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MURRAY–DARLING BASIN AUTHORITY

Sustainable Rivers Audit 2

The ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010)

Volume 1

The second **Sustainable Rivers Audit** (SRA) is the most comprehensive assessment of river health undertaken for the Murray–Darling Basin. Prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin:

Peter Davies | Michael Stewardson | Terry Hillman | Jane Roberts | Martin Thoms

www.mdba.gov.au

Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray–Darling Basin Authority acknowledges and pays its respect to the Traditional Owners and their Nations of the Murray–Darling Basin. The contributions of earlier generations, including the Elders, who have fought for their rights in natural resource management are also valued and respected.

The Authority recognises and acknowledges that the Traditional Owners and their Nations in the Murray–Darling Basin have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. The Authority understands the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin. Further research is required to assist in understanding and providing for cultural flows. The Authority supports the belief of the Northern Murray–Darling Basin Aboriginal Nations and the Murray Lower Darling Rivers Indigenous Nations that cultural flows will provide beneficial outcomes for Traditional Owners.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of Ngarrindjeri elder Tom Trevorrow: 'our traditional management plan was don't be greedy, don't take any more than you need and respect everything around you. That's the management plan—it's such a simple management plan, but so hard for people to carry out.[1]

This traditional philosophy is widely held by Traditional Owners and respected and supported by the Murray–Darling Basin Authority.

1. Tom Trevorrow (2010) Murrundi Ruwe Pangari Ringbalin 'River Country Spirit Ceremony: Aboriginal Perspectives on River Country'.

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About SRA report 2 (volume 1)

The Sustainable Rivers Audit (SRA) is a systematic assessment of the health of river ecosystems in the Murray–Darling Basin. It is overseen by a panel of independent ecologists, the Independent Sustainable Rivers Audit Group (ISRAG), who are the authors of this report. It is based on data collected and analyses by a multi-jurisdictional team from state and federal governments.

The second full SRA assessment report provides assessments of ecosystem health for each of the 23 major river valleys of the Basin, using data gathered in 2008–2010, on the condition of five key ecological components: fish, benthic macroinvertebrates, riverine vegetation, physical form and hydrology.

This document is volume 1 of ISRAG's Sustainable Rivers Audit 2: The ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010), submitted to the Murray–Darling Basin Ministerial Council in 2012. It describes the framework of the SRA, its design and operation, new developments in Themes, analyses and metrics, and recommendations for future implementation and use. It also includes a first assessment of trends in condition of fish, macroinvertebrates and hydrology, based on an initial set of observations through time.

Volume 2 in the series presents the assessment findings for Murray–Darling Basin valleys listed alphabetically from the Avoca to the Loddon. Volume 3 contains the assessment findings for Murray–Darling Basin valleys listed alphabetically from the Macquarie to the Wimmera.

All three volumes, as well as a summary report and summary brochure are available through the Murray–Darling Basin Authority's website:
www.mdba.gov.au.

Contents

Executive summary

The Sustainable Rivers Audit (SRA) is a systematic assessment of the health of river ecosystems in the Murray–Darling Basin. It is overseen by a panel of independent ecologists—the Independent Sustainable Rivers Audit Group (ISRAG)—who are the authors of this report. It is based on data collected and analyses by a multi-jurisdictional team from state and federal governments.

The second full SRA assessment report provides assessments of ecosystem health for each of the 23 major river valleys of the Basin, using data gathered in 2008–2010 on fish, benthic macroinvertebrates, riverine vegetation, physical form and hydrology. A first step is made in describing trends in condition of fish, macroinvertebrates and hydrology, based on a small number of observations through time. The report also describes the framework of the SRA, its design and operation, new developments in Themes, analyses and metrics, and recommendations for future implementation and use.

The Audit framework

The SRA gathers quantitative information on environmental indicators in valleys throughout the Basin. The indicators provide 'windows' on particular components of the river ecosystems, and are grouped as Themes. For this report there are Themes for Fish, benthic Macroinvertebrates, riverine Vegetation, Physical Form and Hydrology. The data for each Theme are acquired systematically using agreed protocols, with quality assurance.

Within each valley there are 1–4 *zones*, defined in most cases by altitude. Sampling locations are either located randomly across the river network within zones, or constitute a comprehensive census across each valley's river system—thus enabling unbiased statistical analyses and representative reporting.

The indicators are combined (or *integrated*) to form quantitative measures of *condition* for each Theme, and Theme Condition ratings are combined to assess *Ecosystem Health* for each valley and its zones.

Condition assessments for each valley are related to a benchmark called Reference Condition. This estimates the status of a component (for example, the value of a measure of the fish community) as it would be in the absence of significant human intervention in the landscape. Reference Condition is a benchmark representing the river ecosystem in good health. It is not used as a target for management.

Condition of each Theme is rated on a five-point rating scale from Good through Moderate, Poor, Very Poor to Extremely Poor, depending on how different the Theme components are from their respective benchmarks. The same scale is applied to Ecosystem Health.

Assessment of the river systems

Assessments of condition and Ecosystem Health for each of the 23 valleys in the Basin for the period 2008–2010 are shown in the accompanying table (Table 1).

A severe drought prevailed over most of the Basin during the entire Audit assessment period. It limited the availability of sampling sites in some valleys for fish and macroinvertebrates, though this did not affect the viability of the assessment.

As this report covers the period up until the break of the long-term drought, it does not report on any response to, or recovery from the drought. Rather it provides data for a sound assessment of post-drought changes in river condition and health, planned for 2013–2014.

Ecosystem Health

Only the Paroo Valley river system was rated in Good Ecosystem Health and only the Warrego Valley was rated in Moderate health. Fifteen valleys were rated in Poor health and six were rated in Very Poor health. The Castlereagh, Condamine and Darling valleys were rated in Poor Health but fell only just below the lower bound for a Moderate Health rating. No valley river system was rated in Extremely Poor Health.

Only one zone was rated in Good Health—the Paroo Lowland. Most zones were rated as being in Poor (38 zones) or Very Poor health (21 zones). Two zones (Lowland and Slopes) from the Warrego were rated in Moderate health. Other zones in Moderate health included: Lowland of the Condamine; the Upper of the Darling; Upper of the Lower Murray; Slopes of the Castlereagh, Upland of the Ovens and the Montane of the Upper Murray. Overall, Upland and Montane zones rated in similar ecosystem health to the Lowland and Slopes zones.

Only one (11%) of the nine northern valleys were rated as being in Very Poor river Ecosystem Health (Macquarie), compared to five (36%) of the 14 southern valleys. In addition, the valleys rated as being in Moderate or Good Health were located in the northern Basin, as were the three highest ranked valleys in Poor Health. All except one of the 21 zones rated in Very Poor Health were in southern valleys.

Fish condition

Fish sampling at 510 sites yielded more than 63,000 individuals in 36 species (27 native, nine alien), weighing around 4.5 tonnes (~1.5 tonnes native, ~3 tonnes alien). 38,500 of these were native, many of them small species, contributing 61% of individuals but only 33% of biomass. All fish were returned to the water after measurement (except for pest species in some states).

Eight *metrics* were calculated from the sampling and Reference Condition data. Three indicators—of Expectedness, Nativeness and Recruitment—were derived from the metrics of abundance, biomass and species composition and were combined to derive the *Sustainable Rivers Fish Index*.

Fish communities in the Condamine and Border Rivers valleys were in Moderate condition; those in eight other valleys were in Extremely Poor condition. Only the fish community of the Paroo was rated in Good condition. Those in the remaining valleys were in Poor or Very Poor condition. Communities in the northern Basin generally were in better condition than those in the southern Basin.

Native fish dominated by numbers and biomass in the Border Rivers, Condamine, Lower and Central Murray, Paroo and Warrego valleys and by biomass in the Darling Valley. Golden perch were recorded in 21 of 23 valleys; and Murray cod, freshwater catfish and silver perch were in 20, 11 and eight valleys, respectively. Bony herring and gudgeon were the two most numerous native species caught during the 2008–2010 survey period.

Alien species rivalled or outnumbered native fish in 13 of the 23 valleys, especially the Broken, Campaspe, Kiewa and Murrumbidgee valleys. The Border Rivers, Condamine, Lower Murray, Darling, Paroo and Warrego valleys all had native species contributing more than 75% of their total fish numbers. Common carp and gambusia (both aliens) were ubiquitous (present in all 23 valleys), and goldfish was caught in 22 valleys. Redfin perch also were abundant and widespread, especially in warm, lowland areas; and brown trout and rainbow trout were common in cooler upland streams. Carp overwhelmingly dominated fish biomass, comprising 60% of the total survey catch.

An average of 6.1 native fish species was caught per zone across the Basin, compared to 14.6 species expected under Reference conditions.

The Lower Murray yielded the largest biomass of fish (26.9 kg/site) though only 31% of this (8.2 kg/site) was contributed by native species.

The Darling and Border Rivers valleys had the highest proportions of fish biomass as native species.

For almost all native species captured during the 2008–2010 sampling period, there was some evidence of recruitment. Thirty-nine silver perch individuals were captured at 17 sites across eight valleys, but none were recruits. This may reflect the lack of appropriate flow signals during drought conditions. Murray cod recruits were observed at more than half of the 97 sampling sites at which the species was recorded.

Macroinvertebrate condition

Macroinvertebrate samples taken from 797 sites included over 216,454 specimens of macroinvertebrates (invertebrates visible to the naked eye) in 116 families. They include leeches and worms, shrimps, snails, beetles, bugs and the young stages of dragonflies, midges and other insects.

One indicator, based on the presence of families and their relative frequency of occurrence, formed the basis of the *Sustainable Rivers Macroinvertebrate Index*.

Macroinvertebrate communities in the Kiewa, Mitta Mitta, Paroo, Upper Murray and Warrego valleys were in Good condition, while those in the Central Murray, Darling and Goulburn valleys were in Poor condition. The communities of the remaining valleys were in Moderate condition. Lowland zone communities continue to be in significantly lower condition than those for all other zones across the Basin.

Twenty-two families were recorded in all 23 valleys. A number of families were rare, including 21 taxa that were recorded at less than 10 sites each. The common families include many species that are tolerant of pollution and other human disturbances; and the rare ones contain sensitive species.

In general, the communities of valleys in the northern Basin were in better condition than those in the southern Basin. Upland zone communities were generally in better condition than those in Lowland zones.

Vegetation condition

Riverine vegetation data were available from a census of collated current and pre-European vegetation mapping resources, as well as site-based observations of canopy height. Considerable effort was made to gather and collate existing vegetation mapping resources and resolve errors and inconsistencies. This assessment relies strongly on the NVIS 3.0 and Integrated Vegetation Cover 2009 current mapping layers, along with the Australian Government (SEWPaC) Estimated Pre-1750 Major Vegetation Groups mapping layer for Reference Condition. Site-based assessments of canopy height condition were made using airborne LiDAR for some 1,600 reaches across the Basin (approximately 70 sites per valley).

Seven vegetation metrics were calculated and two major spatial domains established for assessment within each valley: the Near Riparian and the Lowland Floodplain. These metrics were integrated to produce two indicators: vegetation Abundance and Diversity and vegetation Quality and Integrity—representing changes in the spatial extent, composition, pattern and height of riverine vegetation due to human intervention.

It should be noted that this first assessment of the condition of the Basin's riverine vegetation is primarily based on mapping resources with fairly coarse resolution, a largely terrestrial focus (no riverine-specific vegetation types have been mapped), and was neither fully up-to-date nor uniform in currency. Improved mapping resources are only now becoming available and these, coupled with additional data collection, would substantially improve any future assessment.

The assessment data allows a description of the general characteristics of the Basin's riverine vegetation character, extent and quality. Thus, the most extensive riverine major vegetation group is Eucalypt Woodland, which accounts for 56 and 42% respectively of the total area of all Near Riparian and Lowland Floodplain domains. In addition, the extent and diversity of floodplain vegetation is greater in the northern than southern Basin valleys and floodplain vegetation is substantially more fragmented in the southern valleys. Mean vegetation abundance in the Lowland Floodplain domain is generally higher than in adjacent Lowland zone Near Riparian domains, especially in southern valleys. Vegetation abundance in Lowland Floodplain and Near Riparian domains was strongly correlated for northern valleys, indicating a similar or correlated history of change.

Riverine vegetation in six valleys was rated as being in Good condition, including the Paroo and Warrego valleys. Five were rated in Moderate condition. Three valleys were in Very to Extremely Poor condition, with the Broken, Campaspe and Loddon rated lowest in vegetation condition of all valleys.

Zones which had scores for both indicators (Abundance and Diversity, Quality and Integrity) rated Very Poor or Extremely Poor were all in southern Basin valleys.

A reduction in the number of major vegetation groups compared to Reference Condition was observed in the Near Riparian domains of seven of the 23 valleys, and in three of the ten Lowland Floodplain domains. Tree canopy height was rated as equivalent to or moderately different from reference in all valleys and all except four zones.

The riverine vegetation of northern valleys (on average in Moderate condition), was in substantially better condition than in southern valleys (on average in Poor condition).

Physical Form condition

Physical Form data were derived from airborne radar (LiDAR) surveys at 1,385 sites across the Basin, and from sediment (SedNet) modeling of 96,400 km of river length. Nine metrics were derived from these data, resulting in four indicators (of Bed Dynamics, Channel Form, Bank Dynamics and Floodplain Form), representing changes in geomorphological character of the river channels and floodplain caused by human intervention.

Channel geometry measurements were compared with modeled reference conditions. Results indicate widespread changes to the Basin's river channels, including three types of channel adjustment: simplification, enlargement and contraction. Channel simplification occurred at 63% of sites as a result of channel straightening (41% of sites) and reduced cross-sectional variability (38% of sites). Channel enlargement was indicated at 53% of sites as a result of channel deepening (38% of sites) and channel widening (37% of sites). Channel contraction was indicated at 21% of sites as a result of reduced channel depth (16% of sites) and channel narrowing (12% of sites).

The SedNet modeling results indicate increased sediment loads throughout almost the entire Murray–Darling Basin since European settlement. There have also been widespread increases in the rates of sedimentation on floodplains (99% of river length) and in channels (41% of river length). However, the period since European settlement includes periods of high catchment disturbance immediately following settlement. These results are therefore not necessarily indicative of sediment loads and sedimentation in recent years—more detailed modeling is required to assess the sequence of recent historical changes in sediment loads.

The Physical Form of river systems for 11 valleys was rated as being in Moderate condition, while the remaining 12 valleys were rated in Good condition. The Paroo was unique as its Bed and Floodplain Dynamics were largely unmodified from Reference Condition. Three valleys—the Condamine, Darling and Lower Murray—had the most altered channel Cross-sectional Form overall, coupled with enhanced floodplain sedimentation. Of the Basin's 68 zones, none were rated in Extremely Poor physical condition. Only five were rated as being in Very Poor or Poor condition and these were all Lowland zones. Other zones were rated as either in Moderate (21 zones) or Good condition (42 zones). All Montane zones were rated in Good Physical Form condition.

Channel Form, Bed Dynamics and Floodplain Dynamics contributed most of the variation in the Physical Form Index among valleys.

Hydrological condition

Of 191,000 km of river length considered for assessment across the Murray–Darling Basin, 18,300 km classed as mainstem river and 94,200 km classed as headwater streams could be assessed for this report. For each site, 13 metrics were derived which were integrated into four indicators, representing changes in both the in-channel and overbank flow regime due to human intervention. Site-based assessments of hydrological condition were made, but limitations to data availability and modeling capacity restricted the assessment to two components of the river system in each valley: headwaters and mainstem rivers. The assessment of headwater stream hydrological condition was also limited to the long-term effects of tree-cover change and farm dams.

Over the entire Basin, 56% of the mainstem river length is rated as being in Poor, Very Poor or Extremely Poor hydrological condition. Modifications to all aspects of the flow regime are widespread across the Basin's mainstem river network. The greatest human impacts are on flow seasonality and flow variability. Alterations to high and low flow events, as well as the total volume of flow, are also widespread and severe in many cases.

Based on this assessment, which considered only the impacts of farm dams and altered woody vegetation cover, 99% of the Basin's headwater streams are rated in Good condition. There are some restricted areas (less than 5% of total headwater stream length) where there are moderate alterations to flow seasonality and variability relative to Reference Condition, but no other substantive changes.

Ten valleys were assessed as being in Good hydrological condition. Seven valleys were rated in Moderate condition, five in Poor condition and one was rated in Very Poor condition. Variation in valley-scale hydrological condition was largely determined by condition of mainstem rivers. Despite Good or Moderate condition ratings for many valleys, there was variation in hydrological condition throughout each valley and zone. Nine characteristic patterns in flow alteration were identified across the Basin.

The Hydrology condition ratings reported here cannot be used to evaluate the need for environmental water requirements. Firstly, they represent alteration from the Reference Condition rather than alteration from a 'target' condition to be achieved through delivery of environmental water. Secondly, the rating is an integrated measure of the altered flow regime and includes measures of change in flow variability, frequency, duration, seasonality and magnitude. By contrast, environmental water requirements are often only expressed as flow volumes.

The *Reference Condition for Hydrology* is designed to include wet and dry periods. Condition assessments therefore reflect the overall effects of the current level of development and water use within the Basin on the historical flow regime; rather than that of the recent drought.

Trends

Trends were analysed for the Fish Theme based on only two sampling rounds (2004–2007, 2008–2010), for the Macroinvertebrate Theme based on three sampling rounds (2004–2006, 2006–2008, 2008–2010) and for the Hydrology Theme based on four time periods between 1998 and 2009. These are therefore fairly limited assessments of trend, but mark the first occasion on which Basin-scale changes with time in riverine environmental variables can be assessed comprehensively and systematically. Future additional sampling cycles will add substantial value in assessing long-term trends for the environmental condition of the Basin's rivers.

The Hydrology trend analyses were based on data from 44 gauging stations and cover 12 years—divided into four, three-year 'time slices'—and correction for reference and recent climatic conditions. Analysis of temporal changes in fish and macroinvertebrate condition described here is

Table 1. Condition and Ecosystem Health assessments for valleys in the Murray–Darling Basin, 2008–2010.

VALLEY	ECOSYSTEM HEALTH	FISH	MACRO-INVERTEBRATES	VEGETATION	PHYSICAL FORM	HYDROLOGY
PAROO	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
WARREGO	MODERATE	POOR	GOOD	GOOD	GOOD	GOOD
CASTLEREAGH	POOR	VERY POOR	MODERATE	GOOD	GOOD	GOOD
CONDAMINE	POOR	MODERATE	MODERATE	GOOD	MODERATE	MODERATE
DARLING	POOR	POOR	POOR	GOOD	MODERATE	MODERATE
BORDER RIVERS	POOR	MODERATE	MODERATE	POOR	MODERATE	GOOD
LOWER MURRAY	POOR	POOR	MODERATE	POOR	MODERATE	VERY POOR
OVENS	POOR	POOR	MODERATE	POOR	GOOD	GOOD
GWYDIR	POOR	POOR	MODERATE	MODERATE	MODERATE	POOR
CENTRAL MURRAY	POOR	VERY POOR	POOR	GOOD	MODERATE	POOR
UPPER MURRAY	POOR	EXT'LY POOR	GOOD	MODERATE	GOOD	POOR
WIMMERA	POOR	POOR	MODERATE	POOR	GOOD	MODERATE
NAMOI	POOR	VERY POOR	MODERATE	POOR	MODERATE	GOOD
KIEWA	POOR	EXT'LY POOR	GOOD	POOR	GOOD	GOOD
MITTA MITTA	POOR	EXT'LY POOR	GOOD	MODERATE	GOOD	GOOD
AVOCA	POOR	VERY POOR	MODERATE	POOR	MODERATE	GOOD
MURRUMBIDGEE	POOR	EXT'LY POOR	MODERATE	MODERATE	GOOD	POOR
CAMPASPE	VERY POOR	VERY POOR	MODERATE	EXT'LY POOR	MODERATE	MODERATE
LODDON	VERY POOR	VERY POOR	MODERATE	EXT'LY POOR	MODERATE	MODERATE
GOULBURN	VERY POOR	EXT'LY POOR	POOR	POOR	GOOD	POOR
MACQUARIE	VERY POOR	EXT'LY POOR	MODERATE	MODERATE	MODERATE	MODERATE
BROKEN	VERY POOR	EXT'LY POOR	GOOD	VERY POOR	GOOD	GOOD
LACHLAN	VERY POOR	EXT'LY POOR	MODERATE	POOR	GOOD	MODERATE

based on the revised index values derived using the new updated metrics and indicators applied to the data for ALL sampling cycles. Thus, the values for the first fish and first and second macroinvertebrate sampling cycles have been 'retrospectively' re-calculated—using the original data, but the revised metrics and indicators. *Trends cannot be inferred by comparing the results published in SRA report 1 and this report.* The same is true for comparisons of Ecosystem Health ratings between SRA reports 1 and 2.

For Hydrology, trends in flow alteration were seen in low flows, high flows and in flow seasonality. At many sites where low flows are normally elevated by water management, a decline in low flows typically caused by a drought period was observed, and was delayed and dampened. There were many sites that had extreme reductions in high flows over the period 2007–2009. This alteration in high flows intensified over the drought period. A systematic decline in the amplitude of seasonal flow variations relative to Reference conditions was observed at many sites through the drought.

Since 2009, environmental water provisions have been enhanced by both state and Commonwealth agencies. The effect of this flow restoration will not be detected until trend analysis is updated to include 2010 onwards.

The condition of fish communities improved significantly in seven valleys and declined significantly in seven valleys. The remaining nine valleys exhibited no significant change between the two sampling cycles. The overall patterns in fish condition were, however, quite similar between the two sampling cycles. Exceptions were the Castlereagh and the Paroo for which the Condition Index rose between sampling events. All three Fish indicators (Expectedness, Nativeness, and Recruitment) increased in the Castlereagh, while only the Recruitment indicator increased in the Paroo. This may well evidence a response by the native fish community to an extended period of post-drought and above-average rainfall in the Castlereagh valley. The Central Murray valley SR–FI score declined from 2004–2007 to 2008–2010.

Of the seven valleys that suffered a decline in fish condition, five were in the southern Basin and two—the Namoi and the Macquarie—were in the north. Three of the seven valleys in which fish condition improved significantly were in the north.

SRA fish sampling conducted from 2010 on will provide insight into the capacity of the fish community to respond to the breaking of the drought.

Valley-scale Macroinvertebrate condition ratings showed a substantial degree of variation over time for only six valleys: the Campaspe, Condamine, Goulburn, Gwydir, Warrego and Wimmera. There was a consistency in pattern and magnitude of index values across the remaining valleys over the three cycles. The Kiewa, Mitta Mitta, Ovens, Paroo and Upper Murray valleys maintained the highest values through time, while the Central Murray and Darling valleys maintained the lowest scores.

No consistent pattern of either rise or fall in Macroinvertebrate Index values was evident across all valleys. There was no overall pattern of decline or increase at valley scale across the Basin as a whole, or across the northern (Darling drainage) or southern (Murray drainage) regions. This relative lack of change with time is believed to partially reflect the ongoing impact of the dry conditions which continued in all valleys with the exception of the Castlereagh (where the third cycle of sampling occurred before major rain in 2010). Index values declined for the Gwydir and Macquarie valleys with time and this is believed to be a response to sustained dry conditions and declining flows.

Progress and prospects

The Sustainable Rivers Audit has developed into an effective tool for surveillance of the Basin's river ecosystems. The scope of the Audit has been expanded by the addition of Themes for Vegetation and Physical Form, and now includes aspects of the floodplain environment and trend detection. Major refinements to existing indicators and Reference Condition have been completed.

Any future assessments will be able to robustly describe trends in condition and health.

ISRAG recommends that the following be considered for future SRA-like, large-scale condition surveillance reports:

- Within Themes, there is scope for improvements to some metrics, additions to metrics, and improvements to methods for defining Reference Condition.
- Addition of Themes and spatial components in line with related Basin monitoring programs. The SRA's spatial context should be increased to explicitly assess other parts of the riverine landscape (floodplains, wetlands, terminal lakes). The SRA should also include other ecological components such as birds.
- Alignment of surveillance monitoring with management and policy initiatives and requirements, including the Basin Plan.
- Focusing analyses and assessments on targets as well as differences from Reference Condition, with the latter serving as the assessment benchmark. Ecosystem condition and health targets should be set and integrated across a range of scales, from individual assets to valley scale. Targets should be developed in a way that allows formal assessment of progress against them using monitoring data.
- Improve the diagnostic capacity of monitoring results and interpretation.

ISRAG recommends that Basin-wide surveillance monitoring of river ecosystem condition and health such as the SRA be continued, albeit at varying frequencies depending on the components being assessed and resources available. Surveillance monitoring is the only practical and defensible way in which whole-of-river-system benefits from large-scale investments in environmental management can be assessed. ISRAG strongly supports the strategic integration of larger-scale surveillance and smaller-scale, intervention-focused monitoring (such as for the Basin Plan) to address the need to manage the river ecosystem at a range of scales. To facilitate this, ISRAG recommends the inclusion of common ecosystem components (indicators) across several monitoring programs under a unified conceptual and design framework.

ISRAG also supports the establishment of well-defined and quantitative management goals for river ecosystem health at whole-of-Basin, valley and smaller scales. The SRA, or its various components, can play a valuable role in assessing progress against them.

Acknowledgements

The Independent Sustainable Rivers Audit Group (ISRAG) wishes to record its appreciation of contributions from many dedicated, professional people.

Don Blackmore, former Chief Executive, Murray–Darling Basin Commission, and Professor Peter Cullen, formerly at the University of Canberra, are remembered for their key roles in establishing the Sustainable Rivers Audit. Professor Richard Norris is warmly remembered for his sustained, energetic and seminal work in river bioassessment, in laying the foundation of the Reference Condition approach, and for his early role in the development of the SRA.

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Fish Theme: Regular members of the Fish TAG included: Peter Gehrke, Dean Gilligan, Tarmo Raadik, Jason Lieschke, Michael Hammer, David Short, Qifeng Ye, Darren Smallwood, Michael Hutchinson, Mark Lintermans and Paul Hardiman. Dean Gilligan with Mark Lintermans, Jason Lieschke and Wayne Robinson provided leadership in incorporating new findings regarding historic distribution and rarity of some large native species into a revision of reference condition. Dean, Jason and Wayne, with general support from the TAG, led the development of recruitment metrics.

Macroinvertebrate Theme: Many of the original technical group continued to play a role in technical review and guidance, including Satish Choy, Bruce Chessman and Leon Metzeling. Mike Stewardson, Chris Walsh and Elizabeth Wallis assisted with novel reference and assessment model development and testing.

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Glossary

ACT	Australian Capital Territory
AHD	Australian Height Datum
ANOVA	Analysis of Variance
AUSRIVAS	Australian River Assessment Scheme
ARI	Average Recurrence Interval
BRT	Boosted Regression Tree
CL	Confidence limits
CPUND	Cross-Prediction Using Null Disturbance
DAFF	Department of Agriculture, Fisheries and Forestry (Cwlth)
EMAP	Environmental and Monitoring Assessment Program
FSR	Flow Stressed Ranking
GIS	Geographic Information System
IQQM	Integrated Quantity and Quality Model
ISRAG	Independent Sustainable Rivers Audit Group
IVC	Integrated Vegetation Cover (GIS layer)
LiDAR	Light Detection and Ranging
LF	Lowland Floodplain
M&E	Monitoring and Evaluation
MAF	Mean Annual Flow
MDB	Murray–Darling Basin
MDBA	Murray–Darling Basin Authority
MDS	Multi-dimensional Scaling
MSM–BigMod	Murray Simulation Model – Big Model
NVIS	National Vegetation Information System
MVG	Major Vegetation Group
NR	Near Riparian
OE	Observed to Expected ratio
OP	Observed to Predicted ratio
PLR	Percentage LiDAR returns
Prop_N_abund	Proportion native abundance
Prop_N_biom	Proportion of native biomass
Prop_N_sp	Proportion of native species
RC–F	Reference Condition for Fish
RC–M	Reference Condition for Macroinvertebrates
REALM	Resource Allocation Model
SedNet	Sediment Network Model
SEWPaC	Department of Sustainability, Environment, Water, Population and Community
SIGNAL	Stream Invertebrate Grade Number Average Level
simOE	Metric: difference between community composition observed/expected
SRA	Sustainable Rivers Audit
SR–EC	Sustainable Rivers | Ecological Condition Index
SR–EI	Sustainable Rivers | Ecosystem Health Index
SR–FI	Sustainable Rivers |Fish Condition Index
SR–FI*e*	Sustainable Rivers |Fish Index (expectedness indicator)
SR–FI*n*	Sustainable Rivers |Fish Index (nativeness indicator)
SR–FI*r*	Sustainable Rivers |Fish Index (recruitment indicator)
SR–HI	Sustainable Rivers | Hydrology Condition Index
SR–HI*m*	Sustainable Rivers | Hydrology Condition Index (mainstem indicator)
SR–HI*h*	Sustainable Rivers | Hydrology Condition Index (headwater indicator)
SR–PI	Sustainable Rivers | Physical Form Condition Index
SR–MI	Sustainable Rivers | Macroinvertebrate Condition Index
SR–VI	Sustainable Rivers | Vegetation Index
STEDI	Spatial Tool for Estimating Dam Impacts
TAG	Technical Advisory Group

1. INTRODUCTION

1. Introduction

1.1 Overview

The Sustainable Rivers Audit (SRA) is the most comprehensive assessment of river ecological condition and ecosystem health undertaken for the Murray–Darling Basin. The SRA reports on the condition of key ecosystem components as well as the overall health of the river ecosystem across the entire Basin. It reports on the status of each river valley system within the Basin using standardised, representative, quality-assured data gathered in a systematic manner. Observations are recorded at many locations throughout the entire river system, using standardised protocols for sampling, data-sourcing and analysis, to indicate the status and trends in the ecological condition and health of the Basin's rivers.

The SRA is an audit, in the sense of being a standardised assessment and reporting activity. It is concerned with surveillance rather than measuring compliance with standards or targets. It is focused on detecting and reporting the signs of change rather than the causes. Where changes are indicated, the appropriate response may be to mount an investigation to determine the causes, however, this is not part of the SRA program itself.

The SRA stands apart from the Murray–Darling Basin Plan, providing independent information on the health of the river ecosystems within the Basin. However, aspects of the SRA are being used to support the Basin Plan monitoring and evaluation framework and will assist in assessing the success of Basin Plan-related management actions in reaching ecosystem targets and achieving ecosystem objectives identified in the Basin Plan (Davies *et. al*. 2009).

Now in its second reporting cycle, the SRA is managed by the Murray–Darling Basin Authority (MDBA), in partnership with the Australian government and governments in the Australian Capital Territory, New South Wales, Victoria, Queensland and South Australia. Each state jurisdiction contributes to the collection of data, oversees field and laboratory work by agency staff and also provides technical advice to program management as required. An SRA group within the MDBA is responsible for coordinating the program, processing data and providing executive support. Specialist Technical Advisory Groups and external consultants have also assisted in the development of *Themes* (Section 3).

The scientific integrity of the SRA is overseen by a panel of river ecosystem specialists, the Independent Sustainable Rivers Audit Group (ISRAG). ISRAG reports to the MDBA and the Murray–Darling Basin Ministerial Council; and hence the wider community.

The SRA first reported in 2008, following three years of data collection (SRA report 1, Davies *et al.* 2008, MDBC 2008a). The current report prepared by ISRAG (SRA report 2) presents the second Basin-wide assessment of river health, based on data gathered during 2008–2010 as well as a re-analysis of the data gathered for SRA report 1 during 2004–07. This report represents a significant advance on SRA report 1, with additional Themes (Physical Form and Vegetation), refinement of components within Themes, improved data sources and refined analyses. Data from report 1 are re-analysed and reported here, for those Themes in which trends are assessed (Fish, Macroinvertebrates, Hydrology).

Figure 1.1. The Murray–Darling Basin showing the 23 valleys assessed in the Sustainable Rivers Audit.

1.2 Program design

The SRA combines information about the status and trends of groups of environmental indicators, called ***Themes***, in each of the 23 valleys in the Basin (Fig. 1.1). Themes related to ***Fish, Macroinvertebrates***, ***Vegetation, Physical Form and Hydrology,*** are now active, with aspects of each undergoing continuing development. Each Theme represents a key component of the river ecosystem (Section 2.3).

Sampling locations in valleys are located within *zones* defined, in most cases, by altitude. These zones support the spatial stratification of random samples within biogeographically identifiable units. This allows unbiased reporting of results across the entire Basin at two spatial scales: valley and zone. When sites are used for data collection, they are distributed randomly within zones, to enable statistical analyses, and unbiased assessments and comparisons between times and places. Several Theme components are not assessed using a 'sample' of sites, but involve a full census of data across the entire river system within a valley.

Data are processed in a series of steps leading to ***metrics*** and ***indices*** within each Theme for each zone and valley. The indices represent the ***condition*** of the ecosystem component described by the respective Theme. This condition information from the three biological Themes is then combined to indicate ***Ecosystem Health*** at both zone and valley scales. The Theme Index for Physical Form and Hydrology provides additional information on the condition of two of the drivers of the ecosystem.

The SRA employs the concept of ***Reference Condition*** to facilitate comparisons between valleys, to allow for different background biophysical conditions and contexts, and as a benchmark against which to assess the health of the system. Reference Condition describes the patterns and processes that would be expected to prevail without substantial human intervention in the landscape[1]. It serves as a benchmark against which to compare the values of current data and trend data. It is open to some uncertainty, because it is estimated rather than measured, but does provide a consistent benchmark within each Theme for each valley (and zone) across the Basin as a basis for comparison (and not as a management target). This concept is now used in many large-scale river condition assessment programs around the world (see Section 1.4).

The design of the SRA incorporates flexibility and accessibility, in the spirit of adaptive management. Virtually all facets of the program are open to revision as more data are gathered, as environmental conditions change, and as ideas and analytical techniques develop.

Consistency in the methods used to collect the primary data is paramount. The primary data are inviolable, and there is a strong emphasis on quality control and quality assurance in data collection and handling. On the other hand, the metrics and indicators derived from the raw data, and the methods used to combine and report them, are open to revision. This has already occurred since SRA report 1 and will, no doubt, continue in the future.

Data obtained by sampling or analysis are available to all interested parties, including the public; but the levels of detail, analysis, synthesis and interpretation needed by these audiences may differ. With this in mind, the program is designed to provide information at several levels, from summary assessments of condition and health down to the primary data for each Theme at different sites and times in each valley.

More information about the purpose and design of the SRA is accessible via the MDBA website <http://www.mdba.gov.au>.

1 i.e. more than the traditional activities of the Aboriginal owners.

1.3 Links to regional and national programs

The MDBA has a number of environmental programs, including the SRA, that are linked within the Authority's Ecosystem Management Branch. The SRA contributes data to other programs, and the SRA team in particular, has developed a data-management and quality-assurance system that has been adapted for use in other programs. Related programs include the Basin Plan, the Native Fish Strategy, The Living Murray, the Basin Salinity Management Strategy, the River Murray Water Quality Monitoring Program and other programs concerned with managing risks to shared resources. The SRA contributes also to the operations of River Murray Water, including issues related to the Cap on water diversions.

Other regional, state and national programs are linked to the SRA through shared methods, data, reports and conceptual frameworks. State programs include 'State of the Environment' reporting and monitoring, including the Environmental Health Monitoring Program in Queensland, the Monitoring, Evaluation and Reporting Program in New South Wales, the Index of Stream Condition in Victoria and the Tasmanian River Condition Index. At a national level, the SRA has links to the Framework for the Assessment of River and Wetland Health, the National Monitoring and Evaluation Framework for natural resources management and state of the environment reporting. There have also been strong links to the CSIRO Murray–Darling Basin Sustainable Yields Project and the National Water Commission's National Inventory of Water Stressed Systems project.

From 2009–10 the ISRAG has contributed to the development of aquatic ecosystem objectives and targets of the Basin Plan, as well as to the Monitoring and Evaluation (M&E) component of the Basin Plan, through sharing conceptual frameworks and designs, protocols and data. Substantial components of the SRA will provide core data for Basin Plan monitoring and evaluation from 2011 onward, with a focus on assessing the system-wide changes in the river ecosystem and the degree to which they result from Basin Plan actions and other causes (Davies *et al*. 2009).

1.4 Links to international programs

Few countries have large-scale river condition assessment programs as comprehensive and sophisticated as the SRA. Criteria for selecting and developing metrics used in the SRA were developed from those used in the Environmental and Monitoring Assessment Program (EMAP) of the US Environmental Protection Agency <http://www.epa.gov/emap/index.html>, the basis for their National Aquatic Resource Surveys <http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm>. The South African River Health Program <http://www.dwaf.gov.za/iwqs/rhp/naehmp.asp> and the European Union's Water Framework Directive (WFD) and Standardisation of River Classifications (STAR, completed 2005, <http://www.eu-star.at/mains/text_welcome.htm>) have also developed tools to monitor the condition of river resources at large scales both within and across river basins. The WFD now manages a large-scale, multiple river basin program of assessment of river condition, which is tied to targets and compliance requirements for River Basin Plans <http://ec.europa.eu/environment/water/index_en.htm>.

1.5 Reporting schedule

The SRA was initiated by the Murray–Darling Basin Ministerial Council in late 2000. A framework (Whittington *et al.* 2001) was trialled in an SRA Pilot Audit of four valleys in 2002–03 (MDBC 2004a–e), and the program formally commenced in 2004. The first report of the SRA (SRA report 1, Davies *et al.* 2008) was produced in 2008, and assessed ecological health on the basis of condition assessments for fish, macroinvertebrates and hydrology. An interactive summary report with separate ***report cards*** by valley was also produced in 2008 (MDBC 2008a): *Murray–Darling Basin rivers: ecosystem health check, 2004—2007* (available at <www.mdba.gov.au>.

The SRA was originally designed to operate on a six-year cycle, with the most comprehensive reports issued at the end of each cycle. Annual reporting is precluded by limited resources and capacity. Individual Themes address ecological patterns and processes operating over different scales of time and space, therefore annual reporting will be more relevant for some Themes (e.g. Macroinvertebrates) than others (e.g. Physical Form).

Audit Reports are now being produced at approximately three-year intervals, and provide assessments of condition for each Theme and overall riverine Ecosystem Health, for each zone and valley:

- *SRA report 1* (Davies *et al.* 2008) was produced following three years of data collection (in 2008). It contained a single assessment of condition and health based on three Themes, and did not consider trends.
- *SRA report 2*, produced following year six of data collection (in 2012) includes valley-based assessments of condition and health for five Themes and initial analysis of changes through time for three Themes. Since report 1, intensive development has resulted in the addition of Themes for Vegetation and Physical Form, major development of the Hydrology Theme and refinement of the Fish and Macroinvertebrate Themes. Report 2 includes three cycles of sampling for Macroinvertebrates, two cycles for Fish and four cycles for Hydrology. It therefore includes an initial analysis of temporal changes across the Basin for these Themes. The report also includes one assessment for each of Riverine Vegetation and Physical Form. Later reports will become still more comprehensive as data from more Themes, additional Theme elements, and longer time periods become available.

Reports are submitted to the Murray–Darling Basin Ministerial Council, typically via the Murray–Darling Basin Natural Resource Management Committee and the Basin Officials Committee. The Council then sanctions the public release of the reports. SRA reports are also distributed to state jurisdictions, for comment as appropriate. These jurisdictions have also been involved in aspects of program management, design, data collection and analysis.

This report is SRA report 2. It provides a Basin-wide assessment of river health, indicated by the Fish, Macroinvertebrate, Vegetation, Physical Form and Hydrology Themes, and includes:

- an introduction to the purpose, conceptual foundation, framework and methods of the SRA
- an outline of SRA operations, including compliance and quality assurance
- assessments of ecosystem health and condition for each Theme, across the Basin
- assessments of ecosystem health and condition for each Theme, for each valley
- comparisons of Theme-related information among valleys
- assessment of temporal changes
- progress and plans for future development.

1.6 Expectations

This report DOES provide an assessment of:

- the condition of Fish, Macroinvertebrates, Vegetation, Physical Form and Hydrology for the rivers of the Murray–Darling Basin
- condition (by Theme) and Ecosystem Health (across Themes) that allows comparability among valleys across the Basin, as well as zones within valleys, on as standardised a basis as is currently practicable
- changes with time ('trends') for Fish and Macroinvertebrates over the six years to 2010, and for Hydrology for the 12 years to 2010.

This report also assesses:

- riverine vegetation on the basis of the best combination of vegetation community mapping available for the Basin up until 2010 and from aerial survey of vegetation characteristics; as opposed to a field based survey, for which the resources and capacity were not available
- physical form from an ecosystem and geomorphological point of view, based on differences in key geomorphological state and process measures from Reference Condition
- hydrology from an ecosystem point of view, based on a modified version of the Victorian FSR (Flow Stressed Ranking) procedure, as opposed to a purely quantity-based assessment.

This report DOES NOT provide assessments of:

- specific causes of status or changes in ecosystem condition or health
- the condition of the Basin's river system with respect to effects of Commonwealth activities such as the Water Entitlement Purchases or the Basin Plan, or state and territory management actions
- the effect of the recent extensive flooding (2010–11 onward) within the Basin. Field data collection was conducted largely prior to these events. Ecological effects of these flooding events, some of which will take time to be evident, are likely to be detected by current and subsequent SRA assessments over the next one to five years. Thus this report provides benchmark data, collected during the last six to seven years of drought, from which to assess flooding-induced changes, especially for fish, macroinvertebrates and hydrology.
- the status or dynamics of individual biological communities (such as river red gum forest), or details of species populations (such as Murray cod). Limited resources, data availability, and a focus on assessing at the scale of the whole Basin, have precluded analysis at this level of detail to date
- terminal/floodplain lake/wetland systems (other than as part of the Vegetation mapping-based assessment) or the Lower Lakes (Alexandrina, Albert) or the Coorong
- spatially-explicit changes in floodplain hydrology, including changes in distributary and anabranch flow regimes, wetland water regimes and patterns of floodplain inundation.

These types of assessment will either become possible as components of the SRA are further developed (see Section 7) or are the focus of other existing or pending programs and specific analyses. A discussion of the current relative status of SRA Themes and associated levels of confidence is provided in Section 3.2.

1.7 Making comparisons

1.7.1 Between SRA reports 1 and 2

Due to the difference in the information base and improvements to elements of the Audit data and analysis, the following must be noted:

- direct comparisons between values for those metrics that are in common to the two SRA reports (report 1 and this report) may be valid in some cases; BUT
- direct comparisons between these two reports cannot be made of integrated results (indicators, index scores and ratings) at zone and valley scales, nor of those metrics for which the reference has been updated.

This report represents an update in terms of both time of data collection (2008–2010) and the comprehensiveness of the data collected. As such, this report presents:

- the most current assessment of the condition of key biophysical components of the river ecosystem and of its health
- assessments of change through time (trends) for those components for which repeated data acquisition and analysis is available (Fish, Macroinvertebrates, Hydrology).

1.7.2 With local studies

It should also be noted that while SRA data is acquired at smaller scales (from sites, reaches or domains), the design is predicated on aggregated reporting at zone and valley scales. Thus, if a smaller scale or local study produces different results, then differences between that study and the overall SRA assessment does not mean either are wrong. Differences in scale and also in design and information content may lead to differing conclusions, depending on the management question at hand and the context. The SRA provides a large-scale aggregated assessment, built up from smaller scale information that can provide valuable context to local studies.

1.7.3 With environmental watering priorities

The assessment results for ecosystem health and condition reported here at zone and valley scales will not reflect the relative need for environmental watering interventions. The scale of this SRA assessment is unlikely to reflect the needs of individual assets (river reaches or wetlands) which may require additional water to restore key functions or biodiversity elements. If environmental watering activities were to affect ecological responses at a sufficiently large scale, then one might expect the SRA assessment to indicate the magnitude of those responses. This is as yet not the case.

This scale of assessment also precludes inferences about interactions between flow and biota. For example, if both Hydrology and Fish are rated as being in good condition this does not mean that:

- there are no environmental water needs for that part of the Basin's river system
- the current hydrological regime does not influence the condition of fish communities.

2. THE AUDIT FRAMEWORK

2. The Audit framework

2.1 Nature of the ecosystem

For many years, rivers were viewed mainly as drainage channels linking the land and sea and providers of water and utility for human use. River systems are now recognised as having their own distinctive, self-sustaining communities of animals and plants. They are acknowledged as ecosystems in their own right; the proper functioning of which is fundamental to the health of the river and the successful provision of ecosystem goods and services, including the provision of water suitable for human purposes.

The majority of rivers within the Murray–Darling Basin are 'dryland' systems. Variability is a characteristic feature of 'dryland rivers', both in time (seasons, years, decades) and space (sites, reaches, valleys, regions). River management inadvertently reduces or redistributes this variability, with potentially serious consequences for the ecosystem. In the Murray–Darling Basin, rainfall varies from one year to the next and from one place to another, depending on latitude, topography, distance from the coast and other factors. The nature and intensity of human development in the Basin also varies within valleys and regions. These sources of variability are significant for the SRA because they mean that, in statistical terms, large numbers of samples are needed to describe river ecosystems at the scale of valleys, and to detect differences and trends over time.

Connectivity is another key feature of river systems. Hydrologically they are connected systems in longitudinal, lateral and vertical dimensions over various periods of time. All river valleys in the Basin include sections, especially in their lower reaches, where the stream gradient is small and which are flanked by extensive floodplains—areas that are periodically inundated by high flows which escape the channel, and contain flood tolerant or dependent terrestrial communities, distributary channels and wetlands.

Hydrological connections between the main river channel and its floodplain are controlled by the pattern of flow in the river. The channel and floodplain are functionally and ecologically inseparable. Overbank flows deliver water, sediment and dissolved material, including plant nutrients, to the floodplain and provide temporary access to floodplain aquatic habitats. Depending on floodplain condition, among other things, water returning from the floodplain to the channel may carry carbon—in the form of dissolved carbon and organic detritus, micro-organisms and small planktonic animals—all generated by the productive floodplain ecosystem (and supported by inputs of water from the channel). The biological processes involved in transformation of organic matter are more complex than those involved in transport; so that, for many groups of flora and fauna, most biodiversity resides in floodplain habitats, rather than the channel.

These lateral connections are accompanied by longitudinal connections up and down the stream drainage system. Disruption of these connections, for example by large dams and diversions, can disrupt fish life cycles and change the pattern of material transport (such as carbon and sediment) thus altering the ecology of the system. Exchanges of sediments and dissolved materials between river water and sediments along the river channel lead to transformations and changes in biological productivity. These water—sediment exchanges are important in maintaining ecosystem function.

Key features of river ecosystems that are valued by humans—such as fish, birds and floodplain forests—are the product of a range of ecological processes. These processes result in patterns of material and energy flow and transformation, as well as the distributions of habitats, communities and species. It is the interactions between pattern and process, state and function, status and flux, which present a challenge in assessing the health of the river ecosystem.

The rivers of the Murray–Darling Basin are still responding to past human disturbances; the persistence of which varies in different parts of the Basin and with the nature of the disturbances. These responses to past disturbance have ongoing ramifications—both through time and downstream through a catchment—giving rise to complex longer-term effects. Some trends we observe now will have been caused by human disturbances many decades ago. As a result, parts of the Basin's river system will be slower to respond to management efforts.

In addition, effects of large-scale climatic sequences, such as the recent decade-long drought, have both short- and longer-term impacts. Lagged and even generational responses to dry and wet events are common. These may complicate interpretation of changes in ecological condition through phases of wet and dry conditions.

More information about the ecology of rivers in the Murray–Darling Basin is provided by Mackay and Eastburn (1990), Walker (1992), Crabb (1997), Young (2001), Breckwoldt *et al.* (2004) and Walker (2006), among others.

2.2 Elements of the Audit

2.2.1 Condition and Ecosystem Health

The concept of *Ecosystem Health* is appealing as it provides an intuitive way to describe the complex patterns and processes of an ecological system. It refers to the status of an ecosystem—with all its components—in terms of structure, integrity, vitality and function. Under close analysis, however, the concept is complex, and there has been inconsistency both in definitions and in what is included in assessments of river ecosystem health (e.g. Hearnshaw *et al.* 2005, Vugteveen *et al.* 2006).

Ecosystems are typified by the presence of many links, both within them and with their surrounding biophysical environment. Some of these links are strong, though many are weak. Few show linear relationships; and lags, thresholds and issues of scale are numerous. Although parts of an ecosystem may be lost with changes in the environment or to invasions by alien species, the ecosystems do not 'die'; rather, they are transformed into a different state. Riverine ecosystems are especially influenced by extreme events like floods and droughts, that have no direct counterpart in human health. Further, humans are part of ecosystems, and ecosystem 'health' is influenced by a host of social, political and economic factors, as well as the properties of the surrounding environment (Vugteveen *et al.* 2006).

Unlike human health, the 'health' of an ecosystem cannot readily be judged by comparison with data indicating 'normal' ranges for different variables. Ecosystem health is a relative concept, and is generally assessed in relation to a reference or benchmark set of measures. This reference comparison is generally made using observations of the ecosystem in a 'natural' condition and/or when major human stressors are absent.

In the SRA, data are gathered on *ecosystem components*, represented by Themes (e.g. Fish, Hydrology) that are linked by ecosystem processes (e.g. carbon exchange, energy transfer, nutrient cycling). The capacity of an ecosystem component to support these processes is referred to here as its *Condition*. These are described and quantified in the SRA mainly by structural measurements, though more functional measurements should be included in the future. Information about the condition of one component alone is not sufficient: the SRA approach relies on multiple components in combination—on the principle that together they are more indicative of ecosystem health. The process for combining or integrating the products of data analysis within and between the Themes is developed by ISRAG, leading to assessments of Ecosystem Health for each valley. This *integration* process is not based on simple arithmetic combinations; because these would fail to account for known interactions and non-linear relationships between component metrics. Rather, professional ecological judgement shapes the *integration rules (or 'Expert Systems')*, which are applied consistently, transparently and reproducibly throughout the Basin's rivers.

The SRA's Themes both represent, and are linked by, processes at a range of scales of space and time. When combined, they thereby reflect Ecosystem Health. Future assessments could be greatly strengthened by adding direct measures of fundamental processes like metabolism (production and respiration), carbon and nutrient processing, and the recruitment (the accrual of reproductive individuals to populations) of vegetation and birds, as well as other measures of the system's resilience to external drivers of change.

The condition of ecosystem components within the respective Themes is determined from a suite of measurements, using methods explained in Section 3. A numerical comparison of an observed variable and its value expected under Reference Condition (Section 2.2.2) is called a *metric*. Metrics are combined as *indicators*, and indicators are combined as *indices*. A single index represents the *condition* of the component represented by its Theme. By this means it is possible to measure differences between *current* and Reference Condition status without implying that either condition is necessarily 'good' or 'bad'.

A river ecosystem is deemed 'healthy' when its essential character (its native flora and fauna, for example) and processes are maintained over time; notwithstanding disturbances due to human activities or climate variation. In these circumstances, the ecosystem is resilient enough to withstand disturbances and to continue to support processes and supply resources.

A key aspect of river ecosystem health is its *resilience*, which can be seen as its capacity to absorb recurrent disturbances while retaining essential structures, processes and feedbacks (Adger *et al.* 2005). Resilience of the river system depends on the degree and nature of exploitation or change, as well as inherent properties like biological diversity and patterns and connectivity of water and materials transport, over a range of scales. In future development of the SRA, repeated measures of ecosystem components through time could be used to assess the resilience of the Basin's river ecosystem.

2.2.2 Reference Condition

2.2.2.1 Why Reference Condition?

In the SRA, Reference Condition is designed to indicate the structural and functional state of a river ecosystem that would likely prevail in the absence of significant human intervention[1] in that region. It serves as a benchmark for a healthy ecosystem, and underpins spatial and temporal comparisons by correcting for the confounding influences of regional variation in climate, soils, topography, biogeography or other factors. It is difficult to conceive how we might compare, for example, the invertebrate assemblages sampled in the upland Ovens catchment with those of the lowland Condamine, in the absence of a Reference Condition specific to each region. Our use of Reference Condition is primarily a standardisation device, to allow sensible comparisons across zones and valleys within the biophysically diverse Murray–Darling Basin. It places our observations on a consistent scale, no matter what is being observed and where these observations are made.

Reference Condition may be described at site, zone, valley or even regional scales; depending on the variable of interest and the available information. The concept applies throughout the SRA, but the methods used to estimate it vary among Themes, and depend on available knowledge (see Section 3). Historical data, expert knowledge and modelling are used

1 i.e. where significant human intervention is more than the traditional activities of the Aboriginal owners.

where appropriate, but sometimes these may not be sufficient for reliable estimates of some variables. Observations on those variables for which Reference Condition cannot be quantified with confidence may still be gathered and reported, and could become important in time.

The relative importance of Reference Condition in interpretation of SRA assessments is likely to diminish as the emphasis shifts towards detecting changes with time that relate to specified management targets.

2.2.2.2 Reference Condition is not a target

Although Reference Condition represents a river ecosystem in good health, it is not used here as a target, or an implied objective for management. This would be unrealistic because true pristine conditions in the Murray–Darling Basin may be neither attainable nor desirable, as human alteration, impacts and management have become integral to many parts of the Basin's riverine ecosystem. Further, management targets are properly determined by integrating ecological values with social, cultural and economic ones – a policy underpinning the Basin Plan.

2.2.3 Reporting scale

The SRA reports primarily at the valley scale. A second, smaller-scale reporting unit is the zone. Zones are defined within each valley in order to assign sampling sites in areas with broadly similar biophysical character. Typically, there are two to four zones per valley. As sampling sites are assigned randomly within zones, Reference Condition is often defined at that scale.

Observations made at smaller scales are spatially combined or *aggregated* to provide zone- and valley-scale assessments for each Basin valley. The locations at which observations are collected vary between Themes (see Section 2.2.4). The SRA does not formally report data for individual sample locations, unless there are exceptional circumstances (for example, some site-level data may be of interest to specific audiences). Valley-scale assessments are made by combining (*aggregating*) site- and/or zone-scale assessments—the latter after weighting according to their respective proportions of total stream length.

In most valleys, zones are defined by altitude, as '*Lowland*' (0–200 m AHD[2]), '*Slopes*' (200–400 m AHD), '*Upland*' (400–700 m AHD) and '*Montane*' (>700 m AHD). There are some exceptions to this zonation to enable extensive lowland valleys to be subdivided for reporting.

The River Murray is divided into Lower, Central and Upper Murray valleys. The Lower and Central Murray valleys are divided into Lower, Middle and Upper zones. The Lower Murray valley also has the Mt Lofty zone, including the eastern slopes of the Mt Lofty Ranges. The Darling Valley is partitioned into Lower, Middle and Upper zones, using geomorphic rather than altitudinal criteria. For these three valleys, these are all 'Lowland' zones in terms of altitude, except the Mt Lofty zone which is classed as a 'Slopes' zone. The Upper Murray valley has three altitudinal zones, as above (Slopes, Upland and Montane). The Paroo valley is comprised of a single, Lowland zone.

2.2.4 Sampling locations

Data collection for all Themes is spatially explicit; with data collection from individual gauging stations or river reaches (Hydrology), sampling sites (Fish and Macroinvertebrates), sites flown for aerial data collection (Physical Form and Vegetation), and defined areas (or *spatial domains*) for mapping of the lowland floodplain or near-riparian areas around river channels (Vegetation). For several components of Vegetation and Hydrology, the data were collected for an entire riverine domain, and these provide a complete '*census*'. All other data collection involved a subset or 'sample' of the riverine environment based on sites. The basis for site selection then becomes important if the assessment is to be representative of the river system.

2 Australian Height Datum.

In the Fish, Macroinvertebrate and Physical Form Themes, site locations were determined at random on the stream system, within each zone. Random locations ensure that, together, the sites are truly representative of the valley and zone stream networks; and that data are amenable to unbiased statistical analysis and aggregation. The SRA stream network does not include all drainage lines in the Basin, as this would be impractical and strongly bias selection toward smaller streams at the top of catchments. For these Themes, the river network is based on the 1:250,000 Geoscience Australia 'drainage layer', modified to exclude most low-yielding streams (either <2 or <5 GL mean annual flow at the exit point depending on climate). Each compliant stream is followed as a single thread to the top of the catchment to ensure some low-yielding streams are included (note that they may therefore be under-represented).

For the Themes dependent on sampling in water (Fish and Macroinvertebrates), stream networks in the Condamine, Warrego and Paroo valleys, and in the Mt Lofty zone of the Lower Murray valley, are based on remotely-sensed perennial waterholes rather than entire drainage lines. In all other valleys, the Fish Theme sampling sites were included only if habitats were substantial, so excluded some small headwaters (Section 3.3.2). In the Macroinvertebrate Theme, however, site selection is independent of stream size and is possible right to the top of catchments[3]. The stream network for the Vegetation and Physical Form Themes is not dependent on water for sampling, and the network is not based on perennial waterholes in any valley.

Sampling sites in valleys and zones are selected using a constrained randomisation technique to minimise bias and distribute the sampling effort over space and time. As SRA cycles are repeated, one quarter of sites for the Fish and Macroinvertebrate Themes remain fixed, and the remainder is re-selected randomly.

3 Details on sampling procedures are documented in the SRA sampling protocols from MDBA which are updated every year to reflect the annual sampling schedule. These can be made available upon request.

For the Hydrology Theme, the data was acquired from models based on a census of stream segments in a modified version of the Geoscience Australia AusHydro v1 layer (Section 3.7.2). For computational reasons, the first stream segment at the top of all catchments could not be used. Whilst these are large in number, they are individually small in length. Also, all but the major anabranch and distributary streams were excluded because there is currently no reliable data for distributing flow across these multi-channel systems.

Sampling site selection for the SRA does not *specifically* target icon sites of The Living Murray program <www.mdba.gov.au/programs/tlm/icon_sites>, designated Wetlands of International Importance under the Ramsar Convention, or key assets of the Basin Plan (for example Narran Lakes, Macquarie Marshes, the Barmah–Millewa Forest, the Gunbower–Koondrook–Perricoota Forest, Hattah Lakes, Chowilla Floodplain and Lindsay–Wallpolla Island). The SRA also does not currently sample terminal/floodplain lake/wetland systems (other than as part of the Vegetation mapping-based assessment) or the Lower Lakes (Alexandrina, Albert) and the Coorong. These assets are to be a focus for monitoring under joint arrangements between the Basin Plan Monitoring and Evaluation Program and the SRA in the near future.

2.2.5 Frequency of data collection

Field sampling acquires data for valleys at different rates because of the need to balance sampling frequency and available resources. Therefore, only part of the work required for a full Audit can be completed in any one year. The full complement of valleys is sampled every three years for the Hydrology and Fish Themes, and every two years for the Macroinvertebrate Theme. The future reporting frequency for Vegetation and Physical Form has yet to be finalised, but is likely to be at intervals of more than three years.

2.3 Linking the Audit to ecosystem health

2.3.1 Ecosystem components and Themes

The SRA bases its reports on natural components of the river ecosystem as well as components that are responsive to human interventions in the landscape. Two related conceptual models serve to illustrate the scope of the Audit:

- The *River Ecosystem Function Model* (Fig. 2.1) shows some of the links between ecosystem components and processes across channel and floodplain. It also identifies the components addressed by the SRA Themes. Each Theme represents the condition of a component, and is effectively a 'window' onto the ecosystem.
- The *Human Impact–Condition Response Model* (Fig. 2.2) relates Themes to the effects of human interventions in the environment, linking the causes of change to their biophysical consequences, condition and ecosystem health.

The rationale for selection of Themes is further described in Section 3.1. In each Theme, variables for monitoring condition have been reviewed according to criteria developed from those used in the EMAP program of the US Environment Protection Agency <http://www.epa.gov/emap/index.html>. These include considerations of conceptual relevance, the logistical feasibility and capacity for measurement and analysis, statistical confidence, variability and interpretability. In the SRA, the criterion of interpretability has been extended to include a capacity to estimate Reference Condition.

2.3.2 Attributes of healthy and unhealthy systems

In ecology, as in human biology, it is often easier to define an *unhealthy* system than a *healthy* one. Health cannot be measured directly; instead, we employ a variety of surrogate measurements and other observations that indicate the system's capacity to support key processes (e.g. carbon exchange, nutrient cycling, energy transfer, sediment transport, recruitment) and structural components (e.g. communities, populations) and its resilience. These observations must be integrated to provide a holistic assessment of ecosystem health.

A large variety of observations might be monitored. Ecosystems are complex, dynamic systems that combine the properties of their living and non-living constituents with 'emergent' properties—like diversity and resilience—that are attributes of the system rather than its components. One approach to monitoring health is to look for detrimental changes in components and processes that are sensitive to various kinds of disturbances over a range of scales in space and time. For example, losses of native flora and fauna are a form of imbalance, and the effects may be compounded when these are replaced by alien species. Another approach is to monitor key components that directly represent the products of ecological processes operating over a range of scales, or are suitable surrogates for them.

Both approaches are consistent with the approach followed in the SRA (Section 2.3). A healthy ecosystem (Section 2.2.1), which may include human communities, is seen as one whose character and functionality are maintained over time—despite disturbances because of resource exploitation, changes in climate and other external factors. This does not mean that the system is static—in the Murray–Darling Basin, as with all large river systems, climatic variability leads to naturally wide variations in ecological patterns and processes in space and time. The variability apparent in small-scale biophysical processes also is significant, and should not be dismissed as noise.

An unhealthy system is one substantially changed from its natural state, typically with losses in structural complexity and structural and process variability, as well

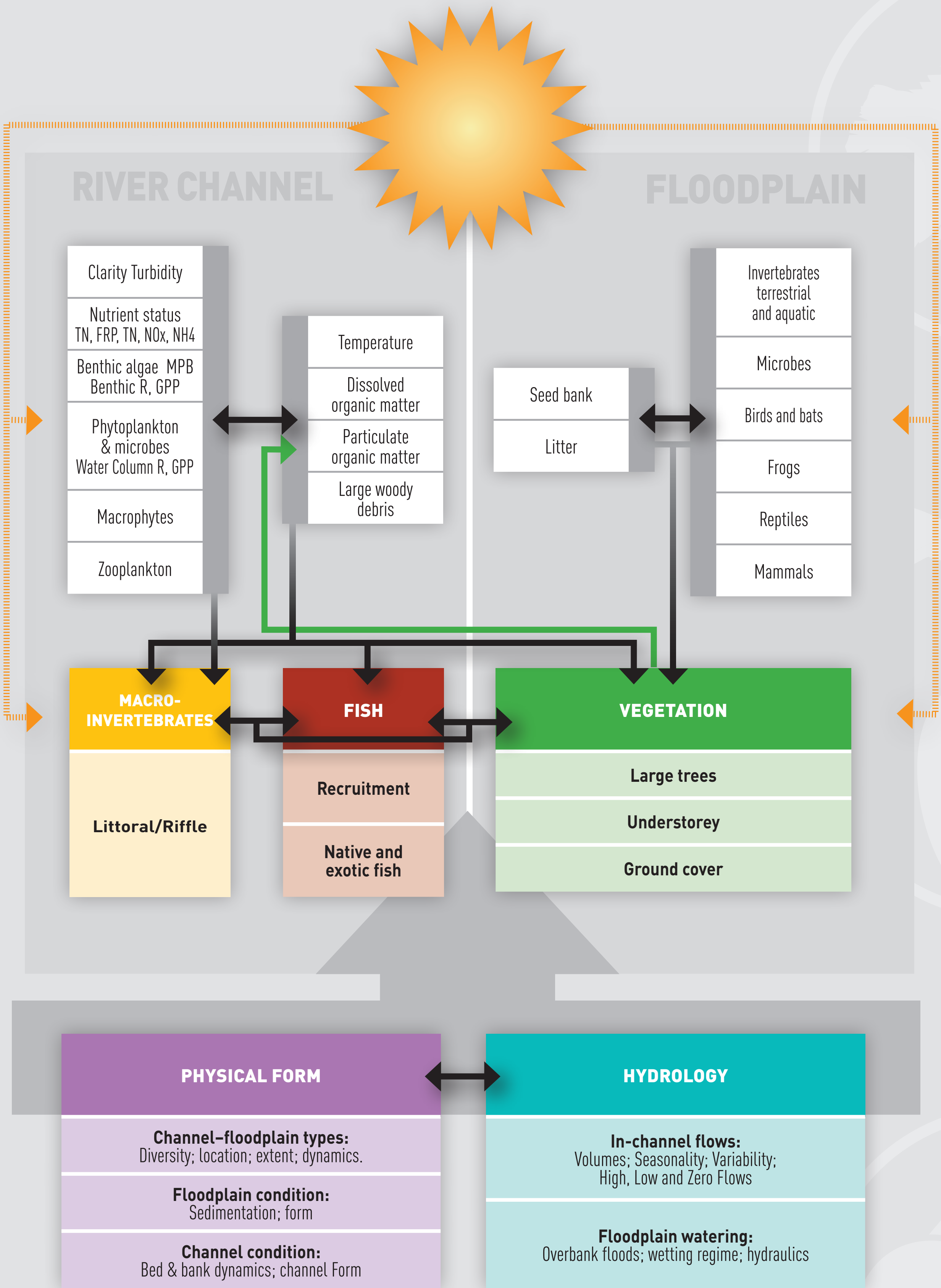


Figure 2.1. River Ecosystem Function Model showing components and processes in a channel-floodplain ecosystem.

(Components addressed at least in part by the SRA Themes are overlaid as 'windows' [titled and in grey] on the ecosystem. Interactions between components are shown as arrows.)

Figure 2.2. Human Impact–Condition Response Model linking human causes of changes in riverine environments to ecosystem components.
(Components are equivalent to SRA Themes, shown in the right-hand box)

Table 2.1. Symptoms of healthy and unhealthy river ecosystems, which can occur in the Murray–Darling Basin.

Feature	Healthy ecosystem	Unhealthy ecosystem	Assessed by SRA?
Connectivity, flow regime	Flow regime includes floods and droughts of diverse magnitude and timing—across seasonal, annual and inter-annual, and decadal scales—ensuring surface water connections between a channel and its floodplain wetlands and woodlands. In lowland regions, channels with few or no instream barriers allow downstream and upstream dispersal of plants and animals, including fish. Floodplain allows dispersal of terrestrial plants and animals laterally and along river corridor. High connectivity with catchment and with groundwater.	Flow regime is altered in ways that limit overbank flows and isolate channel and floodplain for long periods. Channel has instream barriers (e.g. dams, weirs) that impede up- and down-stream dispersal by aquatic plants and animals, including fish. Floodplain fragmented (e.g. land clearing, urbanisation and agricultural development) in ways that impede dispersal of terrestrial species along river corridor. Reduced connectivity with catchment and groundwater.	Yes, in the channel and overbank flow regime in Hydrology Theme. Connectivity with groundwater not assessed. Hydraulics and hence full 'watering regime' of floodplain not assessed.
Sediment regime	Channel and floodplain show periodic erosion or sedimentation—but these are balanced, so that in the long term the system is 'stable' and changing within the range of natural rates.	Balance of erosion and sedimentation disturbed, causing enhanced catchment erosion, bank collapse, channel widening or siltation and/or other signs of instability. Changes in rates and types of channel-floodplain systems fall outside the range of natural rates and states.	Yes, partially—measured using SedNet indicators, and changes in channel form in the Physical Form Theme.
Biodiversity	Native species and communities of flora and fauna persist; alien species scarce or absent.	Alien species of flora and fauna dominant; native species and communities reduced or absent. In more extreme cases, total species and community diversity declines.	Yes, partially—with measures of change in fish, macroinvertebrate and vegetation taxa/communities.

Continued/...

Table 2.1. Symptoms of healthy and unhealthy river ecosystems, which can occur in the Murray–Darling Basin.

Feature	Healthy ecosystem	Unhealthy ecosystem	Assessed by SRA?
Nutrient- and carbon-cycling and transformation	High efficiency of bioavailable nutrient cycling on floodplain and in channel. Storage, transformation and uptake of carbon and other nutrients optimised by natural diversity, trophic complexity and connectivity of biophysical components. Efficiency controlled by high flows. Minimal downstream or lateral 'leakage' of bioavailable nutrients.	Reduced efficiency of bioavailable nutrient cycling on floodplain and in channel. Lower biodiversity, trophic complexity and connectivity, causing reduced transformation and uptake of carbon and other nutrients. Efficiency dictated mainly by human impacts and high flows. Substantial 'leakage' of bioavailable nutrients.	No.
Recruitment	Populations of plants and animals, especially long-lived species (e.g. river red gum, Murray cod), reproduce and recruit (survive to maturity) sufficiently often to maintain numbers across a range of age classes.	Populations of plants and animals, especially long-lived species (e.g. river red gum, Murray cod), fail to recruit sufficiently often to maintain numbers across a range of age classes. Populations may contain disproportionate numbers of young or old individuals.	Yes – in Fish Theme.
Stability	System retains overall character despite changes in climate or levels of resource exploitation. Components and processes remain intact.	System undergoes major changes in character following changes in climate or levels of exploitation. Components and processes radically altered.	Yes, for selected components, by planned analyses of trends over time and integration across Themes.
Resilience	Communities and key processes recover after major disturbances (e.g. fire, drought, flood, pollution). Diversity of components (e.g. species, habitats) and scales of processes maintained (e.g. recruitment, rates of channel change).	Some or all communities lack capacity to recover original numbers and distribution following major disturbance. 'Weed' species may proliferate. Diversity of components and processes decreases (e.g. substantial loss of species, less recruitment).	Yes, partially – by analysis of trends in biophysical components over time, and by assessment of biodiversity, recruitment and hydrologic connectivity to floodplain.
Utility	An absence of exploitation, or level of exploitation that falls within the capacity of the system to recover or maintain its heterogeneity and processes.	Levels of exploitation outstrip capacity of the system to recover; utility of river resources for humans is reduced.	No, but SRA data could contribute within MDBA's Integrated Basin Reporting.

as vigour, resilience and the efficiency of nutrient cycling. It may have lost and/or gained species, it may be affected by environmental changes (e.g. salinisation), or its resources may be intensively exploited (e.g. diversions of water for irrigation). None of these factors is inherently unhealthy, but may become so if they exceed the resilience of the system. The differences between 'healthy' and 'unhealthy' systems, then, may be matters of degree.

Examples of key characteristics and functions underpinning the resilience of a riverine ecosystem include:

- connectivity—of water, biota and material transport and exchange, laterally, longitudinally and vertically, within the river system, and between it and its catchment
- heterogeneity—of biota (biodiversity), habitats, ecosystem unit types, process rates and types, within and among flow, carbon, nutrient and sediment regimes
- recruitment and dispersal—of biota
- transformation—of material (e.g. nutrients and carbon) or sediments.

A key concept is that of scale, with many processes in river ecosystems operating and exchanging across scales in both time (e.g. generational) and space (e.g. reach to catchment to bioregion). The character and functions that the SRA is concerned with are scale-dependent (i.e. they can be observed at different scales, and results of these observations will differ with scale). As the SRA is a surveillance monitoring program, assessing the condition and ecosystem health at valley and Basin scale, appropriate account must be taken of the ability to account for:

- smaller scale processes and conditions (e.g. movement of biota, local recruitment success) influencing assessments reported at larger scale
- larger scale contexts and processes (e.g. climate) influencing smaller scale outcomes.

Table 2.1 illustrates some of differences between healthy and unhealthy ecosystems, as might occur in the Murray–Darling Basin.

2.3.3 Data relationships and integration using Expert Systems

The steps involved in processing SRA data are illustrated in Figure 2.3:

Sample site selection and sampling protocols, data entry, management and analysis are guided by processes developed by the SRA team. The data are defined and integrated as follows:

- *Primary data* are field or modelled observations of variables (e.g. counts, measurements) recorded from individual samples or model runs and validated by quality control. They may be used to derive variables, providing *derived data*. An example is the list of names of fish species present at a site, leading to a derived statistic representing the number of species recorded.
- *Metrics* represent the difference between an observation and its estimated value under Reference Condition, typically as a ratio. They are calculated from primary and/or derived data from both observed (current) and Reference Condition. An example is the OE (observed: expected) ratio for fish, which is the proportion of the number of fish species expected under Reference Condition for a zone that is actually *observed* at a site in the zone.
- *Indicators* are derived by integrating two or more metrics using Expert Systems (see below). Generally, they are monotonically related to condition. They may be ordinal numbers, and may involve comparisons with Reference Condition. Values range between 0 to 100. An example is 'Expectedness', which is derived by combining (integrating) three metrics to yield information about the 'expected' species in a zone.
- An *index* is an integrated value for condition, derived by integrating two or more indicators, using *Expert Systems*

(see below), and aggregated for reporting at valley- and zone-scales. An example is the *Sustainable Rivers Fish Index* (SR–FI), which combines the 'Expectedness', 'Nativeness' and 'Recruitment' indicators to represent the condition of the fish community (Section 3.3.4).

The diverse audience for the SRA requires results to be reported at various levels of detail (see Figure 2.3). To this end, the Audit data are preserved as a complete set of primary data, as well as the derived data, metrics, indicators and indices.

Indicators and indices are calculated from metrics by *integration* using a computational process called 'Expert Systems'. This method allows for the integration of assessment results in ways that reflect ecological insight, but that cannot be achieved by simple mathematic methods such as using averaging or Euclidean distances. It also avoids the need for sharp, artificial boundaries between categories of assessment. This integration process is transparent and open to review in the light of new knowledge (see Section 3.8 and Appendix 1; Negnevitsky 2002, Carter 2011).

For nearly all SRA metrics, a score of (or close to) 1 indicates no change from or equivalence to Reference Condition values, while a score of 0 indicates an extreme change or total loss. For metrics with an unbounded upper limit, such as Number of Patches or Vegetation Height, a score greater than 1 also indicates change from Reference Condition—usually

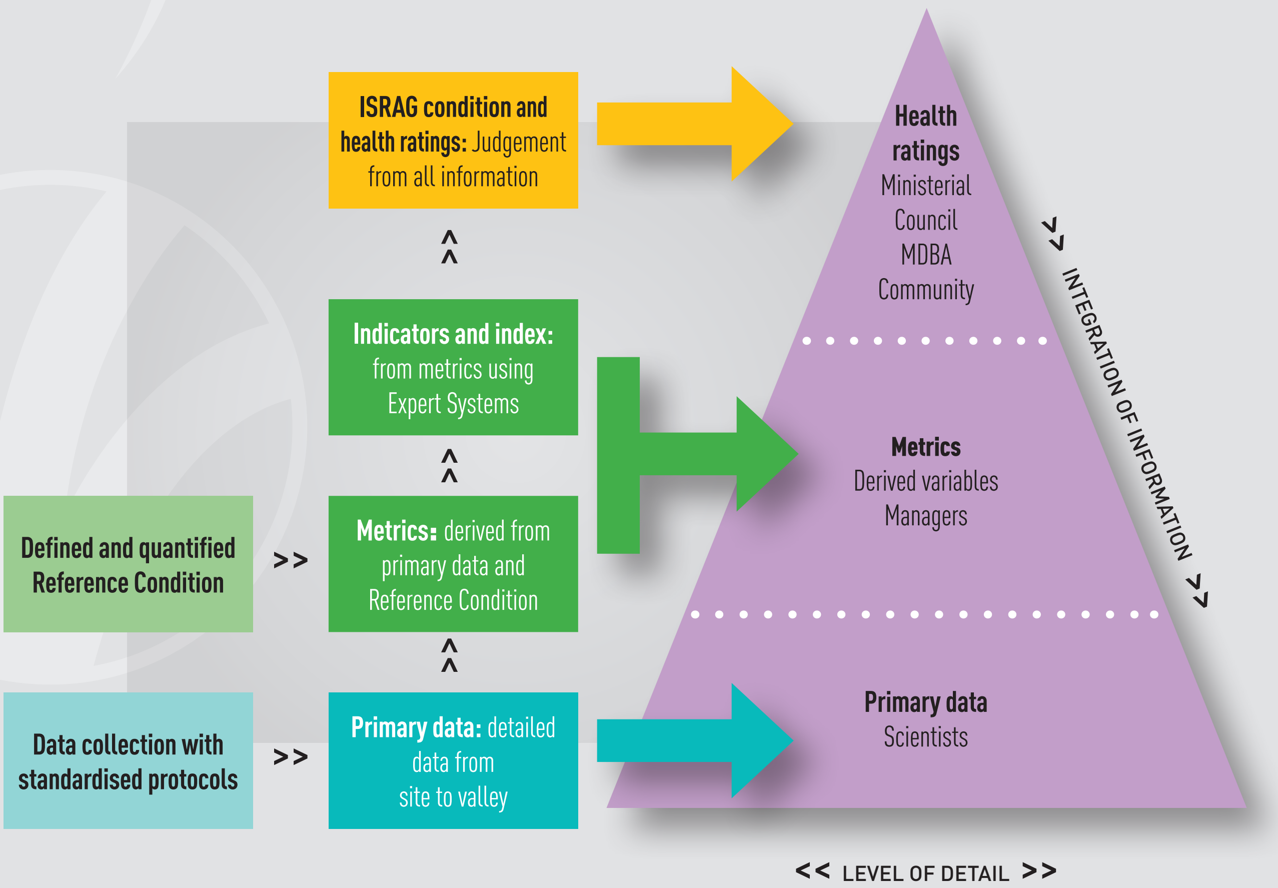


Figure 2.3. Stages in processing information in the SRA, from primary data to assessment of health.

an increase[4]. This occurs in the Vegetation, Physical Form and Hydrology Themes. For these cases, a more complex set of Expert Systems is required that considers the ecological significance of both increases and decreases relative to Reference Condition when combining metrics to produce indicators.

The SRA metric integration system is scripted and automated using the Fuzzy Logic Toolbox in the Matlab® technical computing software package (The Mathworks Inc., USA, release R2010B).

Combinations of extreme values (or 'pinpoints') of inputs (e.g. metrics) are developed by ISRAG, based on ecological concepts, to define values of integrated outputs (e.g. indicators). These combinations are arranged in *Expert Systems definition tables* and are then used to define a set of membership functions. These membership functions are compiled using simple linguistic rule sets, coded using standard mathematical operators (e.g. AND, OR and THEN). The process is tolerant of uncertainty in input and output values, a useful feature because the relationship between observed inputs and outputs are not known with high accuracy.

The membership functions are run for all combinations of input values to derive a *calculation surface* (or decision surface), which describes all values of the output for all values of inputs. Each point in a calculation surface is calculated by activating all the rules in the rule set. At some locations in the surface, several rules can contribute significantly to the calculation. For the SRA, the calculation surface is smoothed using a smoothing routine based on an N-dimensional convolution filter. The shape of the surface is checked to ensure consistency with the 'expert' input.

The membership functions are then applied to each combination of input values from the input data set to generate a set of output values. A 'defuzzification' procedure is then applied to this set of values, typically by deriving the centroid of the values, to generate a single output value for the set of input values.

Please refer to Appendix 1 and Carter (2011) for illustrated examples of this process, and for a full listing of the Expert System definition tables used in the analysis for this report.

Table 2.2. Integration of Biological Themes to derive an Ecosystem Health rating.

(Score values and ratings for the Ecological Condition Index (SR–EI) are used to determine Ecosystem Health ratings. Integration proceeds from left to right.)

Index scores		Rating
Condition (SR–FI)	Fish	Ecosystem Health
Condition (SR–MI)	Macroinvertebrate	
Condition (SR–VI)	Vegetation	

4 Only three metrics, all derived from SedNet model output variables, do not have a Reference Condition centred on 1. These metrics, which describe sediment accumulation rates or loads, all have a Reference value of 0, which represent no net change to rates or depth of sediment accumulation, and have unbounded upper limits.

The rules were used at three levels:

1. *Indicator Expert Systems* determine the values of indicators (or sub-indicators) from metrics, within all Themes.
2. *Index Expert Systems* determine the values of a Theme's Condition Index from indicators, again within all Themes.
3. *Ecological Condition Expert Systems* determine the ratings for Ecosystem Health from values of the three biological Theme indices (Fish, Macroinvertebrates and Vegetation).

This approach requires judgements, based on expert opinion, of the relative contributions of each metric, indicator or index to the integrated result. In particular, assessments of Ecological Condition and Ecosystem Health require judgements about the links between Themes. For example, 'Poor Ecological Condition', as reflected in the Fish, Macroinvertebrate and Vegetation Themes would logically indicate a Poor state of the biotic component of the river ecosystem and hence Poor ecological health, whether or not Physical Form or Hydrology

Table 2.3. Expert rules in river Ecosystem Health assessment.

Selected examples of values and ratings for the Ecosystem Health Index (SR–EI), as determined by combinations of ratings for Theme condition indices. The indices are given different weightings, so that SR–EI scores are not derived by simple summation. Such rules are codified mathematically as Expert Systems using membership functions, and used by ISRAG to support assessments. See above and Appendix 1 for more detail.

Theme condition rating			Ecosystem Health	
Fish	**Macro-invertebrates**	**Vegetation**	**SR–EI Index scale**	**Rating label**
GOOD	GOOD	GOOD	100	GOOD condition
GOOD	MODERATE	GOOD	85	
GOOD	GOOD	EXTREMELY POOR	70	MODERATE condition
GOOD	EXTREMELY POOR	GOOD	60	
EXTREMELY POOR	GOOD	GOOD	50	POOR condition
GOOD	EXTREMELY POOR	EXTREMELY POOR	40	
EXTREMELY POOR	GOOD	EXTREMELY POOR	30	VERY POOR condition
EXTREMELY POOR	EXTREMELY POOR	GOOD	20	
EXTREMELY POOR	POOR	EXTREMELY POOR	10	EXTREMELY POOR condition
EXTREMELY POOR	EXTREMELY POOR	EXTREMELY POOR	0	

are currently in Poor condition. If hydrological and/or geomorphological condition were compromised, but Ecological Condition was not, the health of the ecosystem is likely to be at risk in the future, perhaps with lagged biological responses over a range of scales to changes in the physical environment.

In ISRAG's view, ecosystem health is indicated primarily by biological changes, often caused by changes in physical drivers, subject to human impacts. Thus in this audit, Fish, Macroinvertebrate and Vegetation condition are used as direct indicators of Ecosystem Health, which already reflect the effects of past changes in hydrology, physical form and processes.

In reporting on Ecosystem Health then, the emphasis here is primarily on the results of an integrated assessment of biological condition. Information on the condition of Hydrology and Physical Form is reported as supporting and contextual information.

In SRA report 1 it was not possible to derive scores for an Ecosystem Health Index for the valleys by integrating numerical data from the three Themes that were then active. It was necessary to use rating Bands (Section 2.4) in place of numeric scores, though rules were still used to support relative health assessments within bands.

For this report (SRA report 2), both the Ecosystem Health Rules and Themes have been updated. Numerical scores and band assignments for Ecosystem Health were derived by integrating the Condition Index values for the Fish, Macroinvertebrate and Vegetation Themes (Table 2.2). The Ecological Health Index (SR–EI) scores are used to define the Ecosystem Health rating, using the same band and rating label convention as for all other metrics and indicators (see Table 2.4). Examples of the Expert System pinpoints used as the basis for integrating these inputs are shown in Table 2.3. The process for rating Ecosystem Health is discussed in Sections 2.4, 3.8 and Appendix 1.

2.4 Reporting data in statistical terms

2.4.1 Aggregation

Metric, indicator and index values are derived at both zone and valley scale by spatial *aggregation* of information from smaller scales (e.g. sites).

For zones, most SRA index and indicator values are calculated from multiple site or reach data as arithmetic means (the average of values). The calculated mean is an estimate of the 'true' value that would have been obtained if all possible sites had been sampled.

For the Vegetation Theme, metrics are derived for both sites and areas (called domains) within zones. The former are aggregated as means to zone scale and then combined with the domain values at zone scale.

Scores are aggregated to the valley scale to provide values of metrics, indicators and indices for each valley. These valley-scale values are derived from the weighted-average of scores for zones in the valley, weighted according to the zones' relative stream lengths (for all other Themes).

2.4.2 Confidence limits

The precision of our indicator and index scores is represented by the 2.5 and 97.5 percentiles estimates derived from 2000 random samples (with replacement) of the original site data. This 'bootstrapping' procedure yields confidence limits (CL) for the calculated scores, specifying a range in which we can be 95% sure that the 'true' mean lies. Any bias of the bootstrap resampling method is calculated from the difference between the true sample mean and the mean derived from the median of the boot-strapped estimates. This bias is added to the lower and upper confidence limits to obtain final, bias-corrected confidence limits. This procedure is repeated anew for each metric, index and indicator, at either valley- or zone-scale for the Fish, Macroinvertebrate and Physical Form Themes.

The lower and upper 95% confidence limits are reported in parentheses. For example, an index might have a mean of 50 (35–70), indicating an estimated value of 50 and a 95% probability that the 'true' mean lies between 35 and 70.

Comparisons between indices should take account of the associated confidence intervals. Since most of the variance in the true value of metrics and indicators for most Themes is because of variation between sites (MDBA unpub. data), the range of the confidence limits reflects the variability of site values across the zone. Thus, a wide confidence interval indicates a high degree of variation among sites in the valley or zone for which the mean is calculated. For this reason, means of 40 and 50 may not be different, in statistical terms, if the associated confidence limits overlap.

For the Vegetation Theme, all metrics (except Canopy Height) are derived from a census of mapped data across the riverine domain. Confidence limits cannot be derived for these metrics, or for any indicators derived solely from them, in part due to uncertainty over mapping spatial errors and attribution.

For the Hydrology Theme, the derivation of confidence limits around the mean for zone and valley is inappropriate, as the assessment is based on a complete census of the stream network (i.e. not a sample). The maximum and minimum for reach values are therefore reported alongside the means for valley and zone, to indicate the level of variation that exists across the network. Metrics and scores reported for the Hydrology Theme rely on hydrological models to generate Reference Condition (for the trend analysis and status

Table 2.4. Bands and rating labels applied to assessments of condition and Ecosystem Health.

Score range	Band	Rating label
	Difference from Reference Condition	Theme condition or Ecosystem Health
80–100	Near Reference Condition	GOOD
60–79	Moderate difference	MODERATE
40–59	Large difference	POOR
20–39	Very large difference	VERY POOR
0–19	Extreme difference	EXTREMELY POOR

reporting) and Current conditions (status reporting). These models have been developed by state and commonwealth agencies for use in water resource planning using best-practice calibration procedures. There inevitably is some error in these models, but the level of error is unknown and it is not possible to represent its effect on the Hydrology Theme results.

2.4.3 Bands and labels

In the SRA, the process of assessment leads to five categories (***bands***) that express the ***condition*** of ecosystem components (Themes) in terms of differences from Reference Condition (Section 2.2.2). The bands have corresponding ***rating labels***, used by ISRAG to describe assessments of condition and Ecosystem Health.

In reporting SRA indices and indicators, the following notations apply:

- Mean index and indicator scores are reported, with lower and upper 95% confidence limits (CLs) in parentheses (where they are applicable).
- The mean score is assigned to a *band*, according to Table 2.4.
- The mean score is then associated with the band's *condition* or health *rating*.

Rating labels are used, for example, in the 'boxed' remarks that preface assessments of condition and Ecosystem Health for valleys (Volumes 2 and 3).

To illustrate: a Fish Condition Index (SR–FI) score could be reported as 50 (CL 35–70), indicating a *large* difference from Reference Condition. Note that the confidence limits can extend into one or more adjacent score bands (Table 2.4).

Part of the rationale for distinguishing these ranges (hence bands and rating labels) is as follows:

- Up to 20% lower fish, macroinvertebrate and vegetation diversity; abundance and recruitment; as well as reductions in high- and low-flow events and other hydrological variables; and also in channel form and process measures relative to Reference Condition, are unlikely to represent significant biophysical changes in the current context. This also makes allowances for uncertainties in estimating Reference Condition for each Theme, and for the inherent variability of the system.
- A 20–40% reduction in these variables is likely to indicate significant disruptions to ecological processes.
- Greater changes are likely to represent correspondingly greater disruptions to ecological processes.

3. THEMES

3. Themes

3.1 Selection of Themes

There are five active SRA Themes in this assessment: Fish, Macroinvertebrates, Vegetation, Physical Form and Hydrology. The Fish Theme assesses the condition of fish communities based on measurements of fish numbers, biomass, recruitment and community composition at sites. The Macroinvertebrate Theme assesses the condition of benthic (bottom-dwelling) macroinvertebrate communities based on the presence and frequency of occurrence of macroinvertebrate families at sites. The Vegetation Theme includes measures of the abundance, diversity, quality and integrity of riverine vegetation located within near-riparian zones and lowland floodplains. The Physical Form Theme measures the condition of river system geomorphology based on channel form, and the dynamics of river banks, beds and floodplains. The Hydrology Theme includes measures of ecologically-significant aspects of in-channel and overbank flow regimes, including volume, variability, high- and low-flow events, seasonality, and low and high overbank floods.

Themes provide 'windows' on the condition of key components and the Ecosystem Health of the river system. Collectively they include variables that are readily measured, represent key ecological roles at a range of spatial and temporal scales and are sensitive to river–ecosystem 'drivers' like water and sediment transport. Other reasons for this particular complement of Themes are as follows:

- *Fish* are near the top of the aquatic food chain and are sensitive to environmental changes in the short- to long-term (days to decades) and over small to large spatial scales (reach to catchment). They are a food resource for birds and are exploited and valued by humans.
- *Macroinvertebrates* represent a large part of true aquatic biodiversity and a food resource for fish and other fauna. They play vital roles in carbon and nutrient processing; are sensitive to natural changes and human disturbances over the short- to medium-term; and generally fluctuate and respond at small scales (days to years, habitat patch to reach).
- *Vegetation* is a key part of channel and floodplain biodiversity, a habitat and food resource for plants and animals and a major source and sink for carbon and other nutrients. Riparian and floodplain vegetation responds to the river's water and materials regimes, but also acts as a link between the river ecosystem and the wider catchment. Riverine vegetation in channel and floodplain habitats is sensitive to natural changes and to human disturbances in the short- to long-term (months to decades).
- *Physical Form* includes the fundamental physical structure of the riverine ecosystem, as well as aspects of the river system's sediment regime. The combination of flow and sediment interacting with the landscape results in the core physical structures and processes upon and within which the ecology of the river plays out. The geomorphic environment provides habitats for biota, and sources and sinks for materials transported by the river. It is sensitive to human interventions over the short- to very long-term (days to centuries) and from small to large spatial scales (patch to catchment).
- *Hydrology* is a fundamental driver of all river ecosystems. The flow regime is a natural driver of river form and function, and is often directly modified by human interventions (e.g. dams, diversions and land cover change). The pattern, distribution and magnitude of flow governs the transport of materials in suspension and solution; connectivity between components; and provides

cues for biological processes (e.g. reproduction, migration). It also sustains aquatic and terrestrial organisms in channel and floodplain environments. The resulting watering and hydraulic regime, sustained by riverine hydrology and groundwater dynamics, controls most biophysical processes on the floodplain. The hydrological regime is sensitive to short- and long-term human interventions and controls the core connections between the ecosystem and the regional landscape.

More information about the existing and proposed Themes is provided below.

3.2 The status of SRA Themes

3.2.1 What's new since report 1?

Since SRA report 1, a number of developments and refinements have occurred:

1. The Fish Theme has been broadened to include standardised measures of native fish recruitment throughout the Basin; and a more comprehensive quantification of reference native fish distributions.
2. The Macroinvertebrate Theme has been refined by the development of an improved assessment of Reference Condition for macroinvertebrate communities; and of metric calculation—using Boosted Regression Tree Modelling—an update to the Filters approach used in SRA report 1.
3. The Vegetation and Physical Form Themes have been scoped since report 1, developed using pilot data collected in the Namoi Valley, and then implemented for the first time. This assessment is based on mapping-based assessment; Light Detection and Ranging (LiDAR) data collection; and reconstructed and/or modelled reference values.
4. The Hydrology Theme has been broadened to assess more of the river network, not just individual locations within the regulated components. Reach-based data has now been aggregated to quantitatively assess the hydrological condition of the network at zone and valley scale, which could not be done for report 1. The Theme now includes:
    - improved hydrological modelling, and extent of assessment within valleys
    - the hydrological effects of farm dams and historical changes to catchment forest cover on headwater streams
    - measures of hydrological condition of both the channel and near and far floodplain environments (with four additional metrics to characterise the overbank flooding regime)
    - the condition assessment based on a standardised long term (30 year) record
    - assessments of temporal changes over the past 12 years.
5. Data collection, acceptance and quality assurance processes have been further developed for the three original Themes (Fish, Macroinvertebrates and Hydrology), as have several data analysis components such as Expert Systems and data modelling.
6. Temporal changes in the three original Themes are now reported for the first time—although still limited to two repeat sets of observations across all sites for Fish, three sets for Macroinvertebrates and four for Hydrology.
7. The spatial scale of the assessment is now extended beyond the channel and onto the floodplain (in a limited manner) in the Vegetation and Hydrology Themes.

3.2.2 Relative status and level of confidence in Themes

Condition assessment in the SRA is designed to accommodate new knowledge as it becomes available. ISRAG considers the Fish and Macroinvertebrate Themes to be well established, while three Themes— Vegetation, Physical Form and Hydrology—are either novel or are undergoing continued development. The Themes differ in their stage of development, in their comprehensiveness of spatial and informational coverage, and in their currency.

Table 3.1 summarises the status of key aspects of each Theme. It is important to take these issues into consideration when using or interpreting the results presented in this assessment report.

A number of constraints, including time and resources available, the current state of model development and data currency, prevent us from being able to treat all Themes with equal weight and confidence in an integrated assessment of river ecosystem health.

In SRA report 1, the assessment of ecosystem health was based on information on fish, macroinvertebrates and hydrology. The assessment of hydrological condition from a river ecosystem health perspective was limited and spatial coverage of the Hydrology Theme was incomplete. The SRA 1 ecosystem health assessment was therefore largely based on the results of the fish and macroinvertebrate assessments.

Substantial progress has been made since then in the hydrological assessment, but there are still significant gaps in this Theme's coverage of the stream network and an absence of data accounting for private diversions on unregulated streams. The early stage of methodological development in the Physical Form Theme required a conservative approach when defining the limits for the range of metric values that would be accepted as indicating Reference Condition. This may result in more sites, and hence zones and valleys, being rated in better condition than might be expected.

As a result, ISRAG considers that the assessments for these two Themes in this report are less sensitive than they could be. ISRAG has confidence in the relativities of Condition Index scores and ratings between zones and valleys for Physical Form and Hydrology. The absolute values, by contrast, will be conservative and tend to be biased upward. ISRAG also recognises that the state of both the hydrological regime and geomorphology reflects responses to river and catchment management but that they are also important intermediate drivers or stressors of ecological process and condition. In addition, the current understanding of the relationships between changes in fluvial geomorphology and ecological processes is poorly developed. All of these reasons prevent us from fully integrating the Physical Form and Hydrology assessment results into this report's assessment of river Ecosystem Health.

Given these considerations, the results of the Physical Form and Hydrology Theme assessments are reported here but do not influence the overall rating of river Ecosystem Health. This does not reflect an evaluation of the relative significance of physical form and hydrology to the wellbeing of the river system. It should also be noted that management planning and actions in the Basin are strongly focused on altering aspects of the river system's hydrology, and to a lesser extent its physical environment, emphasising the need for reliable information on their current and changing condition from an ecological point of view.

For this report the river Ecosystem Health assessment is based on integration of results from the three key biological Themes: Fish, Macroinvertebrates and Vegetation (see Section 3.8 and Appendix 1, sub-section 2). The combined condition of these three ecological components is an essential measure of the state of the health of the riverine ecosystem. We also recognise that this assessment lacks several key pieces of information within these Themes; such as fish and macroinvertebrate abundance, recruitment and cover of vegetation and information on key ecosystem processes.

With all this in mind, we have not reported numeric scores for Ecosystem Health, as this gives a false impression of precision. Instead a rating is provided, using the already established bands and rating labels (Good, Moderate, Poor, etc.).

Key points:

- The SRA Themes vary substantially in their state of development.
- The Physical Form and Hydrology Themes are important components of the SRA assessment of the condition of the Murray–Darling Basin river system but are not given a strong influence on this report's assessment of river Ecosystem Health.
- River Ecosystem Health ratings are essentially based on the condition of three key components: Fish, Macroinvertebrates and Vegetation.

3.3 Fish

3.3.1 Background

This Theme addresses changes in key characteristics of fish communities in river channels across the Murray–Darling Basin. More than 60 fish species are known from the Basin, including a complex of species (*Hypseleotris* spp.) awaiting formal description. The total also includes 10 species that are alien (having originated outside Australia) and seven marine or estuarine species that are capable of entering and surviving in fresh water.

SRA methods for using fish as indicators rely on information about the identity, origin and condition of individuals, their size, abundance and the composition of fish assemblages. The methods are developed from those established for the Index of Biotic Integrity in North America (e.g. Karr 1981) and the NSW Rivers Survey (Harris and Gehrke 1997). An indicator evaluating recruitment success among native species has been added for this report so that the condition of fish assemblages is now estimated using indicators of 'expectedness', 'nativeness' and 'recruitment'.

3.3.2 Sampling methods

In each zone, seven fish sampling sites were chosen using a stratified–random procedure, with a minimal 18 sites per valley. Each was the centre point of a one kilometre stream reach. This design was adopted following power analyses and benefit–cost analyses of species-accretion data from the SRA Pilot Audit (MDBC 2004f), showing that further samples were unlikely to yield many more species. For valleys with fewer than three zones, more sites were added to each zone in relation to its proportion of the total valley length. Montane zones are often small, and were included only if the stream length in that zone was longer than 120 km and more than 7% of the total valley stream length. If they were smaller, the montane area was included as part of the Upland zone.

Sampling sites were selected from the stream network following MDBC (2004f). Field teams validated the location and resolved practical issues such as problems of access, lack of water or proximity to instream barriers or impoundments (channel sites only were suitable). The SRA sampling protocols specify methods for choosing alternative sites to deal with these issues.

In a six-year SRA reporting cycle, each valley is sampled twice for fish. In the second round of sampling for this report (IP4 – IP6), approximately one-quarter of sites were 'fixed sites', resampled if they were available (some, for example, may have become dry), and the remaining 'roving sites' were reallocated randomly. This procedure, determined by

Table 3.1 Summary of status and key features of each SRA Theme for this SRA 2 assessment report.

Theme	FISH
Status	Established; refinements implemented. Confidence high in relative and absolute assessment results.
Assessment data	Reliable data from standardised survey effort at representative set of sites.
Metrics & indicators	Range of metrics including key features of interest. New metrics for recruitment added. Further metrics may add value.
Basis for reference	Adequate for nativeness and expectedness. Species expected under Reference Conditions are derived from published literature, historic catch records, museum collections and expert opinion. Reference probabilities of species capture in SRA samples are based on expert experience and knowledge of autecology of each species. Reference Condition is determined for each zone by an expert panel and subject to periodic review. This allows inclusion of new knowledge and back-calculation of past results. Reference for recruitment is empirically based.
Future needs	Metrics: fish recruitment measures should be further developed and levels should be linked to long-term population viability. Trend: for the current assessment, fixed and re-randomised sites are combined to represent two sets of random samples in time for the assessment of condition. At this stage trend estimates at the zone scale should be treated as preliminary. As more data are accrued in future, repeat sampling of the subset of randomly selected sites will provide a sound basis for assessing temporal trend.
Trend assessment	Trend assessment method developed and implemented; limited to two sampling events, mostly 'pre-rains'.
Theme	**MACROINVERTEBRATES**
Status	Established; substantial refinement implemented. Confidence high in relative and absolute assessment results.
Assessment data	Reliable data from standardised survey effort at representative set of sites. Data limited to assemblage composition.
Metrics & indicators	Single, improved metric describing change in assemblage composition. Further metrics for relative abundance and large invertebrates, as well as trait-based metrics desirable.
Basis for reference	Novel and innovative method developed and trialled for this assessment prior to adoption.
Future needs	Metrics: further metrics for relative abundance and large invertebrates required, along with data on large invertebrates (crustaceans, molluscs). Potential for inclusion of trait-based analysis.
Trend assessment	Trend assessment method developed and implemented; limited to three sampling events, mostly 'pre-rains'.

Continued/...

Table 3.1 Summary of status and key features of each SRA Theme for this SRA 2 assessment report.

Theme	VEGETATION
Status	Developmental; needs substantial development, expansion and better quality reference data. Confidence in assessment qualified due to inconsistent mapping data quality and currency.
Assessment data	Dual approach initiated, using census and site-data, to allow for reporting at two temporal scales, long-term and short-term. Sites are as for Physical Form. Landscape is disaggregated into ecological units or spatial domains, to differentiate 'floodplain' from 'near riparian' areas. Assessment is limited relative to its potential. Only two domains feasible at this stage. Assessment is reliant on mapping for current observations, limited use of LiDAR data (height metric) and no field data input.
Metrics & indicators	Metrics: number and range limited. Most are census-type, quantifying long-term change in extent of vegetation types. Data: site-scale data are limited to the LiDAR-derived height metric. Metrics and indicators are static. No measures of intra-vegetation type condition, regeneration or canopy condition. The formulation of Reference Condition is correspondingly simple.
Basis for reference	For census data: based on broad-scale vegetation mapping reconstruction. For finer-scale site data: based on mapping reconstruction, best-available site data and/or expert opinion.
Future needs	Domains: Physical information underpinning vegetation domains needs improvement, especially the SRA drainage network and floodplain delineation. Expand domains to include in-channel and wetlands and model their Reference Condition. Census data: Problems in mapping need rectification: notably currency, variable quality, boundaries, lack of riverine-specific vegetation types. Site scale: Remote sensing data should be integrated with field data. Trend: Benchmarking sites and domains will provide a basis for trend assessment.
Trend assessment	N/A

Continued/...

Table 3.1 Summary of status and key features of each SRA Theme for this SRA 2 assessment report.

Theme	PHYSICAL FORM
Status	Developmental; needs refinement and ground-truthing. Confidence in relative condition and ratings but not absolute values.
Assessment data	Adequate sample set for channel variables, derived from randomly assigned LiDAR swathes. Swathe length too short for some larger lowland channels. Channel and floodplain sediment budget change variables are poor—limited to SedNet modelling over entire historic period.
Metrics & indicators	Includes majority of key geomorphologically relevant variables, though with some smaller scale variables missing. Very coarse description of altered floodplain processes. No measures of changes in geomorphic types.
Basis for reference	Novel and innovative method developed for this assessment. Models function well. Model bounds for Reference Condition deliberately held conservatively wide. This leads to lack of sensitivity and overly high condition ratings.
Future needs	Needs to include larger scale LiDAR swathes and assessment of floodplain features. Needs greatly improved sediment budget modelling, coupled to known response thresholds. Needs inclusion of geomorphic typology to refine metrics. LiDAR data requires some ground-truthing. Review integration rule sets based on comparisons with detailed geomorphic assessments.
Trend assessment	N/A

Continued/...

Table 3.1 Summary of status and key features of each SRA Theme for this SRA 2 assessment report.

Theme	HYDROLOGY
Status	Established; some major refinements implemented, some still required. Confidence in assessment results for regulated stream reaches and influence on headwater streams of farm dams and long-term woody cover change. Lower confidence in overall valley-scale assessment results because of gaps in network data.
Assessment data	Adequate for modelled network at zone, valley and basin scales. Some mix of monthly and daily modelled variables and variable model assumptions for the 'current' scenario. Low for representation of detailed within-zone variation in hydrological alterations (local hydrological assessments should be used for this purpose). Low for representing most anabranch and distributary channels; moderate to low for rest of network. No reliable data for mid-size tributaries which lack spatially explicit data on effects of licensed abstraction/diversions. Effect of woody cover change and farm dams accounted for in headwater streams with some caveats including: (i) no allowance is made for particular farm dam configuration such as low-flow bypass; (ii) modelling of woody cover change impacts in low rainfall areas is unreliable; and (iii) representation of hydrological impacts of farm dams and woody cover change on cease-to-flow condition is unreliable.
Metrics & indicators	Includes majority of key ecologically relevant hydrological variables. Measures of floodplain water regime limited to overbank flow frequency, with no hydraulic or extent based measures. No metrics on flow spells and changes in flood regime where water resources uses a monthly time-step (mostly Victoria) and reliability of daily models (where they are available) to represent these features correctly is uncertain.
Basis for reference	Adequate for mainstem rivers, representing flow regime in absence of historical development. Moderate for headwater streams where modelling methods must make coarse simplification; however, available data and method of extrapolating for gauge sites to the rest of the network increases uncertainties. See further comments in 'Assessment data' column.
Future needs	Expand water resource modelling to include more tributaries representing surface and groundwater uses. Need for consistent use of daily data across entire mainstem river network. Need for inclusion of floodplain flooding regime (extent, connectivity and timing) and hydraulics. Establish uncertainties in metrics for mainstem and headwater streams. Develop metrics for representing altered hydrological connectivity (longitudinal, lateral and vertical). Develop metrics and modelling capability for characterising hydrological alteration in groundwater dependent ecosystems. Improve the ecological evidence to support integration rule-sets including upper and lower limits.
Trend assessment	Trend assessment method developed and implemented; analysis restricted to the period of the extended millennium drought and effects likely dominated by water resource management priorities in response to water scarcity. Furthermore, the modelled reference data over this period may introduce bias under dry conditions if they are outside the range of conditions for which the models were calibrated.

statistical modelling, is designed to adequately represent spatial and temporal variation within valleys. Given limited resources for sampling, it permits trend detection and provides adequately for statistical comparisons between valleys and zones.

Sampling generally is in low-flow conditions in spring/summer/autumn, but with flexibility to allow for high seasonal temperatures in northern areas and high irrigation flows in southern rivers. All main habitat types in the river channel at each site are sampled in proportion to their relative extents. For logistical reasons, floodplain wetlands and ephemeral streams are not sampled, although they are recognised as significant habitats for fish.

Fish are sampled using boat-mounted, backpack or bank-mounted electrofishing gear and bait traps (not 'baited', as often assumed). To standardise the sampling effort, the protocol informs field teams on the appropriate mix and application of methods according to local habitat characteristics (MDBA 2009).

All captured fish greater than 15 mm in length were counted. Up to 50 fish of each species at each site, caught by each method, were identified, measured and examined. Larger catches were sub-sampled. Variables recorded included species identity, abundance and the lengths and condition of individuals (e.g. presence of external parasites, lesions or other abnormalities), based on rapid visual appraisal. Fish were returned alive to the water after examination, except for voucher specimens needed for laboratory confirmation and alien pest species that, in some jurisdictions, must be humanely destroyed.

3.3.3 Reference Condition for Fish

Reference Condition for Fish (RC–F) is the estimated condition of fish communities that would have prevailed now, in a given zone and valley, in the absence of significant human intervention. It does not apply to particular sites, as habitat conditions vary and individual species are not expected to be evenly distributed amongst sites. As it is not possible to measure Reference Condition directly, it is determined by combining expert knowledge, previous research, museum collections and historical data, and is used in the calculation of all metrics. As such, Reference Condition is expected to be refined from time to time as new information becomes available. Periodically scientists from each state have participated in expert committees (Technical Advisory Groups, TAG) to review data on fish distributions throughout the Basin, and state-based research, leading to predictions of the distribution of each species in each valley and zone under Reference Condition. In early 2010, new information including valuable photographic records became available and added significantly to our knowledge of historic fish distributions in much of the Murray–Darling Basin (Trueman 2009). The TAG used this and other new information to refine the current description of Reference Condition.

In addition, a semi-quantitative assessment of 'rarity' was made for each species in each valley and zone. This predicted the likelihood of a species being found at a site, using SRA sampling methods, if the encompassing zone is in Reference Condition, and has also been refined in light of new information.

Estimates of Reference Condition in zones and valleys clearly have a strong influence on assessments of fish condition, hence determinations of Ecosystem Health. In developing protocols for sampling and analysis, a considerable effort was made to consult many sources of information, avoid biases and represent Reference Condition communities as accurately as possible. As sequential measures of the condition of fish assemblages are accrued over time, their relationship to a fixed reference become less of concern than the temporal trends of observed condition.

3.3.4 Variables, metrics and indicators

The *Sustainable Rivers Fish Index* (SR–FI) was generated from eight metrics grouped as three indicators (Table 3.2).

- The *Expectedness* indicator (*SR–FIe*) quantifies the degree to which those native fish species—expected to occur under Reference Condition—are actually observed at both site and zone scales. It derives from integration of two metrics (OE, OP). It takes into account the probability of occurrence (capture) of each fish species across the Basin. It ranges from 0 to 1, representing the complete absence or presence of expected native fish species, respectively.
- The *Nativeness* indicator (*SR–FIn*) quantifies the degree to which the fish community is made up of native rather than alien species, in three ways: number of species, abundance and biomass. It derives from integration of three metrics: prop_N_biom, prop_N_abund, prop_N_sp (Table 3.2). The use of biomass data for the nativeness biomass metric (prop_N_biom) was enabled by estimating the weights of individual fish using empirical length-to-weight relationships for each species. The Nativeness indicator ranges from 0 to 1, representing the complete dominance by alien or native fish species, respectively.

Table 3.2 SRA Fish metrics and interpretation.

Metric	Meaning
Observed to Expected ratio (OE)	Compares number of native species predicted to occur in the zone under RC–F and the mean number actually caught at sites. The number of predicted species is corrected downward for species likely to be rarely sampled under RC–F, using the SRA protocol.
Observed to Predicted ratio (OP)	Compares native species predicted to occur in a zone under RC-F (without correction for rarity) and those caught across all sites in that zone.
Proportion Native Abundance (prop_N_abund)	Proportion of individuals that are native species.
Proportion Native Species (prop_N_sp)	Proportion of species that are native species.
Proportion Native Biomass (prop_N_biom)	Proportion of total biomass contributed by native species.
Recruitment Proportion of Taxa	Proportion of native fish taxa showing evidence of recruitment.
Recruitment Proportion of Sites	Proportion of sites with evidence of native fish recruitment.
Recruitment Proportion of Abundance	Proportion of total native fish abundance with evidence of recruitment.

- The *Recruitment* indicator (*SR–FIr*) quantifies the degree to which native fish species are maintaining recruitment—the accrual of potentially-reproductive individuals to populations. It does this at zone scale, using three variables: proportion of native species, proportion of sites and proportion of total native abundance. It ranges from 0—representing the complete absence of recruitment—to 1, representing the presence of recruitment at reference levels.

The full list of SRA Fish metrics is shown in Table 3.2, with their interpretation.

3.3.5 Integration and aggregation methods for fish

The three indicators were combined, using Index Expert Systems, to yield SR–FI scores for each zone and valley. Scores are scaled from 0–100, where 100 represents Reference Condition (in this case, RC–F). Their interpretation is described in Section 2.4.

The method used to aggregate site-based scores to zone- and valley-scales was as follows (see Table 3.3):

Zone scale

- The zone score for each Expectedness and Nativeness metric (e.g. OE) is the mean metric score for all sites in that zone. The OP metric score is an exception, being derived directly at zone scale.
- The Recruitment metrics are all derived at the zone scale.
- Metric scores were input to the indicator Expert Systems to determine a zone indicator score (e.g. Expectedness, *SR–FIe*).
- Zone indicator scores were input to the Index Expert Systems to determine a zone Theme Index score (e.g. SR–FI).

Valley scale

- The valley score for each metric is the mean of zone metric scores, weighted by total zone stream lengths.
- Valley metric scores were input to the indicator Expert Systems to determine a valley indicator score.
- Valley indicator scores were input to the Index Expert Systems to determine the valley Theme Index score (SR–FI).

Confidence limits in SR–FI, indicators and metrics are derived using the bootstrapping method described in Section 2.4.

The Index Expert Systems, used to integrate the three indicators to form the SR–FI score, reflect the premises that:

- Changes in the numbers of expected species (quantified by the Expectedness indicator, *SR–FIe*) will affect the overall condition of fish communities. A substantial loss of expected native species therefore indicates Poor condition.
- The status of recruitment to native fish populations (quantified by the Recruitment indicator, *SR–FIr*) is critically important to the condition of the native fish assemblage.
- Condition of fish communities is further decreased when Nativeness (*SR–FIn*) is diminished by dominant numbers or biomasses of alien fish, reflecting loss of native biodiversity and changes to trophic relationships.

Thus, a very low SR–FI score would indicate loss of expected native species, very low levels of recruitment of the species present to their existing populations, and dominance by alien species; a high score would mean abundant expected native species recruiting satisfactorily to their populations and few-to-no alien species.

3.3.6 Analysis of temporal patterns

This second SRA report introduces reporting on trend for three Themes (Section 6). For the Fish Theme it is possible to report on fluctuations in the fish metrics and indicators over the last six years (2004–05 to 2009–10), based on two cycles of sampling in all valleys. These recent trends (or more accurately '*temporal patterns*') are reported as the magnitude and significance of differences in the *Fish Condition Index* between times of sampling among valleys.

The Fish Condition Index (SR–FI) values from each sampling cycle are analysed using a randomisation test which tests whether a difference between the two sampling periods is larger than expected by chance alone. The features of this approach are:

- 2000 differences between randomly selected values of the index from both sampling cycles are generated (calculated as $Index_{Cycle2} - Index_{Cycle1}$).
- A null hypothesis is used: that the average difference between the cycle means is 0.
- This hypothesis is rejected if the central 95% of the 2000 possible differences is entirely above or below zero.
- This is the equivalent of a single sample hypothesis test, with no assumptions about the shape of the distribution.

Significant effects of time of sampling by valley and zone are identified, and trends are described.

Table 3.3 SRA Fish Index (SR–FI) and contributing metrics and indicators.
Integration proceeds from left to right.

Metric		Indicator	Index
Name	Scale		
OE	site	Fish Expectedness (SR–FI*e*)	Fish Condition SR–FI
OP	zone		
Proportion Native Abundance	site	Fish Nativeness (SR–FI*n*)	
Proportion Native Species	site		
Proportion Native Biomass	site		
Recruitment Proportion of Taxa	zone	Fish Recruitment (SR–FI*r*)	
Recruitment Proportion of Sites	zone		
Recruitment Proportion of Abundance	zone		

3.4 Macroinvertebrates

3.4.1 Background

Benthic macroinvertebrates (bottom-dwelling invertebrates visible to the naked eye) form an intricate community within aquatic ecosystems, and perform a range of important ecological roles. These include feeding on and processing microbial, plant and other organic material; and providing food resources for fish, birds and mammals. They are abundant, locally diverse, easily sampled and identified, and sensitive to natural and human–caused changes in rivers. Over 140 taxa (mainly at the level of family) have been recorded in SRA sampling throughout the Basin. They include a diverse range of aquatic insects, crustaceans, molluscs, worms and other forms, in varying numbers. The composition of macroinvertebrate communities is strongly influenced by variations in water quality, flow and other habitat conditions within and between sites, and by regional factors like climate and geology. The spatial and temporal scales of community responses to human and natural drivers generally are smaller than those for fish.

Most macroinvertebrate indicators of river health use information about the composition of the community, especially the identity and abundance of individuals. The SRA sampling methods were those developed for the Australian River Assessment Scheme (AUSRIVAS) under the National River Health Program (Davies 2000) that had already been adopted throughout the Basin. The methods were trialled and refined during the SRA Pilot Audit (MDBC 2004a–f, MDBA 2009), and, despite slight variation between states, have been used in a consistent manner since SRA sampling commenced in 2004.

3.4.2 Sampling methods

In each valley, a set of 35 macroinvertebrate sampling sites was selected for each sampling cycle, using a stratified-random procedure, ensuring at least three sites per zone. Statistical power analyses in the SRA Pilot Audit confirmed that use of more than 35 sites per valley was unlikely to improve assessments significantly. The numbers of sites per zone were allocated according to the percentage of total valley stream length within each zone in a valley. Locations were then randomly selected from the stream network, following the SRA sampling protocol, without stratification by stream order or size. On each sampling occasion, field teams validated the locations and resolved practical issues, including problems of access and lack of water. The SRA Sampling Protocol (MDBA 2009) specifies methods for choosing alternative sites.

Each valley was sampled every two years—each valley and zone has been sampled three times for macroinvertebrates since SRA sampling commenced in 2003. In the second and all subsequent sampling events, approximately one-quarter of sites were 'fixed sites', resampled each year if they are available (not dry), and the remaining 'roving sites' have been randomly re-allocated annually. As for fish (Section 3.3.2), this balance between fixed and roving sites is optimal for both evaluation of statistical trends and for comparisons between valleys and zones, given the limits on resources available for sampling. Each sampling site was selected to be at least 1 km away from its neighbouring site wherever practicable.

Sampling has been conducted in base-flow conditions (i.e. not during high-flow events), in spring or autumn, and only in the river channel. Both riffle and edge habitats have been sampled whenever possible. If riffle habitats were absent, as in most lowland reaches, only edge habitats have been sampled (MDBA 2009). Floodplain wetlands and ephemeral pools and streams have not been sampled, for logistical reasons, although they are significant habitats for macroinvertebrates.

Macroinvertebrates have been consistently sampled using the AUSRIVAS kick-sampling method, where the collector disturbs the river substratum for a 10 m stretch of stream bed, including a range of micro-habitats, and captures macroinvertebrates in a standard net. Sample processing also follows standard AUSRIVAS protocols, with laboratory-sorting (for South Australia and the ACT)[1] or live-sorting (in all remaining states) and identification to generate the list of taxa observed at the site.

Identification is at family level for most groups. In this report, for the sake of readability, the term 'families' may be used in preference to the technically correct 'taxa' (singular: 'taxon'). A few groups referred to in this way are actually taxonomic groups other than families (e.g. Acarina, Chironominae, Hirudinea, Ostracoda). For many macroinvertebrates, families represent reasonably discrete functional ecological groupings (e.g. feeding modes, habitat associations etc.).

The AUSRIVAS sampling method does not accurately represent the absolute or relative abundances of macroinvertebrates. Numeric data from samples therefore are not used here in the assessment of condition, though the frequency of occurrence of a taxon in sample pairs within sites is used. The method does not adequately sample several groups of molluscs and crustaceans, especially larger species like freshwater mussels and crayfish. These limitations may be addressed in future refinements of the sampling protocol.

3.4.3 Reference Condition for Macroinvertebrates

The *Reference Condition for Macroinvertebrates* (RC–MI) is the estimated composition of benthic macroinvertebrate communities that would occur now, within a given site, zone and valley, in the absence of significant human intervention. For SRA report 1, Reference Condition was established by developing a 'Filters' approach (Chessman and Royal 2004, Chessman *et al.* 2006, Walsh *et al.* 2007), which defined family tolerance limits to selected stressors, and a refined version 'Filters II' was used in the macroinvertebrate assessment for that report.

1 ACT sites are sampled and processed by NSW and are live-sorted.

Using the Filters model, assessments of community condition were based on the presence or absence of families, and not their relative abundances. No estimates could be made of the probabilities or frequencies of occurrence of families at sites under Reference Condition.

A new modelling approach was therefore developed for this report. This refinement incorporates the frequencies of occurrence of each family in field samples in the calculation of the macroinvertebrate condition metric (Walsh *et al.* 2010). Two samples were taken from each site on each sampling occasion, one each of riffle and edge habitats, or when riffles were absent, from two separate edge habitat locations within the site. Thus on each sampling occasion, the taxon can be recorded as absent, present in one habitat, or present in both habitats (frequencies of 0, 1 or 2).

The frequency of occurrence of families in samples were statistically related to a range of natural and human impact related variables using a powerful modelling technique called Boosted Regression Trees (BRTs, Elith *et al.* 2006, 2008). These models can incorporate data of a wide range of forms, and with a wide range of relationships to the frequency of occurrence of a macroinvertebrate taxon. See Section 3.4.5 for a general description of the approach and more details are available in Walsh *et. al.* 2010.

BRT models were developed separately for each of 96 of 131 macroinvertebrate families for which data were available from a large database (data from 3,428 AUSRIVAS macroinvertebrate sample pairs from 2,258 sites across SE Australia—drawn mainly from the AUSRIVAS archive of the National River Health Program (Gray 2004) but also from various studies and programs from NSW, the Victorian Environment Protection Authority, the ACT Department of Environment and Sustainable Development, B. Chessman, T. Daw Quadros and P. Liston pers. comms.). Environmental data were derived from the 2010 revision of a stream layer database developed by Stein *et al.* (2002) and, for measures of hydrological alteration, from the SRA's Hydrology Theme.

To derive a family's expected frequency of occurrence under Reference Conditions at an SRA site, the site values of environmental variables were entered into that family's model and all human disturbance variables set to zero. A list of all families and their reference frequency of occurrence was thus prepared for each SRA sampling site. This list was then compared to the occurrences actually recorded from a site's SRA macroinvertebrate sample.

A metric, called simOE, was developed equivalent to the Sørensen (Bray–Curtis) similarity measure (see Section 3.4.4). This measure was based on the difference in community composition between an SRA site's 'Observed' combined samples and its 'Expected' reference community (the set of frequencies of occurrence in AUSRIVAS sample pairs as predicted by the 96 BRT models for that site when all disturbance values were set to zero). It is an index of biological impact benchmarked against natural conditions, and which accounts for natural spatial variations in community composition. It captures the combined effect of both changes in taxon presence/absence, and of frequency of occurrence in field sample pairs. Prior to adoption for this report, the performance of simOE against a range of human disturbance gradients in south-eastern Australia was evaluated (Walsh *et al.* 2010), and found to be substantially superior to Filters II scores and to AUSRIVAS O/E scores.

The value of simOE was calculated for all samples collected from all SRA sites that had been sampled in the three sampling cycles since 2004. In this way, all SRA macroinvertebrate data from both the report 1 and report 2 sampling periods (2004–2010) have been re-analysed using the same improved assessment model. This has allowed assessment of:

- the status of macroinvertebrate communities during the SRA report 2 sampling period (2008–2010), and
- a comparison with data collected for SRA report 2 and assessment of trends.

Filters SIGNAL OE (derived for report 1) was not derived for report 2 because of its inconsistent and weak relationship with human disturbance gradients (Walsh *et al.* 2010). The majority of Basin river sites can only attain a low SIGNAL score (< 4) under Reference Conditions (Walsh *et al.* 2010), making SIGNAL OE an inherently insensitive bioindicator.

3.4.4 Variables, metrics and indicators

From the primary data recorded at each site, and outputs from the reference models, one metric is calculated (Table 3.4) and used to derive values for the *Macroinvertebrate Condition Index*, SR–MI:

- *simOE* metric: simOE is calculated from the sum of the differences in frequency of occurrence between all macroinvertebrate families in the SRA site samples and those predicted under Reference Condition (determined by BRT models), divided by the sum of all taxon frequencies in both the sample and Reference Condition. This metric can range from 0 (when all expected families are absent) to 100, when all expected families are present at their expected frequency of occurrence. The metric attains a value of 100 when all expected families are observed and at their expected frequencies, and it falls to zero when no expected families are found. It indicates the effect of disturbance—if the disturbance causes the loss of expected families and/or reduction in their relative abundance within a site. In practice, it

Table 3.4 SRA Macroinvertebrate Index (SR–MI) and metric.

Index	Metric	Meaning
SR–MI	simOE	Community compositional similarity to Reference Condition.

is rare for a disturbance to eliminate all macroinvertebrate families, and low metric values for sites in south-eastern Australia typically are 10–20.

Analysis of a large data set, including sites in and outside the Basin (Walsh *et al.* 2010), shows that, with the current formulation of the models, values for simOE range between 10 and 80. SimOE values are converted to Macroinvertebrate Condition Index (SR–MI) scores, which range between 0 and 100, using Expert Systems. SimOE values of 60–80 give high SR–MI scores, and values of less than 30 give extremely low SR–MI scores.

Additional derived variables are also reported as context to the assessment based on the simOE metric, providing summary information on the number of taxa observed and expected at sites within a zone and valley, and the occurrence of those taxa that are rare and common across the Basin.

3.4.5 Aggregation and integration methods for macroinvertebrates

Expert Systems were used to convert values of simOE to yield the *Sustainable Rivers Macroinvertebrate Index* (SR–MI) (Table 3.4). Values of SR–MI range from 0–100, where 100 is equivalent to Reference Condition for macroinvertebrates, and 0 represents absence of all expected families in both sample pairs from a site.

The Macroinvertebrate Index Expert System, hence values of SR–MI, are based on the premise that changes in the composition of macroinvertebrate communities—through gains or losses of taxa and changes in their frequency of occurrence in samples from a site relative to Reference Condition—both indicate the condition of the macroinvertebrate community. A low SR–MI score would indicate the loss of many expected taxa, coupled with reduction in the frequency of occurrence of the remaining taxa.

The method used to aggregate scores to zone- and valley-scales was as follows:

Zone scale

- The zone score for the simOE metric is the mean metric score for sites in that zone.
- Zone metric scores were input to the Index Expert Systems to determine a zone score for the SRA Macroinvertebrate Condition Index score, SR–MI. Unlike the Fish Theme, there was no intermediate step involving indicators.

Valley scale

- The valley score for the simOE metric is the weighted mean of zone mean simOE scores, weighted by total zone stream lengths.
- Valley-scale metric scores were input to the Index Expert Systems to determine a valley score for the SRA Macroinvertebrate Condition Index, SR–MI. Again, there was no intermediate step involving indicators.

Confidence limits in simOE and SR–MI are derived using the bootstrapping method described in Section 2.4.

3.4.6 Analysis of temporal patterns

This second SRA report introduces reporting on *trend* for three Themes (Section 6). For the Macroinvertebrate Theme it is possible to report on fluctuations in the simOE metric over the last six years (2004–2005 to 2009–10), based on three cycles of sampling in all valleys. These recent trends (or more accurately '*temporal patterns*') are reported as patterns of change among years and valleys.

The simOE data from each sampling cycle are analysed using a Generalised Linear Mixed Model. A traditional repeated–measures ANOVA using Least Squares estimates is inappropriate, as not all sites are sampled on all occasions. Key statistical features of this approach are that:

- sites are identified as repeated measures
- variances are grouped and calculated

according to each sampling cycle's set of site data

- valley means are calculated using weights of total zone stream lengths
- zone means are calculated as unweighted means of sites in that zone
- the correlation of the repeated measure (i.e. between sites) is treated as 'unstructured' (i.e. not known to conform to any specific correlation)
- the residuals of the analysis are exported to investigate the assumption of normality
- the least squares means for each effect in the model are calculated and compared using Scheffe's adjustment for multiple comparisons, with an adjusted probability level of 0.05 used to define statistically significant effects.

Significant effects of time of sampling by valley and zone are identified, and trends and patterns are described.

3.5 Vegetation

3.5.1 Background

Vegetation here means riverine vegetation, that is vegetation connected to, or part of, stream and river systems. This connection is both mechanistic and functional: mechanistic, in that this vegetation is dependent on or adapted to stream flow and the watering regime—so its condition and persistence are strongly influenced by recent and long-term flow history; functional, in that this vegetation provides ecosystem services to the stream—so is strongly influential on stream health as well as being part of it.

Riverine vegetation extends from the top of the catchment—where it is a narrow strip only metres wide that fringes headwater streams—to the bottom where it widens considerably, reaching several kilometres on the broad floodplains that characterise lowland areas of most valleys in the Murray–Darling Basin. Although continuous from headwaters to lowlands, riverine vegetation is not uniform, but rather undergoes longitudinal and lateral changes in species composition, species richness, and the number and range of growth forms. These longitudinal changes are the culmination of plant responses to environmental gradients that affect growth and life history strategies, notably temperature, and to downstream changes in physical character of streams and streamside environment that provide a mix of persistent and transient niches for plants. Maintaining these characteristics is expected to maintain vegetation function in relation to streams and rivers.

At the catchment scale, the notable attributes of riverine vegetation are its extent and continuity, its dimensions, and its heterogeneity. The two indicators that have been developed for the Vegetation Theme—Diversity & Abundance and Quality & Integrity—focus on these attributes. Related characteristics such as the capacity of vegetation to persist in the riverine landscape and its functional importance for stream health, are not assessed in this report.

As with other Themes, this assessment is referential. Contemporary riverine vegetation is compared with its reference as a comparison of two states, rather than of two timeframes. As this is the first assessment of riverine vegetation for the Sustainable Rivers Audit, there is no analysis of trend. However, the remote sensing data collected in 2010 as part of this assessment can serve as the first in a series for reporting on trends in the future.

3.5.2 Spatial organisation

The focus of the Vegetation Theme on riverine vegetation entails areas beyond the river channel. This assessment recognises two areas, here called *spatial domains*: Near Riparian and Lowland Floodplain. Future assessments will expand the number of domains, for example by considering channels, riverbanks and wetlands.

The *Near Riparian* domain is the area beside or parallel to the channel. The Near Riparian spatial domain is used in all zones. For metrics based on mapping, this domain is the area within 200 m either side of all drainage lines in the SRA stream network. This is the minimum width practicable for detecting Major Vegetation Group (MVG) boundaries in the vegetation mapping. Persistent errors in the SRA drainage network mean that the 400 m-wide Near Riparian domain, while always including the channel, is sometimes not centred precisely on it.

For variables based on LiDAR data (Section 3.5.3.3), the Near Riparian domain is that area lying within the LiDAR survey plot but more than 50 m from the top of the bank (green hashed areas in Figure 3.1), as defined in the Physical Form Theme. The 50-metre strip at the top of the bank was excluded so as to more precisely relate current data to Reference Condition descriptions. The rationale for this is that vegetation beside the channel tends to differ both structurally (taller, more complex, higher cover) and floristically from vegetation further away; and that although this distinctiveness would be precisely recorded by remote sensing techniques, an equivalent level of spatial precision is unlikely in both Reference Condition descriptions and the available vegetation mapping. A width of 50 m was selected as being approximately equivalent to two large trees

The *Lowland Floodplain* domain is defined as areas on the floodplain inundated by over-bank flows or river flooding (for example by a 1:100 Annual Recurrence Interval flood). This is an approximation of 'shedding' floodplains; meaning surfaces that are inundated but do not retain water on flood recession. It therefore excludes the larger lentic habitats, such as wetlands, lakes and deflation basins.

The Lowland Floodplain spatial domain used for this report was derived from existing inundation mapping and compiled as a specially-prepared spatial data layer, called '*JRoberts_LowlandFloodplain_GDA94*'. It is used only in Lowland zones and in the Central Murray, Lower Murray and Darling valleys. This was a modified version of the existing 'Kingsford' wetlands layer (Wetlands GIS of the Murray–Darling Basin, Series 2.0). The Kingsford wetlands layer shows the maximum extent of inundation, deemed as wetlands, five hectares or larger, over a ten-year period (1983–1993) which experienced no major floods in the southern part of the Basin, and was based on the presence of water as detected by Landsat MSS imagery. This layer was manually edited by ISRAG to restrict the mapping to areas directly relevant to riverine vegetation, i.e. to areas affected by river flows. Thus lentic habitats such as wetlands, lakes, and storages were excluded; as were non-floodplain areas such as inter-dunal swales and run-on areas, and individual vegetation patches too small to interpret confidently (less than 100 hectares). Confined and pocket floodplains in slopes and upland areas were not consistently mapped between valleys. Therefore, for this SRA assessment, floodplain features were not included for Slopes and Upland zones.

As a result, the floodplain domain applies only to the Lowland zone in a valley, and to all zones in the Central and Lower Murray and Darling valleys. Two valleys have no Lowland zone (the Mitta Mitta and the Upper Murray, and three had Lowland Floodplain spatial domains deemed inadequate for analysis, either because the inundated area was too small (Campaspe) or not detected (Kiewa) or because the vegetation mapping lacked content (Lower Murray/Lower zone). Lowland Floodplain spatial domain polygons are used for 18 of the 23 valleys in the Basin.

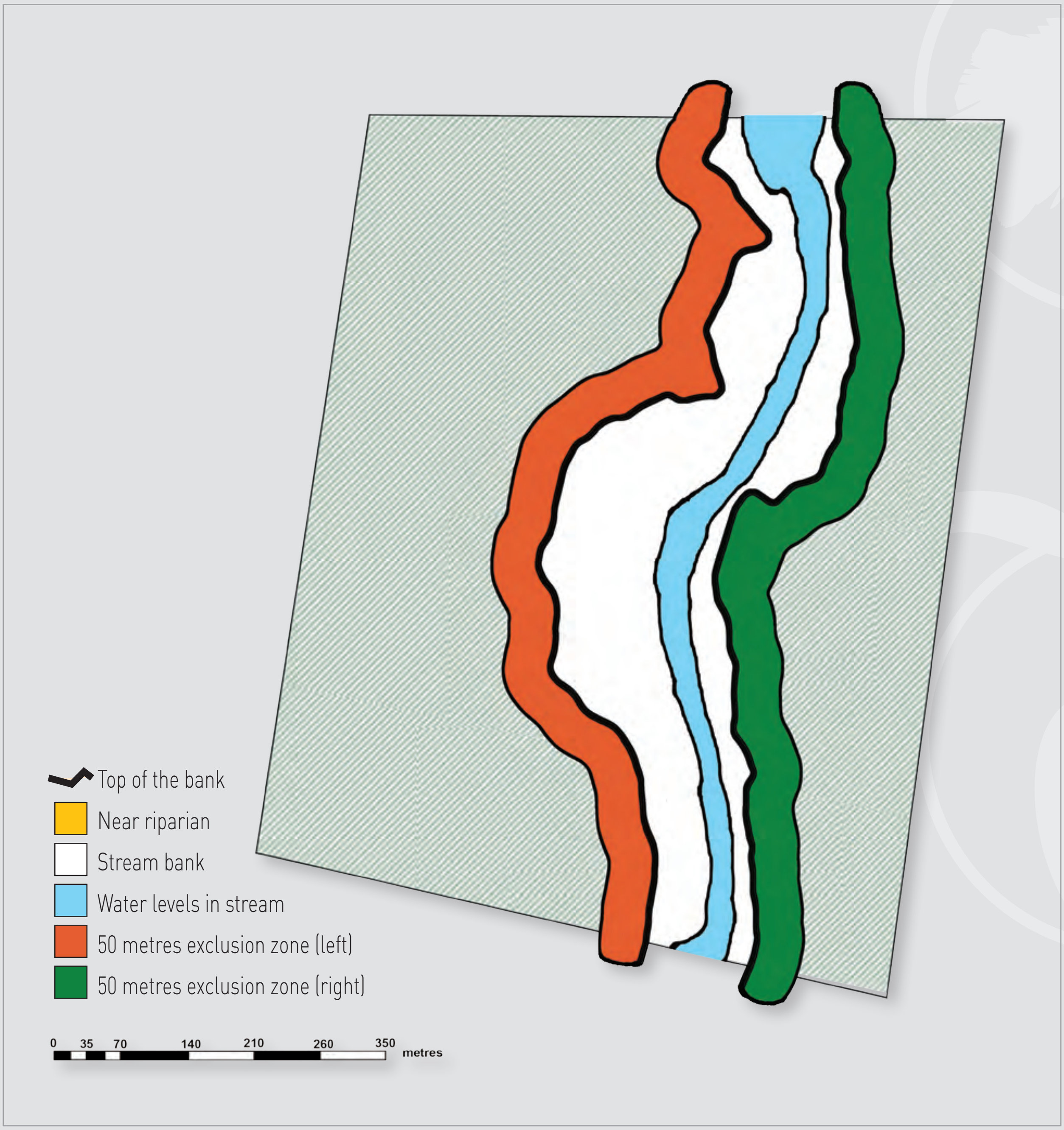


Figure 3.1. Example of LiDAR survey plot, with shading to indicate area used for vegetation data collection.

The Lowland Floodplain layer is not a map of the floodplains in the Basin. It is a conservative estimate of areas believed to be shedding floodplains within Lowland zones (and their equivalents), but these are not mapped comprehensively, nor are their boundaries accurate. The Lowland Floodplain domain is known to be only a small part of each Lowland zone, but is an unknown proportion of actual floodplain present. In the absence of a Basin-wide layer showing floodplains, this approach to defining a spatial domain for focusing on floodplain vegetation was chosen as the best possible option for the SRA Vegetation Theme after extensive consideration of alternatives. It was the only approach which combined a relevant basis for defining representative areas of floodplain vegetation relevance with Basin-wide consistency.

3.5.3 Data sources

3.5.3.1 Data types

Two data types are used in this report:

- *census variables*, which are based on vegetation mapping of Major Vegetation Groups (MVGs) within both the Near Riparian and Lowland Floodplain domains
- *sampled variables*, which are based on aerial surveys using LiDAR for sites (plots) randomly located across the SRA stream drainage network within the Near Riparian domain (Terranean Mapping Technologies, 2010). Census and sampled data differ in scale, detail and currency.

Derivation of mapping data is described below. LiDAR data were collected by aerial survey of some 1600 sites across the Basin (trimmed to just over 1300 for the assessment after quality auditing), and used to derive Canopy height variables (see Section 3.5.3.3).

No field sampling was conducted for this report, restricting the selection of variables used in the assessment.

3.5.3.2 Vegetation mapping

Two vegetation mapping data sets were used as source information from which both observed (i.e. current) and reference (i.e. pre-European) data were extracted.

This is the first time that an attempt has been made to consistently assess change in riverine vegetation across the Basin's river system. Despite the existence of a large number of vegetation mapping data resources; issues of inconsistent coverage, quality and resolution meant that their compilation into a single data set for vegetation assessment across the Basin river network posed a substantial challenge (Williams 2010).

Current census data were derived from a specially-compiled GIS layer called 'NVIS_IntVeg_vz', which combines two existing layers: 'Present Major Vegetation Groups' (NVIS Stage 1, Version 3.0, created and revised 2006, source: DEWHA, now SEWPaC), and 'Integrated Vegetation Cover 2009' (IVC, source: DAFF).

The Present NVIS vegetation mapping is a layer showing native vegetation, mapped as MVGs. MVGs are the outcome of a classification that groups over 9000 vegetation types across Australia into 23 broad groups (MVG 1 to MVG 23, not all present in the Basin), based on similarities in structure (height, crown), growth form (tree, shrub, etc.) and floristic composition (vascular plants only) of the dominant stratum.

The 20 MVGs present in the spatial domains for riverine vegetation across the Basin and used as the basis for this assessment are listed in Table 3.5.

Each MVG is named for the dominant vegetation type present but pockets of other vegetation types are likely to also be present—thus an MVG is not internally uniform. This loss of detail means MVGs are particularly well-suited for large-scale reporting, such as at Basin-scale, but the simplification needs to be acknowledged. The Current NVIS layer includes other mapping units that are also coded as MVG although not part of the original classification of native vegetation, such as MVG 25 (for land cleared of vegetation), MVG 26 (for vegetation that is native but not assigned to an MVG) and MVG 29 (for native vegetation re-growth). MVG 26 and MVG 29 are counted as native vegetation.

The source data and maps for this MVG classification and the Current Vegetation NVIS mapping were provided by the relevant state and territory jurisdictions. These had used various typologies, worked at various scales, and their field data were collected at times ranging from 1997 to 2004. These diverse inputs were translated into a common vegetation descriptive framework (NVIS), then assigned to an MVG in a consultative process involving federal and state representatives. The currency of variables extracted from the Current Vegetation NVIS layer is thus not precisely located in time but is centred around the year 2000.

Table 3.5 List of all Major Vegetation Groups (MVGs) observed within the riverine vegetation domains (Near Riparian and Lowland Floodplain) used for the SRA report 2 Vegetation Theme assessment.

MVG No.	MVG Description
1	Rainforests and Vine Thickets
2	Eucalypt Tall Open Forests
3	Eucalypt Open Forests
4	Eucalypt Low Open Forests
5	Eucalypt Woodlands
6	Acacia Forests and Woodlands
7	Callitris Forests and Woodlands
8	Casuarina Forests and Woodlands
9	Melaleuca Forests and Woodlands
10	Other Forests and Woodlands
11	Eucalypt Open Woodlands
13	Acacia Open Woodlands
14	Mallee Woodlands and Shrublands
16	Acacia Shrublands
17	Other Shrublands
18	Heathlands
19	Tussock Grasslands
20	Hummock Grasslands
21	Other Grasslands, Herblands, Sedgelands and Rushlands
22	Chenopod Shrublands, Samphire Shrublands and Forblands

MVG mapping is the only representation of vegetation distribution across the Basin that is readily available and suitable for SRA use, with a consistent approach to vegetation classification. The NVIS 3.0 mapping has a product resolution of 100 x 100 m and is used here at finer scales than was originally intended, in awareness of this limitation (the subsequent version, NVIS 3.1, defines vegetation more finely to a 67 subgroup level but was not readily available at the time the analyses were done). The Current Vegetation mapping includes some non-native vegetation mapping units which are not considered reliable, and two MVGs (MVG 26 and 29) that—although counted as native—are not a specific type of reference vegetation, so are not counted as MVGs.

Gaps and missing data in NVIS 3.0 were extensive in some parts of the Basin and had to be addressed by the inclusion of another mapping data set: the Integrated Vegetation Cover 2009 (IVC) layer. This layer emphasises land use and land cover. This coverage is compiled from existing layers such as NVIS 2007, Catchment Land Use 2009 and Forests 2007, and is based on satellite image interpretation supported by agricultural census data (Williams 2010). As land use was not the focus for the Vegetation Theme, all categories of agricultural land in IVC, other than barely-modified native pastures, were assigned to non-native vegetation mapping units such as MVG 25 'cleared'. Gaps (no data, null, cleared, non-native vegetation) in the Current MVG coverage were filled as per Reference if the IVC layer indicated native vegetation was present. This was particularly common in parts of western Victoria and some upland-montane areas of New South Wales; hence metrics reporting on vegetation dynamics for these areas may be biased towards being conservative.

For Reference Vegetation, the distribution and extent of MVGs is a layer called the Estimated Pre-1750 Major Vegetation Groups (NVIS Stage 1, Version 3.0), made available by SEWPaC). As with the Current Vegetation mapping of MVG, this layer is a compilation of mapping provided by jurisdictions to a common NVIS format, but is limited to the 23 MVGs that are all native vegetation types.

3.5.3.3 Vegetation plots

Approximately 70 sites were randomly distributed along the drainage network for each valley (Figure 3.2), stratified by zone, for both Vegetation and Physical Form assessment. For Vegetation, each site comprised a 1800 x 600 m plot within the 2000 x 700 m survey 'swathe' (Terranean Mapping Technologies 2010) resulting from flying full wave-form LiDAR (Figure 3.3). Each plot straddled the channel, sampling both left and right banks, though with unequal areas.

The *observed* Canopy Height for each vegetation polygon in a site was the lesser of two estimates: (i) the *absolute maximum height;* or (ii) 90% of the *estimated maximum height* (Eco Logical Australia 2010b). The absolute maximum height was derived from LiDAR returns using a Canopy Elevation Model (Terranean Mapping Technologies 2010) whereas the estimated maximum height was derived using percentage LiDAR returns (PLR) for the topmost height classes; but only where PLR >0 (Eco Logical Australia 2010b). This dual approach was necessary as some of the absolute maximum height estimates appeared to have been affected by factors other than trees (such as birds). This observed Canopy Height was considered the best approximation to the height values in the reference attribute layer.

Canopy Height was one of a range of reference structural variables that were collated for 484 vegetation types in each of 7528 polygons on the left bank and right bank (Figure 3.1, Section 3.5.2) as a series of specially-prepared GIS layers, with one structural variable per layer. These layers were prepared from sources as follows (Eco Logical 2010a) and partly revised to remove inconsistencies (Eco Logical Australia 2010b):

- benchmark descriptions for Ecological Vegetation Classes in Victoria were sourced from the Victorian government

- biometric benchmark data for New South Wales were sourced from the NSW government, except for the Namoi Valley where several approaches were used
- data were extracted from the Bushland Condition Monitoring Manual for SA, prepared by Croft *et al.* (2009 a,b,c)
- regional ecosystem benchmarks, final and draft, for Queensland were sourced from the Queensland government
- outstanding gaps were in-filled using techniques as best suited each location, and included an expert workshop for five regional ecosystems in Queensland
- ecological equivalents in New South Wales were extrapolated for 13 regional ecosystems in Queensland
- biometrics benchmark data were used for the ACT (Eco Logical 2010a).

Reference height refers to the 'typical canopy height' through the tallest part of the canopy. Only polygons with reference values for Canopy Height >= 2 m (if in Queensland) or >= 5 m (other jurisdictions) were used (Eco Logical Australia 2010b). This distinction was made to account for jurisdictional differences in the definition of a tree.

3.5.4 Reference Condition for Vegetation

Reference Condition for riverine Vegetation (RC–VI) is intended to represent its status under 'minimally disturbed' conditions. The method for determining this, and its precise definition, varies across the Basin, because the descriptions or mapping have been developed within the jurisdictions for their respective regional mapping and assessment programs, and are not consistent.

3.5.4.1 Mapping

Reference Condition for NVIS mapping is the estimated distribution prior to European settlement (pre-1750) for those 20 MVGs observed within the riverine vegetation domains across the Basin (Table 3.5). It represents vegetation in the absence of disturbances (principally clearing) resulting from European settlement (Australian Government 2006). The NVIS compilation combined pre-1750 'reference' and reconstructed or pre-European disturbance mapping and treats them collectively as equivalent to the pre-1750 Reference Condition. Inter-jurisdictional differences in how reference has been defined are not specifically considered in the compilation process and are expected here to be of little consequence in determining metrics; as the assessment is largely driven by aspects of vegetation extent. Metrics derived from current and pre-1750 NVIS mapping are predicated on the assumption that the same classification protocols were used for converting jurisdictional mapping to MVGs in both cases, and that the two layers are therefore comparable for any region within the Basin.

3.5.4.2 Plots

Reference values of structural variables, *Canopy Height* and *Canopy Cover,* for nearly 500 vegetation types that were expected to occur in the sampled plots, were sourced from benchmark or reference descriptions prepared by the jurisdictions, as described above. These were prepared using various techniques such as modelling and extrapolation, by analogy with 'best available', and using expert opinion.

Despite considerable effort, problems with adequately defining reference cover values in a manner consistent with LiDAR-collected data, as well as issues with LiDAR data interpretation, finally led to the removal of cover estimates and metrics from this assessment.

The vegetation types expected to occur within each polygon in each plot under Reference Condition were determined from original mapping sources (i.e. independent of the NVIS compilation) showing pre-1750, pre-disturbance or re-constructed vegetation. Mostly these were at 1:50,000 to 1:100,000 scales, thus providing greater precision than in the pre-1750 NVIS compilation vegetation mapping. However for about one-fifth of the plots, coarser scale mapping had to be used (i.e. 1:250,000 to 1:1 million), and NVIS pre-1750 mapping was the sole source of reference types for 3% of plots. Differences between jurisdictions in how reference is defined are not expected to influence the outcome of the assessment.

3.5.5 Variables, metrics and indicators

The *Vegetation Condition Index* (SR–VI) is made up of two indicators (see Table 3.6):

- The *Abundance and Diversity indicator*, which addresses the heterogeneity characteristic of riverine vegetation at a landscape scale, by using MVG as a high-level taxonomic unit.
- The *Quality and Integrity indicator*, which focuses on changes that alter riverine vegetation characteristics at the landscape scale.

The Vegetation Condition Index integrates data on riverine vegetation condition, using data and metrics from two areas (spatial domains): the Near Riparian and Lowland Floodplain (see Section 3.5.2). The full list of SRA Vegetation metrics is shown in Table 3.7, with their interpretation.

3.5.5.1 The Abundance and Diversity indicator

The *Abundance and Diversity indicator* is derived from census data only. It is derived by the combination (integration of) three sub-indicators for Vegetation: Richness, Abundance and Stability; each in turn derived from metrics (Table 3.7). All three metrics in this indicator use the Current and Reference Vegetation mapping, and are based on census data for the 20 of the MVGs numbered 1 to 23 only. These are the MVGs present in the Reference Condition. Novel or derived vegetation types, even if native, are not specifically considered in this indicator. The Richness and Abundance metrics are calculated for the Near Riparian domain for every zone in a valley, but the Stability metric is calculated only for the Lowland Floodplain domain and its Lowland zone.

Richness metric

The *Richness* metric reports on changes in the number of MVGs in the Near Riparian and/or Lowland Floodplain spatial domains by comparing the number currently present with the number expected under Reference Condition. A reduction in the number of MVGs is generally attributable to clearing; however as the Richness metric is not weighted for original extent of MVGs within the domain, it is not a measure of clearing extent, only an indication of its bias. The complete loss of an MVG represents a reduction in biodiversity.

The Richness metric ranges from 0 to 1 and is calculated as:

Richness metric = Observed / Reference

where:
Observed = Number of MVGs with area > 0 ha (Current NVIS–INTVEG mapping); and
Reference = Number of MVGs with area > 0 ha (Reference mapping).

In zones with both spatial domains, Richness metric values for Near Riparian and Lowland Floodplain domains are aggregated to produce a Richness sub-indicator at zone scale. Where Lowland Floodplain domains do not exist, the Near Riparian Richness metric is the only input to the zone scale Richness sub-indicator.

Abundance metric

The *Abundance* metric reports on the proportion of Pre-1750 vegetation area that is present and identifiable as MVGs, after more than 200 years of European settlement. It compares the area of MVGs currently present within a domain with the area of MVGs under Reference Condition. The metric is implicitly weighted, in that MVGs that are large dominate the summed area and so have more influence on the metric than MVGs that are small.

Table 3.6 SRA Vegetation Index (SR–VI) and contributing metrics, sub-indicators and indicators.
The spatial domains of relevance for each metric are indicated. Note that Lowland Floodplain metrics are only derived for Lowland zones.
* = process of aggregation used to report sub-indicator at larger scales. Integration proceeds from left to right.

Metrics	Sub-indicators	Indicators	Index
Vegetation Richness (Near Riparian)	Vegetation Richness (Near Riparian and Lowland Floodplain)	Vegetation Abundance and Diversity	Vegetation Condition, SR–VI
Vegetation Richness (Lowland Floodplain)			
Vegetation Abundance (Near Riparian)	Vegetation Abundance (Near Riparian and Lowland Floodplain)		
Vegetation Abundance (Lowland Floodplain)			
Vegetation Stability (Lowland Floodplain)			
Vegetation Canopy Height (Near Riparian)	Vegetation Structure (Vegetation polygons, sites, zone)*	Vegetation Quality and Integrity	
Vegetation Nativeness (Near Riparian)	Vegetation Nativeness (Near Riparian, Lowland Floodplain)		
Vegetation Nativeness (Lowland Floodplain)			
Number of Patches per MVG (Lowland Floodplain)	Vegetation Fragmentation (MVG polygons, Lowland Floodplain)*		
Mean Patch Area per MVG (Lowland Floodplain)			

Table 3.7 SRA Vegetation metrics and interpretation.

Metrics	Meaning (source of current data)
Vegetation Richness (Near Riparian)	The number of native vegetation types (Major Vegetation Groups or MVGs) in Near Riparian or Lowland Floodplain areas, relative to reference number (NVIS mapping).
Vegetation Richness (Lowland Floodplain)	
Vegetation Abundance (Near Riparian)	The area of native vegetation types (MVGs) in Near Riparian or Lowland Floodplain areas, relative to reference area (NVIS mapping).
Vegetation Abundance (Lowland Floodplain)	
Vegetation Stability (Lowland Floodplain)	The proportion of current native vegetation (MVGs) that is unchanged in location relative to reference proportion (NVIS mapping).
Vegetation Canopy Height (Near Riparian)	Maximum height of top of canopy vegetation within Near Riparian areas, relative to reference values. (LiDAR site surveys).
Vegetation Nativeness (Near Riparian)	The area of native vegetation in Near Riparian or Lowland Floodplain, relative to reference area (NVIS mapping).
Vegetation Nativeness (Lowland Floodplain)	
Number of Patches per MVG (Lowland Floodplain)	The number and mean area of patches of MVGs in Lowland Floodplain areas, relative to reference values (NVIS mapping).
Mean Patch Area per MVG (Lowland Floodplain)	

The Abundance metric ranges from 0 to 1, and is calculated as follows:

Abundance metric = Observed / Reference

where Observed = Sum area of MVG_{1-23} (Current NVIS–INTVEG mapping); and Reference = Sum area of MVG_{1-23} (Reference mapping).

In zones with both spatial domains, Abundance metric values for Near Riparian and Lowland Floodplain domains are aggregated to produce an *Abundance* sub-indicator at zone scale. Where Lowland Floodplain domains do not exist, the Near Riparian Abundance metric is the only input to the zone scale Abundance sub-indicator.

Stability metric

The S*tability* metric records what proportion of the current native (MVG only) vegetation is apparently unchanged in location, with change being by comparison with reference. This targets vegetation dynamics post-European settlement; such as encroachment or thickening (but not clearing with no recovery). It is derived relative to current MVGs, to avoid duplicating information on clearing, and only for Lowland Floodplain domains.

The metric is calculated by preparing a transition matrix of pixels (or areas) of MVG for the two timeframes, Current and Reference. It is sensitive to particular quality aspects of the source data, in particular to the quality and accuracy of the mapping, to changes in typology, to how typology has been applied to modified vegetation, and how all these vary between jurisdictions. In addition, protocols used for gap-filling in compiling NVIS pre-1750 mapping for some parts of NSW and SA involved using existing information, making Stability estimates very conservative.

The metric ranges from 0 to 1, decreasing as more and more MVGs change their location relative to Reference in the Lowland Floodplain. It is calculated as follows:

Stability metric = Observed / Reference = ('persistent') / ('current extent')

where
Observed = count of pixels for all MVG_{1-23} (Current) that are the same MVG in Current and in Reference mapping; and Reference = count of pixels for all MVG_{1-23} (Current).

3.5.5.2 The Quality and Integrity indicator

This indicator is derived from both census (mapping) and sampled (LiDAR) data. It is derived from three sub-indicators for vegetation: Structure, Nativeness and Fragmentation; each in turn derived from a number of metrics (Table 3.6).

Structure sub-indicator

This sub-indicator comprises one metric for canopy height derived from plot data and reference values, and is calculated for every zone in each valley.

The *Canopy height* metric is the ratio of the canopy height of riparian vegetation observed in 2010 in a polygon within a plot, to the reference height for the same polygon, determined from the reference mapping layer of vegetation types and its attributes. The heights refer to the top of the canopy; the target area is riparian vegetation more than 50 m from the top of channel bank (Figure 3.1), so this metric samples a distinct part of the Near Riparian domain. The assessment is limited to polygons where the reference Canopy Height indicated the presence of trees.

Selective removal or loss—for example through fire, of mature and emergent trees, and subsequent regrowth could result in a polygon metric being less than one (<1); whereas clearing will result in a metric value of zero. The metric can exceed 1 with loss of younger age-classes.

The metric value for a site (plot) is calculated as follows:

Canopy height metric = Weighted mean of (Observed $_{\text{polygon } 1..n}$ / Reference $_{\text{polygon } 1..n}$)
where
Observed = canopy height observed for each polygon in the plot; and
Reference = canopy height expected for that polygon; and
Weighted mean = mean of metric values derived for all vegetation types within a plot, with weighting by polygon area.

The *Structure* sub-indicator is the mean metric for all sites in a zone.

Nativeness metrics and sub-indicator

The *Nativeness sub-indicator* is derived from Current and Reference vegetation mapping and is calculated for every zone in each valley for Near Riparian domains, and also for the Lowland Floodplain domain where applicable.

The *Nativeness metric* is a comparison of the current area of native vegetation compared with the area of native vegetation under Reference Condition for that spatial domain. This metric differs from the Abundance metric as it includes not just MVGs in pre-1750 mapping, but also areas mapped as native vegetation in current mapping but not assigned to a specific MVG—such as unclassified regrowth and modified native vegetation (MVGs 26 and 29).

In zones with both spatial domains, Nativeness metric values for Near Riparian and Lowland Floodplain domains are aggregated to produce a Nativeness sub-indicator at zone scale. Where Lowland Floodplain domains do not exist, the Near Riparian Nativeness metric is the only input to the zone-scale Nativeness sub-indicator.

The Nativeness metric ranges between 0 and 1, declining as native vegetation is replaced with exotic or cultural vegetation. The metric is derived separately for the Near Riparian and Lowland Floodplain spatial domains, and is calculated as follows:

Nativeness metric = Observed / Reference
where Observed = sum area of $MVG_{1\text{-}23,\,26,\,29}$; and
Reference = sum area of $MVG_{1\text{-}23}$ (pre-1750).

Fragmentation sub-indicator

The *Fragmentation* sub-indicator represents the degree of fragmentation in native vegetation relative to Reference Condition. It has two metrics as inputs: *Number of Patches* and *Mean Patch Area* for each MVG, each calculated from Current and Reference vegetation mapping for the Lowland Floodplain domain only.

The two metrics are integrated using Expert Systems (see Appendix 1) to provide a *Fragmentation sub-indicator* score for each MVG within a Lowland Floodplain. These are then aggregated by weighted averaging, weighted by MVG area to give a Fragmentation sub-indicator for the zone's Lowland Floodplain.

Number of Patches metric

The *Number of Patches* metric is the ratio of the number of patches (polygons) of an MVG observed in the Current vegetation mapping layer to the Reference number (i.e. expected) for the same MVG, based on pre-1750 vegetation mapping. It is calculated for all MVGs occurring in a Lowland Floodplain domain.

Values for this metric may be greater or less than one. The number of patches may increase as a result of fragmentation, but eventually decreases as clearing persists and intensifies. These processes may happen concurrently. The metric is calculated as follows:

Number of Patches metric =
Observed $MVG_{1..n}$ / Reference $MVG_{1..n}$

where Observed = Number of Patches of $MVG_{1\text{-}23}$ (present); and
Reference = Number of Patches of $MVG_{1\text{-}23}$ (pre-1750).

Mean Patch Area metric

The *Mean Patch Area* metric is the ratio of the mean area of all patches of an MVG observed in current vegetation mapping to the mean area of all patches for the same MVG, determined from reference vegetation mapping. It is calculated separately for all MVGs occurring in a Lowland Floodplain domain.

The values for this metric may be greater or less than one. Mean patch area may increase if small patches only are lost but will dramatically decrease if large patches are lost. The metric is calculated as follows:

Mean Patch Area metric = Observed $MVG_{1..n}$ / Reference $MVG_{1..n}$
where Observed = Mean Patch Area of $MVG_{1\text{-}23}$ (present); and
Reference = Mean Patch Area of $MVG_{1\text{-}23}$ (pre-1750).

3.5.6 Integration and aggregation and methods for vegetation

For each zone, Expert Systems are used to combine, or *integrate*, the SRA metrics to a single Vegetation Index (SR–VI). This index is calculated from the two indicators describing Abundance and Diversity, and Quality and Integrity of riverine vegetation in Lowland Floodplain and/or Near Riparian domains.

The relationships between metrics, sub-indicators, indicators and the SR–VI Index are shown in Table 3.6, and the Expert System tables used as the basis for the integration are in Appendix 1.

Integration uses weighting to accommodate relevance and quality differences as well as relationships between metrics (or sub-indicators) and is not a simple additive process. For example, in the Abundance and Diversity indicator—because backfilling from reference was used to plug gaps in the current data layers in some areas—the Stability metric has been down-weighted when integrated with the Abundance and Richness metrics; and in the Quality and Integrity indicator, the Structure sub-indicator (which here is only a Canopy Height metric) is down-weighted relative to the Nativeness and Fragmentation sub-indicators—as trees could be at reference height but occur as sparse individuals.

Data are also spatially *aggregated* across all LiDAR-surveyed sites and Lowland Floodplain and/or Near Riparian mapping areas to the zone scale using a combination of area-weighted and simple averaging. Aggregation from the zones to the valley scale is then by weighted averaging of zone values, using the total stream length within each zone as weights (derived from the SRA digital river network).

The two indicators are combined, using Index Expert Systems, to yield SR–VI scores for each zone and valley. Scores are scaled from 0–100, where 100 represents Reference Condition.

Confidence limits in SR–VI are calculated for sampled data only, i.e. for the Structure sub-indicator, as described in Section 2.4.

The Vegetation Condition Index Expert Systems, used to combine (integrate) the two indicators to form the SR–VI score, reflect the premises that:

- The abundance and diversity of vegetation—as indicated by the richness of MVGs and their extent and their stability through time in the riverine landscape—reflects the core attributes of vegetation in the riverine landscape from biodiversity and ecosystem process viewpoints.

- The quality and integrity of vegetation—as indicated by the status of vegetation structure, nativeness and fragmentation—reflects not just the inherent structural properties of riverine vegetation, but also its key role in habitat provision at a range of scales for a range of dependent species.
- All the metrics assessed as inputs to these indicators address key aspects of ecosystem process at zone and valley scales, either directly or as surrogates.
- Changes in abundance and diversity are given slightly greater weight than changes in quality and integrity when integrated to produce the Vegetation Condition Index.

Thus, a very low SR–VI score indicates loss of structure, change and fragmentation of native vegetation types; as well as reduction in area, turnover and loss of richness (predominantly through clearing and/or changed water regimes) coupled with replacement by cultural vegetation. The resilience of the vegetation, and its ability to support other species and ecosystem processes, would be severely compromised.

A high score indicates abundant MVGs (with little evidence of clearing or MVG replacement), an intact structure, MVGs distributed across the two domains similar to Reference Condition and—because of this—higher integrity, spatial distribution and patch sizes. This would be coupled with support for a diversity of habitats and ecosystem processes and a more natural level of resilience.

3.5.7 Interpretation

The Vegetation Condition Index is dominated by metrics derived from mapping and very little of the information contributing to it is based on fully contemporary metrics and data. Unlike the other Themes, the Vegetation index is largely reporting on a prior (though recent, c. 2000) condition.

The Expert System integration process used here has a synergistic effect when indicators with extreme and similar scores are combined. If two indicators score poorly, then the resulting index score tends to score lower than if only one indicator scored poorly. This reflects the concept that low values of a larger number of multiple vegetation measures indicate poorer overall condition than of a smaller number. Conversely, if both indicators have high scores, then the Index scores higher.

3.6 Physical Form

3.6.1 Background

River systems, river reaches and sites within rivers display different physical characteristics, or morphologies, that are associated with varying faunal and floral communities and species. River morphology governs the type, abundance, diversity and availability of physical habitat, as well as the transfer of energy and organisms, within and through the riverine landscape. The physical character of the riverine landscape therefore provides a template upon which evolution can develop characteristic species traits.

Rivers are process–response systems whereby their physical character is shaped by the climate, geology, topography, soils, vegetation and land uses in their catchments. These independent variables govern the flow and sediment regime within the catchment, which are in turn the process variables that shape the morphology of the riverine landscape. Alluvial rivers, like many of those within the Murray–Darling Basin, freely adjust their channel and floodplain dimensions (form) in response to changes in flow and sediment regimes (processes). Process–response is a

Figure 3.2. Vegetation and Physical Form LiDAR survey (yellow triangles) and field check sites (red) surveyed in 2010; overlaid on the 23 Murray–Darling Basin valleys.

concept in fluvial geomorphology (Schumm, 1977), whereby changes in discharge (Qw) and sediment load (Qs) induce changes in channel dimensions, planform and slope.

There have been few large-scale assessments of the physical condition of river systems. This is in part because of their morphological complexity, a limited understanding of their dynamic behaviour in space and time, the slow acceptance of relatively simple empirical relationships between process and form, and a lack of appreciation of the importance of scale in understanding process–form relationships. Nonetheless, advances have been made and a new generation of frameworks and approaches are emerging (Thorp *et al*. 2009). The physical form assessment for the Sustainable Rivers Audit is part of this new generation; employing remotely- sensed data obtained from airborne laser altimetry (LiDAR) surveys, modelled sediment data via SedNet (a catchment-based sediment model) and the development of empirical models of Reference Condition.

In this report (SRA report 2)) the new Physical Form assessment provides a simple comparison of current physical form data with Reference Condition, and as yet provides no trend. This comparison is relatively precise, in a temporal dimension, because the current physical form data were collected over a short time span of several months in 2010. In future physical form assessments, it is envisaged that this SRA report 2 data set will represent the starting point for reporting on trends.

3.6.2 Conceptual underpinning

A series of conceptual frameworks underpin the Sustainable Rivers Audit Physical Form Theme. At a higher level, Lane's model of stability, based on the premise that rivers are process–response systems (Lane 1955), suggests that their morphology is influenced by the interaction of a suite of:

- independent variables (at a catchment scale) that set the boundary conditions of riverine landscapes
- processes (e.g. discharge and sediment transport) that sculpture the riverine environment.

Numerous studies have established empirical relationships between discharge and/or sediment transport and the morphology (the physical form) of river systems within different valley settings. The generalised relationship for stable river channels as proposed by Lane (1955) depicts an interaction between sediment discharge (Qs), stream discharge (Qw), particle size (D50), and slope (S), whereby a change in any of these variables initiates a series of mutual adjustments resulting in a direct change in the morphology of the river. Relationships of this type have dominated thinking in fluvial geomorphology for decades. They include empirical relationships between discharge and bankfull width and depth (Leopold and Wolman 1957), bankfull discharge and meander geometry (Leopold *et al.* 1964), as well as sediment size and transport and the type or style of river channel (Schumm 1968). These all demonstrate that the morphology of a river system has been used to infer physical processes at a range of scales.

The second series of conceptual models relevant to the SRA Physical Form Theme is based on concepts proposed by Schumm (1968) and recently expanded by others, notably Thorp *et al.* (2009). Here, it is suggested that alluvial rivers have a number of degrees of freedom, in that they are able to adjust aspects of their bankfull cross sectional morphology [channel width (*w*), depth (*d*) and shape (usually recorded as *F*, the *w/d* ratio)], planform [meander wavelength (λ) and sinuosity (λ) and slope (*s*)] in response to changes in discharge (*Qw*) and sediment (*Qs*) regimes.

This can be described in the form:

$$\Delta Qw, \Delta Qs \approx \Delta[w, d, F, \lambda, \rho, s]$$

where Δ indicates a +/- change.

River systems may adjust their physical character in response to natural events like floods, and to human disturbance, such as catchment vegetation clearing or flow regulation. Physical changes or adjustments vary over a range of spatial and temporal scales and an assessment of the physical condition of river systems must employ a range of metrics that allow the detection of change in physical character at multiple scales or degrees of morphological sensitivity. It has been recommended by Parsons *et al.* (2009) that when assessing river system resilience, both faster and slower responding variables are employed. The SRA Physical Form Theme uses measures of bank morphology and cross sectional form as faster variables and hence responses, and measures of channel planform, bed dynamics and floodplain sedimentation as slower variables and responses.

There are a variety of methods or approaches currently employed to assess the physical condition of Australian rivers. Physical form has not been widely assessed in a quantitative and systematic way; and the majority of current approaches do not meet the present requirements of the SRA. Assessments have been undertaken in different river valleys or regions using a range of assessment protocols, and a wide range of types of data are available. To date these assessments have mainly been of a qualitative or semi-quantitative nature. Issues with inconsistent methods of data collection and assessment, and in establishing a Reference Condition, have meant that most of these data and assessments could not be incorporated into this SRA Basin-wide assessment.

The approach developed for the SRA Physical Form Theme is guided by a strong conceptual framework and has four components: river channel form, bank dynamics, bed dynamics and floodplain sediment deposition. River channel form is characterised by both mean channel dimensions and the longitudinal variability in channel cross-sectional form. Australian river systems are amongst the most hydrologically variable in the world and this produces a high degree of physical complexity or morphological variability. Research suggests that marked changes in physical variability or complexity occur with human disturbance. Measurement of the physical condition of rivers within the Basin focuses on potential changes in channel stability and physical variability. For this SRA assessment, river dynamics is characterised by the dynamics of channel bed and bank, and also in floodplain sedimentation rates, while recognising that processes such as bank erosion and deposition occur naturally in streams.

3.6.3 The spatial domain of the assessment

The Physical Form Theme assessment was undertaken on rivers delineated by the 1:250,000 stream network of the Basin. One thousand, three hundred and eighty-five (1,385) were sites randomly chosen throughout this network, and data were collected on the physical character of the river channel from one kilometre long reaches. Between 60 and 70 sites were established within each of the 23 Basin valleys, with the number of sites for each of the Upland, Montane, Slopes and Lowland zones stratified by the total stream length of the individual zones.

3.6.4 Data sources

Three types of data were employed in this assessment:

1. Data obtained from a single, full waveform LiDAR survey at each of 1385 sites across the Basin (Figure 3.2).
2. Data from the Sediment Network Model (SedNet) of the Murray–Darling Basin.
3. Data derived from reference models of physical character.

No ground-based field sampling was conducted for this assessment. This constrained the selection of variables that could be used. The use of full waveform LiDAR, an optical remote sensing technology measuring heights and distances via pulses from an airborne laser, was the main form of data collection. At 1,385 river sites, full waveform LiDAR allowed ground surface elevation data to be collected at a ground

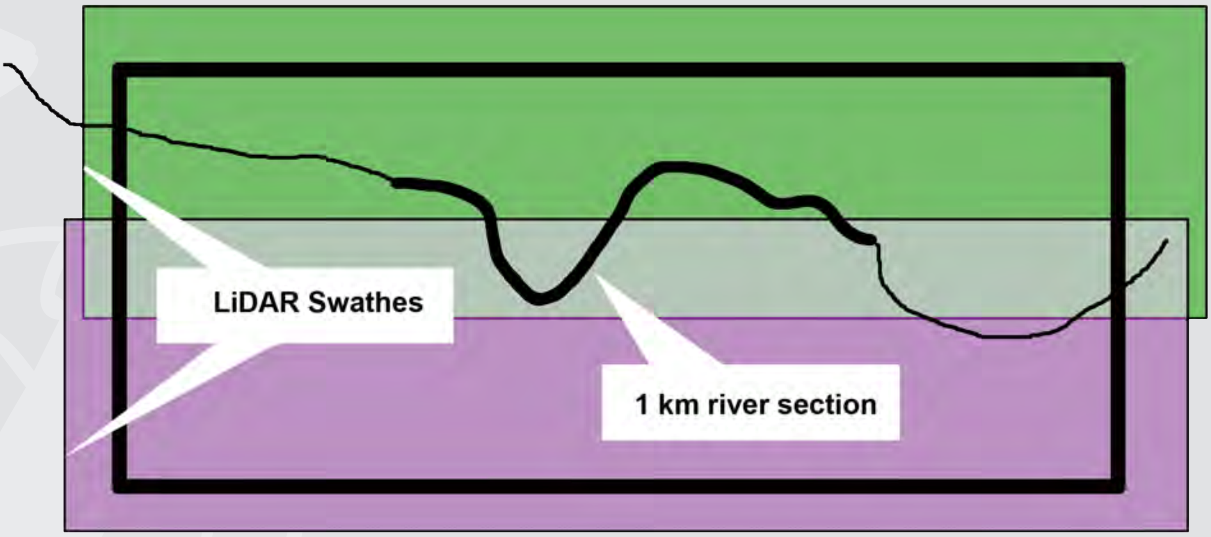


Figure 3.3. LiDAR field sampling site definition.

Note: Each 2000 m x 700 m site is covered by two 577 m wide LiDAR swathes with 35% overlap. A 1 km section of river within each site is analysed.

pixel spacing of 30 cm. Field surveys were undertaken to verify the accuracy of the processed remotely-sensed data. Each sampling site was defined as a 2000 metre by 700 metre rectangle aligned to the main river channel (Figure 3.3). Within this rectangular site, a one kilometre reach of river channel and adjacent riparian zone ground elevation were analysed. These sites are the same locations as used in the Vegetation Theme. The vertical accuracy of the LiDAR for bare ground surfaces was reported to less than 0.5 metres—reduced to 0.15 m with post processing (Terranean Mapping Technologies, 2010).

From the LiDAR data, a digital surface elevation model was created for each site and then interrogated, using automated software, to extract selected channel geometry variables. Initially a series of bankfull channel cross-section and river bank morphological measurements were extracted at 19 evenly spaced transects along each one kilometre reach. These measurements focused on the width and depth of the bankfull channel as well as the angle of the river bank. The sinuosity, meander wavelength and river channel slope were also determined for each one kilometre site. These data were used to derive nine metrics describing aspects of channel form and bank dynamics.

Modelling of sediment transport, inputs and exports throughout the channel network of the Murray–Darling Basin has been undertaken previously using the SedNet model (Prosser *et al.*, 2001, Young *et al.*, 2001, DeRose *et al.*, 2003) and these data formed the basis for calculating the bed dynamics and floodplain metrics. SedNet is a catchment scale model that provides data on loads of suspended (fine) and bed load (coarser than suspended load) for a series of reaches throughout a river network. The model allows for comparisons to be made between current (e.g. past 100 year average) and natural (pre-European) sediment loads. Natural conditions assume a pre-European catchment vegetation cover for estimation of hillslope erosion, no gully erosion, and a level of bank erosion equivalent to that occurring under 98% riparian vegetation cover. While current conditions take into account the presence of reservoirs and their effect on flow regulation along major rivers, they are excluded from the model run for natural conditions. Model outputs can be obtained for not only fine and coarse sediment loads but also for coarse sediment deposition within the river channel and floodplain. First developed for the National Land and Water Resources Audit (Prosser *et al.*, 2001) it has become a standard tool for the assessment of catchment sediment issues in Australia.

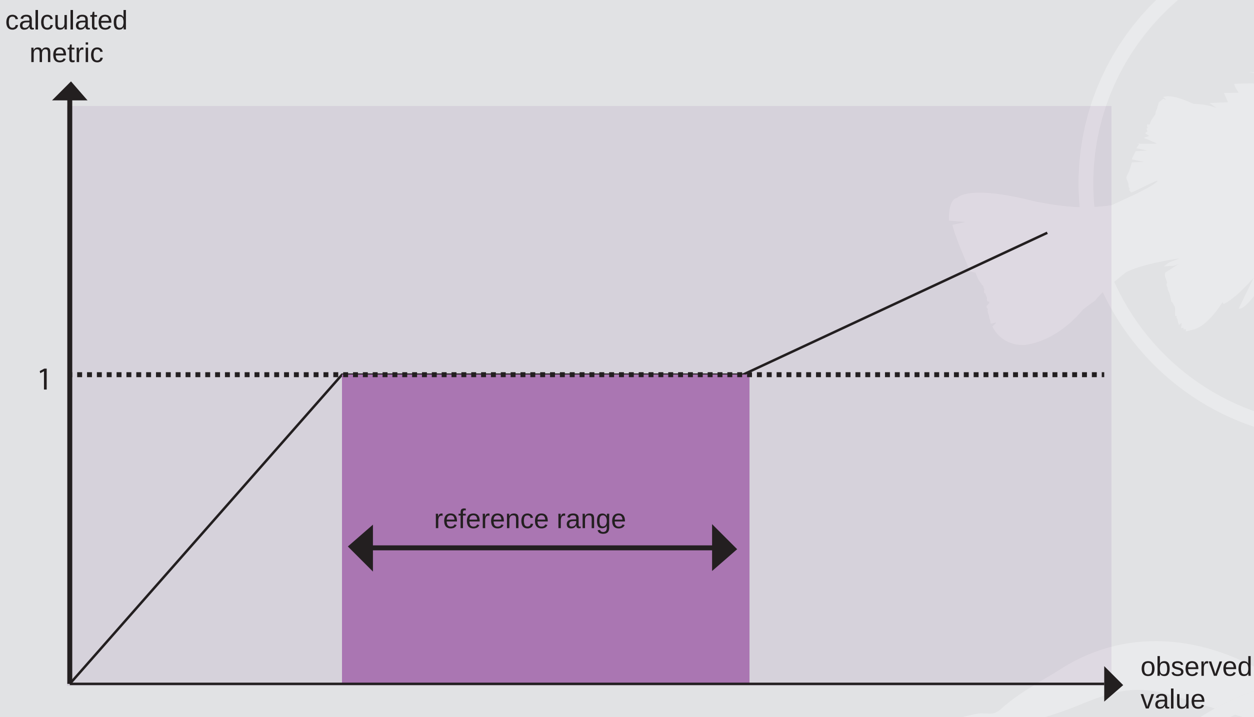


Figure 3.4. Method of calculating channel geometry metric values based on a reference range.

3.6.5 Reference Condition for Physical Form

Reference values have been specifically modelled for each Physical Form variable, with the exception of Channel Sediment Depth and Floodplain Sediment Deposition.

SedNet-derived metrics

The Channel Sediment Ratio was calculated as the ratio of sediment load since European settlement divided by sediment load expected in the absence of European settlement and both were modelled using the sediment budget model SedNet (DeRose *et al.*, 2003). Channel Sediment Depth and Floodplain Sediment Deposition rates were also derived using the sediment budget model SedNet, with the metrics reported as absolute values.

LiDAR-derived metrics

Reference values for the remaining Physical Form variables were modelled specifically for the SRA 2 report (Stewardson, 2012). These were: mean and variability of bankfull channel width and depth; sinuosity; meander wavelength and bank angle variability. These reference values were modelled using Boosted Regression Trees or BRTs (Elith *et al.* 2006, 2008). This is a powerful statistical modelling technique, with the advantage that it does not require assumptions about the distribution of variables and the form of the relation between them. The models developed here mostly used variables compiled by Janet Stein (Australian National University), associated with each segment in the Australian Hydrological Geospatial Fabric Surface Network Stream Lines. Attributes included in this database characterise landscape attributes, climate, substrate, water balance, terrain, vegetation and anthropogenic disturbances (Wealands 2011). Flow alteration metrics from the Hydrology Theme were also used as input variables for the models—to represent changes in hydrology from Reference Condition.

Ideally, one might use data from reference sites, with little anthropogenic disturbance, to develop these models. However, it is difficult to find undisturbed sites, as channel changes have occurred throughout the Basin in response to historic catchment and river disturbances. Historic channel changes (e.g. as a result of mining activity or land clearance) can persist for many decades even after the cause of the disturbance has been removed. Instead, the models were calibrated using the observed channel variables derived from the LiDAR surveys of all sites sampled throughout the Basin (described above).

Table 3.8 Physical Form BRT modelling predictor variables.

Variable Name	Attribute description
CATANNRAIN	Catchment average annual mean rainfall
CATEROSIVITY	Catchment average rainfall erosivity R factor
SUBEROSIVITY	Sub-catchment average rainfall erosivity R factor
CONFINEMENT	Indicator of valley confinement
CATAREA	Catchment area
VALLEYSLOPE	Stream segment slope
CATRELIEF	Catchment relief
CATSLOPE	Catchment average slope
SUBSLOPE	Segment sub-catchment average slope
RUNANNMEAN	Annual mean accumulated soil water surplus
RUNMTHCOFV	Coefficient of variation of monthly totals of accumulated soil water surplus
STRELEMEAN	Elevation of site (AHD)
SCDI	Sub-catchment Disturbance Index
SFRDI	Segment Flow Regime Disturbance Index
FRDI	Flow Regime Disturbance Index
RDI	River Disturbance Index
IMF	Impoundments factor
LUF	Landuse factor
SUBPOPMEAN	Segment sub-catchment average population density
CATPOPMEAN	Catchment maximum population density
STR_MOD	Proportion of stream and valley that is modified land (i.e. not conservation)
SUB_MOD	Proportion of sub-catchment/catchment that is modified land (i.e. not conservation)
CAT_MOD	Proportion of catchment that is modified land (i.e. not conservation)
dv2q	U/S Dam volume divided by mean flow
MAF	Difference between the percentage of time that the reference and current mean annual flows are exceeded in the reference regime
LowFlow	Difference between the percentage of years that the reference and current 91.7% exceedance flows (for the full period) are exceeded by the annual 91.7 percentile flow in the reference regime
HighFlow	Difference between the percentage of years that the reference and current 8.3% exceedance flows (for the full period) are exceeded by the annual 8.3 percentile flow in the reference regime
FlowVariation	Ratio of coefficient of variation of flow in reference and current regime.

Development of a Reference Condition model for this SRA assessment is based on the premise that the physical form at a site can be modelled via a series of catchment-scale variables, both natural and disturbance, upstream of a site. A model was derived separately for each physical form variable that formed an input to a metric. The models can 'conceptually' be described as:

$$Y = \sum_p a_i X_i + \sum_p b_i D_i + C + e$$

where:
Y is the derived physical form variable at a site
Xi is the **i**th 'natural' geomorphic predictor variable (**i** = **1** to **p**)
Dj is the **jth** site disturbance metric (**j** = **1** to **q**)
ai, bi and **C** are model parameters
e is an error term.

These parameters can be used to estimate the physical form variable under Reference Conditions at a site by setting *Dj = 0*.

Data for the construction of the BRT models were those compiled by Janet Stein (Australian National University) and associated with each segment in the Australian Hydrological Geospatial Fabric Surface Network Stream Lines. Details of the relevant variables can be found in Stein *et al.* (2002) and Wealands (2011). Measures of human disturbance were extracted from this database or assembled from Bureau of Rural Sciences land use mapping. A range of variables were selected that quantified 'natural' geomorphic/ landscape drivers and the degree of human disturbance that might be expected to influence channel morphology (Table 3.8).

Disturbance metrics can relate to the entire catchment upstream of each site or relate to the local sub-catchment. All disturbance metrics varied from 0 (least disturbed) to 1 (most disturbed). The only exception was the 'Natural' attribute in the Stein stream layer attribute set, which refers to the proportion of the upstream catchment in a natural state.

Individual models were constructed using BRT modelling; details of the actual approach and methods applied for the SRA report 2 are provided in Stewardson 2012. BRT modelling is an ensemble approach for fitting statistical models which differs fundamentally from conventional techniques that fit a single parsimonious model. BRTs combine the strengths of two algorithms: regression trees (which are models that relate a response to their predictors by recursive binary splits) and boosting (which is an adaptive method for combining many simple models to give improved predictive performance). In BRT modelling, the final model chosen is a linear combination of many regression trees (~ 100's to 1000's), each displayed as a simple regression tree. The advantages of the BRT approach are that it can fit complex non-linear relationships, is not sensitive to outliers and has superior predictive performance to traditional modelling approaches (Elith *et al* 2008).

Reference BRT models were constructed for channel variables at each site with all the predictor variables that relate to anthropogenic disturbance being set equal to zero (i.e. no disturbance). Each channel geometry variable was calculated using an observed value obtained from either the LiDAR surveys or an infilled value.

One tenth of the data set was excluded from the calibration process. The final calibrated BRT models relate channel form to both natural landscape features and anthropogenic disturbances. Reference values were calculated for the excluded tenth of sites, using the calibrated models and setting the anthropogenic disturbances at these sites to zero. This procedure was repeated ten times, each time excluding a different set of sites, until reference values were derived for all sites. We refer to this procedure as Cross-Prediction Using Null Disturbance (CPUND) (Stewardson 2012). The models were also used to infill missing observations for the Current Condition.

As with any model, the BRT-CPUND procedure makes predictions with some error. A cross-validation procedure was used to calculate model errors for each variable at each site. We used these errors to model a reference range for each variable. So instead of a single reference value, we derived a range of values, which might be possible in the absence of European influence. This range was set for each valley using the model residuals for that valley only. The metric value was set equal to one if the observed value falls within this reference range (Figure 3.4).

3.6.6 Variables, metrics and indicators

The *Physical Form Index* (SR–PI) is comprised of four indicators:

- *Channel Form* which quantifies differences in overall form of the river channel relative to Reference Condition, based on measures of the mean and variability of channel depth and width, and of the sinuosity of the channel and the wavelength of meanders.

Table 3.9 Physical Form metrics and their interpretation.

Metrics	Interpretation and data source
Mean Bankfull Channel Width Mean Bankfull Channel Depth	The width and depth of the bankfull or active river channel are used to assess the size of the river channel in a cross-sectional dimension and these data are obtained from LiDAR surveys.
Bankfull Channel Width Variability Bankfull Channel Depth Variability	Variations in bankfull widths and depths along a reach are used to assess reach variability of the size of the river channel and these data are obtained from LiDAR surveys.
Sinuosity Meander Wavelength	Sinuosity and meander wavelength of sites are used to assess planform condition and these metrics are considered to indicate slower driving components of river resilience. These data were obtained from LiDAR surveys of the individual sites.
Bank Angle Variability	Variability in the morphology of the river banks are assessed here through noting changes in the variability of bank angles and bank concavity. These data are obtained from LiDAR surveys.
Channel Sediment Ratio Channel Sediment Depth	Fine and coarse sediment loads are used to assess the sediment budget of river reaches and these data were obtained from SedNet.
Floodplain Sediment Deposition	This is the predicted mean annual deposition of fine sediment on the floodplain resulting from anthropogenic activities. These data were obtained from SedNet.

- *Bank Dynamics* which quantifies changes in the variability of river banks relative to Reference Condition, based on river bank angles.
- *Bed Dynamics* which quantifies changes in the river bed sediment regime relative to Reference Condition, based on the modelled sediment load entering a reach and accumulated sediment depth in the channel.
- *Floodplain* which quantifies changes in sediment deposition rates on the floodplain relative to Reference Condition.

The full list of SRA Physical Form metrics and sub-indicators that are inputs to the four indicators is provided in Table 3.9 along with their interpretation. All metrics are the ratio of the observed value and the reference value, with the exception of the metrics for Floodplain and Channel Sediment Depth, which are modelled absolute values.

Three other metrics were also derived: river channel slope, variability in channel depth and river bank complexity. These were removed from the final Physical Form assessment due to poor statistical performance of the relevant BRT reference models. Several other variables were also developed but rejected due to poor statistical performance or inconsistency (Stewardson, 2012).

All metrics were estimated for all zones, with the exception of floodplain deposition, which was only calculated for the Darling and Lower Murray valleys and all valleys with a Lowland zone.

The conceptual relevance of each metric and sub-indicator and their methods of calculation are summarised below.

Mean Bankfull Channel Width metric

This is one of two metrics that report on the size of the river channel by comparing the Mean Bankfull Channel Width calculated from typically 19 cross-sections obtained from LiDAR data (the current state) with that obtained from a Reference Condition BRT model. Any differences in width can generally be attributed to changes in the flow and sediment regimes of the river system.

Mean Bankfull Channel Width is calculated as:

$$\bar{W} = \exp\left(u\left[\ln W_{1..m}\right]\right) = \exp\left(\sum_{i=1}^{m} \frac{\ln\left(W_1\right)}{m}\right)$$

where W_1 = width of a transect, and m is the number of transects at a site.

Mean Bankfull Channel Depth metric

River channels can adjust their size in response to changes in flow and sediment regimes through either reducing or enlarging their width, depth or both. The cohesive nature of sediments contained in the banks of many Basin rivers often make them resistant to change; and thus changes in bankfull depth can be expected with changes to the flow and sediment regime. *The Mean Bankfull Channel Depth* metric was derived in the same manner as for the Mean Bankfull Channel Width except it is derived as the ratio of the current mean bankfull depth values, obtained from 19 LiDAR transects obtained from the LiDAR to the reference Mean Bankfull Channel Depth metric (Terranean Mapping Technologies, 2010).

Bankfull Width Variability metric

Variability in physical character is a feature of Australian river systems, in response to highly variable flow and sediment regimes. The *Bankfull Width Variability* metric is one of two metrics that assess variation in the dimensions of the river channel at a site. It is the ratio of the coefficient of variation of 19 bankfull observed widths (obtained from the LiDAR survey) to the coefficient of variation derived for the site by the relevant Reference Condition BRT model.

Bankfull Width Variability
was initially calculated as follows:

$$\sigma(\ln W)=\sqrt{\frac{\sum_{i=1}^{m}\left(\ln W_i-\overline{\ln W}\right)^2}{m}}=\sqrt{\frac{\sum_{i=1}^{m}\left(\ln\frac{W_i}{\overline{W}}\right)^2}{m}}$$

where Wi = width of a transect, and
m is the number of transects at a site.

Bankfull Depth Variability metric

The *Bankfull Depth Variability* metric is also a useful surrogate for variations in the physical character of a river channel at a site. The calculation of this metric was essentially the same as for the Bankfull Width Variability metric, and is derived via the ratio of the current coefficient of variation of 19 bankfull observed depths (obtained from the LiDAR survey) to the coefficient of variation derived for the site by the relevant Reference Condition BRT model for channel depth.

Channel Sinuosity metric

Rivers are also able to adjust their planform character in response to changes in governing processes. Planform adjustments involve changes to sinuosity, defined here as the ratio of river channel length to valley length, and also meander wavelength—the distance between meander bends. In a resilience context, adjustments in planform are considered to represent slower responding adjustments to changes in flow and catchment conditions. Changes in sinuosity reflect changes in flow energy and sediment regimes, and relate to changes in channel and hydraulic complexity and to habitat diversity. A reduction in sinuosity involves channels getting straighter, and an increase involves greater convolution of the channel. The *Channel Sinuosity* metric was calculated as the ratio of the observed channel sinuosity (obtained from LiDAR survey data) to that calculated from the Reference Condition BRT model for channel sinuosity. The observed channel sinuosity was the ratio of actual river length to the valley length of the reach. Index values less than 1 (<1) represent a river channel straighter than Reference Condition, whereas values greater than 1 (>1) imply a more sinuous river channel.

Channel Meander Wavelength metric

The *Channel Meander Wavelength* metric is also a measure of a slower river channel response. Changes in meander wavelength reflect changes in flow energy and sediment regimes, and relate to changes in channel stability and complexity and to habitat diversity. The meander wavelength metric is the ratio of current meander wavelength to that calculated from the relevant Reference Condition BRT model. Current meander wavelength values were initially derived from the site LiDAR survey and calculated as the ratio of the reach length to number of bends contained within it.

This was sometimes difficult to derive, as wavelengths in upper catchment reaches sometimes exceeded the preset LiDAR study site length. In these cases, derivation of reference meander wavelengths was based upon the empirical approaches of Langbein and Leopold (1966) and Williams (1986). Meander length was estimated using the angle between the flow direction at a given point and changes in the regional stream flow path with reach distance, to produce a sinusoidal relationship. A meander length was estimated by numerically fitting a sine function to this relationship.

Bank Angle Variability metric

The morphology of river channel margins, especially of river banks, has a significant role in a number of important ecosystem processes. River banks provide habitat and act as refuge for fish, invertebrates and aquatic plants during times of flood and low-flow. River bank morphology also influences channel roughness and therefore has a direct influence on flow conveyance and the sediment retention along river reaches. Research on Basin rivers has demonstrated that river reaches with a more complex and variable river channel margin are able to trap and store organic carbon supplied from the riparian zone. This organic carbon has an important role in river system food webs. Variation in bank angles for the bankfull channel are used here as a surrogate measure for the state of the river channel margin. The *Bank Angle Variability* metric was calculated as the ratio of the coefficient of variation in bank angle for 19 cross-sections at a site obtained from LiDAR survey data (from both left and right banks, i.e. 38 observations per site) to that obtained using the BRT reference model for this metric.

Bank Concavity Variability metric

The state of river banks was also assessed using a measure of variations in bank concavity at a site. A bank concavity variable was determined as the coefficient of variation of:

$$[\ (\text{Concave} - \text{Convex})/\text{Bank Height}\ ]$$

where *Concave* and *Convex* = the sum of bank profile areas above and below the projected bank angle mid-line, respectively, for each bank at each transect.

The *Bank Concavity Variability* metric was calculated as the ratio of the coefficient of variation in bank concavity for 19 cross-sections at a site obtained from LiDAR survey data (from both left and right banks, i.e. 38 observations per site) to that obtained using the BRT reference model for this metric.

Channel Sediment Ratio metric

Conceptually, natural river reaches are in equilibrium—or attain a form of stability—when the input and output of sediment within a reach are equal. The accumulation and load of fine and coarse sediment in the channel was assessed for the Basin using the SedNet model (DeRose *et al.* 2003), and these metrics jointly contribute to the Bed Dynamics indicator. The *Channel Sediment Ratio* metric is the ratio of current fine sediment yield in kilotons/yr (the SedNet output variable FSEDOUT_KT/Y) to the natural (reference) sediment yield (the SedNet output variable NFSEDOUT_KT/Y).

Channel Sediment Depth metric

The *Channel Sediment Depth* metric is the absolute value of the depth of coarse sediment deposited within a river reach under current conditions (as modelled by SedNet). A limitation of the SedNet model is that it cannot yet account for channel erosion, and therefore the reference depth of sediment deposition used here is zero. This metric represents the average depth of coarse sediment deposition within the SedNet stream link, in metres. The corresponding SedNet output variable is CSEDDEPTH_M.

Floodplain Sediment Deposition metric

The accumulation of sediments on floodplain surfaces is a process that occurs during overbank flows and the resulting inundation. It has significant influence on the physical character of the riverine landscape and floodplain ecosystem processes. Rates of floodplain sedimentation can influence the physical structure of the river channel. During periods of inundation there are exchanges of sediment and sediment-associated nutrients between the floodplain and river channel. Rates of pre- and post-European floodplain sedimentation have been determined in a number of studies of rivers within the Murray–Darling Basin. All demonstrate a significant increase in the accumulation of sediment since European occupation, associated with catchment land use changes. The *Floodplain Sediment Deposition* metric is the ratio of the current fine sediment yield to the floodplain in kilotonnes/yr (the SedNet output variable FPDEP_KT/Y) for each Sednet link to the natural (reference) sediment yield. For this metric, values over 5 kt/yr were regarded as extreme.

3.6.7 Integration and aggregation methods for Physical Form

For each valley and zone, Expert Systems are used to combine, or integrate, the SRA Physical Form metrics to a single *Physical Form Index (SR–PI)*. This index is calculated from indicators related to Channel Form, Bank Dynamics, Bed Dynamics for all zones and, for the Lowland zone, an indicator of floodplain condition. Relationships between metrics, sub-indicators, indicators and the SR–PI index are shown in Table 3.10, and the Expert System definition tables used as the basis for the integration are provided in Appendix 1.

All metrics and indicators (derived only from LiDAR-derived survey data) were spatially aggregated across all LiDAR-surveyed sites using a combination of length-weighted and simple averaging. Aggregation from the zone to the valley scale was then by weighted averaging of zone values, using the total stream length within each zone as weights (where stream lengths are represented in the AusHydro digital river network).

The four indicators were combined, using Expert Systems, to yield SR–PI scores for each zone and valley. Scores are scaled from 0 to 100, where 100 represents Reference Condition.

Confidence limits in SR–PI, indicators, sub-indicators and metrics are derived using the bootstrapping method described in Section 2.4.

The Physical Form Condition Index Expert Systems, used to integrate the indicators to form the SR–PI score, reflect the premises that:

- Changes in channel form, bed dynamics and bank dynamics are sensitive indicators of the overall physical condition of a river system, reflecting changes in a number of key underlying processes.
- Changes in channel form and bank dynamics have a greater influence on the overall physical condition rating than bank dynamics in slopes and lowland zones; whereas substantial changes in bed dynamics are seen to reflect major process changes in the upland and montane zones.
- Floodplain physical condition forms a major component of the overall condition assessment of river systems in lowland zones, but has little influence in slopes, upland and montane zones where only pocket floodplains exist.
- For this report we could only use a surrogate measure of change in rates of sediment deposition derived from SedNet modelling. We cannot place a high degree of confidence in the significance of small to moderate changes in this measure. Large changes in channel form and bank dynamics indicator values were therefore still treated as slightly more sensitive indicators of physical condition for lowland zones than large changes in the floodplain indicator values.

Thus, a very low SR–PI score would indicate extreme changes in channel form, bank dynamics and bed dynamics (reflected in substantial decreases and/or increases in mean channel depths, channel sediment loads and depths, variability in channel width and bank angles and in channel wavelength and sinuosity). For lowland zones a very low SR–PI score would also indicate substantial increases in floodplain sedimentation rates. A high score would mean that channel and floodplain dimensions and dynamics are essentially intact and comparable to Reference Conditions under the existing climatic conditions.

Table 3.10 SRA Physical Form Index (SR–PI) and contributing metrics, sub-indicators and indicators.
Integration proceeds from left to right.

Metrics	Sub-indicators	Indicators	Index
Channel Sediment Ratio		Bed Dynamics	Physical Form Condition, SR–PI
Channel Sediment Depth			
Mean Channel Width	Mean Cross-section Form	Channel Form	
Channel Mean Depth			
Channel Width Coefficient of Variability	Cross-section Form Variability		
Channel Depth Coefficient of Variability			
Channel Sinuosity	Channel Planform		
Channel Meander Wavelength			
Channel Slope	Channel Slope		
Longitudinal Bank Variability		Bank Dynamics	
Mean Bank Complexity			
Floodplain Sediment Deposition		Floodplain Form	

3.7 Hydrology

3.7.1 Background

The Hydrology Theme assesses the temporal and spatial pattern of streamflow (or 'flow regime') at sites throughout the Murray–Darling Basin. The Theme provides sensitive measures of hydrological condition from an ecological viewpoint, a means for comparisons between rivers and a context for observations of ecosystem components like fish, macroinvertebrates and vegetation. The Hydrology Theme is a natural complement to the Physical Form Theme. In combination, physical form and hydrology determine the spatial distribution of water and hydraulic conditions that are critical controls on biogeochemical processes and availability of habitats and materials (e.g. nutrients) for freshwater biota.

3.7.2 Data sources

In the previous SRA assessment (SRA report 1), the Hydrology Theme could only provide a report on the status of a small (non-random) sample of sites within each valley. These were sites where data could be provided using available water resource models, and mostly located on larger rivers. As a result, the SRA report 1 Hydrology Theme assessment did not attempt to report quantitatively aggregated hydrological status at the zone or valley scale.

The situation has improved for this report. We now assess flow alteration throughout the mainstem rivers across the Basin and aggregate the scores for these rivers at the zone, valley and Basin scales. These mainstem rivers are defined as rivers explicitly represented in the water resource models used for development of the Basin Plan (Figure 3.5). We also now assess effects of farm dams and woody cover change in all smaller *headwater* streams (defined by an upper catchment area threshold of 100 km^2). An important feature of this Hydrology Theme assessment is the separate treatment of mainstem rivers and headwater streams and the different data sources used for each of them.

Unfortunately it is still not possible to assess flow alteration in the many mid-size tributaries—defined as all streams with a catchment area greater than 100 km^2— that are not represented explicitly in the water resource models. Private diversions, smaller impoundments and groundwater extractions can significantly alter flow regimes in these tributary streams. For SRA report 2 we have no adequate data to assess hydrological alteration in these mid-size tributaries. An investment in water resource model development and spatial disaggregation of water-use data is required to address this shortcoming.

A major improvement in the SRA Hydrology Theme has been to extend the Reference Condition modelling for headwater streams to represent conditions under natural woody cover and without farm dam impacts. In the earlier report, these impacts were mostly retained within reference data and hence influenced the quantification of Reference Condition.

Four data sources have been used in this Hydrology Theme assessment (Table 3.11):

1. water resource modelling
2. farm dam modelling
3. 'forest' (woody plant) cover modelling
4. streamflow gauge records.

The water resource, farm dam and land cover modelling data are used for assessing current hydrological status and condition. The streamflow gauge data are only used for analysis of trends and temporal patterns in measures of hydrological condition.

The hydrological assessment for headwater streams accounts for (i) farm dams; and (ii) catchment woody plant cover change. For each headwater reach, these hydrological disturbances are evaluated separately and then accumulated to represent their combined effect. The effects of groundwater use and any private diversions in smaller streams (<100 km^2 catchment area) are neglected

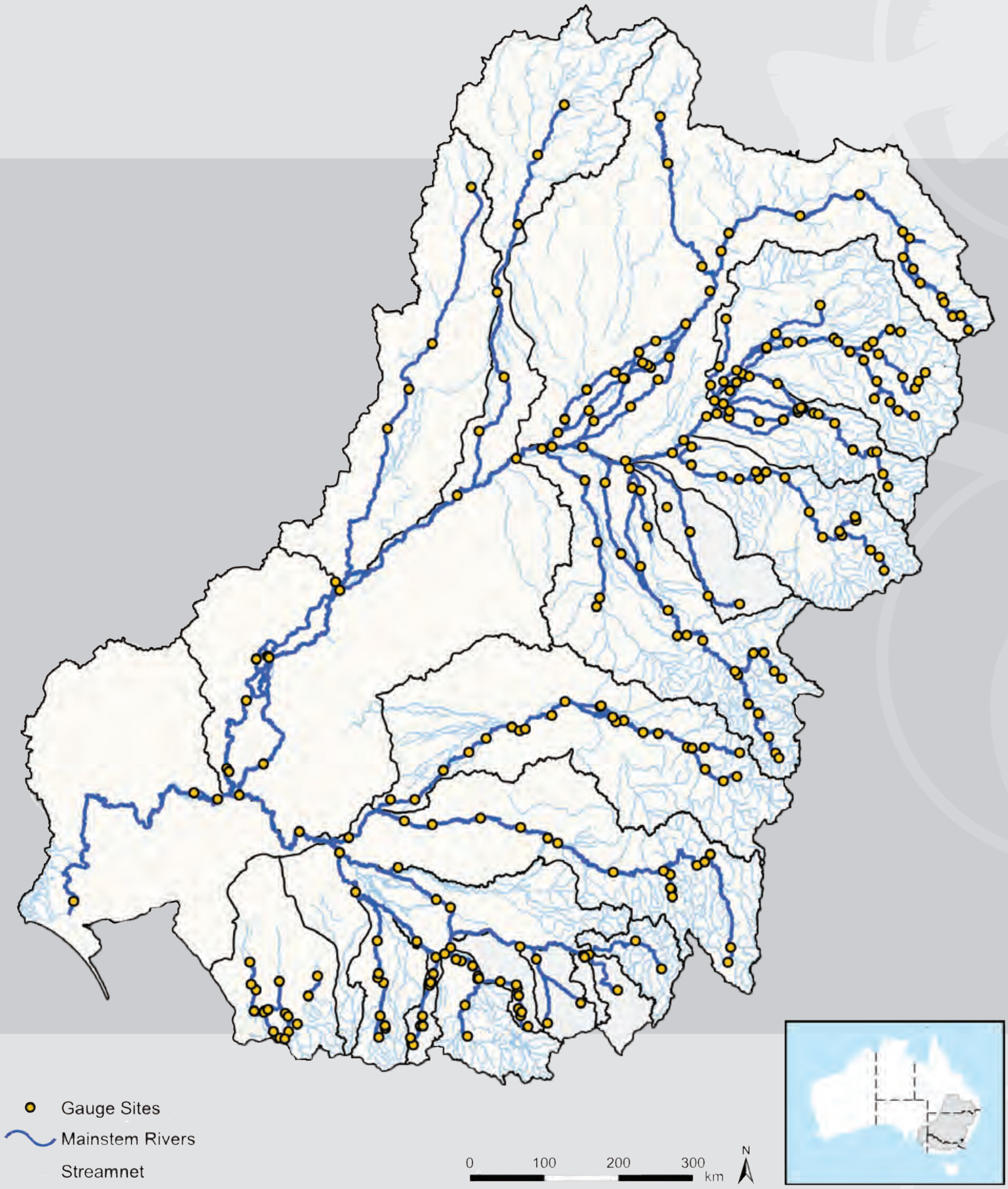


Figure 3.5. Map of mainstem rivers assessed in the SRA using state flow models.

Table 3.11 Data sets used in the Hydrology Theme for SRA report 2.

	Gauge data	Water resource modelling output	Farm dam modelling metrics	Land cover modelling metrics
Type of data	Streamflow time-series	Streamflow time-series	Flow stressed ranking (FSR) metrics	Flow stressed ranking (FSR) metrics
Spatial sample and coverage	45 gauging sites throughout mainstem rivers	Water resource model nodes*	All reaches in AusHydro** network	All reaches in AusHydro** network
Temporal sample and coverage	Monthly streamflow for the period (1997–2008)	Monthly data for Victoria and daily data elsewhere, for the period July 1895–June, 2009	FSR metrics apply to an unspecified multi-decadal period	FSR metrics apply to an unspecified multi-decadal period
Scenarios	Observed streamflows	Current management and pre- water resource development	Based on current development referenced to flows in the absence of farm dams	Based on current development referenced to flows in the absence of post-European settlement woody cover change
Source	Infilled streamflow gauge records***	Basin Plan modelling	SKM (2010a)	SKM (2010b)

* All reaches within AusHydro2 network that are within the coverage of the water resource modelling network have been assigned to one of these model nodes based on locations of tributaries and major points of flow regulation (SKM 2011).

** DEM-derived streamlines in the Australian Hydrological Geospatial Fabric Surface Hydrology product. Flow Stressed Ranking metrics were not estimated for the uppermost river link in the network because of computational limitations.

***Infilling was carried out by SKM using linear interpolation for short gaps, or regression with nearby gauges for longer gaps in the record.

for this analysis and will be minor in a large proportion of these streams.

The assessment for mainstem rivers accounts for major water resource developments and any other catchment disturbances included in the water resource models. The effects of major water resource developments are evaluated using the outputs of water resource models for two scenarios:

- The *Current Scenario*: current development and operational conditions under an historical climate (data drawn from Murray–Darling Basin Plan model run #580).

- The *Reference Scenario*: without development conditions under an historical climate (data drawn from Murray–Darling Basin Plan model run #566).

We refer to streamflow time-series modelled using these two scenarios as the *Current Flow Regime* and *Reference Flow Regime*. It should be noted that the Current Scenario does not include the influence of progressive development over time on the flow regime.

The water resource modelling outputs were produced during Basin Plan development. For these model simulations, the level of development for the entire simulation period is assumed to be the same as the calibration period (recent years). Model output was available at model nodes only. These nodes represent a set of specific locations in the stream network chosen for modelling purposes, and do not collectively provide a spatially unbiased and representative sample of the network. Hydrology Theme metrics calculated using data from these nodes were therefore interpolated throughout the modelled river network as a basis for evaluating zone and valley-wide conditions. The AusHydro digital river network was used for this purpose and metrics were assigned to each segment within the network (that was explicitly represented in the water resource models).

The Current Scenario is modelled using different modelling methods in each state and territory jurisdiction. Queensland and New South Wales mostly use the Integrated Quantity and Quality Model (IQQM) model; the MDBA uses the Murray Simulation Model—Big Model (MSM–BigMod) for the Murray; and Victoria uses the Resource Allocation Model (REALM). South Australia relies on the MSM–BigMod model for the Murray Channel, and uses four catchment models to monitor surface water in the Eastern Mount Lofty Ranges (EMLR). The different jurisdictions can also use different assumptions when representing the 'current' level of water resource development. SKM (2010c) tested for bias in these assumptions by comparing modelled flows under the current scenarios and the observed flows at streamflow gauges in each of the jurisdictions (for the last 15 years). In general, the Current Flow Regime indicated a greater departure from Reference Condition than the recorded flows in Queensland, reflecting the jurisdictional assumption of higher demands for assessment than the actual historical levels for that state. In Victoria, the Current Flow Regime shows less departure from Reference Condition than the recorded flows. This is likely due to the inclusion of recent improvements in environmental flow entitlements (in the modelled scenario) relative to the real historical situation. These inter-state differences were deemed acceptable and considered to reflect true differences in the current levels of water development.

Since SRA report 1, hydrological modelling for the SRA has been refined and extended to include the effect of farm dams on streamflows across the basin (SKM 2011a, b). The computer model STEDI (Spatial Tool for Estimating Dam Impacts) has been used to represent farm dam impacts at 162 streamflow gauging sites across the Basin, and was used to produce SRA Hydrology Theme *metrics*. These metrics were then extrapolated across the entire AusHydro digital river network using regression modelling. Farm dams were counted using Geoscience Australia's Waterbodies layer. This analysis was restricted to private dams that (i) intercept catchment runoff (or overland flow); and (ii) are not primarily filled using extractive water access rights from other water resources. Note that this excludes floodplain storages.

Modelling for this report has also been extended to represent and account for effects of woody plant cover change since European settlement (SKM 2011c). The model applied the Zhang *et al.* (2001) method which estimates the increase in catchment runoff due to changes in woody cover. The model was applied at a monthly time-step using a procedure developed by

Bren (2010). As with the farm dam modelling, woody plant cover impacts were assessed at the 162 streamflow gauging sites to produce the SRA Hydrology Theme metrics. These results were then interpolated across the entire Basin AusHydro network using regression models. Three datasets were adopted for estimating the current and pre-development tree cover:

- National Vegetation Information System (NVIS) pre-1750 vegetation v3.1
- National Vegetation Information System existing vegetation v3.1, with some modification by MDBA to infill unknown vegetation areas within the Basin using key land use categories derived from the BRS land use layer [Australian Government 2006].
- Woody vegetation cover data provided by the Department of Climate Change.

3.7.3 Reference Condition for Hydrology

In SRA report 1, the Reference Condition for the Hydrology Theme was based on modelling streamflow without the effects of major water resource developments; using the available water resource models. This approach is used again for modelling Reference Condition for the mainstem rivers in this SRA report. In some cases, these models account for effects of farm dams and possibly woody cover changes in modelling Reference Condition.

For the headwater streams, Reference Condition has been extended using models to remove effects of farm dams and post-European settlement woody plant cover change (mostly through tree clearing). This is very close to the SRA's standard definition of Reference Condition (i.e. conditions as they would be in the absence of significant human intervention). However, there may be some human effects still retained in the modelled reference data (e.g. private diversions upstream of the major water resource developments and any groundwater extractions that are not represented in river models).

3.7.4 Variables, metrics and indicators

The SRA uses the Flow Stressed Ranking (FSR) procedure for calculating hydrology metrics, with some modifications. This procedure was developed by SKM (2005a) to characterise the degree of hydrologic 'stress' relative to 'unimpacted' flow conditions. The FSR uses metrics calculated from analysis of daily or monthly streamflow series representing both the flow regime being assessed and Reference Conditions. Daily data are used for the mainstem rivers in valleys where the water resource model simulations uses a daily time-step. Monthly data is used for other valleys and for all headwater streams. The formulation of the metrics varies, but all indicate the extent to which the Current Flow Regime has departed from the Reference Flow Regime.

SKM (2004a, 2005a, b) initially proposed ten FSR metrics, based largely on their perceived ecological significance. The first SRA report used only six of these original ten FSR metrics. This decision was based on SKM's (2005b) recommendation that correlation between the original ten meant that some metrics were redundant. However, subsequent consideration and testing in Tasmania showed that the pattern of correlation between FSR metrics varies in different regions (Maunsell Australia, 2009), and that all metrics are required. Based on this, the SRA analysis in this report has been expanded to include nine of the original ten FSR metrics (see Table 3.12). The Flow Duration metric is reported but not used in the analysis because it is highly correlated with the Mean Flow metric and interpretation of this metric was difficult.

The first SRA report used one additional metric (the Median Annual Discharge metric) developed specifically for the SRA. This is not used in the current reporting because changes in median discharge are adequately represented by SKM's (2005b) Flow Duration metric.

None of the original FSR metrics represent alterations in the flood regime because the SKM (2005a) study used monthly data, which is inadequate for characterising flood spells in most streams. Likewise, the low-flow and high-flow spells metrics presented a problem with monthly data. Daily data are now available for much of the Murray–Darling Basin mainstem rivers and consequently four metrics have been added in this SRA report to characterise the flood regime. Unfortunately water resource modelling in Victoria provides monthly streamflows and these flood metrics could not be calculated for the Victorian portion of the Basin. Similarly, flood metrics were not calculated in the farm dam and land cover modelling because a monthly time-step was used. Hence these metrics are only available for the network represented in the water resource models, excluding Victoria.

The full list of SRA Hydrology metrics is shown in Table 3.12, with their interpretation.

A feature of the original FSR procedure is that changes in flow characteristics relative to the Reference Flow Regime provide the same metric value, regardless of whether this is the result of an increase or decrease in the flow variable being considered. If flow is unaltered from Reference Condition, the metric takes a value of one. In the original formulation, any change in flows relative to Reference Condition produces a reduction in the metric value from the maximum value of one (1). In some cases, increasing and decreasing flows will have quite different (and sometimes opposite) effects. For example, the consequences of a 50% reduction in flood frequency will be entirely different from a 50% increase. For this reason, all the FSR metrics (except the Seasonal Period metric) have undergone a minor revision for this report to allow differential reporting and interpretation of directional change in flow conditions. In general, these revised formulations provide values less than one (<1) where they are the result of flow reductions or greater than one (>1) if they are the result of flow augmentation (Table 3.12).

All SRA Hydrology metrics are calculated using data for the full calendar year. Elsewhere, seasonal versions of FSR metrics have been calculated by restricting the calculation to streamflow data for particular months. Preliminary analyses showed that these seasonal versions of FSR metrics were highly correlated with annual versions, and are therefore excluded from SRA reporting to simplify the assessment. In addition, the two FSR metrics relating to flow seasonality (Flow Seasonal Period metric and Flow Seasonal Amplitude metric) specifically assess changes in the seasonal flow pattern.

It is important to understand the time period being considered for this SRA assessment of status in the Hydrology Theme. The other SRA Themes use a direct observation of Current Conditions for their assessments. For the Hydrology Theme, reporting streamflow on a given day—or even flow over a three-year period—is highly sensitive to climate-driven variations in hydrology. So, in contrast to the other Themes, the Hydrology Theme uses metrics calculated from model runs corresponding to the period 1895 to 2009 for the mainstem rivers; and approximately the last 40 years for the headwaters streams.

Importantly, these models have used the current (i) levels of water resource development, (ii) farm dam densities and (iii) woody plant cover applied for the entire period of simulation. The resulting FSR metrics are based on the current level of development across a range of climatic conditions in order to fully characterise the nature of changes in the hydrological regime. The actual 'historic' flow regime status over the period of record may differ from this Current Scenario, particularly where major changes in water management arrangements have occurred in recent decades.

For status reporting of condition in the headwater streams we use two data sources (Table 3.11): (i) farm dam modelling and (ii) woody plant cover modelling. Each provides component FSR values for these different human disturbances. To evaluate the integrated hydrological condition, these two component scores need to be accumulated into an integrated FSR score. Several approaches were tested for this accumulation procedure (SKM, 2011a, b). Based on this testing, the component scores are accumulated based on a simple addition.

Table 3.12 SRA Hydrology metrics and interpretation.

Metric	Interpretation	Interpretation if metric >1
Flow Seasonal Amplitude	Change in the amplitude of seasonal flow variations (range standardised)#	Amplitude has increased from Reference Condition
Flow Seasonal Period	Change in the timing of annual peak and minimum monthly flows.	Not applicable
Flow Variation	Change in flow variability (characterised by the coefficient of variation of flow)	Flow variation has increased from reference
Mean Annual Flow	Change in the mean flow (range standardised).	Mean flow has increased from reference
Flow Duration*	Change in flow distribution (range standardised).	Flows have generally increased from reference
High Flow	Change in magnitude of high flows – defined as flows that are exceeded ~10% of the time (range standardised)	High flows have increased from reference
High Flow Spells**	Change in the duration of high flow spells (range standardised)	Durations of high flow spells have decreased from reference
Low Flow	Change in magnitude of low flows—defined as flows that are exceeded—90% of the time (range standardised)	Low flows have increased from reference
Low Flow Spells**	Change in the duration of low flow spells (range standardised)	Durations of low flow spells have decreased from reference
Zero Flow Proportion	Change in the proportion of zero flow days	The proportion of zero flow days has decreased
OB Flow Duration (ARI 1)**	Change in the cumulative duration of floods exceeding the 1-year ARI peak, using the partial duration series	Flood durations have increased
OB Flow Spells (ARI 1)**	Change in inter-flood duration (ARI = 1 year) (range standardised)	Inter-flood durations have decreased
OB Flow Duration (ARI 8)**	Change in the cumulative duration of floods exceeding the 8-year ARI peak, using the partial duration series	Flood durations have increased
OB Flow Spells (ARI 8)**	Change in inter-flood duration (ARI = 8 years) (range standardised)	Inter-flood durations have decreased

* The Flow Duration metric is reported but not used in the calculation of zone and valley Hydrology indices.

** These metrics are only calculated if daily data are available.

\# 'range standardised' refers to metrics which measure change relative to natural inter-annual variability. For these metrics, greater flow alteration is indicated with increasing departure from the normal range of conditions experienced under Reference Conditions.

Opportunities for further improvement in the Hydrology Theme are discussed in Section 7.

3.7.5 Integration and aggregation methods for Hydrology

For each reach (and gauging site), Expert Systems are used to combine, or *integrate*, the SRA metrics to a single Hydrology Index (SR–HI). This index is calculated from sub-indices related to the In-Channel Flow Regime and Over Bank Flow Regime in lowland zones; and from just the In-Channel Flow Regime elsewhere. The relationships between metrics, sub-indicators, indicators, sub-indices and the SR–HI Index are shown in Table 3.13, and the Expert System definition set tables used as the basis for the integration are summarised in Appendix 1.

Results for all stream reaches are *aggregated*—separately for the mainstem and headwater regions of the stream network—to the zone and valley scale, using a length-weighted average; where length refers to the length of the river reach (as represented by segments in the AusHydro digital river network). This procedure produces two aggregated index values at the zone or valley scales: one each for headwater streams and mainstem rivers. These two index values are combined to calculate the final zone- or valley-scale Hydrology Condition Index (SR–HI).This is done using a simple rule set, in which only mainstem values are used for the Lowland zones, headwater values are used for the Montane zones, a combination of both mainstem and headwater values are used for the Slopes and Upland zones and the combination of mainstem and headwater indices is used at the valley-scale (see Appendix 1).

Indicator and Index scores are scaled from 0–100, where a score of 100 represents Reference Condition. Their interpretation is described in Section 2.4.

The *Hydrology Condition Index* Expert Systems, used to integrate the two sub-indices to form the SR–HI score, reflect the premises that:

- The in-channel flow regime, reflecting changes in volumes, regimes of high- and low-flow events, and the seasonality and variability of flows; is key to all physical and biological processes occurring within the river channel system.
- The hydrology of the floodplain (for which we use the overbank flooding regime as a surrogate but which should ideally include aspects of watering patterns and hydraulics) drives both the biophysical processes on the floodplain and also the connectivity across floodplain and channe systems.

Thus, a very low SR–HI score would indicate extreme changes (both loss and substantial increases) in flow volumes, variability, timing and occurrence of key events, coupled with extreme changes (both decreases and increases) in patterns of floodplain watering and channel–floodplain connections. A high score would mean that the in-channel flow and floodplain flooding regimes are essentially intact and comparable to Reference Conditions under the existing climatic conditions.

3.7.6 Analysis of temporal patterns

This second SRA report introduces reporting on trend for three Themes (Section 6). For the Hydrology Theme it is possible to use long-term streamflow records to report on fluctuations in hydrologic conditions over the full period of record. However, we chose here to analyse recent trends in hydrological conditions using a 12-year period—from 1998 to 2009. For this analysis we use actual gauged streamflows. Unlike the modelled flow data used for current status reporting, these gauged data show effects of time-varying water entitlements, farm dam development and woody plant cover change.

We analyse temporal patterns using 3-year non-overlapping time-slices for this 12-year period. FSR metrics are calculated for each three-year period using the long-term modelled natural flows as the Reference Condition. For clarity we refer to these as 3yr_FSR metrics. To illustrate this calculation

Table 3.13 SRA Hydrology Index (SR–HI) and contributing metrics, sub-indicators, indicators and sub-indices.

Metrics	Sub-indicators	Indicators	Sub-Indices	Index
Mean Annual Flow	Flow Gross Volume	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
High Flow	High Flow Events	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
High Flow Spells	High Flow Events	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
Low Flow	Low and Zero Flow Events	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
Low Flow Spells	Low and Zero Flow Events	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
Zero Flow Proportion	Low and Zero Flow Events	In-channel Flow Regime A (Volume and Flow Events)	In-channel Flow Regime	Hydrology Condition, SR–HI
Flow Seasonal Amplitude	Flow Seasonality	In-channel Flow Regime B (Seasonality and Variability)	Over Bank Flow Regime	Hydrology Condition, SR–HI
Flow Seasonal Period	Flow Seasonality	In-channel Flow Regime B (Seasonality and Variability)	Over Bank Flow Regime	Hydrology Condition, SR–HI
Flow Variation	Flow Variability	In-channel Flow Regime B (Seasonality and Variability)	Over Bank Flow Regime	Hydrology Condition, SR–HI
Over Bank Flow Duration (ARI 1)		Over Bank Floods, Low *	Over Bank Flow Regime	Hydrology Condition, SR–HI
Over Bank Flow Spells (ARI 1)		Over Bank Floods, Low *	Over Bank Flow Regime	Hydrology Condition, SR–HI
Over Bank Flow Duration (ARI 8)		Over Bank Floods, High **	Over Bank Flow Regime	Hydrology Condition, SR–HI
Over Bank Flow Spells (ARI 8)			Over Bank Flow Regime	Hydrology Condition, SR–HI

Note: * only relevant to the Lowland, Upland and Slopes zones; ** only relevant to the Lowland zone.

consider the Flow Variation metric for the three year time-slice which is calculated as:

$$\text{Flow Variation}_{3yrs} = CV_{a\_3yrs}/CV_r$$

where CV_{a_3yrs} and CV_r are the coefficient of variations for the monthly flow series for the flow scenario being assessed (a) and the reference flow scenario (r) respectively.

For the calculation of the 3yr_FSR metric, the flow scenario being assessed is the recorded flows for the three-year period and the reference flow scenario is the modelled unimpacted flows for the entire period of record.

Departures from reference in these metrics will be produced by: (i) human disturbances; and (ii) weather conditions for each period. In the recent drought, we would expect these 3yr_FSR metrics to show a departure from the long-term natural flows, regardless of water resource developments. We correct for this by using a 'reference' version of the 3yr_FSR metrics using the Reference Flow Regime for the three-year period. In this case, the reference value of the Flow Variation metric is given by:

$$\text{Flow Variation}_{ref\_3yrs} = CV_{r\_3yrs}/ CVr$$

where CV_{r_3yrs} is the coefficient of variation derived from the modelled monthly unimpacted flows for the 3-year period.

This 'reference' version of the 3yr_FSR metrics quantifies the departure from Reference Conditions (long-term modelled natural flows) that would have occurred in the absence of water resource development. So, two versions of the 3yr_FSR metrics are used: (i) calculated using the recorded streamflows; and (ii) calculated using the Reference Flow Regime.

Our analysis of trends uses the ratio of these (recorded divided by reference), i.e.

$$\text{Flow Variation}_{trend\_analysis} = \text{Flow Variation}_{3yrs} / \text{Flow Variation}_{ref\_3yrs}$$

In this case (where the FSR metric is based on ratios) the resulting metric for trend analysis can be simplified to :

$$\text{Flow Variation}_{trend\_analysis} = CV_{a\_3yrs} / CV_{r\_3yrs}$$

However, the other metrics do not use a simple ratio and the resultant equations are more complex.

This approach to calculating 3-year metrics for trend analysis was discussed soon after the SRA 1 report was completed and agreed in consultation with the Hydrology Technical Advisory Group active at that time. The need for testing this refined approach was recognized since it was a development on the original and now widely accepted FSR metrics.

We successfully tested this ratio for a statistically significant linear trend of either increasing or decreasing level of flow alteration over the 12-year assessment period. We used a two-tailed test of significance with significance level of $p = 0.2$, a higher probability than might be used in a purely scientific investigation. We did this to balance the chance of failing to observe a real trend (Type II error) and incorrectly identifying a trend (Type I error). This analysis was performed on 45 streamflow gauges located on mainstem rivers. These were selected based on: (i) achieving a good coverage across the SRA valleys; (ii) availability of reference flow series derived from water resource models; and (iii) availability of reliable streamflow records.

The trend assessment in this report discusses metrics that show an increasing or decreasing level of flow alteration over the 12-year period. The trend direction (i.e. increasing or decreasing) is not as important as whether this is an increasing or decreasing departure from the Reference Flow Regime (e.g. as a result of water management, independent of drought effects).

3.8 Integration across Themes: River Ecosystem Health

3.8.1 Background

One of the aims of the SRA Audit is to provide an integrated view of the state of the river ecosystem. This is done by providing separate descriptions, quantitative data and assessments of the condition of five key components, all represented by Themes.

Results for the biological themes are then also integrated to produce a rating for River Ecosystem Health. This integration is based on the following concepts:

- Ecosystem Health reflects the state or condition of a number of key ecosystem components and processes.
- The condition of riverine biota is a key measure of the health of a river ecosystem.
- This condition is strongly influenced by a range of biological and physical processes which are in turn affected by a range of natural and anthropogenic (human) influences.
- The hydrological and sediment regime of the river system and the physical form of channels and floodplains are all key aspects of a river system whose condition is affected by anthropogenic disturbances but also in turn affect river ecology.
- The condition of riverine biota should largely reflect the historical (recent to longer term) influences of changes in the condition of the hydrological regime and the river's physical form (though some lagged responses may become apparent only in the longer term).

ISRAG is well aware that this audit assessment does not include measures for a number of key processes that underpin a healthy or resilient riverine ecosystem. The capacity and resources to routinely assess these processes across the Basin are still unavailable without further investment. Nor do the current Themes represent the full suite of components of interest (e.g. birds, wetlands). In addition, as explained in Section 3.2, our capacity to assess the five key components (Themes) of this Audit in a consistent and comprehensive manner remains limited by data quality and availability and by resources.

These issues underpin the relatively simple method of deriving Ecosystem Health ratings in this audit report.

3.8.2 Aggregation and integration methods for River Ecosystem Health

Expert Systems were used to convert values of SR–FI, SR–MI and SR–VI, to yield a river *Ecosystem Health Index* score (SR–EI, Table 2.2). Values of SR–EI range from 0–100, where 100 is equivalent to Reference Condition for all three Theme scores.

The Index Expert Systems, hence values of SR–EI, are based on the premise that changes in the condition of fish, macroinvertebrate and riverine vegetation communities relative to Reference Condition, associated with changes in their constituent components, indicate the overall health of the river ecosystem.
A very low SR–EI score would indicate a state of very poor Ecosystem Health. Such a low rating is characterised by reductions in extent, nativeness and height structure as well as increases in fragmentation of vegetation in near riparian and floodplain areas; species loss and reductions in recruitment for native fish and dominance by alien fish; and reduction in frequency of occurrence or complete loss of macroinvertebrate families. A high SR–EI score indicates a river system in which all of these features are in near Reference Condition.

SR–EI scores are developed at zone and valley scales from the zone and valley scale condition scores for the three biological Themes using an Expert System (see Appendix 1, sub-section 7.2). In formulating this Expert System, Riverine Vegetation and Fish Condition were seen as having greater influence than Macroinvertebrate Condition on the Ecological Condition Index, as vegetation and fish respond to, integrate and influence processes over a wider range of temporal and spatial scales than macroinvertebrate communities. However, due to a lower level of confidence in the quality of the vegetation data underpinning the assessment, the relative weighting of Vegetation Condition was reduced relative to that of the other Themes in these Expert Systems. This resulted in a weighting of Fish, Macroinvertebrates and Vegetation Indices in decreasing order when integrated into the SR–EI score.

The River Ecosystem Health Rating was then assigned based on the SR–EI value, using the banding of scores shown in Table 2.4. No confidence limits could be generated for the SR–EI scores at valley or zone level, as statistical confidence limits could not be generated for several Theme metrics.

Only the River Ecosystem Health rating is reported for each zone and valley, as reporting the SR–EI numeric scores gives a false impression of precision.

4. OPERATIONS

4. Operations

4.1 Introduction

This SRA report marks the completion of Implementation Periods 4 to 6 (2008–2010). ISRAG considers that the sampling, analyses, program management and quality assurance protocols in the Fish and Macroinvertebrate Themes have been consistent with the scientific design and conceptual basis of the SRA. Implementation of these two Themes has proceeded as planned, despite expected issues associated with the scarcity of sites due to dry conditions, and occasional practical problems with sampling. During the reporting period, fish samples were taken at 510 sites, and macroinvertebrate samples were taken at 797 sites (Table 4.1).

The Fish and Macroinvertebrate Themes have been refined since SRA report 1, but retain the same sampling design and methods. Hence operational and data compliance assessment can be conducted in the same manner as in SRA report 1.

The Vegetation Theme is also a new Theme and, for all metrics bar one, depends on a consolidation of mapping data derived from a variety of sources and (recent) years.

The Physical Form Theme is a new Theme developed for this assessment. It uses a new form of data collection (LiDAR) and a novel modelling method for defining Reference Condition — and is thus considered developmental in nature. Data has been collected systematically from a set of sites distributed throughout each of the Basin valley stream network using LiDAR. In addition, results from SedNet modelling of Basin valley stream networks are used to derive metrics of channel and floodplain sediment deposition. One round of LiDAR sampling was conducted at 1,610 sites during 2009–10 and subject to only limited field-validation.

The Hydrology Theme has been refined and expanded since SRA report 1, though in so doing has experienced delays as well as data and modelling limitations. Some of the analysis and reporting inconsistencies among states noted in SRA report 1 remain unresolved. As a result, assessments in this report are limited to determination of metrics and indicators; at reach, zone and valley scale, for:

- mainstem river channels falling within the domain of jurisdictional river models
- headwater stream reaches for which the hydrological effects of woody vegetation change and farm dams have been modelled.

The assessment does not include the effects of private and other diversions or storages on the many tributary reaches which fall outside the modelled stream network, allowing only qualitative interpretations of hydrological condition at the valley scale. The Hydrology Theme can therefore be regarded as a Theme experiencing ongoing development.

SRA report 2 reports data sourced for five Themes: Fish, Macroinvertebrates, Vegetation, Physical Form and Hydrology. The assessment uses data from a first cycle of Physical Form and Vegetation Theme reporting, as well as a first cycle of a revised iteration of the Hydrology Theme. Assessments are based on a third cycle of the Macroinvertebrate Theme (one series of samples from all valleys, completed in 2010) and a second cycle of the Fish Theme, also completed in 2010. Although macroinvertebrate samples were also taken in a second round of sampling, these are not considered as part of the full Basin assessment reported here (though they form part of the trend assessment, Section 6).

This 'operations' section provides an overview of the data used for SRA report 2, commencing at the sample plan phase through to delivery of the raw data product for analysis. This includes Fish and Macroinvertebrate sampling conducted during SRA Implementation Periods (IP's) 4 to 6. Implementation Periods refer to years of sampling conducted under agreed protocols for the Fish and Macroinvertebrate Themes. The Vegetation and Physical Form Themes report on field data collected during 2009–2010 and mapping data derived from a variety of mapping sources. The Hydrology Theme includes data sets and models developed as described in Section 3.

For the Fish and Macroinvertebrate Themes, this Section:

- summarises state performance against sampling schedules and protocols, by:
    - reporting on the sampling conducted against the sampling schedule
    - reporting on issues encountered during sampling
    - providing a spatial analysis of sampled sites against supplied sites.
- Provides the IP1–IP6 sampling schedule.

For the Vegetation, Physical Form and Hydrology Themes, this Section:

- summarises the performance of the contractors against requirements and sample plans
- reports the quality assurance and control processes undertaken and reasons for eliminating data.

It also comments on:

- data management for all Themes
- program management, including reviews of field sampling procedures, modelling and analysis.

4.2 Fish and Macroinvertebrate Themes

4.2.1 Sample Plans

The SRA Team provided Field Site Sample Plans to sampling teams in each state, identifying prescribed 'SRA sites' on the stream network. In the field, teams located these sites using GPS or topographic maps and recorded locations where sampling actually occurred, following a Site Validation Protocol. Designated SRA sites were presumed to be the centre of a 1000 m reach, but it was possible that the provided site would not fall precisely on the river, requiring teams to relocate prior to sampling. These differences could introduce spatial bias if sampling teams made systematic choices (for example, consistently nearer to road crossings). The SRA protocols prescribe to relocate the provided site to the nearest accessible stream bank and to return field GPS locations to match those of the Field Site Sampling Plans (see section 4.2.2.4).

4.2.2 Sampling compliance

4.2.2.1 Overview

Drought continued to create significant difficulties for site allocation, validation and sampling; particularly in the northern valleys due to the absence of water required for Fish and Macroinvertebrate sampling.

The numbers of sites sampled in each zone and the numbers of sites specified in the sampling plans for the respective Themes are compared in Table 4.1. The table also shows the differences between the number of sites sampled and the number of sites required for each valley–Theme combination. The differences refer to sites missed because of dry conditions, problems of vehicle access or other reasons. Where additional sites were sampled, they have been included in analyses if they conformed to the respective sampling plan.

No sampling was undertaken in South Australia during IP3 (fish were sampled in SA in IP1; macroinvertebrates were sampled in IP2). Practical issues in IP1 delayed fish sampling until early winter at some sites in the Lower Murray Valley, potentially causing a bias in SRA assessments because carp tend to be under-represented in winter catches.

4.2.2.2 Sampling conducted

The MDBA SRA team provided Field Site Sample Plans to sampling teams within each state, including the list of sites and additional 'reserved' or backup sites. Plans also required a minimum number of sites in each valley and zone. A total of 510 sites were sampled for fish and 797 for macroinvertebrates (Table 4.1).

Figure 4.1 below displays the sequence over time of the number of sites sampled for the Macroinvertebrate and Fish Themes for SRA report 2.

The actual number of sites sampled in each valley and zone is shown in Table 4.1 compared against the minimum required under the Sample Plan.

4.2.2.3 State operation summary

Jurisdictional agencies provided progress reports to the MDBA for each IP which included key issues relating to sampling. Unusual circumstances or instances where sampling activity varied from the recommended sampling schedules and protocols are described below. Sites which had been sampled but were deemed suboptimal were given either an 'amber' or 'red' rating.

NEW SOUTH WALES

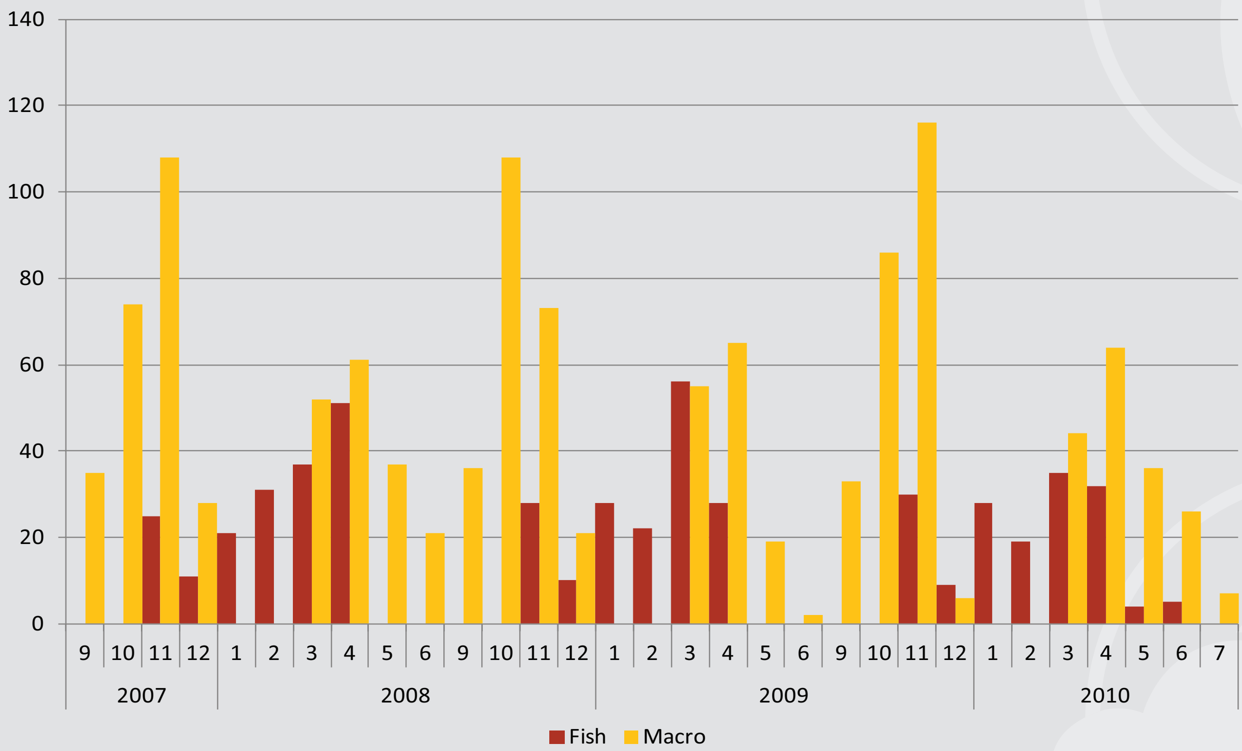


Figure 4.1. The number of sites sampled for fish and macroinvertebrates in each month and year during the SRA report 2 sampling cycle.

Table 4.1. The required number of sites and actual number sampled for fish and macroinvertebrates in each valley and zone for SRA report 2 sampling.

Valleys	Zone	N sites			
		FISH		MACROINVERTEBRATES	
		Required	Sampled	Required	Sampled
Avoca	Lowland	10	9	21	19
	Slopes	8	8	14	14
	Total	18	17	35	33
Border Rivers	Lowland	7	7	10	10
	Montane	7	7	4	4
	Slopes	7	7	17	18
	Upland	7	7	4	4
	Total	28	28	35	36
Broken	Lowland	10	10	24	23
	Slopes	8	8	11	11
	Total	18	18	35	34
Campaspe	Lowland	7	7	13	13
	Slopes	7	7	11	11
	Upland	7	7	11	11
	Total	21	21	35	35
Castlereagh	Lowland	7	7	13	13
	Slopes	7	7	14	15
	Upland	7	7	8	8
	Total	21	21	35	36
Condamine	Lowland	10	10	18	18
	Slopes	8	8	17	17
	Total	18	18	35	35
Darling	Lower	7	7	10	10
	Middle	7	7	18	18
	Upper	7	7	7	7
	Total	21	21	35	35

Continued/...

Table 4.1. The required number of sites and actual number sampled for fish and macroinvertebrates in each valley and zone for SRA report 2 sampling.

Valleys	Zone	N sites			
		FISH		MACROINVERTEBRATES	
		Required	Sampled	Required	Sampled
Goulburn	Lowland	7	7	14	14
	Slopes	7	7	12	12
	Upland	7	7	9	9
	Total	21	21	35	35
Gwydir	Lowland	7	7	11	11
	Montane	7	7	6	6
	Slopes	7	7	11	12
	Upland	7	7	7	7
	Total	28	28	35	36
Kiewa	Lowland	7	7	6	6
	Slopes	7	7	16	16
	Upland	7	7	13	13
	Total	21	21	35	35
Lachlan	Lowland	7	7	13	13
	Montane	7	7	4	4
	Slopes	7	7	11	11
	Upland	7	7	7	7
	Total	28	28	35	35
Loddon	Lowland	10	10	23	23
	Slopes	8	8	9	12
	Total	18	18	32	35
Macquarie	Lowland	7	7	15	15
	Slopes	7	7	10	10
	Upland	7	7	10	10
	Total	21	21	35	35

Continued/...

Table 4.1. The required number of sites and actual number sampled for fish and macroinvertebrates in each valley and zone for SRA report 2 sampling.

Valleys	Zone	N sites			
		FISH		MACROINVERTEBRATES	
		Required	Sampled	Required	Sampled
Mitta Mitta	Montane	7	7	14	13
	Slopes	7	7	7	7
	Upland	7	7	14	14
	Total	21	21	35	34
Murray, Upper	Montane	7	7	8	5
	Slopes	7	7	14	14
	Upland	7	7	13	13
	Total	21	21	35	32
Murray, Central	Lower	7	7	4	4
	Middle	7	7	9	9
	Upper	7	7	22	22
	Total	21	21	35	35
Murray, Lower	Lower	7	7	2	2
	Middle	7	7	7	7
	Upper	7	7	18	18
	Mt Lofty	7	7	8	8
	Total	28	28	35	35
Murrumbidgee	Lowland	7	7	9	9
	Montane	7	7	10	10
	Slopes	7	7	8	8
	Upland	7	7	8	8
	Total	28	28	35	35
Namoi	Lowland	7	7	7	7
	Montane	7	7	4	4
	Slopes	7	7	15	15
	Upland	7	7	9	9
	Total	28	28	35	35

Continued/...

Table 4.1. The required number of sites and actual number sampled for fish and macroinvertebrates in each valley and zone for SRA report 2 sampling.

Valleys	Zone	N sites			
		FISH		MACROINVERTEBRATES	
		Required	Sampled	Required	Sampled
Ovens	Lowland	7	7	7	7
	Montane	7	7	7	7
	Slopes	7	7	12	12
	Upland	7	7	9	9
	Total	28	28	35	35
Paroo	Lowland	18	18	35	35
	Total	18	18	35	35
Warrego	Lowland	10	10	27	27
	Slopes	8	8	8	8
	Total	18	18	35	35
Wimmera	Lowland	10	10	20	18
	Slopes	8	8	15	13
	Total	18	18	35	31
Grand Total		**511**	**510**	**802**	**797**

IP4 (2007–08)

- Floods in the northern catchments in the months before sampling for macroinvertebrates meant there was water for sampling in the Castlereagh and Gwydir. However, water levels fell rapidly and some sites were already drying to pools when sampled.

IP5 (2008–09)

- Macroinvertebrate sampling teams found some sites to be pools within dry river beds, and some dry sites were not sampled. In the Border Rivers Valley three sites were flooded, access was restricted at some sites, and 14 sampled sites were remnant pools in dry river beds.

IP6 (2009–10)

- For fish sampling, five of 77 sampled sites (6%) were given an amber rating.
- In the Castlereagh Valley, 36 sites were sampled for macroinvertebrates, one more than required. No dry sites were found and only one site was a remnant pool. Three sites were flooded when first visited in March; and were sampled in late April when flood waters had subsided.
- In the Macquarie Valley 10 of the 35 macroinvertebrate sites were located in a series of

remnant pools; the Central Murray Valley had 34 of 35 sites with continuous water, although no or very low flows were observed at the majority of these sites. Nine dry sites were not sampled.

QUEENSLAND

IP4 (2007–08)

- Flows had occurred in all valleys prior to sampling, ensuring water availability. Restricted access in some cases resulted in the use of alternative reserved sites.
- For fish sampling for the Border Rivers Valley, seven sites were rejected: three were too deep, three were dry or nearly dry; at one site the sampling boat was unable to launch.
- Some macroinvertebrate sites were not sampled because of access restrictions or localised rainfall during the sampling period.

IP5 (2008–09)

- Flood flows occurred in the southern Condamine valley, the Warrego and Paroo valleys prior to sampling.
- Two sites in Lake Numalla were un-fishable due to high conductivity. These sites were replaced with nearby sites (previously sampled in 2006) and because of time and location constraints were rated amber.

IP6 (2009–10)

- Flood flows occurred in the Condamine–Culgoa system and in the Warrego and Paroo valleys prior to sampling—ensuring water availability at sample sites.
- Major flooding in sampling areas delayed the commencement of sampling for macroinvertebrates until April 2010. Fish sampling was undertaken March and June 2010. Flood conditions impeded sampling for several weeks in April and May.
- Wet conditions precluded access to some fish sites, requiring use of reserved sites.
- Some macroinvertebrate sites were inaccessible due to flooding or rainfall prior to or during the sampling period.

SOUTH AUSTRALIA

IP4 (2007–08)

- Macroinvertebrate sampling was delayed. Six sites (all in NSW[1]) were inaccessible due to rain-closed access tracks.

VICTORIA

IP4 (2007–08)

- Fish sampling: 19 sites in the Loddon valley were rejected because of insufficient water; 31 sites were rejected in the Mitta Mitta and Upper Murray valleys because of access problems. Reserved sites were used to reach the required number of sites per zone.
- Macroinvertebrate sampling: many sites were identified as dry in autumn 2008 by pre-sampling fly-overs.

IP5 (2008–09)

1 The boundaries of the SRA Lower Murray valley cross into NSW and Victoria, but are sampled by South Australia.

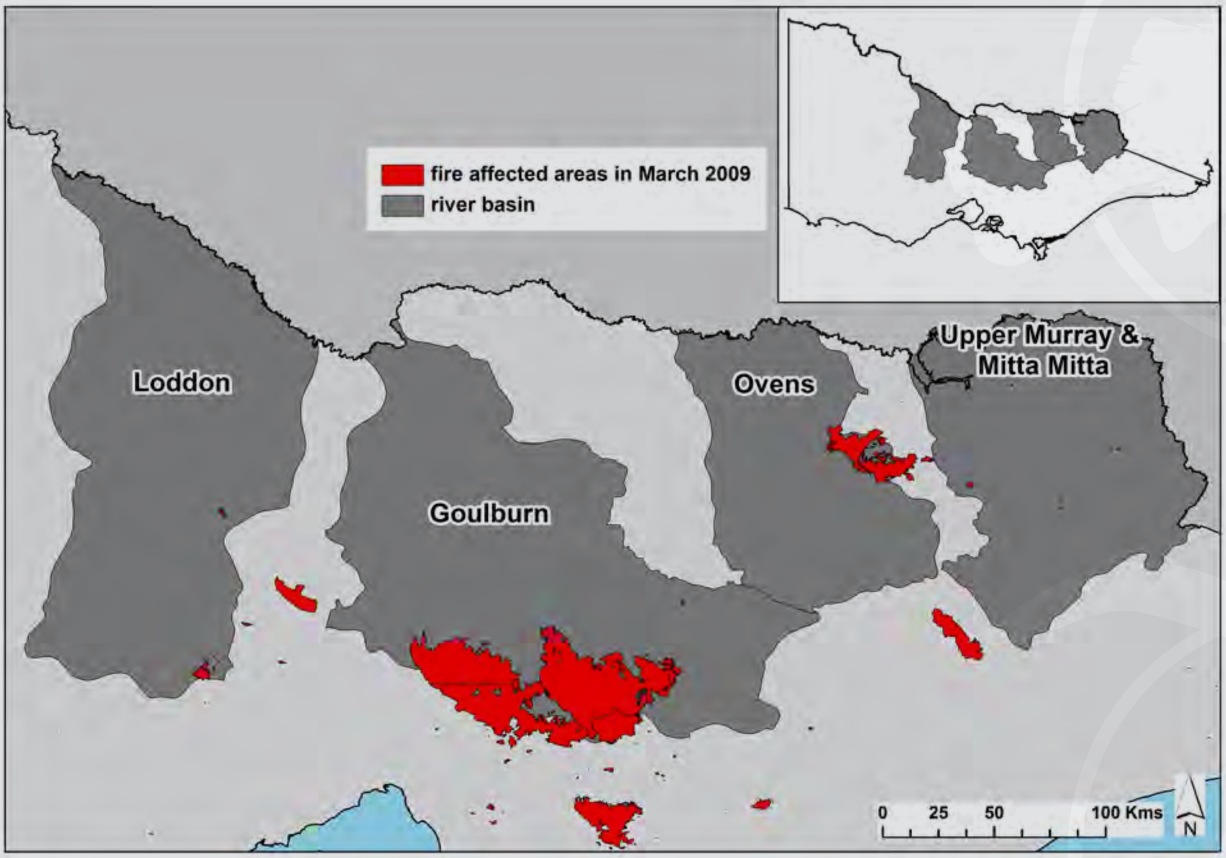


Figure 4.2. Extent of the February/March 2009 bushfires in the SRA valleys in Victoria sampled for fish and macroinvertebrates in the IP6 sampling round.

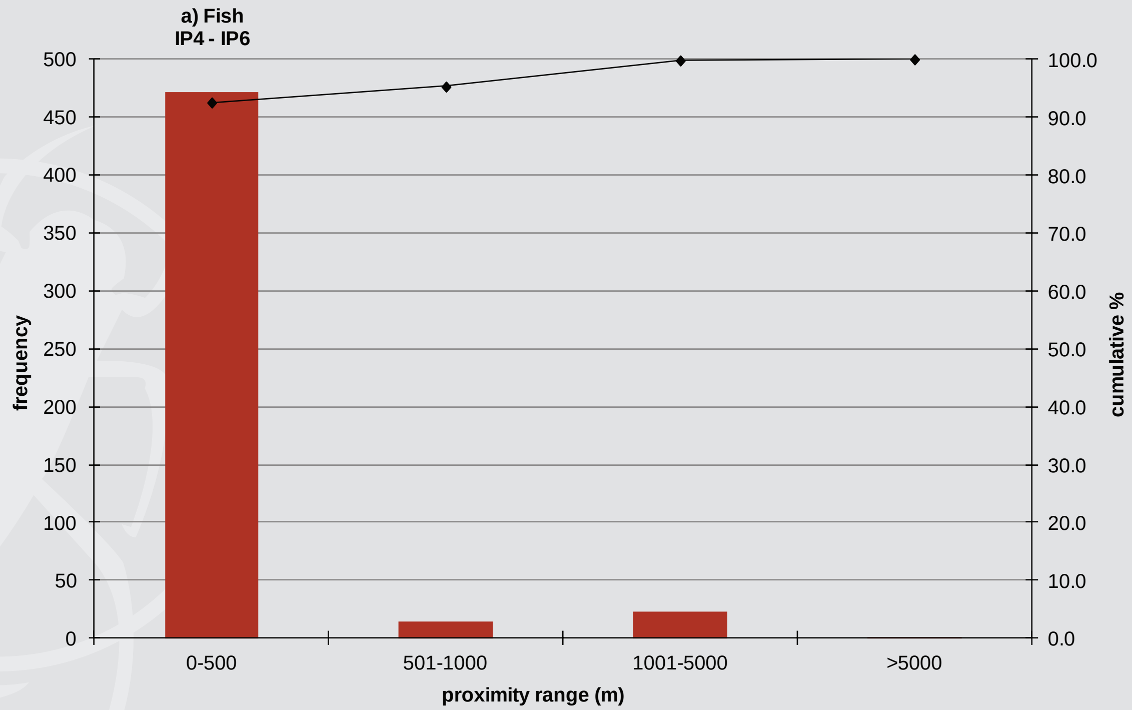
Source: Department of Sustainability and Environment, Victoria.

- Fish sampling: was completed at 17 of the required 18 sites in the Avoca valley. Three Kiewa sites, four Goulburn sites and eight Avoca sites rated amber; one Avoca site rated red. The rated Avoca sites were characterised by high turbidity and the Goulburn sites by fast flow and deep water. One Kiewa site had high turbidity and two Kiewa sites had very low salinity, possibly affecting electrofishing efficiency.
- Macroinvertebrate sampling: 33 of 35 required sites were sampled for the Avoca valley and 31 of 35 required sites were sampled for the Wimmera valley.

IP6 (2009–10)

- 13 sites to be sampled during IP6 were burnt[2] in autumn 2009 (nine and four sites in the Goulburn and Ovens valleys respectively, see Figure 4.2).
- Fish sampling: eight, 12 and seven sites in Wimmera, Campaspe and Ovens valleys, respectively, were assigned amber ratings due to deep water, high turbidity and dense vegetation.
- Macroinvertebrate sampling: only five out of eight sites in the Upper Murray valley montane zone were sampled (mostly reserved sites); most selected sites were dry or inaccessible.

2 All five IP6 valleys (especially the Goulburn and Ovens) were impacted, to varying degrees, by the February/March 2009 bushfires (see Figure 4.2). Vegetation was burnt around at three fish sites and one and two macroinvertebrate sites in the Campaspe, Goulburn and Ovens valleys, respectively.



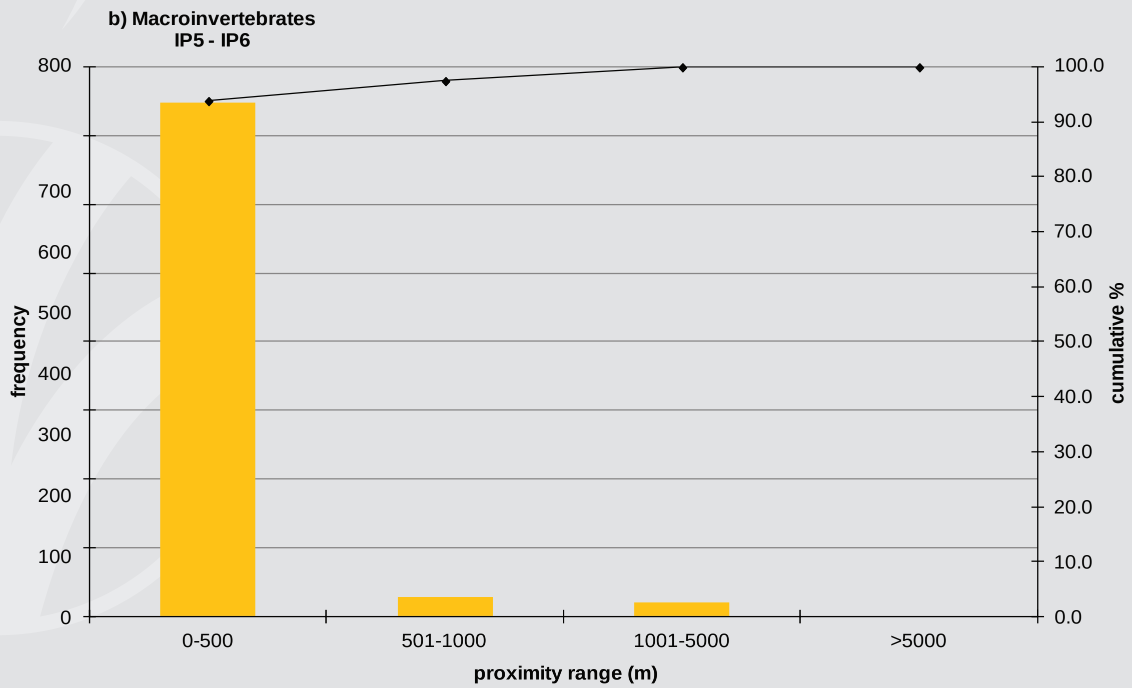


Figure 4.3. Summary of distances between prescribed Sampling Plan SRA sites and final sampling sites for (a) fish and (b) macroinvertebrates during SRA report 2 sampling.

(Columns = frequency; lines = cumulative percentage).
Note: Plan SRA sites were presumed to represent the central point of a 1000 m reach on the river, though occasionally did not, requiring relocation of final sampling sites.

4.2.2.4 Proximity Analysis of sampling sites

The sites in the Sampling Plans were described as 'SRA sites'. Field sampling teams located these sites on the stream network and used GPS or topographic maps to record the final sampling location, according to the Site Validation Protocol. An analysis of the proximity of final field sites to prescribed SRA site locations is summarised in Figure 4.3.

Approximately 90% of Fish and 91% of Macroinvertebrate Theme field sites fell within 500 m of designated Sampling Plan site locations. Approximately 94% of Fish and 97% of Macroinvertebrate Theme field sites were within 1000 m of designated site locations.

The proximity of field sampling sites to SRA Sampling Plan sites improved in IPs 4–6 when compared with IPs 1–3, reflecting field improvements in site validation protocols. During IPs 1–3, only 74% of Fish and 83% of Macroinvertebrate Theme sampling sites fell within 500 m of designated site locations.

4.2.2.5 Implications for the Fish Theme

ISRAG considers that the disparities between numbers of required and sampled sites did not have serious consequences for analyses of fish data, with only one valley being sampled at one site less than required (Table 4.1).

Despite satisfactory compliance with site numbers and overall distribution, 57 designated sites across the Loddon, Mitta Mitta, Upper Murray and Border Rivers valleys were rejected, with some reserve sites rejected because of dry or wet conditions.

4.2.2.6 Implications for the Macroinvertebrate Theme

ISRAG also considers that disparities between numbers of required and sampled sites had no substantive consequences for analyses of macroinvertebrate data (Table 4.1). Most (15) valleys were sampled with the required number of sites, while one less than the required number was sampled for five valleys. Two more noteworthy departures were as follows:

- Wimmera Valley: 88% of the required number of sites was sampled; with two sites less in each of the Lowland and Slopes zones. The data were still considered to be unbiased spatially and were accepted for analysis.
- Loddon Valley: 91% of required site numbers were sampled; with three sites less than the 12 required in the Slopes zone. The data were still considered to be unbiased spatially and were accepted for analysis.

4.3 Vegetation and Physical Form Themes

4.3.1 Contractor operation summary

A series of site investigations (by LiDAR) were commissioned to assess physical form and vegetation across all SRA valleys. A total of 1,610 sites were identified, i.e. 70 sites per valley, and a range of data remotely captured between October 2009 and October 2010.

Processing of these and other data resulted in rejection of some sites, for a range of reasons. Final subsets of data were developed for assessment in this SRA report from 1,385 and 1,319 sites for the Physical Form and Vegetation Themes, respectively. The primary reasons for the rejection of sampled sites are shown in Table 4.2 (Vegetation) and Table 4.3 (Physical Form). The required and the actual final number sampled in each valley and zone for these Themes is shown in Table 4.4.

Extensive flooding occurred during December 2009 to March 2010, which had implications for aerial survey data capture and required some flight re-scheduling. Data capture was restricted to periods when water was not overflowing from river channels (Terranean Mapping Technologies 2010).

Table 4.2. Summary of sites identified for rejection from the Vegetation Theme analysis and noted as rejected in the output shape file.

Primary reason/source for rejection	ID	Date range of rejection	N rejected	N remaining
Failed PF variable extraction.	Veg-1	25/6/10 – 19/11/10	146	1464
PF and Veg measures not created.	Veg-2	9/11/2010	3	1461
No extraction for veg.	Veg-3	10/11/2010	1	1460
All veg polygons removed in VegLevel2Metrics.xls.	Veg-4	25/1/2011	29	1431
CR0228 – rejected due to channel and veg anomalies.	Veg-5	22/2/2011	10	1421
Wrap around 50LP/50RP veg polygons.	Veg-6	22/2/2011	51	1370
CR0231 (Additional ISRAG rejections).	Veg-7	23/2/2011	39	1331
Combination of DR1101 and Veg-3.	Veg-8	23/2/2011	1	1330
As per decision register DR1101 and CR0230 – veg polygons with a FPC<5 removed for veg analysis as all polygons at site removed.	Veg-9	25/2/2011	2	1328
Site 74424 replaced by 74457.	Veg-10	11/3/2011	1	1327
Deemed to not be suitable.	Veg-11	11/3/2011	5	1322
Three sites (73540, 73073, 73828) were not analysed; however no reason for rejection was identified.	Veg-12	Not known	3	1319

Table 4.3. Summary of sites identified for rejection from the Physical Form Theme analysis and noted as rejected in the output shape file.

Primary reason/source for rejection	ID	Date range of rejection	N rejected	N remaining
Failed PF variable extraction.	PF-1	25/6/10 – 19/11/10	145	1465
PF and Veg measures not created.	PF-2	9/11/2010	2	1463
CR0216 – Alluvium class 4 sites (20 sites), bankfull width anomalies and meander wavelength anomalies.	PF-3	16/2/2011	25	1438
CR0231 – Additional ISRAG rejections.	PF-4	23/2/2011	46	1392
CR0232 – missing data for sites 73478 and 73845 due to zero values for channel depth variability.	PF-5	25/2/2011	2	1390
Deemed not to be suitable.	PF-6	11/3/2011	5	1385
Site 74424 replaced by 74457.	PF-7	11/3/2011	1	1384
Three sites (73478, 73681, 73845) identified above as being rejected were included in the analysed set.	PF-8	Not known	-3	1387
Two sites (74384 and 74408) were not analysed; however no reason for rejection was identified.	PF-9	Not known	2	1385

Table 4.4. The required number of sites and actual number sampled for the Vegetation and Physical Form Themes in each valley and zone for SRA report 2.

Zone / valley	VEGETATION		PHYSICAL FORM	
	N sites selected	N analysed	N sites selected	N analysed
Lowland	46	38	46	37
Slopes	24	22	24	20
Avoca – total	70	60	70	57
Lowland	16	13	16	14
Slopes	37	26	37	28
Upland	9	7	9	7
Montane	8	6	8	7
Border Rivers – total	70	52	70	56
Lowland	47	37	47	42
Slopes	23	19	23	19
Broken – total	70	56	70	61
Lowland	25	24	25	25
Slopes	25	22	25	23
Upland	19	18	19	18
Campaspe – total	69	64	69	66
Lowland	22	19	22	20
Slopes	24	19	24	19
Upland	24	20	24	21
Castlereagh – total	70	58	70	60
Lowland	29	16	29	16
Slopes	41	35	41	39
Condamine – total	70	51	70	55
Lower	23	18	23	18
Middle	37	25	37	30
Upper	10	9	10	10

Continued/...

Table 4.4. The required number of sites and actual number sampled for the Vegetation and Physical Form Themes in each valley and zone for SRA report 2.

Zone / valley	VEGETATION		PHYSICAL FORM	
	N sites selected	N analysed	N sites selected	N analysed
Darling – total	70	52	70	58
Lowland	33	27	33	29
Slopes	21	21	21	21
Upland	16	15	16	16
Goulburn – total	70	63	70	66
Lowland	20	15	20	16
Slopes	23	22	23	23
Upland	14	13	14	13
Montane	13	12	13	12
Gwydir – total	70	62	70	64
Lowland	16	15	16	16
Slopes	28	27	28	28
Upland	26	16	26	16
Kiewa – total	70	58	70	60
Lowland	30	15	30	20
Slopes	21	19	21	19
Upland	12	12	12	12
Montane	7	6	7	6
Lachlan – total	70	52	70	57
Lowland	46	34	46	40
Slopes	24	19	24	19
Loddon – total	70	53	70	59
Lowland	24	17	24	18
Slopes	21	17	21	17
Upland	25	23	25	23

Continued/...

Table 4.4. The required number of sites and actual number sampled for the Vegetation and Physical Form Themes in each valley and zone for SRA report 2.

Zone / valley	VEGETATION		PHYSICAL FORM	
	N sites selected	N analysed	N sites selected	N analysed
Macquarie – total	70	57	70	58
Slopes	17	16	17	16
Upland	25	22	25	24
Montane	28	23	28	24
Mitta Mitta – total	70	61	70	64
Lower	6	5	6	5
Middle	14	12	14	13
Upper	50	38	50	45
Murray (Central) – total	71	56	71	64
Lower	4	4	4	4
Middle	14	14	14	14
Mt Lofty	20	19	20	19
Upper	32	30	32	29
Lower Murray – total	70	67	70	66
Slopes	27	25	27	27
Upland	25	22	25	22
Montane	18	12	18	13
Murray (Upper) – total	70	59	70	62
Lowland	20	18	20	19
Slopes	18	17	18	18
Upland	12	10	12	10
Montane	20	16	20	17

Continued/...

Table 4.4. The required number of sites and actual number sampled for the Vegetation and Physical Form Themes in each valley and zone for SRA report 2.

Zone / valley	VEGETATION		PHYSICAL FORM	
	N sites selected	N analysed	N sites selected	N analysed
Murrumbidgee – total	70	61	70	64
Lowland	14	10	14	12
Slopes	29	21	29	23
Upland	18	14	18	15
Montane	9	7	9	8
Namoi – total	70	52	70	58
Lowland	24	19	24	21
Slopes	26	23	26	23
Upland	15	14	15	14
Montane	5	5	5	5
Ovens – total	70	61	70	63
Lowland	70	41	70	40
Paroo – total	70	41	70	40
Lowland	14	10	14	10
Slopes	56	49	56	51
Warrego – total	70	59	70	61
Lowland	48	45	48	47
Slopes	22	19	22	19
Wimmera – total	70	64	70	66
Grand Total	**1,610**	**1,319**	**1,610**	**1,385**

It was noted that site 74560 was recorded in the source shape file as being in the Campaspe Valley due to a buffering around the river centreline. For the purpose of this Audit this site is considered to be in the Central Murray. This results in 69 and 71 assessed sites for the Campaspe and Central Murray valleys respectively.

4.4 Hydrology Theme

Data were obtained from the flow data series used for the Guide to the Proposed Basin Plan; this included updated flow models for a 114-year record to June 2009 provided by the state jurisdictions to MDBA, and integrated for Basin-wide use. Data consisted of daily flows except for the model nodes provided for Victoria, where only monthly flow data are available. More details are provided below.

4.4.1 Data sources

Three data input sources for flow data were used to calculate the FSR metric scores. These included *regulated* (synonymous with mainstem), *farm dam* and *land use*. The metric scores were calculated by SKM and registered in the SRA data vault as R2064 (monthly regulated), R2119 (daily regulated) and R1947 (land use and farm dams).

Metric scores were attributed to relevant segments in the Geofabric streamline layer (known as AHGFN AusHydro v1.0).

Indicators and indices were calculated at the segment scale and were aggregated to zone and valley scale. Scores for farm dam and land use change are reported for catchments less than 100 km^2.

4.4.1.1 Regulated

Flow data for 139 gauging stations were supplied to SKM for the development of trend analysis; however, only 45 mainstem gauging stations were retained for analysis (94 stations did not have the required 12-year flow record).

The development of metric scores by SKM relied upon modelled data sourced by the Murray–Darling Basin Plan modelling team. The outputs of the modelling were designated as model run 684 (based on modelling current regulated environment) and model run 744 (based on natural flow without-development for the flow record period up to June 2009). The raw modelled data was stored and registered as data product R2017.

The number and location of model nodes or stations were predetermined by the models above. Some model stations only produced monthly data while others only produced daily data. Table 4.5 outlines the number of stations which had monthly and daily flow data under the two conditions.

Table 4.5. Number of model stations with daily and monthly flow data from each respective model run.

Model run	N stations with daily data	N stations with monthly data
684 – Current	252	346
744 – Natural	253	346

Table 4.6. Number of model stations (nodes) in each reported zone.

Valley	Zone	N model stations	Mainstem length (km)
Murrumbidgee	Lowland	8	807
	Montane	1	19
	Slopes	7	303
	Upland	1	133
Namoi	Lowland	7	317
	Montane	0	0
	Slopes	8	334
	Upland	2	32
Ovens	Lowland	1	146
	Montane	0	0
	Slopes	1	62
	Upland	1	6
Paroo	Lowland	4	728
Warrego	Lowland	3	395
	Slopes	3	287
Wimmera*	Lowland	14	349
	Slopes	2	15
Avoca*	Lowland	0	0
	Slopes	0	0
Border Rivers	Lowland	13	765
	Montane	1	0
	Slopes	15	567
	Upland	3	85
Broken	Lowland	4	98
	Slopes	3	40
Campaspe	Lowland	6	139
	Slopes	1	40
	Upland	1	1

*No nodes were available for Avoca and Kiewa valleys. The assessment for those valleys was entirely based on headwater streams in the slopes and upland areas.

Continued/...

Table 4.6. Number of model stations (nodes) in each reported zone.

Valley	Zone	N model stations	Mainstem length (km)
Castlereagh	Lowland	1	216
	Slopes	2	167
	Upland	0	0
Condamine	Lowland	17	1231
	Slopes	18	1245
Darling	Lower	6	996
	Middle	6	1314
	Upper	6	485
Goulburn	Lowland	7	338
	Slopes	1	10
	Upland	0	0
Gwydir	Lowland	8	546
	Montane	0	0
	Slopes	8	270
	Upland	3	92
Kiewa*	Lowland	0	0
	Slopes	0	0
	Upland	0	0
Lachlan	Lowland	12	687
	Montane	1	0
	Slopes	8	398
	Upland	0	55
Loddon	Lowland	6	309
	Slopes	1	1
Murray (Central)	Lower	3	384
	Middle	12	764
	Upper	6	359

*No nodes were available for Avoca and Kiewa valleys. The assessment for those valleys was entirely based on headwater streams in the slopes and upland areas.

Continued/…

Table 4.6. Number of model stations (nodes) in each reported zone.

Valley	Zone	N model stations	Mainstem length (km)
Murray (Lower)	Lower	2	99
	Middle	2	282
	Mt Lofty	0	0
	Upper	10	440
Murray (Upper)	Montane	0	0
	Slopes	2	189
	Upland	0	0
Macquarie	Lowland	10	948
	Slopes	8	478
	Upland	6	192
Mitta Mitta	Montane	0	0
	Slopes	1	111
	Upland	0	0

*No nodes were available for Avoca and Kiewa valleys. The assessment for those valleys was entirely based on headwater streams in the slopes and upland areas.

The spatial distribution of the number of model stations and their associated mainstem lengths used within each valley are shown in Table 4.6. Two valleys did not have model stations, and valleys without model stations had no mainstem lengths; or the modelled stream length was so small that it was not reported.

4.4.1.2 Farm dams

Information on the demand of farm dams for incorporation into the Flow Stress Ranking software were derived from a number of data sources.

This project used hydrological geospatial fabric layer (Geofabric) (known as AHGFN AusHydro v. 1.0) and the Murray–Darling Basin Water Bodies Farm Dams (Large Dams Polygons) layer to define a set of locations.

In order to complete the STEDI (Spatial Tool for Estimating Dam Impacts) modelling, streamflow data was required for each of the selected study catchments. The data for each study catchment needed to be from a record of at least 15 years to ensure that the final metric scores were within 5% of the long term result. Catchments were selected if they had more than 15 years of gauged data, although records of 10 years or more were initially considered in special cases to improve the geographic spread of catchments. Overall, the selected catchments had less than 5% of missing records and they represented a reasonable climatic and geographic spread of catchments.

Although 169 study catchments were selected only 162 study catchments were used, because some gauges had unusual properties which rendered them unsuitable for use. These properties included highly erroneous stream data, missing data, significant impacts of built infrastructure, and geographic issues such as being located on a secondary floodplain stream. Figure 4.4 shows the spatial distribution of the 162 catchments used to conduct the STEDI modelling.

4.4.1.3 Land use

Catchments were selected for land use–flow analysis if they had more than 15 years of gauged data, although records of 10 years or more were initially considered in special cases to improve the geographic spread of catchments. Overall, the selected catchments had less than 5% of missing record; and they represented a reasonable climatic and geographic spread of catchments. As with the farm dam section, 162 study catchments were used.

Three datasets were adopted for estimating the current and pre-development vegetation cover:

1. National Vegetation Information System (NVIS) pre-1750 vegetation (v. 3.1).
2. NVIS existing vegetation v. 3.1, with some modification by MDBA to infill unknown vegetation areas within the Basin with key land use categories .
3. Woody vegetation cover data from the Department of Climate Change.

4.5 Data management

4.5.1 Data returns

Field data gathered by state agencies (for the Macroinvertebrate and Fish Themes) were received by the SRA Team and validated using the SRA's *Data Acceptance Protocol*, which included a series of assessments of compliance. A more structured system to classify and document data issues was implemented after IP1. 'Errors' were detected where one or more data elements did not comply with the protocol, and 'Warnings' indicated the need to confirm aspects of the supplied data. Following implementation of this system, a total of 28 'Errors' and 25 'Warnings' occurred, and entire datasets were replaced on two occasions during the present assessment period (IP4-6).

4.5.2 Data quality

Checks were applied at each stage of data processing, from acceptance to derivation of indicators and construction of spreadsheets, charts and other reporting materials. Following acceptance, data integrity was maintained using one-to-one comparisons of supplied data to 'as-held' data, including 'random walks' and comparative analyses of calculations conducted by two different systems, the use of test datasets, step-wise code testing and creation of particular 'modules' for data management across related files and functions.

4.5.3 Contextual analysis

A contextual analysis has been developed, aimed at identifying outliers, anomalies and regionalisation effects in the Basin-wide data set. The results are being used to establish the domain of acceptable values for each attribute and to further improve the data-acceptance process in future.

4.6 Program management

4.6.1 Quality assurance

The SRA *Quality Assurance Project Plan* documents the activities and procedures that contribute to the quality of program data, under the guidance of a Quality Assurance Taskforce. The Project Plan covers document control, protocol management and data verification and validation, and is complemented by documents which detail quality assurance and quality control activities—from site selection to the derivation of metrics, indicators and indexes, and report writing. In addition to documenting current practices, the Project Plan provides a mechanism for improvements to the program. Quality Assurance Protocols were used as quality control tests at each of the stages in data transformation, from acceptance of data to charting of metrics. Much of this is focussed on the Fish and Macroinvertebrate Themes but is being expanded to include new theme content.

4.6.2 Review of field sampling and analysis

Reviews had been carried out by the Murray–Darling Freshwater Research Centre of procedures used in IP2–IP3 (for SRA report 1) by sampling teams for the Fish and Macroinvertebrate Themes. The reviews were intended to evaluate quality assurance and quality control activities among field teams and to provide recommendations to be considered for IP4, through the Quality Assurance Taskforce, in consultation with other SRA taskforces. Key issues for the Fish and Macroinvertebrate Themes are as follows.

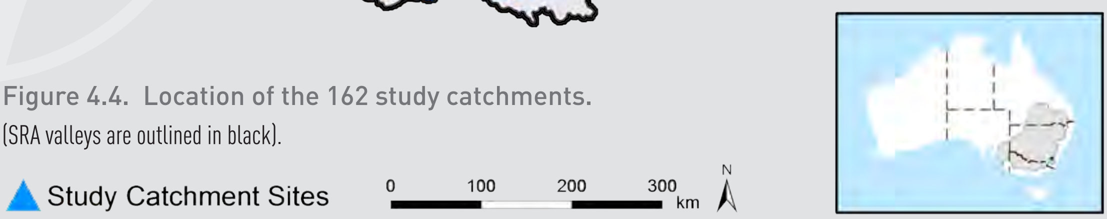
Fish Theme

- Variations between states in applications of the Protocol relating to electrofishing gear and sampling methods and the potential for errors in taxonomic identification were issued and identified during the early reviews.
- New information, especially that provided by Trueman (2009), was incorporated into the refinement of the definition of Fish Reference Condition, following meetings of the Fish Advisory Group (see Section 3.3.3).
- ISRAG considers that these issues have been actively managed; they raise no substantive issues for the quality of data used in this report.

Macroinvertebrate Theme

- The potential for problems in defining Reference Condition across state boundaries caused by variations in state sampling protocols were largely resolved in the development of the BRT modelling technique.
- Discrepancies between states in the taxonomic groups retained by sampling are resolved by exclusion of certain taxa (e.g. Cladocera, Copepoda) from analyses.
- Some differences and errors in taxonomic identification still require resolution; but were resolved in the development of the BRT modelling technique by use of a single taxonomic list.
- ISRAG considers that while these issues require management, they do not affect the final data quality and analysis in this report.

Figure 4.4. Location of the 162 study catchments.
(SRA valleys are outlined in black).



5. BASIN ASSESSMENT

5. Basin assessment

5.1 Basin context

5.1.1 Rainfall and drought

Annual rainfall deficits for the Basin in 2002–09 are shown in Figures 5.1 to 5.2. These maps broadly indicate the environmental conditions that prevailed in each of the valleys during the Audit period. At the Basin scale, they show that dry and severe drought conditions prevailed for most of the Basin rivers during the Audit period (see MDBC 2007b), with the exception of parts of the northern Basin in 2004 and 2008–2009.

Annual modelled natural streamflows across the Basin have been below average for the period July 2001 to June 2009 and less than 30% of the mean flow for the period July 2006 to June 2009 (Figure 5.3). A particularly low-flow year occurred in the year ending June 2007 (~10% of long-term mean) and also years ending June 2003 and 2009 (~30% of long-term mean in both cases). Since the available record began in 1896, flows lower than 30% of the long-term have previously occurred in 1903, 1915 and 1983.

The more recent extensive rain and flooding of 2009–2011 occurred after the data were collected for the assessment described in this report.

Drought before and during sampling will have influenced data from the Fish and Macroinvertebrate Themes. This may result from both shorter- and longer-term effects resulting from severe low-flow events and changed habitat conditions. Thus, the rainfall and hydrology within both the year of, and the years prior to sampling should be considered. The recent rains of 2009–2011 will have had little or no influence on the results for this assessment for the Themes in this assessment report; with the exception of the Castlereagh Valley (which experienced a major rain event in 2009). Note also that the Gwydir Valley experienced a substantial rain event in 2004, at the commencement of 'cycle 1' of SRA sampling.

Although the northern Basin catchments received near-average to above-average rainfall, they contributed comparatively little to the total Basin discharge. Modelled mean annual 'natural' discharge in the Darling is about 1,900 GL, and that for the Murray tributaries (Goulburn, Kiewa, Mitta Mitta, Murray Upper, Murrumbidgee and Ovens) is 12,400 GL. Dry conditions were most persistent and severe in the Murray catchments until 2009, as the rainfall-deficit maps show. Thus, in the latter part of the SRA reporting period, most of the rivers (by length) in the Basin experienced conditions equivalent to the long-term average, but discharge from the Basin as a whole was at an extreme low.

Metrics supporting the Hydrology Theme are based on long-term (114 year) modelled data, and involve comparisons of 'natural' and 'current scenario' flows. They include but are not entirely based on drought conditions. In addition, the Hydrology Theme is focused on the degree to which the flow regime is altered by human impacts within the Basin. As such, the drought is treated as part of the background 'reference' conditions. An evaluation of the human-induced changes in river hydrology that have occurred during these dry conditions is described in the evaluation of trends in hydrology over a 12–year period from 1998 to 2009 (Section 6).

5.1.2 Fires

A number of extensive fires were recorded during the period 2002–2009 (Table 5.1) mostly affecting valleys in the south-eastern Basin; especially Victoria, southern New South Wales and the Australian Capital Territory (Figure 5.4). There was therefore the potential for these fires to affect the ecology of the river systems; especially in the higher elevation zones of the Kiewa, Goulburn, Mitta Mitta, Ovens and Upper Murray regions.

Extensive bushfires can change the hydrology and sediment regimes, and soil and water chemistry of river catchments; leading to changes in water quality, flows and channel morphology. These can in turn lead to declines in aquatic biodiversity and longer-term changes to community composition.

5.2 Ecosystem Health

5.2.1 Ecosystem health ratings

All 23 valleys and their constituent zones were assigned a level of Ecosystem Health based on valley- and zone-scale condition assessments for Fish, Macroinvertebrates, Riverine Vegetation, Physical Form and Hydrology.

Figure 5.5 presents the ratings in map form for all Basin valleys. Since there is no significant difference between the ranking order of some valleys, Table 5.2 shows the valleys ranked according to their Ecosystem Health ratings, accompanied by the Theme-based Condition ratings. Since there is no significant difference between the ranking order of some valleys, Table 5.3 groups those valleys which have similar Ecosystem Health ratings.

More details on the Basin-scale results for each Theme are provided in the following text, while details of health and condition assessments for each valley are provided in Volumes 2 and 3.

Only the Paroo Valley was rated in Good health and only the Warrego was rated in Moderate health. Most valleys were rated in Poor (15 valleys) or Very Poor health (six valleys). None was rated in Extremely Poor health.

Figure 5.6 and Table 5.4 show the river Ecosystem Health ratings for each zone across the Basin. Only one zone was rated in Good health, namely the Paroo Lowland zone (which accommodates the entire Paroo Valley river system). Two zones (Lowland and Slopes) from the Warrego were rated in Moderate health. Other zones in Moderate health included: Lowland of the Condamine; the Upper of the Darling; Upper of the Lower Murray; Slopes of the Castlereagh, Upland of the Ovens and the Montane of the Upper Murray.

Most zones were rated as being in Poor (38 zones) or Very Poor health (21 zones).

Overall, Upland and Montane zones rated in similar Ecosystem Health to the Lowland and Slopes zones. Nineteen of 21 (86%) of the former were rated in Poor or Very Poor health, compared to 40 of 47 (85%) of the latter. A higher proportion of Slopes zones were rated in Very Poor health (50%) than for any of the other zones (5–30%).

Northern (Darling River catchment) valley river systems generally were in better Ecosystem Health than southern (River Murray catchment) valleys. Only one (11%) of the nine northern valleys were rated as being in Very Poor river Ecosystem Health, compared to five (36%) of the 14 southern valleys. In addition, both valleys rated as being in Moderate or Good health were in the northern Basin, as were the three highest ranked valleys in Poor health. All except one of the 20 zones rated in Very Poor health were in southern valleys.

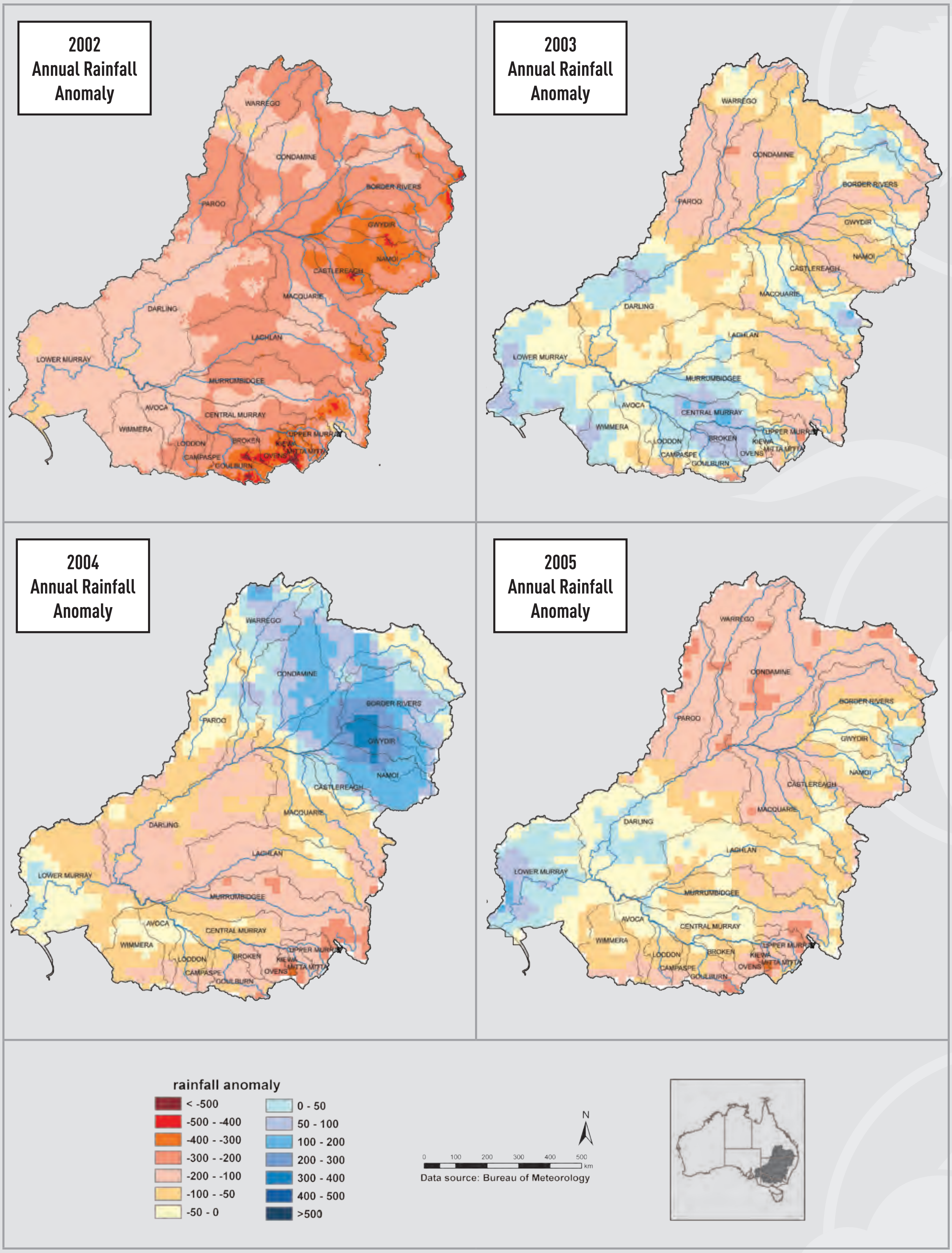


Figure 5.1. Annual rainfall deficit in the Murray–Darling Basin 2003-2005 from the long-term average.
Data source: Bureau of Meteorology

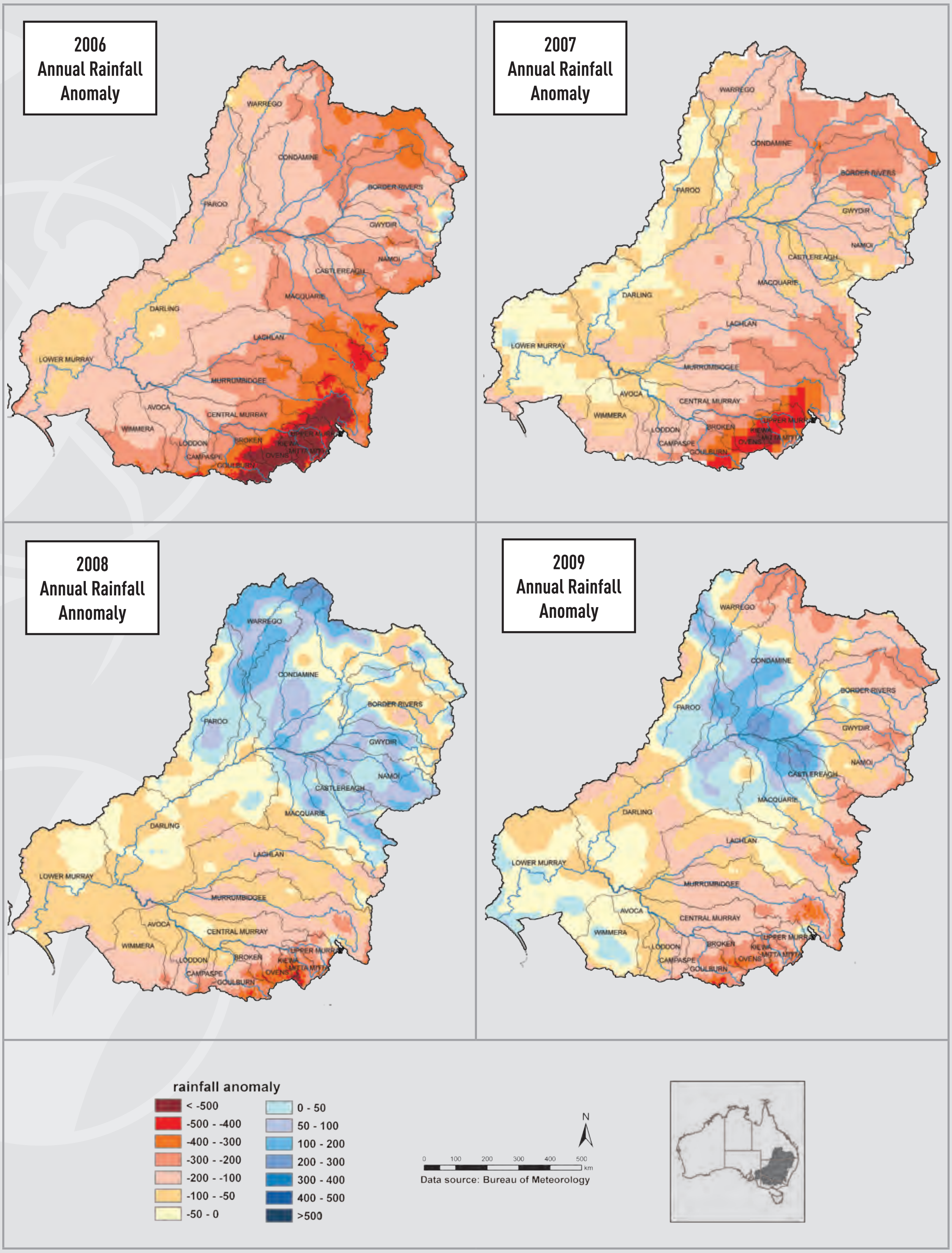


Figure 5.2. Annual rainfall deficit in the Murray–Darling Basin 2006-2009, from the long-term average.
Data source: Bureau of Meteorology

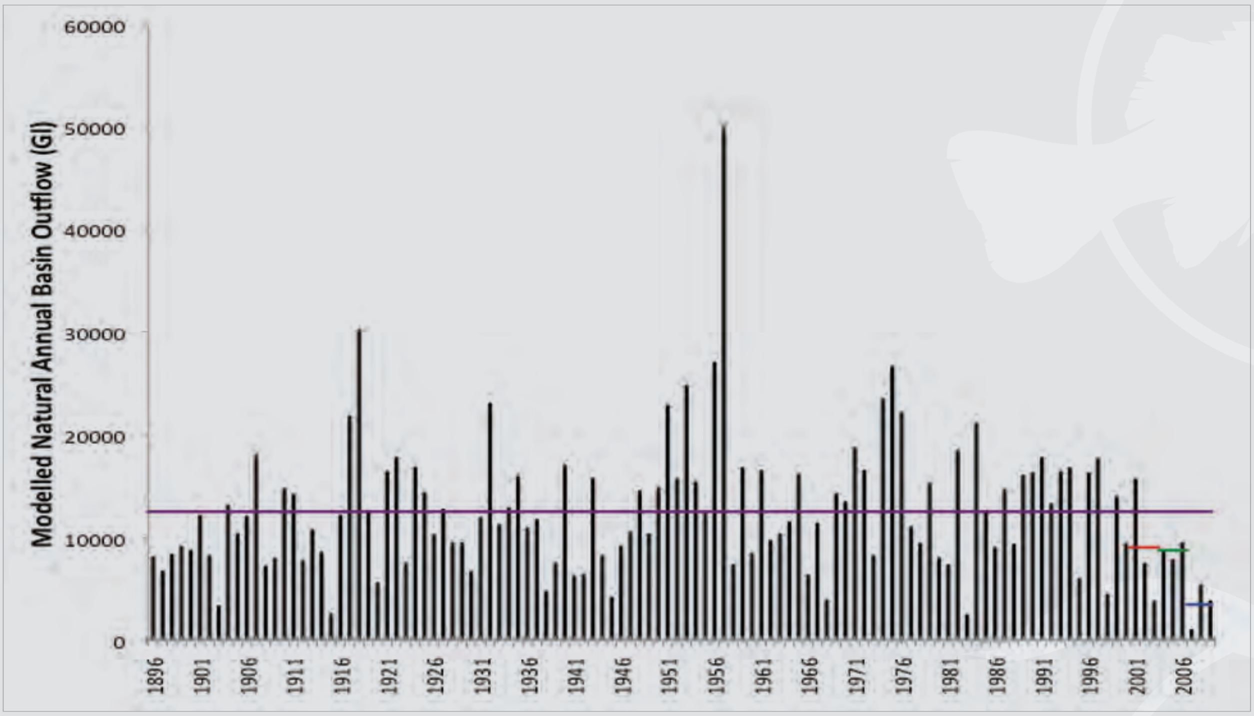


Figure 5.3. Natural Basin outflow series (modelled with all major water resource developments absent).

Mean flows are shown for the full record (purple line) .

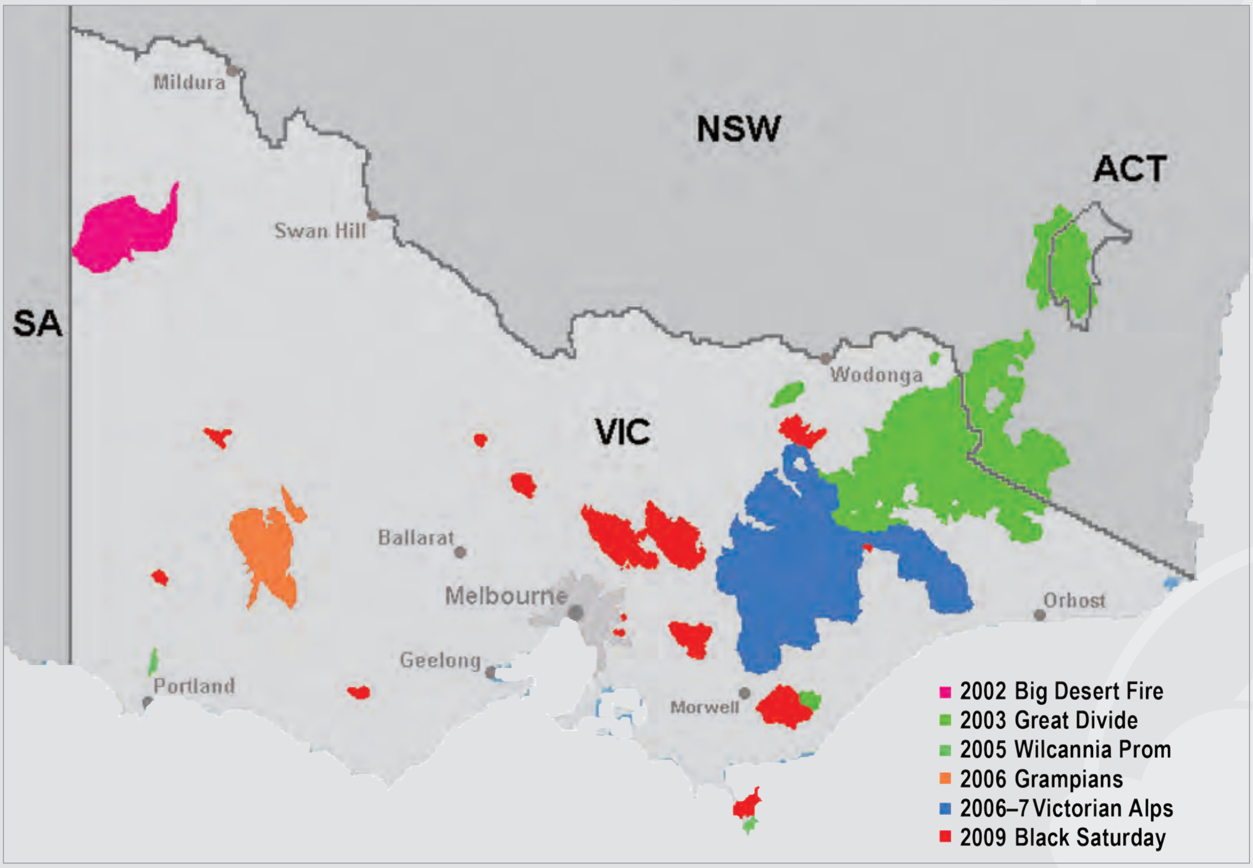


Figure 5.4. Major fire extents in South-east Australia, 2002–2009.

(Map by N Carson 2009).

Table 5.1. Valleys and zone areas that experienced extensive fires, 2001–2009.
Moderate (M) = 10–25%, Large (L) = 25–50%, Very Large (VL) = 50–100%.

Valley	Zone	2001	2002	2003	2004	2005	2006	2007	2008	2009
Campaspe	Slopes									M
Goulburn	Upland						L	M		L
Kiewa	Upland			VL			M			M
Murray (Lower)	Upper		M							
Mitta Mitta	Slopes			VL						
	Upland			VL						
Murrumbidgee	Montane			L						
Namoi	Slopes						M			
Ovens	Upland			M			VL			
	Montane			L			VL			
Murray (Upper)	Upland			M						
	Montane			VL						
Wimmera	Slopes						M			

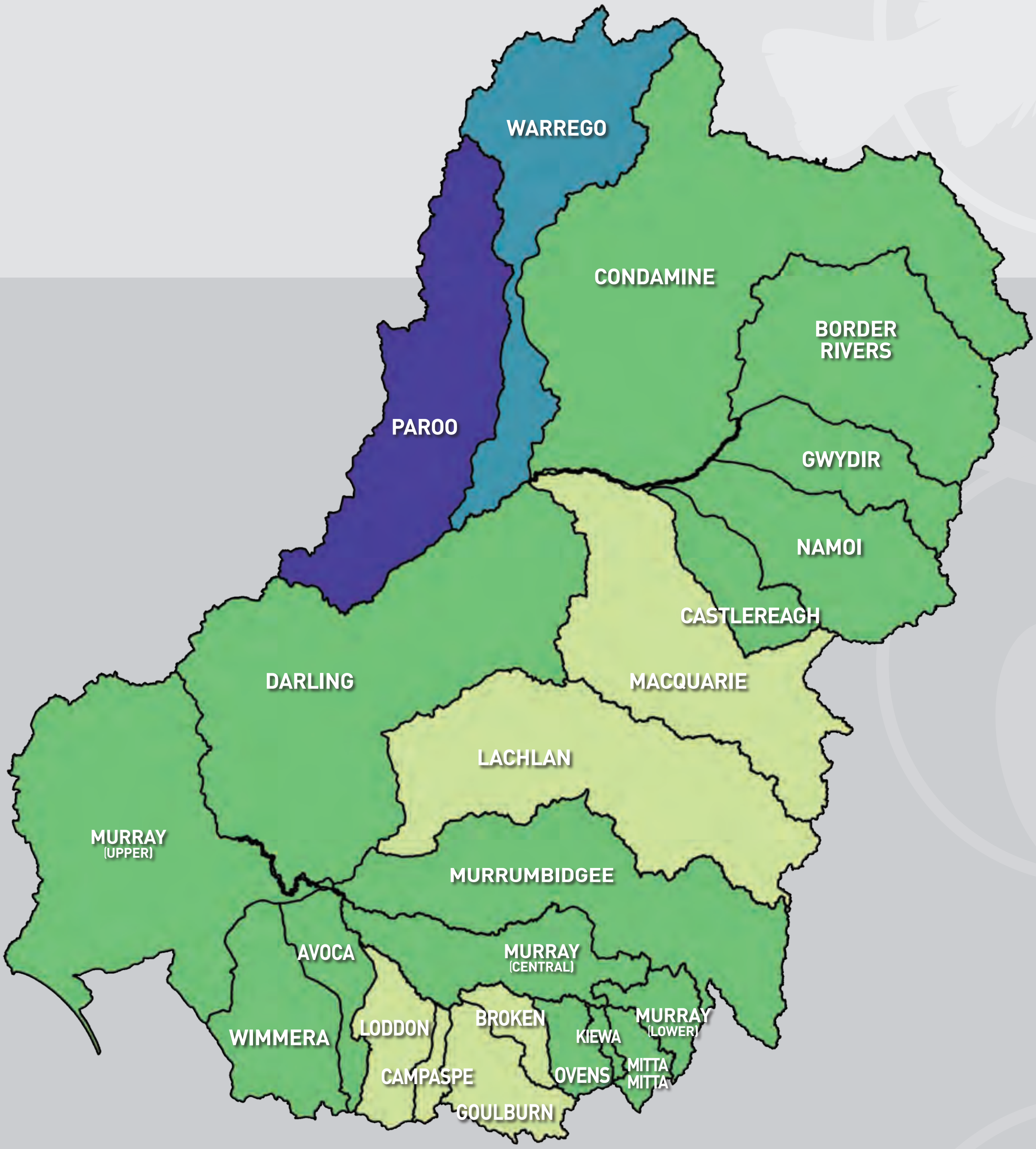


Figure 5.5. River Ecosystem Health ratings for all Basin valleys assessed for the period 2008–2010. Based on integration of the Theme condition assessments for Fish, Macroinvertebrates and Riverine Vegetation.

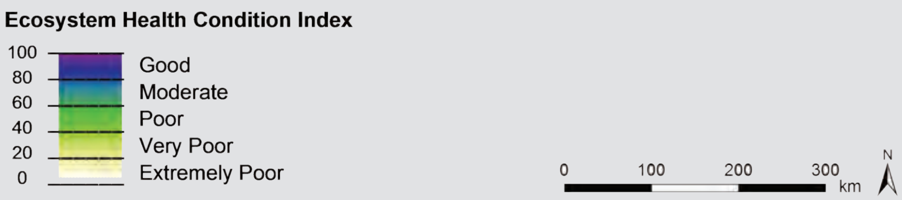


Table 5.2. Sustainable Rivers Ecosystem Health and Theme condition (SR–HI etc.) ratings for all valleys, in order of declining Ecosystem Health.

VALLEY	ECOSYSTEM HEALTH	FISH	MACRO-INVERTEBRATES	VEGETATION	PHYSICAL FORM	HYDROLOGY
PAROO	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
WARREGO	MODERATE	POOR	GOOD	GOOD	GOOD	GOOD
CASTLEREAGH	POOR	VERY POOR	MODERATE	GOOD	GOOD	GOOD
CONDAMINE	POOR	MODERATE	MODERATE	GOOD	MODERATE	MODERATE
DARLING	POOR	POOR	POOR	GOOD	MODERATE	MODERATE
BORDER RIVERS	POOR	MODERATE	MODERATE	POOR	MODERATE	GOOD
LOWER MURRAY	POOR	POOR	MODERATE	POOR	MODERATE	VERY POOR
OVENS	POOR	POOR	MODERATE	POOR	GOOD	GOOD
GWYDIR	POOR	POOR	MODERATE	MODERATE	MODERATE	POOR
CENTRAL MURRAY	POOR	VERY POOR	POOR	GOOD	MODERATE	POOR
UPPER MURRAY	POOR	EXT'LY POOR	GOOD	MODERATE	GOOD	POOR
WIMMERA	POOR	POOR	MODERATE	POOR	GOOD	MODERATE
NAMOI	POOR	VERY POOR	MODERATE	POOR	MODERATE	GOOD
KIEWA	POOR	EXT'LY POOR	GOOD	POOR	GOOD	GOOD
MITTA MITTA	POOR	EXT'LY POOR	GOOD	MODERATE	GOOD	GOOD
AVOCA	POOR	VERY POOR	MODERATE	POOR	MODERATE	GOOD
MURRUMBIDGEE	POOR	EXT'LY POOR	MODERATE	MODERATE	GOOD	POOR
CAMPASPE	VERY POOR	VERY POOR	MODERATE	EXT'LY POOR	MODERATE	MODERATE
LODDON	VERY POOR	VERY POOR	MODERATE	EXT'LY POOR	MODERATE	MODERATE
GOULBURN	VERY POOR	EXT'LY POOR	POOR	POOR	GOOD	POOR
MACQUARIE	VERY POOR	EXT'LY POOR	MODERATE	MODERATE	MODERATE	MODERATE
BROKEN	VERY POOR	EXT'LY POOR	GOOD	VERY POOR	GOOD	GOOD
LACHLAN	VERY POOR	EXT'LY POOR	MODERATE	POOR	GOOD	MODERATE

Table 5.3. Ecosystem Health assessments by valley, 2008–2010.

Valleys are arranged in rank order within health ratings.

HEALTH RATING	VALLEY	GROUP RANK
GOOD	PAROO	1
MODERATE	WARREGO	2
POOR	CASTLEREAGH, CONDAMINE, DARLING	3
	BORDER RIVERS , GWYDIR MURRAY (CENTRAL), MURRAY (LOWER), MURRAY (UPPER) NAMOI, OVENS, WIMMERA	4
	AVOCA, KIEWA , MITTA MITTA , MURRUMBIDGEE	5
VERY POOR	CAMPASPE, LODDON	6
	BROKEN, GOULBURN, LACHLAN, MACQUARIE	7
EXTREMELY POOR		

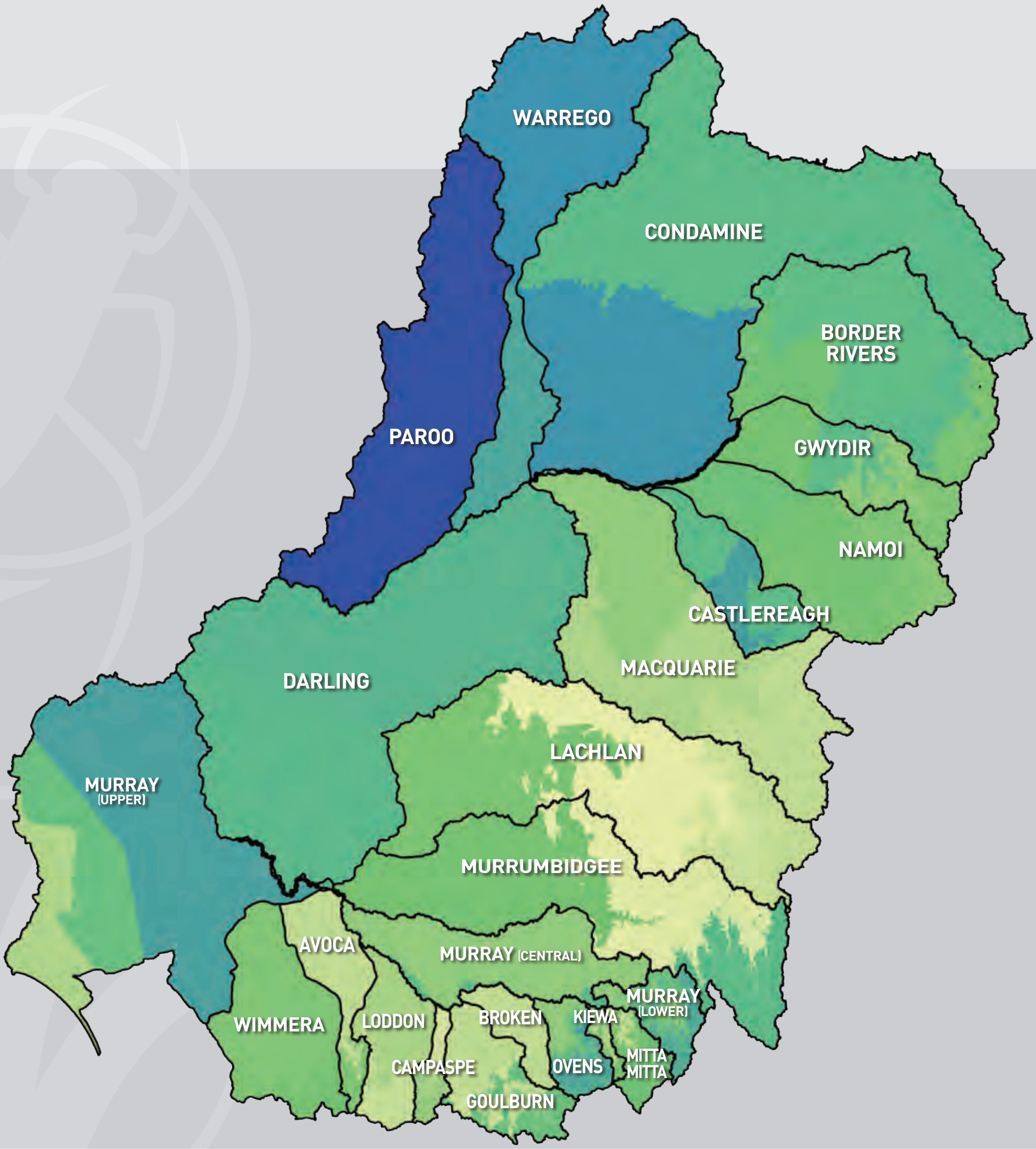


Figure 5.6.
River Ecosystem Health ratings for all Basin zones assessed for the period 2008–2010.
(Based on integration of the Theme condition assessments for Fish, Macroinvertebrates and riverine Vegetation).

Table 5.4. Ecosystem Health assessments by zone, 2008–2010.
All Murray (Central and Lower) and Darling valleys are included as single Lowland zones, except that the Mt Lofty zone (Lower Murray) is counted as a Slopes zone.

HEALTH RATING	ZONE				COUNT
	LOWLAND	SLOPES	UPLAND	MONTANE	
GOOD	Paroo (1)				1
MODERATE	Condamine Darling (Upper) Lower Murray (Upper) Warrego (4)	Castlereagh Warrego (2)	Ovens (1)	Upper Murray (1)	8
POOR	Border Rivers Castlereagh Darling (Lower, Middle) Gwydir Lachlan Central Murray (Lower, Middle, Upper) Lower Murray (Middle) Macquarie Murrumbidgee Namoi Ovens Wimmera (15)	Avoca Border Rivers Condamine Gwydir Namoi Ovens Upper Murray Wimmera (8)	Border Rivers Campaspe Castlereagh Goulburn Gwydir Kiewa Mitta Mitta Upper Murray Namoi (9)	Border Rivers Gwydir Mitta Mitta Murrumbidgee Namoi Ovens (6)	38
VERY POOR	Avoca Broken Campaspe Goulburn Kiewa Loddon Lower Murray (Lower) (7)	Broken Campaspe Goulburn Kiewa Lachlan Loddon Lower Murray (Mt Lofty) Macquarie Mitta Mitta Murrumbidgee (10)	Lachlan Macquarie Murrumbidgee (3)	Lachlan (1)	21
EXTREMELY POOR					0
Count	27	20	13	8	68

5.3 Fish

5.3.1 Condition indices

Figure 5.7 shows indices of Fish Condition (SR–FI) for all valleys, arranged in descending order. The valleys form three reasonably distinct groups (A, B, C) and Group C may be sub-divided into C1 and C2, on the basis of the range of their 95% confidence limits.

Group A contains three valleys, Paroo, Condamine, and Border Rivers. All have SR–FI values above 60; with SR–FI = 83.4 for the Paroo. Though the three valleys supported very different fish densities (Figure 5.8) their fish communities were characterised by high proportions of native species.

Group B includes eight valleys (Darling, Gwydir, Warrego, Wimmera, Murray Lower, Ovens, Castlereagh, Warrego, and Namoi). The SR–FI scores (35–52) and 97.5% confidence range for each of these valleys fell between 20 and 60, indicating Poor to Very Poor Condition. All of the valleys from the northerly, summer-rainfall region of the Basin fall into either Group A or Group B.

Group C (1&2). For the remaining 12 valleys, median SR–FI values and the upper confidence limit fell below 40, placing their condition rating in the range of Very Poor to Extremely Poor. The valleys differed considerably in the number of fish caught per site (Figure 5.9) but alien species made up more than half the fish biomass in every case (Table 5.5) and in most the number of native species was significantly below predicted levels (Table 5.6). All valleys in Group C are situated in the southern part of the Basin.

Group C2 contains six valleys, Goulburn, Murrumbidgee, Macquarie, Broken, Lachlan, and Mitta Mitta. In every case the upper Confidence Limit (95%) does not exceed 20; indicating that the fish communities of these valleys are clearly in Extremely Poor condition.

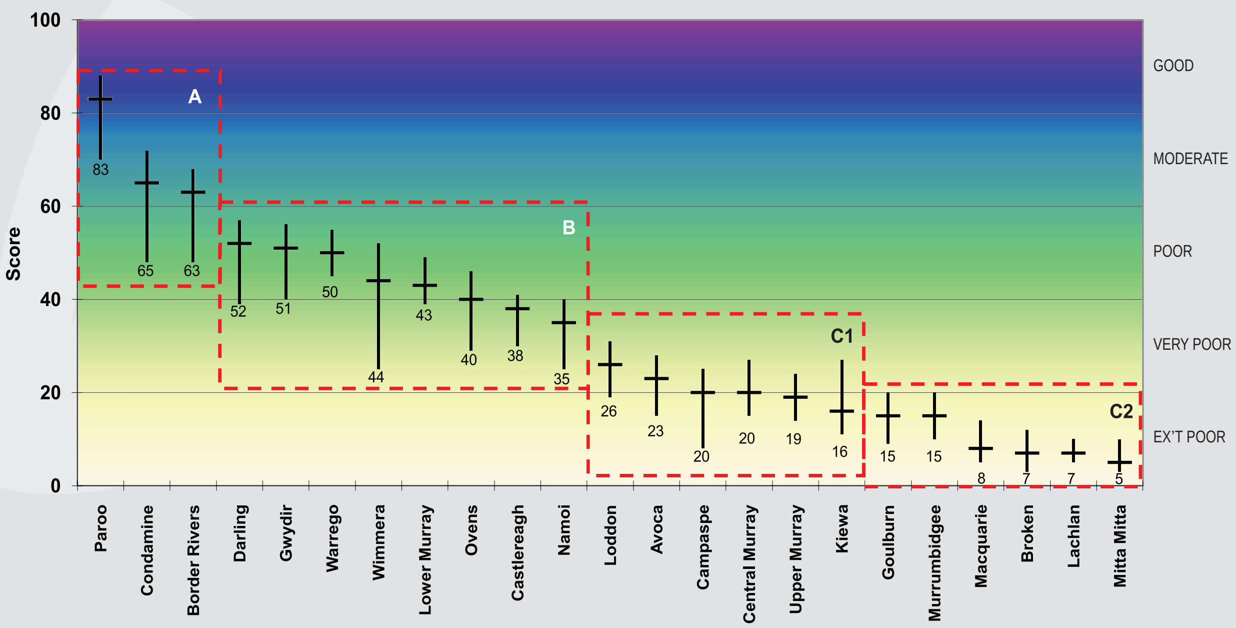


Figure 5.7. Valleys ranked by SR Fish Index (SR–FI) scores.

(Short horizontal bars are means; vertical lines show the associated 95% confidence limits). The range of medians in each of four groups is shown alongside each label (A, B, C1, C2). For explanation of groups, see text. The SRA colour rating standard is shown with condition rating labels. Data derived from the second SRA fish sampling cycle in 2008–2010.

Only around half of the expected native species were caught in these valleys (Table 5.5) and the proportion of total fish biomass contributed by alien species ranged from 60% to 97% (Table 5.5).

5.3.2 Species-specific information

All 23 valleys (510 sites) were sampled once for fish during 2008–2010 (the current reporting cycle 2), yielding 36 species (27 native, nine alien). Samples included more than 63,000 fish (38,500 native; 24,500 alien) weighing nearly 4.5 tonnes (1.5 tonnes native, three tonnes alien). These data are very similar to those for SRA report 1 (cycle 1, the previous round of SRA sampling in 2004–07).

Sampling sites are distributed randomly within zones but restricted to river channels. Randomised sampling[1] is necessary to support unbiased statistical analysis and 'up-scaling' of results, but may result in rare fish, or those with restricted spatial distribution, being missed in sampling. This is particularly true of fish such as the Murray jollytail and Southern pygmy perch which favour wetlands and off-channel habitats. However, the preference of these species for off-channel habitats is reflected in the SRA reference condition, where they are rated 'rare' for in-channel habitats.

Table 5.7 shows the ranked abundances of the 36 sampled species, and also shows the numbers of valleys in which each species was found.

The summary shows that alien species are a major part of the Basin fish fauna, as is well known. Common carp and gambusia—both aliens—were ubiquitous (present in all 23 valleys), and goldfish was caught in 22 valleys. Redfin perch also were abundant and widespread–especially in warm, lowland areas, and brown trout and rainbow trout were common in cooler upland streams.

Bony herring, a moderate-sized native species, was the most numerous fish caught during the current cycle 2 (2008–2010) survey. It favours warm, slow-moving, streams and is well-suited to weir pools in lowland zones. Other numerous native species were small-bodied fish such as carp gudgeons, Australian smelt, spangled perch, mountain galaxias, and unspecked hardyhead, the first two also being wide-spread throughout the Basin. Other widespread native species included golden perch and Murray cod (in 21 and 20 valleys respectively). Some large-bodied natives (such as trout cod and Macquarie perch) were caught in only a few valleys (three in each case).

Figure 5.8 presents maps indicating the zones in which these four popularly valued native species were captured during SRA 2 sampling, relative to Reference Condition. The maps make no comment on current population densities but do indicate substantial changes in the spatial distribution of the two latter species. There is also some indication that these desirable angling species may have been introduced to streams outside their natural range. The influence of fish-stocking programs (and accidental releases) on the current condition of the Basin's fish community, particularly under the recent extended drought conditions, is difficult to assess. Further research is required in this area.

Two native species that were caught during the SRA sampling cycle 1 (2004–07)—barred galaxias and Murray hardyhead—did not appear in 2008–2010 samples; but two specimens of spotted galaxias, not recorded in cycle 1 (2004–07) were caught in the Campaspe during the current cycle 2 (2008–2010) survey.

Of the ten alien species caught during cycle 1, roach did not appear in the cycle 2 survey.

Table 5.8 indicates a substantial reduction in the distribution of many native fish species across the Basin. Under Reference Condition it was expected that an average of 14.6 native species would be caught per zone. The results reveal an average of 6.1 native species per zone: a 58% reduction from reference. Individual species differ significantly in the degree to which their distribution appears to have changed. Some species, widespread

1 Note power estimates for sampling, in pilot study (MDBA 2004a).

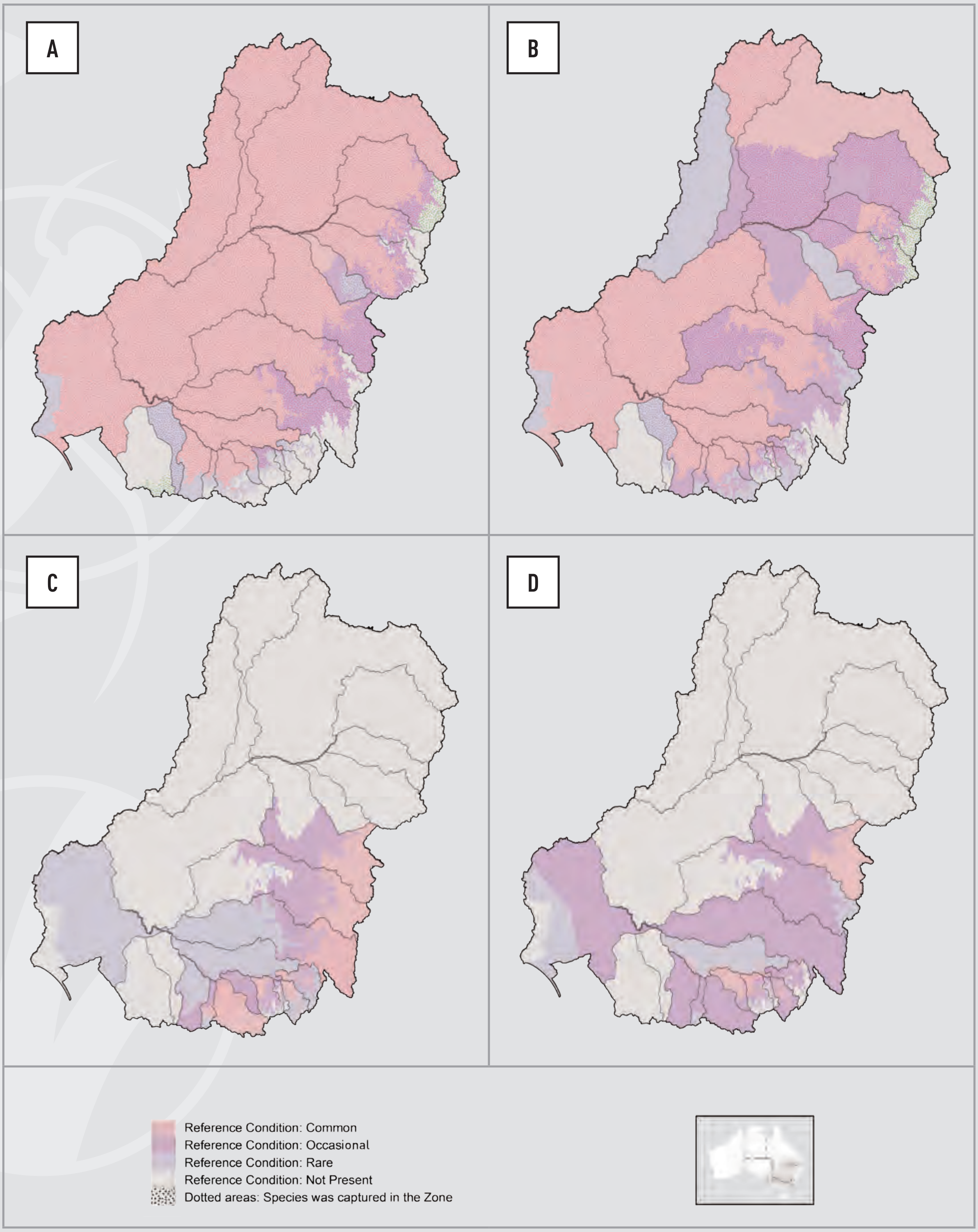


Figure 5.8. Expected and observed spatial distribution (zones) of:
A. golden perch
B. Murray cod
C. Macquarie perch
D. trout cod.

Table 5.5. Average proportions of native and alien fish numbers and biomass (kg) per site.
(Percentages are rounded).

Valley	Composition			
	Percent native		Percent alien	
	Numbers	Biomass	Numbers	Biomass
Avoca	41	4	59	96
Border Rivers	76	63	24	37
Broken	28	22	72	78
Campaspe	19	7	81	93
Castlereagh	50	47	50	53
Condamine	76	57	24	43
Darling	86	65	14	35
Goulburn	65	40	35	60
Gwydir	45	44	55	56
Kiewa	21	22	79	78
Lachlan	66	29	34	71
Loddon	56	25	44	75
Macquarie	56	29	44	71
Mitta Mitta	37	3	63	97
Murray, Central	84	44	16	56
Murray, Lower	66	31	34	69
Murray, Upper	36	8	64	92
Murrumbidgee	23	16	77	84
Namoi	45	33	55	67
Ovens	65	27	35	73
Paroo	90	56	10	44
Warrego	93	59	7	41
Wimmera	39	11	61	89

under Reference Condition, are still found in the majority of zones in which they were expected. These include Australian smelt, carp gudgeons, golden perch and two-spined blackfish. Others such as Macquarie perch and trout cod were caught in only 11% of zones in which they were expected; and some smaller species such as olive perchlet and eastern purple-spotted gudgeon are reduced even further. Murray cod were found in more than half the zones in which they were expected and, with six other species, were caught in zones in which they were not predicted to occur.

Amongst the 28 fish species of which more than 10 specimens were caught during fish sampling cycle 2, silver perch was the only one for which no evidence of recruitment was recorded (from 39 individuals, in 11 zones and eight valleys). This situation may need further investigation in the future.

Figure 5.8 presents maps indicating the zones in which four widely-valued native species, golden perch, Murray cod, trout cod, and Macquarie perch, were captured during cycle 2 (2008–2010) fish sampling, relative to Reference Condition. The maps make no comment on current population densities, but do indicate substantial changes in the spatial distribution of the two latter species. There is also some indication that these desirable angling species may have been introduced to streams outside their natural range. The influence of fish-stocking programs (and accidental releases) on the current condition of the Basin's fish community, particularly under the recent extended drought conditions, is difficult to assess. Further research is required in this area.

Table 5.9 presents a summary of recruitment data for each fish species captured during the SRA 2 sampling cycle (including the spotted galaxias, a native species not predicted to occur in the Basin). The data are ordered according to life-cycle duration. For long-lived species (life-cycle code = 3) and those with a medium life expectancy (code = 2) the status of individual fish (adult or recruit) is determined against a predetermined body length set by expert opinion (through the Fish Technical Advisory Group). Fish with a life-cycle code of 1 are short-lived species for which the presence of individuals is taken as indicating recruitment. It follows that, for these species, the percentage of recruits in any extant population is deemed to be 100%.

The data are presented in two forms: the first dealing with the number of individual fish (total and recruits); the second reporting the number of sampling sites at which individuals of each species were captured and the number of sites at which at least some of those individuals were deemed to be recruits. The former provides a general indication of recent levels of recruitment within extant populations of each species (across the Basin). The latter provides information on the spatial patchiness of recruitment within the current range of each species (excluding short-lived species).

The data indicate that, for almost all native species captured during the SRA 2 sampling cycle (2008–2010), there was some evidence of recruitment. Exceptions include climbing galaxias and spotted galaxias—for which all specimens caught during SRA 2 sampling were considered to be translocations—and the endangered species southern purple-spotted gudgeon, of which six specimens were captured at two sites with none considered to be recruits. Perhaps the most notable failure to recruit was in the silver perch population. A total of 39 individuals were captured at 17 sites spread among eight valleys; but none was considered to be a recruit. This may reflect the lack of appropriate flow signals during the drought conditions that prevailed during and immediately prior to 2008–2010. The species' low densities across its current range heighten the risk from extended recruitment failure in the future. The proportion of recruits amongst the more numerous golden perch was also low a 12.9%.

Macquarie perch and trout cod were also caught in low numbers (12 and 23 respectively)—both in only four of the 35 zones in which they were expected (see Table 5.8). Both species, however, had a moderate proportion of recruits in their populations

Table 5.6. Numbers of fish species predicted and observed in valleys.

'Predicted' (RC–F) species are those listed in the Reference Condition list for each valley. 'Observed' species are those recorded in samples; 'Introduced' species are native to Australian rivers but are not predicted to occur in the Murray–Darling Basin; 'Translocated' species are native to other parts of the Basin, but are not in RC–FI; 'Alien' species are not native to Australia.

Valley	Native species			
	Predicted	Observed	Introduced/ translocated	Alien species
Avoca	16	7	0	5
Border Rivers	15	14	0	4
Broken	23	11	1	5
Campaspe	23	9	0	6
Castlereagh	14	6	0	3
Condamine	18	12	0	3
Darling	18	9	0	3
Goulburn	25	13	0	6
Gwydir	15	11	0	4
Kiewa	17	7	0	7
Lachlan	18	6	0	6
Loddon	22	13	0	6
Macquarie	19	10	0	5
Mitta Mitta	16	8	0	5
Murray, Central	35	15	0	5
Murray, Lower	22	12	0	4
Murray, Upper	16	12	1	6
Murrumbidgee	22	12	0	6
Namoi	15	11	0	4
Ovens	22	12	0	6
Paroo	13	6	0	3
Warrego	14	9	0	3
Wimmera	6	9	3	5

(33% and 35% respectively); though Macquarie perch had recruits at only one sampling site. Murray cod was caught at 97 sampling sites (in 34 of the 58 zones in which it was expected under Reference Condition) and recruits were observed at more than half of those sites. Although 41% of the 122 freshwater catfish caught were recruits, their spatial distribution was patchy; recruits being found in only 16.7% of sites in which the species occurred. Recruitment in the mountain galaxias population was extremely low (12 individuals of a total of 1,704 considered to be recruits) and spatially limited. Populations of river blackfish and two-spined blackfish also contained relatively few recruits; though, for the latter species, recruits were found at more than 60% of sites in which it was captured.

Amongst the alien species, no recruits were observed for tench, crucian carp, and oriental weatherloach; the latter two species being found in very small numbers (one and three individuals) at only one site each. Over 60% of the substantial and widespread population of common carp were judged to be recruits and occurred at more than 60% of sites at which the species was captured.

The proportion of recruits in a population is an expression of a number of drivers including the life strategies of the species, density-dependent factors, and environmental impacts and disturbance. For this reason, two species, though both in dynamic equilibrium within their environments, might have quite different proportions of recruits in their populations. Similarly, a very high proportion of recruits in the population may reflect an extremely successful period of recruitment or the mortality selectively impacting on adult fish (e.g. from disease or fishing pressure). Continuing to measure the pattern of recruitment in key fish species over time will provide valuable and integrated insights into the ecological condition of the Murray–Darling Basin fish community.

5.3.3 Numbers and biomass

Figure 5.9 shows that numbers of alien and native fish per site varied widely among valleys. The Broken, Wimmera, and Campaspe valleys had less than 15 native fish individuals per site; and the Avoca, Goulburn, Kiewa, Loddon, Mitta Mitta, Murrumbidgee, Namoi and Upper Murray valleys had between 15 and 30 native fish per site. During 2004–2007, the Lower Murray Valley recorded the highest number of native fish per site (at 197). Again in 2008–2010, the Lower Murray Valley yielded 197 native fish per site. Two other valleys—the Warrego and the Condamine—both recorded higher catches (of 211 and 348 native fish per site respectively). Both of these valleys experienced higher than average rainfall during the period–at least in some zones. Alien species made up more than half the numbers of fish in ten valleys—with more than 75% of fish numbers in the Campaspe, Kiewa, and Murrumbidgee valleys comprised of alien species. At the other end of the scale: the Border Rivers, Condamine, Darling, Central Murray, Paroo and Warrego valleys all had native species contributing more than 75% of their total fish numbers.

Figure 5.10 shows somewhat different trends for biomass. In four valleys: Avoca, Campaspe, Mitta Mitta and Upper Murray; over 90% of the total fish biomass was in the form of alien species. And for all but five valleys—Border Rivers, Condamine, Darling and Warrego—alien fish provided more than half the total biomass. These proportional data are presented in numerical form in Table 5.9.

Of the total catch of 4.49 tonnes: 3.01 tonnes were alien species; of which 2.71 tonnes—90% (or 60% of the total catch)—were common carp. A major part of the native fish biomass (1.48 tonnes) came from large-bodied species: Murray cod (0.53 tonnes); golden perch (0.39 tonnes); and the smaller but more numerous bony herring (0.42 tonnes).

The Lower Murray yielded the largest biomass of fish (26.9 Kg/site); but only 30.6% of this (8.23 Kg/site) was contributed by native species. The Darling and Border Rivers valleys had the highest proportions of native species in the biomass of fish caught (65% and 63% respectively). Three other valleys: the Condamine, Paroo and Warrego; had more than 50% native species in their fish biomass. In the Avoca and Mitta Mitta valleys less than 4% of the fish biomass caught was made up of native species.

5.3.4 Observed and predicted communities

Table 5.5 demonstrates the prevalence of alien species throughout the Basin, and compares the numbers of observed and predicted species in each valley. The disparities are an indication of the condition of the native community in each valley. 'Predicted' species for the valleys are specified by aggregating the Reference Condition for Fish (RC–FI) in each zone (Section 3.3.5). As a consequence the column headed 'Introduced/Translocated' refers only to species not predicted to occur in the valley. Translocations between zones within a valley are not included (but see Table 5.8).

In the following analysis, the observed differences among valley fish communities were found not to be related to the year (2008–2010) in which the valley was sampled (ANOSIM analysis of un-transformed counts of individuals: $P = 0.55$ NS; PRIMER v.5, Plymouth Marine Laboratory, UK). This validates a comparison between valleys without having to consider the influence of individual sampling years. A similar analysis failed to demonstrate a consistent significant relationship between the observed fish community and rainfall in the year preceding sampling, at the valley scale.

Figure 5.11 shows an ordination 'map' of fish communities in the 23 valleys. Each valley is represented by two points: the Reference

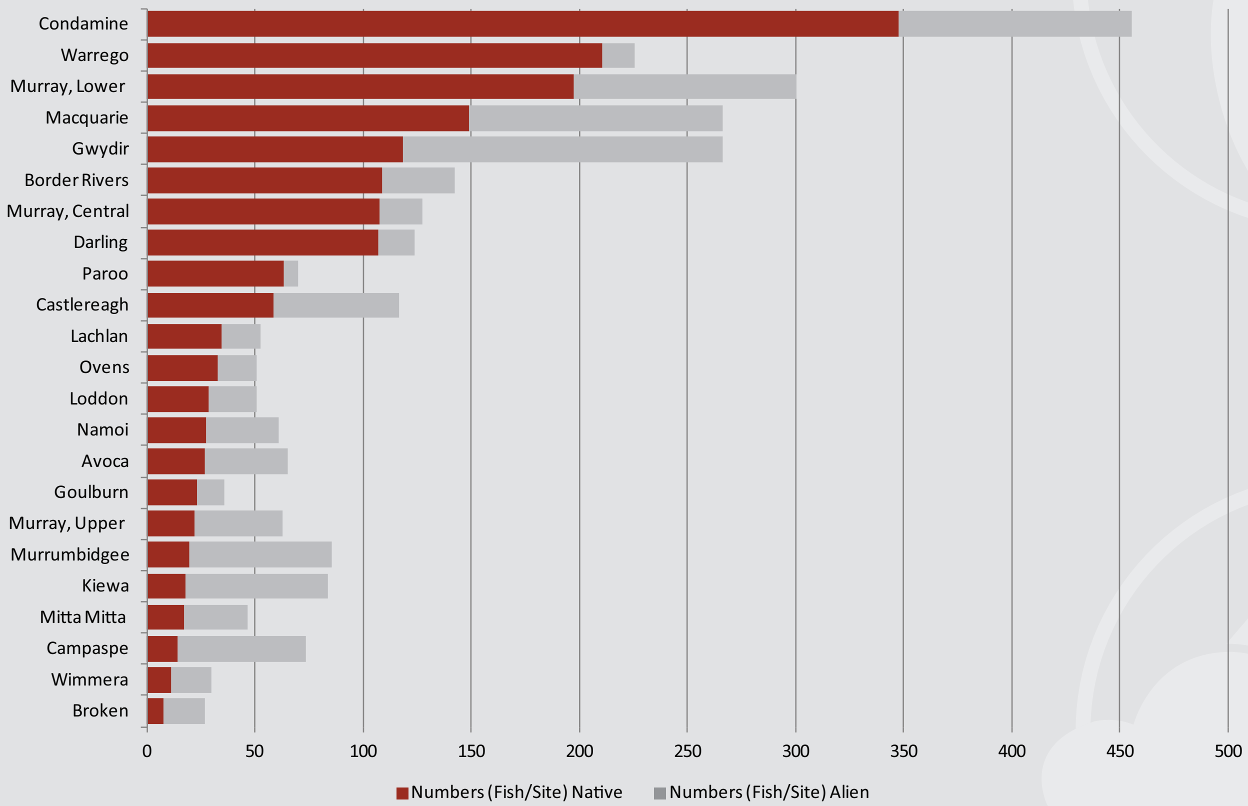


Figure 5.9. Average fish numbers per site in valleys, ranked by numbers of native fish.

Condition community (circled by a dotted line) and the observed community. Each pair is joined by a line, with the valley name against the 'observed' point. The map is generated through non-metric Multi-dimensional Scaling (MDS) which reduces a multidimensional matrix of Bray–Curtis distances between all possible pairings of communities to a two-dimensional representation. Transformation of the data is necessary before comparisons can be made between Reference communities and observed communities. The latter are represented by counts of fish in the samples taken in each valley. Reference communities are represented by the rarity scores for each species expected to be caught. To allow reasonable comparisons to be made the data are 'normalised' by expressing each count/rarity score as a proportion of the total counts/rarity scores for that valley. This means that the data used for the analysis are the *relative* densities of each species within each observed or reference community. The process makes possible the comparison between reference and observed communities; but it does remove the influence of differences in fish densities amongst valleys when comparing observed communities.

The distance between points on the ordination map is reflective of the difference in relative species composition between communities. Figure 5.11 shows that, under Reference Condition, fish communities were more similar among valleys than they were during the 2008–2010 survey. The lines linking reference and observed communities all lie in the same general direction (left to right) suggesting that the nature of differences between these communities is similar for all valleys—presumably involving changes in the relative abundance of native species (including loss of species) and the introduction of alien fish. Variations in the slope of these connecting lines may reflect differences in degree of these changes amongst valleys and other factors including the mix of biogeographic zones within valleys may also contribute.

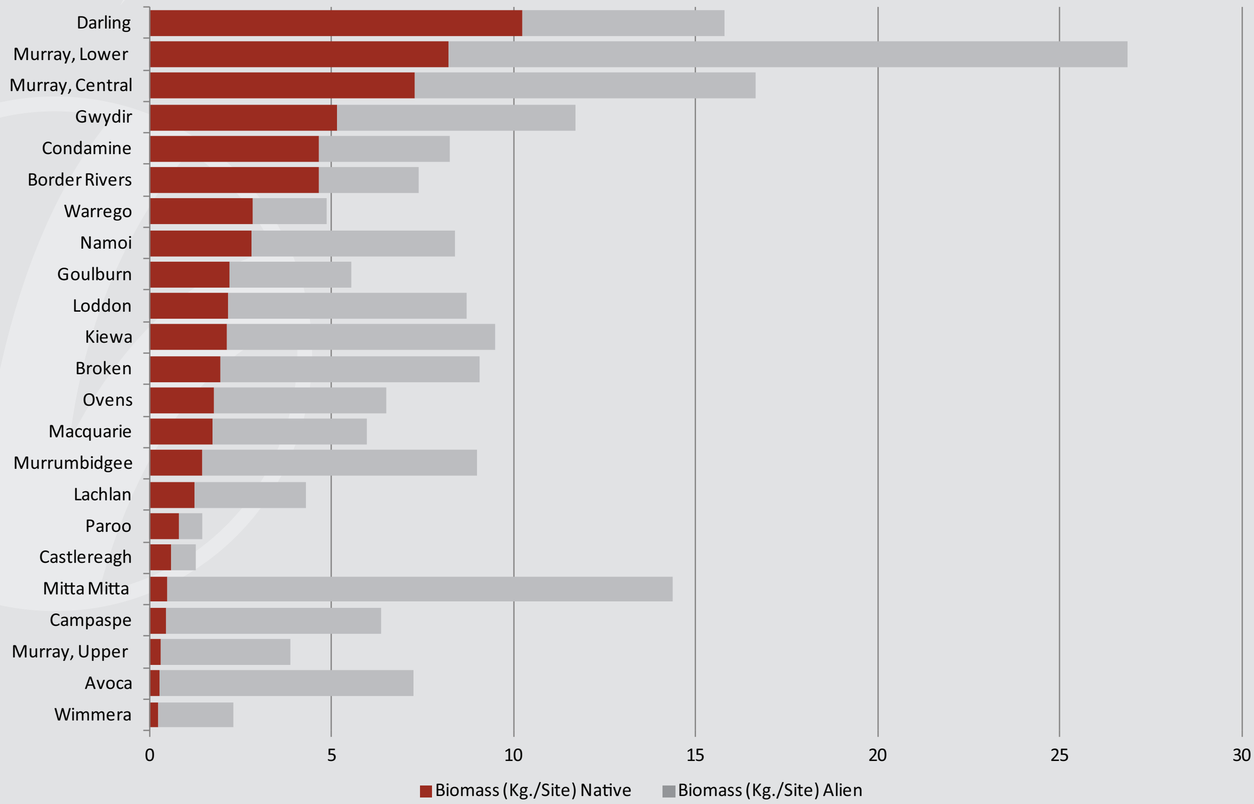


Figure 5.10. Average total fish biomass (kg) per site in valleys, ranked by biomass of native fish.

Table 5.7. **Relative abundance of fish species.**
(The list is ranked by total catch. The numbers of valleys where species were recorded are also shown. Alien species are shaded).

Rank	Species	Common name	Total catch	Valleys
1	*Nematalosa erebi*	Bony herring	14,818	14
2	*Gambusia holbrooki*	Gambusia	14,101	23
3	*Hypseleotris spp*	Carp gudgeon complex	11,280	20
4	*Cyprinus carpio*	Common carp	6,017	23
5	*Retropinna semoni*	Australian smelt	1,987	21
6	*Perca fluviatilis*	Redfin perch	1,749	17
7	*Leiopotherapon unicolor*	Spangled perch	1,709	8
8	*Galaxias olidus*	Mountain galaxias	1,704	11
9	*Craterocephalus stercusmuscarum fulvus*	Unspecked hardyhead	1,413	11
10	*Carassius auratus*	Goldfish	1,064	22
11	*Salmo trutta*	Brown trout	942	11
12	*Gadopsis bispinosus*	Two-spined blackfish	863	7
13	*Philypnodon grandiceps*	Flathead gudgeon	816	12
14	*Melanotaenia fluviatilis*	Murray–Darling rainbowfish	806	13
15	*Macquaria ambigua ambigua*	Golden perch	799	21
16	*Galaxias sp1*	Obscure galaxias complex	712	11
17	*Oncorhynchus mykiss*	Rainbow trout	666	9
18	*Maccullochella peelii*	Murray cod	550	20
19	*Gadopsis marmoratus*	River blackfish	419	13
20	*Galaxias sp2*	Galaxias	160	5
21	*Nannoperca australis*	Southern pygmy perch	157	7
22	*Tandanus tandanus*	Freshwater catfish	122	11
23	*Tinca tinca*	Tench	55	3
24	*Craterocephalus amniculus*	Darling River hardyhead	44	1
25	*Bidyanus bidyanus*	Silver perch	39	8
26	*Neosilurus hyrtlii*	Hyrtl's tandan	32	4
27	*Maccullochella macquariensis*	Trout cod	23	3

Continued/...

Table 5.7. Relative abundance of fish species.

(The list is ranked by total catch. The numbers of valleys where species were recorded are also shown. Alien species are shaded).

Rank	Species	Common name	Total catch	Valleys
28	*Macquaria australasica*	Macquarie perch	12	3
29	*Galaxias brevipinnis*	Climbing galaxias	8	2
30	*Galaxias maculatus*	Common jollytail	7	2
31	*Mogurnda adspersa*	Southern purple-spotted gudgeon	6	1
32	*Ambassis agassizii*	Olive perchlet	5	2
33	*Philypnodon sp1*	Dwarf flathead gudgeon	4	2
34	*Misgurnus anguillicaudatus*	Oriental weatherloach	3	1
35	*Galaxias truttaceus*	Spotted galaxias	2	1
36	*Carassius carassius*	Crucian carp	1	1

The distribution (vertical pattern) of reference communities on the map and also, to a large extent, the distribution of observed communities, reflects the spatial distribution of valleys within the Murray–Darling Basin. This is an indication of the influence of biogeographic factors at that scale on the relative species composition of fish communities.

5.3.5 Zone communities

Each valley in the SRA is divided into zones that provide a basis for spatially stratifying the random location of sampling sites. These zones accord with biogeographical differences that are delineated in reference to altitude, except in the Lower and Central Murray and Darling valleys (Section 2.2.3). In these exceptions, the main-channel zones are comparable to a 'Lowland zone' in terms of altitude and, it is assumed, biogeographically; and the Mt Lofty zone in the Lower Murray Valley is comparable to a 'Slopes' zone. In the following discussion, where zones are reclassified in this way, they are referred to as *altitudinal zones*.

There are several potential bioregional gradients across the Murray–Darling Basin. For instance, it is possible to identify two sub-basins based on annual rainfall patterns: a northern region, in which summer rainfall predominates, significantly influenced by monsoonal cycles; and a southern region, bounded to the north by the Macquarie Valley, in which rainfall peaks during winter and spring. Other characteristics tend to vary along this 'north-south' gradient, including inter-annual flow variability and total flow volume (catchment yield), see Section 5.7.

Table 5.10 presents the fish catch data for sampling cycle 2 (2008–2010) expressed as the mean number of fish per site and the mean fish biomass (g) per site, broken down according to sub-basin and altitudinal zone. On average, northern sub-basin sites had about three times as many individual native fish (124) as did southern sites (44); though fish densities varied substantially between valleys (e.g. Figure 5.9). Native species were numerically dominant in the lowland and slopes zones of northern valleys and the lowland zones of southern valleys. In terms of biomass, native and alien species were approximately equivalent in northern valleys; but alien biomass exceeded that of native species in the southern sub-basin by factors ranging from two in lowland zones to 11 in the montane. The latter ratio probably reflects the

Table 5.8. **Records of predicted fish species by zones.**

Numbers of zones where species were predicted to occur, compared to the numbers of zones in which they were caught. Common names follow Lintermans (2007).

Common name	Zones predicted	Zones captured*	Percent	Translocation
Australian smelt	59	41	69	
Barred galaxias	1			
Black bream	1			
Blue spot goby	1			
Bony herring	37	28	76	
Carp gudgeon complex	2			
Climbing galaxias	1	4		4
Common jollytail	3	2	33	1
Congolli	7			
Darling River hardyhead	9	1	11	
Desert rainbowfish	3			
Dwarf flathead gudgeon	14	3	21	
Estuary perch	2			
Flathead gudgeon	37	21	57	
Freshwater catfish	51	18	33	1
Galaxias	17	10	59	
Galaxias olidus complex	45			
Golden perch	52	43	79	2
Gudgeon	55	44	78	1
Hyrtl's tandan	7	5	71	
Lagoon goby	1			
Macquarie perch	35	4	11	
Mountain galaxias	38	16	42	

Common name	Zones predicted	Zones captured*	Percent	Translocation
Murray cod	58	37	59	3
Murray hardyhead	13			
Murray jollytail	26			
Murray–Darling rainbowfish	41	23	56	
Obscure galaxias complex	24	16	63	1
Olive perchlet	29	2	7	
Pouched lamprey	3			
Rendahl's tandan	3			
River blackfish	48	18	38	
Sandy sprat	1			
Short-finned eel	4			
Shortheaded lamprey	15			
Silver perch	49	11	22	
Small-mouthed hardyhead	1			
Southern purple-spotted gudgeon	44	2	5	
Southern pygmy perch	35	9	26	
Spangled perch	22	16	73	
Spotted galaxias	1	1	100	
Trout cod	35	4	11	
Two-spined blackfish	19	17	89	
Unspecked hardyhead	39	16	41	
Yarra pygmy perch	1			
Yellow-eyed mullet	1			

*including suspected translocations.

Table 5.9. Summary of recruitment data for all fish species caught during report sampling cycle 2 (2008–2010).

Life-cycle code: 3 = long-lived species; 2 = medium life span;
1 = short-lived species for which recruitment is indicated by presence (i.e. total recruits = total individuals). Percentages are rounded.

Common Name	Life-cycle code	Total caught	Recruits caught	% age recruits	Sites in which caught	Sites with recruits	% sites with recruits
NATIVE TAXA							
Freshwater catfish	3	122	50	41	36	6	17
Golden perch	3	799	103	13	154	32	21
Macquarie perch	3	12	4	33	4	1	25
Murray cod	3	550	204	37	97	54	56
Silver perch	3	39	0	0	17	0	0
Trout cod	3	23	8	35	10	6	60
Bony herring	2	14,818	7,105	48	160	122	76
Climbing galaxias	2	8	0	0	6	0	0
Common jollytail	2	7	4	57	5	3	60
Flathead gudgeon	2	816	138	17	79	37	47
Galaxias	2	160	11	7	19	6	32
Hyrtl's tandan	2	32	20	63	13	8	62
Mountain galaxias	2	1,704	12	1	41	3	7
Obscure galaxias complex	2	712	329	46	36	16	44
River blackfish	2	419	37	9	51	10	20
Southern purple-spotted gudgeon	2	6	0		2	0	0
Spangled perch	2	1,709	1,376	81	81	65	80
Spotted galaxias	2	2	0	0	1	0	0
Two-spined blackfish	2	863	159	18	58	37	64
Australian smelt	1	1,987	1,987	100	137	137	100

Continued/...

Common Name	Life-cycle code	Total caught	Recruits caught	% age recruits	Sites in which caught	Sites with recruits	% sites with recruits
Darling River hardyhead	1	44	44	100	2	2	100
Dwarf flathead gudgeon	1	4	4	100	3	3	100
Gudgeon	1	11,280	11,280	100	171	171	100
Murray–Darling rainbowfish	1	806	806	100	82	82	100
Olive perchlet	1	5	5	100	4	4	100
Southern pygmy perch	1	157	157	100	13	13	100
Unspecked hardyhead	1	1,413	1,413	100	52	52	100
ALIEN TAXA							
Brown trout	3	942	451	48	75	53	71
Common carp	3	6,017	3,712	62	291	178	61
Redfin perch	3	1,749	1,614	92	89	75	84
Tench	3	55	0	0	7	0	0
Crucian carp	2	1	0	0	1	0	0
Goldfish	2	1,064	187	18	172	32	19
Oriental weatherloach	2	3	0	0	1	0	0
Rainbow trout	2	666	283	43	53	42	79
Gambusia	1	14,101	14,101	100	231	231	100

large body mass of trout relative to the native species inhabiting these zones. The estimates for introduced/translocated species are based on few individuals (e.g. 20 fish in the northern sub-basin) and are therefore highly variable. The relatively large biomass estimates result from the translocation of large-bodied native species: Murray cod in the montane zones of the Gwydir, Border Rivers, and Namoi valleys in the north; and golden perch in the Wimmera Slopes zone.

Figure 5.11 shows the estimates of the Fish Condition Index (SR–FI) and its constituent indicators (Expectedness, Nativeness, and Recruitment) at the zone scale. At this scale the Index and indicators showed a large range of mean values: 0–83.4; 1.1–100; 0.2–94 and 0–97.1 respectively. The data imply that the condition of fish communities tends to vary systematically across the Basin and among zones within valleys. In general terms, fish communities are in better condition in the northern sub-basin compared to the south and, within this stricture, the fish communities of zones in the lower altitudes (lowland and slopes) tend to be in better condition than those of elevated zones (upland and

Figure 5.11. Ordination of fish communities.

Observed and Reference Condition communities for each valley, with lines linking the members of each pair. Plots generated by Multi-dimensional Scaling on a normalised Bray–Curtis distance matrix. (PC-ORD v. 5.12: MjM Software, Oregon). Stress for 2-D solution: 15%.

montane). Thus 73% of zones in the northern sub-basin (19 of 26) are in the upper 50% of Fish Condition Index scores as against 36% (15 of 42) in the southern sub-basin (Table 5.11a). This pattern is repeated for the three indicators that combine to create the Fish Condition Index (Table 5.11 b. c. and d). Within the differences between northern and southern valleys, fish communities of lower altitude zones (lowland and slope) tend to be in better condition than those of upper altitude zones (upland and montane). In the northern sub-basin, 15 of the 18 lowland and slope zones (83%) had Fish Condition Index scores in the upper half of the range, as compared to 50% (four of eight) for elevated zones (upland and montane). Equivalent values for the southern sub-basin were 41% (12 of 29) and 23% (three of 13) (Table 5.11a). A similar pattern is evident for the three indicator values.

The three indicators that combine to create the SRA Fish Condition Index (FishExpect, FishNative and FishRecruit) emphasise three different aspects of the ecology of fish communities in the Basin. The first reports on 'expectedness' and refers to the

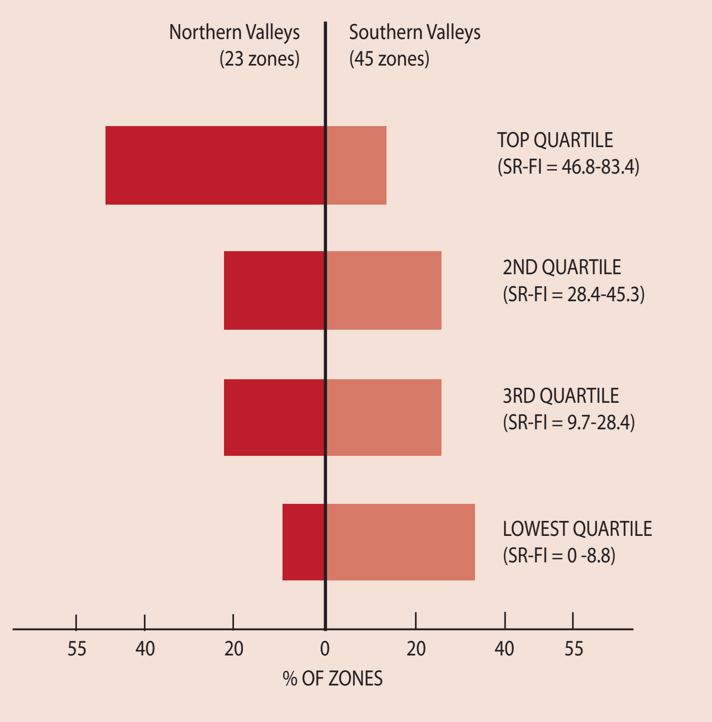
Table 5.10. Numbers and biomass (g) of fish per site, by sub-basin and altitudinal zone.
(Biomass data >10 g are rounded. 'Int/Tran' = Introduced or Translocated native species).

Sub-basin	Alt. zone	No. of sites	Mean fish per site			Mean biomass per site (g)			Mean biomass per fish (g)		
			Native	Alien	Int./Tran.	Native	Alien	Int./Tran.	Native	Alien	Int./Tran.
Summer	Lowland	94	122	53	0.0	3546	3261	0.00	29	62	0.0
	Slopes	51	190	55	0.0	5571	5813	0.00	29	106	0.0
	Upland	35	56	69	0.0	3447	3547	0.00	62	51	0.0
	Montane	21	86	104	1.4	1401	972	1035.86	16	9	725.1
Winter–Spring	Lowland	123	76	26	0.0	5101	11325	5.17	68	438	106.0
	Slopes	95	27	67	0.1	681	6087	28.06	25	91	380.9
	Upland	56	13	36	0.6	435	3868	1.75	35	108	2.7
	Montane	35	29	21	0.1	188	2106	0.71	7	102	12.5

number and population density of native fish species. 'Nativeness' assesses the relative contribution of native and alien species to the fish community and 'Recruitment' reflects the recruitment success of those native fish populations present in a zone or valley. The relative value of the three indicators in a particular zone (or valley) provides some insight into the aspects of fish ecology most influencing fish condition there. In particular, the indicator ranked lowest may point towards characteristics most limiting fish condition in any zone. Table 5.12 reports on zones in which each of the three indicators has the lowest value. In 30 of the 68 zones FishExpect was lowest. FishNative was the lowest fish indicator in 11 zones and FishRecruit in 27 zones. This ratio (30:10:28) was largely reflected in total in the two sub-basins (north and south) and in two of the altitudinal (biogeographical) groups (Slopes and Upland). Lowland zones showed a bias towards low expectedness scores, relative to other indicator; although the percentage of expected species observed in these zones was equivalent to that in Slopes and Upland zones (49% compared to 51% and 43% respectively). Shortfalls in expectedness in these zones may relate to changes in population density of the remaining native species, or possibly to

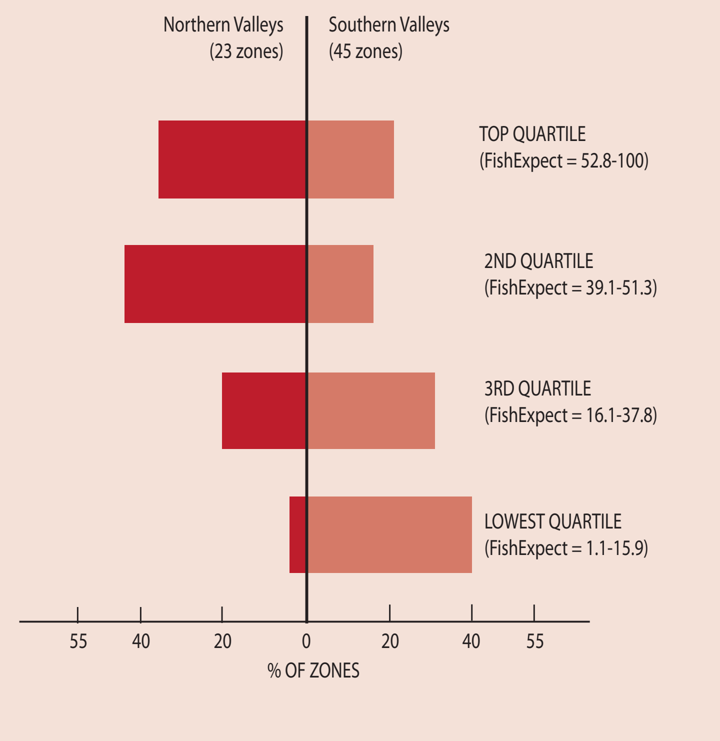
Table 5.11. Distribution of median Fish Index (SR–FI) (a) and Indicator values (b–d) at the zone level sorted by sub-basin and altitudinal zone.

Sub-basin	Alt. zone	Count	1st quartile	2nd quartile	3rd quartile	4th quartile
Northern	Lowland	11	6	3	1	1
	Slopes	7	5	1	1	0
	Upland	5	1	2	1	1
	Montane	3	0	1	2	0
	TOTAL	26	12	7	5	2
Southern	Lowland	16	2	7	3	4
	Slopes	13	3	0	5	5
	Upland	8	0	2	2	4
	Montane	5	0	1	2	2
	TOTAL	42	5	10	12	15



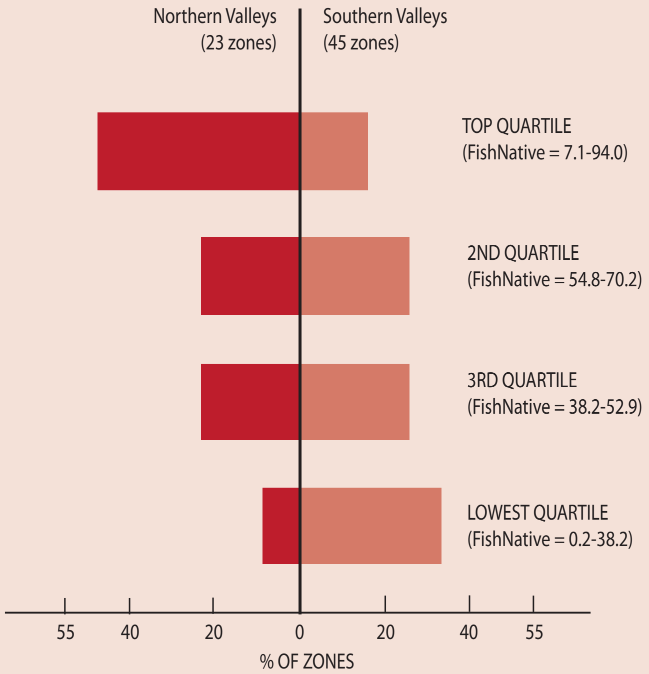
a. (above) Fish Condition Index (SR–FI)

Sub-basin	Alt. zone	Count	1st quartile	2nd quartile	3rd quartile	4th quartile
Northern	Lowland	11	2	7	1	1
	Slopes	7	4	1	2	0
	Upland	5	1	2	2	0
	Montane	3	2	1	0	0
	TOTAL	26	9	11	5	1
Southern	Lowland	16	3	4	6	3
	Slopes	13	3	1	2	7
	Upland	8	0	0	3	5
	Montane	5	2	1	1	1
	TOTAL	42	8	6	12	16



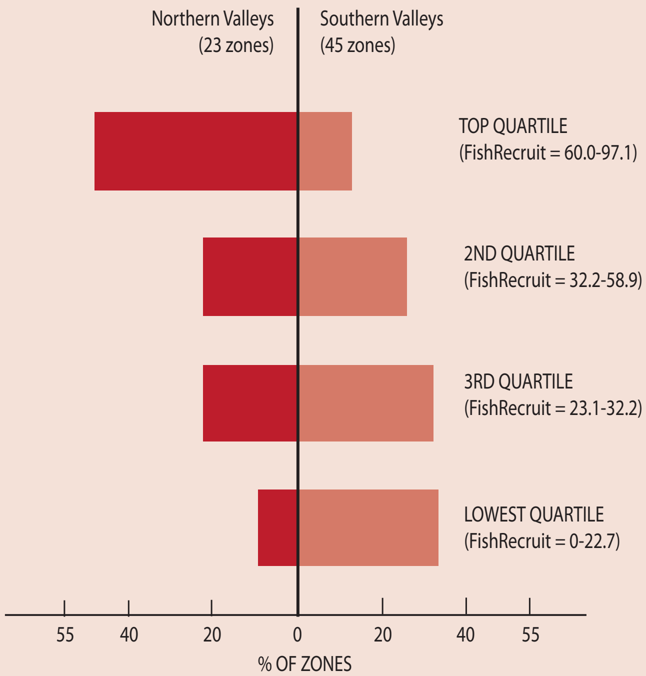
b. (above) Fish Expectedness indicator (SR–FI*e*)

Sub-basin	Alt. zone	Count	1st quartile	2nd quartile	3rd quartile	4th quartile
Northern	Lowland	11	5	3	2	1
	Slopes	7	4	2	1	0
	Upland	5	1	1	2	1
	Montane	3	1	0	1	1
	TOTAL	26	11	6	6	3
Southern	Lowland	16	3	6	3	4
	Slopes	13	2	5	2	4
	Upland	8	0	0	5	3
	Montane	5	1	0	1	3
	TOTAL	42	6	11	11	14



c. (above) Fish Nativeness indicator (SR–FI*n*)

Sub-basin	Alt. zone	Count	1st quartile	2nd quartile	3rd quartile	4th quartile
Northern	Lowland	11	6	3	2	0
	Slopes	7	4	2	1	0
	Upland	5	1	2	1	1
	Montane	3	0	1	0	2
	TOTAL	26	11	8	4	3
Southern	Lowland	16	3	5	7	1
	Slopes	13	1	3	3	6
	Upland	8	2	1	1	4
	Montane	5	0	0	2	3
	TOTAL	42	6	9	13	14



d. (above) Fish Recruitment indicator (SR–FI*r*)

Table 5.12. Number of zones in which each indicator is the lowest, sorted by sub-basin and altitudinal zone.

Lowest indicator	Number of zones	Lowland	Slopes	Upland	Montane	North basin	South basin
FishExpect	30	17	8	5	0	11	19
FishNative	11	2	2	4	3	4	7
FishRecruit	27	7	10	5	5	11	16
TOTAL	68	26	20	14	8	26	42

behavioural response to drought conditions amongst some species. In none of the eight Montane zones was FishExpect the lowest Index. On average, 62% of expected species were observed in these zones. FishRecruit was the lowest Index in five Montane zones. There are a number of potential contributing factors including the possibility that extended drought conditions—perhaps particularly severe in small upland streams—is limiting reproduction; and/or the presence of large piscivorous alien species poses an increased threat to the survival of young fish under refugial conditions. Targeted investigations are needed to test such speculations.

5.4 Macroinvertebrates

5.4.1 Condition indices

Figure 5.12 shows mean Macroinvertebrate Condition Index (SR–MI) for all valleys, arranged in descending order. These are also shown in Table 5.13, alongside values for the simOE metric. The valleys form three broad groups (A, B, C), and Group B may be sub-divided into B1 (near Group A) and B2 (near Group C).

Group A contains the Kiewa, Mitta Mitta, Paroo, Upper Murray and Warrego valleys, with SR–MI scores of 84–90.

Group B1 includes five valleys (Broken, Ovens, Castlereagh, Condamine and Lower Murray with SR–MI scores of 76–80. Four members of Groups A and B1 (Castlereagh, Condamine, Paroo and Warrego) are in the northerly summer rainfall region of the Basin; and six (Broken, Kiewa, Mitta Mitta, Ovens, Lower Murray and Upper Murray valleys) are in the southern winter–spring rainfall region.

Group B2 contains 10 valleys (Avoca, Border Rivers, Campaspe, Gwydir, Lachlan, Loddon, Macquarie, Murrumbidgee, Namoi and Wimmera) with SR–MI scores of 62–72. Six members of Group B2, are in the northern summer rainfall region of the Basin.

Group C contains three valleys with low SR–MI scores of 53–56 (Central Murray, Darling, Goulburn), all in the southern winter-spring rainfall part of the Basin.

Note that the distributions of the valley mean Macroinvertebrate Condition Index (SR–MI) is shown for all three sampling cycles in Section 6.

Values of SR–MI differ considerably between zone types. SR–MI values increase with altitude from Lowland through Slopes to Upland and Montane (Figure 5.13), with considerably higher proportions of Lowland zones rated as Poor (SR–MI = 40–60) than for other zones. Lowland zone SR–MI values are significantly lower than those for all other zones ($p < 0.01$ by Analysis of Variance or ANOVA) across the entire Basin.

There are substantial differences in zone scores between the northern (Darling drainage) and southern (Murray drainage) regions of the Basin (Figure 5.14). There are no differences between these regions in the condition of Lowland zone macroinvertebrate communities, with the majority falling in the Poor to Moderate score ranges (SR–MI = 50–70). By contrast, the Slopes, Upland and Montane zones macroinvertebrate communities in the northern region are more frequently in Good condition (SR–MI = 80–100) than those of the southern region (Figure 5.14). Valleys in the northern Darling sub-basin had significantly lower Lowland zone SR–MI values than in higher altitude zones; but this was not as evident in the southern Murray sub-basin, in which lowland SR–MI values were significantly lower than for Upland and Montane zones combined ($p < 0.05$ by ANOVA), but not Slopes zones.

5.4.2 Families recorded

All valleys (797 sites) were sampled once for macroinvertebrates between September 2008 and July 2010, yielding over 216,454 specimens in 116 families (strictly, a mixture of taxonomic groups, most identified to family level). This

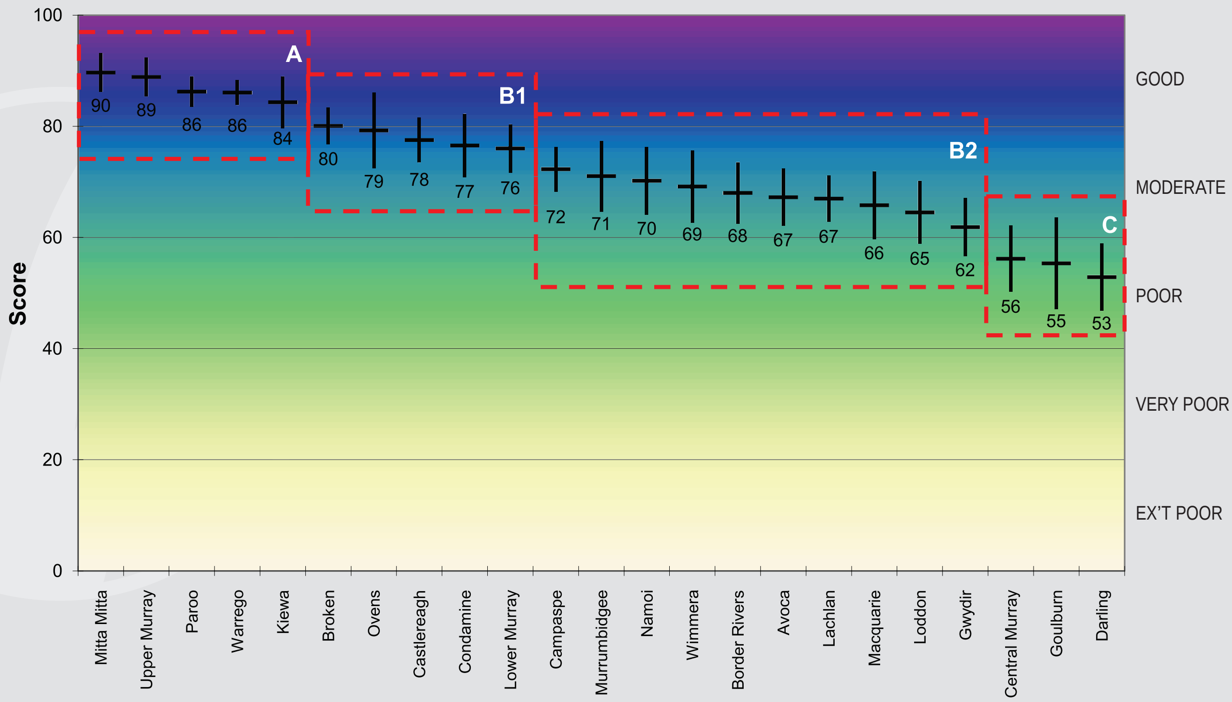


Figure 5.12. Valleys ranked by SR Macroinvertebrate Index (SR–MI) scores.

(Short horizontal bars are means; vertical lines show the associated 95% confidence limits). The range of means in each of four groups is shown alongside each label (A, B1, B2, C). For explanation of groups, see text. The SRA colour rating standard is shown with condition rating labels.
Data derived from the third SRA macroinvertebrate sampling cycle in 2008–2010.

provides a substantial basis upon which to assess macroinvertebrate communities in the Basin's rivers.

These assessments are for benthic (bottom-dwelling) macroinvertebrates in river channels. They are based on the composition of communities, based on the presence of families and their frequency of occurrence in samples. No estimates of absolute abundance or biomass are made; nor are crayfish, freshwater mussels and other large invertebrates considered, as standardised protocols have not yet been implemented. Failure to record a macroinvertebrate family in a valley may not mean that it was absent, but it is a reasonable indication that, if it was indeed present, it was not common.

Samples were taken at randomly selected sites, and exclusively from channels, not wetlands or other 'off-channel' sites (Section 3.4.2). Sampling was in edge and riffle habitats at each site, or in edge habitats only where riffles were absent (as in most lowland sites). Eight of the 23 valleys were sampled in edge habitats only at all sites; nine valleys were sampled mainly in edge habitats with riffles at a few sites; and three valleys were sampled at riffle and edge habitats at most or all sites. More information is shown in Table 5.14.

The frequencies of occurrence of each family across the Basin for the full SRA sampling program to date (reporting cycles 1 to 3, from 2004 to 2010) are summarised in Table 5.15 and 5.16. 'Common' and scientific names are available in identification guides, including Williams (1980), Hawking and Smith (1997), Gooderham and Tsyrlin (2002) and many Internet sources, including a web-based guide, with notes on ecology: www.mdfrc.org.au/bugguide/index.htm.

'Common' families across all valleys in the Basin were identified as being the upper 10% of families found in both all the valleys and the greatest number of sites across the Basin. 'Rare' families were identified as those taxa found in <10% of all the SRA sites sampled across the Basin in the three reporting cycles.

Table 5.15 shows twenty-two families that were ubiquitous (present in all 23 valleys). Many of these are families commonly found in edge and slow flowing river habitats throughout eastern Australia, are readily able to colonise fresh waters and generally are tolerant to pollution or human disturbance. All but three of these common taxa (Acarina [mites], Baetidae [mayflies], Leptoceridae [caddisflies]) have SIGNAL scores (Stream Invertebrate Grade Number Average Level: Chessman 2003) of four or less—out of a possible 10—indicating that they are mainly disturbance-tolerant.

Table 5.16 lists families that range from rare to common in the Basin. The rarer families occupy restricted ranges (for example, 20 families were each found at less than ten of the 783 sampled sites). Many of the rarer taxa had SIGNAL scores indicating moderate to high sensitivity to disturbance.

The valleys with the highest occurrence of rare families—with the greatest number of families at valley and site scales that were rare at Basin scale—are the Mitta Mitta, Murrumbidgee, Ovens and Upper Murray. The number of rare families found in these valleys ranged from 37 to 42, with a rare family being found at an average of every 1.6 to two sampling sites. Two valleys contained no rare taxa in any of the samples collected; i.e. all sites only contained families that were fairly common across the Basin. These were the Darling and the Lower Murray.

As expected, the occurrence of rare families is strongly influenced by location within a river system e.g. by altitudinal zone. Montane and Upland zones had much higher numbers of rare families in their 2004–2010 sample set (with a mean of 18.2 rare families per zone and 1.1 per site, across all Montane and Upland zones) when compared to Lowland zones (with a mean of 4.2 families per zone and 0.2 per site, across all Lowland zones). These differences were highly statistically significant (by ANOVA, at the $p < 0.000001$ level). The maximum values observed for

Table 5.13. **SR Macroinvertebrate Index (SR–MI) and associated metric.**
Data are means (lower–upper 95% confidence limits), in descending order of SR–MI

Valley	SR–MI	simOE	Total *n* families observed	Mean *n* families observed per site
Mitta Mitta	90 (87-92)	59 (57-61)	73	29
Murray, Upper	89 (86-92)	59 (56-61)	74	34
Paroo	86 (83-89)	56 (54-57)	38	18
Warrego	86 (83-89)	55 (53-57)	42	19
Kiewa	84 (80-88)	56 (53-58)	73	28
Broken	80 (77-83)	52 (51-54)	75	28
Ovens	79 (72-85)	53 (50-55)	77	28
Castlereagh	78 (74-81)	51 (49-53)	46	21
Condamine	77 (71-82)	51 (49-53)	44	19
Murray, Lower	76 (72-80)	51 (49-52)	50	16
Campaspe	72 (69-75)	49 (48-50)	49	21
Murrumbidgee	71 (67-75)	49 (47-51)	73	23
Namoi	70 (66-75)	48 (46-50)	67	23
Wimmera	69 (62-75)	48 (45-50)	52	17
Border Rivers	68 (63-73)	47 (45-49)	66	28
Avoca	67 (62-72)	46 (44-48)	43	16
Lachlan	67 (64-70)	46 (45-48)	63	27
Macquarie	66 (61-70)	46 (45-48)	67	21
Loddon	65 (59-69)	46 (43-48)	53	15
Gwydir	62 (57-66)	44 (43-46)	65	23
Murray, Central	56 (50-62)	42 (40-45)	52	22
Goulburn	55 (49-62)	43 (40-46)	82	28
Darling	53 (47-59)	41 (39-43)	41	13

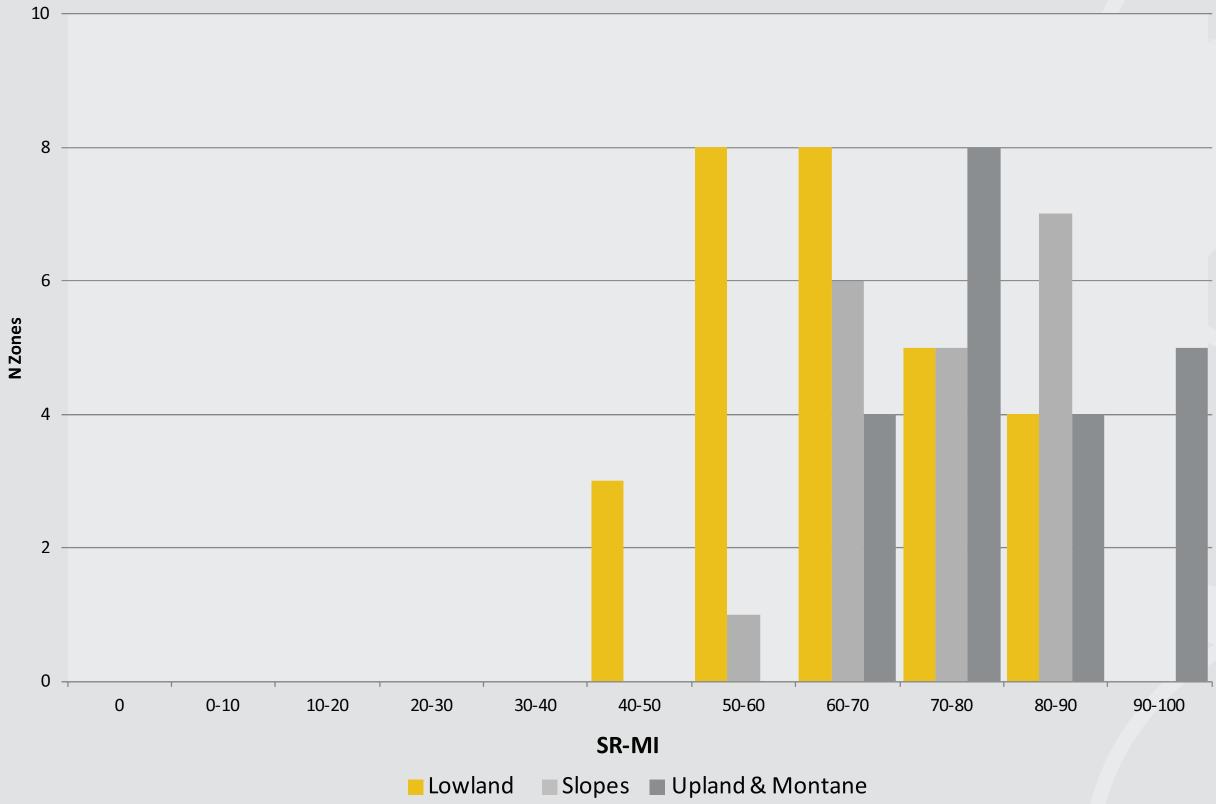


Figure 5.13. Distribution of zones by SR Macroinvertebrate Index (SR–MI) score across the Basin.

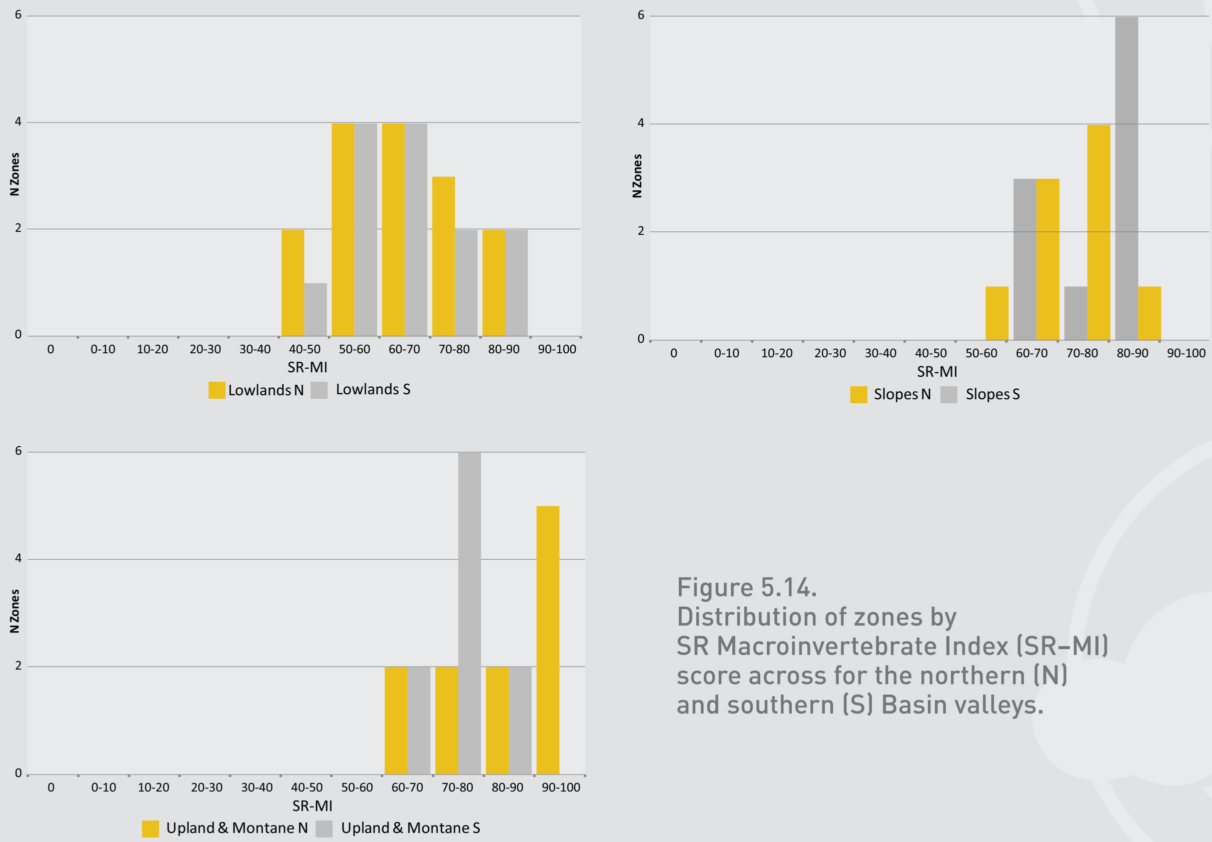


Figure 5.14.
Distribution of zones by
SR Macroinvertebrate Index (SR–MI)
score across for the northern (N)
and southern (S) Basin valleys.

Table 5.14. Macroinvertebrate habitats sampled in each valley.

Only edge (no riffle)	Most or all riffle and edge	Mostly edge (some riffle and edge)
Avoca	Broken (Slopes)	Border Rivers (Slopes, Montane)
Border Rivers	Kiewa (Slopes, Upland)	Castlereagh
Broken (Lowland)	Mitta Mitta	Goulburn
Campaspe	Murray, Upper	Gwydir
Condamine	Ovens (Slopes to Montane)	Kiewa (Lowland)
Darling		Lachlan
Murray, Central		Loddon
Murray, Lower		Macquarie
Ovens (Lowland)		Murrumbidgee
Paroo		Namoi
Warrego		Wimmera

all Montane and Upland zones were 38 rare families per zone and 3.0 per site, while for Lowland zones these values were 15 and 0.6, respectively. These differences reflect the combination of greater natural habitat and biological diversity with better environmental condition found in stream channels at higher altitudes.

5.4.3 Observed and expected communities

An ordination is a useful way to display the differences between the communities in each valley and those expected under Reference Condition. In this analysis, the 'Bray–Curtis distance metric' is applied to records of the presence and absence of families in valleys. Bray–Curtis distances are computed for all combinations of valleys, and then subjected to Multi-dimensional Scaling (e.g. McCune and Grace 2002). This produces a plot, like a map, showing the valley communities as points in space, separated by distances that show their similarity (or dissimilarity) to one another, in terms of composition.

Figure 5.15 shows such an ordination of macroinvertebrate communities. Each valley is represented by two points—the Reference Condition community and the observed community—joined by lines whose length and direction indicate the nature and size of the difference in composition. The distribution of observed and Reference Condition communities is influenced by the kinds of habitats sampled in each valley; it is the difference between observed and Reference Condition communities. However, that reflects a key aspect of condition. The observed valley communities are more widely dispersed, indicating greater variation in composition than for Reference Condition. The 'spread' of Reference Condition communities across the plot in Figure 5.15 reflects genuine

Table 5.15. Incidence of the most common macroinvertebrate families which occur in all valleys.

Note: Families ranked by occurrence at all sites. The numbers of valleys where families occurred are also shown.

Rank	Scientific name	Common name	No. of sites	No. of valleys
1	*Chironominae*	Midges	753	23 (all)
2	*Corixidae*	Water boatmen (bugs)	690	23 (all)
3	*Leptoceridae*	Longhorn caddisfly	648	23 (all)
4	*Tanypodinae*	Midges	643	23 (all)
5	*Dytiscidae*	Predaceous diving beetles	623	23 (all)
6	*Veliidae*	Riffle bugs; Water striders	597	23 (all)
7	*Ceratopogonidae*	Midges	576	23 (all)
8	*Hydrophilidae*	Water scavenger beetles	549	23 (all)
9	*Notonectidae*	Backswimmers (bugs)	544	23 (all)
10	*Acarina*	Aquatic mites	532	23 (all)
11	*Oligochaeta*	Freshwater worms	524	23 (all)
12	*Baetidae*	Mayflies	508	23 (all)
13	*Caenidae*	Mayflies	508	23 (all)
14	*Orthocladiinae*	Midges	497	23 (all)
15	*Hydraenidae*	Small water beetles	465	23 (all)
16	*Coenagrionidae*	Pond damselflies	358	23 (all)
17	*Physidae*	Pond or bladder snails	277	23 (all)
18	*Ecnomidae*	Ecnomid caddisflies	271	23 (all)
19	*Ancylidae*	Freshwater limpets	262	23 (all)
20	*Culicidae*	Mosquitoes	208	23 (all)
21	*Planorbidae*	Ramshorn or left-handed pond snails	181	23 (all)
22	*Gyrinidae*	Whirligig beetles	167	23 (all)

Table 5.16. Incidence of less common macroinvertebrate families.

Note: Families ranked by occurrence at all sites. The numbers of valleys where families occurred are also shown.

Rank	Families	No. of sites	No. of valleys
23–33	Leptophlebiidae, Atyidae, Parastacidae, Palaemonidae, Gerridae, Corduliidae, Simuliidae, Scirtidae, Tipulidae, Gripopterygidae, Gomphidae	200–380	17–22
34–45	Hydroptilidae, Hydrobiosidae, Elmidae, Aeshnidae, Hydropsychidae, Hydrometridae, Tabanidae, Ceinidae, Staphylinidae, Cirolanidae, Psephenidae, Libellulidae	100–200	9–21
46–63	Conoesucidae, Dixidae, Calamoceratidae, Oniscigastridae, Lestidae, Corydalidae, Sphaeriidae, Hirudinea, Glossosomatidae, Coloburiscidae, Mesoveliidae, Philorheithridae, Nepidae, Corbiculidae, Pleidae, Ephydridae, Isostictidae, Philopotamidae	50–99	9–19
64–95	Notonemouridae, Temnocephalidae, Heteroceridae, Diamesinae, Sciomyzidae, Naucoridae, Protoneuridae, Helicopsychidae, Synlestidae, Limnephilidae, Eustheniidae, Podonominae, Pyralidae, Atriplectididae, Calocidae, Athericidae, Hebridae, Ptilodactylidae, Austroperlidae, Paramelitidae, Tasimiidae, Psychodidae, Eusiridae, Diptera, Polycentropodidae, Haliplidae, Phreatoicidae, Sialidae, Odontoceridae, Muscidae, Thiaridae, Neoniphargidae	10–49	3-18
96–111	Megapodagrionidae, Gordiidae, Blephariceridae, Gelastocoridae, Helicophidae, Osmylidae, Ameletopsidae, Anostraca, Syrphidae, Neurorthidae, Nemertea, Diphlebiidae, Perthiidae, Sundathelphusidae, Aphroteniinae, Hemiptera	2–9	1–6
112–116	Viviparidae, Thamnocephalidae, Limnichidae, Siphlonuridae, Nannochoristidae	1	1

differences in family-level diversity and frequency of occurrence between southern versus northern, and lowland versus upland systems. This is partially dictated by shifts in composition toward families tolerant of slower flows and higher temperatures, from right to left in the plot.

The highest diversity (numbers of families in samples) occurs in valleys falling in the lower right hand end of the plot. Most valleys show reduced diversity relative to Reference Condition. The patterns in the ordination are dictated by presence and absence of families at valley scale, and do not entirely reflect condition as quantified in the SRA assessment by the simOE metric, which also takes into account frequency of occurrence within samples.

Overall, most valleys with small distances in the ordination plot between the observed and reference communities have higher condition scores, such as the more diverse valleys of the upper Murray drainage in Victoria. This is not always the case, however. The Paroo Valley community is the most different from Reference Condition (RC–MI) in the ordination.

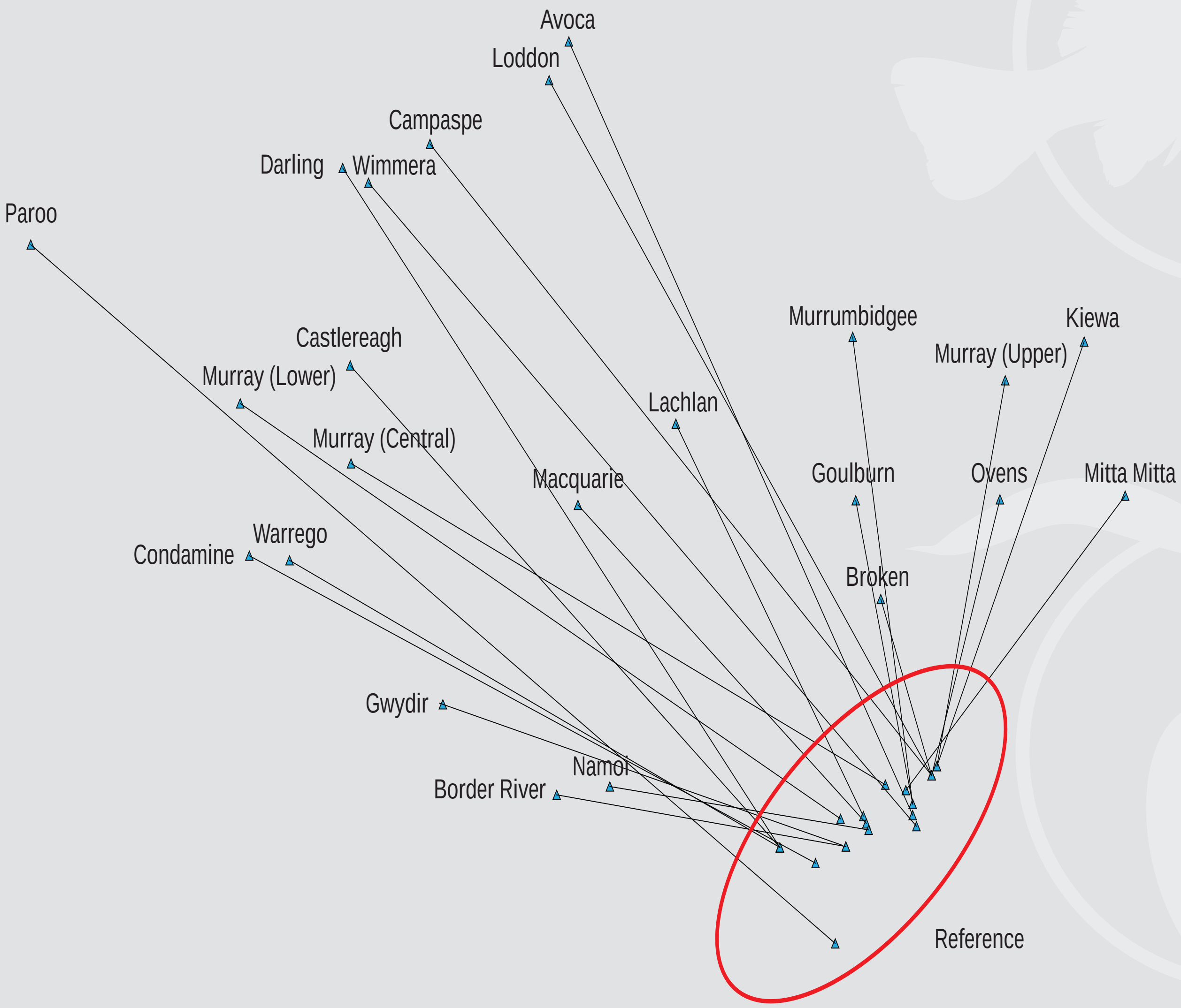


Figure 5.15. Ordination of macroinvertebrate communities.

Reference Condition communities are within the dashed ellipse; observed communities are named triangles. Generated by Multi-Dimensional Scaling on a Bray–Curtis distance matrix derived from family presence/absence data (PC-ORD v. 5.12: MjM Software, Oregon). Stress for 2-D solution: 15.2%.

Compared to the rest of the Basin, the observed community is distinguished by a low number of expected families. This is not fully reflected in the valley's condition assessment score (SR–MI = 86), as the score is also influenced by the relative frequency of families in samples, which tends to be high across the entire valley. This large distance, coupled with the fact that the Paroo scores slightly below the highest scoring valleys for the Basin (e.g. the Mitta Mitta), may also be due to a partial overestimation in the models used to define reference for this valley of family occurrences under Reference Condition.

The extreme drought in many valleys before and during sampling in 2008–2010 will have affected macroinvertebrate communities. Contraction of wetted areas is likely to have reduced habitat quality through changes in water quality, temperature, food resources, competition and predation. An evaluation of temporal trends over the three sampling cycles conducted between 2004 and 2010 is described in Chapter 6.

5.5 Vegetation

5.5.1 Condition indices

Figure 5.16 shows indices of riverine vegetation condition (SR–VI) for all valleys, arranged in descending order. The valleys fall into four groups (A–D), based on valley scores and rankings.

Group A contains six valleys (Paroo, Warrego, Darling, Murray [Central], Castlereagh and Condamine); five of these from the north of the Basin. All have very high SR–VI scores, and the riverine vegetation is in near Reference Condition**.**

Group B contains five valleys (Mitta Mitta, Macquarie, Murrumbidgee, Murray [Upper] and Gwydir); all with headwaters in the Great Dividing Range. These have valley SR–VI scores between 60 and 80, and the overall condition of their riverine vegetation is Moderate.

Group C contains nine valleys (Lachlan, Murray Lower, Border Rivers, Namoi, Ovens, Goulburn, Wimmera, Avoca and Kiewa); seven of them from the southern Basin. The SR–VI scores for these valleys fall between 40 to 60, with the riverine vegetation rated in Poor condition.

Group D contains three valleys (Broken, Campaspe and Loddon); all in the southern Basin, and all with very low valley scale SR–VI scores, (less than 25). Riverine vegetation in these valleys is in Very Poor to Extremely Poor condition.

For two of these valleys, Castlereagh and Kiewa, their assessment is marginal and each could potentially be assigned to a lower ranking (see comment at 5.5.6).

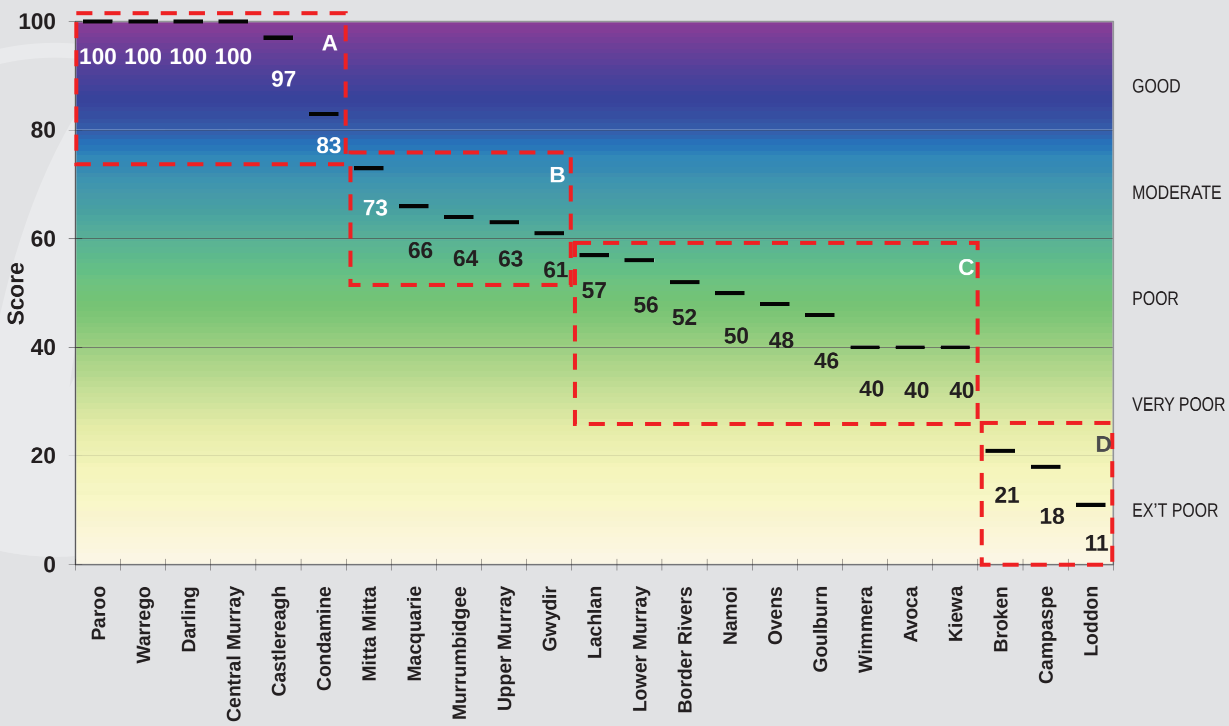


Figure 5.16. Valleys ranked by Riverine Vegetation Index (SR-VI) scores.

Short horizontal bars are means. For explanation of the four groups (A, B, C and D) see text.
The SRA condition colour standard is shown.

General characteristics of these groups are as follows:

- Valleys in **Group A** have high mean valley scores for all aspects of MVG extent (RichnessNRLF, AbundanceNRLF, NativenessNRLF, StabilityLF and FragmentationLF) indicating little change from reference. Most of these valleys include areas where mapping used in this assessment is known to be not current and/or of a coarse resolution. The only contemporary metric is Structure but as it is based only on canopy height, it has a minor influence on the overall condition score.
- **Group B** has high mean valley scores for Richness, Stability and Fragmentation but moderate mean scores for other aspects of MVG extent (Abundance and Nativeness).
- **Group C** has high mean valley scores for Richness and Stability, and moderate mean valley scores for other aspects of MVG extent (Abundance, Nativeness and Fragmentation).
- **Group D** has high mean valley scores only for Richness; other measures of MVG extent are either low (Abundance and Nativeness), or Poor (Stability and Fragmentation).

The character of valley vegetation condition was analysed using ordination, followed by an analysis of similarity between valleys. For the ordination, valley scores for six metrics and sub-indicators were standardised (1–100), a Bray–Curtis matrix of similarity was computed by comparing all combinations of valley scores, and this was subjected to Multi-dimensional Scaling. The Simper routine in Primer (Clarke and Gorley 2006) was used for the analysis of similarities.

The resulting ordination (Figure 5.17) shows how the four groups A to D change from being compact to increasingly dispersed, a trend that corresponds with decreasing group mean scores and increasing spread in values.

The distribution of scores for SR–VI is a near continuous gradient with no major breaks except between Groups C and D (Figure 5.16), thus the average dissimilarity between Groups A, B and C is relatively low, ranging from 18.1% (A and B) to 27.1% (A and C). Group D is more distinct: the average dissimilarity between it and the other three groups ranges from 46.6% (C and D) to 58.6% (A and D).

Within-group average similarity is highest for **Group A** (89.4%), and decreases as SR–VI decreases, from 83.9% for **Group B**, to 72.3% for **Group C** and 46.6% for **Group D**. Not surprisingly, given its consistently high scores in all groups and most valleys (18 valleys have a RichnessNRLF score of 100), the metric contributing most to within-group average similarity is RichnessNRLF. The distinctiveness of each group, however, is dictated by those metrics contributing second and third to overall within-group similarity. The three metrics contributing most to within-group similarity for **Group A** are RichnessNRLF, NativenessNRLF and AbundanceNRLF (collectively accounting for 61% of the within-group similarity); for **Group B,** RichnessNRLF, FragmentationLF and StabilityLF (60.4%); for **Group C**, RichnessNRLF, StructureNR and StabilityLF (62.9%); and for **Group D**, RichnessNRLF, StructureNR and FragmentationLF (85.0%).

A marked difference in Vegetation condition scores is evident between the northern and southern valleys of the Basin. The mean SR–VI score for northern valleys is 78.8 (n = 9), with an average equivalent to Moderate condition; whereas for southern valleys the mean SR–VI score is 48.4 (n = 14), equivalent to Poor condition.

When valleys are ranked in order of decreasing SR–VI score (as per Figure 5.16) and the ranked list divided into four quartiles, the northern valleys occupy the upper parts of the distribution—dominating the fourth quartile—and are completely absent from the first (lowest) quartile (Figure 5.18). The southern valleys show a similar but inverse distribution, dominating the first quartile.

Figure 5.17. Ordination of valley scores for metrics and sub-indicators.

Notes: For the ordination, metrics and sub-indicators were standardised (to 1–100), a Bray-Curtis distance matrix was computed then subjected to Multi-dimensional Scaling. Stress for two-dimensional solution was 0.6%

5.5.2 MVG abundance and richness

Under Reference Condition, the composition of the Basin's riverine vegetation, as given by the relative abundance of major vegetation groups (MVGs) in the Near Riparian and Lowland Floodplain domains, was dominated by one MVG: Eucalypt Woodland (MVG 5). This is consistent with its prevalence across south-eastern Australia and thus this MVG can be considered the characteristic vegetation of both riverine vegetation domains across the Basin. All other MVGs were much smaller in extent (Figure 5.19). This pattern was evident in both northern and southern sub-basins and across all altitudinal zones; except for three where the climate is generally cooler and wetter: the Montane zone in northern and southern sub-basins and the Upland zone in the southern sub-basin. Here, forest was most abundant, and Eucalypt Open Forest (MVG 3) was the dominant MVG.

In this assessment, the combination of mapping scale, vegetation typology and the use of a fixed width (+/- 200 m either side of the drainage network) to define 'riparian' results in a long tail in the distribution of MVGs (Figure 5.19). The tail is longer for the Near Riparian domain, which has 11 MVGs out of 20 that are less than 1% of total domain area, whereas the Lowland Floodplain domain had only five of its 15 MVGs less than 1% of total domain area. In the Vegetation Theme, all MVGs are retained in the assessment, regardless of size.

In the Near Riparian domain, MVG richness ranged from 15 to 19 per altitudinal zone across the Basin; or 12 to 19 when altitudinal zones are divided into northern and southern sub-Basins (Table 5.17). MVG richness was lower in the Montane and Lowland zones, particularly the northern Montane zone and the southern Lowland zone; and highest in the Slopes zone, particularly in the northern Slopes (Table 5.17). Individually, none of the valleys contains the full spectrum of MVGs possible for the zones or domains within them: for example, although there are 16

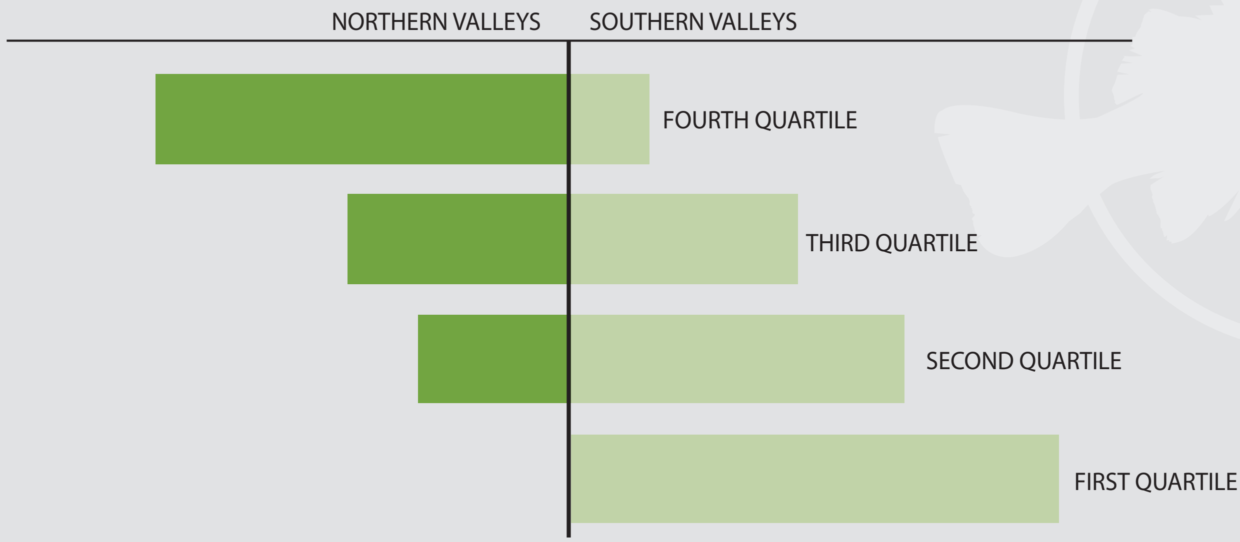


Figure 5.18. Distribution of valley SR–VI scores by region within the Basin.

Valley scores for riverine Vegetation Index (SR–VI) sorted into quartiles and presented by sub-basin. SR–VI scores are 11–40 for the first quartile; 46–57 for the second; 61–83 for the third and 97–100 for the fourth.

MVGs in the Slopes zone in the southern sub-basin, the average per valley was only 6.1, and the range was three to 13.

The Lowland Floodplain domain for the Basin—as defined in this assessment—is nearly twice the size of the entire Near Riparian domain. Most of it (72%) is in the northern sub-basin (Table 5.17), even though this has fewer valleys (11 v. 13). Note that this area difference between the northern and southern Basin is a feature of the inundation layer used to define the Lowland Floodplain domain for this assessment.

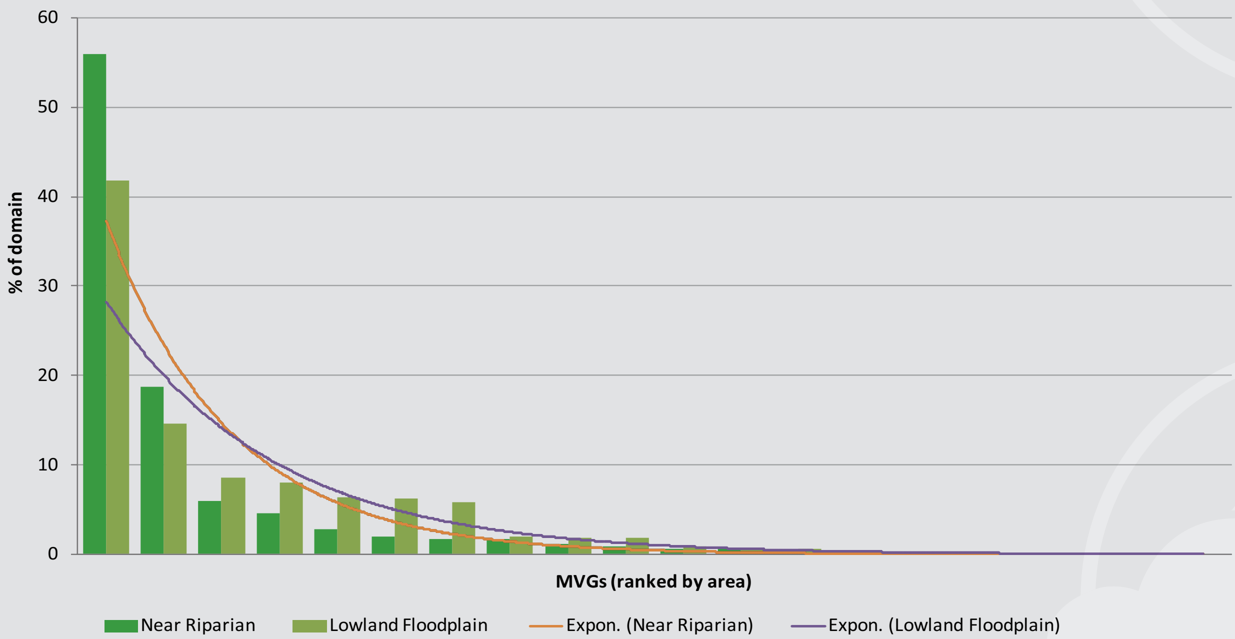


Figure 5.19. Domain composition at the Basin-scale, as MVG ranked relative abundance (area).

The exponential model for the Near Riparian domain is $y = 59.45*e^{-0.47x}$, ($r^2 = 0.86$) and for the Lowland Floodplain domain is $y = 39.98*e^{-0.35x}$ ($r^2 = 0.93$).

Table 5.17. **MVG richness in the Near Riparian domain, by altitudinal zones and sub-basin, under Reference Condition.**

Zone area	Montane 213,241 ha		Upland 450,449 ha		Slopes 1,097,625 ha		Lowland 1,296,806 ha	
Number of MVGs	15		17		19		15	
Sub-basin area as % of zone	N 43%	S 57%	N 62%	S 38%	N 67%	S 33%	N 51%	S 49%
Number of MVGs	12	14	14	14	19	16	15	12
	MVG per Valley							
Mean (range)	7.3 (6 to 9)	7.8 (5 to 12)	8.6 (7 to 12)	6.0 (4 to 10)	11.0 (9 to 14)	6.1 (3 to 13)	9.8 (8 to 13)	7.0 (2 to 10)

Richness in the Lowland Floodplain domain, with 15 MVGs across the Basin (Table 5.18), is higher in the northern sub-basin than the southern (15 vs 12 MVGs). It also tracks the richness of the Lowland zone Near Riparian domain, with a higher average per valley (9.6 vs 7.4 MVGs).

The domains were similar in terms of MVG composition. In the southern basin, the Lowland Floodplain domain also tracks the Lowland zone Near Riparian domain in terms of which MVGs are most extensive—with MVGs 5, 3 and 17 collectively accounting for 77 and 82% of the domain area. In the northern sub-basin, the Lowland Floodplain domain diverges from the Near Riparian domain in that a floodplain grassland (MVG 19 Tussock Grasslands, accounting for 18% of area) is one of the three most extensive MVGs; whereas in the Near Riparian domain all three MVGs were eucalypt forests and woodlands (MVGs 5, 11 and 3).

Reduced MVG Richness was observed in the Near Riparian domain in seven of the 23 valleys, and in three of the 10 Lowland Floodplain domains. In each instance, only one MVG has been lost, and that MVG had been small in extent (typically less than 25 ha under Reference Condition). Because the assessment of Richness weights each MVG equally regardless of its reference area, the

Table 5.18. **MVG richness in the Lowland Floodplain (LFP) domain under Reference Condition.**

LFP area in Basin	4,136,418 ha	
Number of MVG in Basin	15	
Sub-basin area as % of total	N 72%	S 28%
Number of MVG in sub-basin	15	12
Number of MVG per LFP by sub-basin mean (range)	9.6 (7 to 12)	7.4 (3 to 11)

loss of one out of two or three MVGs present under Reference Condition (such as the Near Riparian domain in the Ovens Slope zone or Kiewa Lowland zone) has a greater effect on the Richness metric than losing one out of twelve MVGs (as in the Murrumbidgee Montane zone).

The Richness sub-indicator RichnessNRLF is derived by integrating the Richness metrics for the Near Riparian and the Lowland Floodplain domains. Out of 19 valleys with metric values for both domains: thirteen have no loss of any MVG, five have lost an MVG from one domain, and one (the Ovens) lost MVGs from both domains. Nearly all instances of MVG loss are for southern valleys. In this integration, high metric scores are treated as equivalent to reference, and hence for most valleys the RichnessNRLF sub-indicator scores are 100, with no regional trend.

5.5.3 Abundance and fragmentation

The riverine Vegetation assessment uses vegetation mapping that has a fairly coarse resolution (use of MVGs and the selection and definition of spatial domains); a largely terrestrial focus (the typology contains no riverine-specific vegetation types); and is neither fully up-to-date nor uniform in currency. These data are used to derive a number of metrics and sub-indicators of richness, abundance, fragmentation and nativeness. As a result, the riverine Vegetation Index (SR–VI) is largely influenced by different aspects of MVG extent. Abundance, the simplest indicator, sets the context for the other metrics which tend to correlate with it. Abundance and Fragmentation are used here to explore patterns across the Basin. These patterns can be expected to be broadly in parallel with historical patterns of both development and vegetation protection.

As expected, MVG abundance in the Near Riparian domain does vary across the Basin. At valley scale, abundance ranges from 0.22 to 1 (Table 5.19). It is higher in the northern sub-basin than in the southern (mean = 0.71 and 0.43); and lowest in the Slopes zone (mean = 0.36) which is due to very low scores in some southern valleys. Zone scores suggest an altitudinal trend but with opposite trends in northern and southern basins. In the northern basin, mean riverine vegetation abundance progressively increases down the valley such that the Lowland zone has highest abundance but in the southern basin the montane zone has highest abundance (Figure 5.20).

Mean vegetation abundance in the Lowland Floodplain domain is generally higher than in the adjacent Lowland zone Near Riparian domain (Table 5.19)—most notably

Table 5.19. Riverine vegetation abundance scores by domain at valley scale.

<table>
<tr><th>Domain</th><th colspan="4">Near Riparian</th></tr>
<tr><td>Valley scores across MDB mean (range)</td><td colspan="4">Basin
0.54 (0.22 – 1)</td></tr>
<tr><td>Valley scores by sub-basin mean (range)</td><td colspan="2">Northern
0.71 (0.48 – 1)</td><td colspan="2">Southern
0.4 (0.22 – 0.63)</td></tr>
<tr><td>Valley scores by altitudinal zone mean (range)</td><td>Montane
0.65 (0.35 – 0.96)</td><td>Upland
0.54 (0.3 – 0.81)</td><td>Slopes
0.36 (0.09 – 0.87)</td><td>Lowland
0.63 (0.13 – 1)</td></tr>
<tr><th>Domain</th><th colspan="4">Lowland Floodplain</th></tr>
<tr><td>Valley scores across MDB mean (range)</td><td colspan="4">Basin
0.82 (0.5 – 1)</td></tr>
<tr><td>Valley scores by sub-basin mean (range)</td><td colspan="2">Northern
0.87 (0.57 – 1)</td><td colspan="2">Southern
0.78 (0.5 – 0.9)</td></tr>
</table>

in the southern Basin (0.8 compared with 0.4). In the northern sub-basin there is a tight correspondence between vegetation abundance in the Lowland Floodplain domain and the Near Riparian domain (Figure 5.21; r^2 = 0.80). This implies that these domains share a similar or correlated history of change. This is not the case in the southern sub-basin (r^2 = 0.49), implying differing histories for the two domains. In the Lowland Floodplain domains, three valleys have abundance that is higher than the trend for their sub-basin (Figure 5.21). These are: Lower Murray, Murrumbidgee and Castlereagh. Two valleys have abundances well below the trend for their sub-basin: Loddon and Condamine.

The Fragmentation sub-indicator reports on differences in the spatial characteristics of MVG abundances in the Lowland Floodplain domain from Reference Condition for the 19 valleys where this domain was assessed. It simultaneously considers changes in the number of patches and in mean patch area relative to reference. All MVGs present contribute to this sub-indicator score but the contribution of each is weighted by its reference area; thus the MVG that is most extensive has the greatest influence. In most valleys, this is MVG 5, Eucalypt Woodland (Section 3.5.3).

The highly variable nature of the change in MVG 5 Eucalypt Woodland relative to Reference Condition across the Basin is shown in Figure 5.22 and includes:

- a cluster of valleys with metrics close to 1 for number of patches and mean patch area: indicating little to no change from Reference Condition
- a number of valleys with more patches (i.e. values greater than 1) that are smaller than reference: implying that large areas have been dissected into smaller ones, and some have been lost
- one valley showing extreme fragmentation (far right: Figure 5.22)
- one valley showing extreme loss of extent, with severe reduction in the number of patches and in mean patch area (bottom left: Figure 5.22).

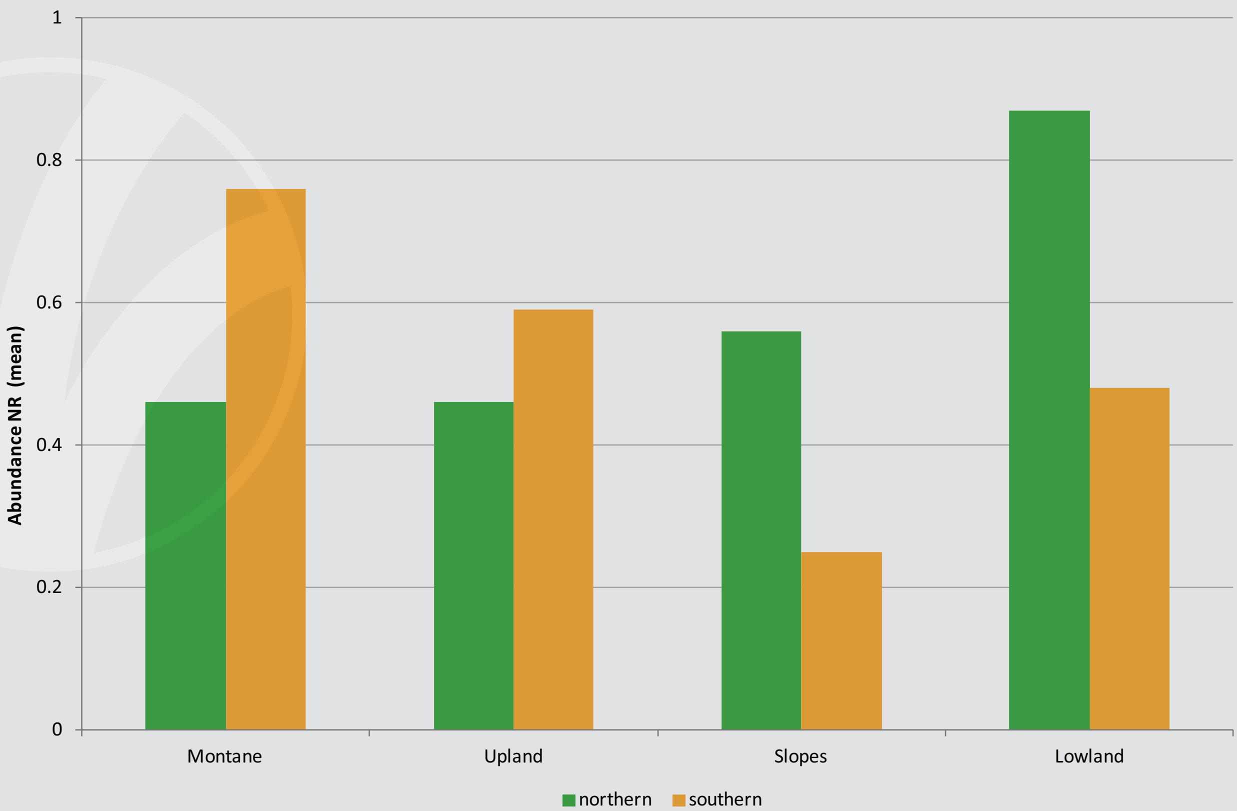


Figure 5.20. Mean riverine vegetation abundance for altitudinal zones by sub-basin.
(Note that abundance is rated relative to Reference Condition).

The fate of other MVGs is less variable, in particular those MVGs covering only a small percentage of a zone under Reference Condition (equivalent to the tail of MVG composition shown in Figure 5.19) and show much less fragmentation unless completely lost.

Fragmentation has a broadly similar geographic pattern to abundance, with higher scores (i.e. closer to Reference Condition) in the northern sub-basin (mean score = 85.7; range 57–98) than in the southern (mean = 67.8; range 40–97). Fragmentation scores are very similar to abundance scores when abundance is near reference, but diverge as abundance decreases from reference ($r^2 = 0.69$).

5.5.4 Structure

The Structure sub-indicator—comprised of a single metric (Canopy Height)—is distinct from other Vegetation Theme metrics and sub-indicators in being a sampled variable (derived from a recently-flown LiDAR survey) for over 1300 randomised sites along the SRA drainage network.

Reference Condition is derived from 'best available' reference vegetation mapping. This was available at individual sites at a finer resolution than that used for Abundance, and associated descriptors were taken from multiple sources. At each site, the assessment is restricted to vegetation patches that had woody (tree-dominated) vegetation present in reference maps. Because it assesses canopy height of whatever trees are present, the Structure sub-indicator is independent of extent; hence abundance and structure are poorly correlated (zone scores: $r^2 = 0.014$).

Valley scores for Structure range from 66 to 85; and valley zone scores range from 44 to 94, with all except four valley zones being equivalent to Moderate or Good condition.

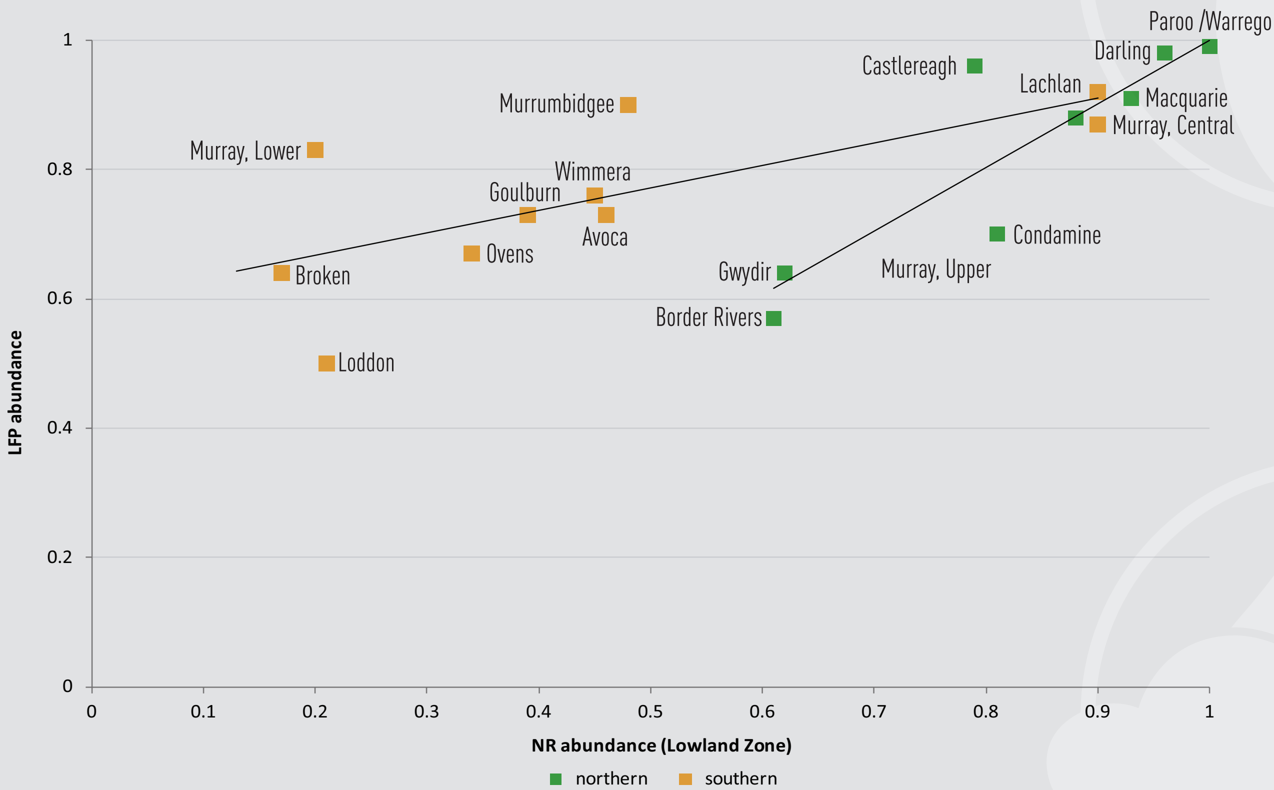


Figure 5.21. Relationship between Riverine Vegetation abundance in the Lowland Floodplain domain (LFP) and the Lowland zone Near Riparian domain (NR); for northern and southern parts of the Basin.

This results in relatively little variation across the Basin. Northern and southern basins have similar average scores (75.7 and 76.6 respectively); and even though the Lowland zone has fewer Good condition scores than the other zones (Figure 5.23) its average score of 70.8 is in the Moderate range; and not markedly different from the other zones (averages of 77.3, 81.3 and 83.9 respectively).

5.5.5 Indicators

Each of the two indicators in the Vegetation Theme is derived by the integration of three metrics and sub-indicators. The Abundance and Diversity Indicator comprises RichnessNRLF, AbundanceNRLF and StabilityLF. The Quality and Integrity Indicator comprises NativenessNRLF, FragmentationLF and StructureLF (where NR =Near Riparian domain; LF = Lowland Floodplain domain). Despite their differing conceptual base and definitions, the two indicators are highly correlated (r^2 = 0.95) and have similar values (regression coefficient >0.9, ie. close to unity), with Abundance and Diversity Indicator scores being consistently slightly higher. The similarity can be attributed to the dependence on one data source (broadscale vegetation mapping) and its particular characteristics.

For the Abundance and Diversity indicator, zones with scores near Reference Condition (>= 80, n = 27) have near reference scores for AbundanceNRLF and RichnessNRLF, or with Moderate scores for AbundanceNRLF and near reference scores for StabilityLF. All altitudinal zones are represented (n = 27) but Lowland zones (all from northern valleys except two) and Montane zones (only southern valleys) are over-represented, while Slopes and Uplands are under-represented.

Zones with Abundance and Diversity indicator scores that are Very Poor or Extremely

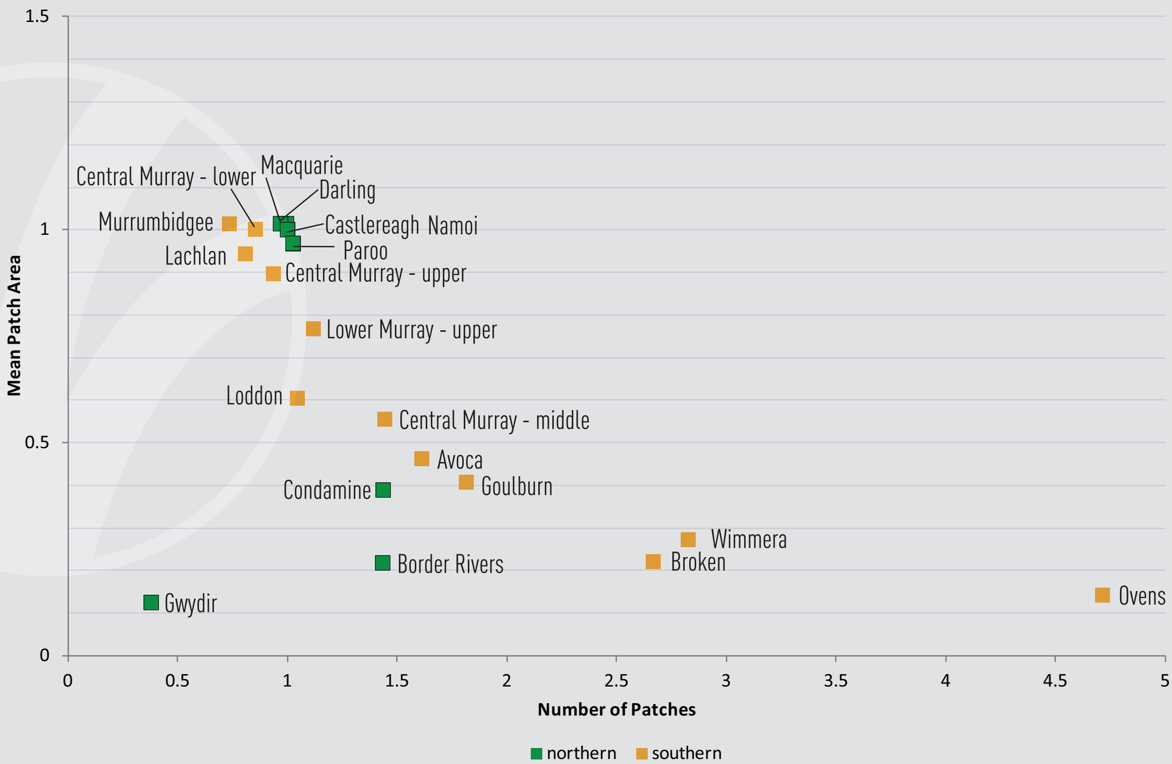


Figure 5.22. Relationship between metrics of mean patch area and the number of patches at valley scale for Eucalypt Woodland (MVG 5), indicating fragmentation relative to Reference Condition.

All points are from the Lowland zone except where stated otherwise.

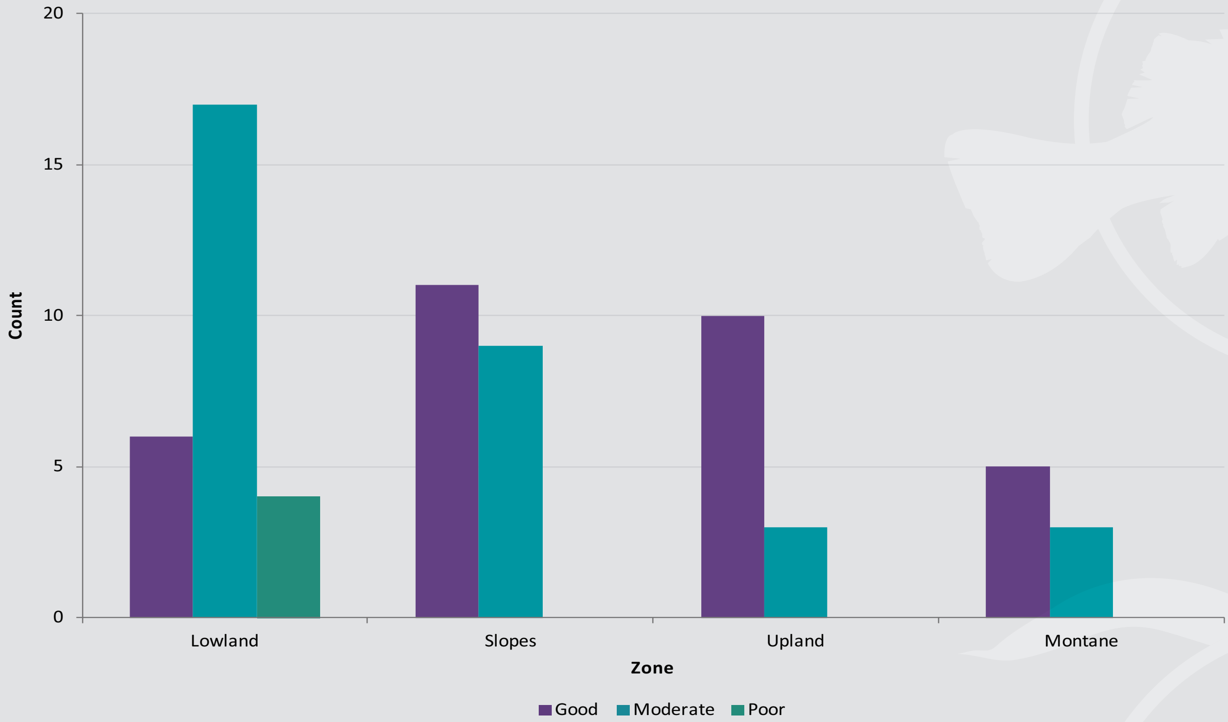


Figure 5.23. Distribution of Structure sub-indicator score

Poor (<40, n = 16) have scores of 30 and less for AbundanceNRLF (n =16). All are from southern valleys, with Slopes particularly well represented (n = 10). As most of the zones in this category do not have LF metrics, the low scores for AbundanceNRLF refer to the Near Riparian domain. The few zones with RichnessNRLF scores that are not Near Reference are all in this category.

For the Quality and Integrity indicator, valley zones with scores near Reference Condition (>= 80, n = 25) have near reference scores for NativenessNRLF or Moderate to Good scores for NativenessNR; Moderate to Good scores for FragmentationLF; and scores for Structure that range from Poor to near reference.

Zones with Quality and Integrity indicator scores that are Very Poor or Extremely Poor (<40, n = 17) are all from southern valleys and one zone, Slopes, is particularly well-represented (n = 11). These zones have Very Poor to Extremely Poor scores for NativenessNR, FragmentationLF scores that are Poor to Moderate and scores for Structure that range from Very Poor to near Reference Condition.

5.5.6 Integration

Integration in the SRA is an interactive, rather than a purely averaging, process for combining information at one level (e.g. indicator scores to derive a condition index). This can occasionally result in Moderate scores at one level returning a near reference score after being integrated, or in two or three Poor scores returning a Very Poor integrated score. Weighting of zone scores (by stream length) then determines the influence of each zone on the valley score.

In the assessment, four zones with Moderate scores (less than 0.7) for the AbundanceNR metric have, after integration, near reference scores for the Abundance and Diversity indicator; and for the Vegetation Condition Index: the Castlereagh Upland, Kiewa Upland, Upper Murray Upland and Castlereagh Slopes zones. At the valley scale, the consequences are that the Castlereagh is rated near Reference Condition although a Moderate score may be more realistic; and the Kiewa is rated Poor although a Very Poor score may be more realistic. Further review of data quality and data integration may be warranted in these cases.

5.6 Physical Form

5.6.1 Condition indices and indicators

The Physical Form Index for the 23 valleys varies between 60 and 99 (Figure 5.24). Valleys across the Basin were rated as either in Moderate condition (11 valleys) or Good condition (12 valleys) for Physical Form. Variation between the valleys according to the Physical Form Theme assessment is illustrated not only by the ranking of the Physical Form Condition Index score (Figure 5.25) but also by the variations among the indicators (Figure 5.25). These variations are best explained by describing six groups of valleys.

The first group (see A in Figure 5.24) consists of only one valley, the Paroo. It has the equal highest valley condition index score for Physical Form of 99. The Paroo stands out largely because Bed Dynamics and Floodplain Dynamics are largely unmodified from Reference Condition, with all other valleys showing considerably greater disturbance based on SedNet modelling.

The second group (part of B in Figure 5.24) has seven valleys: Castlereagh; Gwydir; Kiewa; Mitta Mitta; Murrumbidgee; Ovens and Upper Murray. These valleys have an average Physical Form index of 90 and range between 71 and 99. The Cross-sectional Form indicators (XSectFormMean and XSectFormVar) are higher for these valleys than the others indicating less alteration from channel form. These two indicators are combined to calculate the Channel Form indicator and this is consequently also higher than for the other valleys.

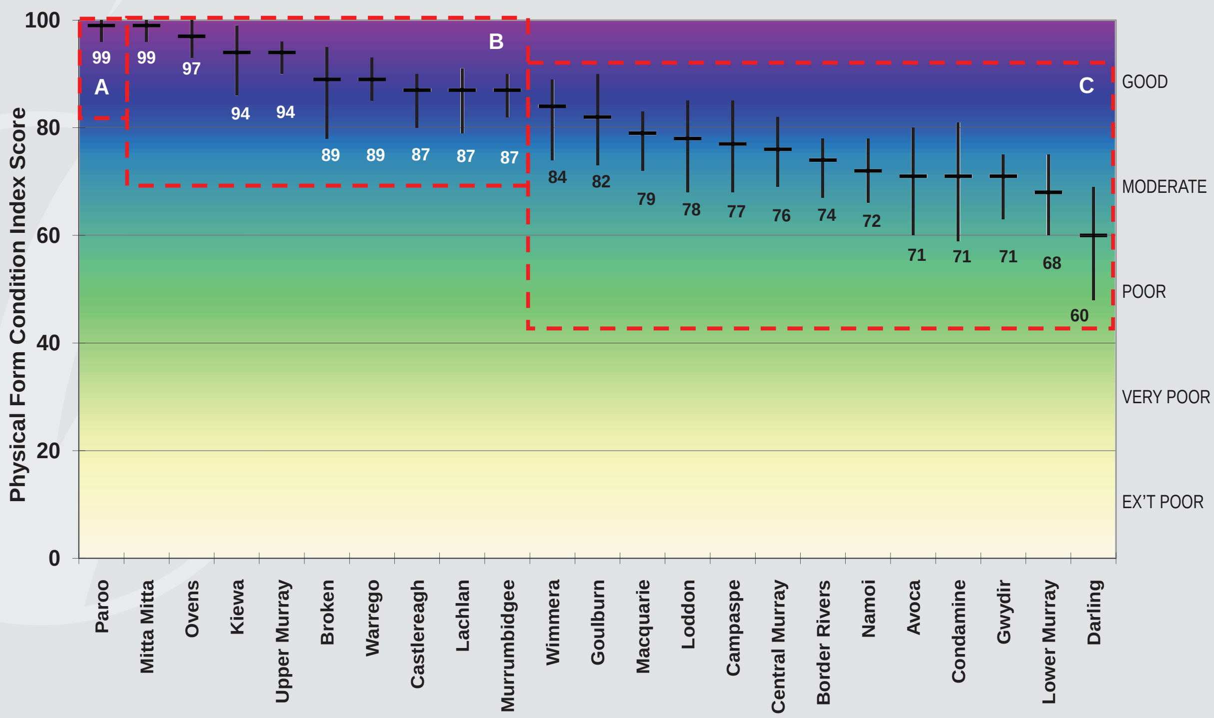


Figure 5.24. Valley results for the Physical Form Condition Index.

(Short horizontal bars are means. Vertical lines indicate confidence limits. For explanation of the three groups (A, B, C) see text. The SRA condition colour standard is shown).

The third group (see B in Figure 5.24) has three valleys: Broken; Lachlan; and Warrego. These valleys have an average Physical Form index of 88 and range between 87 and 89. Their results are within the normal range for all indicators except the Floodplain Dynamics indicator, which is relatively high, indicating less alteration from Reference Condition.

The fourth group (see C in Figure 5.24) has three valleys: Avoca; Loddon; and Wimmera. These valleys have an average Physical Form Index of 78 and range between 71 and 84. They have much lower results for Bed Dynamics than the other valleys.

The fifth group (see C in Figure 5.24) has six valleys: Border Rivers; Campaspe; Central Murray; Goulburn, Macquarie; and Namoi. These valleys have an average Physical Form index of 77 and range between 72 and 82. These valleys have lower results for the Channel Form indicator, primarily as a result of altered Channel Planform.

The final group (see C in Figure 5.24) has three valleys: Condamine; Darling; and Lower Murray. These valleys have an average Physical Form index of 66 and range between 70 and 81. These valleys have lower results for the Channel Form indicator as a result of altered Channel Cross-sectional Form.

Three of the four Physical Form indicators contribute most of the variation in the Physical Form Index among valleys (Figure 5.26). These are Channel Form, Bed Dynamics and Floodplain Dynamics (Bank Dynamics shows little variation across the Basin). For example, the low ranking of the Gwydir is a result of lower condition as measured by the Floodplain Dynamics indicator; the low ranking of the Avoca Valley is due to lower scores for Bed Dynamics; and the low rank for the Darling Valley is the result of lower scores for Channel Form.

5.6.2 Condition of the Basin's river system at zone and site scales

Of the Basin's 68 zones, none were rated as in Extremely Poor physical condition. Only five were rated as being in Very Poor or Poor condition and these were all Lowland zones (Figure 5.27). Other zones were rates as either in Moderate condition (21 zones) or Good condition (42 zones). All the Montane zones were rated in Good condition.

The valley and zone condition indexes are based on aggregated scores. Despite these scores indicating mostly Moderate or Good aggregate condition at these scales, human impacts on physical form condition are prevalent across the entire Basin. It is necessary to examine variations in the condition of individual sites and reaches to describe the extensive nature of human impacts on physical form in the Murray–Darling. The following two paragraphs provide an overview of these impacts.

The Physical Form assessment used results from 1,385 river channel surveys (conducted by Airborne LiDAR). Channel geometry measurements were compared with modelled Reference conditions. Results indicate widespread changes to the Basin's river channels, including three types of channel adjustment: simplification; enlargement; and contraction. Channel simplification is indicated at 63% of sites as a result of channel straightening (41% of sites) and reduced cross-sectional variability (38% of sites). Channel enlargement is indicated at 53% of sites as a result of channel deepening (38% of sites) and channel widening (37% of sites). Channel contraction is indicated at 21% of sites as a result of reduced channel depth (16% of sites) and channel narrowing (12% of sites).

The assessment also used SedNet model results for 96,400 km of river across the Murray–Darling Basin. The results indicate increased sediment loads throughout almost the entire Murray–Darling Basin for the aggregate period since European settlement. There have also been widespread increases in the rates of sedimentation on floodplains (99% of river length) and in channels (41% of river length). These are changes based on comparisons of the entire period since European settlement with the Reference

Condition. However, this includes periods of high catchment disturbance immediately following settlement. Consequently, these results are not necessarily indicative of sediment loads and sedimentation in recent years, and more detailed modelling is required to assess the sequence of historical (including recent) changes in sediment loads.

5.6.3 Condition of the Basin zones

The following sections describe physical form conditions in each of the four zone types across the entire Murray–Darling Basin. While all valleys and most zones have been rated as in Good or Moderate condition overall, a range of changes in physical form is evident for a number of river reaches in every zone across the Basin. Details of these results are presented in Figure 5.28 and summarised in the section below.

5.6.3.1 Basin Lowland zones

There are 611 LiDAR survey sites and 3,327 SedNet river segments in the Lowland zones of the Murray–Darling Basin. Based on these samples, Channel Sediment Ratio and Floodplain Sediment Deposition were modified from Reference Condition throughout most of the Lowland zones. At these sites, Channel Sediment Ratio was generally increased (many sites having large increases) and there was a large increase in Floodplain Sediment Deposition across 10% of the Lowland zone rivers for the post-European period. Channel Depth was modified from reference in more than half of the Lowland zone rivers. At these sites Channel Depth was generally increased (many sites having large increases). Channel Width, Channel Width Variability, Bank Variability and Channel Sediment Deposition were modified from reference

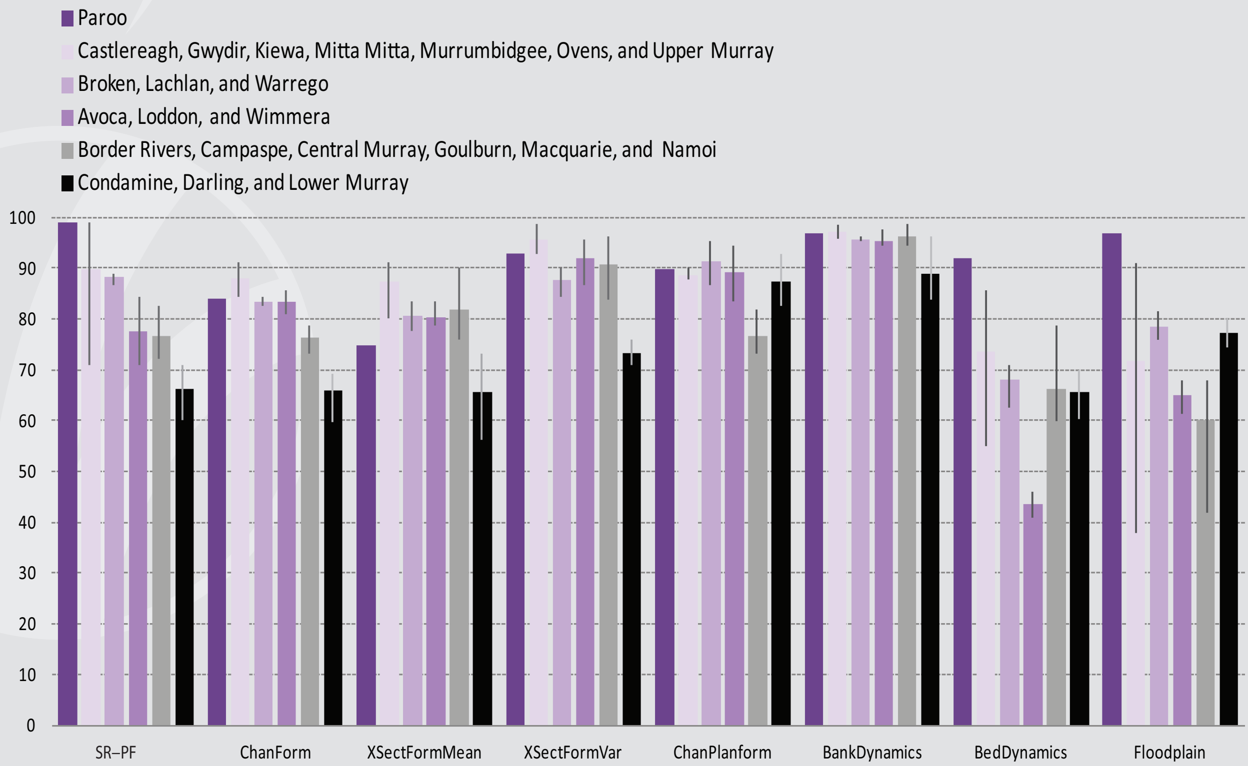


Figure 5.25. Mean Physical Form Index and indicators for six groups of valleys.

(Whiskers indicate range within each group).

Figure 5.26. Valley results for Physical Form Index and the three key Physical Form indicators.
(In decreasing rank order of Physical Form Index).

for approximately half of the Lowland zone rivers. At these sites Channel Width was generally increased, Channel Width Variability was generally reduced, results show both increases and decreases in Bank Variability across the zones and there was a large increase in Channel Sediment Deposition across 20% of the Lowland zone rivers for the post-European period. Sinuosity and Meander Wavelength were modified from reference for less than half of the Lowland zone rivers. At these sites results show both increases and decreases in Sinuosity, and Meander Wavelength was generally increased (many sites having large increases).

5.6.3.2 Basin Slopes zones

There were 471 LiDAR survey sites and 2,583 SedNet river segments assessed in the Slopes zones. Based on these samples, both Channel Sediment Ratio and Floodplain Sediment Deposition were modified from Reference Condition throughout most of the Slopes zone river systems. At these sites Channel Sediment Ratio was generally increased (many sites having large increases); there was also a large increase in Floodplain Sediment Deposition across 10% of the Slopes zone river assessed sites for the period since European settlement commenced. Channel Width, Channel Depth and Bank Variability were modified from reference for approximately half of all Slopes zone sites. At these sites Channel Width and Channel Depth were generally increased (a few sites having large increases) and Bank Variability was generally increased indicating enhanced Bank Dynamics. Channel Width Variability, Sinuosity, Meander Wavelength and Channel Sediment Deposition were modified from reference for less than half of all Slopes zone river sites. At these sites Channel Width Variability was generally reduced,

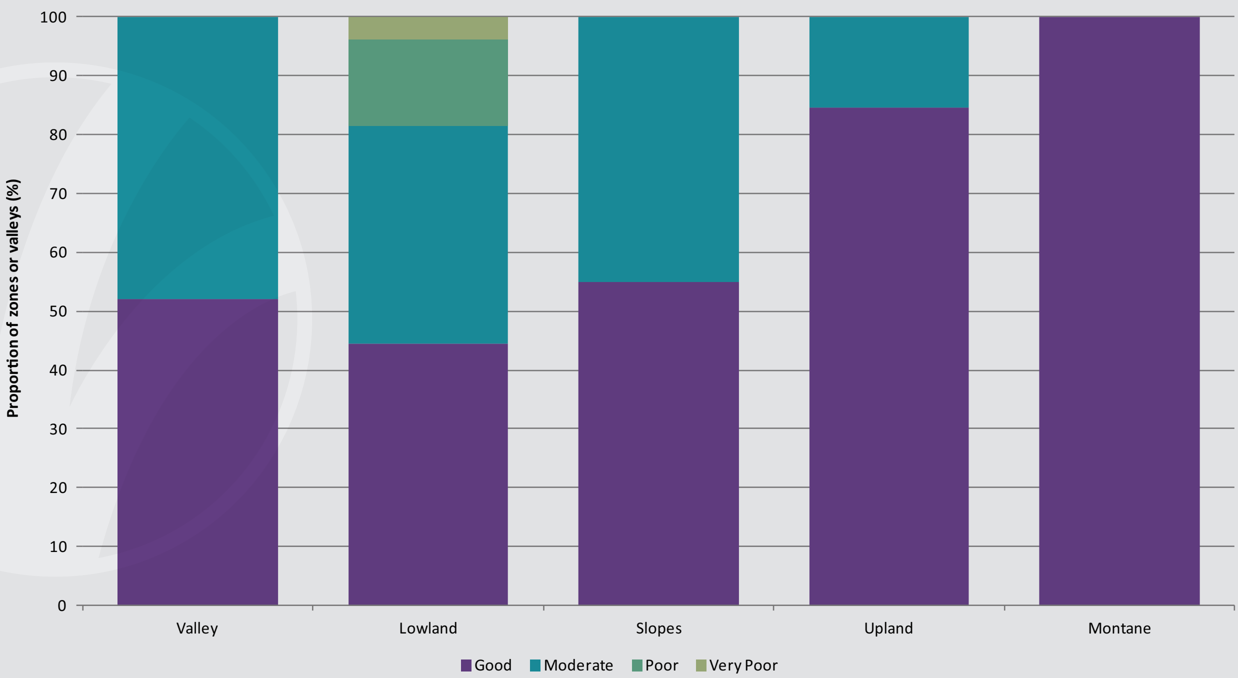


Figure 5.27. The distribution of Physical Form condition across the Basin, at valley scale and for each zone type.

(By rating of the SRA Physical Form Condition Index).

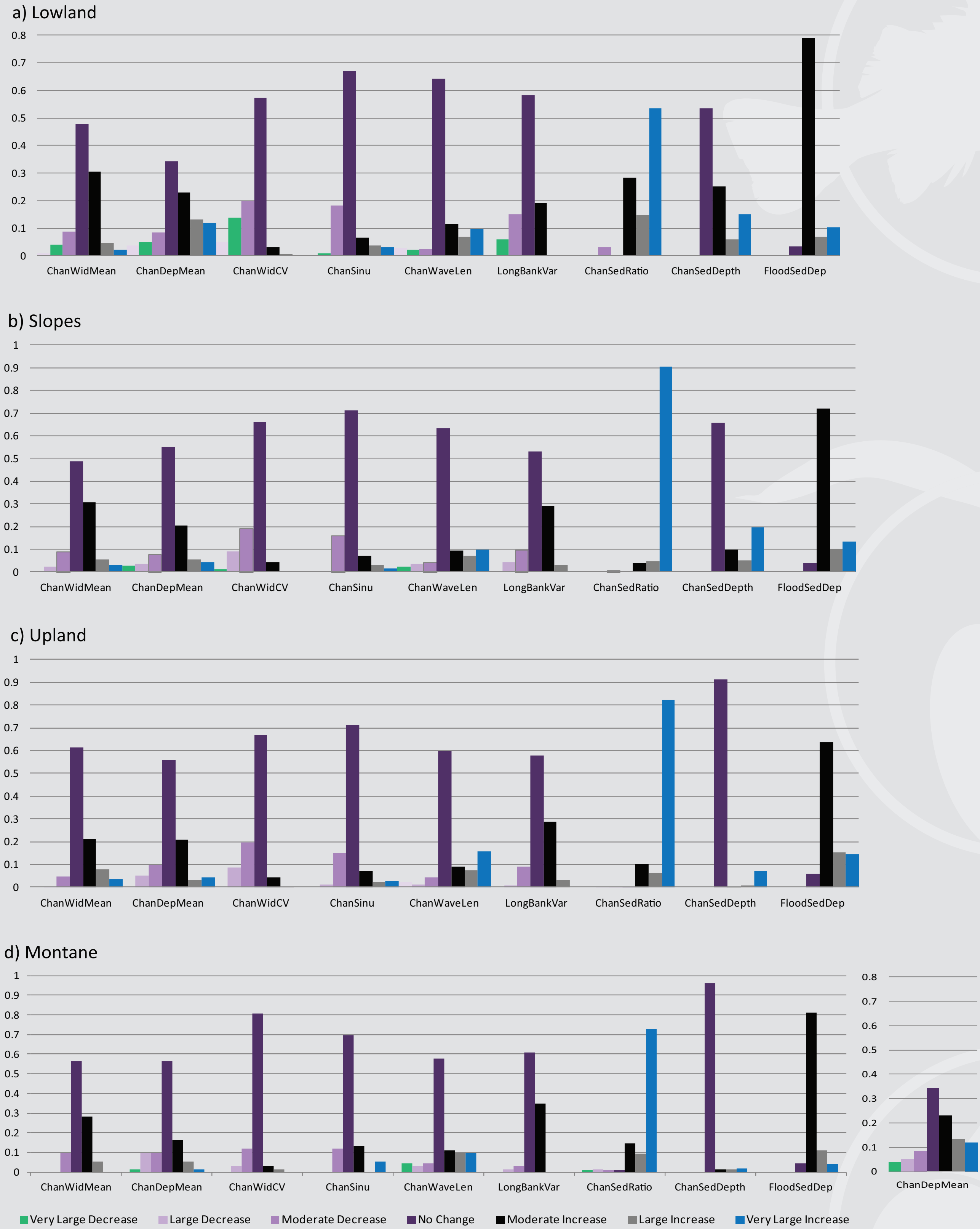


Figure 5.28. Histograms showing the Physical Form metrics for each zone.

(The proportion of each zone for which Physical Form metrics indicate a very large decrease (left hand column); large decrease (second column); moderate decrease (third column); no detectable change (fourth column); moderate increase (fifth column); large increase (sixth column); and very large increase (right-hand column); relative to Reference conditions. Inset figure at right shows how results are presented for each metric.

there were both increases and decreases in Sinuosity, Meander Wavelength was generally increased (many sites having large increases) and there was a large increase in Channel Sediment Deposition across 20% of the Slopes zone rivers for the period since European settlement commenced.

5.6.3.3 Basin Upland zones

There were 211 LiDAR survey sites and 697 SedNet river segments assessed in the Basin's Upland zones. Based on these samples, Channel Sediment Ratio and Floodplain Sediment Deposition were modified from Reference Condition throughout most of the Upland zone river systems. At these sites, Channel Sediment Ratio was generally increased (many sites having large increases); there was also a large increase in Floodplain Sediment Deposition across 10% of the Upland zone rivers for the period since European settlement commenced. Channel Depth, Meander Wavelength and Bank Variability were modified from reference for approximately half of the Upland zone river sites. For these sites, results show both increases and decreases in Channel Depth, Meander Wavelength was generally increased (many sites having large increases) and Bank Variability was generally increased indicating enhanced Bank Dynamics. Channel Width Variability and Sinuosity were modified from reference for less than half of the Upland zone river sites. For these sites, Channel Width Variability was generally reduced and results show both increases and decreases in Sinuosity. Channel Width and Channel Sediment Deposition were largely unmodified from reference in the Upland zones.

5.6.3.4 Basin Montane zones

There were 92 LiDAR survey sites and 240 SedNet river segments assessed in the Basin's Montane zones. Based on these samples, Channel Sediment Ratio and Floodplain Sediment Deposition were modified from Reference Condition throughout most of the Montane zone river systems. At these sites, Channel Sediment Ratio was generally increased (many sites having large increases); there was also a moderate increase in Floodplain Sediment Deposition across 10% of all Montane zones for the period since European settlement commenced. Channel Width, Channel Depth and Meander Wavelength were modified from reference for approximately half of the Montane zone river sites. For these sites, Channel Width was generally increased, results show both increases and decreases in Channel Depth and Meander Wavelength was generally increased (many sites having large increases). Sinuosity and Bank Variability were modified from reference for less than half of the Montane zone river sites. For these sites, results show both increases and decreases in Sinuosity and Bank Variability was generally increased indicating enhanced Bank Dynamics. Channel Width Variability and Channel Sediment Deposition were largely unmodified from reference in the Montane zones.

5.7 Hydrology

5.7.1 Overview

A total of 191,000 km of river length across the Murray–Darling Basin was considered for assessment in the Hydrology Theme. Of this, 10% (or 18,300 km) was classed as mainstem river reaches and these are found in all the SRA valleys except the Avoca and Kiewa (Figure 5.30). In individual valleys, mainstem rivers represent up to 23% of total river length. Of the total mapped river length for the Basin, 40% (or 94,200 km) was classed as headwater streams. These are distributed across all valleys and represent between 20% and 73% of total river length in each valley. Reliable hydrology metrics were unavailable for approximately half of the river length across the Basin and these river reaches could not be included in these assessment.

For individual valleys, the proportion of river length excluded from this assessment varied between 20% and 58%.

5.7.2 Basin hydrological condition

5.7.2.1 Mainstem rivers

Over the entire Basin, 56% of the mainstem river length is rated as being in Poor, Very Poor or Extremely Poor hydrological condition (Figure 5.30). Modifications to all aspects of the flow regime are widespread across the Basin's mainstem river network. The greatest human impacts are on flow seasonality and flow variability (the Flow Seasonality and Flow Variability sub-Indicators in Figure 5.30). However, alterations to high and low flow

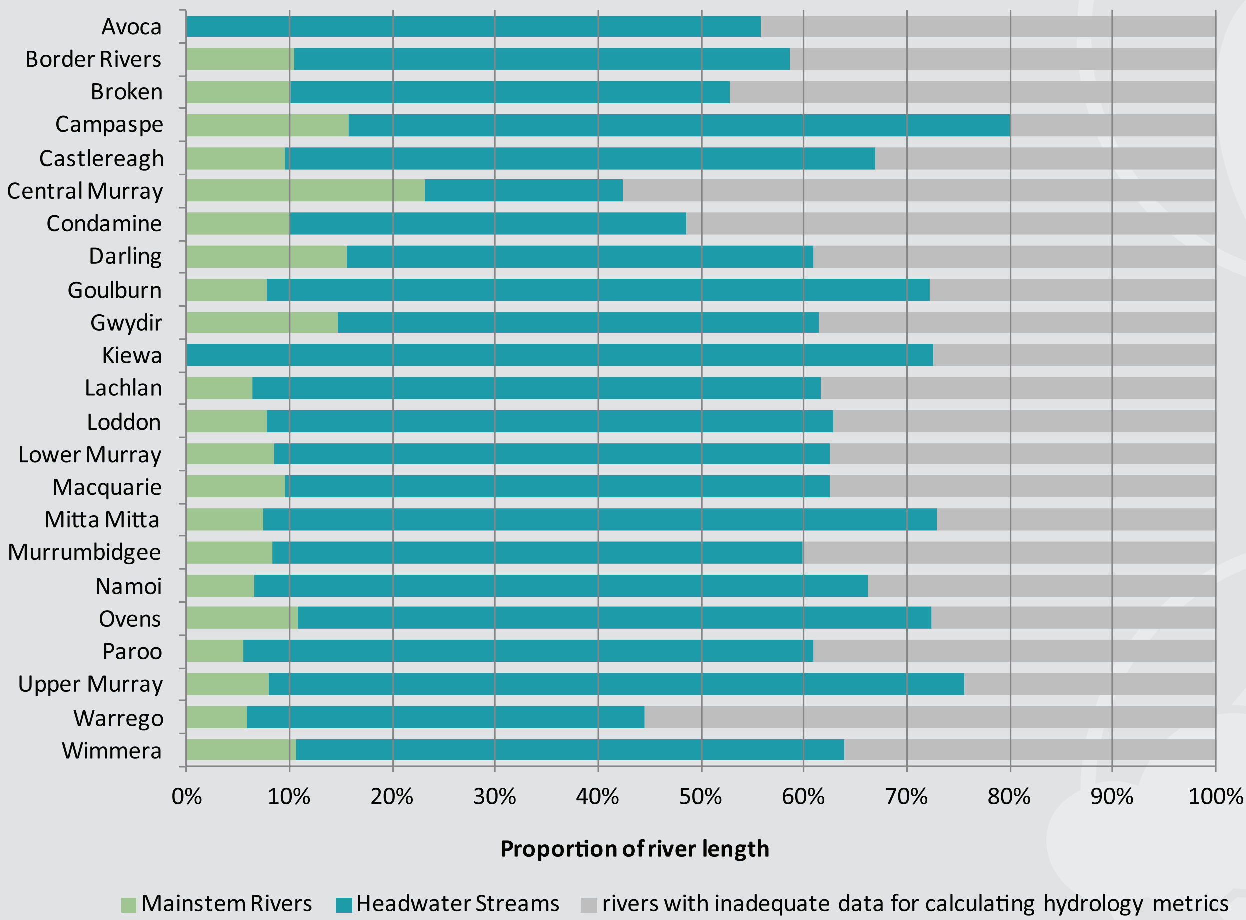


Figure 5.29. Proportion of river length that is assessed as mainstem river or headwater stream or is not assessed.

events, as well as the total volume of flow, are also widespread and severe in many cases.

5.7.2.2 Headwater streams

In headwater streams, this SRA assessment could only consider impacts of farm dams and altered woody vegetation cover. Based on this assessment, 99% of the Basin's headwater streams are rated in Good condition. There are some restricted areas (less than 5% of the total headwater stream length) where there are moderate alterations to flow seasonality and variability relative to Reference Conditions, but little or no change to other hydrology metrics.

5.7.3 Comparison of valleys

5.7.3.1 Valley Index and ratings

For ten valleys, the hydrological condition of the river system was assessed as being Good (Table 5.20, Figure 5.31). Seven valleys were rated in Moderate condition, five in Poor condition and one was rated in Very Poor condition. Variation in overall valley condition was largely determined by the mainstem river condition because headwater streams did not vary greatly in hydrology condition between valleys (Figure 5.32). The Darling and the Central Murray valleys only include Lowland zones and their overall valley index is based on mainstem scores only.

A classification of Good or Moderate does not mean that all river reaches within a valley conform to this rating. There is variation in hydrological condition throughout each valley and zone. This is illustrated by examining the individual valley hydrology condition maps in Volumes 2 and 3, which show values for each assessed reach. Local, detailed assessments of flow alteration are required to fully describe this variability and characterise river reaches that are flow-stressed. Local studies using more detailed methods may be a more accurate guide for flow stress at the reach scale than this Basin-wide assessment.

For a number of reasons, the Hydrology Condition Index scores cannot be used to evaluate the need for an environmental water requirement. Firstly, they represent alteration from the Reference Condition rather than alteration from a 'target' condition to be

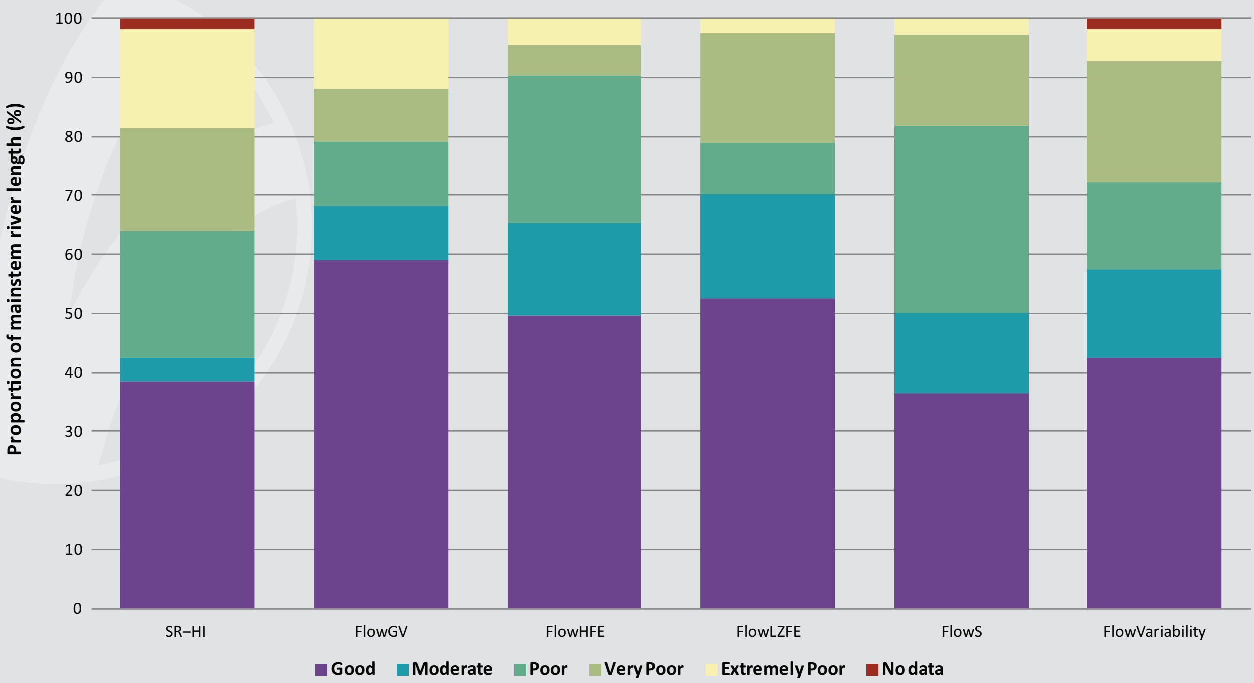


Figure 5.30. Proportion of total Basin mainstem river length by condition rating of the Hydrology Theme Index and five sub-indicators.

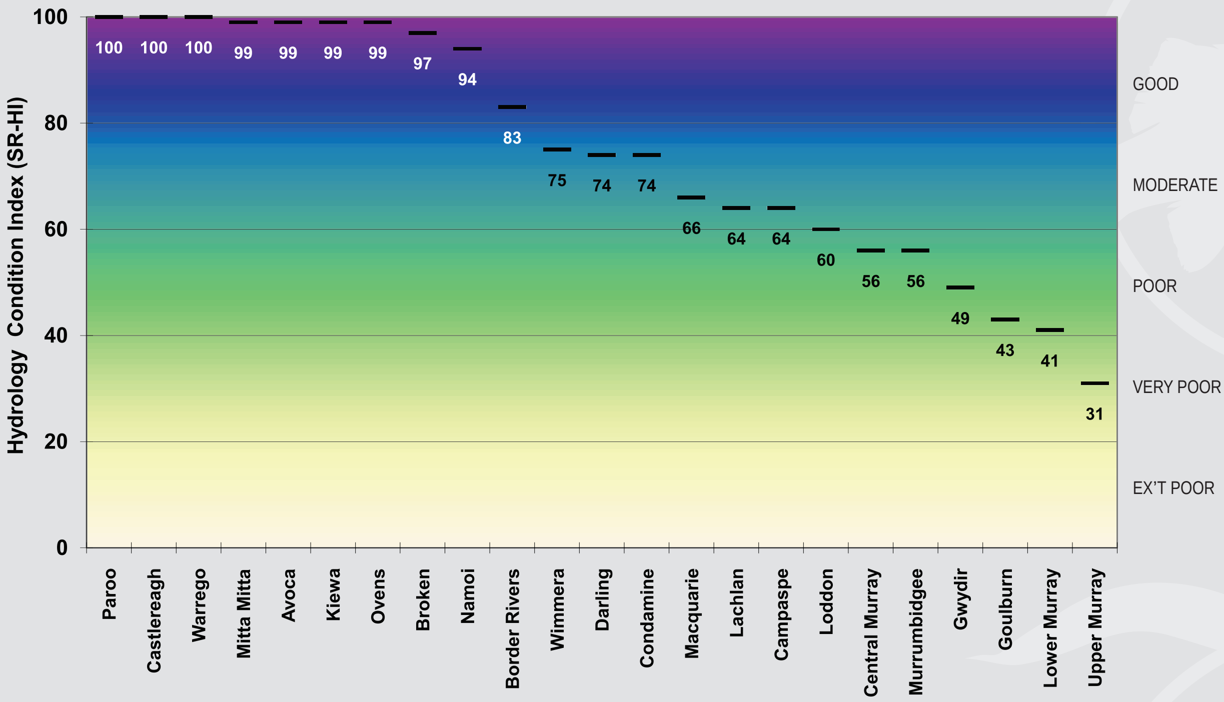


Figure 5.31. Hydrology Condition Index (SR–HI) scores for each Basin valley.

In decreasing order of Index value. Derived by combination (aggregation) of mainstem river and headwater stream results. Short horizontal bars are means. The SRA condition colour standard is shown.

achieved through delivery of environmental water. Secondly, the index is an integrated measure of the altered flow regime and includes measures of change in flow variability, frequency, duration, seasonality and magnitude. Environmental water requirements are often expressed as a flow volume only, although its delivery and effectiveness depend on these other aspects of the flow regime. Finally, the environmental water requirement within a valley is often defined relative to the river reach with the greatest alteration from a target condition and does not relate to an overall average requirement across all river reaches – as is the case for the SRA Hydrology Condition Index and rating.

5.7.3.2 Mainstem rivers

Two valleys, the Upper Murray and Lower Murray, have their mainstem rivers rated in Extremely Poor hydrological condition (Table 5.21). The mainstem rivers of four valleys are rated in Very Poor condition: the Goulburn, Gwydir, Murrumbidgee and Central Murray. Four valley mainstem river systems are rated in Poor condition: the Loddon, Lachlan, Macquarie and Campaspe; and four are rated in Moderate condition: the Condamine, Wimmera, Darling and Border Rivers. The mainstem rivers of the remaining seven valleys, the Namoi, Broken, Mitta Mitta, Warrego, Paroo, Ovens and Castlereagh are in Good hydrological condition.

Variation in valley mainstem Index results is correlated with variation in all the sub-indicators used in the Hydrology Theme. The flow variability sub-indicator shows a particularly consistent trend with Hydrology Condition Index values, suggesting that regardless of whether flow regulation affects high or low flows, it results in reduced flow variability. The flow volume indicator has the weakest association with the Hydrology Condition Index, reinforcing that the SR–HI score is not a surrogate measure for volumetric changes and hence the need for an environmental water requirement.

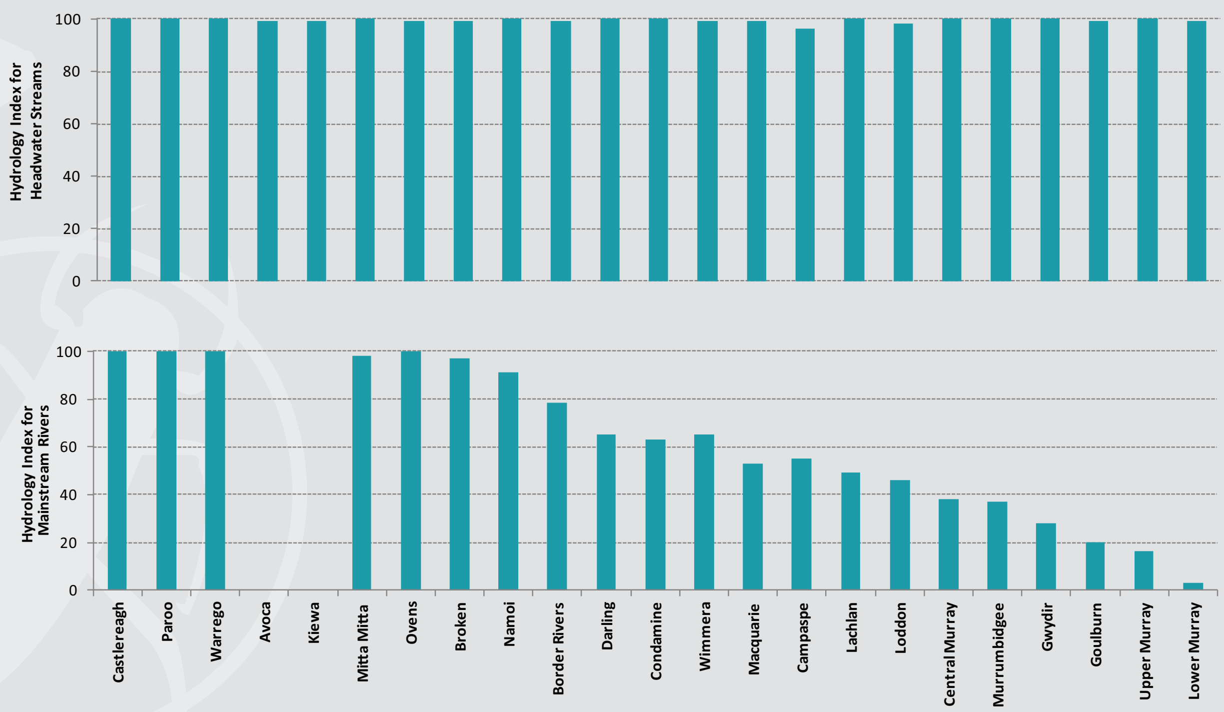


Figure 5.32. Hydrology Condition Index (SR–HI) scores for headwater streams and mainstem rivers for each Basin valley.

(In decreasing order of valley-scale Hydrology Condition Index value).

Table 5.20. Hydrology condition ratings for the SRA valleys.

Hydrology Condition			
GOOD	MODERATE	POOR	VERY POOR
Avoca	Campaspe	Gwydir	Murray, Lower
Broken	Condamine	Goulburn	
Border Rivers	Darling	Murray, Central	
Castlereagh	Lachlan	Murray, Upper	
Kiewa	Loddon	Murrumbidgee	
Mitta Mitta	Macquarie		
Namoi	Wimmera		
Ovens			
Paroo			
Warrego			

Note: score derived by aggregation of condition score for headwater streams and mainstem rivers).

Table 5.21. Hydrology Theme Index (SR–HI) and sub-indicator scores or mainstem rivers in all Basin valleys.

Valley	Index rating	Sub-indicator ratings				
	Mainstem Hydrology Index	Flow gross volume	High flow events	Low and zero flow events	Flow seasonality	Flow variability
Castlereagh	100	100	99	98	100	100
Ovens	100	100	100	98	100	100
Paroo	100	100	99	98	100	100
Warrego	100	99	96	96	99	97
Mitta Mitta	98	100	97	98	56	89
Broken	97	99	97	85	81	94
Namoi	91	94	88	71	87	78
Border Rivers	78	85	81	72	77	88
Darling	65	55	59	89	68	47
Wimmera	65	85	73	65	70	78
Condamine	63	67	67	78	76	68
Campaspe	55	96	83	73	49	73
Macquarie	53	95	88	54	65	67
Lachlan	49	93	88	37	63	81
Loddon	46	94	83	68	35	64
Murray (Central)	38	47	56	72	39	69
Murrumbidgee	37	51	54	59	40	47
Gwydir	28	82	74	40	64	41
Goulburn	20	83	64	44	23	47
Murray (Upper)	16	58	81	33	71	23
Murray (Lower)	3	7	42	66	34	29

(In order of decreasing Hydrological Condition Index score).

Table 5.22. Descriptions of ten flow alteration classes for the Murray–Darling Basin mainstem rivers.

Class number	Description
0	Minor levels of flow alteration across all aspects of the flow regime
1	Winter flow volumes are reduced and summer flow volumes are increased
2	Flow volumes are moderately reduced year-round including reduced floods
3	Reduced winter low flows and flow durations; floods less frequent
4	Increased low flows year-round and increased inter-flood spells
5	Reduced flows year round and altered seasonality (more extreme version of Class 3)
6	More zero-flow days, reduced flows, reduced floods and inter-flood spells
7	Flow augmentation: increased flow duration, less low flows
8	Reduced low and high flows, reduced winter flow volumes, and reduced flooding
9	Reduced summer high flows and flow volumes, reduced annual low and mean flows.

5.7.4 Classification of mainstem river sites based on flow alteration

To characterise patterns in flow alteration across the Basin, 274 sites on the mainstem rivers were classified using the SRA Flow Stress Ranking (FSR) metrics. These statistics compared modelled monthly streamflow series for two scenarios: (i) the current (i.e. 2008) level of water resource development; and (ii) Reference Conditions. Because monthly data are used for the purpose of classifying flows, flow spell and over bank flow metrics could not be included. In addition to the annual form of the FSR metrics used in the SRA Hydrology Theme condition assessment, we included seasonally-based FSR metrics calculated for winter and summer periods. Counting all seasonal and annual metrics, a total of 33 Flow Stress Ranking (FSR) metrics were used in this analysis. These were reduced to a set of 15 metrics using a redundancy analysis based on minimizing multi-colinearity. The classification method was a Bayesian finite mixture modelling implemented through the AutoClass C program (v 3.3.4 – Hanson, Stutz & Cheeseman, 1991; Cheeseman & Stutz, 1996). This method is fully probabilistic, both in the nature of the classification and in the explicit reporting of uncertainty in terms of data specification, class specification and final classification.

The classification identified ten classes (Table 5.22) distributed across the Basin (Figure 5.33). There are distinct classes associated with river reaches with a generally low level of flow alteration (Class 0), river reaches receiving irrigation releases (Class 1) and those downstream of irrigation off-takes (Class 2). The mid- and lower-Murray are assigned to a unique class of their own (Class 3), characterised by reduced winter low flows and flow durations and less frequent flooding.

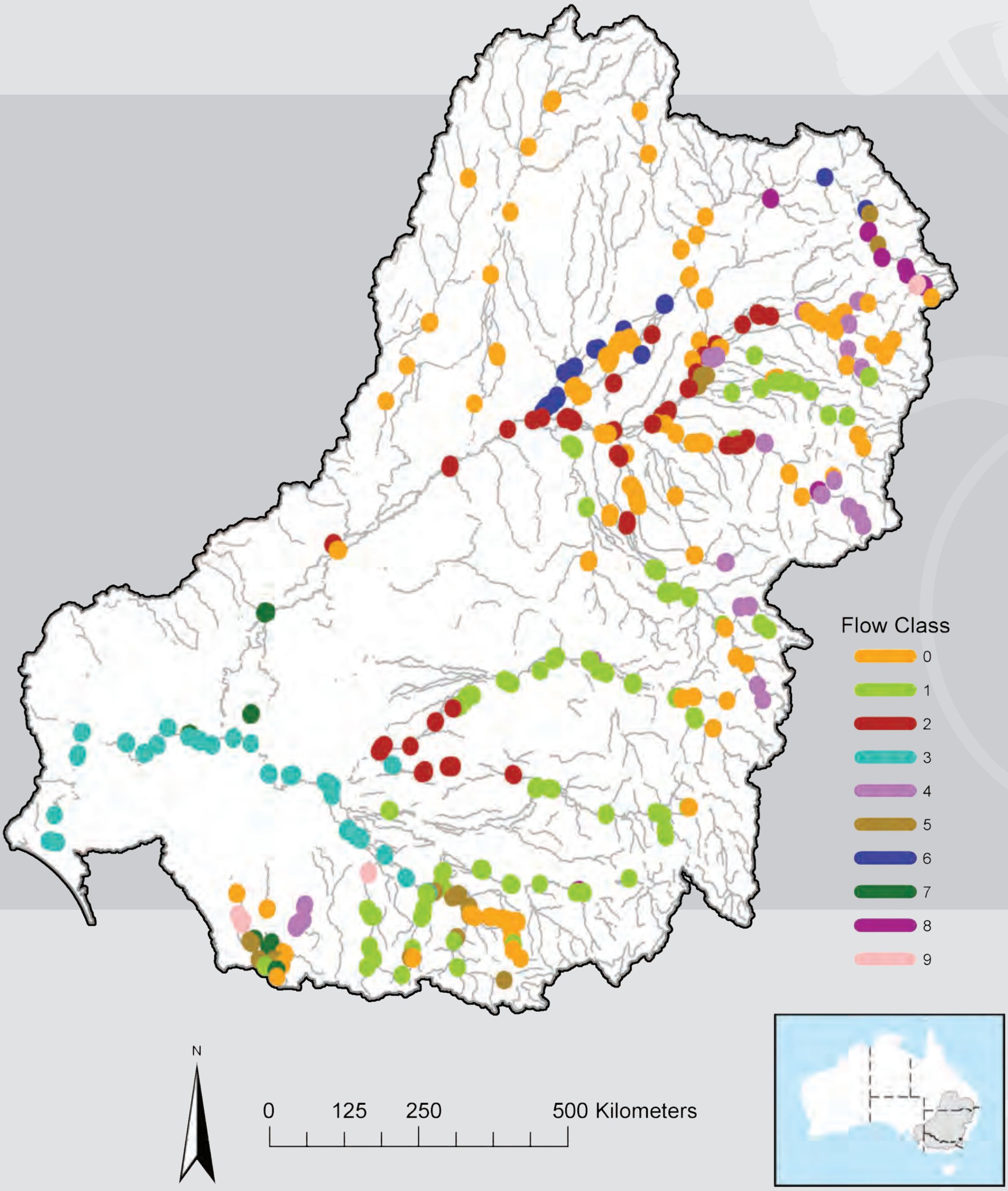


Figure 5.33. Ten flow alteration classes characterised by Flow Stress Ranking (FSR) metrics for 274 sites across the Murray–Darling Basin.

(Site colour indicates the most probable flow alteration class).

6. TEMPORAL PATTERNS AND TRENDS

6. Temporal patterns and trends

6.1 Introduction

To date the SRA has provided an 'instantaneous' appraisal of the health of the Murray–Darling Basin and its constituent valleys—through an assessment of the condition of individual components of the ecosystem (represented as 'Themes'). The value of such information is greatly enhanced if changes in condition can be tracked over time. Reliable data on temporal changes in condition, and thereby ecosystem health, provide feedback necessary for adaptive management. They also help inform the Basin community, managers and planners in progressing sustainable management. The SRA has been designed to support reporting on trends in that it:

- has a field sampling design that seeks to optimise both unbiased reporting at appropriate spatial scales (zone and valley) and also reliable assessment of changes over time
- manages the collection, quality assessment, and storage of raw data such that refinements in analysis and interpretation can be applied retrospectively to archived data, enhancing future trend assessments.

The SRA can now commence to describe changes in condition of three Themes through time. The small number of repeated assessments allows a quantification of changes between sampling events, but this cannot yet be described as an analysis of trends.

This report evaluates temporal patterns for the three Themes (Fish, Macroinvertebrates and Hydrology) that were originally assessed in SRA report 1. Over the period 2004–2010 there have been two complete cycles of fish sampling and three cycles of macroinvertebrate sampling. The Hydrology assessment is based on recorded gauge data and modelled flows over time. Temporal changes in Hydrology condition are assessed in this report using four 'time-slices' of these data.

6.1.1 Basis for comparisons

For the three repeated Themes (Fish, Macroinvertebrates, and particularly for Hydrology) the methods of assessment have been substantially refined for the current report. As a result, direct comparisons between the metrics and indices reported in SRA report 1 and those calculated for this report cannot usefully be made. To make meaningful comparisons across time, two steps are required:

1. Use the current metric calculations, expert system rule sets and revised assumptions applied to the earlier data sets.
2. Establish protocols for comparison that are both unbiased and provide a level of confidence in the outcomes of the analysis.

Estimates of the Hydrology Condition Index (SR–HI) have been updated substantially from that in SRA report 1. These changes include updates to metrics and indicators, greater spatial coverage within valley drainages, inclusion of impacts of farm dams and vegetation change, improved flow modelling, and data integration (see Section 3.7). The trend analyses described here are based on data from gauging stations and cover 12 years: divided into four, three-year 'time slices'; and corrected for reference and recent climatic conditions.

Estimates of the Fish Condition Index (SR–FI) for SRA report 2 are now based on a revision of a number of constituent indicators and metrics and differ significantly from that used in SRA report 1. This includes refinement of Reference Condition, revised calculation of the Fish Nativeness indicator, and addition of a Fish Recruitment indicator (see Section 3.3). The analysis of temporal patterns in fish condition described here is based on the new SRA report 2 SR–FI Index formulation applied to data from the most recent (second) and the initial (first) sampling cycles. An explanation of the differences resulting from these changed analytical methods can be found in Section 3.3.

Estimates of the Macroinvertebrate Condition Index (SR–MI) for SRA report 2 are now based on an advance from the previous Filters approach used in SRA report 1 (see Section 3.4). Two important changes have been made: replacement of the AUSRIVAS O/E metric with the new, more sensitive simOE metric; and removal of the SIGNAL O/E metric from the assessment (because of the inadequate basis for its estimation in the low diversity communities of the Basin).

The SR–MI values previously reported in SRA report 1 cannot be used as a basis for evaluation of temporal patterns. It is important to note that the analysis of temporal changes in macroinvertebrate condition described here is based on index values derived using the new simOE metric and SR–MI indicator; applied to the data for ALL three macroinvertebrate sampling cycles. An explanation of the differences resulting from these changed analytical methods can be found in Section 3.4.

The methods for assessment of temporal changes are described in Chapter 3, and differ between Themes because of differences in the nature of the data collected and the time periods involved.

For the Fish Theme (Section 3.3.6), confidence limits around the difference between mean values for two sampling occasions are estimated by a bootstrapping technique. This uses the difference between 2000 randomly sampled pairs to establish a distribution of possible differences around the mean value. The difference between pairs of valley SR–FI values (separated by time) is considered to be significantly positive if the 2.5 percentile of the population of 2000 possible differences is greater than zero; and significantly negative if the 97.5 percentile is less than zero. This is likely to be a conservative test.

For the Macroinvertebrate Theme (Section 3.4.6), trends are analysed using a Generalised Linear Mixed Model, with an adjusted probability level of 0.05 used to define statistically significant effects based on Scheffe's adjustment for multiple comparisons of least squares means for each effect in the model.

The methods for the Hydrology trend analysis are described in Section 3.7.6. Reference-corrected ratios of hydrology metrics were evaluated for a statistically significant linear trend—of either increasing or decreasing level of flow alteration over the 12-year period—using a two-tailed test of significance. Trends are described for ratios of flow metrics derived relative to reference natural flows modelled for the same time period. This means that trends detected are due to departures of the flow regime from natural as a result of water management; not natural changes in runoff (e.g. as a result of the recent drought).

6.2 Temporal changes in Fish

The relative condition of fish communities in the valleys during 2004–2007 (SRA cycle 1) and 2008–2010 (SRA cycle 2) is shown in Figure 6.1. Overall the patterns are quite similar between the two sampling cycles. Exceptions are the Castlereagh, which moved from SR–FI = 6 in 2004–2007 to SR–FI = 38 in 2008–2010; and the Paroo in which the SR–FI increased from 52 to 83. A significant increase in all three Indicators (Expectedness, Nativeness, and Recruitment) was observed in the Castlereagh. The increase in the Paroo related solely to Recruitment. At the other end of the scale, the Central Murray Valley changed from a SR–FI score of 48 in 2004–2007 to 20 in 2008–2010. Table 6.1 presents these data in tabular form, indicating those valleys judged to have exhibited statistically significant changes in the condition of fish communities between the two sampling cycles.

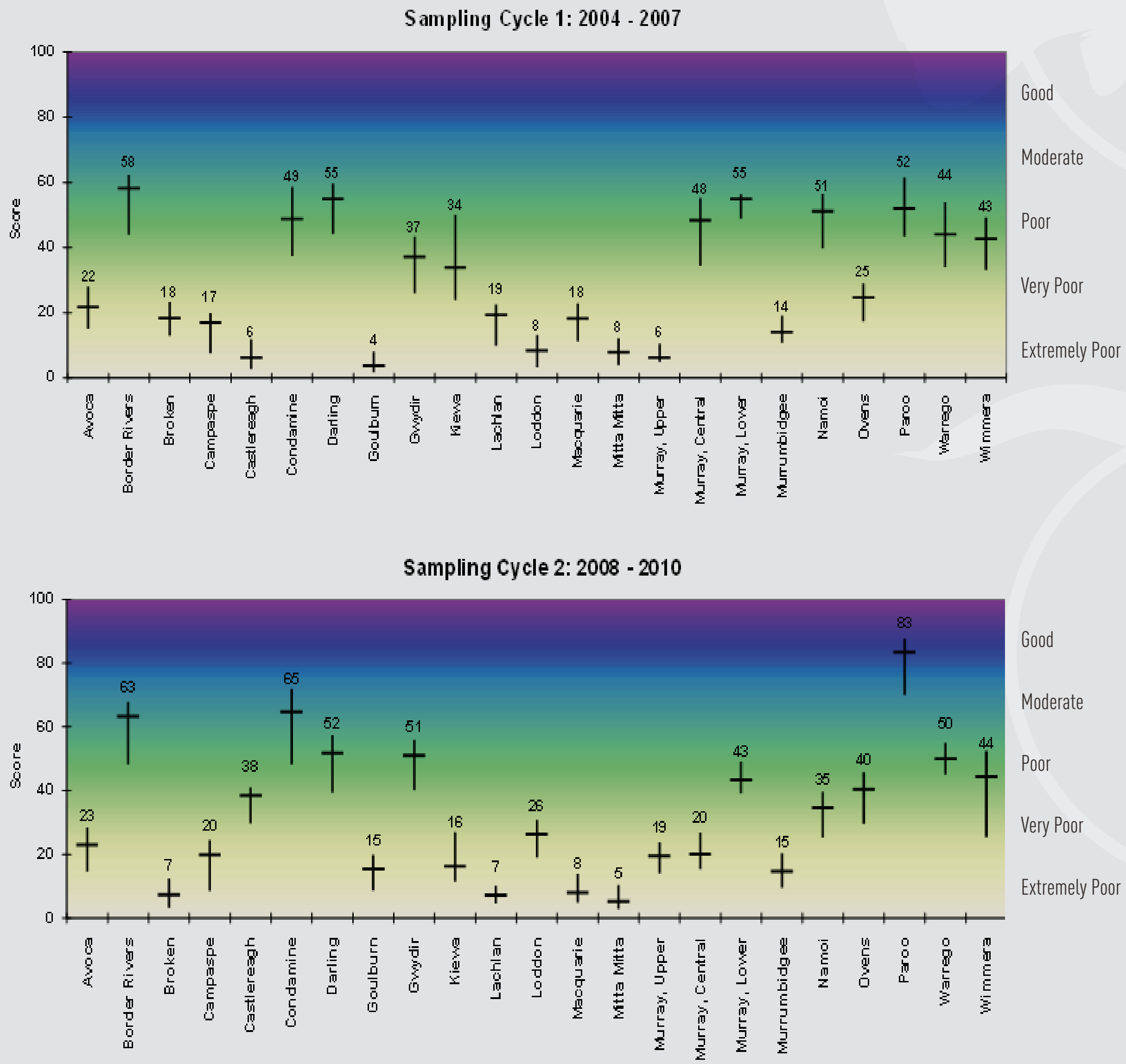


Figure 6.1. Valley SR Fish Index (SR–FI) scores for both SRA reporting cycles.
Short horizontal bars are means; vertical lines show the associated 95% confidence limits. The SRA colour standard is shown, with condition labels.

Table 6.1. SRA Fish Index with upper and lower 95% confidence limits, for the two sampling cycles in 2004–2007 and 2008–2010.

Colour codes indicate statistical significance of temporal change between cycle 1 and cycle 2: **grey** = no significant change, **red** = significant decrease in SR–FI from cycle 1 to cycle 2, **green** = significant increase in SR–FI from cycle 1 to cycle 2.

SRA valley	Sampling cycle 1 2004–2007		Sampling cycle 2 2008–2010	
	SR–FI	95% confidence limits	SR–FI	95% confidence limits
Avoca	21.8	15.0–28.0	22.9	14.5–28.4
Border Rivers	58.2	43.9–62.3	63.3	48.1–67.8
Broken	18.3	12.8–23.3	7.3	3.2–12.4
Campaspe	16.9	7.5–19.8	19.9	8.4–24.5
Castlereagh	6.2	2.6–11.8	38.5	29.7–41.1
Condamine	48.8	37.4–58.6	64.6	48.2–71.9
Darling	54.9	44.1–59.7	51.8	39.4–57.3
Goulburn	3.8	1.7–8.0	15.4	8.6–19.9
Gwydir	37.2	25.9–43.4	51.1	40.1–55.8
Kiewa	33.9	23.8–50.1	16.3	11.5–27.7
Lachlan	19.3	9.8–22.6	7.2	4.6–10.2
Loddon	8.4	3.3–13.1	26.3	18.9–30.9
Macquarie	18.2	11.2–22.8	7.9	4.9–13.9
Mitta Mitta	7.9	3.9–12.2	5.2	2.8–10.3
Murray, Central	48.4	34.5–55.2	20.2	15.3–26.8
Murray, Lower	55.0	48.8–56.3	43.3	39.0–49.1
Murray, Upper	6.3	4.8–10.5	19.4	14.0–23.7
Murrumbidgee	14.1	10.7–19.1	14.6	9.5–20.4
Namoi	51.2	39.7–56.4	34.6	25.3–39.6
Ovens	24.7	17.3–29.0	40.4	29.5–45.8
Paroo	52.0	43.4–61.5	83.4	69.9–87.7
Warrego	43.6	33.9 – 53.6	50.0	45.0–55.0
Wimmera	42.6	33.1–49.3	44.4	25.4–52.4

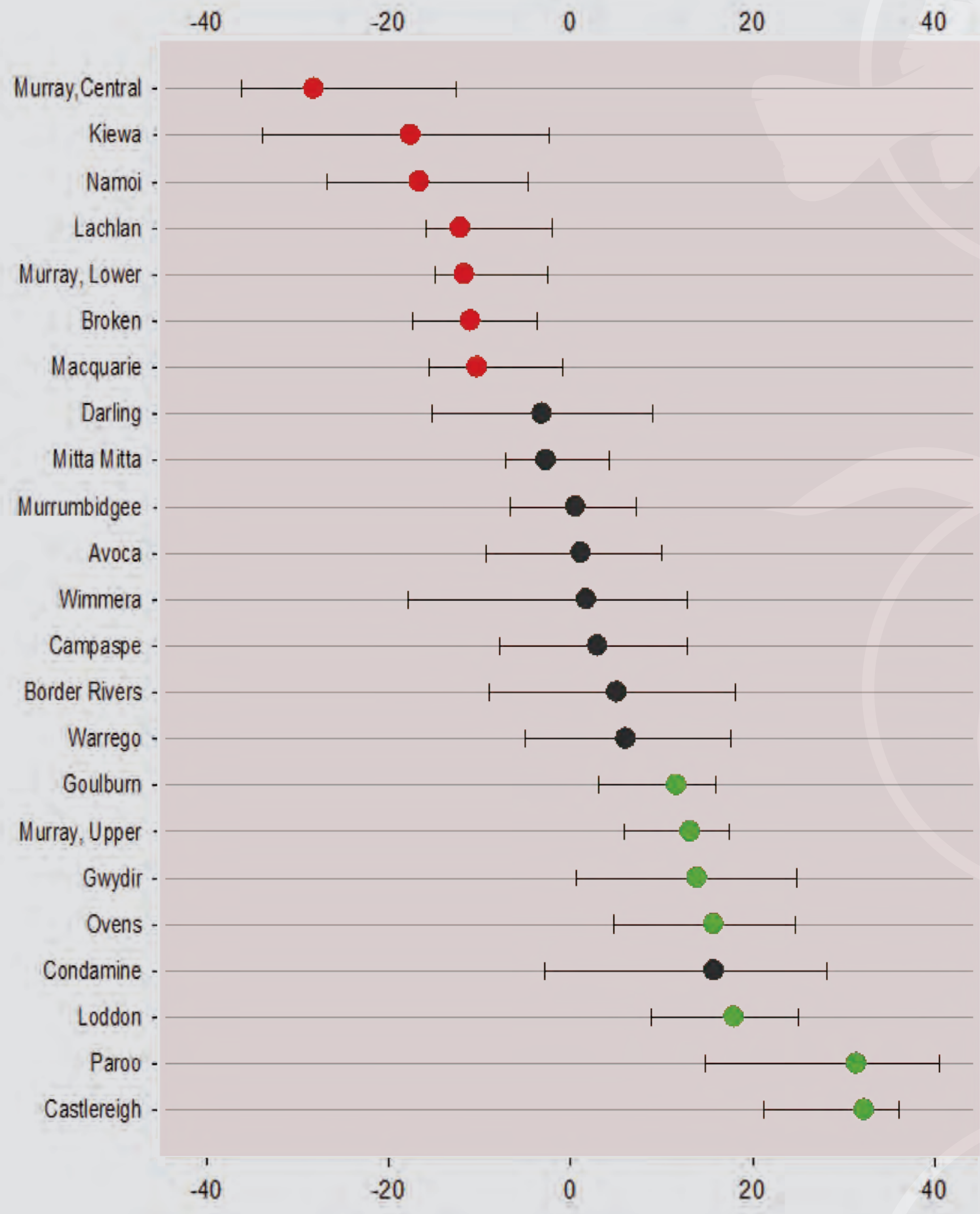


Figure 6.2. Difference between SR–FI scores in sampling cycle 2 (SRA 2, 2008–2010) and sampling cycle 1 (SRA 1, 2004–2007).

Solid circles = mean value; horizontal bars = 95% confidence limits; green indicates an increase over time and red indicates a decrease.

In all, the condition of fish communities improved significantly in seven valleys and declined significantly in seven valleys. The remaining nine valleys exhibited no significant change between the two sampling cycles. Figure 6.2 presents the valleys in order of the size and direction of change in SR–FI between the two sampling cycles. These data were the basis upon which the statistical significance of the difference between sampling cycles was determined.

Of the seven valleys that suffered a decline in fish condition: five were in the southern part of the Murray–Darling Basin, and two—the Namoi and the Macquarie—were in the northern part. Three of the seven valleys in which fish condition improved significantly between samples were in the northern sub-basin. A one-way Simper analysis (Primer 6, Clarke and Gorley 2006) failed to demonstrate a significant relationship between the composition of fish communities and the three possible directions of change (increase, no significant change, decrease) at the valley scale. A nested two-way analysis, including sub-basin with direction of change, similarly showed no significant link with fish community structure. Given that SR–FI is derived from eight separate metrics, only some of which relate directly to community structure, this result is not surprising.

Table 6.2 presents data on the incidence of bushfire and on annual rainfall across the Murray–Darling Basin during all sampling for fish and macroinvertebrates. There are several valleys in which fish sampling took place during a year of high rainfall; but the response time of fish communities to rainfall events is not clear and probably dependant on the ecological parameter measured. The valley that exhibited the greatest positive change in SR–FI was the Castlereagh (Figure 6.2). Fish sampling was carried out in the first quarter of 2010 and was preceded by wet conditions in 2008 and, for the Lowland zone, in 2009. At the valley scale, the Castlereagh exhibited significant increases in the three sub-indices (Expectedness, Nativeness, and Recruitment) as well as in the SR–FI overall.

This may well evidence a response by the native fish community to an extended period of above-average rainfall in the valley. It should be noted, however, that the Condamine Valley (sampled at the same time and experiencing a similar rainfall regime in the preceding two years) did not show a significant increase in the SR–FI or the three sub-indices, though, on average, all were higher for 2010 samples than for 2007 samples. (Expectedness increased significantly in the Lowland zone; the part of the valley that experienced the most consistent rainfall increase.) Further, the Paroo showed a similar improvement in SR–FI without unusually high (or low) rainfall in preceding years. The significant increase in SR–FI in the Castlereagh may well reflect a response to more favourable rainfall and differences between this valley and the Condamine could reflect any of a number of factors. For example:

- SR–FI values for the two valleys in the first cycle of sampling (2007) were quite different (Castlereagh 6; Condamine 49) indicating quite different 'starting points' in terms of the condition of fish communities in the two valleys over the period 2007–2010. It may be that, in the Castlereagh, the favourable rainfall conditions permitted fish condition to improve to a level at which other limiting factors, not directly driven by rainfall, began to operate. It may also reflect inconsistencies in the link between ecological condition of fish communities and the numerical value of SR–FI across its range—though this would be expected to be more obvious across the range of valleys if it were a significant factor.
- Intra-annual rainfall patterns may be important and are not reported here. Also, the valleys support significant irrigation industries based on harvesting of high flows and off-stream storage. This might complicate any relationship between regional rainfall and aspects of the flow regime significant to the fish community, particularly in a period immediately following extended drought.

Table 6.2. Timing of fish and macroinvertebrate sampling, rainfall and fire events.

1, 2, 3 = sampling round. Rainfall deviations for each year from long-term average are shown as: XD <– 400 mm, VD = –200 to –400, D = –50 to –200, W = 50 to 200, VW =200 to 400, XW > 400 mm. Blanks indicate annual rainfall within -50 to 50 mm of long-term average. Relative area of fires within zones is shown as: SMALL (5 to 15%), **MODERATE** (15 to 25%), **LARGE** (25 to 75%), and **X-LARGE** (75 to 100%), and where **BLANK** is regarded as minimal (< 5%).

Valley	Zone	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Avoca	Lowland	D	VD	.	D	.	D	D	D	D	W
	Slopes	D	D	D	D	D	VD	D	D	D	W
	Fish sampling					1			2		
	Macroinvertebrate sampling					1	2		3		
Border Rivers	Lowland	D	VD	.	.	.	VD	VD	D	D	W
	Slopes	.	VD	D	.	.	D	VD	D	D	W
	Upland	.	VD	.	.	.	D	D	D	D	W
	Montane	W	VD	.	.	.	D	D	D	D	VW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	
Broken	Lowland	D	VD	W	D	D	VD	VD	D	D	VW
	Slopes	VD	VD	.	D	D	XD	XD	VD	VD	VW
	Fish sampling				1			2			
	Macroinvertebrate sampling					1	2		3		
Campaspe	Lowland	D	VD	.	D	D	VD	D	D	D	VW
	Slopes	D	VD	.	D	D	VD	D	VD	D	VW
	Upland	D	VD	D	D	D	VD	VD	VD	D	VW
	Fish sampling						1			2	
	Macroinvertebrate sampling					1	2		3		
Castlereagh	Lowland	D	VD	.	.	D	D	D	W	W	VW
	Slopes	D	VD	.	.	D	VD	D	W	D	VW
	Upland	D	VD	.	.	D	VD	D	.	VD	XW
	Fish sampling							1			2
	Macroinvertebrate sampling						1		2		3
Condamine	Lowland	D	VD	D	W	D	VD	D	W	(W)	VW
	Slopes	D	VD	D	.	D	VD	VD	.	VD	XW
	Fish sampling							1			2
	Macroinvertebrate sampling						1	2		3	
Darling	Lower	D	D	.	D	.	D	D	D	.	W
	Middle	D	D	.	D	.	D	.	.	D	W
	Upper	D	D	.	D	D	D	D	.	.	VW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	
Goulburn	Lowland	D	VD	.	D	D	VD	VD	D	D	VW
	Slopes	D	VD	.	D	D	XD	XD	VD	VD	VW
	Upland	VD	ZD	D	D	VD	XD	XD	VD	VD	VW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	

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Table 6.2. Timing of fish and macroinvertebrate sampling, rainfall and fire events.

1, 2, 3 = sampling round. Rainfall deviations for each year from long-term average are shown as: XD <– 400 mm, VD = –200 to –400, D = –50 to –200, W = 50 to 200, VW =200 to 400, XW > 400 mm. Blanks indicate annual rainfall within -50 to 50 mm of long-term average. Relative area of fires within zones is shown as: **SMALL** (5 to 15%), **MODERATE** (15 to 25%), **LARGE** (25 to 75%), and **X-LARGE** (75 to 100%), and where **BLANK** is regarded as minimal (< 5%).

Valley	Zone	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gwydir	Lowland	W	VD	.	VW	.	D	D	W	D	VW
	Slopes	.	VD	.	W	.	D	D	.	D	VW
	Upland	.	VD	.	W	.	D	D	.	D	VW
	Montane	D	VD	.	W	.	D	D	D	D	VW
	Fish sampling							1			2
	Macroinvertebrate sampling						1		2		3
Kiewa	Lowland	D	VD	.	D	D	XD	XD	VD	VD	VW
	Slopes	D	VD	.	D	D	XD	XD	VD	VD	VW
	Upland	D	XD	D	VD	VD	XD	XD	XD	VD	XW
	Fish sampling						1			2	
	Macroinvertebrate sampling					1	2		3		
Lachlan	Lowland	D	VD	.	D	D	VD	D	D	D	VW
	Slopes	D	VD	.	D	D	VD	VD	D	D	VW
	Upland	D	VD	D	D	D	VD	VD	D	D	VW
	Montane	D	VD	D	D	D	VD	VD	D	D	VW
	Fish sampling						1			2	
	Macroinvertebrate sampling				1		2		3		
Loddon	Lowland	D	VD	.	D	D	VD	D	D	D	VW
	Slopes	D	VD	D	D	D	XD	VD	VD	D	VW
	Fish sampling				1			2			
	Macroinvertebrate sampling					1		2		3	
Macquarie	Lowland	D	VD	.	D	D	VD	D	W	(W)	VW
	Slopes	D	VD	.	D	D	VD	D	.	D	VW
	Upland	D	VD	.	D	D	VD	VD	D	VD	VW
	Fish sampling						1			2	
	Macroinvertebrate sampling					1		2		3	
Mitta Mitta	Slopes	D	VD	.	D	D	XD	XD	VD	VD	VW
	Upland	D	VD	.	D	D	XD	XD	VD	VD	VW
	Montane	D	VD	D	D	D	XD	XD	XD	VD	VW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	

Continued/...

Table 6.2. Timing of fish and macroinvertebrate sampling, rainfall and fire events.

1, 2, 3 = sampling round. Rainfall deviations for each year from long-term average are shown as: XD <– 400 mm, VD = –200 to –400, D = –50 to –200, W = 50 to 200, VW =200 to 400, XW > 400 mm. Blanks indicate annual rainfall within -50 to 50 mm of long-term average. Relative area of fires within zones is shown as: SMALL (5 to 15%), **MODERATE** (15 to 25%), **LARGE** (25 to 75%), and **X-LARGE** (75 to 100%), and where **BLANK** is regarded as minimal (< 5%).

Valley	Zone	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Murray (Upper)	Slopes	D	VD	.	D	D	XD	XD	D	D	VW
	Upland	D	VD	D	D	D	XD	XD	VD	D	XW
	Montane	D	VD	D	VD	D	XD	XD	VD	VD	XW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	
Murray (Central)	Lower	D	VD	.	D	.	D	D	D	D	VW
	Middle	D	VD	.	D	.	VD	D	D	D	VW
	Upper	D	VD	.	D	.	VD	VD	D	D	VW
	Fish sampling					1			2		
	Macroinvertebrate sampling					1		2		3	
Murray (Lower)	Lower	.	D	.	.	.	D	D	D	.	W
	Middle	.	D	.	.	.	D	.	D	.	W
	Mt Lofty	.	D	.	.	W	D	D	D	.	W
	Upper	.	D	.	D	.	D	D	D	.	W
	Fish sampling					1			2		
	Macroinvertebrate sampling						1		2		3
Murrumbidgee	Lowland	D	VD	.	D	D	VD	D	D	D	VW
	Slopes	D	VD	D	D	D	VD	VD	D	D	VW
	Upland	D	VD	D	D	D	XD	VD	D	D	VW
	Montane	D	D	D	VD	D	XD	XD	D	VD	XW
	Fish sampling							1			2
	Macroinvertebrate sampling				1			2	3		
Namoi	Lowland	D	VD	D	W	D	VD	D	W	D	VW
	Slopes	D	VD	D	W	.	VD	D	W	D	VW
	Upland	D	VD	D	W	D	VD	D	W	D	VW
	Montane	.	VD	D	W	D	VD	D	W	D	VW
	Fish sampling						1			2	
	Macroinvertebrate sampling					1		2		3	

Continued/...

Table 6.2. Timing of fish and macroinvertebrate sampling, rainfall and fire events.

1, 2, 3 = sampling round. Rainfall deviations for each year from long-term average are shown as: XD <– 400 mm, VD = –200 to –400, D = –50 to –200, W = 50 to 200, VW =200 to 400, XW > 400 mm. Blanks indicate annual rainfall within -50 to 50 mm of long-term average. Relative area of fires within zones is shown as: **SMALL** (5 to 15%), **MODERATE** (15 to 25%), **LARGE** (25 to 75%), and **X-LARGE** (75 to 100%), and where **BLANK** is regarded as minimal (< 5%).

Valley	Zone	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ovens	Lowland	D	VD	W	D	D	XD	XD	D	VD	VW
	Slopes	D	VD	.	D	D	XD	XD	VD	VD	VW
	Upland	D	VD	.	D	D	XD	XD	VD	VD	XW
	Montane	D	XD	D	VD	D	XD	XD	XD	VD	XW
	Fish sampling							1			2
	Macroinvertebrate sampling					1		2		3	
Paroo	Lowland	D	VD	D	.	D	D	.	.	.	.
	Fish sampling						1			2	
	Macroinvertebrate sampling						1		2		3 3
Warrego	Lowland	D	VD	D	.	D	D	D	W	W	VW
	Slopes	D	D	D	W	D	D	D	W	D	XW
	Fish sampling						1			2	
	Macroinvertebrate sampling						1		2		3 3
Wimmera	Lowland	D	D	.	D	D	D	D	D	.	W
	Slopes	D	D	.	D	D	VD	D	D	D	W
	Fish sampling						1			2	
	Macroinvertebrate sampling					1	2		3		

Table 6.3. Summary of temporal patterns in SR–FI scores amongst zones.

Sub-basins treated separately. 'Up' = significant increase in SR–FI between first and second sampling cycle; 'N.D.' = no significant difference; 'Down' = significant decrease in SR–FI.

Zone	Number	Temporal pattern in SR–FI								
		Northern sub-basin (26)			Southern sub-basin (42)			Basin-wide (68)		
		Up	N.D.	Down	Up	N.D.	Down	Up	N.D.	Down
Lowland	27	3	7	1	1	13	2	4	20	3
Slopes	20	1	5	1	2	8	3	3	13	4
Upland	13	0	5	0	1	5	2	1	10	2
Montane	8	0	2	1	0	5	0	0	7	1
TOTAL	**68**	**4**	**19**	**3**	**4**	**31**	**7**	**8**	**50**	**10**

During 2010 and 2011 extensive rainfall has occurred throughout the Basin, ending an extended drought, particularly in the southern part of the Basin. It is anticipated that fish samples taken subsequent to the second SRA cycle (2008–2010) will provide insight into how drought recovery is evidenced in different aspects of ecological condition; and how the capacity of the fish community to respond to the breaking of the drought is affected in turn by its condition.

Temporal patterns in SR–FI at the zone level are presented in Table 6.3. Most zones showed no significant difference in SR–FI values between sampling cycles 1 and 2. There was only one significant rise in SR–FI amongst the 21 Montane and Upland zones. It is possible that these small unregulated streams respond more drastically to extended severe drought conditions than larger, lower altitude streams. This may be because the latter, partly through regulation, often have fewer and/or shortened extreme low-flow events and in-stream storages may provide additional drought refuge for some species.

6.3 Temporal changes in Macroinvertebrates

Three sampling cycles for macroinvertebrates have now been completed, with each valley in the Basin sampled once in each of spring 2004–autumn 2006; spring 2006–autumn 2008; and spring 2008–autumn 2010. Analysis of temporal changes in the Macroinvertebrate Theme Index (SR–MI) over this entire sampling period from 2004–2010 was conducted by testing for differences between sampling cycles in the value of the Macroinvertebrate Index for each valley and zone (see Section 3.4).

Values and plots of SR–MI values are shown for each of the three sampling cycles in Table 6.4 and Figure 6.3. Valley scale SR–MI values show a substantial degree of variation over time for only six valleys: the Campaspe, Condamine, Goulburn, Gwydir, Warrego and Wimmera. There is otherwise a broad consistency in pattern and magnitude of SR–MI values across most valleys over the three cycles. The Kiewa, Mitta Mitta, Ovens, Paroo and Murray (Upper) valleys maintain the highest values through time, while the Murray (Central) and Darling valleys maintain the lowest scores.

Plots of changes in mean SR–MI for each valley over time are shown in Figure 6.4 and Figure 6.5. Ten valleys showed significant differences in SR–MI values (at $p < 0.05$) between sampling cycles. These were the Broken, Campaspe, Murray (Central), Condamine, Gwydir, Kiewa, Macquarie, Mitta Mitta, Namoi, Warrego and Wimmera valleys.

Of these, three (the Gwydir, Macquarie and Mitta Mitta) showed a decline through the sampling period, though these declines only ranged between six and 10 SR–MI units (8–13%). For the Macquarie Valley these declines were significant only for the Slopes zone. For the Mitta Mitta Valley the decrease occurred between sampling cycles 1 and 2 (spring 2005 and spring 2007), followed by no significant change by sampling cycle 3 (spring 2009). For the Macquarie Valley the decrease also occurred between sampling cycles 1 and 2 (spring 2005 and spring 2007), and was followed by a slight rise by 2.5 units by sampling cycle 3 (spring 2009).

SR–MI showed an increase over the sampling period for two valleys (the Warrego and Wimmera), though again these increases were small, ranging between 8 and 13 SR–MI units (14–18%). For the Warrego Valley this increase was particularly significant in the Lowland and Slopes zones. For the Wimmera Valley the increase occurred between sampling cycles 1 and 2 (autumn 2005 and spring 2006),

Table 6.4. SR Macroinvertebrate Index (SR–MI) and associated metric values for Basin valleys from the three SRA sampling cycles to date.

SR–MI values derived from mean simOE metric values as described in Section 3. Data are means (lower–upper 95% confidence limits), in alphabetical order.

Valley	Sampling cycle 1	Sampling cycle 2	Sampling cycle 3
	2004–2006	2006–2008	2008–2010
Avoca	66 (61-72)	64 (56-72)	67 (62-72)
Border Rivers	71 (67-75)	66 (62-71)	68 (62-74)
Broken	74 (69-78)	81 (77-85)	80 (77-83)
Campaspe	68 (64-73)	76 (71-81)	72 (68-76)
Castlereagh	74 (68-80)	72 (67-76)	78 (74-82)
Condamine	76 (72-81)	67 (62-72)	77 (71-82)
Darling	56 (51-61)	58 (53-63)	53 (47-59)
Goulburn	65 (57-73)	65 (59-72)	55 (47-64)
Gwydir	72 (66-77)	68 (63-73)	62 (57-67)
Kiewa	88 (84-92)	92 (89-94)	84 (80-89)
Lachlan	63 (58-69)	68 (64-72)	67 (63-71)
Loddon	67 (62-72)	68 (64-72)	65 (59-70)
Macquarie	71 (64-77)	66 (60-73)	66 (60-72)
Mitta Mitta	92 (88-96)	87 (82-91)	90 (86-93)
Murray, Central	58 (52-65)	64 (59-68)	56 (50-62)
Murray, Lower	74 (68-80)	76 (69-82)	76 (72-80)
Murray, Upper	86 (83-90)	82 (75-88)	89 (85-92)
Murrumbidgee	66 (60-72)	72 (66-78)	71 (65-77)
Namoi	68 (62-74)	67 (62-72)	70 (64-76)
Ovens	81 (76-86)	77 (72-83)	79 (72-86)
Paroo	85 (82-88)	84 (81-88)	86 (84-89)
Warrego	77 (70-83)	83 (81-85)	86 (84-88)
Wimmera	63 (57-68)	73 (68-78)	69 (63-76)

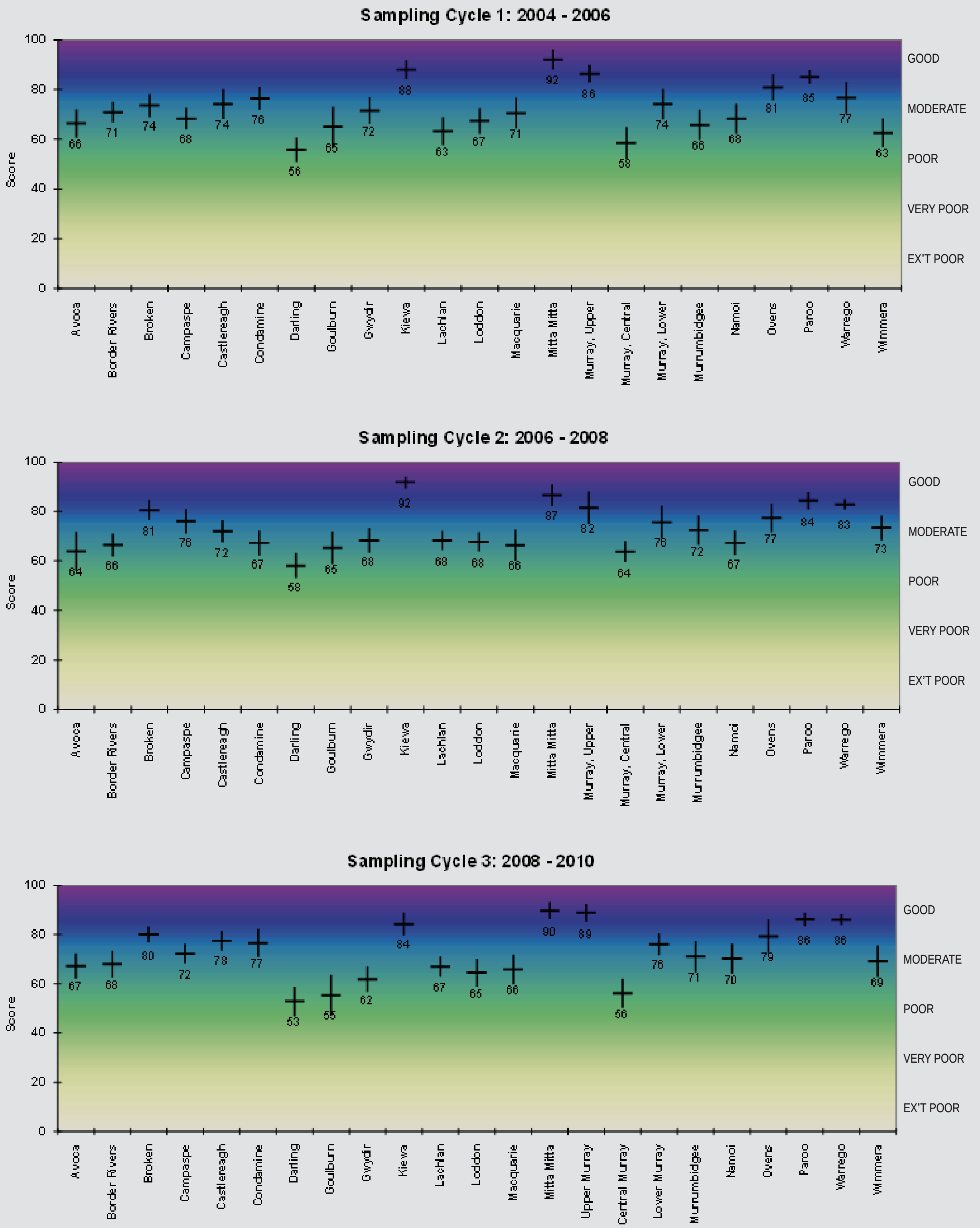

Figure 6.3. Valley SR Macroinvertebrate Index (SR–MI) scores for all three SRA reporting cycles to date.
Short horizontal bars are means; vertical lines show the associated 95% confidence limits. The SRA colour standard is shown, with condition labels.

followed by a marginal fall by sampling cycle 3 (spring 2008).

Of the remaining five valleys with significant changes in SR–MI with time, the index increased in value for four of them in the second cycle, falling again in the third cycle (the Broken, Campaspe, Murray (Central) and Kiewa). For two valleys, SR–MI decreased in value in the second cycle, rising again in the third cycle (the Condamine and Namoi).

Differences in SR–MI were of only marginal statistical significance between cycles (with $p < 0.1$) for the Goulburn, Murray (Lower), Murray (Upper) and Murrumbidgee valleys.

Overall therefore there was no consistent pattern of either rise or fall in the value of the index across all valleys. There was no overall pattern of decline or increase in SR–MI at valley scale across the Basin as a whole, nor across the northern (Darling drainage) or southern (Murray drainage) regions. There was also no consistent temporal pattern in SR–MI values among zones of similar type, either at Basin or regional level.

On inspection of the timing of sampling for macroinvertebrates (see Table 6.2), changes in the index value for most valleys and zones were not related to antecedent rain and flow conditions. This is understandable, as most valleys and zones experienced consistent dry to extremely dry conditions over the three cycles of the entire sampling period. Also, at least for Lowland zones in highly regulated systems, the links between local rainfall and river conditions are generally weak or complex.

Exceptions were the:

- Castlereagh Valley, where wet conditions prevailed in 2008–2009 prior to sampling in the Lowland zone. However, no substantive response was observed in SR–MI values at the zone scale. The third cycle of sampling occurred before major rain events in 2010.
- Gwydir Valley where SR–MI values declined in all zones with time. This may be a response to ongoing dry conditions and declining flows, with the Lowland zone having the lowest values in sampling cycle 3 (autumn 2010). This third cycle of sampling occurred before the major rain events for 2010.
- Macquarie Valley where SR–MI values declined in the Slopes and Upland zones with time, possibly due to sustained very dry conditions.

Several large-scale fire events occurred during and prior to SRA sampling (Table 6.2). All SRA sampling in the Kiewa, Mitta Mitta and Murray (Upper) valleys commenced two years after the extensive fires of 2003. The Ovens and Goulburn valleys experienced extensive fires in 2006, and again in 2009 for the Goulburn. While local effects might have been observed at the scale of sites, no substantive changes were observed in valley- or zone-scale SR–MI index values that could be unequivocally related to these fire events.

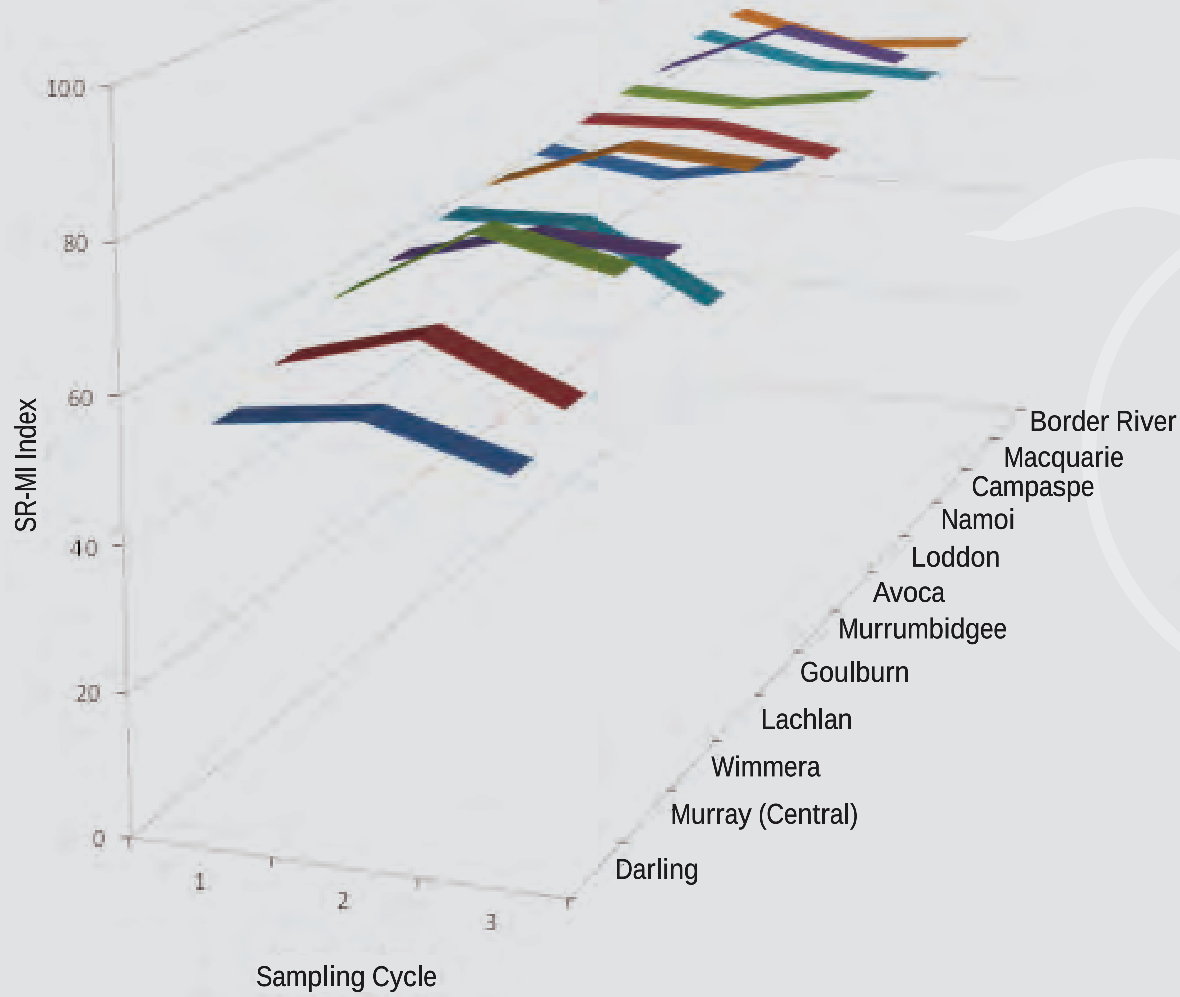

Figure 6.4. Plot a. valley-scale SR–MI values for the three sampling cycles.
Sampling cycles are: 1 = spring 2004–autumn 2006; 2 = spring 2006–autumn 2008; and 3 = spring 2008–autumn 2010. See Table 6.2 for each valley's sampling times.

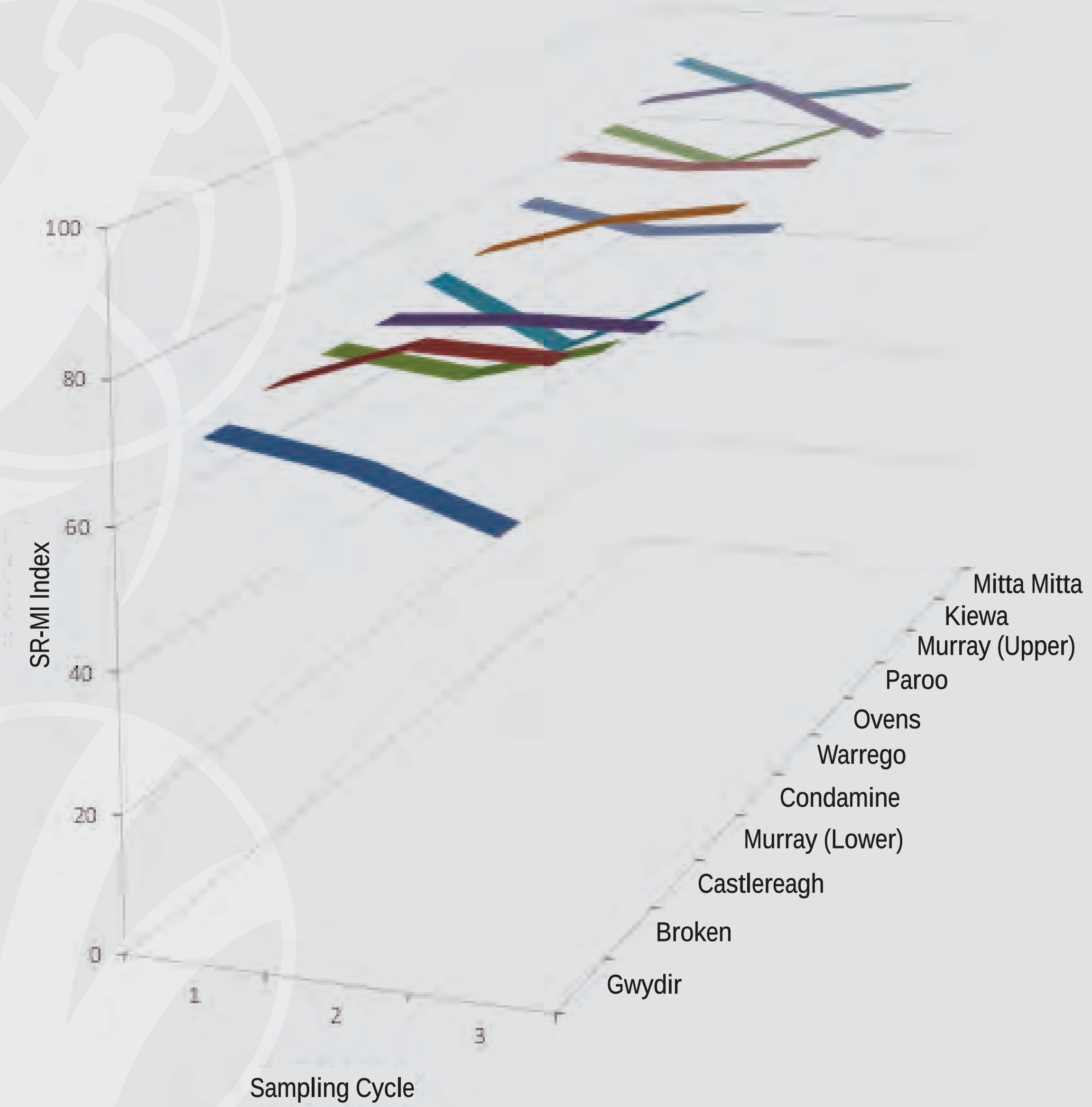

Figure 6.5. Plot b. valley-scale SR–MI values for the three sampling cycles.
Sampling cycles are: 1 = spring 2004–autumn 2006; 2 = spring 2006–autumn 2008; and 3 = spring 2008–autumn 2010.
See Table 6.2 for each valley's sampling times.

6.4 Temporal changes in Hydrology

Changes in hydrology metrics were evaluated at 44 streamflow gauging stations, all located on mainstem rivers across the Basin. These sites were unevenly distributed across the SRA valleys; with some valleys having no sites. They were selected based on: (a) achieving a good coverage across the SRA valleys; (b) availability of reference flow series derived from water resource models; and (c) availability of reliable streamflow records. Trends were tested for the 12-year period 1998 to 2009. Changes were analysed using flow alteration (FSR) metrics. For this trend analysis, these metrics relate to the difference between streamflow gauging records and streamflow that would have occurred for the same period in the absence of water resource development (provided by river models).

Changes are discussed for each valley in the following sections. At the Basin level, the drought led to a general decline in catchment runoff over this period. Similarly, flow alteration from Reference Condition generally increased over this drought period. This was most apparent at sites where water management imposes a strong control on flow.

Water management generally follows a hierarchy of priorities— with a primary need to protect basic human needs under extended dry conditions. It is unlikely that this short-term sequence during the extended drought represents longer-term trends in response to altered water entitlements and management rules. In particular, the benefits of enhanced environmental water provisions are likely to have been obscured by overriding effects of (and responses to) the exceptional drought sequence. In addition, the modelled reference flows used for this trend analysis were provided by river models which may not be well calibrated for very dry conditions. The significance and consequence of this is uncertain, but it is possible that model errors in the reference flow series produce bias in the observed trends for drying catchments.

The results of trend evaluation for the hydrology metrics are summarised in Table 6.5 for each gauging station.

Trends in flow alteration were seen in the low flows, the high flows and in flow seasonality:

- *Low flows*: At many sites where low flows are normally elevated by water management, the decline in low flows typically caused by a drought period was delayed and dampened.
- *High flows:* There were many sites that had extreme reductions in high flows over the three-year period 2007 to 2009. Alteration in high flows relative to reference flows intensified over the drought period.
- *Flow seasonality:* There was also a systematic decline in the amplitude of seasonal flow variations relative to Reference Conditions at many sites through the drought period. The timing of annual high and low flows was also increasingly modified relative to reference at some sites.

Since 2009, there have been enhanced environmental water provisions through planned or held environmental water by both state and Commonwealth agencies. However, this flow restoration will not be detected until the trend analysis is updated to include 2010 onwards.

The following section describes the trends detected for the gauging stations, by valley (refer to Table 6.5).

Avoca
The hydrology trend analysis did not include any sites in the Avoca Valley.

Border Rivers
Trend analysis was applied at one site in the Border Rivers Valley (Gundablouie on the Moonie River) 27 km upstream of the Barwon

Table 6.5. Trends in hydrological metrics at streamflow gauge sites over the period 1998 to 2009 as a result of water management.

(i.e. the reported trends are independent of any trends produced by declining catchment runoff through the drought). Red and green = increasing and decreasing flow alteration, respectively.

Valley name	Zone	Streamflow gauge	Stream flow gauge number	Trends in Hydrology metrics					
				Flow Duration	Flow Variation	Low Flow	High Flow	Seasonal Amplitude	Seasonal Period
Border Rivers	lowland	Moonie@Gundablouie	417001						
Broken	lowland	Broken@Gowangardie	404224						
	slopes	Broken@Moorngag	404206						
Campaspe	lowland	Campaspe@Echuca	406265						
Condamine	slopes	OakeyCreek@Fairview	422350						
	slopes	Condamine@Cotswold	422325						
	slopes	Condamine@ChinchillaWeir	422308						
	slopes	Condamine@Loudoun'sBridge	422333						
	slopes	Condamine@CecilWeir	422316						
	slopes	Condamine@LonePine	422345						
	slopes	Condamine@TalgaiTailwater	422355						
	slopes	Condamine@Warwick	422310						
	slopes	Condamine@ElbowValley	422394						
Darling	middle	Darling@MenindeeWeir32	425012						
	middle	Darling@Bourke	425003						
	upper	Barwon@Brewarrina	422002						
	upper	Barwon@Walgett	422001						
	upper	Barwon@Collarenebri	422003						
	upper	Barwon@MogilMogil	422004						
Goulburn	lowland	Goulburn@Trawool	405201						
Gwydir	slopes	Gwydir@Pallamalawa	418001						
Lachlan	lowland	Lachlan@HillstonWeir	412039						
Loddon	lowland	Loddon@D/SCairnCurran	407210						
	lowland	Loddon@LoddonWeir	407224						
Macquarie	slopes	Macquarie@Dubbo	421001						
Murray (Central)	lower	Murray@D/SEuston	414203						
	middle	Murray@Tocumwal	409202						
	middle	Murray@Barham	409005						
Murray (Lower)	upper	Murray@U/SLock6	426510						
	upper	Murray@D/SLock3	426517						
Murrumbidgee	slopes	Murrumbidgee@Gundagai	410004						
	lowland	Murrumbidgee@WaggaWagga	410001						
	lowland	Murrumbidgee@DarlingtonPt	410021						
Namoi	upland	Peel@ChaffeyDam	419045						
	upland	Peel@Piallamore	419015						
	slopes	Manilla@Brabri(Merriwee)	419020						
	slopes	Namoi@ManillaRailwayBridge	419022						
	slopes	Namoi@Keepit	419007						
	slopes	Namoi@Gunnedah	419001						
	slopes	Namoi@Boggabri	419012						
	slopes	Namoi@Mollee	419039						
	lowland	Namoi@Goangra	419026						
Warrego	lowland	Warrego@Ford'sBridge	423001						
Wimmera	lowland	Wimmera@Horsham	415200						
	lowland	Wimmera@Glenorchy	415201						

River confluence. The trend analysis indicates increasing impact alteration in high flows over the period 1998 to 2009. In the three-year period 2007–2009 the High Flow metric was less than 0.1; indicating an extreme difference from Reference Condition (under which this metric would have been close to 0.4 for this same three-year period). The only other consistent trend detected at this site applies to flow variability, but changes in the Flow Variation metric over this period are minor (0.99 to 0.93).

Broken

Trend analysis was applied at two sites in the Broken River Valley: Moorngag in the Slopes zone and Gowangardie in the Lowland zone. Both sites are downstream of Lake Nillahcootie, the major water storage in the catchment. A second off-stream storage (Lake Mokoan) was filled from a diversion downstream of Moorngag and released water back into the Broken River upstream of Gowangardie.

At both sites, low flows are elevated relative to Reference Condition and this alteration is intensified over the drought period. The effect of water management is to sustain the Low Flow metric at a similar level throughout this period (between 1.5 and 2.0) when it would have decreased (from 1.7 to 0.8) in the absence of water resource development. Mean and high flows were severely reduced in the final three-year period (2007 to 2009) as a consequence of dry climate. However, the level of flow alteration relative to Reference conditions remained constant over this period.

Campaspe

Trend analysis was applied at one site in the Campaspe Valley—the Campaspe River at Echuca— which is close to the River Murray confluence. At this site, there was increasing flow alteration from Reference conditions. The effect is apparent in both Low and High Flow metrics. Even in the absence of water resource development there would have been a severe reduction in high flows; but flow alteration has intensified this effect. In the three-year period 2007–2009, the High Flow metric was 0.01 (an extreme difference from Reference conditions) but would have been 0.21 under Reference conditions. Interestingly, an increase in the Low Flow metric (0.9 to 1.3) occurred when it would have decreased under Reference conditions (1.3 to 0.5). In combination, these opposite trends produced a small but consistent declining trend in the Flow Duration metric (1 to 0.9).

Castlereagh

The hydrology trend analysis did not include any sites in the Castlereagh Valley.

Condamine

Trend analysis was applied at nine sites in the Condamine Valley; eight of which are located along the Condamine River and one on Oakey Creek at Fairview (a northern tributary of the Condamine River). Importantly, no sites are located in the lower part of the catchment (downstream of the St. George irrigation district and the large volumes of private off-stream storages in the lower portion of the valley). The Condamine River sites are (from upstream to downstream): Elbow Valley, Warwick, Talgai Tailwater, Lone Pine, Cecil Weir, Loudoun's Bridge, Chinchilla Weir and Costwold. All sites (except at Lone Pine) showed increasing flow alteration through the drought. However, the particular metrics showing this trend varied across the sites. No site showed a trend towards reduced flow alteration over the analysis period.

For the period 1998 to 2009, there were intensifying reductions in high flows at Warwick, Cecil Weir, Chinchilla Weir and Fairview; and low flows at Talgai Tailwater (relative to reference conditions).

Conversely, at Elbow Valley, high and low flows were elevated relative to reference flows; and this alteration intensified over the analysis period. This is a curious result since there is no obvious water storage upstream of this gauge that could produce a significant flow augmentation effect. There was also a trend of increasing flow enhancement in the Flow Duration metric at Cecil Weir.

Darling

Trend analysis was applied at six sites in the Darling Valley. Four of these are on the

Barwon River: Mogil Mogil, Collarenebri, Walgett, Brewarrina (listed from upstream to downstream) and two are on the Darling River (Bourke and Menindee Weir 32).

There was consistent evidence of increasing flow alteration over the period 1998 to 2009 along the Barwon–Darling Rivers.

High flow reductions have intensified at all sites, although this trend is not statistically significant at Brewarrina. Similarly, low flow reductions have intensified at Collarenebri, Walgett and Bourke (reductions also occur at Brewarrina but are not statistically significant).

Reductions in flows across the full range of magnitudes have intensified at Collarenebri, Walgett, Brewarrina and Bourke.

There were severe reductions in high flows along the length of the Barwon–Darling Rivers over the analysis period. This included reductions in the High Flow metric at Mogil Mogil (1.0 to 0.1), Collarenebri (0.7 to 0), Walgett (0.4 to 0), Brewarrina (0.8 to 0.1), Bourke (1.0 to 0) and Menindee Weir 32 (0.8 to 0).

Goulburn

Trend analysis was applied at one site in the Goulburn Valley: Trawool on the mid-Goulburn River between Lake Eildon and the major irrigation off-take at Nagambie. No significant trend was detected.

Gwydir

Trend analysis was applied at one site in the Gwydir Valley: the Gwydir River at Pallamalawa, which is upstream of Moree and the main irrigation district and downstream of Copeton Dam, the main irrigation storage in the river's headwaters.

The trend analysis indicated increasing augmentation of low flows. The Low Flow metric was maintained between 1.9 and 1.7 throughout the analysis period (1998 to 2009). However, under Reference conditions, there would have been a reduction in the Low Flow metric over this period (from 1.7 to 0.6).

Kiewa

The hydrology trend analysis did not include any sites in the Kiewa Valley.

Lachlan

Trend analysis was applied at one site in the Lachlan Valley: Hillston Weir on the lower Lachlan River. The analysis indicated increasingly altered high and low flows over the analysis period (1998 to 2009). The Low Flows metric fell between 1.5 and 2.0 over this period; whereas it would have declined from 1.3 to 0.6 under Reference conditions. In contrast, the High Flow metric declined from 1.0 to 0.0; whereas it would have declined from 1.3 to 0.2 under Reference conditions. The Flow Variation, Seasonal Periodicity and Seasonal Amplitude metrics also declined over this period.

Loddon

Trend analysis was applied at two sites in the Loddon Valley. Both sites are on the Loddon River with one downstream of Cairn Curran reservoir, the major irrigation storage in the catchment; and the other at Loddon Weir, the primary irrigation off-take.

All metrics indicate reductions in flow over the period 1998 to 2007 downstream of Cairn Curran reservoir but no clear trend relative to Reference conditions. The only exception was an enhanced reduction in the Seasonal Amplitude metric and an attenuated effect on the Seasonal Period metric relative to Reference Condition.

There was an enhanced reduction in the Seasonal Amplitude and Flow Duration metrics at Loddon Weir. At the start of the analysis period, the Low Flow metric was 2.0 (the upper limit) indicating augmented low flows. The Low Flow metric remained at this value throughout the analysis period. Under Reference conditions, the Low Flow metric would have reduced from 1.5 to 0.5.

Over the period of analysis, there was a severe reduction in the high flows at Cairn Curran and Loddon Weir, but this reflects changes that would have occurred under Reference Conditions and there is no trend in the level of flow alteration relative to this reference.

Macquarie

Trend analysis was applied at one site in the Macquarie Valley (at Dubbo on the Macquarie River), which is located downstream of the major headwater storages and upstream of the major irrigation area.

There was increasingly severe alteration of low and high flows over the period 1998 to 2009. Low flows increased and high flows were reduced relative to Reference Condition. The Low Flow metric was maintained between 1.6 and 1.1; whereas it would have reduced from 1.4 and 0.5 over this period under Reference conditions. The High Flow metric decreased from 1.0 to 0 over this period but would have reduced from 1.2 to 0.6 under Reference conditions.

There was also a severe reduction in the amplitude of seasonal flow variations during the analysis period, relative to trends in the reference regime.

Mitta Mitta

The hydrology trend analysis did not include any sites in the Mitta Mitta Valley.

Murray, Central

Trend analysis was applied at three sites in the Murray Valley (Central) along the mid-River Murray. The sites are at Tocumwal (downstream of Yarrawonga), Barham (downstream of Torrumbarry Weir) and Euston (downstream of the Murrumbidgee confluence). At Tocumwal, the Seasonal Amplitude metric declined from 1.0 to 0.04 over the analysis period but under Reference conditions would have varied between 1.7 and 0.7 during this period. The extent to which high flows were altered from reference declined over the analysis period. However, the drought (regardless of water management impacts) resulted in extreme reductions in high flows during the final three-year period (2007–2009).

There was no trend in flow alteration at Barham through the drought, with the exception of increasing alteration in the seasonal flow pattern. The Seasonal Period metric at this site reduced from 0.5 to 0 over the 12-year period. Under Reference conditions, the drought would have produced a smaller reduction (from 0.7 to 0.5). There is no trend detected at Euston.

Murray, Lower

Trend analysis was applied at two sites in the Lower Murray Valley. One site is upstream of Lock 6 and the other is downstream of Lock 3 on the River Murray. There was a severe decline in the amplitude of seasonal flow variations relative to reference. The Seasonal Amplitude metric declined from 1.5 to 0 at Lock 6 and 0.5 to 0 at Lock 3. A value of 0 indicates an extreme modification from Reference conditions. High flows show no trend but are extremely altered from Reference Condition throughout the analysis period at both sites.

Murrumbidgee

Trend analysis was applied at three sites in the Murrumbidgee Valley. The sites were on the Murrumbidgee at Gundagai, Wagga Wagga and Darlington Point (from upstream to downstream). All three sites showed a similar trend over the period 1998 to 2009; with increasing intensity of high flow reductions and a decline in the amplitude of seasonal flow variations. Over this period, there was a severe declining trend in the High Flow metric at Gundagai (1.1 to 0) and Wagga Wagga (0.8 to 0). At Darlington Point, which is downstream of irrigation off-takes, the High Flow metric remained low throughout the analysis period with a slight declining trend (0.03 to 0).

Namoi

Trend analysis was applied at nine sites in the Namoi Valley. This included six sites on the Namoi River at Manilla, Keepit, Gunnedah, Boggabri, Mollee and Goangra (from upstream to downstream). In addition, there was one site on Manilla River at Brabri (downstream of Splitrock Dam) and two on the Peel River at Chaffee Dam and further downstream at Piallamore.

At Chaffee Dam in the Peel River, there was a declining trend in flow variability over the period 1998 to 2009 relative to Reference Condition. The trends further downstream in the Peel River at Piallamore were somewhat different. At Piallamore, there was a decline in the High Flow metric (1.5 to 0.4) and amplitude of seasonal flow variations (1.3 to 0). The Low Flow metric was maintained over this period (between 1.8 and 1.4); when it would have declined (from 1.5 to 0.6) under Reference conditions.

Through the analysis period, there were declining flows at Keepit, Gunnedah, Boggabri and Mollee—the Namoi River sites located between headwater storages and the major irrigation off-take. However there is no indication of a trend in the level of flow alteration relative to Reference conditions (Table 6.5). The High Flow metric declined over this period to between 0.3 and 0.4 at these four sites.

At Goangra (downstream of the irrigation off-take) there was a declining trend in high flows and seasonality of flows. The High Flow metric at this site declined from 1.3 to 0.1.

Ovens, Paroo, Upper Murray

The hydrology trend analysis did not include any sites in the Ovens, Paroo or Upper Murray Valleys.

Warrego

Trend analysis was applied at one site in the Warrego Valley—Ford's Bridge on the Warrego River, close to the confluence with the Barwon River. At this site, there was a declining trend in high flows and seasonality of flows. The High Flow metric at this site declined from 0.6 to 0.2 from 1998 from 2009; compared to a decline from 1.1 to 0.8 under Reference conditions.

Wimmera

Trend analysis was applied at two sites in the Wimmera Valley: Glenorchy and Horsham, both on the Wimmera River. There was a decline in the Flow Duration metric at Horsham over the period 1998 and 2009. Under Reference conditions, the Flow Duration metric would have declined from 1 to 0.9. Based on streamflow gauging, this metric showed a major decline from 0.9 to 0.1. The High Flow metric was outside of the reference range (i.e. equal to zero) for the entire analysis period; and hence no trend could be detected at these sites. There was no trend in flow alteration at Glenorchy.

6.5 Summary

Substantial trends in Hydrology metrics were detected during the 1998–2009 period. This was as a result of changes in water management under the influence of the drying impacts of the drought— often with intensification of drought-induced changes in low flows, flow variability and duration—coupled with changes in seasonal amplitude.

These substantive effects did not appear to be accompanied by systematic changes in the condition of either fish or macroinvertebrates across the Basin. This does not mean that changes induced in the flow regime by dry conditions and water management had no impact on the condition of fish and macroinvertebrate communities. All SRA sampling for fish and macroinvertebrates occurred during the prolonged drought, and many of the major effects of drying are likely to have occurred prior to the first round of SRA sampling.

In addition, the hydrological trend analysis was conducted on only a small subset of the Basin's stream network, because of constraints imposed by data quality and availability. It cannot therefore be portrayed as representative of the trends in the entire Basin's hydrology over the assessment period, though it provides a description of the type of changes observed. This is in contrast to the fish and macroinvertebrate sampling, which was dispersed representatively across the Basin.

The techniques applied here have shown that the SRA program is capable of demonstrating and quantifying changes in condition over time.

It is expected that a true assessment of the response in condition of fish and macroinvertebrate communities to major changes in the flow regime is likely to emerge only once results from sampling conducted over the years following the major rains and associated flooding of 2010–2011 onward has been completed and analysed.

7. PROGRESS, PROBLEMS AND PROSPECTS

7. Progress, problems and prospects

7.1 Introduction

This assessment report describes the results of the latest round of sampling and assessment for the SRA Fish, Macroinvertebrate and Hydrology Themes, with an initial description of trends with time. A single assessment of riverine Vegetation and Physical Form has also been provided.

Assessments have been made of condition and health at zone and valley scales, with accompanying measures of statistical reliability where practicable. This section describes issues that affect the efficacy of the Audit, potential for further improvement, and engagement with related activities.

7.2 Audit progress and issues

A number of major advances have occurred in the SRA assessment framework since SRA report 1. These have included improvements in the underlying data sources and models (Hydrology Theme), improvements in defining Reference Condition (Fish, Macroinvertebrates), addition of metrics describing further aspects of a Theme (Fish, Hydrology), and removal of poorly performing metrics (Macroinvertebrates). The addition of the Vegetation and Physical Form Themes also represents a substantial expansion of the assessment conducted in this report.

7.2.1 Fish

The Fish Theme has been refined by addition of the recruitment metrics. These, for the first time, allow assessment of shorter-term dynamics of the fish communities across the Basin. They are based on the abundance, distribution and species composition of recruits. A key challenge is to refine the definition of Reference Condition, in particular around levels of recruitment required to sustain populations at zone and valley scales over the medium to longer term and to better accommodate the variety of recruitment strategies employed by native fish species. For species with life histories characterised by large-scale movements this will require careful thought, as well as sustained, long-term data on changes in fish numbers.

In addition, improvement in the definition of Reference Condition across all Fish Theme metrics should be pursued using a variety of techniques, especially modeling. The introduction of relative abundance measures into the assessment would greatly improve its utility and sensitivity.

7.2.2 Macroinvertebrates

The shift from a Filters approach to the BRT (Boosted Regression Tree) modelling of individual macroinvertebrate taxa, in order to quantify Reference Condition, was a significant technical advance in the assessment of macroinvertebrate community status—evidenced by improved performance of metrics against a range of disturbance gradients (Walsh *et al*. 2010). These models may need refining in the future by incorporating improved measures of human disturbance in the landscape, and of improved hydrological and water quality parameters.

The recommendations made in SRA report 1 for incorporation of 'mega–invertebrates' (crayfish and mussels) and relative macroinvertebrate abundance into the assessment have not been advanced, and we re-state the need for these components into the future. While the macroinvertebrate assessment has improved, it is still largely based on presence/absence of family level taxa at site scale, which remains relatively crude. Changes induced by flows and water quality tend to manifest strongly in terms of relative (or absolute) abundance rather than loss or gain of families. Inclusion of a metric based on absolute abundance would be compromised by uncertainty over reference values. By contrast, quantification of reference values for a measure of relative abundance (e.g. in relative abundance classes) is likely to be feasible. Inclusion of a relative abundance metric would add considerable value, in terms of sensitivity and ecological significance, to the macroinvertebrate assessment for the Basin.

7.2.3 Vegetation

The resources and time available for this new Theme precluded a major field assessment program, and resulted in reliance on remotely-accessed data sources: vegetation mapping and LiDAR survey. The former was constrained by the quality and spatial extent of available vegetation mapping, the quality of attribute descriptions associated with the various vegetation layers and the degree to which the mapping layers were compatible. Considerable effort was made to overlay and unify the various vegetation mapping resources to provide a consistent assessment of vegetation types and their extent across the Basin's riverscape. This solution was not ideal, and forced the use of high-level vegetation groupings (MVG's), losing the ability to assess status at the level of specific riverine vegetation communities (such as black box and red gum forest).

A substantive ongoing effort in vegetation mapping is required to address many of the systematic errors and issues with the current quality of vegetation data (Williams 2010; Eco Logical 2010c), and particularly to address the need for dedicated mapping of riverine (riparian and floodplain) vegetation. A substantial effort would be required for the approach taken in this report to be repeated in future. We note that this is unlikely in the near future, and that there is little opportunity to detect future large-scale changes in riverine vegetation across the Basin using the currently available mapping resources.

One thousand, six hundred sites were surveyed across the Basin river systems using LiDAR. This resulted in an intensively collected data set which formed the basis of much of the Physical Form Theme. The LiDAR data was able to be collected consistently within the true riparian (bankside) areas of the river channels. However, the ability to interpret this information was severely compromised by the inadequacy of reference attribute descriptions for riparian vegetation communities across the Basin; an issue tied to the frequently poor and inconsistent resolution of vegetation mapping at the scale of riparian zones (Eco Logical 2010c). Assessments of riparian vegetation condition would not have a standardised basis for comparison without resolution of this issue. Assessment of 'Near Riparian' vegetation was not compromised in this way and was adopted as the basis for the current assessment. The degree to which the condition of the Near Riparian domain reflects that of the true riparian zone (e.g. as a correlate/surrogate) is, however, unclear. We strongly recommend that investment be made in the characterisation and mapping of riparian vegetation to overcome this problem.

It was also planned to deliver data on vegetation cover and height for each unit ('polygon') of vegetation within the Near Riparian zone. However, inconsistency in the ability to define cover levels from the LiDAR data, coupled with the inadequacies of existing ground-truth data sets and existing Reference Condition estimates, led to highly variable cover estimates and a low confidence in their interpretation. For this reason, the use of vegetation cover metrics in this assessment was abandoned, and only height metrics were derived from the LiDAR survey data. There remains a considerable need to derive a well-designed collection of ground-truth data in synchrony with LiDAR data collection, and investment in a small program to better define reference cover estimates. This will allow the data collected by the MDBA for this assessment to be used to its full potential, and allow future re-surveys and re-assessments of riverine vegetation status using LiDAR. The combination of optical imagery and LiDAR should also be further explored.

Floodplain mapping remains a key challenge for the management of the Basin. There is no consistent spatial definition or resources which can be used to assign the areas of active floodplain across the Basin's river system. The 'Kingsford layer' was developed in an attempt to define the wetlands of the Basin, and captures much of what forms the floodplain of the Basin system. However, it does not provide a single consistently-defined floodplain area for the Basin. For the purposes of this SRA 2 report, a subset of the wetland areas defined in the Kingsford layer was selected to represent a core sample of floodplain habitats in each Lowland zone. This selection does not represent the entire floodplain—which ideally would be defined both hydrologically and hydraulically based on areal extent of wetting under floods of a prescribed return interval. This is a key data need for the effective management of floodplain resources and of floodplain watering into the future, and should ideally be accompanied by spatial hydraulic modelling capacity.

The ability to develop reference attributes for the various main vegetation groups communities across the Basin remains a challenge. A varied range of sources of information (often regional experts) can be used to compile values of Reference Condition attributes for cover, height etc., but there are problems with consistency of definitions and knowledge across the variety of vegetation types in the Basin's riverscape.

Overall, the assessment conducted for this report provides the first evaluation of the status of riverine vegetation Basin-wide. It does so, however, at a fairly high level, and the results mainly reflect the legacy of structural vegetation change caused by the combination of clearing and conversion, long-term climate and hydrological change. The data and information presented here cannot be used to assess short or medium term responses to changes in climate or water management. By contrast, it provides a valuable context for vegetation condition within which changes due to future management actions can be assessed at a more detailed level.

There are a number of aspects of the vegetation of riverine habitats and associated wetlands that cannot be assessed using remotely-collected data. These include emergent and submerged macrophytes and aspects of vegetation structure, diversity, and physiological condition; which are key components of riverine vegetation communities and their ecological role. If such information were included, it would necessitate field surveys, and raises the challenge of establishing Reference Condition for these attributes.

7.2.4 Physical Form

Our use of a LiDAR survey for the Physical Form assessment, as opposed to an extensive field-based program of assessment, combined with objective model-based reference definition, represents a significant shift in approach in the area of fluvial geomorphological assessment. LiDAR data conversion to useful and defensible variables was a challenge, and it required support by custom variable extraction software. Further quality assurance against ground-truthed field measurements is recommended in future. A greater risk was whether Reference Condition could be defined quantitatively and sufficiently robustly to develop defensible metrics. All existing assessment approaches and data sets had limitations in data quality, in reproducibility or in spatial (and river 'type') coverage. It was apparent that only a model-based numerical solution would satisfy SRA requirements. The use of the BRT-CPUND modelling approach (Stewardson 2012) provided satisfactory models for all but three metrics. Further model development is required to enable these (and potentially other) metrics to be included in the assessment. Overall the approach shows substantial promise as an ongoing approach to assessment to changes in Physical Form, and perhaps other assessment components.

The current approach would be enhanced by spatial integration with data on a geomorphological typology, to refine the modelled quantification of Reference Condition and to guide interpretation of changes in variable values relative to reference. Some of this typological characterisation exists, but still needs a fuller attribution with features at spatial scales from valley to reach.

We also recommend the development of a remote-sensing approach (whether LiDAR or by satellite) to the assessment of floodplains—for vegetation, wetland and floodplain form—accompanied by a field-verification QA/QC program.

7.2.5 Hydrology

Improvements in the Hydrology Theme have addressed several important shortcomings present in SRA report 1. Attempts to resolve them were only partially successful, and there remain areas for further improvement.

The most significant is to evaluate flow alteration as a result of water storage, diversions and transfers along stream channels upstream of the current modelled network. The aim would be to fill the substantial omission in the current report's assessment of data for stream sections between the 'headwater' and 'mainstem' parts of the river system. This represents a major gap in both the Authority's and the Basin states' ability to model and manage water in the Basin's river systems, and is a major need for integrated water resource management. The SRA, the Basin Plan and CSIRO Sustainable Yields Project have relied to date on data and models of the Basin's regulated mainstem river channels. Most major water resource developments are represented in these models, but the effect of them is only represented for mainstems and not the tributary network upstream. Their cumulative effect is taken into account at the upper end of the regulated mainstem network. However, the substantial proportion of the Basin's tributary stream network is not, at present, adequately modelled and has not been assessed in a consistent manner. This results in a significant bias in assessment for programs like the SRA which aim to characterise hydrological condition across the entire river network. The member states have access to much of the data required to develop this capacity, but it requires further integrated investment and model development. The states are required to provide this information to BoM under the Water Act, but to date this information has not been fully integrated and made accessible for use in water resource assessments.

An important development in the Hydrology Theme has been the inclusion of farm dam and land cover change effects within the assessment. We used separate, relatively crude though uniform, modelling of farm dams and land cover change impacts on hydrology. We were not able (within the time frame available) to apply them across all parts of the river catchment. There is a need to integrate farm dam and land-cover modelling within the water resource modelling framework —again this is a broad challenge for water resource planning and not just the SRA. A further improvement will be to extend water resource modelling to represent all diversions within the catchment, including in the smaller unregulated streams.

Future development of Hydrology assessment must focus on the definition of Reference Condition. It is becoming increasingly necessary to consider Reference Condition in the light of anthropogenic climate change. At this stage 'reference' represents the historic climate sequence with no accounting for possible future climate change trends. The capacity to do this exists within the different jurisdictions but needs a coordinated, collaborative approach to be applied consistently across the Basin.

Another important need is to link data used in the Physical Form and Hydrology Themes to assess hydraulic conditions and connectivity—including wetting/drying of the streambed, inundation of bank and bench habitat, mobilisation of bed sediments and floodplain/wetland inundation. This functional assessment could be extended to consider landscape-scale metrics related to artificial barriers and inundation of habitats by man-made impoundments, and create a framework within which the use of infrastructure to reinstate desirable aspects of the Reference flow regime might be assessed.

It is particularly important to build an improved understanding of hydrological change on the Basin's lowland floodplains. Floodplains represent the vast majority of the aerial extent of riverine landscapes and are not monitored in the stream gauging network nor represented in river models. These areas are the most severely impacted by water resource development (in addition to floodplain management) and also receive a major portion of environmental water allocations in the Basin. This was explicitly recognised during the development of MFAT (the Murray Flow Assessment Tool, SRP 2003[1]) but limited investment and progress has been made since then in implementing a modelling framework which includes floodplain hydrology for assessment and management. Attempts were made during development of the Hydrology Theme for SRA report 2 to model floodplain watering regimes using an approach called GRADFLOW (Pickup et al. 2008), but limitations in floodplain digital elevation model (DEM) accuracy, in regional flood frequency relationships and flood gauging have prevented its successful deployment to date. Investment in a standardised high resolution Digital Elevation Model for Murray–Darling Basin catchments, as well as floodplain extent mapping, is a high priority.

Clearly we need significantly better information to describe hydrological change in the Basin, both across the river network and to include floodplains.

The use of SedNet model outputs was driven by the need for a component that captured shifts in river sediment regimes, in addition to more traditional measurements of channel and bank dimensions. The substantial limitations of the current SedNet data need to be addressed in the future; in particular the inability to model channel bed and floodplain surface degradation (e.g. loss of bed sediment), improvements to model performance with regard to reach-scale sediment storage, the need for field validation of bed sediment and the use of time series of changes to vegetation cover and land use to generate the history of sediment dynamics instead of long-term sediment budgets.

7.3 SRA report 2 assessment

The assessment conducted for this report has several features:

7.3.1 The drought

The period spanned by SRA monitoring between 2004 and 2010 was primarily one of intense dry and drought conditions (see Section 5). Biological sampling (for fish and macroinvertebrates), and most LiDAR observations were made during or toward the end of this prolonged dry period throughout the Basin.

As a result, the SRA data gathered to date provides an assessment of Basin rivers under drought, with only the responses in fish recruitment and macroinvertebrate community composition observed in the Paroo and Warrego in 2010 as (minor) exceptions.

There is likely to be a strong public expectation that the current report will provide an assessment of the river system's response to the recent (2010 onwards) wet period. It does not do that. However, these SRA data can form a basis for assessing the response of

1. CRC for Freshwater Ecology Interim Scientific Reference Panel report, MDBC October 2003.

the river ecosystem to the flooding events of 2010–2011 to 2011–2012, as sampling for fish and macroinvertebrates is now continuing into 2012–2013 to 2013–2014.

Similarly, if LiDAR and imagery data collection were repeated for both Physical Form and Vegetation in the next two to six years this should, once the 2010 data are fully analysed, allow assessment of responses of these components to the floods.

7.3.2 Trend

The SRA has only just begun to collect data that can be used to assess trends in ecological condition and ecosystem health. We recommend routine ongoing sampling and assessment continue for the SRA to document trends in Fish, Macroinvertebrates and Hydrology across the Basin. We also recommend initiation of repeat assessments for Physical Form and aspects of Vegetation within the next five years. Trend analysis will become increasingly important as the Basin Plan is implemented.

7.3.3 Vegetation

The vegetation assessment conducted in this report is primarily mapping-based. It therefore mainly provides information on the legacy of clearing, landuse and land management in the riverine vegetation of the riverine landscape. This is in contrast to the more subtle and often smaller-scale responses of individual communities and populations to events like floods and fires. It is preferable to couple these two scales of assessment; and a combination of mapping and survey (field and/or LiDAR) based assessment is highly desirable. This could not be achieved for this report, due to constraints on resources, data analysis and interpretation. We also note that several new vegetation mapping data resources are now becoming available.

We expect greater information content to be available from the LiDAR data and imagery collected during the 2010 assessment, if it is mined further. We believe that the combination of LiDAR and imagery can provide an assessment of more responsive vegetation characteristics, as well as trends, in the near future. Some focussed investment is required to bring this to fruition.

7.3.4 Physical Form

The Physical Form assessment results reported here are strongly driven by changes in sediment delivery and accumulation in the channel and on the floodplain relative to natural conditions, coupled with changes in channel depth and width. These therefore reflect a mix of the legacy of the influence of past catchment–wide changes in hydrology and erosion on channel dimensions, and current processes controlling the sediment regime.

We acknowledge the importance of quantifying the current state of geomorphological character as dictated by past events. However, we recommend further investment in LiDAR data collection and reference modelling to improve the capacity of this theme to detect changes caused by current hydrological and sediment processes. This may require an improved quantification of within-channel changes at a smaller spatial scale, using LiDAR, accompanied by further calibration against field measurements. Current limitations of LiDAR to measure channel depth under wet conditions for wide river channels needs to be resolved. There is a need to develop models to address this and/or to investigate LiDAR or ultrasound applications that can make below water measurements. We also recommend incorporating a geomorphological 'typology' within the modelling approach to refining the quantification of Reference Condition for LiDAR-derived Physical Form Theme metrics.

7.4 Future assessment, monitoring and evaluation

7.4.1 Integration of surveillance and other monitoring activities

The SRA was initially conceived as a Basin-wide surveillance program focused on the condition and health of the Basin's river system. In the changing organisational climate, there is some uncertainty about its future. Several improvements to the SRA design are proposed here for incorporation into future assessments—if a program with the purpose of surveillance of condition and health of the river system at valley and Basin scales is to continue.

ISRAG recommends that these be considered for future SRA-like, large-scale condition surveillance reports:

- Within Themes, there is scope for improvements to some metrics, additions to metrics, and improvements to methods for defining Reference Condition. Key points have been discussed above.
- Addition of Themes and spatial components in line with related Basin monitoring programs. The SRA's spatial context should be increased to explicitly assess other parts of the riverine landscape (floodplains, wetlands, terminal lakes). The SRA should also include other ecological components such as birds.
- Alignment of surveillance monitoring with management and policy initiatives and requirements, including the Basin Plan (see below).
- Focusing analyses and assessments on targets as well as differences from reference, with the latter serving as the assessment benchmark. Targets should be set and integrated across a range of scales, from individual assets to valley scale.
- Improve the diagnostic capacity of monitoring results and interpretation.

More sophisticated analyses are required to diagnose factors causing changes in health, to assist explorations of data for individual valleys or regions, and to evaluate large-scale responses to management and climate change. These applications have already commenced, such as:

- linking aspects of SRA monitoring to the aquatic ecosystem monitoring and evaluation (M&E) requirements of watering interventions under instruments like the Basin Plan (Davies *et. al.* 2009)
- conducting analyses of the relationships between SRA variables and metrics and hydrological and other related 'drivers' to support management of flows in the Basin.

There is a growing need for information that links human drivers such as water and land management to ecosystem responses. Design and analysis within the SRA (or its future replacements) should evolve to facilitate such diagnostic interpretation, while not losing a primary surveillance role. It should be emphasised, however, that the SRA database—containing primary data collected according to uniform and statistically sound protocols and subject to rigorous QA—represents a substantial platform upon which future refinements can be developed.

The current framework still focuses on the ecological health of river–channel elements, with a limited evaluation of floodplain systems. An expansion of vegetation, hydrological, hydraulic and geomorphological assessment for floodplains is required to truly capture this key element of the river ecosystem. ISRAG again recommends the inclusion of assessments of wetland and woodland systems, including the Lower Lakes and

Coorong and other key assets, as identified under the Basin Plan. There remains little linkage between asset-focussed monitoring and evaluation proposed around specific watering interventions under the Basin Plan and 'whole of river system' surveillance monitoring and assessment.

ISRAG strongly recommends that these links be established as soon as possible, under a fully integrated monitoring program by:

- developing an integrated M&E framework which explicitly describes the policy and conceptual basis, design, analysis and interpretation for monitoring across scales from valley to asset, short to long term, and 'intervention' to 'surveillance'
- inclusion of common ecosystem components (indicators) across several monitoring programs under a unified design framework
- developing common sets of ecosystem targets that each monitoring activity should address, under a common conceptual and design framework.

Without this, ecosystem condition monitoring activities are at risk of lacking focus, limited in applicability and lacking in flexibility to respond to a changing management and policy environment.

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APPENDIX 1

1. Expert systems

A. Background and introduction

This Appendix describes the schema for metric, sub-indicator, and indicator integration and spatial aggregation for each Theme, and it describes the process for deriving the River Ecosystem Health ratings used in this report. This final integration step is also described in Section 3.8 of the main report.

Integration from metrics to Indexes in the SRA is carried out using expert systems. Carter *et al*. (2012) provide a technical description of the SRA expert systems, and an introduction to the use of expert systems in the SRA is also provided in Section 2.3.3 of the main report, followed by some explanatory context for each Theme in Sections 3.3.5, 3.4.6, 3.5.6, 3.6.5 and 3.7.2. Carter (2011) also provides a primer on expert systems.

Matlab

The data processing, including spatial aggregation and metric integration, was carried out using Matlab®, including a total of 48 expert systems that were coded using Matlab's fuzzy logic toolbox. MatLab is a technical computing software package that is widely used by the scientific and engineering communities. Carter (2011) describes the SRA data processing software programs developed with MatLab, and the version of these programs held by MDBA was used to process the final data sets for each Theme in this SRA report.

Integration inputs

There are two kinds of inputs to the SRA integration exercise. Metrics such as Fish OE vary from low values that correspond to Poor condition, to high values that correspond to Good condition (i.e. equivalent to Reference Condition). All sub-indicators, indicators, and indices have the same form as this kind of metric, varying from 0 to 100.

> For this type of expert system input, the minimum and maximum values of 0 and 100 are denoted in the expert system definition tables as 'Extremely Low' and 'Good' respectively.

An example of the second kind of metric is the Hydrology Mean Annual Flow metric (the ratio of current to reference mean annual flow). This metric ranges from low values that correspond to poor condition (e.g. caused by intensive abstraction), to higher values that correspond to near-reference condition (the modelled natural flow regime) and to even higher values that again correspond to poor condition (e.g. caused by inter-basin flow enhancement). For this kind of metric, extreme low values may equal zero or may be unbounded, highly negative numbers. Extreme high values are often unbounded positive numbers. In these unbounded cases, lower and upper thresholds are established so that the rule system recognises very high or low values as extreme departures from reference.

For this type of expert system input, the values of the low threshold, the Reference Condition, and the high threshold, are denoted in the expert system definition tables as Extremely Low, Good (= 100), and Extremely High respectively.

Expert system definition tables

The SRA expert systems are each developed from an *expert system definition table* produced by ISRAG. The conceptual basis for integration was considered when developing each expert system definition table, and a brief description of this basis is provided for each Theme in Sections 3.3.5, 3.4.6, 3.5.6, 3.6.5 and 3.7.5 of the main report.

An expert system definition table specifies required output (indicator) values corresponding to the Extremely Low, Good, and (if appropriate) the Extremely High values of the metrics being integrated; or the required Index values corresponding to Extremely Low and Good values of the indicators being integrated. The expert system is then designed to calculate these exact outputs from the specified input values, and to calculate sensible outputs for other combinations and intermediate values of the inputs.

Put another way, the performance of an expert system that integrates two inputs is fully defined by a *calculation surface* that shows the expert system's output for every combination of input values. The expert system definition table specifies the points at which the calculation surface is pinned (i.e. fixed), and the expert system is designed so its calculation surface varies in an acceptable fashion between these pin-points.

This approach extends easily to integration of more than two inputs, although the calculation surface can only be inspected for two inputs at a time, holding the other inputs at a constant value.

The expert systems

Carter (2011) and Carter *et al.* (2012) describe technical aspects of the SRA expert systems. In brief, an expert system represents its input and output variables by membership functions, and carries out the required calculation using a set of linguistic rules that link the inputs to the output. Linguistic operator functions enable the rules to be evaluated, the results are summed, and the final calculation result is then determined. There are choices to be made in all these components of an expert system, and different expert system designs may produce identical results.

Expert systems use the mathematics of fuzzy logic, which is unfortunate because the word 'fuzzy' tends to trigger fears that the integration calculation is somehow vague or uncertain, which is not the case.

The key message for end users of expert systems is that the performance of an expert system is fully defined by its calculation surface. The calculation surface maps out the integration results for all possible combinations of inputs. Once the experts (in this case ISRAG) approve the expert system definition table and the calculation surface derived from it, the formulation of the expert system is automatically adopted.

A strength of the SRA expert systems approach is that a viable preliminary expert system can quickly be produced by writing a rule corresponding to each pin-point in the expert system definition table. The notation used in the definition table, and the notation used in the preliminary linguistic rule set, are kept similar, which aids this process.

This approach to producing a preliminary linguistic rule set is accompanied by a systematic approach to developing the other aspects of the expert system.

The preliminary expert system is usually refined before its calculation surface meets ISRAG approval. This is done by using additional rules, or by fine-tuning the membership functions.

Example one

Table APP 1 shows the expert system definition table used to integrate two metrics that both vary naturally from extremely low values to good (reference) values, as discussed above. The expert system shown is for the Fish Expectedness indicator, and its two inputs are a metric which measures the average difference in fish assemblage composition at the site scale from what is expected under Reference condition (MeanOE); and a metric which measures the state of the fish assemblage at the zone scale (OP).

The indicator values reflect ISRAG's judgement that the indicator is more sensitive to declines in the OP metric (reflecting the overall species pool) than in MeanOE (reflecting the site assemblage).

Figure APP 1 shows the calculation surface of the expert system developed from this definition table, with the circles denoting the pin-points specified in the definition table.

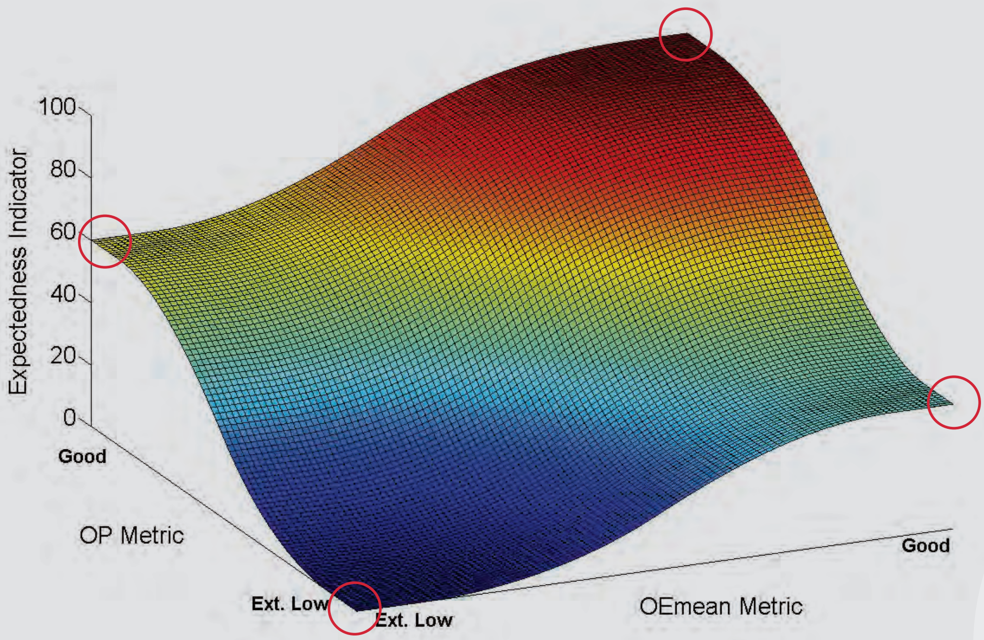


Figure APP 1. Expert system calculation surface for the Fish Expectedness indicator.

The circles denote the pin-points specified in Table APP 1.

Table APP 1. Expert system definition table – Fish Expectedness indicator

MeanOE metric	OP metric	Expectedness indicator
Good	Good	100
Good	Extremely Low	40
Extremely Low	Good	60
Extremely Low	Extremely Low	0

Example two

Table APP 2 shows the expert system definition table used to integrate the Hydrology Theme's Flow Seasonal Period metric, which varies naturally from extremely low values to good (reference) values; and the Flow Seasonal Amplitude metric, which has values that can depart from reference in either of two directions – with extreme values either higher or lower than the Reference Condition value. The integration produces the Flow Seasonality indicator.

Figure APP 2 shows the calculation surface of the expert system developed from this definition table, with the circles denoting the pin-points specified in the definition table.

Table APP 2. Expert system definition table – Flow Seasonality indicator

Flow Seasonal Period metric	Flow Seasonal Amplitude metric	Flow Seasonality indicator
Good	Good	100
Good	Extremely High	50
Extremely Low	Good	20
Good	Extremely Low	20
Extremely Low	Extremely High	10
Extremely Low	Extremely Low	0

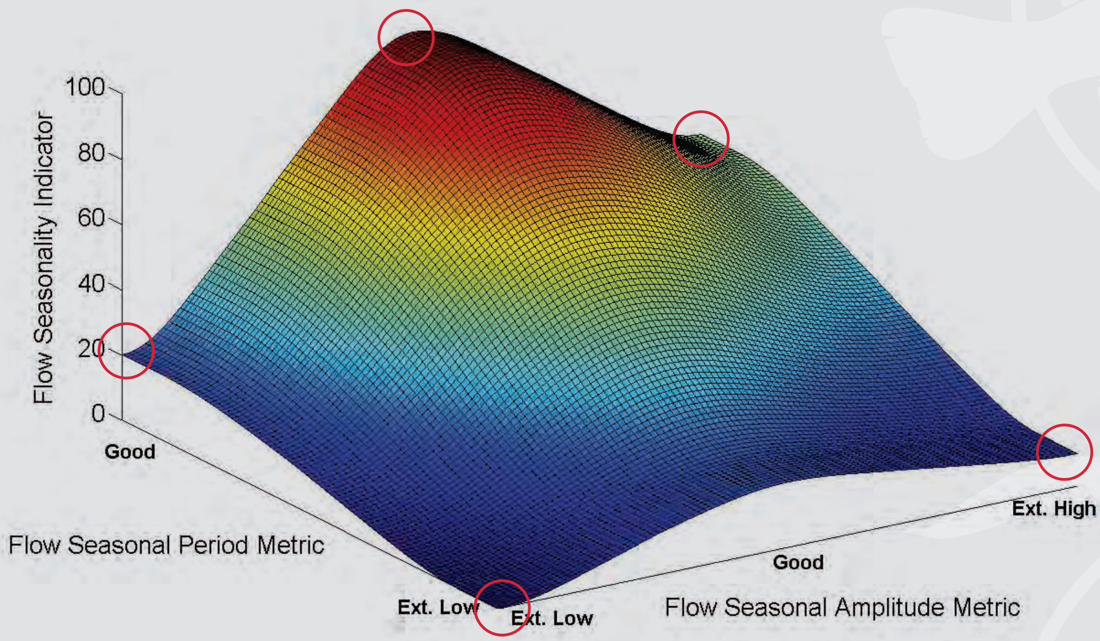


Figure APP 2. Expert system calculation surface – Flow Seasonality indicator
The circles denote the pin-points specified in Table APP 2 .

The power of an expert system approach to the SRA integration exercises is apparent in Figure APP 2, whose calculation surfaces could not easily be produced using conventional mathematics.

B. Expert system definition tables

This section presents each Theme's data processing strategy to achieve the necessary integration and spatial aggregation, progressing from metrics to the final Theme Condition Index.

The expert system definition tables specified by ISRAG for each integration exercise are given in the following sections, and the tables also show how ISRAG ranked the importance of the inputs in terms of their influence on the calculation.

As discussed in Section A, the expert system definition tables specify expert system calculation surface pin-points, which are the required calculation results associated with various combinations of input values:

- 'Good' denotes an input value equivalent to Reference Condition.
- 'Extremely High' denotes a high input value which is extremely different from the reference value. In the definition tables, it is set equal to the high threshold value for that input, which defines the upper bound for values for a metric above which its (downward) influence on the output indicator is maximised.

- 'Extremely Low' denotes a low input value which is extremely different from the reference value. For metrics that vary naturally from Extremely Low to Good, the value is usually 0. This is also the case for all sub-indicators, indicators, and sub-indices. For metrics that can depart from the Reference Condition in either direction, the value is set equal to the low threshold value which defines the lower bound for values for a metric below which its (downward) influence on the output indicator is maximised.

The values of upper and lower thresholds selected by ISRAG are shown below for those metrics which have unbounded values above and below their reference values. In the expert system, if a value for such a metric lies outside these thresholds, it is assigned the threshold value.

Similarly, for metrics that generally range between Extremely Low and Good, values outside this range are assigned the relevant threshold value.

1.1 River Ecosystem Health

1.1.1 River Ecosystem Health work flow

The two steps in the production of the River Ecosystem Health rating were as follows.

First, a zone-scale score for the River Ecosystem Health Index (SR–EI) was generated using the zone-scale Condition Index values for each of the three biological themes using an expert system based on the expert system definition table shown below. Secondly, the River Ecosystem Health rating was assigned based on the band within which the resulting score fell. This procedure was repeated at valley scale to generate the valley-scale River Ecosystem Health rating. Score values are seen only as a guide to the health rating and broad relative rank among valleys, and are not reported to avoid erroneous perceptions of precision.

The context and conceptual basis for this is provided in Section 3.8.

1.1.2 River Ecosystem Health Index expert system definition table

River Ecosystem Condition Index

Table APP 3. Index Expert System Definition Table – River Ecosystem Condition Index

Fish Condition Index SR–FI	Macroinvertebrate Condition Index SR–MI	Vegetation Condition Index SR–VI	Ecological Condition Index SR–EI	
Good	Good	Good	100	Good
Good	Good	Extremely Low	70	Moderate
Good	Extremely Low	Good	60	Moderate
Extremely Low	Good	Good	50	Poor
Good	Extremely Low	Extremely Low	40	Poor
Extremely Low	Good	Extremely Low	30	Very Poor
Extremely Low	Extremely Low	Good	20	Very Poor
Extremely Low	Extremely Low	Extremely Low	0	Extremely Poor
Rank: 1	Rank: 2	Rank: 3	Index	Rating

1.2 Fish Theme

1.2.1 Fish work flow

Integration followed the schematic shown below.

Table APP 4. Integration steps for the Fish Theme

Integration proceeds from left to right, with values of each indicator and the Index produced by an expert system which combines the inputs in the column to the left. The relative order of influence of each input on each output is indicated by the vertical order in the table (see also the rank shown in each rule table that follows).

Metric		Indicator	Index
Name	Scale		
OP	Zone	Fish Expectedness (SR–FI*e*)	Fish Condition, SR–FI
OE	Site		
Recruitment Proportion of Sites	Zone	Fish Recruitment (SR–FI*r*)	
Recruitment Proportion of Taxa	Zone		
Recruitment Proportion of Abundance	Zone		
Proportion Native Abundance	Site	Fish Nativeness (SR–FI*n*)	
Proportion Native Biomass	Site		
Proportion Native Species	Site		

The Fish Nativeness Indicator expert system was implemented at site scale. The Fish Expectedness Indicator expert system was implemented at zone scale after aggregation of site-scale OE metric values. The Fish Recruitment Indicator expert system was implemented at zone scale.

The final integration step to produce the Fish Condition Index (SR–FI) was conducted at zone scale, after aggregation of site scale values of the Fish Nativeness Indicator. Valley-scale values of SR–FI were produced by aggregation of zone scale values by stream-length weighted mean, as per all other Themes (see Section 3.6.5).

1.2.2 Fish expert system definition tables

Fish Expectedness indicator

Table APP 5. Expert system definition table – Fish Expectedness indicator

OP metric	MeanOE metric	Fish Expectedness indicator
Good	Good	100
Good	Extremely Low	60
Extremely Low	Good	40
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

Fish Nativeness indicator

Table APP 6. Expert system definition table – Fish Nativeness indicator

Proportion Abundance metric	Proportion Biomass metric	Proportion Species metric	Fish Nativeness indicator	Fish Nativeness indicator
			PERCH List N* <=5	PERCH List N* >=6
Good	Good	Good	100	100
Good	Good	Extremely Low	90	90
Good	Extremely Low	Good	70	70
Extremely Low	Good	Good	70	70
Extremely Low	Extremely Low	Good	40	40
Good	Extremely Low	Extremely Low	20	30
Extremely Low	Good	Extremely Low	20	30
Extremely Low	Extremely Low	Extremely Low	0	0
Rank: 1	Rank: 2	Rank: 3		

*PERCH List N = number of fish species predicted in the Reference Condition (PERCH) List.

Fish Recruitment indicator

Table APP 7. Expert system definition table – Fish Recruitment indicator

Recruitment Proportion of Sites metric	Recruitment Proportion of Taxa metric	Recruitment Proportion of Abundance metric	Fish Recruitment indicator
Good	Good	Good	100
Good	Good	Extremely Low	70
Good	Extremely Low	Good	50
Good	Extremely Low	Extremely Low	30
Extremely Low	Good	Good	20
Extremely Low	Good	Extremely Low	10
Extremely Low	Extremely Low	Good	10
Extremely Low	Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	Rank: 3	

Fish Condition Index

Table APP 8. Expert system definition table – Fish Condition Index

Fish Expectedness indicator	Fish Recruitment indicator	Fish Nativeness indicator	Fish Condition index SR–FI
Good	Good	Good	100
Good	Good	Extremely Low	70
Good	Extremely Low	Good	50
Extremely Low	Good	Good	40
Good	Extremely Low	Extremely Low	30
Extremely Low	Good	Extremely Low	20
Extremely Low	Extremely Low	Good	10
Extremely Low	Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	Rank: 3	

1.3 Macroinvertebrate Theme

1.3.1 Macroinvertebrate work flow

Only one metric was generated for the macroinvertebrate theme, simOE. Site-scale values of simOE were used to generate values of the Macroinvertebrate Condition Index (SR–MI) based on the expert system definition table below.

Zone scale values of SR–MI were generated by taking the mean of site-scale values (see Section 3.7.5). Aggregation from zone- to valley-scale values of simOE and SR–MI was by stream-length weighted mean, as per all other Themes.

4.2 Macroinvertebrate expert system definition table

Macroinvertebrate Condition Index

Table APP 9. Expert system definition table – Macroinvertebrate Condition Index

simOE metric	Macroinvertebrate Condition Index (SR–MI)
Good	100
Extremely Low	0

1.4 Vegetation Theme

1.4.1 Vegetation work flow

Integration followed the general schematic shown in Table APP 10. Several aggregations steps were also required prior to final integration for both indicators.

Table APP 10. Integration steps for the Vegetation Theme

Integration proceeds from left to right, with values of each sub-indicator, indicator, sub-index and Index produced by an expert system which combines the inputs in the column to the left. The relative order of influence of each input on each output is indicated by the vertical order in the table (see also the rank shown in each rule table that follows). NR = Near Riparian Domain; LF = Lowland Floodplain Domain.

Metric		Sub-indicator		Indicator	Index
Name	Spatial Domain	Name	Spatial Domain		
Abundance	NR	Abundance	NR & LF	Abundance & Diversity	Vegetation Condition, SR–VI
Abundance	LF				
Richness	NR	Richness	NR & LF		
Richness	LF				
Stability	LF				
Nativeness	NR	Nativeness	NR & LF	Quality & Integrity	
Nativeness	LF				
N Patches	LF	Fragmentation	MVG polygons, LF		
Mean Patch Area	LF				
Canopy Height	NR	Structure	MVG Polygons, sites, zone		

The sequence of integration and aggregation differed between Lowland and other zones, as shown in Figures APP 3 to APP 6.

Most Lowland zones had a Floodplain Domain associated with them. In these cases, three metrics (Abundance, Richness and Nativeness) were generated for both the Floodplain Domain and the Near Riparian Domain for Lowland zones, necessitating additional integration steps. In addition, an aggregation step was required in order to combine these values of the same metric derived for Lowland Floodplain and Near Riparian domains within the same zone. This was carried out using the Vegetation Spatial Domain to Zone Aggregation expert system described in Section 5.2.

Aggregation from zone- to valley-scale values of Indicators and of the SR–VI Index was by stream-length weighted mean, as per all other Themes.

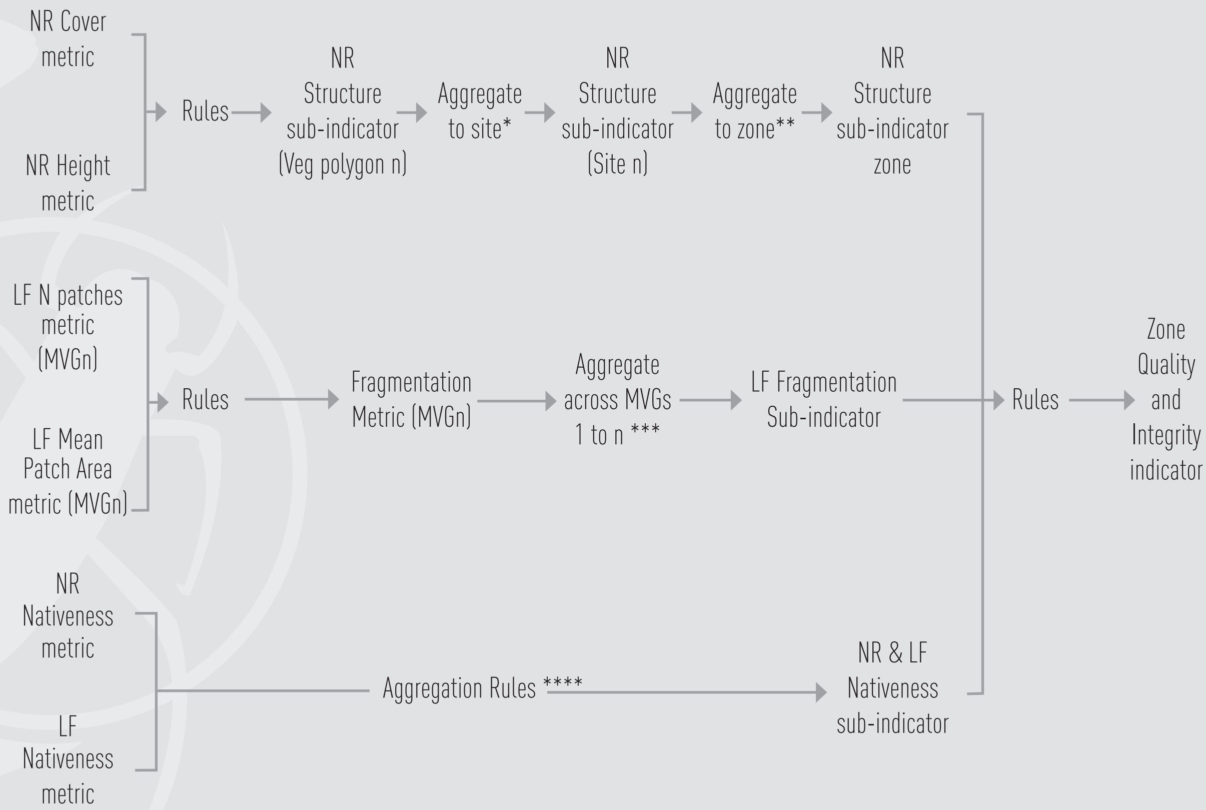
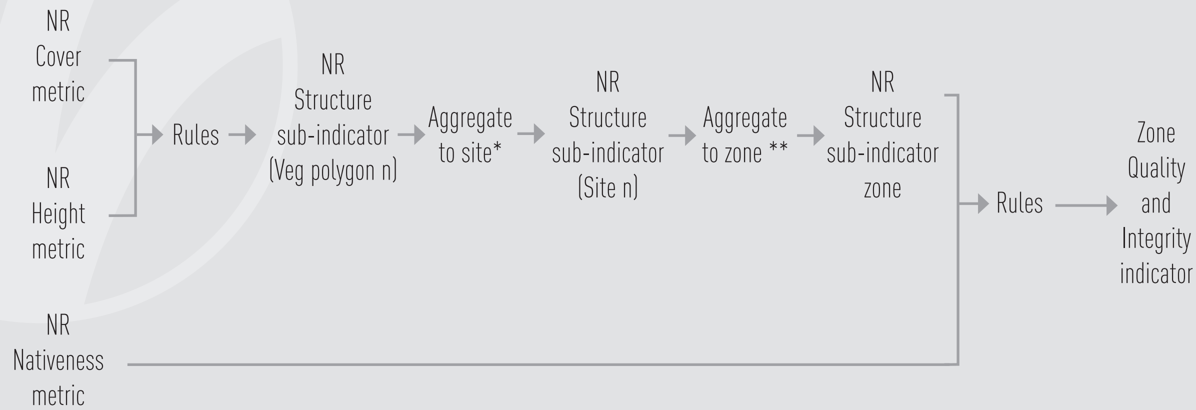


Figure APP 3. **Sequence of Vegetation Theme data integration and aggregation to produce the Quality and Integrity indicator for Lowland zones with defined Floodplain Domains**

NR = Near Riparian, LF = Lowland Floodplain.
* Aggregation by weighted mean, weighted by polygon area.
** Aggregation by mean of all site values.
*** Fragmentation metric aggregation by reference value of weighted areas of all MVGs within the LF polygon.
**** Aggregation by applying the Vegetation Spatial Domain to Zone Aggregation expert system (see Section 5.2).



NR = Near Riparian, * Aggregation by weighted mean, weighted by polygon area ** Aggregation by mean of all site values

Figure APP 4. **Sequence of Vegetation Theme data integration and aggregation to produce the Abundance and Diversity Indicator for Lowland zones without defined Floodplain Domains, and for the Slopes, Upland and Montane zones**

* Aggregation by applying the Vegetation Spatial Domain to Zone Aggregation expert system (see Section 5.2).

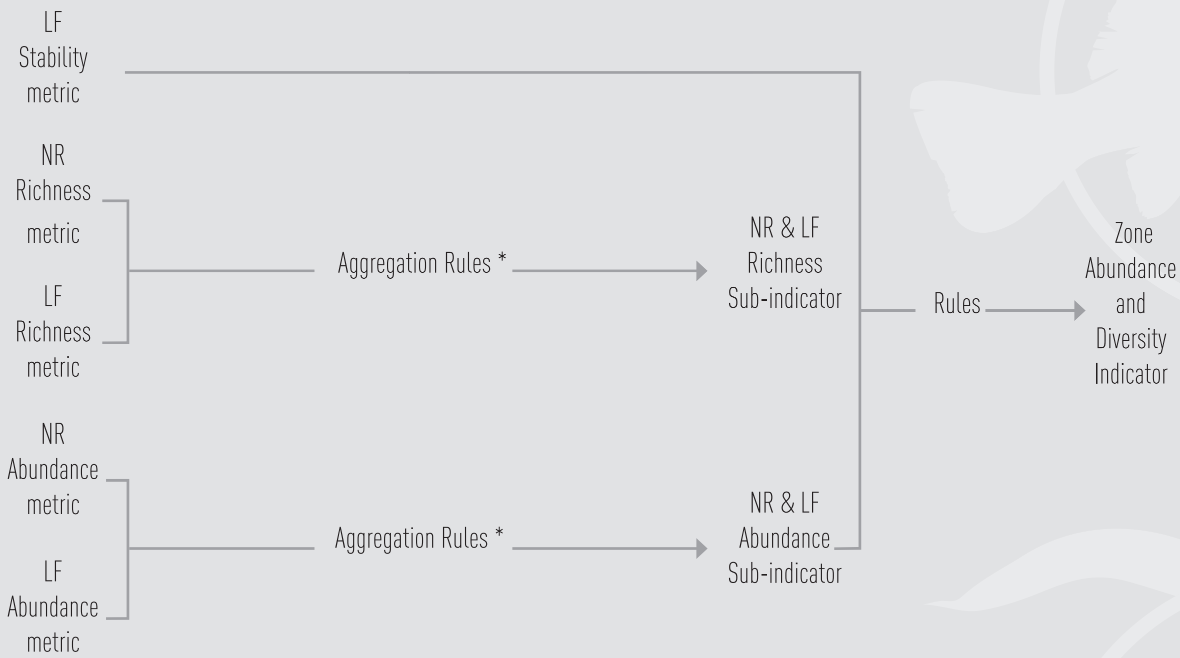


Figure APP 5. Sequence of Vegetation Theme data integration and aggregation to produce the Abundance and Diversity Indicator for Lowland zones with defined Floodplain Domains.

NR = Near Riparian, LF = Lowland Floodplain * Aggregation by applying the Vegetation Spatial Domain to Zone Aggregation expert system (see Section 5.2).

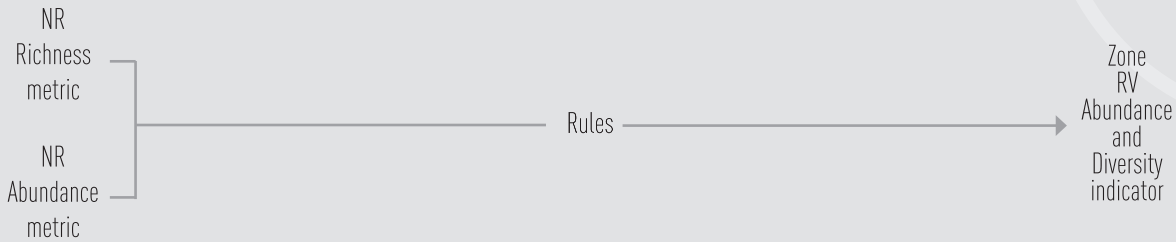


Figure APP 6. Sequence of Vegetation Theme data integration and aggregation to produce the Abundance and Diversity Indicator for the Slopes, Upland and Montane zones.

NR = Near Riparian, LF = Lowland Floodplain. No intermediate aggregation step required.

1.4.2 Vegetation expert system definition tables

Vegetation Fragmentation sub-indicator (Lowland Floodplain domain)

This expert system applies only to Lowland zones containing Lowland Floodplain domain polygons. Threshold values for both metrics are Extremely Low = 0.1, and Extremely High = 2.0.

Table APP 11. Expert system definition table – Vegetation Fragmentation sub-indicator

Rule set applies only to Lowland zones containing Lowland Floodplain domain polygons. L+, H and L- thresholds for both metrics equal 2.0, 1.0 and 0.1 respectively.

Mean Patch Area Vegetation metric	N Patches Vegetation metric	Vegetation Fragmentation sub-indicator
Good	Good	100
Extremely High	Good	70
Good	Extremely High	70
Extremely High	Extremely High	70
Extremely High	Extremely Low	70
Good	Extremely Low	50
Extremely Low	Extremely High	40
Extremely Low	Good	10
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

Vegetation Structure sub-indicator (Near Riparian domain)

This expert system applies only to Lowland zones. Threshold values are Extremely Low = 0.4 and Extremely High = 1.4.

Table APP 12. Expert system definition table – Vegetation Structure sub-indicator

Vegetation Canopy Height metric	Vegetation Structure sub-indicator
Good	100
Extremely High	60
Extremely Low	0

Vegetation Quality and Integrity indicator

Table APP 13. Expert system definition table – Vegetation Quality and Integrity indicator

*Near Riparian (NR) & Lowland Floodplain (LF)

Zone stratum	Vegetation Nativeness (NR & LF*) sub-indicator	Vegetation Fragmentation (LF*) sub-indicator	Vegetation Structure (NR) sub-indicator	Vegetation Quality & Integrity indicator
Lowland (with defined Floodplain Domain)	Good	Good	Good	100
	Good	Good	Extremely Low	70
	Good	Extremely Low	Good	50
	Good	Extremely Low	Extremely Low	30
	Extremely Low	Good	Good	30
	Extremely Low	Good	Extremely Low	20
	Extremely Low	Extremely Low	Good	20
	Extremely Low	Extremely Low	Extremely Low	0
	Rank: 1	Rank: 2	Rank: 3	
		Vegetation Nativeness (NR) metric	Vegetation Structure (NR) sub-indicator	Vegetation Quality & Integrity indicator
Lowland (without defined Floodplain Domain), Slopes, Upland & Montane		Good	Good	100
		Good	Extremely Low	60
		Extremely Low	Good	30
		Extremely Low	Extremely Low	0
		Rank: 1	Rank: 2	

Vegetation Abundance and Diversity indicator

Table APP 14. Expert system definition table – Vegetation Abundance and Diversity indicator
* Near Riparian (NR) and Lowland Floodplain (LF)

Zone stratum	Vegetation Abundance (NR & LF*) sub-indicator	Vegetation Richness (NR & LF) sub-indicator	Vegetation Stability (LF) metric	Vegetation Abundance & Diversity indicator
Lowland (with defined Floodplain Domain)	Good	Good	Good	100
	Good	Good	Extremely Low	90
	Good	Extremely Low	Good	50
	Good	Extremely Low	Extremely Low	40
	Extremely Low	Good	Good	30
	Extremely Low	Good	Extremely Low	20
	Extremely Low	Extremely Low	Good	10
	Extremely Low	Extremely Low	Extremely Low	0
	Rank: 1	Rank: 2	Rank: 3	
Lowland (without defined Floodplain Domain), Slopes, Upland & Montane	Good	Good		100
	Good	Extremely Low		50
	Extremely Low	Good		30
	Extremely Low	Extremely Low		0
	Rank: 1	Rank: 2		

Riverine Vegetation Condition Index

Table APP 15. Expert system definition table – Riverine Vegetation Condition Index

Vegetation Abundance & Diversity indicator	Vegetation Quality & Integrity indicator	Riverine Vegetation Condition Index SR–VI
Good	Good	100
Good	Extremely Low	30
Extremely Low	Good	10
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

Vegetation spatial domain to zone aggregation rules

This expert system is for aggregation (not integration) of Lowland Floodplain and Near Riparian domain values of the same metric, to derive a zone-scale value of the metric. It is only applied to the Abundance, Richness and Nativeness metrics in Lowland Floodplains containing a Lowland Floodplain Domain.

Table APP 16. Vegetation spatial domain to zone aggregation rules

Lowland Floodplain Spatial Domain	Near Riparian Spatial Domain	Zone score
Good	Good	100
Good	Extremely Low	50
Extremely Low	Good	30
Extremely Low	Extremely Low	0

1.5 Physical Form Theme

1.5.1 Physical Form work flow

Integration followed the schematic shown below.

Table APP 17. Integration steps for the Physical Form Theme

Integration proceeds from left to right, with values of each sub-indicator, indicator, sub-index and Index produced by an expert system which combines the inputs in the column to the left. The relative order of influence of each input on each output is indicated by the vertical order in the table (see also the rank shown in each rule table that follows).

<table>
<tr><th>Metric</th><th>Sub-indicator</th><th>Indicator</th><th>Index</th></tr>
<tr><td>Channel Sediment Depth</td><td rowspan="2"></td><td rowspan="2">Bed Dynamics</td><td rowspan="9">Physical Form Condition
SR–PI</td></tr>
<tr><td>Channel Sediment Ratio</td></tr>
<tr><td>Mean Channel Width</td><td rowspan="2">Mean Cross-section Form</td><td rowspan="5">Channel Form</td></tr>
<tr><td>Channel Mean Depth</td></tr>
<tr><td>Channel Width Variability</td><td>Cross-section Form Variability</td></tr>
<tr><td>Channel Meander Wavelength</td><td rowspan="2">Channel Planform</td></tr>
<tr><td>Channel Sinuosity</td></tr>
<tr><td>Longitudinal Bank Variability</td><td></td><td>Bank Dynamics</td></tr>
<tr><td>Floodplain Sediment Deposition</td><td></td><td>Floodplain</td></tr>
</table>

All the expert systems were implemented using inputs generated at site scale, with the exception of the Physical Form Condition Index expert system, which was implemented at zone scale. This was because the Channel Sediment Ratio, Channel Sediment Depth and Floodplain Sediment Deposition metrics were generated for a different suite of locations (SEDNET reaches) than the other six metrics, which were generated for the randomly assigned LiDAR sites.

All indicator values were aggregated to zone scale prior to being input into the Physical Form Condition Index expert system to generate the zone scale value of SR–PI.

Aggregation of Sednet reach values for the Channel Sediment Ratio, Channel Sediment Depth and Floodplain Sediment Deposition metrics is by Sednet-reach length weighted mean for the zone. Aggregation of site values for all other LiDAR-derived metrics is by deriving the mean of site values for the zone. Aggregation of zone-to valley-scale values for all metrics, indicators and the SR–PI is by total reach-length weighted means.

1.5.2 Physical Form expert system definition tables

Bed Dynamics indicator

Table APP 18. Expert system definition table – Bed Dynamics indicator

Threshold values for the Sediment Ratio metric are: Extremely Low = 0.1 and Extremely High = 10.0. The pin point values for the Channel Sediment Depth metric are Good = 0 and Extremely High = 0.01. The Channel Sediment Depth is unusual in that it is an actual depth, not a metric (i.e. not a ratio of an observed to an expected reference value).

Channel Sediment Depth metric	Sediment Ratio metric	Bed Dynamics indicator
Good	Good	100
Good	Extremely High	70
Good	Extremely Low	70
Extremely High	Good	30
Extremely High	Extremely Low	20
Extremely High	Extremely High	0
Rank: 1	Rank: 2	

Mean Cross-section Form sub-indicator

Table APP 19. Expert system definition table – Mean Cross-section Form sub-indicator

Threshold values for both metrics are: Extremely Low = 0.5 and Extremely High = 2.0.

Channel Mean Width metric	Channel Mean Depth metric	Mean cross-section Form sub-indicator
Good	Good	100
Good	Extremely Low	50
Extremely High	Extremely Low	40
Good	Extremely High	30
Extremely High	Good	30
Extremely Low	Extremely Low	30
Extremely Low	Good	20
Extremely High	Extremely High	10
Extremely Low	Extremely High	0
(Rank depends on metric values).		

Cross-section Form Variability sub-indicator

Table APP 20. Expert system definition table – Cross-section Form Variability sub-indicator

Threshold values for the Channel Width Coefficient of Variability (CV) metric are: Extremely Low = 0.5 and Extremely High = 2.0.

Channel Width Coefficient of Variability metric	Cross-section Form Variability sub-indicator
Good	100
Extremely High	70
Extremely Low	0

Channel Planform sub-indicator

Table APP 21. Expert system definition table – Channel Planform sub-indicator

Threshold values for both metrics are: Extremely Low = 0.7 and Extremely High = 1.3.

Meander Wavelength metric	Sinuosity metric	Channel Planform indicator
Good	Good	100
Extremely Low	Extremely High	90
Extremely Low	Good	80
Good	Extremely High	80
Extremely High	Extremely High	60
Extremely Low	Extremely Low	50
Extremely High	Good	30
Good	Extremely Low	20
Extremely High	Extremely Low	0
Rank: 1	Rank: 2	

Additional expert systems were developed to address the situations in which either the Sinuosity metric is missing, or the meander wavelength metric is either missing or has a null value. However, the Physical Form data set did not have any missing metrics, so neither of these expert systems was required.

Bank Dynamics indicator

The Longitudinal Bank Variability metric was originally conceived as the mean of three metrics: the CV (coefficient of variation) of Bank Angle metric, the CV of Bank Complexity metric, and the CV of Bank Concavity metric. However, due to data limitations, for SRA report 2, the Longitudinal Bank Variability metric was set equal to the CV Bank Angle metric.

Table APP 22. Expert system definition table – Bank Dynamics indicator

Threshold values for the Longitudinal Bank Variability metric are: Extremely Low = 0.5 and Extremely High = 2.0.

Longitudinal Bank Variability metric	Bank Dynamics indicator
Good	100
Extremely High	60
Extremely Low	0

Floodplain Form indicator

The Floodplain Sediment Deposition metric is an absolute measure derived from the SEDNET model. Sediment deposition rates in reality may increase (aggradation) or decrease (erosion) with respect to reference, but SEDNET does not calculate erosion and negative metric values are therefore absent. The high threshold value (i.e. the Extremely High value) of 5.0 kt/yr. indicates what is considered to be a lower bound for extreme increases in sediment depth relative to reference (0 kt/yr).

Table APP 23. Expert system definition table – Floodplain Form indicator

Floodplain Sediment Deposition metric	Floodplain Form indicator
Good	100
Extremely High	0

Channel Form indicator

Table APP 24. Expert system definition table – Channel Form indicator

Mean Cross-section Form sub-indicator	Cross-section Form Variability sub-indicator	Channel Planform sub-indicator	Channel Form indicator
Good	Good	Good	100
Good	Good	Extremely Low	40
Good	Extremely Low	Good	40
Extremely Low	Good	Good	40
Good	Extremely Low	Extremely Low	20
Extremely Low	Good	Extremely Low	20
Extremely Low	Extremely Low	Good	20
Extremely Low	Extremely Low	Extremely Low	0
Rank: 1	Rank: 1	Rank: 1	

The expert system definition table for when the Channel Planform sub-indicator is absent is:

Table APP 25. Expert system definition table – Channel Form indicator, when Channel Planform sub-indicator is absent

Mean Cross-section Form sub-indicator	Cross-section Form Variability sub-indicator	Channel Form indicator
Good	Good	100
Good	Extremely Low	30
Extremely Low	Good	30
Extremely Low	Extremely Low	0
Rank: 1	Rank: 1	

Physical Form Condition Index (SR–PI)

Table APP 26. Expert system definition table – Physical Form Condition Index

Zone stratum	Channel Form indicator	Bank Dynamics indicator	Bed Dynamics indicator	Floodplain indicator	Physical Form Condition Index SR–PI
Montane, Upland[1]	Good	Good	Good	Good	100
	Good	Good	Good	Extremely Low	100
	Extremely Low	Good	Good	Good	50
	Extremely Low	Good	Good	Extremely Low	50
	Good	Good	Extremely Low	Good	40
	Good	Good	Extremely Low	Extremely Low	40
	Good	Extremely Low	Good	Good	40
	Good	Extremely Low	Good	Extremely Low	40
	Good	Extremely Low	Extremely Low	Good	10
	Good	Extremely Low	Extremely Low	Extremely Low	10
	Extremely Low	Good	Extremely Low	Good	10
	Extremely Low	Good	Extremely Low	Extremely Low	10
	Extremely Low	Extremely Low	Good	Good	10
	Extremely Low	Extremely Low	Good	Extremely Low	10
	Extremely Low	Extremely Low	Extremely Low	Good	0
	Extremely Low	Extremely Low	Extremely Low	Extremely Low	0
	Rank: 2	Rank: 1	Rank: 1	Rank: 3	

CONTINUED/...

Zone stratum	Channel Form indicator	Bank Dynamics indicator	Bed Dynamics indicator	Floodplain indicator	Physical Form Condition Index SR–PI
Slopes[2]	Good	Good	Good	Good	100
	Good	Good	Good	Extremely Low	90
	Good	Good	Extremely Low	Good	50
	Good	Good	Extremely Low	Extremely Low	40
	Extremely Low	Good	Good	Good	40
	Good	Extremely Low	Good	Good	30
	Good	Extremely Low	Good	Extremely Low	30
	Extremely Low	Good	Good	Extremely Low	30
	Extremely Low	Good	Extremely Low	Good	20
	Extremely Low	Good	Extremely Low	Extremely Low	20
	Good	Extremely Low	Extremely Low	Good	10
	Good	Extremely Low	Extremely Low	Extremely Low	10
	Extremely Low	Extremely Low	Good	Good	10
	Extremely Low	Extremely Low	Good	Extremely Low	10
	Extremely Low	Extremely Low	Extremely Low	Good	0
	Extremely Low	Extremely Low	Extremely Low	Extremely Low	0
	Rank: 2	Rank: 1	Rank: 3	Rank: 4	

CONTINUED/...

Zone stratum	Channel Form indicator	Bank Dynamics indicator	Bed Dynamics indicator	Floodplain indicator	Physical Form Condition Index SR–PI
Lowland[3]	Good	Good	Good	Good	100
	Good	Good	Extremely Low	Good	100
	Good	Good	Good	Extremely Low	50
	Good	Good	Extremely Low	Extremely Low	50
	Good	Extremely Low	Good	Good	30
	Good	Extremely Low	Extremely Low	Good	30
	Good	Extremely Low	Good	Extremely Low	20
	Good	Extremely Low	Extremely Low	Extremely Low	20
	Extremely Low	Good	Good	Good	20
	Extremely Low	Good	Extremely Low	Good	20
	Extremely Low	Good	Good	Extremely Low	10
	Extremely Low	Good	Extremely Low	Extremely Low	10
	Extremely Low	Extremely Low	Good	Good	10
	Extremely Low	Extremely Low	Extremely Low	Good	10
	Extremely Low	Extremely Low	Good	Extremely Low	0
	Extremely Low	Extremely Low	Extremely Low	Extremely Low	0
	Rank: 1	Rank: 2	Rank: 4	Rank: 3	

1 = Floodplain minimal/absent; 2 = Floodplain present often only in pockets; 3 = Floodplain well-developed.

1.6 Hydrology Theme

Hydrology data processing

Aggregation for Hydrology is by means of site values within zones (separately for mainstem rivers and headwater streams), and weighted average of zone values (by stream length) to valleys. Integration followed the schematic shown in Table APP 27, with all integration occurring at site (reach) scale, followed by aggregation of site values to zone scale for mainstem and headwater streams as above. A final aggregation step was conducted to combine mainstem and headwater stream Index values to produce the valley scale values for SR–HI (see Table APP 40).

Table APP 27. Integration steps for the Hydrology Theme

Integration proceeds from left to right, with values of each sub-indicator, indicator, sub-index and index produced by an expert system which combines the inputs in the column to the left. The relative order of influence of each input on each output is indicated by the vertical order in the table.

<table>
<tr><th>Metric</th><th>Sub-indicator</th><th>Indicator</th><th>Sub-index</th><th>Index</th></tr>
<tr><td>OB Flow Duration (ARI 8)</td><td rowspan="2"></td><td rowspan="2">Over Bank Floods High</td><td rowspan="4">Over bank Flow Regime</td><td rowspan="13">Hydrology Condition, SR–HI</td></tr>
<tr><td>OB Flow Spells (ARI 8)</td></tr>
<tr><td>OB Flow Duration (ARI 1)</td><td rowspan="2"></td><td rowspan="2">Over Bank Floods Low</td></tr>
<tr><td>OB Flow Spells (ARI 1)</td></tr>
<tr><td>Zero Flow Proportion</td><td rowspan="3">Low and Zero Flow Events</td><td rowspan="6">In-channel Flow Regime A (Volume & Flow Events)</td><td rowspan="9">In Channel Flow Regime</td></tr>
<tr><td>Low Flow</td></tr>
<tr><td>Low Flow Spells</td></tr>
<tr><td>High Flow</td><td rowspan="2">High Flow Events</td></tr>
<tr><td>High Flow Spells</td></tr>
<tr><td>Mean Annual Flow</td><td>Flow Gross Volume</td></tr>
<tr><td>Flow Variation</td><td>Flow Variability</td><td rowspan="3">In-channel Flow Regime B (Seasonality & Variability)</td></tr>
<tr><td>Flow Seasonal Amplitude</td><td rowspan="2">Flow Seasonality</td></tr>
<tr><td>Flow Seasonal Period</td></tr>
</table>

Flow Seasonality sub-indicator

This sub-indicator is calculated according to the natural flow regime seasonality of the river reach, with an expert system corresponding to each situation. Threshold values for the Flow Seasonal Amplitude metric are Extremely Low = 0, and Extremely High = 2.0.

Table APP 28. Expert system definition table – Flow Seasonality sub-indicator

Ranks dependent on metric values.

Natural seasonality	Ratings		Score
	Flow Seasonal Amplitude metric	Flow Seasonal Period metric	Flow Seasonality sub-indicator
Monsoonal	Good	Good	100
	Extremely High	Good	50
	Good	Extremely Low	20
	Extremely Low	Good	20
	Extremely High	Extremely Low	10
	Extremely Low	Extremely Low	0
Weak or absent	Good	Good	100
	Extremely High	Good	70
	Extremely Low	Good	40
	Good	Extremely Low	30
	Extremely High	Extremely Low	20
	Extremely Low	Extremely Low	0
Strong	Good	Good	100
	Good	Extremely Low	50
	Extremely High	Good	50
	Extremely High	Extremely Low	30
	Extremely Low	Good	20
	Extremely Low	Extremely Low	0

Gross Volume sub-indicator

Table APP 29. Expert system definition table – Gross Volume sub-indicator

Threshold values for the Mean Annual Flow metric are Extremely Low = 0 and Extremely High = 2.0.

Mean Annual Flow metric	Flow Gross Volume sub-indicator
Good	100
Extremely High	50
Extremely Low	0

Flow Variability sub-indicator

Table APP 30. Expert system definition table – Flow Variability sub-indicator

Threshold values for the Flow Variation metric are Extremely Low = 0.5 and Extremely High = 1.5.

Flow Variation metric	Flow Variability sub-indicator
Good	100
Extremely High	30
Extremely Low	0

Over Bank Floods (High and Low) indicators

Table APP 31. Expert system definition table – Over Bank Floods (High and Low) indicators

Threshold values for both the OB Flow Duration and OB Flow Spells metrics are: Extremely Low = 0, and Extremely High = 2.
The Overbank Floods High indicator is calculated for an Average Recurrence Interval (ARI) of 8 years. The Overbank Floods Low indicator is calculated for an Average Recurrence Interval of one year.

OB Flow Duration (ARI=8) metric	OB Flow Spells (ARI=8) metric	Over Bank Floods High indicator
Good	Good	100
Good	Extremely High	60
Extremely Low	Good	60
Extremely High	Good	40
Extremely High	Extremely High	30
Extremely Low	Extremely High	30
Extremely High	Extremely Low	0
Good	Extremely Low	0
Extremely Low	Extremely Low	0

OB Flow Duration (ARI=1) metric	OB Flow Spells (ARI=1) metric	Over Bank Floods Low indicator
Good	Good	100
Extremely High	Good	70
Good	Extremely High	60
Extremely Low	Good	60
Good	Extremely Low	30
Extremely Low	Extremely High	10
Extremely High	Extremely High	0
Extremely High	Extremely Low	0
Extremely Low	Extremely Low	0

(Rank dependent on metric values).

Table APP 32. Expert system definition table – High Flow Events sub-indicator

Threshold values for both the High Flow and High Flow Spells metrics are: Extremely Low = 0, and Extremely High = 2.0.

High Flow metric	High Flow Spells metric	High Flow Events sub-indicator
Good	Good	100
Extremely Low	Good	70
Good	Extremely High	60
Good	Extremely Low	50
Extremely High	Good	40
Extremely Low	Extremely High	40
Extremely High	Extremely High	20
Extremely High	Extremely Low	20
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

The expert system definition table for when the High Flow Spells metric is absent (i.e. not derived by the flow model) is:

Table APP 33. Expert system definition table – High Flow Spells metric absent

High Flow metric	High Flow Events sub-indicator
Good	100
Extremely High	20
Extremely Low	0

Table APP 34. Expert system definition table – Low- and Zero-Flow Events sub-indicator
Threshold values for all three input metrics are: Extremely Low = 0, Extremely High = 2.0.

Zero Flows Proportion metric	Low Flow metric	Low Flow Spells metric	Low and Zero Flow Events sub-indicator
Good	Good	Good	100
Good	Good	Extremely Low	60
Extremely Low	Good	Good	60
Good	Good	Extremely High	50
Good	Extremely High	Good	50
Good	Extremely Low	Good	40
Extremely High	Good	Good	40
Good	Extremely Low	Extremely High	30
Extremely Low	Good	Extremely High	30
Extremely Low	Good	Extremely Low	30
Extremely Low	Extremely High	Good	30
Extremely Low	Extremely Low	Good	30
Good	Extremely High	Extremely High	20
Good	Extremely Low	Extremely Low	20
Extremely High	Good	Extremely High	20
Extremely High	Good	Extremely Low	20
Extremely High	Extremely High	Good	20
Extremely High	Extremely Low	Good	20
Extremely Low	Extremely High	Extremely High	10
Extremely Low	Extremely Low	Extremely High	10
Extremely Low	Extremely Low	Extremely Low	10
Extremely High	Extremely High	Extremely High	0
Extremely High	Extremely High	Extremely Low	0
Extremely High	Extremely Low	Extremely High	0
Extremely High	Extremely Low	Extremely Low	0
Good	Extremely High	Extremely Low	0
Extremely Low	Extremely High	Extremely Low	0
Rank: 1	Rank: 2	Rank: 2	

The expert system definition table for when the Low Flow Spells metric is absent (i.e. not derived by the flow model) is:

Table APP 35. Expert system definition table – Low Flow Spells metric absent

Zero Flows Proportion metric	Low Flow metric	Low and Zero Flow Events sub-indicator
Good	Good	100
Extremely Low	Good	60
Extremely High	Good	40
Good	Extremely High	20
Good	Extremely Low	20
Extremely Low	Extremely High	10
Extremely Low	Extremely Low	10
Extremely High	Extremely High	0
Extremely High	Extremely Low	0

In-channel Flow Regime A (Volume & Flow Events) indicator

Table APP 36. Expert system definition table – In-channel Flow Regime A indicator

Low and Zero Flow Events sub-indicator	High Flow Events sub-indicator	Flow Gross Volume sub-Indicator	In-channel Flow Regime A (Volume & Flow Events) indicator
Good	Good	Good	100
Good	Good	Extremely Low	60
Good	Extremely Low	Good	50
Extremely Low	Good	Good	30
Good	Extremely Low	Extremely Low	20
Extremely Low	Extremely Low	Good	10
Extremely Low	Good	Extremely Low	10
Extremely Low	Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	Rank: 3	

In-channel Flow Regime B (Seasonality & Variability) indicator

Table APP 37. Expert system definition table – In-channel Flow Regime B indicator

Flow Variability sub-indicator	Flow Seasonality sub-indicator	In-channel Flow Regime B (Seasonality & Variability) indicator
Good	Good	100
Good	Extremely Low	40
Extremely Low	Good	20
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

In-channel Flow Regime sub-index

Table APP 38. Expert system definition table – In-channel Flow Regime sub-index

In-channel Flow Regime A (Volume & Flow Events) indicator	In-channel Flow Regime B (Seasonality & Variability) indicator	In-channel Flow Regime sub-index
Good	Good	100
Good	Extremely Low	30
Extremely Low	Good	10
Extremely Low	Extremely Low	0
Rank: 1	Rank: 2	

Over Bank Flow Regime sub-index

Table APP 39. Expert system definition table – Over Bank Flow Regime sub-index

Zone stratum	Over Bank Floods High indicator	Over Bank Floods Low indicator	Over Bank Flow Regime sub-index
Lowland	Good	Good	100
	Good	Extremely Low	50
	Extremely Low	Good	30
	Extremely Low	Extremely Low	0
	Rank: 1	Rank: 2	
Upland, Slopes		Good	100
		Extremely Low	0
Montane			Not applicable

Hydrology Condition Index (SR–HI)

Table APP 40. Expert system definition table – Hydrology Condition Index

Zone stratum	In-channel Flow Regime sub-index	Over Bank Flow Regime Sub-index	Hydrology Condition Index
Montane	Good		100
	Extremely Low		0
Upland, Slopes	Good	Good	100
	Good	Extremely Low	40
	Extremely Low	Good	20
	Extremely Low	Extremely Low	0
	Rank: 1	Rank: 2	
Lowland	Good	Good	100
	Extremely Low	Good	40
	Good	Extremely Low	20
	Extremely Low	Extremely Low	0
	Rank: 2	Rank: 1	

When Over Bank Flow Regime indicator is absent (i.e. not derived by flow model), the Hydrology Condition Index is set equal to the In-channel Flow Regime sub-index.

Final Hydrology Aggregation Rules

After all the integration steps were completed, a final hydrology expert system was applied to the zone-scale values of Hydrology Condition indices for mainstem and headwaters to generate an aggregated zone-scale Hydrology Condition Index value.

Table APP 41. Expert system definition table – aggregated zone-scale Hydrology Condition Index

Zone stratum	Mainstem Hydrology Condition Index	Headwaters Hydrology Condition Index	Hydrology Condition Index
	SR–HI*m*	SR–HI*h*	SR–HI
Lowland	Good		100
	Extremely Low		0
Slopes, Upland	Good	Good	100
	Extremely Low	Good	30
	Good	Extremely Low	20
	Extremely Low	Extremely Low	0
Montane		Good	100
		Extremely Low	0

1.7 List of tables and figures