing be conducted every 5 to 10 years when suitable conditions exist. Water column position and snag diameter should be recorded whenever cross sectional profiles of reaches are made. Visual assessments based on the Queensland DPI technique and overall assessment of condition should be conducted annually.

In-Channel patches

Proportion of clay, silt, sand, gravel, cobble, boulders, bedrock, detritus

Four transects of the channel shape will be undertaken as described above. For the wetted channel additional information will be gathered using a protocol similar to that undertaken by AUSRIVAS. Within the wetted channel water depth and current velocity should be measured at 15 evenly spaced points. While transects are being performed the operators will take note of the sediment type and presence of macrophytes, filamentous algae, periphyton and detritus. Transect data will be used to derive the coefficient of variation for depth and current velocity.

Once transects have been completed the bed material, macrophytes, filamentous algae and detritus should be characterised based on a visual assessment of percentage.

Embeddedness

The embeddedness or degree of infilling of interstitial spaces provides information on the capacity of sediments to support aquatic life. High embeddedness can reduce habitat availability, but low embeddedness can result in significant bed movement which may also reduce habitat suitability. Embeddedness can be measured using sediment cores. However, this is likely to be expensive and time consuming. A visual assessment similar to that used by Queensland DPI (Sheet 8 Bed and Bar Condition) is the preferred rapid assessment method. Emdeddedness can change rapidly with changing land use and catchment management activities, and should be measured annually.

Proportion of each patch covered in algae/periphyton/biofilm

Benthic surfaces are important for providing habitat for colonisation by biofilms. Biofilms contribute to carbon supply to rivers and provide a food source for many organisms. The extent of biofilm can also provide an indication of the nutrient status of a waterway. For example, excessive filamentous algal growth may indicate nutrient enrichment and reduced scouring flows; heavy layers of inorganic sediment on benthic surfaces (snags and cobbles) can indicate excessive erosion and sediment delivery as a result of catchment activities.

The amount and composition of biofilm on benthic surfaces, including wood and bed materials should be visually assessed. The proportion of surfaces covered by algae or fine silt should be noted as well as the type of biofilm (e.g. filamentous, diatomaceous, inorganic) and the thickness (e.g. thick >5 mm, medium 2–5 mm, thin <2 mm).

Process Measures

Riparian Regeneration

Regeneration of riparian vegetation is an important component to monitor as a process maintaining the quantity and quality of habitat provided by the vegetation. It is also important as a predictor of invasions by introduced species. Due to difficulties with monitoring regeneration of all the vegetation in this zone, we recommend focusing on the large and common species only (e.g. river red gum, willows). There are problems associated with monitoring regeneration given the sporadic nature of germination and recruitment of many native riparian species such as river red gum, which require flooding during specific seasons for successful regeneration — random quadrats may miss hotspots of regeneration. However, for a given length of stream side to have appropriate riparian cover in the future, it is essential that some representation of younger generations of plants occurs in the present. Assessment would involve incorporation of riparian demography data from on-site transects into equations based on survivorship curves for the dominant species, producing an estimate of expected population demography for the future based on current vegetation status.

Potential input of Large Woody Debris

The abundance and composition of snags in the river channel, which are important components of in-stream habitat, are dependent on recruitment of large woody debris from riparian vegetation. Width of vegetation overhang and distance from the canopy to the channel have major implications for potential snag input. If all the trees are further from the channel than 1 x tree height, snag recruitment won't occur until regeneration of riparian vegetation adjacent to the channel occurs, or the channel moves. An indication of the quantity and composition of large woody debris available for potential input into the channel can be obtained through combining measurements of a range of vegetation, geomorphology and flow parameters. Vegetation overhang/distance to channel, tree height, species composition & demography, average basal area, vegetation vigour, bank stability and rate of water level decrease all contribute to snag recruitment for a given area of stream bank, which can then be scaled using vegetated stream-length and tree density.

Connectivity

The River Murray Expert Panel identified connectivity among habitats as an essential element in protecting the health of rivers. One of the impacts of water resource development has been the dramatic reduction in connectivity, both longitudinally along the river and laterally with the floodplain. The loss of connectivity can be regarded as a threatening process and should be assessed as part of the physical habitat assessment because it has an impact on habitat availability. AUSRIVAS and the Queensland State of the Rivers program both categorise longitudinal connectivity based on the shape of the wetted channel. This technique is flawed as the ability of fish to move along the channel will vary in response to flow. The issue that becomes important is not whether the fish can move at the time of assessment but whether the timing and duration of suitable conditions for fish migration are similar to those found at the reference condition. This is a further example where integration of channel morphology and hydrological analyses will yield a more thorough understanding of the condition of a river.

Levees although not always effective, are designed to “protect” floodplains from floods. In the short term this allows the uninterrupted exploitation of the floodplain’s natural resources, but in the long term they lead to the decline of both river and floodplain condition. It is proposed that a floodplain connectivity index (CI) could be determined for each site with the use of remote sensed images and aerial photographs.

The floodplain connectivity index (CI) is a measure of the degree of floodplain isolation caused by levees at a site. The technique involves generating a plot of floodplain area inundated under natural conditions and also in the presence of levees. These curves can be generated by two methods. The first would utilise a series of aerial photographs or remotely sensed images taken at different periods of over bank in order to derive a relationship between flow and area of floodplain inundated both with and without levees. The second approach would utilise a Digital Elevation Model (DEM) of the floodplain surface. Once this was acquired the area inundated with various flows could be calculated and levees then included onto the DEM.

Calculating the difference among the two relationships between flow – floodplain area inundated, then derives the floodplain connectivity index (CI). This is derived from any number of percentile points along the curve. The statistic CI is shown in Equation 1, where n is the natural (without levees) floodplain inundated area value for percentile point i, p is the number of percentile points and c is the floodplain inundated area with levees value for percentile point i. The statistic CI gives equal weighting for floodplain area inundated, from the lowest area to the highest area.

Equation 1

$$\text{If } n > c \text{ then } M = \frac{1}{p}\sum_{i=1}^{p}\frac{c}{n} \text{ else } M = \frac{1}{p}\sum_{i=1}^{p}\frac{n}{c} \qquad \text{Equation 1}$$

In-stream barriers such as weirs and dams have a number of detrimental effects on both physical habitat and organisms' ability to access that habitat. Barriers prevent fish migration, denying native species access to spawning sites. Barriers also alter the movement of sediment and organic matter downstream, creating sedimentation problems within the weir pool and erosion problems downstream. The distance to the nearest weir is recorded as part of the AUSRIVAS program, and we believe should be included in the Audit. A survey of barriers should have already been conducted for each state in the MDBC. This information can be used to determine whether test reaches are affected by barriers. Flow related channel morphology will also provide information on the connectivity of pools, backwaters and floodplains during different flow levels.

Sediment Regime

There are two important elements to the sediment regime in rivers. The first is the input of sediment to the river through erosion. The second is the movement of sediment within the channel.

It is generally thought that the input of sediment to rivers has increased due to vegetation clearing and grazing. The extent of vegetation cover will be assessed as described in the section above. We also recommend that an assessment of grazing be incorporated into the Audit. This would involve surveying the appropriate land holders to determine stock density, whether stock have unlimited access to riparian areas and whether they are provided with watering points.

Direct assessment of erosion is currently undertaken by a visual assessment of river banks. This form of assessment is particularly limited due to the fact that lowland rivers naturally experience erosion as the channel moves across the floodplain. It is, therefore, difficult to assess whether the rates of apparent erosion lie within those that would be expected in a healthy river.

The measurement of erosion can be simply undertaken using aerial photography. This technique is regularly used to determine bank erosion and channel migration at a reach scale. Aerial photographs taken at different time periods for the same reach of river are simply compared to determine channel migration, loss of vegetation and expansion of gullies. Once established, rates of bank erosion can be compared among test and reference reaches.

The sediment regime within the river is also important in creating and maintaining habitat. In addition to erosion, the sediment regime within rivers has been affected by water resource development. An assessment of sediment dynamics can be carried out by determining the sediment load carried under different flow levels, and integrating this information with the natural and existing flow regime. If this were to be undertaken at each site, it would involve an increase in sampling effort, but if suspended solid sampling were undertaken in conjunction with existing nutrient and water quality monitoring programs the additional cost would be minimal. Sediment data need only be collected once with subsequent analysis performed by comparison with the hydrograph for the latest sampling interval.

Costing

It will be apparent that the proposed protocol will involve a greater investment than most existing programs. The major and most significant difference in effort is in the area of remote sensing. We believe that the information generated by this form of analysis represents a major advance in the power of physical habitat assessment and enables the cost-effective collection of information that would be vastly more expensive if collected by conventional techniques. The costs of imagery currently appear significant in terms of cash, but in terms of information gained the technique is comparable to field techniques. In addition we anticipate that image costs will decrease while resolution increases. We believe, therefore that this type of analysis represents a sound investment in knowledge acquisition.

We recommend the use of aerial photography until equivalent satellite imagery becomes available which will probably be in the second 5-year cycle. The aerial photography will allow the evaluation of all the indices proposed in most circumstances. The major exception to this will occur where the floodplain is very large. In these cases, we would suggest that additional low resolution LandSat 7 imagery be used for the floodplain scale analysis. This additional imagery will not significantly increase the costs of assessment.

We cannot currently provide accurate estimates for the total costs associated with remote sensing because the cost depends on the number of sites and the distribution of those sites in the Basin. There are cheaper sources of imagery available, but the trade-off is that the resolution tends to decline. There are currently two types of satellite imagery available, LandSat 7 and the French Spot Satellite (Table 2). While some of the indices could be determined using this imagery there would be a loss of accuracy, and in some of the smaller rivers the resolution would prevent collection of the information. The consequence of this is that field workers would have a greater work load. We do not anticipate that this will prevent the information being gathered, but the cost of assessing these sites may be marginally more expensive.

The majority of the ground truthing techniques are currently undertaken by one of the existing programs (Table 3) and appear to be relatively cost effective. The difference between the methods recommended and those of the existing programs is our emphasis on quantitative, spatially explicit data rather than categorical data. We believe that this type of data will provide a much better foundation for monitoring change at sites and for allowing the integration of habitat data with water quality and hydrological data.

Table 2. Costs of various methods of obtaining data

Indicator	LandSat 7	Spot	Spot 2 5	Aerial Photo	
Cost	$1,400 image	$1700	~$2,000	$650 / h	
Footprint	180 x180 km	60 x 60 km	60 x 60 km	300 x 400 m	
resolution	30 m	20 m	10 m (20m for shortwave IR reqrd for SVI's)	0.5 m	
Diversity	**X**	**X**	✓	✓	
% contribution	**X**	**X**	✓	✓	
Riparian width	**X**	**X**	**L**	✓	
Richness	**X**	**X**	**L**	✓	
Abundance	**X**	**X**	**L**	✓	
Fragmentation	**X**	**X**	**L**	✓	
Veg Overhang	**X**	**X**	**X**	✓	
Veg Vigour	**L**	**M**	**M**	✓	
% pool etc	**X**	**L**	✓	✓	
Snag Abundance	**X**	**X**	**X**	✓	
%sediment	**X**	**L**	**M**	✓	
Weir Location	✓	✓	✓	✓	
Veg Stream Length	**X**	**X**	**L**	✓	

X – not possible, ✓ — possible, L – low resolution, M – medium resolution

Tasks	Time/site	Cost
Travel and Accommodation	8 h	$640
Imagery		$650
Image Analysis	70 min	$ 50
Riparian Vegetation Assessment	1.5 h	$120
Canopy Assessment		
Species Composition		
Litter		
Overhang		
Riparian Demography		
Macrophyte Assessment	30 min	$ 40
Transects,	5 h	$400
sediment characterisation,		
flow measurement		
snag assessment		
Process Assessment	30 min	$ 40
Pin Measurement		
Levees		
Weirs		
TOTAL (per site)	15.5 h	$1,940
TOTAL (20 sites per valley* 22 valleys)		$853,600
E-ball model development		$50,000
5 year TOTAL		**$903,600**

Reporting

As described above, we anticipate that the physical habitat assessment will be undertaken once every five years. The data may need to be collected over a period of 18 months to allow the analysis of aerial photography to precede the site visits. We recommend that an O/E score be generated for the three spatial scales (floodplain, feature and patch). This would allow separate determination of the condition of the floodplain and stream feature components, both of which are heavily influenced by the vegetation community.

There are several ways to provide a single score for physical habitat. The assessment of physical habitat reported in the Audit could be the lowest score of the three scales. This would represent the most conservative measure of physical habitat. Alternatively, scores for the three scales can be integrated to form an average physical condition score. This approach may hide significant degradation at one spatial scale that might otherwise act as an indication of future degradation at the other spatial scales. This can be overcome by always providing reports at the three scales as well as the average score.

Priority Tasks

To undertake the assessment the agencies will need to undertake a number of tasks. These include:

1. accepting the recommended protocol,
2. selecting both test and reference sites,
3. developing the assessment data sheets (see AUSRIVAS data sheets),
4. purchasing imagery,
5. undertaking image analysis,
6. surveying reference sites,
7. synthesising reference condition for test sites using E-ball,
8. surveying test sites,
9. undertaking assessment,
10. reviewing assessment sampling regime.

It is also recommended that the Commission undertake a number of tasks that will assist with the development of a better assessment of physical habitat. These tasks include:

1. undertaking investigations of the natural state of rivers in the basin using a variety of data sources,
2. developing methods for integrating disparate data into a description of reference condition,
3. developing indicators and protocols for assessing changes in the spatial arrangement of habitat,
4. developing indicators and protocols for assessing changes in the temporal characteristics of habitat.

Table 3. Indices measured in current programs and proposed for the Audit

Index	AUSRIVAS	Border Rivers	Queensland DPI	Victorian ISC	River Styles	NSW PBH	Audit proposal
Floodplain Diversity*	C				✓		✓
% contribution of habitats*		C	C	I			✓
Riparian Species No.			C				✓
% Native Species*		C	✓	C			✓
Riparian Diversity*			C				✓
Riparian Basal Area							✓
Riparian Stem Density							✓
Riparian width*		C	✓	C			✓
% Cover of Floodplain*	C				✓		✓
Vegetated Streamlength*	C			C			✓
No of Discontinuities*				C			✓
Average Patch Size*							✓
Riparian Connectivity*	C						✓
% cover trees > 5m*	✓	C	✓	C			✓
% cover shrubs < 5m	✓	C	✓	C			✓
% cover understorey	✓	C	✓	C			✓
% cover herbs	✓	C	✓	C			✓
Riparian demography				C			✓
Standing Litter							✓
Vegetation Overhang*	C	C	✓			I	✓
Vegetation Vigour*							✓
Macrophyte Species No.	✓	C					✓
% Native Macrophyte Species	✓		✓			I	✓
Macrophyte Diversity	✓						✓
% Macrophyte Area*	C		✓				✓
% Macrophyte Cover within patches							✓
Bank Slope	C		✓	✓		I	✓
Bank Shape	C		✓	✓		I	✓
Channel complexity	C					I	✓
Channel Form	✓			✓		I	✓
% pool, riffle, run etc*	I	C	✓			I	✓
Snag abundance*	C			C		I	✓
Snag distribution*				C			✓
CV Depth	✓	C	✓			I	✓
CV Current	C	C	✓		I		✓
% Sediment Patch	✓	C	✓		I	I	✓
Embeddedness	C	C	✓				✓
% algae	✓		✓				✓
Levees							✓
Distance to Weir*	✓	✓	✓				✓
Erosion	C	C	✓	C	I	I	✓
Sediment Transport		C		C		I	✓

- * Indicates measurements that can be, at least partially undertaken by remote sensing.
- ✓ indicates this information is currently collected by the program
- C indicates that this information is collected as a category or rating.
- I indicates that this information is included in an index within the program.

Table 4. Audit habitat assessment

Component	Measurement units	Number of units per site	Measurement variables	Method
1. Floodplain	100 m wide transect extending to 1 in 100 year flood level	4 non-random (different channel forms)	• Proportions of major habitat types	Orthophoto imagery / GIS / ground truth
2. Bank	High bank Low bank	4 non-random channel transects (different channel forms)	• Bank slope • Bank shape • Erosion type • Erosion extent (proportion of bank) • Slumping (proportion of bank) • Lateral scour (proportion of bank) • Local scour (proportion of bank) • Aggradation (proportion of bank)	On-ground visual estimation
3. Riparian vegetation species	Transects up to 100 m long	4 non-random riparian transects	• Dominant tree and shrub species	On-ground presence/absence and percent cover of species on checklist of expected species at a site
4. Riparian vegetation cover	Reach defined by meander wavelength	1	• Relative cover of dominant species	High-resolution multi-spectral digital aerial photography
5. Riparian vegetation density	10 m to 30 m radius quadrat	12 quadrats	• Bitterlich basal area of dominant species • Stem density of dominant species	'Established forestry practice'

6. Riparian vegetation width	Transects up to 100 m long	4 non-random riparian transects	• Distance from edge of channel to cleared or developed land • Channel width • Width of floodplain • Density of floodplain 'vegetation'	Adaptation of Queensland/NSW Border Rivers Flow Management program (aerial photography)
7. Riparian habitat fragmentation	Reach scale	Reach	• Length of bank with 'vegetation' >5 m wide • Number of gaps • Patch size • Length of gaps	Aerial photography
8. Riparian canopy complexity	Riparian transects	4 non-random riparian transects	• Percent cover of trees • Percent cover of shrubs • Percent cover of understorey • Precent cover of ground vegetation	On-ground visual assessment (plus aerial photography for tree layer)
9. Riparian demography	Riparian transects	4 non-random riparian transects	• Proportion of individuals of each species of 'major riparian plants' (trees only?) in each age class	On-ground visual assessment. Method for age class determination unspecified
10. Standing litter	Points along riparian transects	40	• Depth and percentage cover of litter in quadrats	Depth measurement and visual assessment
11. Vegetation overhang	Randomly selected positions along channel edge	8	• Distance of canopy from channel • Distance from canopy to channel	Aerial photography
12. Vegetation vigour	Reach scale	Reach	• Spectral vegetation indices	Multi-spectral digital imagery

13. Emergent aquatic macrophyte species richness and diversity	Quadrats or transects	4 channel transects. 15 points within wetted channel. 4 replicate quadrats (size variable)	• List of species • Relative abundance of each species	On-ground visual assessment
14. Emergent aquatic macrophyte area and relative abundance	Reach assessment for remote sensing Quadrats (size and location unspecified) for on-ground assessment	0.04–1 m^2 depending on density	• Cover of aquatic macrophytes • Biomass of aquatic macrophytes • Stem density of aquatic macrophytes	High-resolution digital aerial photographs On-ground visual assessment
15. Channel form	Transect of bank-full channel	4 non-random channel transects	• Deviation from U-shape • Location of large woody debris • Location of macrophytes • Amount of organic matter • Sediment type	Theodolite survey. Visual assessment
16. Pools	Pool	Depth via transects width and length from remote imagery	• Pool length • Pool width • Pool depth	Cross sectional surveys Low level aerial photography
17. Snags	Surface area per m^2 river bed	20 transects	• Snag number • Snag type • Snag diameter • Snag water column position	Aerial photography (with ground truthing) Cross-sectional profiles Visual assessment
18. Proportion of clay, silt, sand, gravel, cobble, boulders, bedrock, detritus	Wetted channel transects	4 non-random channel transects	• Proportion of bed material	Visual assessment
19. Embeddedness	Wetted channel transects	4 non-random channel transects	• Embeddedness category	Visual assessment (Qld DPI sheet 8)

20. Cover of algae/periphyton/ biofilm	Wetted channel transects	4 non-random channel transects	• Proportion of surface covered by algal categories • Proportion of surface covered by fine silt • Type of biofilm • Thickness of biofilm	Visual assessment
21. Riparian regeneration	Riparian transects	4 non-random riparian transects	• Expected future proportion of individuals of 'large and common species' in each age class	Survivorship curves applied to demography data from 9 above
22. Potential input of large woody debris	Riparian transects	4 non-random riparian transects	• Snag recruitment per unit area of bank	
23. Connectivity	Reach scale	Reach	• Presence of levees • Distance to the nearest weir	Aerial photography, DEM, connectivity index Visual assessment
24. Sediment regime (and grazing)	Transect lines (dimensions unspecified)	Unspecified	• Stock density • Stock access to riparian areas • Stock watering points • Channel movement, area of gullying • 'Sediment load'	Landholder survey Aerial Photography

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Final Report
Project R2004
Development of a Framework for the Sustainable Rivers Audit

Appendix 8
Response to SRA Taskforce questions on Draft Report

Cooperative Research Centre
for Freshwater Ecology

SRA Taskforce Questions on Draft Audit Report

	General Questions	CRCFE Project Team Response
1	Would it be possible to include the sequence of steps involved in implementing the full monitoring framework, indicating which steps this report covers. NSW provided a draft 34 step process used for the implementation of IMEF as guide (attached within NSW's comments).	Implementing a full monitoring program at the Basin-scale is a complex undertaking. The task can be broken down into discrete steps. These steps include articulating the objectives of the program and then designing a study to meet these objectives that includes issues of sampling, analysis and reporting. DLWC (NSW) supplied a list of possible steps to be undertaken in designing and implementing a river health sampling program (See Attachment 1). This list is comprehensive and has a strong focus on implementation. A number of steps appear out of order, for example we would consider that issues such as data storage and management (Step 19), selection of sampling points (Step 21) and development of communication and reporting strategies be included in the design stage (Step 1). Since the list of steps provided by DLWC has not been evaluated for effectiveness, we would caution against their adoption until this had occurred. In the meantime, they provide a guide to the issues that need to be addressed in developing a monitoring program. Clearly, most of the steps on the NSW list are beyond the scope of the CRCFE's brief (e.g. steps 2,3,5,9–34 and parts of the remaining points). The Tasks addressed by the Framework and the outstanding Tasks are covered in the Final Report.
2	Could you bring forward to the Executive Summary more discussion on the frequency of reporting, its costs and benefits and which indicators should be reported annually?	Information on the frequency of reporting, its costs and which indicators should be reported annually was reported in the Draft Executive Summary. This discussion has been enhanced in both the Executive Summary and the text of the Final Report.
3	Would it be possible to design the Pilot to provide better evidence of the benefits (vs costs) of the Audit?	After receipt of the Draft Framework for the Development of the Sustainable Rivers Audit, the Taskforce recommended that a Pilot Audit be undertaken prior to commencement of a Basin-wide Audit. There is considerable merit in undertaking an appropriately scaled and resourced Pilot Audit. The benefits of this are outlined in the Final Report. Briefly, the Pilot will allow further development of methods and a trial of all indicators before full implementation. Analysis of the Pilot data will provide considerable guidance in indicator refinement, site selection and number of samples required. This is because much of the Audit framework is new and consequently little is currently known of the behaviour of the proposed indicators.

		For example, many of the current sample size recommendations have been made on modelled data. The Pilot will allow more rigorous statistical evaluation of this issue.
4	Given the demand for the Audit to be used Regionally, could you provide costs for increased sensitivity (e.g. down to FPZs or reaches which are more relevant management units)?	The draft final report provided indicative costs associated with data collection and analysis based on reporting at the river-valley scale. These cost estimates were based on current commercial rates for sampling. The number of sample sites is dictated by the desired sensitivity and power of the assessment. If there is an intention to report at the Functional Process Zone scale a much greater number of monitoring sites would be required than for the reporting at the river-valley scale. At the FPZ scale there are several monitoring strategies that could be of interest; reporting on the condition of each FPZ in each river valley, or reporting on the condition of a one FPZ (e.g.. armoured) in a particular river valley. There are a total of 291 discrete FPZs across the MDB. Providing an assessment of individual condition would require measuring each of the indices at a set of spatially random sites within each FPZ. The number of sites would be determined by the yet unknown spatial variability of each index within each FPZ. Although it is likely that the spatial variability within an FPZ would be less than that within a river valley, so requiring fewer sites, reporting at the FPZ scale could require approximately ten times the number of sites required to report at the river-valley scale. It would seem more likely that a management agency would be more interested in the condition of a particular FPZ in a river valley of concern. Assessing the condition of a single FPZ would require monitoring a spatially random set of sites within the FPZ. Again, because it is likely that the spatial variability within an FPZ would be less than that within a river valley, fewer sites would be required than for assessing a single river valley.
5	Could you emphasise the fact that the referential approach does not equate with an objective of returning to natural? (see also AFFA's comments).	This was discussed at length in the draft report on pages 11–13. This point has been further emphasised in that section and further comments to this effect have been included in the Executive Summary.
6	Could you provide additional information/justification on the approach to defining reference condition (i.e. WQ sites, physical habitat)?	Water Quality: The selection of water quality sampling sites is traditionally based on 'well mixed' sites, capable of providing a 'representative' sample. Typically, these sites are riffle FPZs in the case of upland and mid-slope Valley Process Zones, and channel (pool) reach FPZs in the case of lowland valley process zones. This is also the basis of selection of sampling sites adopted in the Audit framework. The selection of reference sites for water quality sampling needs to reflect the Valley, Valley Process Zone (VPZ) and FPZ of each monitored site VPZ & FPZ category, on a valley by valley basis.

		In tabulating the list of possible reference sites meeting these criteria, there is a need to exclude non-representative sites such as sites immediately downstream of river junctions or point-source discharges (problem of transverse stratification of flows). A random selection of reference sites is then made from the tabulation of possible sites. In the case of lowland Process Zones, there are few unmodified streams available for reference purposes. In these cases, it is proposed to generate the best available estimate of reference conditions, drawing on data from modified streams, and estimates provided by the application of an interactive transport, sedimentation, sediment redox & biofilm uptake process based model (daily time step). Fish: There will be two approaches for fish. '*Sampling best available sites*': a set of reach and site based criteria will be used, similar to those for macroinvertebrates (with the addition of a criterion in relation to proximity to dams), as originally described by Davies (1994) for the AUSRIVAS program to screen site suitability. '*Historical species list*': a 'historical' list of fish species, derived by a group of fish biologists for each valley/reach, will act as a secondary reference for direct comparison with site data. No specific reference site sampling will be needed for this approach. Macroinvertebrates: For defining reference sites for the assessment of invertebrates it is recommended that criteria similar to those used for the QLD WAMP process are adopted. (Refer to Appendix 3 Table A10.)
7	Could you update ISC sampling procedure with most recent version?	Paul Wilson (Victoria DNRE) has informed the Project Team that the "Index of Stream Condition — Reference Manual (1999)" contains the most recent description of the ISC sampling procedures and method for calculation of the ISC score. The details on the ISC given in the Draft Final Report reflect this information. In particular, details on the recent changes to the sampling protocol (to 3 transects sampled at 3 sites) are given on page 9, and details of the revised method for calculation of the ISC score (using inverse ranking) are given on page 35.
8	Could you accommodate a 'movement from current condition' as a short term alternative to 'distance from reference'?	The use of 'natural' condition as reference condition has several advantages. These are discussed in the Final Report. There are several major problems with using 'current condition' as a reference. Using current condition as reference does not allow current condition to be interpreted. Is current condition good, bad or otherwise? Following from this, changes in condition measured over time cannot be interpreted. Is a change a good change or a bad one? How do you know how far it has changed?

9	Does the report need to reiterate the basis for selecting the five indicators, or to acknowledge other indicators? Might stressor/threat indicators have more success in preventing decline?	The Project Brief for the Development of a Framework for the Audit clearly states that indicators to be developed by the CRCFE for the framework were: Macroinvertebrates, Fish, Water Quality, Hydrology and Habitat. The final report has been amended to make this point clear. These indicators were recommended in a scoping study (Cullen *et al*. 2000) undertaken prior to this project. The scope document used the following criteria to identify suitable indicators: • they built upon existing programs and data as much as possible • were consistent with the conceptual models of river function developed for the Functional Process Zones • responsive to disturbance • measurement and analysis are rapid (analysis is built into reporting of the indicator) • standardised methods are available and are technically appropriate for State agencies to undertake • output can be interpreted relatively unambiguously • indicator has meaning to the wider Basin community
10	Could you include a summary table of the tasks, time, resources and costs of the steps required to implement the framework, to assist in cost-benefit analysis? Could you include the tasks for the staged development of indicators in that table?	It is beyond the Scope of this project to fully cost the implementation of the Audit. This project provides cost estimates for undertaking the recommended sampling and analysis (see Final Report, ''Indicative Costing'', pp. 39–42). Costs associated with the ISRAG, project management by the Commission and jurisdictions, communication activities and data archiving have not been calculated.
11	Could you include comment on how reporting arrangements might provide access to the source data i.e. to help overcome the problem of masking?	ISRAG will have to ensure that they have adequate access to the source data to ensure that they can effectively audit the jurisdictional reports. How ISRAG manages this process is a matter for ISRAG and the jurisdictions to determine. A danger to the integrity of the Audit is using data to report at scales other than those for which the Audit has been designed. Unfettered access to the source data will need to be managed to minimise the chance of this occurring. The Framework is designed to report river health at the scale at which the sampling regime has been developed e.g. the river-valley scale or valley process zone scale. For example, reporting reach condition on the basis of one sampling location would be unreplicated therefore there is no estimate of the variability at that scale.

12	Can you include comment on the integration with existing monitoring programs? For example the new paradigm inherent in the water quality theme is quite different to existing arrangements. Explain why we can not use existing programs as much as some would hope.	Appendix 1 "Review of existing programs that measure and report river health in the Murray-Darling Basin" describes in detail existing river health programs and what they purport to measure. The outcomes of the review presented in Appendix 1 are discussed in the Final report. In summary, the review concluded that current programs undertaken by partner governments and the Commission do not fully satisfy the information and reporting requirements of the Audit for several reasons. Therefore, the Final Report argued that the Audit could not be built directly upon ongoing programs and data sources. Rather, elements of various programs may provide data to the Audit, where appropriate. The 'new paradigm inherent in the water quality theme' reflects the objectives of the Audit. Fundamental to the Audit is the assessment of river health and therefore the water quality indicators are developed to assess river health (e.g. indicators reflect outcomes of primary and secondary production and the mineralisation of organic material). In the past, water quality monitoring programs have not been developed to assess river health. Consequently, it should not come as a surprise that a new paradigm will require a different approach to water quality sampling.
13	Can you elaborate on how the Audit will inform target setting or revision within catchments?	An accurate picture of river condition is a critical element in the process of setting targets for river health. By reporting at the river-valley scale and potentially at other within valley scales the Sustainable Rivers Audit will provide a Basin-wide assessment of river condition. Ongoing monitoring of river health is critical in knowing whether actions are moving river health towards the desired targets. The Audit will also provide information on the likely drivers of river health, e.g. habitat, hydrology, etc. This information will help in determining appropriate management actions to reach river health targets. It is not the role or function of the Audit to set targets for river health. Targets for river health are being developed for the Murray-Darling Basin as part of the ICM in the Murray-Darling Basin 2001–2010 — delivering a sustainable future (MDBMC 2001) pp. 8–10.
14	Could you elaborate on how the conceptual models in Appendix 2 influence the selection of indicators and the locations and parameters to be sampled? Options to reduce costs might exist in tailoring where/what to monitor.	The selection of the water quality health indicators has built directly on the conceptual models and Functional Process Zones, as outlined in Appendices 2 and 5. The selection of water quality indicators has been based on the assessment of river health, in terms of the physical and chemical outcomes of in-stream biological processes. As the dominant biological processes vary according to VPZs & FPZs, it has been necessary to set the upland and mid-slope Process Zones indicators different to those for the lowland Process Zones.

		In order to assess the monitored indicator values, in some cases, information is required on a range of associated potential modifiers of bio-geochemical processes. For example, ideally, monitoring is required of the diurnal pattern of instream DO and pH, in order to assess primary or secondary production and respiration balance and rates. As a requirement for 24 hours monitoring at each site would be resource intensive, it is proposed to compare a daylight based sample with calculated equilibrium for the prevailing flow, temperature and alkalinity conditions, to assess production & respiration rates. Fish — fish are central to all conceptual models. Sampling to focus on instream communities. Invertebrate composition is an integral part of ecosystem structure and processes, as shown by the conceptual models (Appendix 2). Invertebrate indicators were chosen to measure composition and sensitivity compared to what should be at a site (Appendix 3 section A2). Loss of community components will affect the structure and processes described in the conceptual models. Specific habitats of importance for invertebrates, indicated by the conceptual models, are proposed for sampling. To reduce costs, sampling should address only the key parameters required to adequately represent the biological community and influential environmental variables at a site. Conceptual models can be used to infer potential effects and causes if key indicators are monitored
15	Could you review the criteria for reference site selection and suggest more detailed criteria? How should weir pools be dealt with?	The current Audit framework excludes standing water bodies such as weir pools and reservoirs. The approach could be expanded to include these 'Functional Process Zones'. A distinctly different set of indicators would be required to reflect the ecological health of these systems. More detailed criteria for reference site selection can be developed for regions as appropriate. Weir pools are unlikely to be sampled for invertebrates as they are a limited habitat and sampling sites must be representative of the whole valley.
16	Could you elaborate on the criteria for stratifying rivers for sample site selection? Are major human impacts (e.g. structures) an important layer for stratifying?	The criteria for stratifying rivers is detailed in the Final Report. The Final report recommends two scales for stratification, valley process zones and Functional Process Zones — see Final Report for descriptions of these. The choice of scale will depend on the desired reporting scale. These zones are based on regions of relatively homogeneous geomorphology. VPZs are defined by their sediment transport characteristics and are built up from FPZs, which are defined by a combination of geomorphology and hydrology. The number of sites within a zone is allocated by proportion of total catchment (by area) in each zone. If a zone represents 30% of the catchment area then 30% of the sites will be allocated to that zone. Stratification ensures representation of all river types in the final assessment of river health.

		The zones are defined by the geomorphic and hydrological conditions that occurred prior to regulation. Consequently major dams and other human impacts are not considered in the stratification process. The rationale for this is that the primary objective of the Audit is to provide an assessment of river health at the valley scale. Stratification based on major geomorphic zones ensures appropriate representation of the major geographic regions of the river valleys which may not occur if stratified by zones defined by river management or other structures.
17	What physical dimensions define a 'site'?	Water Quality: In the case of the water quality indicators, the site comprises a riffle or well mixed zone in the case of upland and mid-slope Process Zones, and a channel (pool) reach in the case of lowland Process Zones. Sampling needs to be taken clear of edge effects in each case, in order to reflect channel water quality. In the case of the lowland Process Zones, under low flow conditions, the 'channel' water quality will of course reflect local transverse inputs and bio-geochemical processes. In summary, a site comprises a randomly selected river reach having a pre-defined Functional Process Zone characteristic, and a sampling location in respect to the distance from the steam edge. In the case of the deeper lowland Valley Zone channel (pool) reach sites, some vertical stratification in indicator values is possible. In these cases, sampling should be based on integrated (tube) sampler rather than a jar sampler. Fish — a site will consist of at least one meander wavelength, and will fall between 20 and 40 times the river width. Approx.4–500 m in source-transport zones and 1–3 km in deposition zones. Macroinvertebrates - The standard AUSRIVAS protocol is to use 10 times the bankfull width to define the site.
18	Could you better explain the $8.2M — what it covers and over what period.	How the cost estimate of $8.2M for the Audit was determined is described in the Final Report and in the various Appendices for each theme. The Final Report clearly states that the exact cost of undertaking the Audit cannot be calculated at this stage of its development because several key decisions about the Audit model have not yet been resolved, e.g. the reporting scale. The indicative cost of $8.2M represents the cost of sampling the sites required for a river-valley scale assessment. These costs were calculated based on standard commercial rates obtained from several laboratories in SE Australia. The estimated cost also includes costs associated with development of several models and analysis tools required to undertake the project. The indicative costs do not include the costs of abstracting the hydrology data from existing models and databases. The indicative costs does not include provision for costs associated with project management (either within the Commission or within the jurisdictions), with reporting or with the ISRAG. These costs

		may be significant, depending upon the efficiency of the respective groups.
19	Could you include the objectives and purpose of the Audit as approved by Council?	The objectives and purpose of the Audit, as agreed by the Ministerial Council, have been included in the Final Report.
20	How might an adaptability capacity be established in the Framework?	The science underpinning ecological assessment will continue to improve through research projects and experience with assessment programs. As new knowledge becomes available the Audit requires the flexibility to respond to this. Tempering this is the need to acquire comparable data over long periods so that changes in river condition can be assessed. Any changes made to the indicators will need to be undertaken cautiously so as not to compromise the ability of the Audit to monitor long term trends in condition. Balancing the need for adaptability with the constancy required to detect long term changes is a complex task and one that should be the responsibility of ISRAG. The Pilot Audit provides an excellent opportunity to review the indicators and to undertake various analyses to determine if they are optimised. The 5 yearly CSA is also an appropriate time to review the performance of the indices.
21	Use of sustainable/sustainability — Phrases such as ‘assurance that water is being managed sustainably’ (page 3) and ‘the ecological sustainability of current management’ (page 11) should either be replaced with words such as ‘managed according to the principles of ecologically sustainable development’ or defined explicitly. At the moment they are open to wide interpretation.	It is agreed that the use of the concept ‘sustainable’ in the Report needs to be clearly defined. There is no commonly agreed definition of the term sustainability. It is frequently argued (e.g. Garcia and Staples 2000) that sustainability is not a stable property of a system that can be defined but rather it is a journey — is what we are doing now driving us in a direction that is sustainable? The National Strategy for ESD (Commonwealth of Australia 1992) defines ecological sustainable development as ‘using, conserving and enhancing the community’s resources so that the ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased. ESD refers not only to the quality of the ecological system but also to the quality of life of the community. The Audit is focussed only on assessing the condition of the ecological system and so does not measure ‘sustainability’ in the broader context. The text of the Final Report has been amended as suggested.
22	Table 5. It is unclear what a change of, for example, 10% means. Is it a percentage of the proportion or a change from .6 to .7?	This section has been significantly revised. See Final Report.

23	Comment on the use of sensitivity analysis on the Pilot data — to see if indices can be rationalised	Sensitivity analysis should be performed on the Pilot Audit data to see if indices can be rationalised.
24	Provide a Section on the value of a Pilot to the Audit? —e.g. what sort of valleys should be chosen.	The Audit Taskforce has proposed that there be a Pilot of the Audit that reports in 2003. During the Pilot, all indicators will be developed and be trialled, probably in four river valleys across the Basin. • The Pilot is a logical step in implementing the full Audit. Data from the Pilot can be used to determine how to improve the efficiency of the indicators — does everything that is being measured need to be measured? • The number of samples required and the frequency of sampling are driven by a number of factors including the magnitude of the desired detectable change, the confidence in detecting that change, the initial condition score, the variability in the indicator and the reporting scale. While the sample size estimates presented in the report are based on best information available to the Project Team, a number of assumptions about the behaviour of the indicators have been made. Better estimates of sample size can be made once the behaviour of the indices is better known through the Pilot processes. • The Pilot provides an opportunity to assemble and train the technicians required to undertake the monitoring to a an appropriate standard. • It will enable the analysis and reporting of the assessment to be trialled; these are often monitoring elements that are overlooked • It could enable a more accurate assessment of the costs of a full implementation.
General comments across Indices		
25	Can you establish consistency with ANZECC's Core Environmental Indicators for reporting on SoE?	The 'Condition or State Environmental Indicators' for National State of the Environment Reporting (Fairweather & Napier 1998) comprised the Guidelines levels in ANZECC Water Quality Guidelines 1992 (turbidity, salinity, pH, toxic substances, DO, temperature, nutrients). There is substantial similarity between the SoE and Audit water quality indicators (turbidity or suspended solids, salinity, pH, DO, temperature, nutrients). TOC has been added to the Audit indicators, as an important indicator of organic material recycling efficiency, while toxicants have been excluded on the basis of monitoring being beyond the capability of the Audit at this stage. The revised Water Quality Guidelines (2000) have moved away from the guideline levels identified against each of the indicators, on the basis of inappropriateness of a single set of numbers to cover all ecosystems for all geographic regions of the continent, and the inappropriateness of absolute (magic) numbers to highly variable and multi-stressor based systems.

		The approach adopted in the revised Water Quality Guidelines (2000) and proposed in the Audit framework is levels based on reference systems. AUSRIVAS is a core indicator for SOE reporting on inland water quality, thus use of AUSRIVAS in the Audit will ensure consistency.
26	Could you discuss further the integration and relationships between indicators?	The indices developed for the five environmental themes can be broadly classified into driver and outcome indices. Driver indices describe the state of the physical environment and provide a diagnostic function for the condition reported by the biotic and biological process (outcome) indicators. The combination of indicators developed will assess the ecological condition of the rivers and will provide information of the likely causes of that condition. This will allow targeted studies to focus on problem areas. The Final Report does not recommend using a mathematical function to integrate scores for the five themes to produce a single river health score. The rationale for this is given in the Final Report. The report proposes that each of the five environmental themes be reported independently. If a single score for river health is required (e.g. for the river valley). It is recommended that one of the two biotic theme scores (for fish or macroinvertebrates) be used to represent river health. This approach assumes that the biota integrate the combined effects of alterations in the biotic and abiotic environment. Ideally, the scores for both biotic themes will be reported. If however, a single score is required the Final Report recommends that the lower of the two biotic indices (fish or macroinvertebrates) be reported.
27	Can the concept of FPZ be further discussed in relation to index development	As outlined in Appendix 5, the water quality index is based on the capacity of streams to transform inputs to streams into food forms (primary & secondary production) sustaining higher trophic levels, and maintain a food web of similar complexity to that of the reference system. The water quality index has drawn on a range of indicators reflecting the physico-chemical outcomes of instream primary and secondary production processes. The dominant bio-geochemical processes for each Functional Process Zone are described in Tables 1A & 1B of Appendix 5. The Water Quality Index is the sum of the individual ratios of monitored to reference site indicator values. Riffles have been adopted as the basis of sampling in the case of the upland and mid-slope Process Zones, on the basis that their water quality is representative of outcomes of the epilithon or biofilm (assuming equilibrium conditions along the riffle reach). Channel (pool) reaches have been adopted as the basis of sampling in the case of lowland Process Zones, on the basis that their water quality is representative of outcomes of the microbial

		decomposition and mineralisation and planktonic and attached algae nutrient uptake processes. The approach limits sampling to median to low flow conditions. ie: instream biological processing of inputs to the stream and instream recycling are the dominant determinants of ambient water quality, and that local reaches are in equilibrium with local inputs and recycling. Macroinvertebrate — this is likely to be an issue for study design rather than the actual index. (Also see response to Question 14.)
28	How are the VPZ indices aggregated into a River Valley Index?	The scores for each index are aggregated to the reporting scale from site scores for each index. The aggregation protocol from sites to reporting scale is the same for each reporting scale. The aggregation protocol is described in the Final Report.
29	Could you include reference lists for Appendices 5, 6 and 7 and any further case studies of the experimental or trial use of these indicators?	Water Quality : The proposed Audit approach to water quality indicators of health represents a significant shift from previous approaches. The proposal to undertake a Pilot Run therefore provides an important means of further developing and testing the approach. The approach is entirely consistent with the conceptual models, risk assessment and reference condition basis of the revised ANZECC Guidelines for Fresh and Marine Water Quality 2000. A number of the indicators are well established as sensitive measures of net primary production (diurnal DO change, pH change), secondary production & mineralisation (NH_4/NOx, NOx/TN), and the processing of organic material & mineralisation ((FPOM+DOM)/(TOC, NOx/TN) in the case of upland Process Zones. Lawrence *et al.* (2000) demonstrated the sensitivity of the NH_4/NOx ratio as an indication of reducing levels. For non-point source based river systems, runoff derived from elevated rainfall events constitutes the major driver of inputs of suspended solids, nutrients and organic material to streams. Research reported by Hart, Grace & Beckett indicate that particulate material rapidly adsorbs nutrients and toxicants, and develops biological coating of organic material. The particulates with their coating of nutrients, organic material and toxicants, settle to the sediments under less turbulent flow conditions in deeper pools or on the falling arm of the flow event hydrograph. There has been extensive laboratory and reservoir and lake based demonstration of P release from sediments under low redox conditions. Laboratory based sediment core experiments (Armitage 1995) demonstrated the capacity for a range of carbon sources to reduce sediments, with significant remobilisation of N and P. The research demonstrated the potential for nutrient limitation of the microbial growth, slowing or limiting the sediment reduction and transformation and release of nutrients. Field observations of river sediment release of P are confounded by

		the heterogeneity of sediments, limited duration (limited redox development) of benthic chamber experiments, lack of redox measurement, limited labile C to drive redox conditions down, and the rapid uptake of a component of released P by bacteria. Hart et al. 2000 reported that benthic chamber analysis of stream sediment fluxes indicates that monitored P releases do not necessarily increase even when sediments turned anoxic. The application of sediment diagenesis models, linked to redox conditions, indicates rapid to slow release of P from sediments, depending on the depth of $Fe(OH)_3$ layers and redox conditions (Harper 2001). There is extensive published material reporting on instream N release rates from sediments. De-nitrification at low levels of DO and moderate redox level conditions, and an order higher level of N than P. Analysis of a range of organic materials indicates algae and some grasses have a labile carbon content some 20 times that of eucalyptus derived litter. The analysis also highlighted the slow rate of bio-degradation of a range of native vegetation derived carbon materials, in excess of 100 days in some cases, and the nutrient limitation as a significant factor in determining slow decomposition rate for some materials (Esslemont 2000).
30	Could you include a table of the status of development and trialling of each of the indicators, including any validation of sensitivity against known stressors, and including where current State programs are spatially and temporarily adequate? <we presume you mean temporally and not temporarily adequate?>	A table that has the status of development and trialling of indicators is presented in the Final Report. Validation of macroinvertebrate indices against some environmental stressors is described for the macroinvertebrate indicators in Appendix 3. It is not appropriate to validate the fish, water quality, habitat or hydrology indicators against known stressors as these have not yet been trialled. The Final Report argues that current programs of the partner governments do not meet all the requirements of the Audit. However, there may be specific examples where appropriate information is collected by the State agencies. This will need to be assessed on a site by site basis. Issues that will need consideration include detailed description of site location, the motivation for choosing that location, the time of the year that those sites are sampled and the exact methods used. This is a matter for the jurisdictions to address in the site selection process.
31	Could you include more detail on how the numbers of sites for sampling per indicator was arrived at, for example was it based on empirical studies of natural variation, or other analyses?	See Final Report.

32	Can you include for each indicator an analysis of how they meet the criteria for indicator selection (as done for macroinvertebrates)?	A number of criteria have been proposed for the selection of indicators for each environmental theme in the Audit: • *builds upon existing programs and data as much as possible* • *consistent with the conceptual models of river function developed for the Functional Process Zones* • *responsive to disturbance* • *measurement and analysis are rapid (analysis is built into reporting of the indicator)* • *standardised methods are available and are technically appropriate for State agencies to undertake* • *output can be interpreted relatively unambiguously* • *indicator has meaning to the wider Basin community*
33	Could you include comment on acceptable levels of change and is there any technical basis for it? e.g. terms such as impairment need to be carefully defined.	It is not the role of the Audit to comment on acceptable levels of change. Acceptability of change is a decision that needs to be made by the broader community. The role of the Audit is to inform the debate on levels of change. The Audit has chosen to do this as change from a natural condition. In the case of the AUSRIVAS O/E indicator, which is scaled between 0 and 1+, each 0.1 change reflects the absence of 10% of the predicted biota at a site. The Audit will determine the level of the indicator (e.g. 0.6). Whether the community accepts a loss of 40% of the predicted macroinvertebrate taxa is for them to decide.
34	How is natural variability allowed for in the power analysis and hence the required sampling numbers?	
35	How does lack of consistency between the States, in things like site selection, sampling and modelling, affect the framework?	One of the primary motivations for the development of the Audit is the lack of consistency between the States in the way river health is assessed and reported. It is for this reason that the Final Report has recommended a new framework which defines the study design including; site selection, methods and models.
36	What are the State by State totals for numbers of sites?	See Final Report.
	Could you clarify the geographic coverage of the indicators, e.g. Lower Lakes?	The Audit framework was developed to assess the condition of the Basin's rivers. The Framework, as it stands is not appropriate for assessing the ecological condition of the Lower Lakes (e.g. Lake Alexandrina). While some of the indices developed for the framework may be readily adapted to assess the condition of the Lower Lakes the indices have not been tested in these environments. It is recommended that a separate project be undertaken to develop a framework for assessing condition of the Lower Lakes, if this is an objective of the Audit.

WQ Index		
37	Does the approach consider opportunities to rationalise sample sites?	The initial costing did not incorporate economies available in common sites and sampling dates. Typically, the water quality index site selection requirements are consistent with the macroinvertebrate site selection requirements. Consequently, water quality sampling could be taken at the same site and time as the macroinvertebrate surveys. Additional water quality samples will be required in order to meet the statistical significance probability criteria.
38	Is it the case that this index is comparatively less developed than the Fish index and requires a development plan similar to that proposed for the Fish index?	There is a need to further develop and refine this Index as part of the Pilot Audit.
39	Can you elaborate on how the index will be calculated, interpreted and then used as a trigger? Are the two separate components given any weighting? Is a 20% change an adequate basis for sample design?	The Physico-chemical index approach currently comprises the measurement of 'outcomes of ecological processes' indicators, and measurement of 'potential modifiers of ecological processes' indicators. The modifiers indicators include flow level, temperature, elevated SS, elevated nutrients, elevated organic material & elevated total dissolved salts. The 'indicators of outcomes of biological processes' already reflect changes in biota and processes due to modifiers. Consequently, it is now proposed to remove the modifiers from the Index calculation, but to still include them as a basis for explanation of observed shifts in indicator values, and as required to 'normalise' the monitored and reference site conditions (remove variance due to differences in 'natural' background factors). By removing the modifiers component from the Index, the Index becomes a much simpler and more powerful measure of the health of the stream. Retention of the monitoring of the modifiers is however important in providing a basis for interpretation of shifts in the physico-chemical index values. Over and above the Index related indicators, the measurement of a range of other indicators of conditions are required: • to 'normalise' reference and test site measurements in the case of available reference sites, and • to estimate reference conditions appropriate for the test site conditions in the case of the modelled reference conditions. Flow (and possibly temperature) are required to adjust reference values to remove differences due to differences in 'natural' background factors between the reference and test sites. Information on flow, temperature, suspended solids, organic carbon, nutrients and possibly total dissolved salts is required in the case of application of models in estimating reference conditions.

		Details on the individual Index calculation basis for each Indicator have been included in Appendix 5. The 20% change values is a judgement on my part, guided by ANZECC Water Quality Guidelines 1992 'limits to acceptable change' in relation to potential for impairment of biota. It is intended as the identification of an 'increment' of change that is likely to be significant in ecological terms, without any overlay of acceptable or unacceptable bands at this stage. The proposed Pilot Project will be invaluable in further testing and developing this aspect of the approach.
40	Could you review Victoria's analysis of power vs practicality (to be provided by Jane Doolan)?	
41	Could you further describe and include references and justification for the sampling of organic carbon?	In the case of the upland Process Zone, the dominant process is one of breakdown of organic detritus material by mechanical, leaching and microbial processes. Robertson *et al*. 1999 notes that the input of carbon to streams is the major energy source driving microbial food webs. In the case of the mid-slope and lowland Process Zones, it is the input of carbon to streams that is the major energy source driving microbial food webs, and driving the remobilisation of nutrients from the sediments to sustain biofilm and algal growth. The instream fixing of carbon in Australian streams is typically nutrient limited, as a result of soils and native vegetation low in nutrients, and adsorption of nutrients on particulates and their sedimentation (removal from the water column) and burial in the sediments. The larger macro-plants are able to access the sedimented nutrients through their root systems. They recycle the nutrients via leaf fall and decomposition of stem material. External inputs of organic material are important drivers of benthic microbial processes, mineralisation of organic material (release of constituent nutrients), and driving down redox conditions such that nutrients in sediments are remobilised. The composition of organic material provides an indicator of the breakdown and mineralisation of coarse particulate organic material by biofilm, microbial processes, or macroinvertebrate grazing and any divergence to expected conditions.
	How will different sources of inflow (wetlands, tributaries) be accommodated?	The current Audit framework excludes standing water bodies such as weir pools, lakes and reservoirs. The approach could be expanded to include these 'Functional Process Zones'. A distinctly different set of indicators would be required to reflect the ecological health of these systems.
43	Having further	This is a matter for individual States and Territories. The advances

	developed this indicator, could you now include a review the relevant State WQ programs in Appendix 1?	made in our application of new knowledge to interpretation of data, as represented by the Audit framework, will inevitably influence approaches to river health assessment nationally.
44	Will the exclusion of high flow events from sampling adequately cater for unregulated event-based rivers?	In the case of upland (unregulated) streams, the proposed cut-off in flows, beyond which sampling should be excluded, is the 30 percentile duration flow. As explained in the Map of dominant bio-geochemical processes Tables 1A & B, under the event flow conditions, the physical processes of flow and sediment transport, sedimentation and re-suspension dominate, rather than the instream biological processes. As noted in Appendix 5, the focus of the stream health assessment is on the water quality indicators of instream ecological processes (instream responses following a flow event). The Appendix also notes that as the few grab samples are totally inadequate in terms of characterising the event flow conditions, this data is of limited value.
45	Should cost of flow gauging be incorporated into this — what level of flow gauging is required?	The initial costing did not include stream gauging. It was assumed that based on the existing gauging network, and the application of hydraulic models, estimates of flows of sufficient accuracy for the purposes of the Audit could be generated without the need for additional gauging stations. Where gauging stations are required, it may be sufficient that staff gauges are installed at sampling sites (officers collecting water quality samples to note level), rather than incurring the high cost of establishing fully automated stations.
46	Could you provide greater explanation of where in the water column Organic C is to be sampled.	In the case of the limited depth of the riffle zone based sampling sites for the upland and mid-slope Process Zones, this will not be an issue. In the case of the deeper channel (pool) reaches for the lowland Process Zones, it is proposed that an integrated sampler (tube) be used to integrated variation in indicator values across the depth of the pool.
Physical Habitat		
47	A table provided by NSW (attached) lists information that allows costings in the physical habitat sampling - can you provide a similar breakdown of attributes that would allow more detailed costings?	The table provided by Bruce Chessman has been completed to provide more detailed description of the protocols recommended. It is now located at the end of Appendix 7 (Table 4).

48	Could you review the recommendations to ensure their consistency with the discussion e.g. aerial techniques, what can be picked up from orthophotos and what cannot. ?	We have reviewed the document and endeavoured to make the recommendations consistent. To facilitate this we have also included a summary table of the indices and the technique to be employed (see Table 4 in Appendix 7).
49	Is it possible to refine or reduce variables to better match existing programs? (The large number of variables mean either high cost or low replication and need prioritising)	This question needs to be answered in two parts. For most of the remotely sensed indices the statement about replication and cost is not applicable or is trivial. Second, the vast majority (31 of 37) of indices are already measured by existing programs and we therefore believe there is a reasonable match between our recommendations and existing programs. Where we recommend a different technique it is because we believe that our recommendation will lead to a dramatic improvement in the quality of the data collected without adding significantly to the cost of the assessment. Finally, it is possible to delete any of the measurements we recommend, from the Audit. We believe that any deletion will, however, result in a loss of information that we have endeavoured to make explicit in the appendix. We strongly recommend that all the proposed indices be assessed during the Pilot. Once the Pilot is complete it would be appropriate to undertake a sensitivity analysis to determine whether some measures could be omitted from the Audit without any loss of information.
	Is the 1 m in-channel patch size realistic and would a 10 m size be appropriate?	It is unclear to which measurement this question is directed. In general, however, 10m grain size would be too large to adequately assess macrophytes, snags or sediment types.
50	How will FPZs inform sample site design for the VPZs? At what scale is the lowest 10% of disturbance interpreted — Basin, valley, VPZ or FPZ and what are the implications of this?	The 1st part of the question is harking back to the misunderstanding about the role of FPZ. Currently FPZs will not affect study design for reporting at VPZ scale. That is sites are being randomly stratified by VPZ, not FPZ. However, if the jurisdictions decide to report at the FPZ level then stratification will be by FPZ, not VPZ. The selection of reference sites is a vexing question that will need ongoing attention. We do not pretend that we have resolved this issue, but the proposed guidelines will provide the basis for the selection of reference sites until more powerful techniques can be developed. This issue does not have any impact on the collection of data from test sites, merely the interpretation of that data and so we do not think that this issue should be viewed as an excuse to stall the Audit. The assessment of disturbance will be on a site basis. In most cases this will involve the use of the floodplain transects to quantify the level of disturbance at the site.
51	What is the assumed travel distance for field trips (p.41) and the	We assumed a travel time of 8 hours per site. It was not possible to provide a more accurate estimate until sites are selected and determination of which agency staff will undertake the monitoring

	effect of remoteness and access?	is made.
52	Can you provide more detail on the process models and E-ball technique? How will O/E be generated for each spatial scale? How will E-ball deal with attributes of varying type, scale and statistical distribution, and with variables for which the expected natural value is infinity?	More detail of E-Ball has been incorporated into the Appendix. The O/E is always calculated at the site scale. Aggregation to higher spatial scales can be made using averages as per the invertebrate O/E measure. No variables with an expected natural value of infinity will be used in the habitat index. Varying statistical distributions are accounted for by range and variance standardisation in the calculation of Euclidean distance from the test to the reference sites. The variables used to calculate the expected values are always measured at a higher scale than the variables being predicted.
53	How do you establish a natural erosion rate using pins, given the stochastic nature of change?	The question encouraged the team to re-examine the proposed protocol. Erosion pin data would be highly variable which we had envisaged would be dealt with by having a large number of replicates. The cost of replication has led the team to change its recommendation such that we now suggest the use of aerial photography to assess channel movement and erosion.
54	What criteria should be used to define a site? Can you address issues of downstream extent of impact (dams, towns), 'significance' of source discharge, impoundment of site, criteria for alien species, relationship to past or present activities?	Issues of site selection are detailed in the Final Report, ''Site Selection'', p. 33. We have changed the Appendix text to make it more explicit. Site selection is governed by the sites selected for other components. Issues of dams, towns, discharges, impoundment, past and present activities are not part of the assessment of condition. We believe that they are stressors or drivers of condition and therefore lie outside the scope of the Audit. At this point, it is proposed that the only criteria to be used to define sites are the Valley Process Zone and Functional Process Zone categories, and the requirement for sites capable of providing a representative (mixed) sample. The framework proposes a random selection of sites from the sites meeting these three criteria, on a valley by valley basis.
55	Can you suggest alternatives to the spatial sample design of 100m transects? Can other techniques such as systematic sampling, two-stage sampling or stratified random sampling been considered?	The imperative for the Audit was to develop a cost effective means of assessing physical habitat. While other sampling designs could be employed we believe that they would involve greater cost, or would be more difficult to apply across all rivers in the Basin.
56	For floodplain habitats, can you comment on: - the scale of the habitat types relative to the size of the transect and the need to increase transect size - the potential for	The scale of the habitats is only marginally related to the size of the transect. We do not believe that increasing the size of the transect above 100 m will have any impact on the results. There is considerable scope for remote sensing, which is why all the metrics recorded from the 100 m transects will be remotely sensed. As stated in the Appendix, it is hoped that in the future there will be integration between physical habitat and hydrology metrics that will allow assessment of wetting and drying regimes in floodplain wetlands. Any on-ground assessment of this would require a

	remote imaging - the attributes to be assessed (for example in billabongs - wetting and drying?)	dramatic increase in sampling frequency which we believe would add significant costs.
57	For riparian vegetation, given the importance of rigour and repeatability in assessing species diversity and richness. have you considered other techniques such as systematic sampling, two-stage sampling or stratified random sampling?.	See answer to Q 55
58	Should habitat fragmentation be measured on a site scale or over a larger scale using aerial photography?	We recommend that habitat fragmentation be measured using aerial photography. We believe that the floodplain and riparian definitions we use represent an appropriate scale, but believe that the proposed Pilot will give us an opportunity to evaluate whether issues of scale need to be revised.
59	Should the sampling techniques for riparian demography be refined?	Most of the techniques we recommend should be refined. We believe that the Pilot will provide an opportunity to refine all the indices where appropriate.
60	For emergent macrophytes, can you explain: • how a measure of grazing pressure might be incorporated • how the extent and abundance of submerged macrophytes might be assessed in turbid conditions • what 'spot sampling' is • what sample units are used, over what length of river.	We have amended the description of the techniques to make our intent clearer. We have not incorporated any measure of grazing pressure as we regard it as a stressor and therefore outside the scope of the Audit.
61	For snags, have you considered a series of line transects at different elevations? Could snags be measured with a random selection from the first 100 encountered?	For each transect, the height of the snag in the channel is recorded, this can be referenced to base flow or some stage level. By doing this you can build a profile of snag surface area/volume at different river heights. Snags could be measured with a random selection from the first 100, or 1000 sampled, but all that would tell you was the average size of a piece of wood based on a sub-sample of some population. To get the most value, the measurement needs to be referenced to a reach length or bed area. The random sample method would only be useful if all you wanted to say were that the snags in one river are big, longer, heavier, etc., than the snags in

		another river. You can still get this information from the line intersect method (at least a diameter comparison) as well all the other information, like density, SA/m^2, vertical and horizontal distribution with the channel, etc.
62	For levees, can you include comment on: • how the data will guide management • how their impacts on connectivity will be quantified • how position and alignment will vary their influence on connectivity • how a more comprehensive inventory of levees might aid floodplain management.	• The Audit is designed to guide management. We do not believe that each measure should be justified or described in terms of management guidance. • We have altered this component to quantify the effects of levees on connectivity, although there will be a one-off cost associated with this determination. • The last dot-point is outside the scope of the current project.
63	Can you include the missing section on transects (p.54)?	We have included this component.
64	How feasible is the aerial photography in discriminating between species, between structural variations and for snags, depth and macrophytes?	The snag and macrophyte techniques have been trialled and the results published in refereed journals. The techniques proposed do not require remote imagery to distinguish among species, merely among species groups, such as willow, acacia and eucalypt.
Hydrology		
65	Could you include a definition of regulated and unregulated, and is the assumption that unregulated streams are unimpacted valid?	In order to answer this question one must separate out legal and administrative definitions and those which pertain to the functioning of riverine ecosystems. The Sustainable Rivers Audit is concerned with the development of a framework with which to assess the condition of rivers through out the Murray-Darling Basin. Hence an ecosystem perspective should be used in defining a regulated river. Thus, for the purposes of the Audit a regulated river is *any river or section of river that has a structure (e.g. dam, weir or barrage) on it or is subject to anthropogenic additions or withdrawals of water*. An extra paragraph has been added to the Appendix that provides this definition.
66	Could you overcome the dampening effect of averaging deviations over the FDC by using current vs natural and return time over time for specific percentile ranges? Given dampening, should the	There is no dampening effect of averaging deviations. The Flow Duration Curve Difference parameter provides a measure of the overall difference between current and natural flow duration curves. In the absence of 'rigorous scientific' evidence to the contrary, all flows are considered to be of equal importance to the ecological functioning of the river. Consequently, this approach weights all percentile flows equally. Moreover, given that river channels are governed by the full range of flows it would appear not to be sensible to choose specific flows.

	four indicators be averaged or not?	
	Given the above, is weighting an option?	No — see above
67	Will the use of means rather than medians and annual rather than monthly/daily bias the extent of departure from natural?	No. The Mean Annual Flow parameter is designed to indicate the total volume of water extracted from or added to the river. Use of medians would not encapsulate this information. Differences in the monthly flows are represented by the Flow Duration Curve parameter.
	Will the use of monthly flows (for the year rather than a period) limit the seasonal amplitude index and also lead to high flow biasing?	No
68	Could you include comment on: • The use of frequency indicators for special events (return frequency) • Relating flow to other indices • Sensitivity to change, compared to the component indices • Sensitivity to “anticipated” environmental flow releases • Accuracy of the IQQM model • the time scales that the indicators reflect	• THE USE OF FREQUENCY INDICATORS FOR SPECIAL EVENTS (RETURN FREQUENCY) The aim of Sustainable Rivers Audit (Audit) is to provide on-going assessment of river health in the Murray-Darling Basin and as such it has assembled a group of hydrological indicators suitable to apply to all the rivers in the Basin. Each river will have a set of frequency indicators that is relevant to its structure and function. For example, many use the Frequency of an event with a recurrence interval of 2.33 years (annual series) and assume this to be the frequency of bankfull events. This has proven to be unsuitable for many rivers in the Basin (see Woodyer 1968). Therefore, the physical, chemical and biological character of a river is a reflection of all flows not just specific flows of certain frequencies (Pickup and Reiger 1979). The hydrological parameters used in the Audit are measures of the entire flow regime of the river. • RELATING FLOW TO OTHER INDICES The Audit has developed a series of hydrological indices that measure the health of biological processes and complementary indices that measure the condition of the physical and chemical processes that may impact on the biota within a river. In doing this we recognise that it is difficult to deconvolve the effects of individual physical and chemical processes on biota. It is therefore not possible to state, for example, that a 50% reduction in flow will result in a 50% reduction in macroinvertebrates. Instead, physical and chemical indices should be used in conjunction with the biological indices to indicate either possible reasons for biological impairment or the potential for future biological impairment. • SENSITIVITY TO CHANGE, COMPARED TO THE COMPONENT INDICES Analysis of sensitivity requires additional model runs for both existing and natural flows. While it is possible to perform sensitivity analysis, the data requirements are substantial and the State agencies have not been in a position to supply the data for this.

		• SENSITIVITY TO "ANTICIPATED" ENVIRONMENTAL FLOW RELEASES Require modelling runs do this — none provided — see above comment • ACCURACY OF THE IQQM MODEL The hydrology index has been designed to make use of modelled data from the State agencies. IQQM is the standard hydrologic model used by NSW DLWC and QLD DNRM and the use of IQQM as a water resource management tool has been documented in the literature (see Black et al. 1997) It is not within the scope of the Audit to comment further. • THE TIME SCALES THAT THE INDICATORS REFLECT The Sustainable Rivers Audit was required to report the condition of rivers in Basin at a reach scale. Relationships between spatial and temporal scales are well documented in the literature (Frissell 1986, Schumm 1988, Thoms 2001) hence setting of a reach as the reporting scale sets the temporal scale in which one must view the hydrology of a river in terms of auditing. The parameters used fit within the scale set for the Audit.
69	Comment on the question "Having calculated Hydrology Index in year 1, is it necessary to ever do it again, unless this is triggered by a major change in operation rules?"	It is recommended that calculation of the hydrology index will take place if there is a change in operation rules and/or with the improvement or refinement of the various hydrological models that are in use within the Basin.
Macroinvertebrates		
70	Are you aware that the lowland Murray valley is rated by AUSRIVAS as good by the NLWRA theme 7 assessment and should you include comment on that discrepancy with other literature, on other habitat types that may need to be monitored and on the sensitivity of AUSRIVAS and SIGNAL scores in stressed conditions.	It is unclear which literature is being referred to here and what the discrepancy is. It may be related to the definition of 'good' or an assumption of poor valley condition that has not been thoroughly tested. It is also possible that AUSRIVAS scores may be conservative for the river valley and could overestimate condition in some cases. However, it is proposed that scores should be adjusted based on agreed departure of reference condition from pristine (see Appendix 3, section A3.6).
71	Does the sensitivity of Regional models need to be addressed? - 3 in Vic but 1 in NSW and 1 in	Regardless of the model, the final outputs (including O/E values) should be comparable. However, it is proposed that this assumption should be tested using Victorian data, for which a large number of models are available.

	QLD. How do you deal with the different models? Are the extrapolated correlations with WQ and the responsiveness to flow and habitat adequate?	
72	Can you include costings for identifying to species level?	The initial costing was provided in the scoping document at $208,000.
73	Is one 10 m dab net sweep adequate?	This issue has been researched extensively and it has been found that one 10 m sweep is adequate to represent the health of a site (see Appendix 3, section A3.2).
74	Will the main channel, edge habitats and wetlands be treated as discrete habitats?	Yes, these are all discrete habitats, representative of the river valley. Habitats will be sampled separately to provide an overall measure of health for a valley.
75	What happens in SA where there are no riffles in the Murray?	The main habitat in each case should be sampled. In the case of the Murray in SA another habitat such as main channel, edge or macrophytes should be sampled. The final O/E score for the valley should be representative, regardless of which habitat has been sampled.
Fish		
76	Would historical literature and expert opinion be the best way to establish reference condition for this indicator?	Not the best way (there is no best way), but it will be used as one of two reference approaches, in combination. It is recognised that it will be biased (toward 'big' fish and specific valleys/reaches) and patchy, but will be critically reviewed prior to use.
77	Can you include further detail on selection of sites to allow calculation of costs.	Not without a preliminary round of data collection followed by gear comparison, and power analysis.
78	Can South Australia be included in the Pilot, and explain how habitats other than the main channel will be included?	Yes, but this will require the agency to change approach. Currently only commercial fishery data are collected. A survey can target stratified selection of off-channel habitats.
79	Can the pilot fish index development be rescheduled to fit with the pilot Audit?	Yes, they should be one and the same.
80	Can fyke nets be set at dawn and dusk, not left out overnight.	Possibly; we need agency input on this prior to Pilot.

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