



## NSW MONITORING, EVALUATION AND REPORTING PROGRAM

### Technical report series

#### Riverine ecosystems



Leading policy and reform in sustainable water management

## Publisher

### NSW Office of Water

Level 17, 227 Elizabeth Street

GPO Box 3889

Sydney NSW 2001

T 02 8281 7777 F 02 8281 7799

information@water.nsw.gov.au

www.water.nsw.gov.au

The NSW Office of Water is a separate office within the Department of Environment, Climate Change and Water. The Office manages the policy and regulatory frameworks for the State's surface water and groundwater resources to provide a secure and sustainable water supply for all users. The Office also supports water utilities in the provision of water and sewerage services throughout New South Wales.

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### Authors:

Monika Muschal (NSW Office of Water),

Eren Turak (NSW Department of Environment, Climate Change and Water)

Jan Miller (NSW Department of Environment, Climate Change and Water)

Dean Gilligan (Industry and Investment NSW)

Jon Sayers (NSW Office of Water)

Michael Healey (NSW Office of Water).

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## NSW Monitoring, Evaluation and Reporting Program

### Technical report series

- Native vegetation
- Native fauna
- Threatened species
- Invasive species
- **Riverine ecosystems**
- Groundwater
- Marine waters
- Wetlands
- Estuaries and coastal lakes
- Soil condition
- Land managed within capability
- Economic sustainability and social wellbeing
- Capacity of natural resource managers

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[http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/Man/Sampling/NSW/NSW\\_Contributors.pdf](http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/Man/Sampling/NSW/NSW_Contributors.pdf)

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# 1. Introduction

The Natural Resource Commission (NRC) recommended 13 state-wide targets for reporting progress towards natural resource management in New South Wales (NSW) in 2005 (NRC 2005). The NRC recommendations were adopted by the NSW government, and the NSW Natural Resources and Environment CEO Cluster Group (NRE CEO) prepared the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (the Strategy) (NRECG, 2006). The Strategy aimed at integrating disparate monitoring information within NSW and providing a co-ordinated approach to measure progress towards NSW natural resource condition targets and providing information that enables targeted natural resource management investment decisions.

Within the NSW State Plan, the targets were linked to Priority E4: Better environmental outcomes for native vegetation, biodiversity, land, rivers and coastal waterways (NSW Premier's Department 2006). One of the 13 state-wide targets, Target 5, focused on the condition of riverine ecosystems. The key aim of Target 5 is: 'By 2015 there is an improvement in the condition of riverine ecosystems'. There are other targets that address groundwater ecosystems (Target 6), marine waters (Target 7), wetlands (Target 8), and estuaries and coastal lakes (Target 9). In the context of this report the term 'riverine ecosystems' is restricted to within-channel freshwater rivers and streams. While it is recognised that out-of-channel wetlands and floodplains are connected to riverine ecosystems, these are being reported through the other targets. The 2006 State Plan has now been updated and E4 has been replaced by the Green State (NSW Department of Premier and Cabinet 2010) but the 13 NRM Targets remain unchanged.

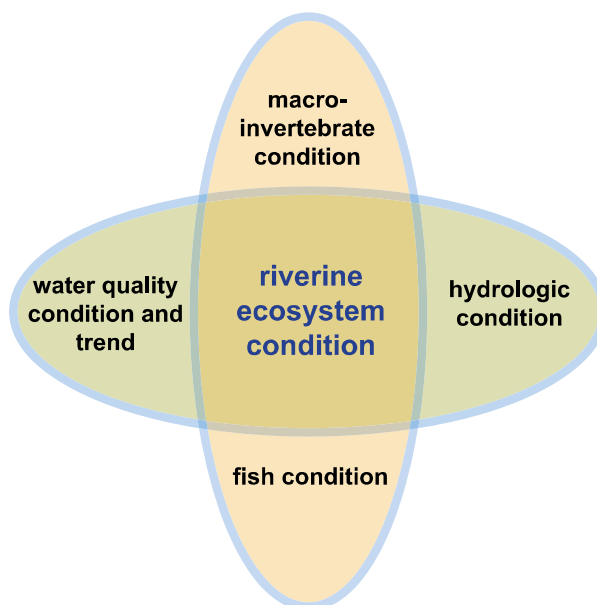
There is no recommended 'standard' to assess river condition in Australia, yet it is a critical step in the planning and management of many diverse river systems (Whittington 2002). Assessing river condition can help identify pressures affecting rivers, and with the appropriate assessment steps in place, may allow the determination if a river has changed or improved (Whittington 2002). In Australia, a number of river condition assessment programs have occurred at a national scale (NLWRA 2002, Norris *et al* 2007) and the state or basin scale (Whittington 2002; Gippel 2007). A National Framework for the Assessment of River and Wetland Health (FARWH) was developed to support the baseline Australian Water Resources 2005 assessment, and focused on six key indicators of riverine health (Norris *et al* 2007). Many river condition assessments have either used a few or many indicators, with a common set of indicators frequently used across assessments (Whittington 2002; Gippel 2007). The National Land and Water Resources Audit developed a National Monitoring and Evaluation Framework for natural resource management (NRMCM 2003) that covered broad thematic areas or 'Matters for Target', with the aim of co-ordinating indicators and sampling protocols across jurisdictions (<http://lwa.gov.au/products>). Where possible, consideration was given to adopting the common indicators across all these assessments, which generally rely on the availability of existing data. The original National Framework has now been replaced by another broad overarching approach (<http://www.nrm.gov.au/publications/frameworks/meri-framework.html>).

This technical background report focuses on the methods used to make a preliminary assessment against Target 5, as a baseline for comparison in 2015. The report tests whether existing data and methods are valid and available at spatial scales sufficient for state-wide reporting across 13 regions in NSW. The indicators used and described in this technical report have been utilised in many other river condition assessments throughout Australia and they were selected by an interagency Indicator Working Group (IWG) for use after meeting specific criteria for inclusion (NRECG 2006). These indicators had the best available existing data at the time that enabled the reporting of a baseline level of river condition that can be queried at a range of spatial scales for 13 regions across NSW. These methods also provide the basis for natural resource managers to interpret the river condition outcomes presented in the State of the Catchment (SOC) reports for riverine ecosystems. This technical support

document provides an understanding of how the methods were developed, in some cases from existing methods such as the Sustainable Rivers Audit (SRA).

The NSW Office of Water is the lead agency for Target 5, riverine ecosystems, coordinating the input of riverine condition information across NSW natural resource management agencies. The Office of Water undertakes the monitoring and reporting of water quality and hydrologic condition, while I&I NSW and DECCW carry out the monitoring and reporting for fish and macroinvertebrates respectively, (Figure 1). There was however, no attempt to define a single index of river condition within this iteration of the SOC reporting.

**Figure 1. Riverine ecosystem condition components**



A range of undesirable changes to riverine ecosystems in NSW were identified by the IWG and broadly fall into the following themes:

- changes in fluvial geomorphology, including erosion and sedimentation
- changes to ecologically important flows
- degradation of water quality
- decline in native vegetation, macroinvertebrate, fish and frog populations.

The components of riverine ecosystem condition included in this report are a subset of this list. These components are water quality, hydrology, macroinvertebrates and fish. This assessment was limited to these four components because the focus of this preliminary report was on the assessment of the best available existing data, and these components are supported by the SRA, and the nationally agreed indicators for monitoring water quality under the National Monitoring and Evaluation Framework.

This technical report is based on one of 13 natural resource themes, in accordance with the NSW state-wide targets (NRC 2005). The methods for the Riverine Ecosystem theme, while primarily developed to work in conjunction with the State of the Catchment reports and provide support to reporting against Priority E4 of the then NSW State Plan (2006), are also associated with information made available to the forthcoming State of the Environment (SOE) reporting for NSW.

## 2. Riverine ecosystems methods

### 2.1 Water quality condition

#### 2.1.1 Indicators/justification

The two water quality indicators, turbidity and total phosphorus were chosen to represent water quality condition. Phosphorus was chosen as it is often the limiting nutrient in freshwaters for nuisance algal and aquatic plant growth, and a key nutrient for measuring eutrophication (or nutrient enrichment). Turbidity was chosen to represent the effect of catchment disturbance, erosion and sedimentation on riverine condition. Both indicators are nationally agreed indicators for monitoring water quality (<http://lwa.gov.au/products>) and can be assessed by comparing recent data against relevant trigger values suggested in the Australian water quality guidelines for further action if exceeded (ANZECC & ARMCANZ 2000). Turbidity measured as Nephelometric Turbidity Units (NTU) measures the effect of suspended sediment on water clarity and when elevated is an indicator of erosion and sedimentation. Total phosphorus (mg/L) is a measure of all forms of phosphorus in suspension (dissolved and adsorbed onto sediment particles) and can occur both naturally or via inputs from factors such as erosion, sedimentation and from urban and rural runoff or discharge. While high turbidity and total phosphorus concentrations may occur naturally in some rivers, they are frequently used as indicators of catchment disturbance and the degree to which the physical and chemical components of streams are degraded.

The condition analysis reported here for total phosphorous and turbidity was also used in the NSW State of the Environment reporting due to the relevance of the indicators as justified above and the good state-wide data coverage. Total nitrogen, electrical conductivity, temperature and total suspended solids are also sampled through the Office of Water's state-wide water quality monitoring program, however, suitable trigger values for water quality condition reporting at appropriate spatial scales are not yet available. Modelling approaches such as 'SedNet' were not available at the state scale in the timeframe available for this analysis. Such analyses may be explored in future reporting if appropriate.

#### 2.1.2 Sampling design / sampling sites

The study was undertaken across all NSW Catchment Management Areas (CMAs) except the Northern Rivers CMA where there was no data.

All sites that had suitable data for analysis were considered in this study. Water quality monitoring is undertaken across NSW by the Office of Water as part of the state-wide monitoring program that has the objective of monitoring and reporting ambient water quality conditions at sub-catchment, regional and state scales. Sites are located across upland, mid and lowland catchment positions to characterise major spatial components of each valley such as; elevation, slope, rainfall and vegetation. All sites are located on permanently flowing streams; ephemeral streams are not represented. Samples are collected where the river is mixed and away from the direct influence of point source pollution. In the Murray River catchment and Border Rivers area additional sampling is undertaken as part of the Murray-Darling Basin Authority's, and Dumaresq Barwon Border Rivers Commission's water quality monitoring programs respectively. Sampling at most sites is generally undertaken at a monthly frequency, except for the south coast where sampling was once every two months and more frequently in the Murray River catchment during summer.

The number of sites per Catchment Management Authority (CMA) ranged from only five in the Sydney Metropolitan and Lower Murray-Darling CMAs through to 40 sites in the Border Rivers/Gwydir CMA. Although the Murray and Murrumbidgee CMAs also had many sites available for reporting; some sites

were omitted from the final reporting due to lack of data, with preference given to sites that had both turbidity and total phosphorus data available. Future reporting will likely include 10-15 sites per inland CMA due to a recent rationalisation of sampling effort across NSW. Sampling in the Northern Rivers CMA has resumed and will be included in future reporting.

The sampling design did not distribute sites randomly across large catchment scales, therefore agglomerating the data to provide a single estimate (e.g. average) of condition across the whole valley or CMA area was not statistically sound. The temptation to compare water quality condition between two or more catchments using summary statistics of data combined from all sites within a catchment should be resisted, as this assumes the variation between catchments is greater than within catchment variation – an assumption that is not dealt with in the sampling design.

### 2.1.3 Analysis

The data analysis was undertaken by the Office of Water except for the Sydney Metropolitan CMA where information was provided by the Sydney Water Corporation (2008), and the Hawkesbury-Nepean CMA where information was provided by Krogh *et al* (2008) and the Sydney Catchment Authority (2008).

The Triton archive is the NSW repository for discrete-sample water quality data collected in the field and subsequently analysed in the laboratory where applicable. Quality coded archival data are publicly available via request through the NSW Government water information website <http://waterinfo.nsw.gov.au/>. Data were downloaded to Excel™ for the three year period 2005-2008 for all sites except those located in the Central West and Lachlan CMAs, where data was only collected from 2007 to 2008 due to operational issues. The external information obtained for the Sydney Metropolitan CMA was for the period 2007-2008 and for the Hawkesbury-Nepean CMA was for the period 2005-2008 (upper catchment) and 2003-2007 (lower catchment). The differences in time periods for the external and internal data were due to the variety of reporting requirements placed on the different jurisdictions responsible for water quality monitoring and reporting.

Data confidence was determined based on the degree to which data met two criteria: firstly, the completeness of record over the three year period of sampling and secondly, the regularity of monthly sampling intervals. Data confidence was high when the data record satisfied – or nearly satisfied – the ideal situation of a complete three year sampling period with regular monthly sampling. Data confidence decreased as the data record departed further from the ideal, with the lowest confidence being for data collected over less than a year and/or with sampling intervals of six months apart or greater.

According to the Australian water quality guidelines (ANZECC & ARMCANZ 2000), the data were compared to the default trigger values for south-eastern Australia (Table 1). The upper guideline limit was used for this analysis. Using Excel™ spreadsheets, the percentage of discrete water quality results for each indicator at each site that exceeded the appropriate trigger value was calculated.

**Table 1 Water quality guideline trigger values for south-eastern Australia (ANZECC Guidelines; NWQMS 2000).**

|                          | Inland        |                | Coastal       |                |
|--------------------------|---------------|----------------|---------------|----------------|
|                          | Upland rivers | Lowland rivers | Upland rivers | Lowland rivers |
| Turbidity (NTU)          | 25            | 50             | 2             | 6              |
| Total Phosphorous (mg/L) | 0.02          | 0.05           | 0.02          | 0.05           |

The classification of sites as belonging to upland or lowland rivers was based on altitude as recommended by the guidelines; upland > 150 m and lowland < 150 m above sea level. The exceptions were the Namoi and Border Rivers/Gwydir CMAs where prior reports have classified upland rivers as those lying east of Boggabilla, Moree and Gunnedah.

## 2.2 Water quality trend

Water quality trend analysis focused on changes to selected parameters over time whereas water quality condition, described above, compared recent data against relevant trigger values suggested in the Australian water quality guidelines, and assessed the proportion of samples that exceed these guidelines.

For a full description of the assessment the reader is referred to Muschal *et al* (in prep.)

### 2.2.1 Indicators/justification

Water quality parameters were selected that were most likely to indicate change in riverine ecosystem condition from the implementation of natural resource management, and where long term continuous discrete or time series datasets were available for analysis:

- Water temperature (°C) is influenced by many factors related to natural resource management; riparian vegetation cover, changes to river flows, large impoundments and potentially due to long term changes to climate.
- Electrical conductivity ( $\mu\text{S}/\text{cm}$ ) is a surrogate measure of salinity. Clearing of catchment vegetation, irrigation, wastewater discharges, and changes in groundwater connectivity with surface waters all influence salinity concentrations in surface waters.
- Turbidity (NTU) is a measure of light scattering properties of water as a result suspended sediment particulates in the water column. Widespread clearing of vegetation and allowing livestock access to waterways increases bank erosion and increases bed and suspended sediment load. Agricultural and urban stormwater runoff and wastewater discharge is another source of sediment load in rivers and streams.

These three water quality indicators are considered to have had reasonably robust analytical techniques over the monitoring period. The nutrient data available for analysis was not comparable on either temporal or spatial scales to the other water quality indicators used in this trend assessment.

### 2.2.2 Sampling design/sampling sites

The study was undertaken by the Office of Water across all NSW CMAs except in the Sydney Metropolitan and Hawkesbury-Nepean CMAs. Data and information published by the Sydney Water Corporation (2008) were used for the Sydney Metropolitan CMA and publications from Krogh *et al* (2008) and the Sydney Catchment Authority (2008) were used for the Hawkesbury-Nepean CMA. No further analysis of this external information was undertaken as part of this study.

Within the coastal CMA areas 10 or 11 were investigated in each region, while an average of nine sites were investigated in each inland river catchment. A total of 100 sites were investigated across NSW (Figure 2).

Sites were selected based on three selection criteria:

1. the existence of a comparatively long data set (~ 30 years)
2. a spatial distribution of sites that represented the major characteristics of each catchment, such as; elevation, slope, rainfall and vegetation
3. the availability of a flow record at or near the water quality site as instantaneous flow data was required for the modelling.

## 2.2.3 Analysis

### 2.2.3.1 Data evaluation

The Triton archive is the NSW repository for discrete-sample water quality data collected in the field and subsequently analysed in the laboratory where applicable. Data were downloaded from Triton by site. For electrical conductivity and turbidity, preference was given to laboratory data because of the greater confidence in collection procedures, laboratory instrumentation and analytical techniques over the long term, compared to readings taken using field meters. Often the laboratory data record was not complete, in which case gaps were filled using field recorded data. Temperature data was recorded in the field.

Time-series hourly instantaneous flow (ML/day) data were downloaded from the NSW hydrological database HYDSTRA, the data storage system for NSW gauging station or river flow data. In some instances, temperature and electrical conductivity data from HYDSTRA were compared with the data from Triton and used to fill in missing data gaps where necessary. This water quality data was also time series collected at the gauging stations.

The data from Triton and HYDSTRA were merged by first sorting and matching the data by date and time. For each water quality parameter, the data were culled so that there were no more than 12-15 samples per year per site, at approximately monthly time steps. The purpose of culling the data to approximate monthly time steps was to normalise the data over time to reduce the influence of more frequent data collection periods on the trend assessment. Outlier data points were checked against the original hardcopy registry or data source where possible. If the datum was within the range of feasibility for that site and the data source demonstrated a consistent collection mode covering a reasonable period of time, then the datum was retained. Data that was outside the range of feasibility due to apparent typographical error or could not be confirmed due to an historically unknown operator record were not used in the analysis. This was an infrequent occurrence and generally the data was retained.

**Figure 2 Map of NSW indicating CMA boundaries and location of water quality trend assessment sites (black and white squares)**



To quantify the level of confidence in the archived data, a debit point system was developed to assess operational issues, excessive data gaps, site network issues, data collection issues and archival issues. The scoring system provided an objective approach to applying a low, medium or high confidence value to the data record. The data record was examined and assessed for each sampling site and water quality parameter.

### 2.2.3.2 Statistical approach

The statistical method used semi-parametric regression models. Arbitrary smoothing curves, called Generalised Additive Models (GAMs) were fitted, using an Ordinary Least Squares algorithm in the regression. The statistical software package S-Plus® was used for the analysis. This study attempts to describe the behaviour of historical trends, it does not forecast future trends.

The techniques used in this study are the result of a decade of research and development into the best approach for analysis of stream salinity trends and details of the statistical approach can be found in Harvey *et al* (2009).

The statistical approach used incremental models, where additional explanatory independent variables were added, making subsequent models increasingly complex. The simplest models attempted to explain the data in terms of season, hour of the day (for temperature and turbidity) and then by flow. The models became more complex when the data were adjusted to account for variation due to flow

and season. The adjusted data were then combined in a model with time in years. Finally, all variables were combined in the most complex model of water quality behaviour explained by season, hour of the day (for temperature and turbidity), instantaneous flow and year. Splines were applied to components of the models to investigate whether the data exhibit non-parametric or 'cyclical' behaviour; the smoothing parameter of 2 was used for flow and 4 for year (Harvey *et al* 2009).

Additional incremental models were included in the turbidity analysis to assess whether there was a relationship between electrical conductivity and turbidity at any of the study sites. The final turbidity model included both flow and electrical conductivity components.

How well the models explained the observed data-sets is reflected by the coefficient of determination ( $R^2$ ). Comparing the performance of each incremental model is a diagnostic step to infer the additional value of each variable in explaining the behaviour of the water quality parameter. These incremental improvements in the  $R^2$  values are a guide to the user and are not quantitative. An  $R^2$  greater than 0.5 in the final model was considered a good result, an  $R^2$  less than 0.3 was considered a very poor fit of the model to the data.

The consequence of auto correlated data collected through time is that standard errors, and hence  $p$  values, for the trend component may be under-estimated. A test for autocorrelation was applied to all statistically significant ( $p \leq 0.05$ ) trends of the final linear model outputs. Standard errors and  $t$  statistics were adjusted after calculating the autocorrelation factor (Harvey *et al* 2009). The interpretation of a linear significant trend was re-appraised where the adjusted  $t$  statistic was less than  $|2.00|$ , suggesting that the true probability of the linear trend is not significant ( $p > 0.05$ ). Generally,  $|1.96|$  is the accepted test for the adjusted  $t$  statistic (Harvey *et al* 2009), this study was slightly more conservative.

Multiple factors were considered when characterising the long-term behaviour of the water quality parameters; both the linear and cyclical statistical significance of the final model, the graphical outputs, the performance of each incremental model to explain the data (i.e. the  $R^2$  value), the adjustment for autocorrelation, the period of record (especially whether there is recent data), and data confidence (especially substantial data gaps). The *State of the Catchment 2008* reports required a definitive statement of trend, and hence, the following decision rules were applied:

1. If the final models were not linear significant, then a rising or falling trend was not evident and the trend was deemed stable.
2. If the final models were linear significant, then a rising or falling trend was assigned, unless
3. the cyclical component of the data was statistically significant, and/or
4. the graphical output did not support a statistically significant linear rise or fall in trend over the entire ~30 year period, and/or
5. a very poor fit of the final linear models to the observed data, i.e. a low  $R^2$  value, and/or
6. the test for autocorrelation suggests the final linear equations were not significant.
7. If one of the above occurred a rising or falling trend was not conclusive and the trend was deemed stable.
8. If there were excessive data gaps (debit points  $\geq 2$ ), a very poor fit of the final linear models (very low  $R^2$  value) or no recent data in the historical record, then the trend was unclear.

## 2.3 Macroinvertebrate condition

The aquatic macroinvertebrates that are present in a waterway can be used as indicators of river health. Methods for using macroinvertebrates as indicators can vary, but generally rely on information about the identity of individual taxa, community composition, expected presence of taxa and comparison to reference sites.

This section provides information on the methods used to provide the macroinvertebrate condition sections of the catchment technical reports. The methods used for the Murray-Darling Basin catchments are different to those used for the coastal catchments because of the different programs under which the data was collected, as well as the geomorphological and biological differences between east- and west-flowing rivers. These two methods are described below.

### 2.3.1 Murray-Darling Basin methods

#### 2.3.1.1 Sampling design

The Sustainable Rivers Audit (SRA) (Davies *et al* 2008) is a sampling program that was designed by the Murray-Darling Basin Authority (MDBAa) to provide 'whole of catchment' information on river health in the Basin. The program began with a pilot sampling of the Lachlan in 2002, and collects macroinvertebrate data from each valley in the Basin once every two years.

#### 2.3.1.2 Site selection

In each valley, 35 macroinvertebrate sampling sites were chosen from the stream network using a stratified-random procedure, ensuring at least three sites per elevation zone of lowland (0-200m), slopes (200-400m), upland (400-700m) and montane (>700m). Approximately 25% of the sites were fixed sites to be sampled once each two years while the remaining 'roving sites' were re-allocated annually.

#### 2.3.1.3 Sampling methods

Macroinvertebrates were sampled using the AUSRIVAS protocols, where the collector identifies aquatic habitat types (for example submerged logs, trailing vegetation or undercut banks) within a 100 m reach and samples a 10 m discontinuous section that includes all habitats present. A net was used to sweep aquatic vegetation and edge habitats, while in a riffle the stream substrate was disturbed and dislodged macroinvertebrates were collected into a net. Full details on the AUSRIVAS sampling method are available at <http://ausrivas.canberra.edu.au/>. The material collected in the net was placed into white trays and macroinvertebrates were live sorted into jars of ethanol. Identification was to family level for most groups and was carried out in the laboratory.

#### 2.3.1.4 Analyses

The macroinvertebrate data was analysed using a 'Reference Condition for Macroinvertebrates', which is the estimated composition of benthic macroinvertebrate communities that would occur in the absence of significant human intervention. A 'Filters' approach was used, based on the traits of families that determine distributional limits for temperature, hydrology, geomorphology and biogeography. From the primary data recorded at each site, and outputs from the Filters model, two metrics were calculated. These are the observed to expected ratio (Filters OE), which is the proportion of the number of families observed at a site predicted to occur under Reference Condition, and observed to expected Signal ratio (Filters Signal OE), which is the sensitivity of macroinvertebrates to pollution or other disturbances that are recorded at a site compared with that expected under Reference Condition.

The Filters OE and Filters Signal OE metrics were aggregated to provide valley elevation zone and valley-scale scores. The zone scores for each metric were the median scores for the sites within that

zone. The valley score for each metric was the mean of median metric scores for zones, weighted by stream length.

The zone and valley scores for each metric were integrated to provide a Zone Theme or Valley Theme Condition Index score. This was done using expert rules, which were developed based on expert opinion and then encoded using the Fuzzy Logic Toolbox in the computer program MatLab (The Mathworks Inc., USA).

The results were published in the Sustainable Rivers Audit SRA Report 1, 'A report on the ecological health of rivers in the Murray-Darling Basin, 2004-2007', June 2008. This report provides a complete description of the methods used for site selection, analyses and results, and is available online at <http://www.mdba.gov.au/programs/sustainable-rivers-audit> or can be obtained by contacting the Murray-Darling Basin Authority.

## 2.3.2 Coastal catchments methods

### 2.3.2.1 Sampling design

The data used to assess the health of the coastal catchments was collected for the National River Health Program (NRHP), between 1994 and 2000 (Turak *et al* 2002) and since 2006 for the Coastal Sustainable Rivers Audit (CSRA). The NRHP sampling was designed to provide information on riverine health spatially across NSW, as well as temporally with the same sites being sampled over successive seasons and years. The CSRA follows the MDBA SRA sample design to provide whole-of-catchment assessment of river health.

### 2.3.2.2 Site selection

The selection of the sites for the NRHP was done using different approaches for 'reference' and 'test sites'. Reference sites represented the best available reference condition for rivers and were selected by first dividing the state into broad regions followed by smaller natural regions and then selecting suitable sites that represented both large and small rivers (see Turak 2007 for a detailed description). The test sites were sites that were of management interest, include highly disturbed and relatively undisturbed sites and were usually nominated by local government agencies or community groups (see Turak *et al* 2002 for details).

The site selection for the CSRA followed a stratified-random procedure with sites being assigned zones based on elevation (0-30 m, 30-200 m, 200-700 m, 700-1100 m and >1100 m) and distance from source (<10 km, 10-30 km and >30 km). Approximately 25 per cent of sites were fixed sites, which generally correspond with previous NRHP sites, and the remainder of sites were 'roving' and are re-assigned each time the catchment is sampled. The five coastal CMA areas are sampled once each two years.

### 2.3.2.3 Sampling methods

Sampling methods follow the AUSRIVAS protocol, as described above in the Murray-Darling Basin methods section, and detailed in full online at <http://ausrivas.canberra.edu.au/>. At the time of macroinvertebrate collection, the geomorphological and physical attributes of the sampling site are described, and water quality parameters measured as per the AUSRIVAS protocol.

### 2.3.2.4 Analyses

To predict macroinvertebrate condition for all points on river networks, a linear regression model was fitted to predict O/E values as a function of the River Disturbance Index (RDI) and its component indices (Stein *et al* 2002). Separate regression models were developed for five regions:

1. Northern Rivers CMA region
2. Hunter Central Rivers CMA region

3. Hawkesbury-Nepean and Sydney Metro CMA regions
4. Southern Rivers CMA region coastal Sub-region
5. Snowy River Catchment (NSW Part)

Both cumulative disturbances upstream and local disturbances (including the changes to the riparian zone and land use in the immediate surrounding areas) will affect instream biota at any location so the measures of local disturbance as well as the accumulated disturbance measures as potential input variables were included in the model. The main assumption was that the relationships between upstream catchment disturbances and biodiversity measures may vary across the regions depending on the location and river type. To account for such differences maximum distance from source, elevation, slope, mean annual rainfall, and ecological river types (Turak & Koop, 2008) as potential input variables were considered in the model.

The NRHP sampling sites that were used for this assessment were not randomly selected. A large proportion of sites had been selected as reference sites for the development of AUSRIVAS predictive models in NSW and were therefore in very good condition. This left a low proportion of sites in poor condition. A graph of the O/E values predicted from the linear regression against the actual O/E values suggested that the regression relationship was dominated by the large number of sites having good condition. Given the current lack of sufficient data from sites with poor condition, as a temporary 'work-around', the regression relationship between biological condition and disturbance was weighted, to give more weight to the relatively small number of poor condition sites. An ad hoc weighting was used – all points were weighted inversely according to their observed O/E values. This meant that the lower the observed O/E value of a site, the greater was its influence on the regression.

To ensure that model predictions were well grounded and that over-fitting was not taking place in model predictions due to insufficient data available to test the predictions of the regressions on an independent data set, two cross-validation approaches were used. A stepwise variable selection procedure, using both forward and backward selection, to select the most appropriate models for both unweighted and weighted regressions was used. Based on data from those sub-catchments for which such assessments were available, the regression relationship relating disturbance measures and topographical data to biological assessments was then used to make predictions for the remaining subcatchments, for which no biological assessment data were available. The resulting predicted O/E values were then standardised, so that their values all lay between 0 and 1, by dividing them by the maximum predicted value in the catchment. The standardised values were mapped using different colour bands to represent seven biodiversity condition categories.

## 2.4 Fish condition

The freshwater fish condition monitoring component of the MER Riverine Ecosystems theme includes estimates of fish numbers, biomass and community composition and reports on two key aspects of condition: species loss or 'expectedness' and the 'nativeness' of the fish community. Sampling is based on a standardised electrofishing and bait-trap sampling protocol undertaken at 132 established I&I NSW /DECCW long-term monitoring sites and around 410 new randomly generated sampling locations dispersed throughout NSW. The methods used for freshwater fish sampling and analysis under the MER program are consistent with those developed and implemented under the NSW Rivers Survey (Harris and Gehrke 1997) and the Murray-Darling Basin Authorities *Sustainable Rivers Audit* (SRA) program (MDBC 2004, Davies *et al* 2008, MDBC 2008a).

The MER freshwater fish sampling program is heavily dependent upon (and encompasses) the SRA for data to report on condition of the eight inland CMA regions, but is supplemented with additional data collected from an additional 23 I&I NSW long-term freshwater fish monitoring sites (Harris and Gehrke 1997) spread throughout the eight CMA regions. The SRA provides well defined and robust

site selection, fish sampling and data analysis procedures developed by a large team of representatives from all fisheries management and research agencies in south-eastern Australia, with sampling intensity and methodological refinements derived from an extensive pilot exercise in 2002/03 (MDBC 2004). The NSW MER freshwater fish sampling program builds upon the SRA by applying the same design principles, but collecting data from coastal and far-west catchments in order to provide a consistent state-wide freshwater fish monitoring and reporting program. The condition of freshwater fish within the five coastal CMA regions was assessed by sampling at 42 long-term I&I NSW sites (Harris and Gehrke 1997) plus 36 DECCW long-term macroinvertebrate monitoring sites and 189 new randomly generated sites selected using similar site selection processes to those developed for the SRA, with some minor modifications as outlined below. Field sampling protocols and data analysis methods were also consistent with those developed for the SRA with some minor modifications necessary for application in coastal catchments.

### 2.4.1 Stratification/zonation

The primary reporting unit for the inland regions under the SRA program is the 'valley', but with valleys stratified into four zones based on altitude: lowland (0-200 m), slopes (201-400 m), upland (401-700 m) and montane (>700 m)<sup>1</sup>. In contrast, the primary reporting unit for the MER program is CMA regions. To maintain consistency with the SRA, coastal regions were also stratified into 'valleys' as defined by the Office of Water derived shapefile *BasinHydroInd* (from the internal Enterprise Database) and into the same four altitude zones as defined by the SRA. However, the lowland zone was further sub-divided in a coastal plains zone (3-30 m) and lowland (31-200 m) within coastal regions in recognition of the predominance and importance of diadromous fishes in coastal rivers.

### 2.4.2 Site densities

A power analysis and assessment of performance curves of data collected from the Murray-Darling Basin catchments (MDBC 2004) suggested that a minimum of 18 sites be sampled in each valley and a minimum of seven sites be sampled in each altitude zone within valleys. In valleys with only two altitude zones, the additional four sites required for the valley are allocated according to the percentage of total valley stream length within each zone.

However, given the large number of valleys present within coastal regions (22) and logistical constraints on the number of sites that could be sampled, site densities equivalent to those of the SRA were not possible within all coastal regions. Instead, minimum site densities of seven sites per altitude zone per CMA area, and seven sites within any one valley within CMA areas were adopted.

Unlike the SRA, the density of sites within altitude zones, valleys and CMA areas was dependant on catchment area, with one site per 750 km<sup>2</sup>. Therefore, altitude zones and valleys larger than 5,250 km<sup>2</sup> could have more than the SRA minimum of seven sites per zone. The number of sites per zone within valleys was allocated proportional to stream length within each zone. Zones with < 50 km of stream were merged with neighbouring zones.

### 2.4.3 Stream network

The same criteria were used to define the stream network for both the SRA and MER programs. The state-wide stream network was derived from the AUSLIG 1:250,000 stream network as a base layer clipped according to the following criteria (MDBC 2008a):

- flow > 5 ML per day (based upon version 2.92 of the Fenner School of Environment and Society, Australian National University, unpublished) stream model (Stein 2008a,b)
- catchment area > 50 km<sup>2</sup> at the downstream connection to the larger stream

<sup>1</sup> The Central Murray, Darling and Lower Murray valleys were stratified into geomorphic zones given that almost the entirety of these valleys occupies just a single altitude zone (lowland).

But unlike the SRA, impounded waters were not excluded from the stream network within coastal regions.

#### 2.4.4 Site selection

Sites within the Murray-Darling Basin were generated by the MDBA's SRA team and delivered to jurisdictions as database files containing randomly generated coordinates in prioritised order (see MDBC 2008a, Section 4). In coastal and far west regions, I&I NSW generated random site coordinates using the following GIS procedure in ArcGIS 9.3:

1. convert the stream network from vector to raster with 100 m pixels using the Spatial Analyst toolbox
2. randomly selected 10,000 points from within the raster layer using the 'Generate random points' tool in HawthTools (Beyer 2004) with no minimum distance between selected points
3. stratify sites within valley zones but retaining a selection order indicator.

#### 2.4.5 Ground-truthing

Each site was ground-truthed in sequential order to identify if the site is sampleable, to establish access, identify any occupational health and safety (OH&S) issues and to determine the most suitable sampling gear required to sample the site. Sampling must be possible within 500 m of the randomly selected coordinates. If the site was dry, inaccessible, the electrical conductivity exceeded 1000  $\mu\text{S}/\text{cm}$  at backpackable sites and 3,000  $\mu\text{S}/\text{cm}$  at large boat electrofishing sites, or insufficient water exists to undertake the full sampling protocol, the site was rejected and the next random site was assessed. A maximum travel time of two hours from the vehicle or boat ramp to the randomly selected coordinates was applied for access to remote sites with no vehicle access. If travel times were greater than two hours, the site was rejected.

#### 2.4.6 Sampling methods

Sampling took place between 1 November and 30 April for the inland regions and 1 October and 30 April for coastal regions. All sampling protocols were identical to those developed for the SRA (see MDBC 2008a). However, in addition to the requirements of the sub-sampling procedure for measuring individuals of abundant species (over 50 individuals per site) described in MDBC (2008a, Section 6.3.4), up to an additional 20 individuals (randomly selected from the catch) were measured in each operation after the SRA sub-sampling procedure had been completed. Further, in addition to those species requiring the preservation of voucher specimens for verification of field identifications (IDs) in inland regions (MDBC 2008a, Table 8.3), Table 2 lists taxa from coastal and far-west catchments where voucher specimens were required.

**Table 2** Species requiring the preservation of voucher specimens (or a photograph) for laboratory validation of IDs. These are in addition to those specified in Table 8.3 of MDBC (2008a)

| Species                          | Notes                                    |
|----------------------------------|--|
| <i>Anguilla australis</i>        | When < 150 mm.                           |
| <i>Anguilla reinhardtii</i>      | When < 150 mm.                           |
| <i>Craterocephalus marjoriae</i> |  |
| <i>Glossamia aprion</i>          |  |
| <i>Kuhlia rupestris</i>          |  |
| <i>Leiopotherapon unicolor</i>   | North coast only.                        |
| <i>Macquaria colonorum</i>       | Preserve if small – photograph if large. |
| <i>Mordacia praecox</i>          | Preserve both ammocoetes and adults.     |

| Species  | Notes   |
|--|---|
| <i>Prototroctes maraena</i>  | When < 100 mm.  |
| <i>Rhadinocentris ornatus</i>  |   |
| All estuarine fishes   | Preserve if small – photograph if large.                                |
| All forms of Gobiidae in all catchments  |   |
| All species from far-west catchments   |   |
| All species of Cyprinidae  | When < 50 mm.   |
| All species of Mugilidae   | When < 100 mm.  |
| All species of Plotosidae  | Darling/Paroo/Warrego/ Condamine-Culgoa/ Border Rivers catchments only. |
| All species of Salmonidae  | When < 100 mm.  |
| All species when collected outside their known natural range (including ornamental fishes) | Preserve if small – photograph if large                                 |

### 2.4.7 Biomass estimation

For those species listed in Table 3, biomass (weight) of each individual measured was estimated based on their length using derived length:weight relationship equations. For those species not listed in Table 3, individuals were weighed as well as measured and the measured weight was used to represent biomass.

**Table 3 Regression coefficients (*b*) and intercepts (*a*) in model.**

| Species                                 | <i>a</i> | <i>b</i> | N    | Minimum (mm) | Maximum (mm) | <i>r</i> <sup>2</sup> | Source      |
|---|----------|----------|------|--------------|--------------|-----------------------|-------------|
| <i>Anguilla australis</i>               | -6.9445  | 3.4632   | 107  | 32           | 1200         | 0.9815                | FFRD        |
| <i>Anguilla reinhardtii</i>             | -7.6576  | 3.811    | 153  | 100          | 1400         | 0.9638                | FFRD        |
| <i>Bidyanus bidyanus</i>                | -5.229   | 3.1615   | 309  |              |              | 0.995                 | MDBC (2004) |
| <i>Carassius auratus</i>                | -4.3294  | 2.9457   | 256  |              |              | 0.9863                | MDBC (2004) |
| <i>Craterocephalus</i>                  | -4.1892  | 2.4278   | 406  | 14           | 84           | 0.7596                | FFRD        |
| <i>Cyprinus carpio</i>                  | -4.5612  | 2.9394   | 5094 | 44           | 870          | 0.992                 | FFRD        |
| <i>Gadopsis bispinosus</i>              | -4.5985  | 2.7054   | 906  |              |              | 0.9925                | MDBC (2004) |
| <i>Galaxias brevipinnis</i>             | -5.6292  | 3.3145   | 109  | 37           | 196          | 0.9858                | FFRD        |
| <i>Galaxias maculatus</i>               | -5.466   | 3.0881   | 214  | 23           | 154          | 0.9327                | FFRD        |
| <i>Galaxias olidus</i>                  | -5.387   | 3.1513   | 112  | 41           | 121          | 0.8746                | FFRD        |
| <i>Gambusia holbrooki</i>               | -5.1854  | 3.1421   | 215  | 15           | 58           | 0.8504                | FFRD        |
| <i>Gobiomorphus australis</i>           | -5.597   | 3.3201   | 995  | 20           | 174          | 0.9771                | FFRD        |
| <i>Gobiomorphus coxii</i>               | -5.8237  | 3.3903   | 128  | 33           | 195          | 0.9652                | FFRD        |
| <i>Hypseleotris compressa</i>           | -5.6725  | 3.4099   | 129  | 35           | 100          | 0.9256                | FFRD        |
| <i>Hypseleotris spp</i>                 | -5.7476  | 3.6294   | 1948 |              |              | 0.8982                | MDBC (2004) |
| <i>Leiopotherapon unicolor</i>          | -4.2737  | 2.887    | 664  |              |              | 0.9457                | MDBC (2004) |
| <i>Maccullochella macquariensis</i>     | -5.1428  | 3.0953   | 1039 |              |              | 0.9902                | MDBC (2004) |
| <i>Maccullochella peelii</i>            | -5.234   | 3.1227   | 2077 |              |              | 0.9917                | MDBC (2004) |
| <i>Macquaria australasica</i> (eastern) | -4.9895  | 3.0787   | 200  | 48           | 269          | 0.9943                | FFRD        |
| <i>Macquaria australasica</i> (western) | -5.1026  | 3.072    | 138  | 49           | 380          | 0.9944                | FFRD        |

|                                   |         |        |     |    |     |        |               |
|-----------------------------------|---------|--------|-----|----|-----|--------|---------------|
| <i>Macquaria novemaculeata</i>    | -4.95   | 3.091  | 845 |    |     | 0.971  | Harris (1987) |
| <i>Melanotaenia fluviatilis</i>   | -4.6434 | 2.817  | 396 | 16 | 86  | 0.8943 | FFRD          |
| <i>Misgurnus anguillicaudatus</i> | -5.1021 | 2.9316 | 170 |    |     | 0.949  | MDBC (2004)   |
| <i>Mugil cephalus</i>             | -5.0215 | 3.0838 | 284 | 29 | 486 | 0.9962 | FFRD          |
| <i>Nannoperca australis</i>       | -4.6693 | 2.8748 | 103 | 27 | 65  | 0.9431 | FFRD          |
| <i>Nematalosa erebi</i>           | -5.2317 | 3.1961 | 784 |    |     | 0.9862 | MDBC (2004)   |
| <i>Oncorhynchus mykiss</i>        | -4.6787 | 2.9073 | 424 |    |     | 0.9749 | MDBC (2004)   |
| <i>Perca fluviatilis</i>          | -5.3735 | 3.2617 | 178 |    |     | 0.998  | MDBC (2004)   |
| <i>Philypnodon grandiceps</i>     | -4.8517 | 2.8671 | 124 | 21 | 101 | 0.9291 | FFRD          |
| <i>Philypnodon macrostomus</i>    | -4.7797 | 2.8002 | 155 | 22 | 93  | 0.765  | FFRD          |
| <i>Potamalosa richmondia</i>      | -5.9561 | 3.4685 | 198 | 96 | 404 | 0.9414 | FFRD          |
| <i>Retropinna semoni</i>          | -5.6923 | 3.4186 | 657 |    |     | 0.7711 | MDBC (2004)   |
| <i>Salmo trutta</i>               | -4.985  | 3.0304 | 228 |    |     | 0.9789 | MDBC (2004)   |

FFRD – NSW DPI Freshwater Fish Research Database data.

MDBC (2004) – Regression equation parameters reported in MDBC (2004).

**Note:** Regression coefficients (*b*) and intercepts (*a*) used to convert Log(length) to log(weight) using the formula  $\log(\text{weight}) = a + b \times \text{Log}(\text{length})$ . Weight was measured in grams and length in millimetres. *N* is the number of individuals used to develop the regression equation and  $r^2$  is the coefficient of determination of the relationship. Minimum and maximum sizes represent the smallest and largest fish used to develop the model.

## 2.4.8 Quality and data management

Following confirmation of the identity of those species where voucher specimens were collected, data were transferred from field data sheets into intermediate tables within a Microsoft Access database (the I&I NSW Freshwater Fish Research Database – FFRD) and the original datasheets stored in fire-proof safes. Data in intermediate tables were run through a series of 50 range-checks to identify any outliers and inconsistencies in data recording. All potential errors are referred to the senior operator responsible for data collection at that site for confirmation and/or correction. The corrected intermediate tables are then appended into the FFRD for storage. A level 3 data audit is also undertaken by the supervising scientist after each year's sampling in order to ensure compliance with sampling protocols.

## 2.4.9 Data analysis

### 2.4.9.1 Reference condition

To represent pre-colonisation condition of fish communities within each valley zone, the SRA adopted an approach of establishing or estimating the presence/absence and rarity (the probability of collecting a species at randomly selected sites if it were sampled using the SRA protocol prior to 1770) for each fish species within each valley zone, based on historical and current data, museum collections and expert knowledge (Davies *et al* 2008). For the SRA, rarity was scored as 1 (median probability of occurrence of 0.1), 3 (0.5) or 5 (0.85) and these values were termed the Reference Condition for Fish (*RC-F*). Those *RC-F* values derived for the SRA were used for Murray-Darling Basin valleys. A similar process was adopted to estimate *RC-F* values to represent reference condition for fish in coastal and far-west regions. However, within coastal regions an additional rarity score was added for species considered estuarine/marine vagrants with a probability of occurrence estimated as 0.01.

### 2.4.9.2 Metrics, indicators and the overall fish condition index.

Five fish metrics are derived from the raw data and are described by Davies *et al* (2008, Table 3.3-1). The *Nativeness Indicator (SR-F<sub>n</sub>)* represents the proportion of native versus alien fishes within the river and is calculated from three input metrics; proportion native biomass, proportion native abundance and proportion native species, combined using Nativeness Indicator Expert Rules (Davies *et al.* 2008 – Appendix 1). The *Expectedness Indicator (SR-F<sub>e</sub>)* represents the proportion of native species that historically occupied the river that are still present and is calculated by combining two input metrics; the observed native species richness (at sites) over the zones *RC-F* value corrected for rarity (*OE*)<sup>2</sup> and the total native species rich within zones over the zones uncorrected *RC-F (OP)* using Expectedness Indicator Expert Rules (Davies *et al* 2008 – Appendix 1). These two indicators are then combined using Index Expert Rules (Davies *et al* 2008 – Appendix 1) to calculate an overall fish condition index (*SR-F<sub>i</sub>*). Expert Rules analysis was undertaken using the Fuzzy Logic toolbox in MatLab (The Mathworks Inc. USA). The same indicator and index rule sets were used across all valleys.

The zone score for each indicator and the overall index was estimated using the median metric scores for sites in each zone, with the exception of *OP* which is derived at the zone scale. The valley and CMA scale metrics were estimated as the mean of the median zone metrics weighted by stream length within each zone. These valley and CMA scale metrics were then processed using the Indicator and Index Expert Rules to produce the valley and CMA scale Indicators and the overall *SR-F<sub>i</sub>* index.

An incorporation of 95% confidence intervals was used for each metric, indicator and index following 2000 bootstrap iterations (with replacement).

All indicator and index scores produced by the Expert Rules are scaled between 0 – 100 where 100 represents reference condition. A low score represents the loss of native species diversity and the dominance of alien fish. Descriptive labels associated with ‘bands’ of indicator and index scores are defined in Davies *et al.* (2008) as: 0 - 19 Extremely Poor, 20 – 39 Very Poor, 40 – 59 Poor, 60 – 79 Moderate and 80 – 100 Good.

## 2.5 Hydrologic condition

### 2.5.1 Inland catchments

The Office of Water adopted the Sustainable River Audit (SRA) set of Hydrologic Indicators developed by Sinclair Knight Merz (SKM) for the Victorian Government. The development of the indicators is documented in the report ‘Development and Application of a Flow Stressed Ranking Procedure’ (Nathan *et al* 2005). The SRA calculated hydrologic indicators for all the Murray-Darling Basin catchments of NSW. The SRA approach was to derive indicators by comparing observed (current development) to expected (or reference) flow sequences. These indicators were generated from the Office of Water Integrated Quantity and Quality Model (IQQM) model data comparing reference modelled flows (an estimation of natural flows not including catchment impacts: eg clearing, forestry, and small farm dams) to current development modelled flow sequences. This approach used monthly data as other jurisdictions were not able to supply daily modelled data.

Sites were selected from within the IQQM models to represent the streamflows of the various river systems. The models are node link models and subsequently are limited in the locations that can be selected. Generally, locations in the models that represent gauging station sites were selected in the in various altitude zones for each of the major river systems.

<sup>2</sup> The definition of the OE metric in Davies *et al.* (2008) is inaccurate and we referred to the definition of the OE metric in MDBC (2004, Table 14)

The five SRA Hydrology Indicators include:

- 1 A High Flow Event Indicator – that is a high flow metric derived from comparing the changes in magnitude of high flow events between the current development and reference flow sequences;
- 2 A Low & Zero Flow Event Indicator – that is a combination the low flow and zero flow metrics derived from comparing the changes in magnitude of low and frequency of zero flow events between the current development and reference flow sequences;
- 3 A Flow Variability Indicator – that is a variability flow metric derived from comparing the changes in coefficient of variation between the current development and reference flow sequences;
- 4 A Seasonality Indicator – that is a seasonality flow metric derived from comparing the changes in timing of minimum and maximum flows between the current development and reference flow sequences, and
- 5 A Gross Volume Indicator - a combination the average annual discharge and median annual discharge metric derived from comparing the changes in these statistics between the current development and reference flow sequences.

Some results for individual site were presented in the *Murray-Darling Basin Rivers: Ecosystem Health Check, 2004–2007* (MDBC, 2008b) showing the five indicators derived for some sites, allowing the type of hydrology modification to be viewed. More detailed results are presented in ‘SRA Report 1’ (Davies *et al* 2008).

These individual site indicators are combined to derive an overall hydrology condition for each of the altitude zones in each of the major catchments. The individual site indicators are weighted by stream length when combined. The method for calculating the indicators and the process to combining them into an overall Indicator is presented in *SRA Report 1* (Davies *et al* 2008).

The overall hydrology condition for the Catchment Management Authority (CMA) areas was assessed by averaging the SRA overall hydrology condition ratings. In some cases the CMA have the same boundary as a single catchment, hence the SRA’s condition rating is the same as the State of the Catchments (SoC) hydrology condition. In other cases where the CMA covered more than one catchment the SRA’s condition rating was averaged.

## 2.5.2 Coastal catchments with models

The coastal catchment assessment aimed at being consistent with the SRA hydrologic indicators calculated for the inland, especially in the ten largest coastal catchments in NSW, which cover 83% of the coastal catchment area (not including the Snowy or Genoa). This was not possible in the Clarence, Macleay, and Hastings River systems. This is because there are no IQQM models developed for the Macleay and Hastings River systems, and in the case of the Clarence the existing model needs to be updated to represent current levels of development.

Sites were selected from within the IQQM models to represent the streamflows of the various river systems. These locations were gauging station sites in the various altitude zones for each of the river systems. Not all altitude zones were represented in the models, meaning that there was no data to evaluate the condition of the hydrology. In some streams this could be addressed as there was no human interference of streamflow and measured sequences at a gauging station represented both current development and natural flows.

Models were available for a number of the coastal catchments, but the durations over which the models ran varied considerably. The catchments modelled and the periods simulated are presented in Table 4.

**Table 4 Modelled River Systems and the Duration of Simulations**

| River System with IQQM model   |                              | Duration of simulation |
|--------------------------------|------------------------------|------------------------|
| Bega River System              | Brogo Bega Reg model         | 1890 – 2007            |
|                                | Bemboka Bega Unreg model     | 1890 – 2001            |
| Hawkesbury-Nepean River System |                              | 1909 – 2003            |
| Hunter River System            | Hunter River Reg model       | 1892 – 1995            |
|                                | Williams River Unreg model   | 1932 – 1999            |
|                                | Paterson River Reg model     | 1940 – 1992            |
| Karuah River System            |                              | 1945 – 1999            |
| Manning River System           | Manning River model          | 1962 – 2000            |
|                                | Gloucester River model       | 1945 – 2004            |
| Richmond River System          |                              | 1892 – 2002            |
| Shoalhaven River System        | Lower Shoalhaven River model | 1909 – 1999            |
|                                | Kangaroo River lump model    | 1903 – 1992            |
| Tweed River System             |                              | 1892 – 2004            |

The overall hydrology index derived using the SRA method for each site was used to classify the condition of the hydrology in the altitude zones. Similarly the overall hydrology condition for the CMA areas was also derived from the overall hydrology index derived using the SRA method. The modelled coastal sites were all in good condition except for the modelled sites in the Hawkesbury-Nepean catchment and subsequently averaging gave a classification of 'good' in most cases. In the Hawkesbury-Nepean catchment averaging was not appropriate as there were no sites modelled in the higher altitude zones. The upper sites would likely be in good condition and subsequently the dominate classification was indicated.

## 2.5.3 Coastal catchments without models

### 2.5.3.1 Selecting an alternative hydrologic indicator

Only eight river systems of the 189 estuarine coastal river systems have IQQM models developed to simulate their flow. Along the NSW coast there is presently 756,000 ML of *Water Act (WA 1912)* entitlement and 620,000 ML of *Water Management Act (WMA, 2000)* entitlement. Virtually all of this entitlement is located in the estuarine catchments. Only 443ML is scattered along the coast outside the 189 estuary catchments, in very small coastal water bodies that do not included an estuary (eg: gullies that run over cliffs into the sea, and small freshwater lagoons that do not connect to the ocean). The majority of the coastal catchments are unregulated. Only three catchments (Hunter, Bega, and Richmond) have reaches with regulated flows that improve water supply reliability to multiple extractors along the regulated reaches of river. Although, there are many other structures (dams, weirs, and discharge works) used for Urban Water Supply, Waste Water Treatment, and Power Generation controlling flows on rivers categorised as unregulated.

In the remaining 181 coastal systems, an alternative hydrology indicator has been adopted for the SoC reporting. This is an indicator of the pressure on the instream habitat associated with extraction of water from the river systems.

Daily hydrologic indicators (a measure of impacts on daily flow) have been developed twice prior to this initiative for all of NSW unregulated rivers. For a high majority of coastal unregulated rivers the main problem is the drying out of the rivers during low flow periods, and hence the past hydrologic

indicators have focused on the loss of low flows. The Stressed River Approach (DLWC, 1998) produced four low flow hydrologic indicators for unregulated river consistent across the State. The Macro Water Sharing Plan (WSP) Planning Approach (DNR, 2006) produced a low flow hydrologic indicator for potential impact which was consistent only within planning regions. Both of these indicators estimate daily flow and compared them to daily demands for extraction. Neither of these indicators were used – the Stressed River Approach indicator, as the data used was out of date, and the Macro Planning Approach indicator, because it was not consistent across the State.

Another alternative that was evaluated was a study, 'State-wide modelling of natural flow and upstream water allocations' (Stein *et al* 2007), which estimated annual flows and compared this to annual entitlement. A number of indicators were derived comparing Annual Entitlement to various annual flows. One of these indicators was the proportion of a low flow year that the Annual Entitlement makes up (equation 1). Unlike the Stressed River Approach and Macro daily indicators, which calculate indicators for sub-catchments, it used a geographic information system (GIS) approach to provide a much more distributed indicator along the river system. While the results of this study could not be used a similar approach was developed.

For the remaining 181 coastal catchments, and the NSW parts of the Snowy and Genoa river systems, a similar approach to the Stein *et al* (2007) hydrologic indicator has been adopted, with the intention of improving the entitlement totals and the estimates of annual flows. The indicator is the proportion of entitlement that makes up in the estimated 90<sup>th</sup> exceedance percentile annual flow (equation 1). This indicator is being used for each individual estuary catchment to complement the Estuary Theme SoC reporting. Unlike the Stein *et al* (2007) approach the indicator is for the whole catchment and is not distributed to individual reaches of river.

$$\text{Equation 1} \quad \dots\dots\dots \text{Hydro Indicator} = \frac{(\text{Annual Entitlement})}{(90^{\text{th}} \text{ annual exceedance percentile})}$$

This indicator reflects the level of potential development in the catchment and infers the potential implications for low flows if there are no major instream structures. That there are no major instream structures is a reasonable assumption in a high proportion of the estuary river system that does not have IQQM models. The Clarence River System is an exception to this; hence hydrology indicators were not derived.

This indicator has its limitations. In small catchments even farm dam development may be considered major structures. This may be the case in Tilba Tilba Lake catchment (on the south coast). Although the amount of entitlement often reflects the level of dam development this is not always the case as not all dams require a licence or entitlement. Secondly, the amount of entitlement in an area may not reflect the level of current water extraction as the proportion of inactive entitlement varies as rural practices/industries change over time. Also, the annual patterns of extraction are also not reflected in this type of indicator as town water supply has a much more consistent pattern of use to that of summer cropping.

### 2.5.3.2 Determining catchment entitlement totals

There are 11,600 surface water licences in NSW coastal catchments. Of these 8,500 are *Water Act (1912)* licences and 3,100 *Water Management Act 2000* licences (Note, five of these licences are for Major Water Utilities which are not administered through the main licensing database). There are further licences in areas such as Tidal Pools (tidal reaches of river where fresh water persists for long periods e.g. in the Hunter and Richmond) where extractions have yet to be licensed, and highly connected alluvial aquifers (e.g. in the western Hunter) where the groundwater licences have yet to be linked to the rivers, that should also be considered when they can be defined.

Many of the 11,600 coastal licences are decades old and were licensed prior to the geographic tools that are now used as a matter of course (Global Positioning Systems (GPS), GIS). And hence, geographic information collected at the time included map forms in paper on files, and Catchment Codes (as stream numbering system for named rivers and creeks). Transferring this information into the GIS layers is onerous and while most licences are located correctly in the GIS layer there are still some licences with incorrect coordinates, hence the GIS layer can not be relied on for the most accurate information. Improving the coordinates of these licences is being addressed when a licence is being processed as part of another administrative task.

Although the GIS layer has these limitations the total entitlement in each estuary catchment can be derived more accurately using these tools. Cross referencing with the catchment codes enables the geographic location of the *Water Act 1912* licences to be checked and corrected. This technique is able to check 99 per cent of the licence locations, but the GIS layer is necessary for some of the licences on unnamed watercourses.

The *Water Management Act, 2000* Water Access Licenses (WAL) are linked to water sources, and hence these entitlements can be totalled for sub-catchments without the use of coordinates. The Major Water Utility licences have to be assessed individually as the licences are not part of the License Administration System (LAS) database.

### 2.5.3.3 Estimating catchment annual flow duration curves

This indicator, as mentioned earlier, is the same as that used by Stein *et al* (2007), but with improved entitlement figures and improved estimates of annual flows. The annual flows estimates by Stein *et al* (2007) when compared to measured flow (only eight locations along the coast), were found to underestimate the median and low flow years. The underestimation was more significant in the south of the State than in the north of the State.

In conjunction with the Estuary Theme SoC reporting another GIS based modelling package, 2CSalt, was used to estimate monthly flows for each of the estuary catchments. Estimated flows were compared to measured flows at 78 gauging stations along the coast. The correlation of the monthly flows was not high with 80 per cent of the modelled monthly sequences giving a coefficient of determination ( $R^2$ ) greater than 0.75. This meant that a monthly indicator, such as those used in the SRA method could not be adopted, and an annual indicator was necessary. This modelling, like the Stein *et al* (2007) modelling, also underestimated annual flows so regional scaling factors were used to increase the flows to improve the coefficient of determination of the estimated 90<sup>th</sup> exceedance percentile annual flow volume.

### 2.5.3.4 Hydrology condition classification

Hydrology condition for the unmodelled rivers is significantly different to those with models. The index, proportion of a dry year's flow (90<sup>th</sup> percentile of yearly volumes exceeded e.g. 90 per cent of years wetter and 10 per cent dryer) issued as water entitlement for extraction, can not be directly compared to the SRA indicator (derived from eight indices). While a direct comparison can not be made, the entitlement to annual 90<sup>th</sup> percentile flow index will in many cases reflect the SRA Gross Volume Indicator (derived from the change in annual mean and median flow) and the Low and Zero Flow Event Indicator, where higher entitlement levels usually result in high pressure on the low flows on unregulated rivers. In unregulated rivers it could be expected to see adopted indicator of unmodelled rivers reflected in the SRA Gross Volume indicator and Low Flow Indicator.

The following levels of entitlement were adopted for classification in unmodelled coastal catchments:

- where less than 10 per cent of a river's flow in a dry year is issued as entitlement the hydrology is in good condition

- where less than 30 per cent of a river's flow in a dry year is issued as entitlement extraction is still sustainable and the hydrology is in moderate condition.
- Where more than 50 per cent of a river's flow in a dry year is issued as entitlement extraction the hydrology is in very poor condition, keeping in mind that majority of the annual extraction would be in high demand periods (i.e. summer) when flow is low and cease to pump conditions, where they exist, would come into force.

The classifications are summarised in Table 5.

**Table 5 Classification outcomes for unmodelled coastal catchments**

| Levels of Entitlement   | Classification Outcomes |
|-------------------------|-------------------------|
| Entitlement < 10%       | Good                    |
| 10% > entitlement > 30% | Moderate                |
| 30% > entitlement > 50% | Poor                    |
| 50% > entitlement > 75% | Very poor               |
| Entitlement > 75%       | Extremely poor          |

The indicator was calculated for each of 179 unmodelled estuary catchments, as well as sub-catchments of the Hasting and Macleay Rivers systems due to their large size. The indicator for each of the 179 estuary catchments are not present separately in the reports. They are rolled up to the larger scale Australian Water Resource Council Basin areas (NLWRA 2001), which in some cases included many small coastal catchments and in other cases included a larger river system and a number of smaller ones. So that the indicator for the larger basin area was not biased by the smaller estuary catchments they were weighted by the areas of the catchments. In the Hasting and Macleay Catchments the sub-catchment Indicators were used. The overall hydrology condition for the CMA regions were assessed by averaging the classifications given to the Australian Water Resource Council Basin and sub-catchments.

#### 2.5.3.5 Presentation of results

The results were presented graphically on the maps in each of the 13 riverine ecosystems report cards. While the Hydrology Condition classifications for both the modelled and unmodelled areas are presented on the same map using the same classifications and colours they are distinguished by hatching of the unmodelled areas. The two methods cannot be directly compared as they are significantly different although they are both reasonable indicators of hydrology condition.

The unmodelled areas (hatched areas in the report card maps) are presented in the Australian Water Resource Council Basins all the way along the coast except for the three largest unmodelled catchments. Two of these, the Hasting and Macleay Catchments were broken into sub-catchment. The Clarence River system which has significant infrastructure within it was not classified.

The modelled catchments (not hatched) were broken into altitude zones, consistent with the inland rivers, and classification shown using the same colour scheme. In altitude zones where there were no modelled sites no colour is shown.

### 3. Potential future directions for the riverine ecosystems theme

Further developments of the methods to define riverine ecosystem condition will progress in the coming years. The Office of Water will build on a more collaborative framework to try and integrate the indicators into a single index of riverine condition. The Office of Water has been working with the Natural Resources Commission and CMAs to develop spatial products to assist in better aligning catchment and water planning through common values and risk (Hamstead in press) to assist in prioritising investment. Through this method (Hamstead in press) a River Condition Index using the Framework for Assessment of Riverine and Wetland Health (FARWH) was developed. Through review of this project and this first iteration of the SoC Reporting, the next iteration of the NSW MER Strategy should lead to an improved integrated assessment of riverine condition. This will be a collaborative effort with DECCW and I&I NSW. There are also other options that may be considered such as the development of a process similar to the 'expert rules' process used by the SRA (Davies *et al* 2008), to apportion river condition scores to whole regions in coastal regions. The details below provide an indication of the future activities to help refine methods and assessments for each of the key attributes listed in this report.

#### 3.1 Water quality

- The Office of Water is in the process of developing regional water quality management guidelines and /or targets for NSW. These will be developed in consultation with key stakeholders, primarily to provide appropriate measures against which to report riverine ecosystem condition using ambient water quality indicators and may include development of appropriate reference water quality. This work will continue into a stakeholder consultation phase during 2010-2011.
- Water Quality trend analysis should be repeated every 3-5 years.
- Further development is required to model turbidity trend as it generally performed poorly in this report.
- The Office of Water is continuing to consider technical advancements in water quality monitoring and is adding analytes to its state-wide water quality monitoring program in order to better measure condition into the future.

#### 3.2 Macroinvertebrates

The macroinvertebrate assessments are likely to continue with very substantial improvements.

The monitoring of river health in the Murray-Darling Basin in its current form is planned to continue until the end of autumn 2010. Monitoring in the eastern catchments will continue into the foreseeable future.

The rigours and reliability of the assessments are likely to be improved substantially before the next reporting period for the following reasons:

1. New AUSRIVAS predictive models will be developed for the entire state using a large volume of data collected for the SRA and CSRA programs. These models will be more reliable and relevant because
  - they will use reference site macroinvertebrate data that are more recent and of better quality than those used in the current AUSRIVAS models
  - the selection of reference sites will be done more objectively using catchment and local disturbance indices estimated consistently across the State

- estimates for predictor variables will be less subjective and more accurate because they will be derived using advanced remote sensing and GIS methods
  - the reference site data collected will be of higher quality and more relevant because the old data collected when the methods and protocols were still being developed will be replaced with more recent data collected using refined protocols and better trained operators
  - The State wide – AUSRIVAS models will be replaced with regional models, which are likely to have greater accuracy in predicting the composition of macroinvertebrate assemblages at river sites
2. Rigorous comparative analyses will be performed on assessments based on a number of different methods. For these analyses the filters method currently used only in the MDB will be adapted to assess eastern rivers and the regression modelling approach used in the spatial extrapolation of AUSRIVAS O/E values will be applied to the MDB rivers.
  3. The River Disturbance Index (RDI) will be revised and modified to improve its usefulness for assessing the effect of human induced disturbances on river macroinvertebrates. This will include using a much larger number of land use classes than is currently used, introducing a decay factor in calculating cumulative impacts, incorporating the effect of downstream disturbance (e.g. instream barriers), and a specific measure of disturbance in the riparian zone. Primary disturbance data underpinning the CDI will also be updated which will mean substantial improvements in data quality as well as closing major spatial gaps in existing datasets.
  4. New and more accurate methods will be used to extrapolate spot measurements to entire river networks. This will most likely be done by replacing the regression modelling with geostatistical analysis methods.

### 3.3 Fish

Sampling within the Northern Rivers CMA area and the far-western catchments (non MDB) of the Western CMA will be undertaken in 2009. This will achieve complete state-wide coverage of freshwater fish monitoring.

The fish monitoring program requires further development of:

1. the reference condition values (*RC-F*) for coastal and far-west catchments need to be further refined following compilation of additional historical data and expert peer review
2. power analyses and assessment of performance curves of data collected from the initial round of sampling in coastal catchments are required to assess whether the minimum site number criteria per CMA altitude zone and valley (section 2.4.2) are sufficient
3. a third indicator, representing recruitment, should be integrated into the overall Fish Index. Recruitment metrics that can be derived from existing data need to be developed and applied across all CMA areas
4. data on the relative catch efficiency of backpack versus boat electrofishing methods need to be collected in order to validate the assumption that the two methods represent a consistent amount of sampling effort and that the resultant metrics, indicators and index are directly comparable
5. stratification of sites into additional 'stream-size' categories may improve the resolution of the condition assessments.

## 3.4 Hydrology

Hydrology condition reporting for the SoC is linked to hydrology assessment for a range of initiatives, with Water Sharing Plan (WSP) performance monitoring being the most extensive of the Office of Water's reporting and evaluation responsibilities. Significant efficiency can be realised through rolling up performance monitoring of WSP to provide the SoC reporting and other reporting requirements. Future changes to how hydrologic condition is reported will need to consider the following:

1. On many unregulated rivers the major hydrologic impacts are on the low flows. On the coast, and some inland streams, where many unregulated rivers flow quite persistently the rivers provide irrigation water during the dry periods for direct irrigation from the river. The ecology in these streams is adapted to continuous flowing water and is generally more impacted by lack of flow than the ecology of ephemeral flowing streams. In these periods of high demand for water, often less than a month in duration, the stream flow can stop if cease to pump conditions have not been established. Therefore using daily flow sequences, rather than monthly, when deriving the SRA Low Flow Indicator, is required to pick up on these high impact periods. This may be more significant for the coastal Low Flow Indicator, but should be pursued for all rivers and all indicators.
2. Selecting sites in altitude zones poses considerable problems for the hydrology indicators. The reason for this is that current models have limited locations within them where sequences can be accurately provided. Another aspect to this is that rivers have distinct location where the hydrologic impacts are most critical (e.g. below dams) and other locations where the impact is cumulative (e.g. the end of system) making the number of sites that would need to be selected randomly to represent an altitude zone significantly large. And hence, the number of sites required to make a random selection process valid is not possible. Possibly, selection of critical sites, and/or subjective selected representative sites, may be the only practical options available. Certainly the use of the same sites each time will provide the ability to compare trends of indicators over time.
3. The need to simulate hydrology in unregulated Water Sources that have been developed for water sharing across the State may need to be reflected through incorporating them into current IQQM models. Often small lump models are used to simulated head water unregulated Water Sources which form the inflows to regulated rivers. The ability to compile the two types of models may provide efficiencies (e.g. using the same stream flow sequences, assessing the implication of the unregulated rules on the regulated rivers). Note, the unregulated Water Sources are already reflected in the regulated IQQM models where it is practical and there may be no efficiency in changing regulated models if it made the models onerously more complicated and/or increase uncertainty through additional assumptions.
4. There is little additional information to be gained in developing new hydrological indicators/indices in any of the unregulated streams until water use monitoring results are available. The SoC indicators used here as well as the Stressed River Approach indices and the Macro hydrologic stress index certainly provide valuable information. To progress from these indices requires measured extraction otherwise it would be presenting the same information in a different form.
5. The hydrologic stressors on the coastal rivers are not as great in flow terms, but potentially they are still significant ecologically. On a different but related topic, strategic decision making along the coast suffers from limited modelling which leads to locally made decisions, often due to inadequate regional understanding of Water Resources. Improved maintenance of coastal IQQM models may help in improving strategic water related decisions.

More multi-reach models and lump models can be developed for the larger coastal rivers, but it is not practical to model all the 189 coastal rivers/streams. Future approaches for unmodelled catchments should see indicators derived at the Water Source level or estuary catchment scale which ever is the smaller. Greater evaluation needs to incorporate the level of low flow protection, fresh protection and high flows protection (presence of cease to pump (CtP) and daily rules, compliance with daily rules) provided by current and future WSPs. Possibly deriving new surrogate indicators for each of the five SRA hydrologic indicators for the unmodelled rivers may include for example:

- daily demand comparison to 80<sup>th</sup> percentile and assessment of change in cease to flow days equivalent to Low Flow Indicator
- annual metered extraction comparison to 90<sup>th</sup> annual flow percentile equivalent to Gross Volume Indicator
- presence of large dam capacity and/or large pump capacity equivalent to High Flow Indicator,

with seasonality and variability generally not a issue on these unmodelled rivers.

## 4. References

- ANZECC & ARMCANZ (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy, Paper No 4. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra. ISBN 09578245 0 5.  
[http://www.mincos.gov.au/publications/australian\\_and\\_new\\_zealand\\_guidelines\\_for\\_fresh\\_and\\_marine\\_water\\_quality](http://www.mincos.gov.au/publications/australian_and_new_zealand_guidelines_for_fresh_and_marine_water_quality)
- Beyer, H. L. (2004). Hawth's Analysis Tools for ArcGIS. Available at:  
<http://www.spatial ecology.com/htools>.
- Davies, P.E., Harris, J.H., Hillman, T.J., Walker, K.F. (2008). SRA Report 1: A Report on the Ecological Health of Rivers in the Murray–Darling Basin, 2004–2007. Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council. MDBC Publication No. 16/08.
- DLWC. (1998). Stressed Rivers Assessment Report NSW State Summary. NSW Department of Land and Water Conservation. pp 52. ISBN 0 7313 0363 6
- DNR. (2006). Macro water sharing plans The approach for unregulated rivers. NSW Department of Natural Resources. pp 56. ISBN 0 7347 5668 2
- Gippel, C.J. (2007). Scoping document: Stocktake of river health protocols. Fluvial Systems Pty Ltd, Stockton. Water Quality & River Health Section, Department of the Environment and Water Resources, Canberra.
- Hamstead, M. (in press). Alignment of water planning and catchment planning. Waterlines report, National Water Commission, Canberra.
- Harris, J.H. and Gehrke, P.C. (1997). Fish and Rivers in Stress: The NSW Rivers Survey. NSW Fisheries, Cronulla.
- Harvey, F., Koen, T., Miller, L.M., McGeoch, S.J., (2009). *2006 Stream EC trends for inland New South Wales*. Department of Environment and Climate Change (formerly the Department of Natural Resources) DECC 2009/55. ISBN 978 1 74122 870 0.
- Krogh, M., Wright, A. and Miller, J. (2008). Hawkesbury Nepean River Environmental Monitoring Program. Final Technical Report. Waters & Coastal Science Section, Scientific Services Division, Department of Environment & Climate Change.
- MDBC (2004). Fish Theme Pilot Audit Technical Report – Sustainable Rivers Audit. Murray–Darling Basin Commission, publication number 06/04, Canberra.
- MDBC (2008a). Sustainable Rivers Audit Protocols: Approved manual for Implementation Period 5: 2008-09. Murray-Darling Basin Commission, Canberra.
- MDBC. (2008b). Murray–Darling Basin Rivers: Ecosystem Health Check, 2004–2007. A summary report based on the Independent Sustainable Rivers Audit Group's SRA Report 1: A Report on the Ecological Health of Rivers in the Murray–Darling Basin, 2004–2007'. Murray–Darling Basin Ministerial Council. pp 69. MDBC Publication No. 19/08
- Muschal, M., Harvey, F., McGeoch, S., Mawhinney, W. and Ryan, D. (In Prep). *Evaluation of water quality data and historical trends in New South Wales, Australia*. NSW Office of Water.
- Nathan, R., Morden, R., Lowe, L., and Austin, K. (2005). Development and Application of a Flow Stressed Ranking Procedure. Sinclair Knight Merz. pp 149. Project number: WC02795. Commissioned by Victorian Department of Sustainability and Environment
- NLWRA (2001) Australian Water Resources 2000: Surface water and groundwater, availability and quality. National Land and Water resources Audit. Land & Water Australia, Canberra. Australian Natural Resources Atlas.  
<http://www.anra.gov.au/topics/water/overview/index.html>

- NLWRA (2002). Australian Catchment, River and Estuary Assessment 2002, Volumes 1 and 2. National Land and Water Resources Audit, Natural Heritage Trust. Australian Natural Resources Atlas V2.0. Land & Water Australia. Department for the Environment and Heritage. Commonwealth of Australia, Canberra.
- Norris, R. H., Dyer, F., Hairsine, P., Kennard, M., Linke, S., Merrin, L., Read, A., Robinson, W., Ryan, C., Wilkinson, S. and Williams, D. (2007). Australian Water Resources 2005. A baseline assessment of water resources for the National Water Initiative Level 2 Assessment River and Wetland Health Theme Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands. National Water Commission, Canberra.
- NRMMC (2003) The National Land and Water Resources Audit developed a National Monitoring and Evaluation Framework for natural resource management that covered broad thematic areas or 'Matters for Target', with the aim of co-ordinating indicators and sampling protocols across jurisdictions (<http://lwa.gov.au/products>).
- NRC (2005). Recommendations. State-wide Standard and Targets. Natural Resources Commission: Sydney.
- NRECG (2006). NSW Natural Resources Monitoring, Evaluation and Reporting Strategy. NSW Natural Resources and Environment CEO Cluster Group.
- NSW Premier's Department (2006). State Plan. NSW Government. <http://www.nsw.gov.au/stateplan>
- NSW Department of Premier and Cabinet (2010). Investing in a Better Future: NSW State Plan March 2010. <http://www.nsw.gov.au/stateplan>
- NSW government water information website <http://waterinfo.nsw.gov.au/>.
- Muschal, M., Harvey, F., McGeoch, S., Mawhinney, W. and Ryan, D. In Prep. *Evaluation of historical data and historical trends in New South Wales, Australia*. Department of Water and Energy technical report.
- Stein J.L., Stein J.A. & Nix H.A. (2002) Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia *Landscape and Urban Planning*, 60, 1-25.
- Stein, J.L., Hutchinson, M.F., and Stein, J.A.. (2007). Statewide modelling of natural flow and upstream water allocations. Australian National University. pp 15. Water Resources Division, NSW Department of Natural Resources.
- Stein, J. L., Hutchinson, M. F. and Stein, J. A. (2008a) Appendix 7. Development of a continent-wide spatial framework. In Pusey, B. J., Kennard, M. J., Stein, J. L., Olden, J. D., Mackay, S. J., Hutchinson, M. F. and Sheldon, F. (Eds.) *Ecohydrological regionalisation of Australia: a tool for management and science*. Innovations Project GRU36, Final Report to Land and Water Australia.
- Stein, J. L., Hutchinson, M. F., Pusey, B. J. and Kennard, M. J. (2008b) Appendix 8. Ecohydrological classification based on landscape and climate data. In Pusey, B. J., Kennard, M. J., Stein, J. L., Olden, J. D., Mackay, S. J., Hutchinson, M. F. and Sheldon, F. (Eds.) *Ecohydrological regionalisation of Australia: a tool for management and science*. Innovations Project GRU36, Final Report to Land and Water Australia. (describes the calculation of the catchment water balance)
- Sydney Catchment Authority (2008) Annual Water Quality Monitoring Report 2007-08.
- Sydney Water Corporation (2008) Receiving Water Quality of Sydney's Inland and Coastal Waterways. Performance Assessment Monitoring Program: Data Report 2007-08. Sydney Water Corporation.
- Turak E. (2007) An Ecological Typology of the Rivers of New South Wales, Australia. PhD thesis. University of Technology Sydney, NSW Australia.
- Turak E., Hose G., & Waddell N. (2002) Australia-wide assessment of River Health: New South Wales Bioassessment Report (NSW Final Report), Monitoring River Health Initiative Technical

- Report no 2a. Commonwealth of Australia and NSW Environment Protection Authority, Canberra and Sydney.  
<http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/nsw/index.html>(last accessed 24 June 2009)
- Turak, E., Waddell, N. and Johnstone, G. (2004) *New South Wales (NSW) Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual 2004*. Department of Environment and Conservation (NSW), Sydney.
- Turak E. & Koop K. (2008) A multi-attribute ecological river typology for assessing river condition and conservation planning. *Hydrobiologia*, 603, 83-104.
- Turak E., Ferrier, S., Barrett, T., Mesley E., Drielsma M. Manion, G., Doyle, G. and Stein J.(In review) Planning for persistence of river biodiversity: exploring alternative futures using process-based scenario modelling. *Freshwater Biology*.
- Whittington, J. (2002) *Assessing River Condition Using Existing Data - River management Series Part 2*, CRCFE, Canberra.