Lake Eyre Basin Rivers Assessment Implementation Plan Project

Milestone 2 Report: Proposed LEB Rivers Assessment Methodology

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RESEARCH WITHOUT BOUNDS
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LAKE EYRE BASIN
MINISTERIAL FORUM

ABOUT KIRI-GANAI RESEARCH

Kiri-ganai Research Pty Ltd is a Canberra based company that undertakes consultancy and analytical studies concerned with environmental policy, industry performance, natural resource management and sustainable agriculture. Our strength is in turning knowledge gained from public policy, markets, business operations, science, and research into ideas, options, strategies and response plans for industries, governments, communities and businesses.

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Project team

The LEB River Assessment Implementation Plan Project is managed by Kiri-ganai Research Pty Ltd. The project team comprises Dr Richard Price, Professor Martin Thoms and Dr Samantha Capon. Doug Watkins contributed to the “pressure’ indicators section.

Acknowledgements

The project team gratefully acknowledges the many individuals who are giving their valuable time, insight and knowledge during meetings with the consultants as this project progresses. We have been impressed by the professionalism of all the people that we have met and spoken to so far, and we trust that their passion and commitment to achieving a positive contribution to the Lake Eyre Basin is reflected in this report.

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Overview

What we say

This is the second report covering a series of steps leading to the development of an implementation plan for resource assessments in the Lake Eyre Basin. Like the first report, this report covers the technical aspects of the resource assessment methodology. Future reports will focus on governance and business planning to support effective assessments.

As reported previously, Kiri-ganai Research found the resource assessment process in the Lake Eyre Basin indeed required improvement, as had been flagged by the Basin's Scientific Advisory Panel. The agreed method established in 2005 was not used in the assessment undertaken in 2008. Neither the original method nor the subsequent method adopted were designed to provide a comprehensive landscape scale assessment of the Lake Eyre Basin, and although supplemented with a socio-economic study undertaken separately, a comprehensive understanding of the Basin's condition is yet to emerge.

This report considers the efficacy of the current assessment process and makes suggestions as to its improvement. Agreement on the purpose, nature and constituent activities of the assessment is a fundamental precursor to establishing the governance principles and arrangement to enable effective assessments to be undertaken. Form must follow function if governance arrangements are to have a legitimate role and work effectively. It is because of this that this report represents the critical point at which agreement on function (the assessment process) must be reached.

A proposed assessment process is dealt with in two complementary ways. The report makes recommendations on the indicators to be used in future assessments that provide a more comprehensive understanding of Basin-wide condition. However, the report also proposes a strategic adaptive approach to monitoring and the management of the natural resources of the Lake Eyre Basin based around the concept of thresholds of probable concern (TCPs).

Many river health issues are directly related to the connectivity between rivers and their catchments, floodplains and wetlands; therefore working at the landscape scale is a suitable means of gaining a proper understanding of condition. No single indicator alone is best and a synthetic approach that adopts a group of relevant metrics may prove most effective. It is the variability and complexity of environmental processes at multiple spatial and temporal scales in response to a range of disturbances that needs to be captured in a management and monitoring programme for the Lake Eyre Basin. While this may seem daunting, frameworks exist for incorporating such characteristics into management and monitoring programmes.

Essentially the original approach taken for the recommended Lake Eyre Basin Rivers Assessment was a trend based assessment. As suggested, the challenges to this are in not only selecting appropriate indicators but also in incorporating the enhanced spatial and temporal variations in natural "condition" that are evident across the Lake Eyre Basin. At any one point in time, natural variations in flooding and rainfall will mean sections will naturally be in "good" condition while others are in "poor" condition. Therefore a traditional trend assessment may not be appropriate to the Lake Eyre Basin because of the length of time required in data collection to construct statistical relevant trends.

What we recommend

In progressing to the next stages of this project, which deal directly with the implementation plan and governance arrangements covering future assessments (Milestones 3 and 4), Kiri-ganai Research makes the following recommendations:

i. A revised LEB assessment method should be agreed to be based around whole-of-Basin condition, in line with the terms of the LEB Intergovernmental Agreement. An outline of such a method is provided in this report. Six components are considered to be able to monitored immediately; these being physical habitat, fish, water birds and riparian vegetation.

ii. It is the variability and complexity of environmental processes at multiple spatial and temporal scales in response to a range of disturbances that needs to be captured in any future development of a management and monitoring programme for the Lake Eyre Basin. A Strategic Adaptive Management system is recommended for an assessment of the Lake Eyre Basin with resilience of the natural resources of the basin being the ultimate aim of the programme. This provides the context for the selection of indicators, collection of data and establishment of Thresholds of Probable Concern.

iii. The timing of future assessments should be every 5 to 10 years, with ongoing monitoring reported annually, even where this is minimal monitroring.

iv. Governance arrangements in respect to future Assessments should be adopted that support a strategic adaptive management approach. Such arrangements should allow for continuous learning and improvement, and ensure that assessments inform stakeholders responses.

v. The workshop proposed for August 2009 should include discussion around the technical component of the assessment process as well as the governance and implementation components.

1. Background

The Australian Department of the Environment, Water, Heritage and the Arts (DEWHA) requires the development of a Lake Eyre Basin Rivers Assessment Implementation Plan to identify how regular on-going monitoring of key indicators will be implemented within the Lake Eyre Basin Agreement Area. To meet this aim DEWHA has engaged the services of Kiri-ganai Research Pty. Ltd to undertake a consultancy for this purpose.

The main objectives of this consultancy are to undertake:

- a review of achievements to-date under the Lake Eyre Basin Rivers Assessment;
- a review of the Lake Eyre Basin Rivers Assessment methodology and recommend on an approach and key indicators to be monitored, their scale and frequency (including rationale for decisions);
- support development and documentation of governance arrangements; development of a business model (including the cost of monitoring, managing data and report; funding for future monitoring and possible funding arrangement).

In accordance with the project contract, there are six milestones for this consultancy:

- Review of achievements to date under the Lake Eyre Basin Rivers Assessment (Step 1)
- An agreed Lake Eyre Basin Rivers Assessment Methodology (Step 2)
- Development and documentation of governance arrangements (Step 3).
- Development of a business model (Step 4)
- Lake Eyre Basin Rivers Assessment Implementation Plan (Step 5)
- Workshop (Step 6)

This report is submitted in accordance with the terms of reference for this consultancy and addresses Step 2 (review of the agreed Lake Eyre Basin Rivers Assessment Methodology). Building on the first report, submitted in May 2009, this report reviews documents and activities pertaining to the Lake Eyre Basin Rivers Assessment Methodology in terms of the successes and failures in meeting their original aims and objectives. As part of this task Kiri-ganai Research was asked to:

1. identify the monitoring already being undertaken within the Lake Eyre Basin which will be included in the Implementation Plan (addressed in Section 3 of this report);

2. identify the recommendations from previous Lake Eyre Basin work that will be included in the Implementation Plan (addressed in Section 4 of this report);
3. identify the indicators that were suggested in Method for Assessing the Health of Lake Eyre Basin Rivers that will be included in the Implementation Plan (addressed in Section 5 of this report);
4. identify linkages with national monitoring, evaluation and reporting frameworks (addressed in Section 6 of this report);
5. identify monitoring actions that can be undertaken immediately – summarise their methods and costs (addressed in Section 7 of this report);
6. identify monitoring actions that require further research and development(addressed in Section 8 of this report); and
7. advise on the appropriateness of reporting on a ten year basis or other timeframe (addressed in Section 9 of this report).

2. Introduction to the Lake Eyre Basin

The biophysical environment

The Lake Eyre Basin covers an area of 1,140,000 km2 (15 percent of the Australian landmass) and is similar in size to the Murray-Darling Basin (MDB). There are a number of large iconic river systems within the Lake Eyre Basin, notably Cooper Creek (catchment area 306,000 km2, river length 1500 km) and the Diamantina River (catchment area 160,000 km2, river length 1000 km), that are important international and national ecosystems. These ecosystems are amongst a handful of large river systems that remain relatively untouched by human development, especially water resource development, and they are Australian folklore icons – especially the Cooper and Diamantina.

The Lake Eyre Basin contains areas of high economic value. These include activities such as pastoralism, tourism, oil and gas extraction and mining, as well as areas of social, cultural and heritage value. Sustainability of the environmental and economic significance of the Lake Eyre Basin depends, in part, upon the continued health of its riverine landscape; its sub catchments, main river channels, flood plains, lakes, wetlands and overflow channels.

The rivers of the Lake Eyre Basin are dryland rivers being characterized by extremely variable and unpredictable flows, low gradients and complex flow paths. Lake Eyre Basin rivers, namely the Thompson, Barcoo. Cooper Creek, Georgina, Diamantina, Neales and the Warburton, and their tributaries, change from a series of waterholes in dry times to slow moving ‘inland seas’ that are often kilometres wide during large flood events. Although the rivers of the Lake Eyre Basin are largely unmodified by large-scale water resource developments there are a range of activities in the broader catchment that could potentially impact on the ‘health’ of these river systems.

“Dryland” rivers typically occur where annual rainfall is less than 500 mm and the annual evaporation rate exceed rainfall. Australian dryland rivers have some of the most variable flow patterns in the world. Large floods, which cover large areas of the riverine landscape, and extensive droughts, when water availability is restricted to a few permanent waterholes, are prominent features. Despite the variable and unpredictable nature of flow in dryland rivers, the animals and plants inhabiting the rivers and associated floodplains are well adapted to the nature of this flood-drought variability. Indeed, the integrity of dryland river ecosystems, especially in their lowland areas, depend upon the irregular inundation of the floodplain (period of flooding) and the drying out of the majority of the riverine landscape during periods of drought.

Pressures of development

In 1995 a consortium of cotton growers put forward a proposal for irrigated cotton farming at Currareva, on the headwaters of Cooper Creek in the Queensland section of the Lake Eyre Basin. The development proposed to withdraw 42 000ML of water from the Cooper each summer to irrigate 3 600 ha of cotton, and to construct two off-stream storages (total capacity 15 000ML) as reservoirs for low-flow years. While this diversion represents only 2.5% of the median annual flow (1.7 million ML) it potentially would have significant impact on the river ecosystem especially during low or no flow periods. The Currareva proposal provoked dismay among river scientists and conservationists because the development would be in sharp contrast to the boom-and-bust character of the regional dryland environment. On 29 October 1996 the Queensland Minister for Natural Resources announced that the Currareva proposal would be rejected by a special Act of Parliament citing the `overwhelming weight' of ecological evidence predicting environmental damage from the development.

Catchment management in the Lake Eyre Basin: a brief history

The Lake Eyre Basin Intergovernmental Agreement grew from a process that began in the mid 1990s. People from various Lake Eyre Basin community groups and from government began discussing how to ensure the long-term sustainability of the Basin's natural resources. The Lake Eyre Basin Steering group, formed in 1995, brought together stakeholders and interest groups from the pastoral industry, the Queensland and South Australian governments, conservation groups, the mining and petroleum industries, Landcare groups, Indigenous organisations and local government. The task of this group was to find out from people interested in the Basin whether they would like to set up a mechanism for community input into, and coordination of, natural resource management decision-making. Several years later it was decided to adopt a catchment management approach for the Basin and the Lake Eyre Basin Coordinating Group was established with the support of Natural Heritage Trust funds. This was followed by the establishment of the Cooper's Creek Catchment Committee and the Georgina Diamantina Catchment Committee in 1998. Collectively, the Lake Eyre Basin Coordinating Group and the two catchment committees developed a series of catchment management strategies that were based on issues identified through wide public consultation.

At the same time, the Commonwealth, Queensland and South Australian Governments began negotiating an intergovernmental agreement for the Lake Eyre Basin. The Lake Eyre Basin Heads of Agreement was signed in 1997 as the basis to negotiate a formal inter-governmental cooperative agreement for integrated catchment management and water resources management of the Lake Eyre Basin. The Lake Eyre Basin Intergovernmental Agreement was signed by Ministers of the

Commonwealth, Queensland and South Australian governments in October 2000, and ratified by Acts of Parliament in all three jurisdictions in 2001. The Agreement applied to the Coopers Creek and Georgina Diamantina River systems in South Australia and Queensland, and established the Lake Eyre Basin Ministerial Forum, with responsibility for achieving the objectives of the Agreement. Part of the Agreement required the Ministerial Forum to appoint a Community Advisory Committee, a role previously performed by the Lake Eyre Basin Coordinating Group until late 2002. The Ministerial Forum also appointed a Scientific Advisory Panel to provide scientific and technical advice, in particular to provide advice on monitoring the condition of rivers and catchments within the Lake Eyre Basin Agreement Area.

Values of the Lake Eyre Basin

The following environmental and social values in the Lake Eyre Basin have been identified by various community groups and government agencies.

Values identified in the Lake Eyre Basin Intergovernmental Agreement

- Continued health of the Thomson/Barcoo/Cooper, Georgina and Diamantina river systems (to maintain nationally and internationally significant areas and other values dependent on the health of the river systems);
- Conservation and promotion of important social, environmental, economic and cultural values;
- Landscapes and watercourses that are valuable for aesthetic, wilderness, cultural and tourism purposes;
- Aquatic ecosystem health which is maintained by naturally variable flow regimes and water quality;
- Flow variability and seasonality to maintain ecological processes and biodiversity;
- Maintenance of beneficial flooding for pastoralism and floodplain ecosystem processes;
- Integrated management;
- Precautionary management to protect environmental attributes;
- Management to be undertaken within a framework of ESD principles and national and international obligations;
- Local knowledge and experience;
- Best available scientific and technical information.

Values identified by the Ministerial Forum and included in the agreed policies adopted on 25 October 2002

- Maintenance of ecological integrity and natural functioning of in-stream and floodplain ecosystems;
- Viable economic, social, cultural and other activities which do not threaten the above environmental values.

Values identified by the LEB community in its strategic plans for the Lake Eyre Basin Basin-wide

- Sustainable and wise use of natural resources;
- Conserving biodiversity;
- Economic prosperity;
- Respect for and use of local knowledge;
- Outback lifestyle;
- Healthy systems with high ecological integrity;
- Forward looking, vibrant communities;
- Sustainable and diverse regional economy.

3. Current monitoring within the Lake Eyre Basin

Regular monitoring of a range of components is currently being undertaken across the Lake Eyre Basin by various state government jurisdictions. However, there is a high degree of inconsistency in terms of what is being or has been monitored by the different State jurisdictions, the scale and the applicability of various components used for an assessment of the Lake Eyre Basin as a whole. In addition, the quality of the data collected and the length of time over which monitoring has been undertaken is also highly variable. Monitoring activities undertaken within the Lake Eyre Basin can be grouped into the components of hydrology, the physical form of waterholes, biota and water quality and landscape factors. The details of each are provided below.

Hydrology component

- The hydrology of the Lake Eyre Basin has been analysed by McMahon *et al* (2008) using data from gauging stations with >10yrs of data.
- Overall, the hydrology of the Lake Eyre Basin was assessed in the Lake Eyre Basin State of the Basin Report (2008). Here the hydrological condition was assessed by Lake Eyre Basin Scientific Advisory Panel and Lake Eyre Basin Steering Committee using expert opinion and best available data (not specified). This assessment was based on storage water volumes and percentage of flow diverted from the channel network within the basin as monitored by State Agencies.
- There is a surface water monitoring network within the Lake Eyre Basin and this has been reviewed by Ladson *et al* (2006) who provided recommendations for additional monitoring sites and instrumentation.
- A limited number of water level loggers have been installed in the South Australian section of the Lake Eyre Basin as part of the ARIDFLO project, as outlined in Good *et al* (2008). Data from these loggers have been downloaded from and analysed by Costelloe (2007; 2008).
- A pilot study is underway to evaluate the potential for use of Remote Sensing (Lake Eyre Basin Scientific Advisory Panel 2009) for the determination of the extent of flooding throughout the Lake Eyre Basin.

Physical form of waterholes component

- The location, permanency and connectivity of various waterholes have been mapped in the Queensland, eastern South Australia and Northern Territory sections the Basin using a series of remotely sensed images. The methods used and analysis of this exercise is outlined in Lake Eyre Basin Scientific Advisory Panel (2009) report.

Biota component

Regular monitoring of two biotic components has occurred throughout the Lake Eyre Basin:

Fish

- Fish were monitored as part of the ARIDFLO (Good *et al* 2008) and the CRC for Freshwater Ecology Dryland Refugia projects.
- In addition there have been regular surveys of fish within the Queensland section of the Lake Eyre Basin as well as the Northern Territory Section as noted in Bailey and Long (2001) and Duguid *et al* (2005) respectively.
- A project to determine the natural trajectory of fish diversity and abundance in relation to hydrology and season within the Lake Eyre Basin has been undertaken by Humphries *et al* (2007). The resultant model has been tested in the South Australian section of the Lake Eyre Basin by McNeil and Reid (2008) and in the Queensland section by Balcombe and Kerezy (2008).
- Overall fish communities within the Lake Eyre Basin were assessed as part of the Lake Eyre Basin State of the Basin Report in 2008 using the using data outlined above but the actual methods employed were not stated.

Waterbirds

- Surveys of waterbirds have been undertaken in some parts of Lake Eyre Basin for up to 24 years. Kingsford and Porter (2008) have reviewed the validity of using waterbird data for assessing river condition.
- Water birds were assessed in the Lake Eyre Basin State of the Basin report (2008) using the expert knowledge of Professor Richard Kingsford who utilized the above long-term datasets.

Water quality component

- Ongoing water quality monitoring has been undertaken in the Queensland section of the Lake Eyre Basin. Assessments of the water quality of rivers in the Queensland section of the Lake Eyre Basin are provided by Bailey (2001) and Choy *et al* (2002).
- Water quality was a component included in the Lake Eyre Basin State of the Basin report of 2008 and this used data from the State-based water

quality monitoring programmes (information has not been provided on this) as well as an expert review of results by the Lake Eyre Basin Scientific Advisory Panel and Steering Committee. This assessment was done using the ANZECC Ecosystem Protection Guidelines.

Landscape stress component

- A landscape stress component was included in the Lake Eyre Basin State of the Basin Report (2008) and was based on the method developed for the National Land and Water Resources Audit. The landscape health assessment as outlined by Morgan (2000), and further elaborated in Herr *et al* (2007), is based on the following variables:
    - percentage of subregion with least impact from total grazing pressures
    - value of native vegetation in land tenures associated with conservative land use practices
    - weed density
    - feral animal density
    - number of threatened species
    - susceptibility of resources to degradation.
- The National Land and Water Resources Audits landscape stress rating was conducted on a sub-regional basis with the majority of the Lake Eyre Basin being assessed as ‘extensive land use zone’ and ‘intensive land use zone’ for the Cooper catchment headwaters. Conversion to a sub-catchment scale has been undertaken by the Lake Eyre Basin Steering Committee through visually overlaying layers.

4. Recommendations for monitoring activities within the Lake Eyre Basin

Past recommendations

The Lake Eyre Basin Intergovernmental Agreement provides for the sustainable management of the water and related natural resources associated with the major river systems of the Lake Eyre Basin. In terms of natural resource management and conservation, the Agreement is important for two reasons. First it allows for the protection of economic, social and environmental values that depend on the natural resources of the basin, especially its river systems. Second, it serves to avoid potential cross-border impacts. The literature contains numerous examples of cross border jurisdictional conflicts both here in Australia and elsewhere, and in the majority of circumstances this has been associated with a decline in the condition or functioning and the overall integrity of natural resources. Part of the Lake Eyre Basin Agreement requires an assessment of the condition of the major river systems and catchments within the Agreement Area and for the assessment to be repeated every 10 years.

The Lake Eyre Basin Rivers Assessment (LEBRA) required the following:

- development of an appropriate assessment methodology;
- a number of conceptual models of the river systems and how they function;
- the identification of suitable indicators of condition; and
- the development of monitoring and reporting protocols (including identification of representative monitoring sites).

Further, the methodology that was to be developed for the LEBRA was required to be scientifically rigorous and credible, and deal effectively with the challenges of remoteness, vast distances, lack of existing monitoring infrastructure and baseline data, and the complexity and variability of the Lake Eyre Basin system.

Recommendations for monitoring activities within the Lake Eyre Basin have been made from the LEBRA and other environmental studies undertaken in the Basin. These past recommendations are outlined in Table 1 according to the themes noted in the Lake Eyre Basin Implementation Plan. The themes being: 1) flow and flood, 2) waterholes and wetlands, 3) riparian and floodplain, 4) physical form and 5) general.

Table 1. Recommendations for implementation from past Lake Eyre Basin River Assessment work.

THEME	Report	Recommendations
1) FLOW and FLOOD		
General	*Lake Eyre Basin Data Logging Review*, December 2006	• Priorities for monitoring locations are provided but should be confirmed in consultation with scientists involved in Lake Eyre Basin projects, governments and stakeholders. Stakeholder workshop suggested to consider report findings and 'Methods'. Sites to be prioritised on basis of information needs of Lake Eyre Basin assessment and budget scenarios. The way to move beyond a 'wish list' of monitoring sites is to apply discipline in prioritising sites and information needs (p.27). • Suggested that 2 types of sites are considered: 1. Long-term sites: with 'sensor to web' technology, to develop rating curves and 2. Large number of stage recording sites (without telemetered data), similar to existing ARIDFLO sites (p.27). • Selection of new instrumentation and measurement techniques require expert advice to be drawn from within Lake Eyre Basin jurisdiction. Recommendations for a committee (people listed in Table 6).
Water use	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• To be calculated initially for pilot region, e.g. upper Thomson River. Volumes of water held in storages to be calculated initially using area of storage and assuming average depths.
Waterhole depth	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Need to address question of wether permanency of water is affected by water removal at low levels and assess change in duration of inundation at key sties.
Flood extent	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Errors too large to determine accurate discharge/flood extent relationships. This area requires research and development.
Alluvial groundwater		• Important to monitor for Upper Georgina waterholes in the Northern Territory only. Need piezometers associated with depth loggers.

THEME	Report	Recommendations
2) WATERHOLES and WETLANDS		
General	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Site-based, regular monitoring and frequent reporting. • Augmented waterholes, e.g. Longreach town water supply need further consideration. • Sufficient data exists to conduct Power analysis for water quality, fish and macro invertebrate data. • Need to develop conceptual model for impacts of cane toads.
Water quality	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23* *State of the Basin 2008: Rivers Assessment - Background and Reference*, April 2009	• Need to consider more useful data loggers to get dissolved oxygen and temperature. • Total Nitrogen and Phosphorus very costly and not very informative. • Need to develop regional and local water quality guidelines.
Waterhole process and function	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Some indicators too expensive and not all indicators necessary for routine analysis. • Blue-green algal dominance may be useful. Pilot study required.
Fish	*Report on the LEBRA Workshop: Determining the natural trajectory of fish within the Lake Eyre Basin,* November 2006	• Fish monitoring must be linked with hydrological and water quality monitoring (p. 7). • Fish sampling should occur biannually; once after wet season recedes in March/April and again near end of dry season in November (p. 7). • Recommended spatial arrangement for sampling and reporting is at 1. catchment level, 2. biogeographic/climatic/hydrological regions within each catchment and 3. representative reaches and critical sites. Minimum of 2 representative reaches required for each region with 3 being best (p. 8). Research into Lake Eyre Basin fish taxonomy, conservation status, genetics etc. required (p. 8).

THEME	Report	Recommendations
2) WATERHOLES and WETLANDS cont . . . **Fish cont . . .**	*Preliminary Fish Surveys for the Lake Eyre Basin Rivers Assessment: Testing the Fish Trajectory Model in South Australia,* August 2008	• Final monitoring framework needs a survey protocol that maximises species detection and provides comparable abundance data with realistic degree of effort. Need appropriate timeframe for surveying larger habitats to ensure even levels of survey effort (p.83). • Fyke nets required in most sites, particularly large waterbodies (p.83). • Collation and analyses of data from AridFlo, Dryland Refugia and Wet/Dry projects needed to guide future surveys (p.83). • Need information on genetics and distribution of key taxa, taxonomy and conservation status of LEB fish, tolerances of taxa to physicochemical parameters, implications of alien taxa, impacts of livestock and terrestrial alien taxa and impacts of tourism, fishing and mining, and fish community structure response to flow (p. 83). • Future monitoring should consider strong local support, particularly at populated centres, e.g. Innamincka, and from landholders (p.84). • Arid regions and reaches of Lake Eyre Basin likely to be particularly important indicators of declines in river health and monitoring outputs from these sites will provide comparative targets (p. 86). • Need to link fish monitoring to biological, ecological and hydrological research projects in order to maximise value of monitoring outputs (p.86).
	Preliminary fish sampling for the Lake Eyre Basin Rivers Assessment: testing the Fish Trajectory Model in Queensland, undated	• The effectiveness of the Fish Trajectory Model improved by including waterhole level or similar descriptive term in the 'Antecedent condition' headings so that responses of communities or species to concentration effect by predicted and explained (p. 35). • The Fish Trajectory Model needs to reflect that expected flooding benefits likely to persist beyond 12 months (p. 35). • Need for further targeted research to understand life-history aspects of Lake Eyre Basin fish assemblages (p. 36). • Need to retain alien fish species as indicator despite lack of relevance at present due to low numbers (p. 36). • Need to adjust trophic groups if these are to be monitored. Herbivorous species are absent in Lake Eyre Basin and *Nematolosa erebi* is only truly non-carnivorous species. • Prevalence of fish disease not thought to be a useful indicator except during periods of low fish abundance (p. 37).

THEME	Report	Recommendations
2) WATERHOLES and WETLANDS cont . . . **Fish cont . . .**	*Joint recommendations for fish monitoring in Lake Eyre Basin Rivers: testing the Fish Trajectory Model in Queensland and South Australia,* undated	• Analysis of fish species richness, abundance in arid systems needs to be more than site specific and consider broader spatial patterns (p. 1). • Length/weight curves need to be developed for species and catchments so biomass can be estimated from length (p. 1). • Alterations needed to recruitment indicator with allowances made for variability in responses between species, climates and hydrological conditions (p. 2) • Research required into spawning and biology of Lake Eyre Basin fish species (p. 2). • Population size structure response curves needed for different species (p. 2) • Abundance of herbivores indicator to be replaced by abundance of detritivores (p. 2). Abundance of macro-carnivores and microcarnivores not as useful as species-specific data and ontogenetic classes within species (p. 2).
3) RIPARIAN and FLOODPLAIN **General**	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Should be based on site measurements able to be upgraded to catchment measures.
Riparian vegetation condition	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Same dataset to pick up all indicators. Floating macrophytes should be included. Woody perennials should be identified to species.
Floodplain vegetation condition	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Same as above but lower priority.
Waterbirds	*Scientific validity of using waterbird measures to assess river condition in the Lake Eyre Basin,* September 2008	• Inclusion of waterbirds as key biological indicator in LEBRA • Identification of thresholds for waterbird abundance, diversity and composition for important wetland sites in Lake Eyre Basin • Development of a program focusing on surveys of iconic and important sites at least annually using repeatable methodology. More frequent surveys required during significant flow events. • Identify major colonial waterbird breeding sites in LEB and monitor breeding events. • Integration of river flow data and waterbird data. • Analysis of long-term waterbird data sets to determine current status of waterbirds • Use of aerial survey data to identify wetlands of importance in the Lake Eyre Basin.

THEME	Report	Recommendations
4) PHYSCIAL FORM		
General	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Should be reviewed regionally on 5 year cycle
Channel system integrity	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Need pilot to assess validity of using aerial photography to assess disappearance of anabranches etc with flow changes • Need pilot study to develop rapid appraisal methodology for assessing within-waterhole complexity (e.g. from Ausrivas). Also, need to consider using snags as subsidiary. Noted that large amount of work required to collect data for within-waterhole complexity indicator.
Erosion potential and land use and landscape change	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	Need to look at changes in vegetation cover in response to events. Requires research and development and pilot study.
Floodplain salinisation	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Probably data readily available for pilot studies in lower Goyder's Lagoon, Diamantina NP and Durham Downs floodplain. • Frequency should be between 2 and 5 years in areas where salt transition is going to occur.
5. GENERAL	*Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23* *Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23*	• Indicators developed under Ephemeral Rivers project need to be considered for inclusion for headwaters of the Northern Territory rivers. • Conceptual models need to be re-addressed to demonstrate links with selected indicators with references to literature in order to justify selection of indicators. • Need to define what moderate and poor condition classes constitute (p. 10) • Future Lake Eyre Basin assessments should align with nationally agreed resource condition indicators from NRM MERI Framework and with FARWH for national reporting (p. 10) • FARWH recommends use of hydrology indicators developed for MDB SRA by SKM plus NWC groundwater assessment. Since no model for natural flows in Lake Eyre Basin, SRA methods cannot be directly applied to Lake Eyre Basin and time series approach is required (p. 12)

In summary, the reports reviewed, suggest:

The sole focus of hydrological activities has been on the installation of data loggers for recording water levels which can be used to construct reliable rating tables of water level and discharge.

Biological monitoring appears to relatively advanced although poor in comparison to other river assessment programs in Australia.

State of the Basin Report

Data collected from the various monitoring activities have been used to construct the State of the Basin Report (2008). Two documents outlining the State of the Basin 2008 have been produced. The first is essentially a score card of condition for various regions across the basin while the second provides technical information underpinning the score card. The State of the Basin reports on broad measures of hydrology, landscape stress, water quality, fish and waterbirds. The methods supporting the report card are based on the FARWH approach of condition assessment and does not use the method developed in the Lake Eyre Basin River Assessment Project.

The four key points of the State of the Basin Assessment are:

- The rivers and catchments of the Lake Eyre Basin are in generally good condition. A low degree of hydrological modification was stress as being particularly important.
- Intact aquatic ecosystem within the basin the Lake Eyre Basin rivers unique compared to other arid rivers in Australia and globally.
- Cooper Creek is the most studied river in the basin but knowledge of the structure and function of this system is considered to be below that of other Australian river systems.
- Potential threats to the condition of rivers within the basin include water resource development, invasive pests and land use intensification.

Conclusions of the State of the Basin Report were based on the following:

- Five indicators were used in this assessment; hydrological condition, landscape stress, water quality, fish and waterbirds.
- The actual approach to assessing the condition of rivers within the basin appears to follow the FAWRH framework rather than that proposed by the Lake Eyre Basin River Assessment Methodology.
- Apart from the Hydrological Condition, which was reported at a catchment scale, the other indicators were reported at the sub catchment scale of Headwaters, Channels and Waterholes and Terminal

Wetlands, as recommended by the Lake Eyre Basin River Assessment Methodology.

- Some of the data used in the river assessment were accessed from regional data sets that were complied before 2000.
- The assessment was based on a variety of sources of information, these being; existing reports, scientific data (but these were not stipulated) and expert opinion and once again the experts and their views are not noted.
- Most indicators were reported to be in ‘good’ condition across the basin but a clear definition of what ‘good’ was not provided.
- In addition, it was noted that defining what constituted ‘moderate’ and ‘poor’ condition must be developed.

Consultant’s assessment

A total of 39 cited actions were noted as part of the implementation recommendations from the Rivers Assessment Methodology and these address the four main themes of Flow and Flood, Riparian and Floodplain, Waterholes and Wetlands and Physical Form. These listed actions can be grouped as addressing 11 different attributes like hydrological variability, fish assemblage diversity and ecosystem processes as examples.

35 of the 39 listed actions have either not been addressed or reported. Completed achievements that have been listed include those on the broad scale assessment of hydrological condition, a review of data logging, the hydrology of the Lake Eyre Basin and a vegetation condition report for the basin.

The assessment of the State of the Lake Eyre Basin is not a comprehensive substitute for an assessment of the rivers (river network) of the basin, despite it being undertaken with best available data and information at the time. Catchment and river ecosystems are different entities. Despite being interlinked, they are primarily shaped and controlled by different variables operating over different spatial and temporal scales. Because of this they require separate strategies, study designs and indicators for monitoring their respective states and conditions.

5. Indicators to include in the Method for Assessing the Health of the LEB: some considerations

Selecting indicators

An important role for the river manager and river scientist in determining the condition, health or resilience of river systems is to identify and employ appropriate indicators. This task is often not easy as indicators must be unambiguous in terms of their response to the threats to river health. Because environmental river processes interact in complex ways the task of measuring river health is often difficult. Finding a single robust, sensitive indicator is unlikely (Fairweather 1999) and some trade-offs are needed. Occasionally, indicators may be chosen because they are `charismatic' and it may be a species that has a high public profile (e.g. platypus) or is readily associated with a sensitive high profile issue (e.g. cyanobacteria – blue green algae). Indicators must be able to be validated.

In practice, the choice of an indicator, or group of indicators, often reflects personal bias, technical considerations, and constraints of knowledge. There are three types of indicators: those that are early warning indicators that signify impending decline in health; compliance indicators that reveal deviations from acceptable limits; and diagnostic indicators that show the causes of the deviations (Cairns and McCormick 1992). Most of the suite of indicators used by the various state jurisdictions for river monitoring in the Lake Eyre Basin is for compliance purposes and not directly applicable for use in assessing the condition of highly variable large systems.

Three contemporary approaches for selecting indicators of river health have been identified by Fairweather (1999). The first group of approaches essentially represent a haphazard selection of indicators from divergent perspectives, such as chemistry or biology. Here the selection of indicators is based on personal biases of managers and politicians. Second, there is the adoption of a single perspective that is either better developed, favoured by circumstance or seen as an umbrella for protecting other sets of values (e.g. the Australian River Assessment System – 'AusRivAS'). Synthetic approaches that integrate distinct perspectives, such as in the Sustainable Rivers Audit of the Murray Darling Basin, represent the third group. Of these Fairweather (1999) suggest the synthetic approach may best suit the current requirements of determining river health in large, highly variable Australian river systems like those of the Lake Eyre Basin. This type of approach requires a larger suite of variables to be used and integrated but is heavily scale-dependent (Townsend and Riley 1999). The selection of appropriate spatial and temporal scales for measures (indicators) of river condition is crucial. Commonly, measurements are spot samples (e.g. concentration, abundance, species richness) and the assessment of river health is based on changes in ecological processes. Many have commented that this is not appropriate in river systems where process events operate at large spatial and temporal scales.

Indicators that have previously been recommended to be included in assessing the condition of the Lake Eyre Basin are outlined in Table 2. These indicators are grouped according to the components of hydrology, physical form of waterholes, biota and water quality and landscape factors. It is pertinent to note that these indicators do collect data at different scales and therefore provide data that may of may not be relevant to the current condition of the river network within the Lake Eyre Basin because of this.

Table 2. Indicators previously recommended for the Lake Eyre Basin Rivers Assessment

THEME/ ATTRIBUTE	Indicator	Scale[1]		Region[2]			Implementation	Rationale for inclusion
		Data collection	Reporting	HW	C&W	TW		
FLOW & FLOOD								
Water use	▪ Volume of water held in storage	Whole basin	Sub-catchment	✓	✓	✓	Immediate with pilot study using existing data	Fundamental driver of catchment condition and function.
	▪ Percent of flow diverted	Whole basin	Sub-catchment	✓	✓	✓	Immediate with pilot study using existing data	
Hydrological variability	▪ Flow variability				✓	✓	Pilot study using existing data	
Waterhole depth	▪ Depth	Site/waterhole	Waterhole		✓	✓	Immediate	Importance of refugial waterholes to water-dependent fauna.
Flood extent	▪ Flood extent				✓	✓	R & D	
Alluvial groundwater	▪ Depth to alluvial groundwater	Upper Georgina only (NT)	Upper Georgina only (NT)		✓		Pilot study using existing data	

THEME/ ATTRIBUTE	Indicator	Scale[1]		Region[2]			Implementation	Rationale for inclusion
		Data collection	Reporting	HW	C&W	TW		
WATERHOLES & WETLANDS								
Waterhole & wetland biodiversity	▪ Fish assemblage diversity - sp. richness - abundance - abundance of alien sp. - recruitment - population size structure - abundance of detritivores - prevalence of disease	Water body/ critical sites	Catchment, sub-catchment/ regional, water body & critical sites	✓	✓	✓	Immediate and assessment of existing data	Community priority, iconic and cultural asset. Good indicator of ecosystem health.
	▪ Colonial water birds diversity and breeding - total abundance - species richness - abundance of functional groups - community composition - presence/absence of selectedspecies - abundance of breeding birds - species richness of breeding birds	Breeding colony	Breeding colony	✓	✓	✓	Immediate and assessment of existing data	Iconic group. Indicates 'booms are booming'.
	▪ Iconic species			✓	✓	✓	R & D	
	▪ Cane toads			✓	✓	✓	R & D	
Waterhole & wetland water quality	▪ Water quality - conductivity - pH - DO - turbidity - water temperature	Water body	Water body	✓	✓	✓	Immediate and assessment of existing data	Easy to measure for little extra cost. Need to relate to biological trends.
Waterhole process & function	▪ Ecosystem processes	Water body	Water body		✓		Pilot study	

THEME/ ATTRIBUTE	Indicator	Scale[1]		Region[2]			Implementation	Rationale for inclusion
		Data collection	Reporting	HW	C&W	TW		
RIPARIAN & FLOODPLAIN								
Riparian vegetation	▪ Riparian vegetation structure - % cover of dominant woody species - % ground cover - % cover aquatic vegetation - % cover exotics - native regeneration - width of riparian zone - longitudinal continuity	Site	Water body to sub-catchment	✓	✓		Immediate	Represents important linkages between riparian zone and river condition as well as biodiversity values of riparian zones in own right. Also measures pressures on riparian zones from land use, ferals, weeds and tourists.
Wetland vegetation	▪ Wetland vegetation condition - floristic composition - species richness - % canopy cover - % cover of understorey species - height ranges of layers - tree vigour - population size structure	Site	Water body	✓	✓	✓	Immediate	

THEME/ ATTRIBUTE	Indicator	Scale[1]		Region[2]			Implementation	Rationale for inclusion
		Data collection	Reporting	HW	C&W	TW		
PHYSICAL FORM								
Channel system integrity	▪ Channel system integrity	River reach	River reach to regional		✓	✓	Pilot study	Measure of change in channel form associated with changes to flow.
Erosion potential and land use and landscape change	▪ Erosion potential and land use change	Headwaters and upper catchments (higher rainfall areas)	Sub-catchment	✓	✓	✓	R & D	Need measure of broad catchment-scale drivers of change, especially in water shedding areas.
Floodplain salinisation	▪ Salinity scalds	Regional (as per channel system integrity)	Regional	✓	✓	✓	Pilot study and assessment of existing data	Major political issue and priority in all NAP and NHT programme material.

1. From *Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23* and other LEBRA studies where relevant.

2. HW: Headwaters, C & W: channels and waterholes, TW: terminating wetlands (after Sheldon et al., 2005)

Other factors to consider for the Lake Eyre Basin Rivers Assessment

Recent advances in the area of Resilience and Strategic Adaptive Management have implications for the Lake Eyre Basin River Assessment. Like much of the world, Australian practices of terrestrial and aquatic ecosystem management have relied on notions of an equilibrium state, where the focus has been on increasing or optimizing efficiency and performance in order to deliver defined benefits, including supply or sustainability. This paradigm continues despite the recognition of the enhanced natural variability, in pattern and process, and its importance within Australia's river systems. Indeed, variability, unpredictability and resource scarcity are a feature of the river network of the Lake Eyre Basin and are key components of the 'dryland syndrome' (Stafford Smith et al., 2009) that characterise much of inland Australia.

Yet Australian river ecosystems are still under pressure and continue to degrade under existing management practices. This is not surprising. Ecosystems are moving targets characterized by episodic change, patchiness, cross-scale interaction and multiple equilibria, or multiple stable states. Time and time again, ecosystems managed for some type of equilibrium carrying capacity have been thwarted by surprise events, changes in thresholds and market failures. Time and time again it has been shown that optimizing efficiency to deliver a defined benefit does not lead to sustainability, but rather to collapse. New ideas are required to improve the management of Australian river and floodplain ecosystems. We suggest that such ideas should consider emerging paradigms that move away from notions of optimal efficiency for delivering a defined benefit, and consider rivers as complex social-ecological systems characterised by variability, heterogeneity, adaptability, diversity, multi-scaled dynamics, change and innovation in interacting social, economic and ecological spheres.

Resilience thinking provides one umbrella under which to consider the sustainable management of natural resources especially water. Resilience in terms of system change, is the amount of change a system can undergo (its capacity to absorb disturbance) and remain within the same regime that essentially retains the same function, structure and feedbacks (Walker and Salt, 2006). The ability of an ecosystem to absorb disturbance is a function of several properties: adaptive loops, thresholds, slow variables, cross scale interactions, multiple states, regime shifts, adaptability, transformation and adaptive management. In terms of river assessment and monitoring it is the first building block which is important and this pertains to the concepts of thresholds, multiple states, slow variables, transformation and regime shifts.

Resilience thinking recognises that rivers change and do so naturally. Change is driven by two types of variables – fast and slow variables. Current understanding of thresholds between regime states in ecosystems suggest that although system dynamics are driven by many variables operating at different scales, system trajectories will be driven by a small set of controlling (or slow) variables. These variables determine the boundaries beyond which disturbances may push the system into another state. As such, changes in controlling variables must be the focus for a regime shift across a threshold (Carpenter et al., 2001) and the primary focus for monitoring, especially in highly variable systems. Some demonstrated examples of controlling variables include land use, nutrient stocks, soil properties, river channel morphology, vegetation pattern, biomass of long-lived organisms and biodiversity. These types of variables are often slower than the types of variables that tend to be monitored currently in many resource management programmes, which have important implications for detecting the position and status of systems in relation to thresholds.

Groffman et al. (2006) reviewed the utility of thresholds for environmental management. There are three main applications of thresholds in environmental management:

- *Analysis of surprising and dramatic shifts in ecosystem state* – where a small change in a driver causes a marked change in ecosystem condition. An example is the switch from an oligotrophic clear water system dominated by sea grass to a turbid system dominated by phytoplankton in Florida Bay.
- *The determination of critical loads* – which represent the amount of pollutant that an ecosystem can safely absorb before there is a change in ecosystem state and/or in a particular ecosystem function. An example is emissions standards for air pollutants.
- *Analysis of extrinsic factor thresholds* – where change in a variable at a large scale alters relationships between drivers and responses at a small scale. An example is the threshold of incipient movement for streambed particles under a certain velocity. Extrinsic factor thresholds are common in riverine ecosystems, but we lack an understanding of how drivers interact to regulate ecological responses or processes.

The identification of thresholds can be undertaken using a number of methods, including statistical identification from empirical data (Scheffer and Carpenter, 2003; Carpenter and Brock, 2006), rule-based modelling (Mackenzie et al., 1999) and conceptual modelling (Rogers and Bestbier, 1997). In general, however, there is a critical need for the development of variables and monitoring approaches that can determine if an ecosystem is approaching a threshold (Groffman et al., 2006).

A form of Strategic Adaptive Management was developed over a number of years as a local tool for the management of rivers within Kruger National Park, South Africa (Biggs and Rogers, 2003). Strategic Adaptive Management offers a framework for natural resource management and decision making in environmental, social and institutional situations characterized by variability, uncertainty, incomplete knowledge and multiple stakeholders. Three key tenets form the basis for the management and decision-making process in Strategic Adaptive Management (SAM):

- *Strategic and value based* - Purposeful and goal-directed, with the first step in planning and management being the description of a desired future state of the protected area based on scientific and societal needs and values;
- *Adaptive* - In the face of uncertainty, management actions are treated as an opportunity to learn by doing. Management is planned as a learning experience and improves through frequent review of policy and action; and,
- *Participatory* - Meaningfully involving all stakeholders to serve their needs, access their inputs and secure their cooperation. Governing cooperatively with other agencies to coordinate and integrate goals and actions (Rogers et al., 2008).

Generation of a set of Thresholds of Potential Concern to define the acceptable levels of change in ecosystem / biodiversity composition, structure and function is a key component of monitoring and assessing the rivers of the park. Essentially, the desired outcomes of management are expressed as limits of acceptable change – termed Thresholds of Potential Concern. Thresholds of potential concern (TPCs) are upper and lower levels of change in selected indicators.

Strategic Adaptive Management has been used to manage the rivers of Kruger National Park. Within an overarching vision for the park, a biodiversity objective to 'maintain biodiversity in all its facets and fluxes' guides an ecosystem objective to understand and manage the KNP as part of the lowveld savanna and its river catchment areas in such a manner as to conserve and restore its varied natural structure, function and composition over time and space, and its wilderness qualities, through an approach integrating the different scales and types of objectives'. The water in the landscape objective sits within the ecosystem objective and aims to 'develop an integrated understanding of non-terrestrial ecosystem diversity and dynamics (including sub-surface water) and its links with terrestrial systems, and to maintain the intrinsic biodiversity as an integral component of the landscape and maintain or where necessary restore natural structure, function, composition and processes'. Commensurate with the goals of these objectives, TPCs have been set for the Sabie River to facilitate prediction and monitoring of biodiversity in response to hydrology, sediment supply and water quality (Rogers and Biggs, 1999). Geomorphological and vegetation indicators were developed to indicate ecosystem response to the main agents of change. Thresholds of Potential Concern that fall outside upper and lower limits of acceptable change are flagged and investigated further.

What does all this mean for monitoring and the selection of indicators in the Lake Eyre Basin? There are two points to consider. First, the selection of indicators must focus on the 'controlling variables' that drive change. Variables that address land use, vegetation patterns, channel morphology and relatively long live organisms such as fish and water birds. Second, in the absence of a historical data base, monitoring must be orientated to establish 'threshold of potential concern'. The initial development and selection of thresholds of potential concern can be guided from reliable conceptual models.

Towards a thresholds approach: selecting indicators for the Lake Eyre Basin

The Lake Eyre Basin River Assessment Project along with a host of other individual studies in the Lake Eyre Basin have produced an extensive and detailed list of indicators that could be used in a Lake Eyre Basin River Assessment Implementation Plan. An important outcome of this review process is that there is no `holy grail' of indicators of river health common to all riverine landscapes let alone the Lake Eyre Basin. Ideal indicator variables have features that include ease of measurement and relevance to river health, and can deliver early warning, or check compliance, or diagnose causes of poor health. Sampling to evaluate the indicators must be as stringent as any river science study and it is in the choice, scale, sampling and analyses of these variables that is the key to their applicability and success of determining the health of riverine landscapes. Issues of temporal and spatial scale are crucial when collecting data and interpreting the results. Many river health issues are directly related to the connectivity between rivers and their catchments, floodplains and wetlands; therefore working at the landscape scale is the most suitable. No single indicator alone is best and a synthetic approach that adopts a group of relevant metrics may prove most effective.

Management of rivers in semi-arid and arid regions does pose special problems when synthetic approaches are employed. This is because of the over-riding influence of the highly variable river-flow regime. Enhanced natural variability within the Basin has been used as an excuse in some jurisdictions to do as little as possible in terms of monitoring. It is recommended that indicators of river health that are selected take into account the scale of the Basin and its inherent flow variability and be used to generate hypotheses about or define the limits of acceptable change in river ecosystem structure and function. Monitoring for monitoring sake cannot be justified and is not sustainable in the long term for efficient natural resource management. Establishing a monitoring program that is orientated to establishing `Thresholds of Probable Concern' or TPCs; (Rogers & Biggs 1999) provides a clear and concise objective for monitoring and makes the choice of indicator (s) to be used in a whole of basin assessment easier.

Careful choice of TPCs provides indicators of threats to river health in the Basin. In Kruger National Park, for example, sedimentation threatens the biodiversity of bedrock-controlled rivers so a TPC reflecting permissible rates of change in bedrock in specific reaches is generated (Rogers & Biggs 1999). This approach extends to other aspects of the rivers in the park and yields a subset of the possible criteria that indicate threats to river health, resulting in a manageable number of indicators with which to assess ecosystem condition relative to stated goals. Choice of indicator must always be based on specific hypotheses of changes in response to threats.

6. Linkages with national monitoring, evaluation and reporting frameworks.

The Australian federal government and the various state and territory governments have a history of investment in developing methods for and assessing the health or condition of the nation's streams, rivers and watercourses. At the time of commencing the Lake Eyre Basin River Assessment Methodology project there were several other national programs on river health that were either in the final throes of completion, being developed or just about to be implemented. A short summary of each of these is provided in the following section in order to place the work done in a broader context of river health assessment within Australia. Three particular programs are of direct relevance to the Lake Eyre Basin River Assessment Methodology project; the first National Assessment of River Health and its precursors undertaken within the intensive land zone of Australia, the Sustainable Rivers Audit of river systems within the Murray Darling Basin and the development of the First Assessment of Wetlands and River Health, Australia.

The First National Assessment of River Health.

The first major investment in a river health program on Australia began with the development and implementation of the First National Assessment of River Health. This river health program focused on the in-channel environment and relied upon the routine collection of water and biological (macro invertebrates) samples and essentially provides a rapid assessment of the 'health' of rivers. While aquatic biota have been widely recognised as good indicators of river health and were a major focus of this assessment program, it is recognised that catchment and habitat conditions are important drivers of river health and these factors were not considered strongly in this program. The objectives of this River Health Program were to:

- Provide a sound information base on which to establish environmental flows;
- Undertake a comprehensive assessment of the health of inland waters, identify key areas for the maintenance of aquatic and riparian health and biodiversity, and identify stressed inland waters;
- Consolidate and apply techniques for improving the health of inland waters, particularly those identified as stressed; and
- Develop community, industry, and management expertise in sustainable water resources management and raise awareness of environmental health issues and needs of our rivers.

The AUSRIVAS (Australian River Assessment System) was a key component of the First National Assessment of River Health and one that has been implemented either it is entirety or derivations, in many regions of Australia. AUSRIVAS has two streams, Bioassessment and Physical assessment, that correspond with rapid biological assessment protocols and rapid geomorphic, physical and chemical assessment protocols respectively. There are different bioassessment streams: Macroinvertebrates, Fish, Diatoms, Macrophytes and Riparian Vegetation. Of these, the macroinvertebrate stream is the most highly developed. There have been a number of derivatives of the approach including the development of “Dirty Water Models” for streams in highly disturbed landscapes. Essentially AUSRIVAS is a multivariate approach to river assessment and like all methodologies has a number of advantages and disadvantages.

AUSRIVAS either samples and processes a variety of habitats separately or focuses on only one habitat. In this way it avoids confounding differences due to habitat representation with differences in community structure. The method does have temporal replication which indicates a degree of stability between years in only some regions. However, seasonal fluctuations are considered important, and therefore autumn and spring models have been developed. The methods have an objective procedure for matching environmental variables and macroinvertebrate community structure.

Noted disadvantages of the method include O/E ratio cutoff for impairment being arbitrary. This will require testing in other ecoregions like the Lake Eyre Basin. Indeed, there are limited data for systems like those in the Lake Eyre Basin that demonstrate how the O/E score responds to natural variability. Research has shown that O/E score for rivers within the Lake Eyre Basin do have considerable variability even in the absence of any major human disturbances. This variability can only be attributed to natural changes in assemblages associated with waterbodies drying. Thus there is a risk that AUSRIVAS only detects severely degraded sites, particularly in large floodplain rivers such as those of the Lake-Eyre Basin.

Since the inception of First National Assessment of River Health there has followed a number of other similar programs, most notably the National Land and Water Audit conducted in 2000.

National Land and Water Resources Audit

In 2000 the National Land and Water Resources Audit was commissioned to assess the condition of rivers within the intensive land zone of Australia. It provided an assessment of river condition (ARC) in terms of the environmental and biological condition for more than 14 000 river reaches (average length 14 km) within 193 catchments (average area 13 500 km^2) that covered most of the

Australian Capital Territory, New South Wales, Queensland, Victoria and significant areas of South Australia, Western Australia and Northern Territory (ASRIS 2001). The ARC assumes that a series of environment indices (ARCE) measure important environmental drivers to which biota respond, with the biota themselves being important measures of condition. Essentially the Biota Index (ARCB) represents the response of biota to environmental changes and in this audit it was calculated only using aquatic invertebrate data because there was a widespread and consistently collected data set. Invertebrate data collected at a site had been previously used extensively to assess the biological health of Australian rivers. The ARCE was composed of four sub indices, these being a Hydrological Disturbance Index; Suspended Sediment and Nutrient Load Index, Habitat Index and a Catchment Disturbance Index. The ARCE was used for general assessment and the sub-indices for more specific interpretation of the physical condition. All indices were calculated at the scale of river ‘reach’, defined on geomorphological principles. Details of the approach taken, development of methods, their application, analysis, and the preliminary interpretation of results are provided in Norris *et al* (2007).

The Sustainable Rivers Audit of the Murray Darling Basin

The Sustainable Rivers Audit (SRA) is a program designed to measure the health of the rivers at this large Basin scale. It aims to:

- determine the ecological condition and health of river valleys in the Murray-Darling Basin;
- provide a better insight into the variability of river health indicators across the Basin and over time;
- eventually help us detect trends in river health over time; and
- trigger changes to natural resource management by providing a more comprehensive picture of river health than is currently available.

The SRA was initiated by the Murray-Darling Basin Commission involving partner agencies in each state and territory within the Basin. It uses scientific indicators of health to determine the current status of the Basin's rivers and any potential trends. Groups of indicators or “themes” for immediate implementation include fish, macroinvertebrates and hydrology. Indicator themes to be further developed over the forthcoming years include floodplains; riparian vegetation and the physical form of river channels. Fish communities and populations are sampled during normal flow conditions, across entire river valleys in the one season, and once every three years at all 23 valleys in the Basin. Macroinvertebrate populations are also be sampled during normal flow conditions, across entire river valleys in the one season, but once every two years across the Basin. Hydrology information is also collected every six years and evaluated using long term river flow sequences developed by the States. When there are major changes to river flows through new structures being built or environmental flow allocations, additional computer modelling will be needed. The assessment and interpretation of the SRA's results are done by an Independent Sustainable Rivers Audit Group (ISRAG) which reviews data from each valley in detail by looking at results related to each indicator theme (fish, macroinvertebrates, hydrology); across indicator themes; across valleys; and over time.

Framework for the Assessment of River and Wetland Health

The National Water Commission has developed a national framework that aims to form the basis of future national river and wetland health assessments, and to provide the capacity to bring together results of existing broad-scale assessments conducted at state, territory and basin scales.

Understanding the environmental condition of Australia's aquatic ecosystems is central to their management. The Framework for the Assessment of River and Wetland Health (FARWH) was developed when scoping undertaken for the Australian Water Resources 2005 baseline assessment identified difficulties in reporting on river and wetland health in a comparable manner within and across jurisdictions, and deficiencies in the level of information available for current NWI reporting requirements.

The FARWH aims to:

- develop an approach that can be used by the Australian Government and all states and territories to provide nationally comparable assessments of river and wetland health;
- incorporate a critical suite of river and wetland attributes that indicate key ecological processes and are conceptually appropriate for comprehensive assessments of river and wetland health; and
- interpret and prioritise the causes of observed environmental degradation using the measured attributes.

The FARWH does not generate data itself or replace existing monitoring and assessment programs. Rather, it provides a methodology to integrate and aggregate the data collected by the states and territories to be reported at a water management area scale. This provides an important link between aquatic ecosystem health and water management planning. It has also been designed to ensure that the outputs from previously conducted and future monitoring and assessment activities in the states and territories are nationally comparable.

The FARWH uses a conceptual model of river and wetland function, based on six ecologically significant components that should be represented in all future river and wetland health assessments. These key ecological components are:

- catchment disturbance;
- hydrological change;
- water quality and soils;
- physical form;
- fringing zone; and
- aquatic biota.

The Australian Rangelands Information System

The Australian Rangelands Information system is based on four key types of information

1. changes in biophysical resources (eg. Nutrients, water, plants and wildlife);
2. changes in impacts on these biophysical resources (eg. Trends in land use intensity, climate and fire history, land clearing, spread of weeds);
3. trends in social and economic factors; and
4. institutional responses.

Landsat satellite data for vegetation cover is a particular relevant tool from the Australian Rangelands Information System Operational Manual seen as potentially useful in ephemeral river catchments. This involves the use of Landsat MSS and TM data to indicate change in the capacity of landscapes to conserve resources. The method employs a landscape-cover change analysis measuring changes in the trend of a cover index (such as perennial species vs. bare ground) or changes in the variability of cover over time (such as perennial species vs. annual species). The method is an extremely useful approach for determining floodplain and catchment scale indicators of ecosystem health.

The Index of Stream Condition (ISC)

The Index of Stream Conditions (ISC) was developed in Victoria as a tool to assist the management of Victoria's waterways. It was designed to assess the "health" or condition of rural streams, with results reported approximately every 5 years for stream reaches of lengths between 10 and 30 kilometres long.

For each stream reach the ISC provides a summary of the extent of changes to:

- hydrology (flow volume and seasonality);
- physical Form (stream bank and bed condition, presence of, and access to, physical habitat);
- streamside zone (quantity and quality of streamside vegetation and condition of billabongs);
- water quality (nutrient concentration, turbidity, salinity and acidity); and
- aquatic life (diversity of macroinvertebrates).

The ISC was intended to provide measures of the health of both the aquatic biota and the drivers that may impact on this health. The following sub-indices are included in the overall condition index.

Hydrology Sub-Index

This sub-index had the following indicators:

- The Annual Proportional Flow Deviation
- Flow variation due to a change in catchment permeability
- Flow variation due to peaking hydroelectric stations

Physical Form Sub-Index

This sub-index had the following indicators:

- Bank and bed stability
- Impact of artificial barriers on fish migration
- Instream physical habitat

Streamside Zone Sub-Index

This sub-index had the following indicators:

- Width of streamside zone
- Longitudinal continuity
- Structural intactness

Water Quality Sub-Index

This sub-index had the following indicators:

- Total phosphorous
- Turbidity
- Salinity / Conductivity
- Alkalinity / Acidity (pH)

Aquatic Life Sub-Index

This sub-index had the following indicators:

- AUSRIVAS Scores
- SIGNAL Scores

Cover of exotic vegetation
Regeneration of indigenous woody vegetation
Billabong condition

The inclusion of both pressure and response indicators makes the ISC is appealing for many assessment studies. However, the ISC has only one component measuring the aquatic life of rivers systems; that being macroinvertebrates. These are not the ideal biotic monitor for the large, highly variable rivers systems like those in the Lake Eyre Basin.

Integrated Monitoring of Environmental Flows (IMEF)

IMEF was established by the former New South Wales Department of Land and Water Conservation to provide an understanding of the response of seven major rivers and associated floodplains and wetlands to the provision of environmental water allocations.

The objectives of the IMEF were to:

- investigate the relationships between water regimes, biodiversity and ecosystem processes in the major regulated rivers systems of NSW and the Barwon-Darling River;
- assess responses in hydrology, habitats, biota and ecological processes associated with specific flow events targeted by environmental flow rules, and
- use the resulting knowledge to estimate likely long-term effects of environmental flow rules and provide information to assist in future adjustment of rules.

Variables suggested for measurement were:

Flow volume (use of gauge data)	Organic matter (dissolved and particulate organic carbon)
Wetted Area (surveying, satellite data)	Cyanobacteria (chlorophyll a)
Current velocity (hydraulic current meters)	Bioflims (floristic analysis; pigment analysis)
Channel Morphology (surveying)	Water plants (transect / Quadrat surveys)
Temperature	Invertebrates (sweep and kick nets)

Turbidity	Fish (electrofishing)
Dissolved Oxygen	Frogs (call identification)
Salinity	Water birds (transect or point surveys)
Sediment laminae	Production & respiration (chamber measurement)
Nitrogen & Phosphorous	Food sources (stable isotope analysis)

Many of the suggested indicators have also been used and incorporated in other Assessment Programs.

Queensland State of the Rivers

The aim of Queensland's State of the Rivers Assessment was to obtain data that accurately described the condition of surveyed river systems. The method was to also provide a way of assessing the extent of degradation, the potential for problems to exist, and identify the possible causes of degradation. The method was not designed to establish current or historical trends, nor does it indicate the rate of change in stream condition. However, follow-up projects were anticipated to occur in order that historical trends may be obtained. The final output of the Queensland State of the Rivers Assessment is the description of the physical and ecological condition of river systems along with an extensive data base of the natural attributes of these systems. The State of the Rivers procedure was developed to provide the Queensland DPI with a tool to assess the physical and environmental health of rivers and streams. The approach focuses on the collection of habitat data (geomorphology and vegetation).

The following attributes are measured:

- Reach environmental condition – assessment of land-use, vegetation, floodplain features, tenure and an estimation of water level
- Channel Habitat Diversity – assessment of the range of channel habitats such as waterfall, riffle, rapid, run, pool etc. in a reach
- Bed, Bank and Bar Condition – assessment of the distribution of bars, the stability of banks and bed and any restrictions to fish passage
- Vegetation – assessment of the aquatic and riparian vegetation recorded in terms of percentage cover, structure and presence of key species

- Aquatic Habitat – assessment of the diversity of in-stream habitat types (eg. Logs, branches, substrate etc).
- Scenic, recreational and conservation values – assessment of the recreational opportunities, scenic quality and conservation status of the stream

Considerations for monitoring and evaluating

Monitoring programs need to be specifically developed or modified for use in arid zone rivers, like those within the Lake Eyre Basin, because of their naturally high levels of hydrological variability and associated high degree of spatial heterogeneity in biophysical character. Any monitoring program is dependent on the researcher having first articulated the desired state to which the system should conform. Within arid zone river systems 'state' will by necessity be a dynamic state with a range of characters, populations or communities over space and time. Thus any monitoring of arid zone river systems will require knowledge of the system's attributes and behaviour (structure, composition, function and dynamics), either gained through intensive prior study (baseline surveys) or through modelling (which itself must be based on a combination of sound theory and intensive study of comparable systems elsewhere).

It is evident that at the time of development there was no program or method specifically available to assess the condition of rivers within the Lake Eyre Basin. Indeed, as further demonstrated by the results of two significant aquatic research programs conducted on the river systems of the Lake Eyre Basin (Aridflow and the CRC for Freshwater Ecology's Dryland Refugia Program), important components of a sound adaptive management cycle must include theory-driven hypothesis articulation (conceptual models of river function, health and predicted responses); focussed study (gap identification, data acquisition, information gain); indicator selection; target setting (incorporating ecosystem modelling); and monitoring of selective indicators. In this way the twin objectives of (i) increasing understanding of how and why ecosystems function, and (ii) refinement of indicators and their expected response to drivers of change, can be met through time with each repetition of the management cycle.

7. Monitoring actions that can be undertaken immediately

The following outlines those monitoring actions that can be undertaken immediately and the methods for the collection of these data. It is pertinent to note that the components recommended represent a combination of 'controlling or slow variables', 'responding or fast variables' and potential drivers of change that can be used to assess resilience of the river ecosystems within the Lake Eyre Basin. This list does not represent as exhaustive list as there is much Research and Development to be undertaken. The six components recommended are Physical Habitat, Fish, Waterbirds, Riparian Vegetation (controlling variables), Water Quality (responding or fast variable) and Hydrology (both a driver of change and a controlling variable). In order for hydrology to be used as a controlling variable, a catchment based hydrological model would need to be constructed. This hydrological model would then enable the effects of climate and land use to be assessed on the spatial and temporal availability of water through out the Lake Eyre Basin. Detailed for each of these six components are:

- the value and pressures to the component
- drivers and risks to the component as well as management actions to be taken
- a list of indicators for each component
- recommended sampling methods, including frequency and scale of sampling
- analysis and reporting methods and the costs of undertaking this monitoring exercise.

Fish assemblage diversity indicator

(Waterholes and wetlands theme, Waterholes and Wetland Biodiversity Attribute)

Acknowledgements

Stephen Balcombe, ARI, Griffith University

Values

- iconic element
- cultural significance
- indicator of cumulative aquatic ecosystem condition

Pressures, drivers, risks and management actions

Table 3: Links with pressures, drivers, risks and actions: Fish assemblage set

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• floodplain harvesting	• creation of barriers to fish movement across floodplain channels	High
• damming	• reduced habitat complexity of waterholes • reduced connectivity between waterholes • form barriers fish movement	High
• water extraction	• alterations to amount and quality of habitat • removal of juvenile life stages	Moderate - High
• pumping from shallow groundwater	• alterations to amount and quality of habitat • removal of juvenile life stages	Moderate - High
Grazing		
• floodplain grazing during dry phase	• altered water quality (increased nutrients) • reductions in primary productivity through trampling of algal 'bath-tub ring'	Moderate
• total grazing on floodplain	• altered soil structure, nutrient content and vegetation may influence amount & quality of food for fish on re-flooding. • changes to amount and quality of nursery habitat in riparian and floodplain areas	Moderate
Tourism		
• tourism during dry phase	• increased nutrient inputs • removal of woody debris and vegetation (for firewood)	Moderate
• recreational fishing	• reductions in refugial fish stocks and potential to re-populate satellite waterholes following flows/floods • removal of large-bodied adults and recruitment potential • use of non-LEB live bait may introduce alien fish and invertebrates	Moderate

Pressure / driver / risk	Potential impacts	Level of risk
Fishing		
• overfishing	• reductions of refugial fish stocks	Moderate
• introduced species	• shifts in fish assemblages	Moderate
• failure to recognise key species, e.g. Cooper catfish, Finke goby and Finke hardyhead.	• shifts in fish assemblages	Low - Moderate
• translocation of native fish from other basins	• shifts in fish assemblages	Low - Moderate
Other		
• road crossings and culverts	• local threat to fish assemblages and ecological functioning of waterholes	Low
• toxic impacts of stock vaccination via faeces	• reductions in water quality	Uncertain at present
• feral animals	• as for grazing	Uncertain at present
• climate change	• altered ecological functioning of waterholes	Moderate - High

(Sourced from information in McNeil et al. 2006)

Alignment with national reporting frameworks

1. FARWH

- Aquatic biota index

2. National Framework for NRM Standards and Targets

- Fish community assemblages (Integrity of inland aquatic ecosystems (rivers and other wetlands): river condition)
- Significant native species and ecological communities
- Ecologically significant invasive species

Specific indicators

Table 4: Specific indicators for Fish Assemblages set

Indicator	Links to pressures/drivers/risks
Species richness	- overall indicator of fish assemblage condition - narrow range but should be relatively stable at regional and within-catchment scales - changes indicate anthropogenic disturbance
Abundance	- broad ranges and sensitive to antecedent flow conditions - increases indicate recruitment - decrease indicate mortality during disconnection phase
Abundance of alien species	- narrow range and relatively stable - increases indicate changed conditions (e.g. increase number of weirs pools) - increased number of species indicates new introductions (eg.

Indicator	Links to pressures/drivers/risks
	common carp & tilapia)
Recruitment	- indicates successful spawning - broad range depending on antecedent flow conditions - absence of recruitment in most species in any year should indicate anthropogenic disturbance
Population size structure	- indicator of past recruitment - truncated length frequencies may indicate fishing pressure
Abundance of detritivores	- sensitive to antecedent flow conditions
Prevalence of disease	- may be useful as warning of poor waterhole condition

(Sourced from information in McNeil et al. 2006)

Sampling

Sampling methods

A combination of seine, fyke and dip nets may be used depending on the amount of surface water present at the time of survey (McNeil & Reid, 2008). Standard mesh sizes and inlet diameters should be selected and fyke nets should be set overnight (c. 15 hours). Fish from emptied nets should be identified to species, measured (standard length in mm), visually inspected for signs of external disease and returned to the water alive.

Water quality parameters should be measured in conjunction with fish sampling (see below).

Sampling frequency

Sampling should be conducted twice a year; once near the end of the dry season (November) and once after the wet season recedes (March/April). This will enable assessment of fish assemblage resistance, i.e. tolerance of dry and disconnected conditions, and resilience, i.e. response to flows or floods (McNeil et al. 2006).

Spatial scale of sampling

The spatial arrangement of sites should be broadly based on recommendations provided by Sheldon et al. (2005) with each catchment divided into 3 regions as appropriate; Headwaters, River Channels & Waterholes and Terminating Wetlands. Sheldon et al. (2005) recommend a minimum of i) 20 sites across all of the headwater zones of the Thompson, Barcoo, Georgina and Diamantina Rivers, ii) 50 sites across the River Channels & Waterholes zone of the Cooper channel country, lower Cooper, Diamantina channel country, lower Diamantina and the western rivers, including the Neales, and iii) 10 terminal wetland sites including Lake Galilee, Buchanan and Yamma Yamma in Queensland and Lakes Frome, Blanche and Eyre in South Australia.

Sampling should be conducted from waterbodies (or sites) within representative reaches that comprise a permanent waterhole (persistently sampled) and several semi-permanent satellite waterholes (which may change between sampling events depending on water levels) (McNeil et al. 2006). At least 2, but preferably 3, representative reaches should be sampled within each region in each catchment. In terminal wetlands that do not have clusters of lakes or waterholes, multiple representative sites should be included. Additionally, critical or potentially impacted sites should be included, e.g. waterholes around Longreach or Innamincka.

Table 5 provides an indication of the potential spatial arrangement of fish monitoring sites. Site selection would need to be finalised prior to the commencement of sampling.

Analysis and reporting

Prior to analysis combined samples from fyke and seine nets should be standardised to set durations or areas respectively in order to describe abundance (see Balcombe & Kerezy, 2008).

For each representative reach (or critical site) at each survey time, the following variables should be calculated:

- species richness
- abundance/proportion of each taxon present (including alien species)
- size distributions of common taxa (plots)
- abundance/proportion of detritivores present
- the proportion of individuals in each taxon exhibiting signs of disease

Data across sites should also be scaled-up to region and catchment for the following variables:

- species richness
- abundance/proportion of each taxon present (including alien species)
- frequencies of length/size classes of common taxa
- abundance/proportion of detritivores present
- the proportion of individuals in each taxon exhibiting signs of disease

Assessment of variables should then be based on the fish trajectory model (FTM) developed for the LEBRA as described in McNeil et al. (2006) and Humphries et al. (2007) and demonstrated in Queensland (Balcombe & Kerezy, 2008) and South Australia (McNeil & Reid, 2008).

Table 5. Spatial arrangement of fish monitoring sites

Catchment	Region	# Representative Reaches	# Sites	Potential reaches / critical sites for inclusion
Cooper	Thompson headwaters	2-3	~ 5	- Aramac Springs (DIWA) - Cauckingburra Swamp (DIWA) - upper Thomson River at 'Camoola Park' (historic QNRM Water quality monitoring sites: Sheldon et al. 2005) - Aramac Creek (historic QNRM Water quality monitoring sites: Sheldon et al. 2005)
	Barcoo headwaters	2-3	~ 5	- upper Barcoo River at Blackall (historic QNRM Water quality monitoring sites: Sheldon et al. 2005)
	Channel Country river channels & waterholes	3-4	~ 15	- Cooper Ck – Wilson River junction (DIWA) - Cooper Ck Overflow Swamps – Windorah (DIWA) - Cooper Ck Swamps – Nappa Merrie (DIWA) - Longreach township - CRCFE Dryland Refugia Sites
	Lower Cooper river channels & waterholes	2-3	~ 8	- Strzelecki Creek Wetland System (DIWA) - Innamincka township - ARIDFLO sites
	Terminal wetlands	n.a.	~ 5	- Lake Buchanan (DIWA) - Lake Galillee (DIWA) - Lake Cuddapan (DIWA) - Lake Yamma Yamma (DIWA) - Lake Blanche (part of Strzelecki Ck system, DIWA)
Diamantina / Georgina	Diamantina headwaters	2-3	~ 5	- Elizabeth Springs (DIWA)
	Georgina headwaters	2-3	~ 5	- Austral Limestone Aggregation (DIWA)
	Channel Country river channels & waterholes	3	~ 15	- Birdsville-Durrie Waterholes Aggregation (DIWA) - Diamantina Lakes Area (DIWA) - Diamantina Overflow Swamp – Durrie Station (DIWA) - Georgina River – King Creek Floodout (DIWA) - Mulligan River – Wheeler Creek junction (DIWA) - Muncoonie Lakes Area (DIWA) - Toko Gorge and Waterhole (DIWA)
	Lower Diamantina / Georgina river channels & waterholes	2	~ 8	- Diamantina River Wetland System (DIWA) - ARIDFLO sites
	Terminal wetlands	n.a.	~ 5	- Coongie Lakes (Ramsar, DIWA) - Lake Constance (DIWA) - Moondah Lake – Shallow Lake Aggregation (DIWA) - Lake Mipia Area (DIWA)

Catchment	Region	# Representative Reaches	# Sites	Potential reaches / critical sites for inclusion
				- Lake Phillipi (DIWA - Lake Torquinie Area (DIWA) - Lake Eyre (DIWA)
Western Rivers	Channels & waterholes	1-2	~ 4	
	Terminating wetlands	1-2	n.a.	- Lake Frome (Inland Saline Lakes: DIWA)
Total # sites in headwater regions			**~ 20**	
Total # sites in river channels & waterholes region			**~ 50**	
Total # sites in terminating wetlands			**~ 12**	
TOTAL # sites			**~ 82**	

Table 6: Costs for Fish Assemblage set

Item	Estimated cost	# of days	Total	Frequency	Annual Total
Field preparation Final site selection (workshop?)				once at beginning of monitoring programme	$15,000
Field surveys Field staff	$1,000 per day ($500 p.p. per day x 2 field staff)	90 days per sampling date (1.5 days per site (including travel) x 82 sites + extra travel time	$90,000	twice per year	$180,000
Accommodation	$140 per night ($70 p.p. per night x 2 staff)	90 nights per sampling date	$12,600	twice per year	$25,200
Consumables (food etc.)	$100 per day ($50 p.p. per day)	90 days	$9,000	twice per year	$18,000
Travel	$15,000 (20,000 km @ $0.75 km) N.B. mileage estimate for 2 cars travelling from Brisbane (6,000 km trip) & 2 cars travelling from Adelaide (4,000 km trip)	-	$15,000	twice per year	$30,000
Field equipment				once at beginning	$10,000
Total Field Survey costs			**$126,600 per sampling date**		**$263,200 per year (+$10,000 initially)**
Data analysis & reporting					
Data entry	$500 per day (2 x junior staff)	10 days	$5,000	twice per year	$10,000
Data analysis	$1,000 per day (2 x senior staff)	10 days	$10,000	twice per year	$20,000
Report preparation	$1,000 per day (2 x senior staff)	10 days	$10,000	twice per year	$20,000
Total data analysis & reporting			**$25,000 per sampling date**		**$50,000 per year**
TOTAL			**$151,600 per sampling date**		**$313,200 per year (+$25,000 initially)**

(N.B. The above staff and time requirements and costs are based on advice provided by Dr. Stephen Balcombe, ARI, Griffith University)

Colonial waterbirds diversity and breeding indicator

(Waterholes and wetlands theme, Waterholes and Wetland Biodiversity Attribute)

Acknowledgements:

John Porter, Australian Rivers & Wetlands Group, University of New South Wales

Values

- iconic element
- cultural and political significance
- indicator of broad-scale environmental health
- existence of long-term data sets for trends-based analyses

Pressures, drivers, risks and management actions

Table 7: Links with pressures, drivers, risks and actions: Waterbird set

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• reduction of flows to wetlands	• reductions in waterbird abundance, diversity and breeding	Moderate - High
• reduced durations and depths of wetland flooding	• reductions in waterbird abundance, diversity and breeding	Moderate - High
• conversion of floodplain lakes to storages	• reductions in waterbird abundance, diversity and breeding	Moderate - High
Grazing		
• vegetation management (e.g. lignum burning, clearing)	• reduced quantity and quality of nesting habitat	Moderate
Tourism		
• tourism during dry phase	• disturbance of waterbirds at refugial sites	Low
Other		
• invasive species	• potential colonisation of wetland habitats and reduction of primary productivity and food availability	Low - Moderate
• climate change	• altered ecological functioning of wetlands	Moderate - High

(Sourced from information in Kingsford & Porter 2008)

Alignment with national reporting frameworks

1. FARWH

- Aquatic biota index

2. National Framework for Natural Resource Management Standards and Targets

- Significant native species and ecological communities
- Ecologically significant invasive species

Specific indicators

Table 8: Specific indicators for Waterbird set

Indicator	Links to pressures/drivers/risks
total abundance of colonial waterbirds	- overall indicator of waterbird assemblage condition - changes may indicate altered water quality or flow regime
species richness of colonial waterbirds	- reflects changes in flooding regime
abundance of functional groups of waterbirds	- reflects changes in flooding regime - reflects condition of habitat and food supply
community composition	- overall indicator of waterbird assemblage condition - changes may indicate altered water quality or flow regime
presence/absence of particular species (e.g. threatened species)	- reflects changes in flooding regime
abundance of breeding birds	- sensitive to antecedent flow conditions - reflects condition of habitat, e.g. lignum and reed swamps
species richness of breeding birds	- sensitive to antecedent flow conditions - reflects condition of habitat, e.g. lignum and reed swamps

(Sourced from information in Kingsford & Porter 2008)

Existing monitoring

The Aerial survey of waterbirds in eastern Australia, currently managed by NSW DECC and executed by the Australian Rivers and Wetlands Group at the University of New South Wales, has been conducted annually in October since 1983. One of the ten 30 km wide survey bands passes through Lake Eyre and the lower Cooper and some other significant wetlands in the eastern part of the basin, e.g. Lake Galilee, are also covered by this survey. A list of other waterbird monitoring data from historical surveys, mostly at finer spatial resolutions, is provided in Kingsford and Porter (2008).

Sampling

Sampling methods

Waterbirds should be monitored using aerial surveys following the existing methodology currently employed in the ongoing Aerial survey of waterbirds in eastern Australia (see Kingsford & Porter 2008 for a summary). Kingsford & Porter (2008) also recommend monitoring of key breeding events using additional on-ground surveys. Whilst likely to be very valuable and informative, these are considerably more expensive than aerial surveys and are not included in this initial proposal for immediate monitoring.

Sampling frequency

Aerial surveys should be conducted once a year during the spring period (October) and more frequently in years with significant flow events. It is recommended that the current eastern aerial survey which is conducted in October be extended to incorporate wetlands of known significance for waterbirds in the parts of the Lake Eyre Basin not currently covered by the survey. In wet years, it is proposed that an additional stand-alone aerial survey of flooded wetlands in the basin also be undertaken in order to monitor breeding colonies. This would be best conducted a month or two following maximum wetland inundation, e.g. March or April. The proposed timing of these surveys would also allow comparisons between waterbird and fish monitoring data.

Spatial scale of sampling

Waterbirds should be monitored at the wetland scale. Wetlands significant to waterbirds in the Lake Eyre Basin are reasonably well known (*pers comm.* John Porter) from previous aerial surveys, e.g. eastern aerial survey, 2008 National Waterbirds Survey and additional surveys within the basin as listed in Kingsford and Porter (2008). The survey would concentrate on wetlands listed in the Directory of Important Wetlands (see Table X above) and those known to support high concentrations of waterbirds following inundation, e.g. Lake Eyre, Lake Galilee, Lake Hope, Lakes Torquinie and Mubmleberry, Lake Machattie, Lakes Koolivoo and Mippia (Kingsford & Porter, 2008).

Analysis and reporting

Analysis and reporting could be done at wetland, catchment and whole-of-basin scales.

Costs

The following costs have been developed in consultation with Dr. John Porter of the Australian Rivers & Wetlands Unit at the University of NSW.

Table 9: Costs for Waterbirds set

Item	Estimated cost	Annual Total
Expansion of existing eastern aerial waterbird survey (October annually)		
Aircraft & pilot	$450 hr x approx. x ~ 30 hrs (+30 % multiplier)	$17,550
Project coordinator (0.5 FTP – surveys, data entry, analysis & reporting)	$60,00 (+ 30 % multiplier)	$78,000
Survey staff	$1000 p.p. per day x 2 staff members x 3 days (+ 30 % multiplier) (salary and travel expenses)	$7,800
Total for expansion of existing survey		**$103,350**
Stand-alone survey in wet years (March/April)		
Aircraft & pilot	$450 hr x approx. x ~ 96 hrs (+30 % multiplier)	$56,160
Project coordinator (0.5 FTP – surveys, data entry, analysis & reporting)	already covered by expansion of existing survey (above)	$0
Survey staff	$1000 p.p. per day x 2 staff members x 12 days (+ 30 % multiplier) (salary and travel expenses)	$31,200
Total for expansion of existing survey	**$103,350**	**$87,360**
TOTAL	**in dry year**	**$103,350**
	in wet year	**$190,710**

Riparian vegetation structure indicator

(Riparian and floodplain theme, Riparian and Floodplain Biodiversity Attribute)

Values

- iconic
- social and cultural significance
- economic importance
- significant for ecosystem function

Links with pressures, drivers, risks and management actions

Table 10: Links with pressures, drivers, risks and actions: Vegetation set (riparian)

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• altered hydrological regimes	• changes in composition, structure and condition of riparian vegetation communities • declining condition and mortality of structural perennial species, i.e. red gums, coolabah, lignum, reeds • reduced recruitment in woody species • increased invasion by exotic species • encroachment by mesic and xeric species	High
• pumping from shallow groundwater	• changes in composition, structure and condition of ground-water dependent/influenced communities	Moderate
Grazing		
• floodplain grazing during dry phase	• changes in composition, structure and condition of riparian vegetation communities • reduced recruitment of riparian trees	Moderate - High
Tourism		
• tourism during dry phase	• removal of vegetation • introduction of exotic species	Moderate
Other		
• road crossings and culverts	• altered flooding patterns may result in changes in composition, structure and condition of riparian vegetation communities	Low
• feral animals	• as for grazing	Uncertain at present
• climate change	• altered ecological functioning of waterholes and wetlands	Moderate - High

Alignment with national reporting frameworks

1. FARWH

- Fringing zone index

2. National Framework for Natural Resource Management Standards and Targets

- Riparian vegetation community assemblages (Integrity of inland aquatic ecosystems (rivers and other wetlands): river condition)
- Vegetation (Integrity of inland aquatic ecosystems (rivers and other wetlands): wetland condition)
- Significant native species and ecological communities
- Ecologically significant invasive species

Specific indicators

Table 11: Specific indicators for Vegetation set (riparian)

Indicator	Links to pressures/drivers/risks
% cover of 3-5 dominant woody species in upper (e.g. red gum, coolabah, river cooba) and middle (e.g. lignum) layers	- changes may indicate altered flow regime or anthropogenic disturbance
% herbaceous ground cover	- sensitive to antecedent flow conditions
% cover aquatic vegetation (submerged, floating, emergent)	- sensitive to antecedent flow conditions
% cover of exotics	- changes may indicate altered water quality or flow regime or anthropogenic disturbance
native regeneration	- reflects changes in flooding regime
width of riparian zone	- changes may indicate altered flooding regime or anthropogenic disturbance
longitudinal connectivity	- changes may indicate altered flooding regime or anthropogenic disturbance

(Adapted from Appendix A, River Condition Indicator Status: http://www.nrm.gov.au/publications/factsheets/me-indicators/index.html)

N.B. It should be noted that the above indicators, recommended by the NRM Standards and Targets, differ slightly from those in the most recent Index of Stream Condition. A decision on final indicator selection will be necessary prior to initiation of monitoring and may depend on expertise of field staff.

Sampling

Sampling methods

Sampling methods should follow those developed for the Index of Stream Condition, until a nationally applicable monitoring technique, currently under review, is developed (see Victorian DSE, 2006. Index of Stream Condition: User's Manual 2nd edition).

Spatial scale of sampling

Riparian vegetation structure should be surveyed at the site or waterbody level in conjunction with fish sampling.

Sampling frequency

Riparian vegetation structure should be surveyed annually in conjunction with March/April fish sampling, i.e. following recession of floodwaters.

Analysis and reporting

Analysis and reporting should follow methods developed for the index of Stream Condition as per 'Streamside Zone sub-index' (see ISC Factsheets http://www.ourwater.vic.gov.au/monitoring/river-health/isc/resources).

Costs

It is recommended that riparian vegetation structure be assessed in conjunction with fish surveys. As most of the specific indicators require minimal training, an additional staff member could join fish survey teams. Due to the timing of fish survey activities, field staff could then assist each other as required. This would also reduce travel costs significantly. Reporting and analysis would need to be conducted separately.

Table 12: Costs for Vegetation set (riparian)

Item	Estimated cost	Annual Total
Field surveys		
Staff (1 additional staff member on fish surveys)	$500 per day x 90 days (1.5 days per site (including travel) x 82 sites + extra travel time (salary and travel expenses)	$45,000
Travel	$0 if accompanying fish survey team	**$45,000**
Data analysis and reporting		
Staff	~0.25 FTP + on-costs	$30,000
TOTAL		**$75,000**

Wetland vegetation condition indicator (DIWA wetlands)

(Riparian and floodplain theme, Riparian and Floodplain Biodiversity Attribute)

Background

The state and territory governments have identified 33 nationally important wetland complexes covering over 5 million ha within the LEB (Directory of Important Wetlands in Australia). These are:

Aramac Springs, Austral Limestone Aggregation, Birdsville - Durrie Waterholes Aggregation, Cauckingburra Swamp, Coongie Lakes, Cooper Creek - Wilson River Junction, Cooper Creek Overflow Swamps - Windorah, Cooper Creek Swamps - Nappa Merrie, Dalhousie Springs, Diamantina Lakes Area, Diamantina Overflow Swamp - Durrie Station, Diamantina River Wetland System, Elizabeth Springs, Finke River Headwater Gorges System, Georgina River - King Creek Floodout, Inland Saline Lakes, Lake Buchanan, Lake Constance, Lake Cuddapan, Lake Eyre, Lake Eyre Mound Springs, Lake Galilee, Lake Mipia Area, Lake Phillipi, Lake Torquinie Area, Lake Yamma Yamma, Mitchell Swamp, Moonda Lake - Shallow Lake Aggregation, Mulligan River - Wheeler Creek Junction, Muncoonie Lakes Area, Strzelecki Creek Wetland System, Sturt National Park Wetlands, Toko Gorge and Waterhole.

Two of these wetlands (Coongie Lakes and Lake Pinaroo) are listed under the Ramsar Convention on Wetlands of International Importance.

Values

- iconic
- social and cultural significance
- economic and political importance
- significant for ecosystem function

Alignment with national reporting frameworks

1. FARWH

- Fringing zone index

2. National Framework for Natural Resource Management Standards and Targets

- Riparian vegetation community assemblages (Integrity of inland aquatic ecosystems (rivers and other wetlands): river condition)
- Vegetation (Integrity of inland aquatic ecosystems (rivers and other wetlands): wetland condition)
- Significant native species and ecological communities
- Ecologically significant invasive species

Links with pressures, drivers, risks and management actions

Table 13: Links with pressures, drivers, risks and actions: Vegetation set (wetland)

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• altered hydrological regimes	• changes in composition, structure and condition of riparian vegetation communities • declining condition and mortality of structural perennial species, i.e. red gums, coolabah, lignum, reeds • reduced recruitment in woody species • increased invasion by exotic species • encroachment by mesic and xeric species	High
• pumping from shallow groundwater	• changes in composition, structure and condition of ground-water dependent/influenced communities	Moderate
Grazing		
• floodplain grazing during dry phase	• changes in composition, structure and condition of riparian vegetation communities • reduced recruitment of riparian trees	Moderate - High
Tourism		
• tourism during dry phase	• removal of vegetation • introduction of exotic species	Moderate
Other		
• road crossings and culverts	• altered flooding patterns may result in changes in composition, structure and condition of riparian vegetation communities	Low
• feral animals	• as for grazing	Uncertain at present
• climate change	• altered ecological functioning of waterholes and wetlands	Moderate - High

Specific indicators

Table 14: Specific indicators for Vegetation set (wetland)

Indicator	Links to pressures/drivers/risks
Floristic composition	- sensitive to antecedent flow conditions - changes may indicate altered flow regime, water quality or anthropogenic disturbance - changes may indicate impacts of exotic species
species richness	- sensitive to antecedent flow conditions - changes may indicate altered water quality or flow regime or anthropogenic disturbance - changes may indicate impacts of exotic species
% canopy cover	- changes may indicate altered flooding regime or anthropogenic disturbance
% foliage cover of understorey species	- sensitive to antecedent flow conditions - changes may indicate altered water quality or flow regime or anthropogenic disturbance - changes may indicate impacts of exotic species
foliage cover	- changes may indicate altered flooding regime or anthropogenic disturbance
height ranges of vegetation layers (trees, shrubs, understorey)	- changes may indicate altered flooding regime or anthropogenic disturbance
tree vigour	- changes may indicate altered flooding regime, water quality or anthropogenic disturbance
population size structure	- changes may indicate altered flooding regime or anthropogenic disturbance

(Adapted Wetland Ecosystem Condition: Vegetation - Indicator Status: http://www.nrm.gov.au/publications/factsheets/me-indicators/index.html)

Sampling

Sampling methods

Sampling methods should follow those described in detail in the Wetland Ecosystem Condition: Vegetation - Indicator Status fact sheet (part of the National Framework for Natural Resource Management Standards and Targets) available at: http://www.nrm.gov.au/publications/factsheets/me-indicators/index.html.

In summary, these methods involve surveying between 3 and 6 permanently established transects running from upland areas into the lowest elevations of the wetland, preferably where emergent macrophytes are present. The number and location of transects per wetland will depend on its vegetation diversity and should be selected from aerial photos etc. prior to the first field survey. Transects should comprise contiguous 20m x 20m quadrats in which measurements will be taken at varying scales including % canopy cover, % cover of understorey speciesand DBH of trees.

Spatial scale of sampling

Wetland vegetation composition should be conducted in all of the wetlands listed in the Directory of Important Wetlands.

Sampling frequency

Wetland vegetation condition should be surveyed annually. The timing of surveys may vary depending on hydrological conditions but should be conducted at the same time of year where possible. An April survey date may be appropriate for many wetlands in the Lake Eyre Basin as this should enable access following floodwater recession whilst still allowing surveys of flood-responsive vegetation to occur.

Analysis and reporting

Analysis and reporting will need to be conducted at the scale of individual wetlands.

Table 15: Costs for Vegetation set (nationally important wetlands)

(Based on 28 DIWA wetland sites.)

Item	Estimated cost	# of days	Annual Total
Field preparation			
Transect selection using aerial photos etc.	0.5 days per wetland x $500 per day		$14,000 (once at beginning)
Field surveys			
Field staff	$1,000 per day ($500 p.p. per day x 2 field staff)	90 days (3 days per wetland (including travel) x 28 sites + extra travel time	$90,000
Accommodation	$140 per night ($70 p.p. per night x 2 staff)	90 nights	$12,600
Consumables (food etc.)	$100 per day ($50 p.p. per day)	90 days	$9,000
Travel	$12,000 (20,000 km @ $0.75 km) N.B. mileage estimate for 2 cars travelling from Brisbane (6,000 km trip) & 1 car travelling from Adelaide (4,000 km trip)	-	$12,000
Field equipment			$5,000
Total Field Survey costs			**$128,600**
Data analysis & reporting			
Data entry	$500 per day (2 x junior staff)	10 days	$10,000
Data analysis	$1,000 per day (2 x senior staff)	10 days	$20,000
Report preparation	$1,000 per day (2 x senior staff)	10 days	$20,000
Total data analysis & reporting			**$50,000**
TOTAL			**$178,600** **per year (+$14,000 initially)**

Physical habitat indicator

(Physical form theme,* Channel system integrity and erosion potential/land use/ landscape change *Attribute)

Values

- maintenance of healthy aquatic ecosystems
- contributes to social, cultural and aesthetic values of channels and waterholes
- potential indicator of climate change and anthropogenic disturbance including land use

Links with pressures, drivers, risks and management actions

Table 16: Links with pressures, drivers, risks and actions: Physical Habitat set

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• water storage and diversion	• changes in the flow regime resulting from alterations in in-stream flows and floodplain inundation and therefore changes to sediment regime • loss of physical diversity within the channel network and on key floodplain surfaces	Moderate - High
• construction of barriers across floodplain surfaces and within the channel network	• interruptions to the natural flow and sediment regime within the channel network and across key floodplain surfaces	Moderate - High
Land use change		
• shift from grazing to cropping	• altered water quality in channels and wetlands as a result of changes in runoff patterns and nutrient and sediment supply	Moderate
• overgrazing on floodplain	• altered soil structure, nutrient content and vegetation may influence nutrient and sediment loads entering channels and wetlands	Moderate
Other		
• feral animals	• as for grazing	Uncertain at present
• climate change	• altered flow and sediment regimes resulting from changed runoff and flow patterns and sediment and nutrient loads	Moderate - High

(Sourced from information in Parsons et al. 2004)

Alignment with national reporting frameworks

1. FARWH

- Physical form index

Specific indicators

Table 17: Specific indicators for Physical Habitat set

Indicator	Links to pressures/drivers/risks
Physical diversity	- indictor of flow and sediment variability - loss of physical habitat diversity will may be deleterious to aquatic biota
Channel instability	- indicator of overgrazing and land use and may be deleterious to aquatic biota

(Sourced from information in Parsons et al. 2004)

Existing monitoring

At present, there is no routine collection of physical habitat in the Lake Eyre Basin.

Sampling

Sampling methods

The proposed water quality monitoring programme recommended here comprises two components:

1. Physical habitat should be sampled in conjunction with fish sampling at each survey time. The physical habitat protocol of Parsons et al., (2004) is recommended. Basic measurements of channel stability and the presence/absence of physical habitat units can be measured in the field using hand-held surveying equipment.

2. It is also recommended that data from any rapid biological assessment program be assessed for their quality to supplement the proposed fish sampling sites.

Sampling frequency

Sampling in waterholes should be conducted once a year in conjunction with fish sampling.

Spatial scale of sampling

The first component of the physical habitat sampling should be conducted at the site or waterbody level in conjunction with fish sampling.

Additionally, it is recommended that electrical conductivity and temperature probes be installed in several of the re-opened gauges in Queensland which are currently only recording river heights and rainfall. Of the 11 new sites in the Queensland portion of the LEB, 9 were historically operated as water quality monitoring sites. It has been suggested that it would be appropriate to install water quality probes at around 2 to 3 of these sites initially with preference for sites at the lower end of the catchments, e.g. Nappa Merrie, Diamantina Lakes and Barcoo River at Retreat.

Analysis and reporting

Analysis and reporting of waterhole scale data may be conducted in conjunction with that relating to fish surveys in order to assess possible linkages. Data from any additional studies through out the basin would be incorporated into the analysis and reporting framework currently implemented in that State. Collation and analysis of physical habitat data from 1. fish monitoring, 2. Queensland rapid biological assessment sites and 3. South Australian rapid biological assessment sites could be incorporated if undertaken and this would require collation and analysis at a catchment and basin scale within the reporting timeframe of the LEBRA.

Costs

Costs of sampling in waterholes should be minimal as measurements can be taken in conjunction with fish sampling. Equipment, e.g. theodolites, may present an initial expense depending on the access of these to fish sampling project teams. There may be an additional cost for data analysis and reporting beyond the scope of the fish monitoring programme. An estimate of costs associated with this component based on advice provided by researchers experienced with rapid physical habitat surveys, is provided below.

Table 18: Costs for Physical Habitat set

Item	Estimated cost	Total	Frequency	Annual Total
Equipment	$10,000 per survey item	$10,000	once at beginning of monitoring programme	$5,000
Staff (3 people required)	$500 p.p. per day (salary and travel expenses)	$13,500	once at beginning of monitoring programme	$13,500
Total Installation costs		**$23,500**		**$18,500**

Water quality indicator

Acknowledgements:

Bill Reurich, QLD Department of Environment and Resource Management

Peter Old, QLD Department of Environment and Resource Management

Values

- maintenance of healthy aquatic ecosystems
- contributes to social, cultural and aesthetic values of channels and waterholes
- potential early indicator of anthropogenic disturbance
- existence of long-term data sets for trends-based analyses

Links with pressures, drivers, risks and management actions

Table 19: Links with pressures, drivers, risks and actions: Water Quality set

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• water storage and diversion	• changes in water quality resulting from alterations in in-stream flows and floodplain inundation and therefore sediment and nutrient loads	Moderate - High
• change in depth of alluvial groundwater	• alterations to quality of water in refugial waterholes	Moderate
Land use change		
• shift from grazing to cropping	• altered water quality in channels and wetlands as a result of changes in runoff patterns and nutrient and sediment supply	Moderate
• overgrazing on floodplain	• altered soil structure, nutrient content and vegetation may influence nutrient and sediment loads entering channels and wetlands	Moderate
Tourism		
• tourism during dry phase	• increased nutrient inputs	Moderate
Other		
• toxic impacts of stock vaccination via faeces	• reductions in water quality	Uncertain at present
• feral animals	• as for grazing	Uncertain at present
• climate change	• altered water quality resulting from changed runoff and flow patterns and sediment and nutrient loads	Moderate - High

(Sourced from information in Sheldon et al. 2005)

Alignment with national reporting frameworks

1. FARWH

- Water quality index

2. National Framework for Natural Resource Management Standards and Targets

- Water quality (Integrity of inland aquatic ecosystems (rivers and other wetlands): river condition)
- Dissolved oxygen and temperature (Wetland ecosystem condition)
- Transparency (Wetland ecosystem condition)
- Turbidity (Turbidity/suspended particulate matter in aquatic environments)
- Electrical conductivity (Surface water salinity in freshwater aquatic environments)

Specific indicators

Table 20: Specific indicators for Water Quality set

Indicator	Links to pressures/drivers/risks
conductivity	- indictor of salinity - elevated salinities may be deleterious to aquatic biota
pH	- extreme pH may be deleterious to aquatic biota
dissolved oxygen (diel range)	- highly significant for aquatic biota - high DO levels during and levels close to zero in the evening may indicate a high pollution load
turbidity	- indicator of amount of suspended solids in water - influences light penetration and primary production - decreases in turbidity may result in increased primary productivity
water temperature (diel range)	- highly significant for aquatic biota

(Sourced from information in Sheldon et al. 2006)

Existing monitoring

At present, the Queensland Department of Environment and Resource Management continuously monitor conductivity and temperature (as well as river height and rainfall) at a single location in the Queensland portion of the Lake Eyre Basin: Thompson River @ Longreach (003202A). A further 11 sites have operational instantaneous river height and rainfall gauges. There is historic water quality data available for 9 of these sites.

In South Australia, water quality is currently assessed by the EPA for 7 sites in the Lake Eyre Basin: Cooper Creek, Warburton Creek, Yardaparinna Creek, Neales River, Margaret Creek, Mount Chambers Creek and Arakola Creek. Water quality parameters, including oxidised nitrogen, total nitrogen, total phosphours, soluble phosphorus, turbidity and salinity, are measured every 3 months in these remote locations.

Sampling

Sampling methods

The proposed water quality monitoring programme recommended here comprises two components:

1. Water quality should be sampled in conjunction with fish sampling during each survey time. Conductivity, pH and turbidity can be measured in the field using hand-held probes and diel ranges in dissolved oxygen and water temperature can be measured over 24 hours using probes and data loggers.

2. It is also recommended that additional water quality monitoring probes be installed in the Queensland portion of the Lake Eyre Basin to supplement the existing network of gauges and enable the assessment of long-term trends through analyses against historic data. As per the remainder of Queensland's water quality monitoring network, these should comprise in situ electrical conductivity and temperature probes.

Sampling frequency

Sampling in waterholes should be conducted twice per year in conjunction with fish sampling. Water quality monitoring via in situ probes will occur continuously.

Spatial scale of sampling

The first component of water quality sampling should be conducted at the site or waterbody level in conjunction with fish sampling. Additionally, it is recommended that electrical conductivity and temperature probes be installed in several of the re-opened gauges in Queensland which are currently only recording river heights and rainfall. Of the 11 new sites in the Queensland portion of the LEB, 9 were historically operated as water quality monitoring sites. It has been suggested that it would be appropriate to install water quality probes at around 2 to 3 of these sites initially with preference for sites at the lower end of the catchments, e.g. Nappa Merrie, Diamantina Lakes and Barcoo River at Retreat.

Analysis and reporting

Analysis and reporting of waterhole scale data may be conducted in conjunction with that relating to fish surveys in order to assess possible linkages. Data from any additional water quality monitoring stations in Queensland would be incorporated into the analysis and reporting framework currently implemented in that State. Collation and analysis of water quality data from 1. fish monitoring, 2. Queensland water quality monitoring sites and 3. South Australian water quality monitoring sites would require collation and analysis at a catchment and basin scale within the reporting timeframe of the LEBRA, i.e. once every 10 years.

Costs

Costs of sampling in waterholes should be minimal as measurements can be taken in conjunction with fish sampling. Equipment, e.g. probes and data loggers, may present an initial expense depending on the access of these to fish sampling project teams. There may be an additional cost for data analysis and reporting beyond the scope of the fish monitoring programme. An estimate of costs associated with the installation and maintenance of additional water quality probes in Queensland, based on advice provided by staff members of QLD Department of Environment and Resource Management, is provided below.

Table 21: Costs for Water Quality set

Item	Estimated cost	Total	Frequency	Annual Total
Installation of probes (3)				
Equipment	$15,000 per probe	$45,000 (3 new probes)	once at beginning of monitoring programme	$45,000
Staff (3 people required)	$500 p.p. per day (salary and travel expenses)	$13,500 (3 days per probe including travel)	once at beginning of monitoring programme	$13,500
Total Installation costs		**$58,500**		**$58,500**
Maintenance and calibration				
Staff and travel	$1,000 per day ($500 p.p. per day x 2 field staff x 1 probe per day)	$3,000	annually	$3,000
Equipment	$1,000 per probe	$3,000	annually	$63,000
Total Maintenance costs		**$6,000 per year**		**$6,000 per year**
TOTAL				**$6,000** **per year (+$58,500 initially)**

Hydrology indicator

Acknowledgements

Tony Ladson, Erwin Weinmann, Justin Costelloe, John Tilleard

Values

- maintenance of healthy aquatic and floodplain ecosystems
- contributes to social, cultural and aesthetic values of floodplains, channels and waterholes
- potential indicator of anthropogenic disturbance, especially climate, land use and floodplain
- existence of long-term data sets for some trend-based analyses

Links with pressures, drivers, risks and management actions

Table 22: Links with pressures, drivers, risks and actions: Hydrology set

Pressure / driver / risk	Potential impacts	Level of risk
Water resource development		
• water storage and diversion	• changes in the spatial and temporal availability of water through the basin resulting from alterations in in-channel flows and floodplain inundation • reduced filling of terminal lakes and wetlands	High
• pumping from water holes	• alterations to the availability of water in refugial waterholes	High
Land use change		
• vegetation structure changes via mining, grazing and other development	• changes in the spatial and temporal availability of water • less water for waterhole filling	Moderate
• floodplain developments	• altered patterns of floodplain inundation	Moderate
Other		
• climate change	• altered water availability resulting from changed runoff and flow patterns	High

Alignment with national reporting frameworks

1. FARWH

- Hydrological change

Specific indicators

Table 23: Specific indicators for Hydrology set

Indicator	Links to pressures/drivers/risks
Total surface water availability	- Water resources development - Climate change - Land use change
Water storage capacity	- Water resources development
Water licensing	- Water resources development
Filling of terminal lakes	- Water resources development - Climate change - Floodplain development - Land use change - Presence of in-channel structures
Floodplain inundation	- Water resources development - Climate change - Floodplain development - Land use change
In- channel events	- Water resources development - Climate change - Floodplain development - Land use change - Presence of in-channel structures
Persistence of key waterholes	- Water resources development - Climate change

Existing monitoring

Water surface information has been collected at over 150 locations throughout the Lake Eyre Basin and the available data are of variable quality, length of record and availability. These networks include:

- • Stream monitoring stations maintained by the governments of South Australia, Queensland and Northern Territory;
- • Flood warning stations maintained by the Bureau of Meteorology;
- • Sites established as part of the Arid Flow Project to investigate floodplain, waterhole and wetland ecology;
- • Sites used in the Dryland Refugia Project to investigate waterhole ecology; and,
- • A hydrologic network set up by Santos Ltd for the specific purpose of warning of flood threats to mining infrastructure.

Stream monitoring stations are specifically set up to provide long term records of flow information. These are reviewed in detail in the report *Hydrology of Lake Eyre Basin* (HLEB) including, length of record, and adequacy of gauging. Much of the stream monitoring data are available via the internet. According to HLEB, there are only 17 stations in the Lake Eyre Basin with at least 10 years of record and only 12 stations have at least 20 years of record. In order to undertake a valid statistical analysis of the frequency of floods at least 30 years of data are recommended by the Institution of Australian Engineers. The HLEB also includes an assessment of accuracy of flow information at these gauging stations in terms of how adequately the streams are rated. Only four gauges had good high flow ratings: Cooper Creek at Nappa Merrie (003103a), Cooper Creek at Callamurra Water Hole (AW003501), Thomson River at Longreach (003202A) and Thomson River at Stonehenge (003202A). It may be appropriate to improve the high flow ratings at other gauges (see section 7). Three gauges have recently been reinstated which is consistent with the recommendations of the HLEB report: Diamantina River at Diamantina Lakes, Burke River at Boulia and Georgina River at Roxborough Downs.

In addition to the state network of water level recorders, a series of 17 water level loggers have been installed by the ARIDFLO Project in three sub catchments of the Lake Eyre Basin in South Australia.

Sampling

Sampling methods

It is proposed that two types of surface water monitoring should occur in the Lake Eyre Basin:

A network of surface water level recorders should be used to determine flows at various locations through out the Basin. The number, location and type of measurements required for monitoring depend on the specific issues to be addressed, the variability of the natural system, and of course, the available budget. For efficient and cost-effective operation of the networks that serve the Rivers Assessment Program, it is desirable that these networks be integrated with monitoring networks set up and operated for other purposes. Ladson et al., (2008) proposes the following priorities for the hydrology network in the Lake Eyre Basin.

Priority 1:

Highest priority sites are those that assist in the understanding large scale hydrology of the multi-channel, ecologically diverse reaches of the Cooper Creek, Diamantina River and Georgina Rivers. Good flow data is required at the upstream and downstream ends of these reaches.

- Cooper - Improve the high flow rating of the Barcoo River at Retreat. The other sites on the Cooper are probably adequate.
- Diamantina – continue with the re-establishment of the site Diamantina River at Diamantina Lakes, in particular, the high flow rating at this site needs to be improved and data needs to be brought online (data from this site are not currently accessible via the Queensland Watershed database).

- Georgina (upstream) – continue restablishment of gauging stations, Georgina River at Roxborough Downs and Burke River at Boulia. We understand that stage data are currently being collected and telemetered from these sites, but the information is not accessible via the Queensland Watershed database. The publicly available records for these sites suggest they ceased operation in 1988. Additional work will be required to establish reliable ratings at these sites.
- Georgina (downstream) – a new site is required at the downstream end of the multichannel reach of the Georgia River. We recommend that the gauging station, Eyre Creek at Glenglyle, be restablished as it has about 20 years of data before ceasing operation in about 1990. This site should incorporate telemetry, via satellite phone if necessary, and 'sensor to web' technology.
- In addition, remotely sensed data on flood pattern and extent should be captured as this can guide hydrologic modelling and ecological assessment of these reaches.

Priority 2:

Priority 2 sites should be established to monitor land use influences on the hydrology of the Lake Eyre Basin. These influences include activities such as mining and catchment clearing in the headwaters of Cooper Creek, Diamantina River and Georgina River. These sites need to be located in areas where impacts are greatest so that there is the highest change of detecting changes. There would need to be further work to identify areas with the highest land use and the best sites for monitoring, but the following should be considered:

- Torrens Creek at Torrens Creek (003206A) – reinstate
- Mistake Creek at Wololla (003305A) - reinstate
- Diamantina at Tulmur (002903) – install

Priority 3:

Other monitoring sites could include:

1. Neales River near Algebukina Bridge (or Macumba River at Macumba Station) (AW004104) – install full gauging stations (currently stage measurements are recorded). These sites are importance because these western LEB tributaries are poorly gauged. The Neales site is an excellent location to measure flows and there is a ecologically important wetland nearby. There may also be some high flow information available this site from debris line surveys undertaken in the 1980s.

2. A series of water recorders for determining the persistence of key wetlands and waterholes through out the Lake Eyre Basin. Here the similar procedures as in the Arid Flow project where low cost stage loggers are set up and downloaded during site visits.

Priority sites could include:

- Durrie waterholes aggregation, Birdsville
- Cooper Creek Overflow swamps, Windorah
- Cooper Creek – Wilson River Junction
- Diamantina Overflow Swamp, Durrie Station
- Georgina River, King Creek Floodout
- Mulligan River – Wheeler Creek junction

  These sites would need to be confirmed with ecologists. In addition, the existing Arid Flow sites should be continued.

Sampling frequency

Technological improvements have meant that daily readings can now be obtained from most sensors. Issues concerned with instrumental servicing and calibration are dealt with below.

Analysis and reporting

Analysis and reporting of waterhole scale data may be conducted in conjunction with that relating to fish surveys in order to assess possible linkages. Data from any additional water quality monitoring stations in Queensland would be incorporated into the analysis and reporting framework currently implemented in that State. Collation and analysis of water quality data from 1. fish monitoring, 2. Queensland water quality monitoring sites and 3. South Australian water quality monitoring sites would require collation and analysis at a catchment and basin scale within the reporting timeframe of the LEBRA, i.e. once every 10 years.

Costs

Typical costs for the hydrological monitoring component are listed in Table 24. These are approximate as actual costs will be dependent upon site conditions and remoteness. It is recommended that monitoring to be done by the state agencies and the data collected should also be handled by the state agencies and incorporated into their databases. In general, site visits by technical staff are much more costly than the purchase price of instruments. Reliable sensors, data loggers and telemetry systems, even if they have a higher initial cost, may be a way of reducing the total cost of measuring systems.

Two types of sites should be considered. Long term sites with 'sensor to web' technology i.e. where data are collected, telemetered via satellite phone if necessary, and made available in the internet in close to real time. These sites would require development of rating curves. In addition there should be a larger number of cheaper sites where stage is measured but where data are not telemetered. These sites would be similar to the existing arid flow sites. The selection process for any new instrumentation and the techniques to undertake the actual measurements would benefit from technical advice from experts drawn from all the jurisdiction covering the Lake Eyre Basin.

Table 24: Costs for Hydrology set

(Typical costs for monitoring system components)

No.	Item	Cost
1	Field visit by a team of two people	$2,000 per day
2	Satellite phone modem	$2,000 to $3,000
3	Satellite phone network access and phone calls	$1,000 per year
4	Data logger	$1,000 to $10,000
5	Sensor	$1,000 to $5,000
6	Set up costs for high quality long-term gauging site that	$20,000 to $100,000 depending on stream size, remoteness, and chosen equipment.
7	High flow gauging of a remote site e.g. Diamantina River at Diamantina Lakes	$30,000 This includes helicopter access
8	Set up costs for 'project' sites e.g. an Aridflo sites. These could be used to monitor a series of waterholes	$40,000 for 10 sites within a radius of a few hundred kilometres.

Pressure Indicators

The indicators listed in the previous section will provide an assessment of the “condition” of the aquatic ecosystems of the LEB. However these indicators do not provide information on what activities may be causing the changes in condition. To address this issue an additional set of “pressure indicators” have been developed to provide a context of the major changes in landuse and land management impacting on the aquatic ecosystems of the LEB.

The key pressures impacting of the condition of the aquatic ecosystems of the LAB have been identified in the development of the condition indicators (Table 3, 7, 10, 13, 16, 19 and 22). The high and moderate pressures identified are:

- Land use changes impacting on water use
- Management of grazing lands
- Tourism
- Invasive species
- Climate Change

Table 25 Key pressures, impacting activities and indicators

Pressures	Impacting activities associated with the pressure	Indicator areas
Land use changes, especially those impacting on water use • Irrigated agriculture • Intensification of grazing • Mining and petroleum extraction • Road construction • Earthworks to harvest water	Water extraction, water storage and diversion, construction of barriers across floodplain surfaces and within the channel network, damming, conversion of floodplain lakes to storages, floodplain harvesting, pumping from shallow groundwater, pumping from water holes	Development applications, Environmental Impact Assessments, water permits issued, updates of water management plans
Management of grazing lands	Increased grazing pressure, vegetation management	Vegetation cover, burnt areas
Tourism	Recreational visitors, localized fishing impacts	Number of visitors
Invasive species	Establishment/spread of exotic animal and plant species (on the floodplains)	Occurrence of Weeds of National Importance, exotic fish species
Climate Change	Changes in the amount and pattern of rainfall and the associated changes in river flows, intensity of storm events	National level conclusions on changes in climate

Existing Monitoring

While the state indicators are to be assessed on the basis of data collected during field programs, a more cost effective approach can be used for the pressure indicators. Government agencies have existing procedures and programs that collect information on many of the pressures in the LEB. Accordingly, the approach will be collate the information available on changes in relation to each pressure.

Reporting

Information on the pressure indicators will be collated and reported in the mid-term and 5 years reports.

Costs

Costs will be limited to the time involved in identifying and collating information on the pressures.

Table 26 Costs for Pressure Indicators

Item	Estimated Cost	Total	Frequency	Total
Data collation and reporting				
Initial identification of data sets	$1000 / day * 20 days	$20 000	Year 2	$20 000
Collation of information	$1000 / day * 15 days	$10 000	Mid term and Final Assessment	$20 000
Report preparation	$1000 / day * 15 days	$15 000	Mid term and Final Assessment	$30 000

Setting Thresholds of Potential Concern (TPCs)

An important component of natural resource management is to ensure the maintenance of determinants that influence all vital attributes of the system under consideration. This must then involve listing all the determinants of, and the constraints and threats to, the condensed list of vital attributes. Determinants are those factors or processes that determine, strengthen or ensure persistence, while threats are those factors or processes that threaten, erode or inhibit these attributes or their determinants. Threats can also be factors within, or outside, a partnership that undermine its values and inhibit the pursuit of the mission or future desired state. Knowledge of the environmental and cultural "goods and services" the system has the potential to deliver is essential part of this process.

Development of a desired state is important in nay natural resource management exercise and is one based on a vision for a set of desired future ecosystem conditions. It is important to note that this refers to a 'desired set of varying conditions' rather than a static state. Ecosystem conditions are not fixed but inherently dynamic. We cannot aim to achieve specific and unchanging ecosystem conditions, but only to maintain natural variation and processes as the basis for ecosystem resilience – resilient ecosystems are able to absorb environmental stressors without undergoing an irreversible change in their state.

Some changes are undesirable as they form part of a long-term trend moving the ecosystem away from the desired state to another less preferred state. Over time this trend may become irreversible. The desired outcomes of management are therefore expressed as limits of acceptable change – termed Thresholds of Potential Concern (TPCs). TPCs are upper and lower levels of change in selected indicators. If TPCs are reached it is very likely that the desired state will not be achieved or will not be able to be achieved into the future.

In essence TPCs should be seen as red flags to managers warning that management intervention could be necessary to defend the desired state. They also indicate what management actions should be done, where it should occur and when the actions should take place. Modelling is also used to predict the results of future monitoring and thus give early warning that a TPC is likely to be breached. Indeed, any management process that is working towards the rehabilitation of a desired state, TPCs represent achievable goals for management to work toward. A collective of TPCs represent a multidimensional envelope in which natural resource managers and stakeholders wish the system to remain, "bouncing around" as much as possible, without going to the undesirable zone.

Examples of possible Thresholds of Potential Concern for the Lake Eyre Basin are provided in Table 25.

Table 27. Examples of Thresholds of Potential Concern for the Lake Eyre Basin

Trigger	Thresholds exceeded or expected to be exceeded
Reduction in waterhole persistence	Significant change in the cumulative duration of water availability within the key waterholes of the Lake Eyre Basin
In-channel flow events or flow pulses	Significant change in the flow duration curve of no flow events for gauging within the Lake Eyre Basin
Total surface water availability	Reduction in total annual volume of surface water expected from catchment rainfall at key gauging stations located throughout the Lake Eyre Basin
Silt and pollutant release episode from upstream mining operation	Increased turbidity in waterholes resulting in fish kills
River sedimentation	Loss of physical habitat diversity between and within waterholes
Change in community of native fish	- New occurrence of an alien fish with a high index of potential threat - Significant change in size distribution of fish communities within the individual sub catchments of the Lake Eyre Basin
Change in riparian vegetation structure	- New occurrence of an alien plant with a high index of potential threat

8. Monitoring actions that require further research and development

It is the variability and complexity of environmental processes at multiple spatial and temporal scales in response to a range of disturbances that needs to be captured in a management and monitoring programme for the Lake Eyre Basin. While this may seem daunting, frameworks exist for incorporating such characteristics into management and monitoring programmes. In particular, Kruger National Park, South Africa, has developed a successful Strategic Adaptive Management system that supports that park's mission to preserve biodiversity in all it's facets and fluxes (Biggs and Rogers 2003). This system was initially developed as part of a river-research programme, where it was realized that river management approaches needed to capture the heterogeneity and variability of pattern and process in space and time because this was the driver of biodiversity in the park's rivers – a situation similar to the scenario observed in the Lake Eyre Basin. Here we outline the basics of Strategic Adaptive Management as used in Kruger National Park, and suggest how this type of approach might be used to for management and a monitoring programme in the Lake Eyre Basin.

Strategic adaptive management

With its roots in management theory, Strategic Adaptive Management was developed over a number of years as a local tool for the management of Kruger National Park (Biggs and Rogers 2003) and more recently as part of the framework for managing all National Parks in South Africa (Rogers *et al* 2008). Strategic Adaptive Management offers a framework for natural resource management and decision making in environmental, social and institutional situations characterized by variability, uncertainty, incomplete knowledge and multiple stakeholders. Three key tenets form the basis for the management and decision-making process in Strategic Adaptive Management (SAM):

Strategic and value based - Purposeful and goal-directed, with the first step in planning and management being the description of a desired future state of the protected area based on scientific and societal needs and values;

Adaptive - In the face of uncertainty, management actions are treated as an opportunity to learn by doing. Management is planned as a learning experience and improves through frequent review of policy and action; and,

Participatory - Meaningfully involving all stakeholders to serve their needs, access their inputs and secure their cooperation. Governing cooperatively with other agencies to coordinate and integrate goals and actions (Rogers *et al* 2008).

There are five interacting steps in Strategic Adaptive Management (Figure 1), each of which will be described in the following sections.

Describe the desired state

The description of the desired state involves developing a shared vision of the system, translating that vision into ecosystem objectives/outcomes and generating a set of thresholds of potential concern.

Visioning – Understand, with stakeholders, the social, economic and ecological context of the system to be managed, and the principles/values that guide management. Develop a broadly acceptable vision of the future (Rogers *et al* 2008).

Translate the vision into ecosystem objectives/outcomes – Develop an 'objectives hierarchy' that documents the sequential reasoning used in translating a broad societal values-based vision into science-based ecosystem outcomes (Rogers *et al* 2008).

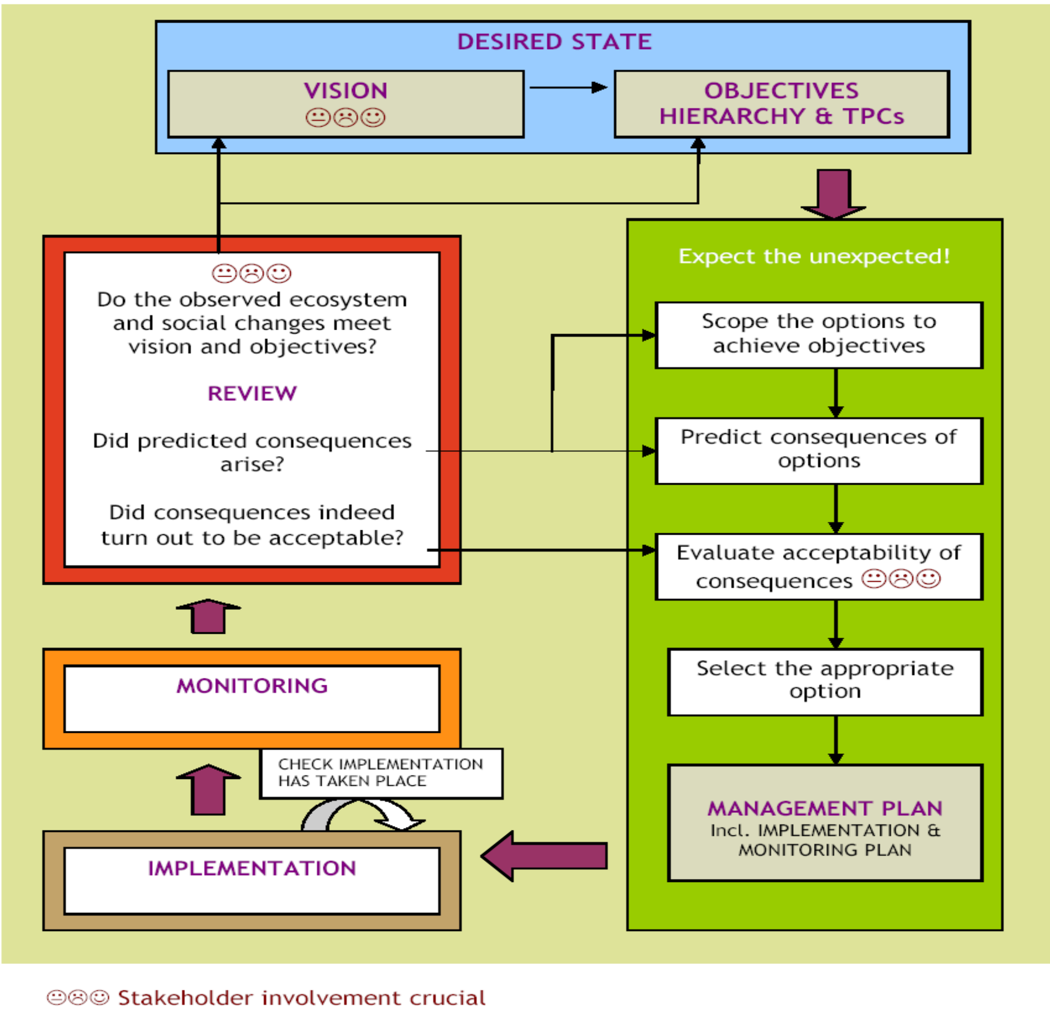

Figure 1. The Strategic Adaptive Management (SAM) process. After Rogers *et al* (2008).

Generate a set of TPCs to define the acceptable levels of change in ecosystem / biodiversity composition, structure and function – The desired state refers to a range of varying conditions, acknowledging that ecosystems are variable and heterogeneous in time and space. The desired outcomes of management are therefore expressed as limits of acceptable change – termed Thresholds of Potential Concern (Figure 2). Thresholds of potential concern (TPCs) are upper and lower levels of change in selected indicators. If TPCs are reached it is very likely that the desired state will not be achieved or will not be able to be achieved into the future (Rogers *et al* 2008).

Develop a plan to achieve or maintain the desired state

Expect the unexpected – Use a variety of tools (scenario planning, systems thinking, models, historical records, etc.) to scope the range, and likely spatiotemporal limits, of unusual events and their implications for management towards the desired future conditions (Rogers *et al* 2008).

Scope the range of management options – Scoping is undertaken to achieve the desired future conditions and predict (formally or informally) their likely outcomes under different scenarios (Rogers *et al* 2008).

Select the best options – In co-operation with stakeholders decide which management options provide the best potential learning opportunities, and social-ecological system outcomes (Rogers *et al* 2008).

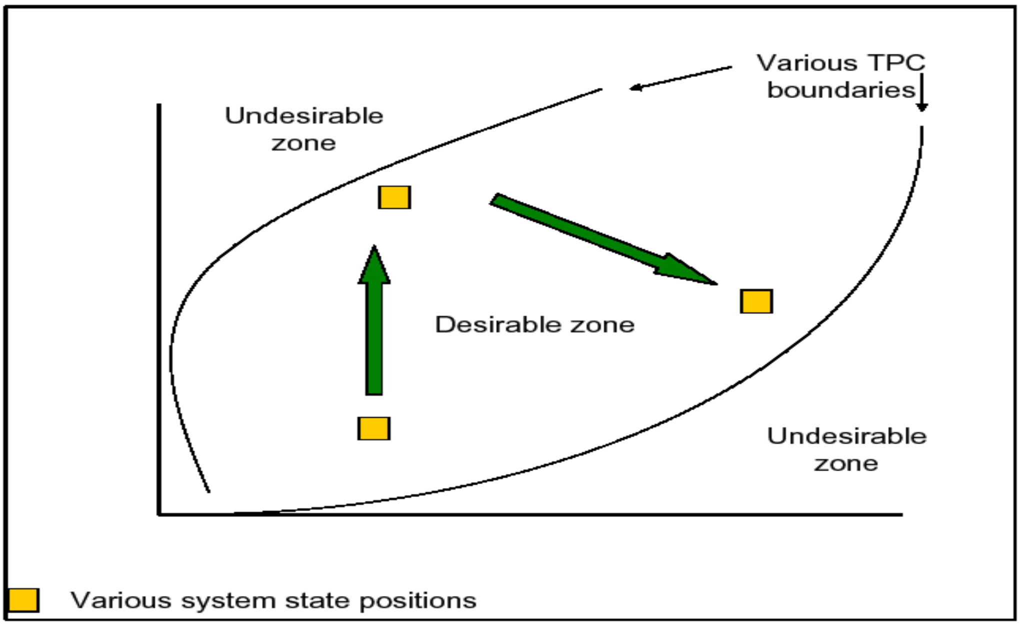

Figure 2. Thresholds of potential concern (TPCs) as boundaries of the desired state. After Rogers *et al* (2008).

Implement

Implement the planned management interventions

Monitor

Monitor and audit achievements – Use a range of research projects, traditional monitoring, modeling and surveys to understand system response to natural flux and management intervention. Weigh this against the desired outcomes (Rogers et al., 2008).

Review

Reflect at each step – Is thinking and action congruent with principles, values and vision? What does knowledge gained tell us about (1) our understanding of the ecosystem, (2) its responses, (3) how realistic are the desired outcomes and (4) how useful are the processes used to achieve them (Rogers *et al* 2008)?

Strategic Adaptive Management has been used to manage the rivers of Kruger National Park. Within an overarching vision for the park, a biodiversity objective to 'maintain biodiversity in all its facets and fluxes' guides an ecosystem objective to understand and manage the KNP as part of the lowveld savanna and its river catchment areas in such a manner as to conserve and restore its varied natural structure, function and composition over time and space, and its wilderness qualities, through an approach integrating the different scales and types of objectives'. The water in the landscape objective sits within the ecosystem objective and aims to 'develop an integrated understanding of non-terrestrial ecosystem diversity and dynamics (including sub-surface water) and its links with terrestrial systems, and to maintain the intrinsic biodiversity as an integral component of the landscape and maintain or where necessary restore natural structure, function, composition and processes'. Commensurate with the goals of these objectives, TPCs have been set for the Sabie River to facilitate prediction and monitoring of biodiversity in response to hydrology, sediment supply and water quality (Rogers and Biggs 1999). Geomorphological and vegetation indicators were developed to indicate ecosystem response to the main agents of change (Table 26). Thresholds of Potential Concern that fall outside upper and lower limits of acceptable change (Figure 2) are flagged and investigated further.

Table 28. Monitoring the a) geomorphic and b) riparian vegetation components of biodiversity in the Sabie River, Kruger National Park. Thresholds of Potential Concern (TPCs) represent the use of an indicator to monitor the effects of driving processes. After Rogers and Biggs (1999).

(a)

Measurement criteria	Measurement units	Measurement scale	Thresholds of probable concern (TPCs)
Selected channel types (5 of 9) in designated representative reaches	Area of selected geomorphic units (4 of 14) on aerial photographs	Temporal: every five years and events (floods, droughts) greater than 1 in 25 years return interval	Directional loss of bedrock influence and water surface area at winter low flow (20 years prediction)
Bedrock anastomosing	Bedrock core bar	Spatial: 10^2–10^3 m per representative reach; 20 × 20 m grid square	Anastomosing channel types: bedrock core bars 50% cover or more; of other units, three must occupy 2–10% of total area
Alluvial anastomosing	Anastomosing bar		Pool–rapid channel types: lateral and point bars ≤ 20%; pools ≥ 15% of total area
Mixed anastomosing	Bedrock pavement		
Bedrock pool–rapid	Bedrock pool		
Mixed pool–rapid			

(b)

Measurement criteria	Measurement units	Measurement scale	Thresholds of probable concern (TPCs)
Population structure of key species from each of 6 vegetation units	Size class frequency distribution	Temporal: every 3 years and events greater than 1 : 25 years	*B. salicina*: negative *J*-curve population structure in pool–rapid channel types
Breonadia salicina		Spatial: all representative reaches except:	Other trees: recruitment at least once in 10 years; mortality threshold uncertain
Ficus sycamorus		*B. salicina* pool-rapid reaches only	*P. mauritianus*: directional increase in areal extent (20 years prediction)
Phragmites mauritianus		*C. erythrophyllum* alluvial reaches only	
Trichilia emetica		*S. africana* macro-channels banks only	
Combretum erythrophyllum			
Spirostachys africana			

More specifically the following recommendations for the individual components of the Lake Eyre Basin Implementation Plan are provided.

Flow and flood theme

Development of catchment based flow model is a priority. It would allow the hydrological impacts of climate and land use to be assessed, thereby treating the hydrology of the basin as a response variable. It would also enhance the ability to model these potential impacts on the other ecosystem components of the rivers assessment.

Modelled stream flow is important for any river assessment. There have been several attempts to model flows through the rivers of the Lake Eyre Basin. All of these approaches are constrained by the limited data available, but the results may be useful for assessing hydrologic characteristics and change in Lake Eyre Basin Rivers and floodplains. In some circumstances, modelling could be used to extend the usefulness of measured data and can provide input to ecological studies. A key challenge in modelling the major rivers of the Lake Eyre Basin is to simulate the complex flow patterns on the vast floodplains of these rivers. Each of the main waterways, Cooper Creek, the Diamantina River and the Georgina River has large, multichannelled reaches with wide floodplains and many ecologically important waterholes. There are key stream gauging sites which would assist with monitoring and modelling these reaches.

Existing modelling approaches

The existing modelling approaches are outlined below.

- IQQM Modelling of Cooper Creek

  An IQQM (Integrated Quantity and Quality Model) daily flow simulation model has been developed for Cooper Creek as part of the preparation of a water management plan. Thoms and Cullen comment on the limitations of this approach for assessing the ecological impacts of water withdrawals from Cooper Creek.

- Flow transmission modelling

  Flow transmission modelling was undertaken by Knighton and Nanson. They showed that a 3 parameter Muskingum model can be used to route flood waves down Cooper Creek.

- Modelling of the Diamantina River and part of Cooper Creek

  Justin Costelloe and others at the University of Melbourne have modelled flow and flood extents in the Diamantina River and Cooper Creek.

- Modelling of Lake Eyre floods

  Modelling of floods and flow extents in the whole of the Lake Eyre Basin has been undertaken using the RORB computer model

- Rainfall runoff modelling of the Lake Eyre Basin

  The SIMHYD rainfall runoff model was used by McMahon et al. to determine the spatial distribution of mean annual runoff throughout the Lake Eyre Basin.

  Peel et al used SIMHYD to derive unimpaired i.e. ‘natural’ monthly streamflows for 331 catchments in Australia. Unfortunately, there was only one station in the LEB, Todd River at Wigley Gorge. However, because of this work unimpaired streamflows are now available at this site from 1901 to 1998. It is likely to be possible to extend this methodology to other small to medium catchments in the LEB. The approach will be less accurate in large catchments with high transmission losses.

Flood Extent Attribute

- Flood extent indicator

  Objectives: Investigation into relationships between discharge and flood extent relationships using flow data and analysis of satellite imagery are required. Linked projects include WLD wetland mapping, SA projects SGFP (Phelps), Santos and Dave Roshier's work (Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23). Justin Costelloe's recent work conducted at University of Melbourne may have addressed some of these knowledge gaps but this report has not been provided.

Waterholes and wetlands theme

Waterhole and Wetland Biodiversity Attribute

- Iconic species indicator

  Objectives: develop conceptual models and identify indicators for species under threat, e.g. frogs, turtles, water rats, monitors, brush tail possum, Cooper Ck catfish etc.

- Cane toads indicator

  Objectives: Development of a conceptual model to consider cane toad impacts in LEB is required.

Riparian and floodplain theme

Riparian and Floodplain Biodiversity Attribute

- Bird biodiversity indicator could be developed.

Riparian Vegetation Condition Attribute

- Riparian vegetation composition and extent indicator

  Objectives: To develop techniques for assessing regional, catchment and basin-scale indicators of riparian vegetation condition and extent using remotely sensed data and explore collaboration with existing State programmes, eg. SLATS (Qld).

Floodplain Vegetation Condition Attribute

- Floodplain vegetation composition and extent indicator

  Objectives: develop techniques for assessing regional, catchment and basin-scale indicators of floodplain vegetation condition and extent using remotely sensed data. Explore collaboration with existing State programmes, eg. Rapid Mobile Data Collection (see http://www.environment.gov.au/land/publications/acris/report08.html)

(Qld) or National programmes, eg. ACRIS, AussieGrass.

Physical form theme

Erosion Potential and Land Use and Landscape Change Attribute

- Erosion potential and land use change indicator

  Objectives: The development of models that are able to predict responses to events, e.g. expected vegetation cover changes in response to rainfall work (Notes from March 2005 Lake Eyre Basin Rivers Workshop, March 22 & 23).

- Stream network model to assess impact of land use and climate change

  Objectives: Development of a model that characterises the entire stream network of the Lake Eyre Basin and compares this against a reference stream network.

Water quality theme

River bed sediment geochemistry audit

- Sediment geochemistry indicator

  Objectives: Development of a geochemical data base of river bed sediment through out the basin to determine the longer term impact of mining and land uses in the Lake Eyre Basin.

9. Appropriateness of reporting timeframe.

The assessment challenge

The Lake Eyre Basin River Assessment project recommended a “hybrid approach” for the assessment of rivers within the Basin. This involved the collection of data at three spatial scales – local, regional and catchment and over a range of time scales. A network of locations across the basin was to be employed where strategic sites and a number of randomly selected sites were to be sampled for a “site-based” or local assessment. This was to be done in order to quantify within location variability. Site based indicators were then to be up-scaled into providing the larger catchment based assessment. In conjunction with this network of strategic sites, a network of regions was also to be assessed for landscape change and physical form indicators. Some of the suggested indicators recommended to be sampled at either a local scale (site based measurements), regional scale (multiple site measurements, regional surveys or remotely sensed data) or for the hydrological indicators at the catchment scale are presented in Table 2.

Essentially the approach taken for the recommended Lake Eyre Basin Rivers Assessment was a trend based assessment. However, challenges to this are in not only selecting appropriate indicators but also in incorporating the enhanced spatial and temporal variations in natural “condition” that are evident across the Lake Eyre Basin. At any one point in time, natural variations in flooding and rainfall will mean sections will naturally be in “good” condition while others are in “poor” condition. Therefore a traditional trend and assessment may not be appropriate to the Lake Eyre Basin because of the length of time required in data collection to constructed statistical relevant trends. In excess of 30 years of high quality data, collected at a single site, are required in order to provide statistical significant trends in highly variable systems (Ladson 2000). Instead, the dynamic and changing nature of these natural conditions must be captured in the interpretation of any indicator assessment and from a management perspective should be incorporated in managing the dynamic mosaics of the Lake Eyre Basin.

Furthermore, the exact number of sites required to make an assessment of condition and detect possible change (power) for each indicator will ultimately need to be determined for the Lake Eyre Basin from continued analysis of assessment data and a series of Pilot Studies. In the Murray Darling Basin Sustainable Rivers Audit between 18 and 30 sites per river valley (sub-catchment) were needed for various indicators to make a catchment assessment of condition. Indeed, this estimate of the number of sites required, was made by assuming a nested sampling design, with replicate sites sampled within different locations; giving broad geographic coverage, but also the ability to quantify the within-site variability.

For the Lake Eyre Basin assessment at the local scale strategic sites were to include Wetlands of National significance, Ramsar sites or other strategic conservation sites as well as established monitoring or research sites with existing data. Additional sites were to be located in the Headwaters, where sites should be nested within sub-catchments along with sites in the Channels & Waterholes and Terminal Wetlands. In terms of the regional scale assessment, it was recommended the Physical Form indicators be measured only. The catchment based assessment focused on the Flow Theme indicators.

Given the reliance on trends based assessment a standard assessment timeframe for each indicator was recommended combined with ad-hoc events based monitoring. In particular, the events based monitoring was to be based around rainfall and flows in the headwater regions. Any assessment of trends in this region needs to consider the initial condition and variability associated with seasonal extremes. Scale factors and indicators chosen will determine the choice of frequency of assessment. Different indicators will be assessed at different frequencies within the 10 year reporting framework. The suggested frequency of assessment is provided in the summary table.

The recommendations for spatial and temporal sampling within the assessment program have been made based on professional opinion.

An alternate approach

It is widely acknowledged that Australian river landscapes are under pressure and continue to degrade under existing management practices. This is not surprising. Landscapes and ecosystems are moving targets characterized by episodic change, patchiness, variability, multiple scales of operation and multiple stable states in both the social and biophysical domains (Gunderson and Holling 2002). Time and time again, landscapes and ecosystems managed for some type of equilibrium carrying capacity have been thwarted by surprise events, changes in thresholds and market failures (Carpenter and Folke 2006). Time and time again it has been shown that optimizing efficiency to deliver a defined benefit does not lead to sustainability, but rather to collapse (Walker and Salt 2006). New ideas are required to improve the management and monitoring of Australian river landscapes and ecosystems. Resilience Thinking provides one umbrella under which to consider the future management of river ecosystems.

Resilience is the amount of change a system can undergo (its capacity to absorb disturbance) and remain within the same regime that essentially retains the same function, structure and feedbacks (Walker and Salt 2006). Resilience Thinking seeks to determine how societies, economies and ecosystems can be managed to confer resilience, that is, how to maintain the capacity of a system to absorb disturbance without changing to a different state.

Resilience Thinking offers nine fundamental principles that may form components of a framework for managing and monitoring the resilience of the Lake Eyre Basin:

1. Recognition of the potential for alternate stable states to exist within riverine landscapes.
2. Recognition that riverine landscapes properties can vary significantly within a stable state.
3. Riverine landscapes properties can display significant spatial and temporal variability at different scales within a stable state.
4. Thresholds do exist within riverine landscapes and act as tipping points between alternate stable states.
5. Thresholds exist at multiple scales but not all result in a shift to an alternate state.
6. Slow variables are important in driving regime shifts.
7. Riverine landscapes cycle through adaptive loops and their position within the loop sets their form and function.
8. Riverine landscapes are essentially social-ecological systems integrating ecosystems and human society.
9. Managing and monitoring riverine landscapes for resilience requires adaptability or the capacity to adapt to and influence change.

There are two additional approaches that are complementary to Resilience Thinking, which provide different components of a framework for managing and monitoring of resilience in riverine landscapes. The ecosystem approach focuses on the interactions among ecological entities and their environments, and thus, takes an encompassing and synthetic view of nature rather than a fragmented view (Likens 1992). The ecosystem approach recognizes the influences of disturbance, scale spatial heterogeneity and spatial variability on the relationships between ecological entities and their environments. Contemporary views of ecosystems also view humans as a keystone species within the ecosystem.

The ecosystem approach offers six fundamental principles that may form components of a framework for managing and monitoring resilience in riverine landscapes:

1. Variability and heterogeneity are fundamental drivers of pattern and process in riverine landscapes.
2. Fluxes and cycling of materials and energy are important drivers of riverine landscapes.
3. Riverine landscapes are hierarchically organised whereby patterns and processes must be viewed at different scales.

4. Understanding riverine landscapes requires a focus on interactions between different disciplinary elements (e.g. biological, chemical geomorphological, hydrological, social and economic).
5. Riverine landscapes can be understood via causal or correlative approaches: the choice of method depends on prior knowledge and the scale of focus.
6. Human are keystone elements of riverine landscapes: they are drivers of change and users of ecosystem goods and services.

Strategic Adaptive Management was developed as a local tool for the management of biodiversity in Kruger National Park, South Africa (Biggs and Rogers 2003). Strategic Adaptive Management offers a framework for natural resource management and decision making in environmental, social and institutional situations characterized by variability, uncertainty, incomplete knowledge and multiple stakeholders. Three key tenets form the basis for the management and decision-making process in Strategic Adaptive Management: strategic and value-based planning based on scientific and societal needs and values; a learning by doing approach to management planning; and, participatory engagement of all stakeholders to serve their needs, access their inputs and secure their cooperation (Rogers *et al* 2008).

Strategic Adaptive Management offers six fundamental principles that may form components of a framework for managing and monitoring resilience in riverine landscapes:

1. All stakeholders are involved in the process of developing a vision for the desired state of riverine landscape condition.
2. A vision for the desired state of riverine landscape condition is translated into an objectives hierarchy.
3. TPCs (Thresholds of Potential Concern) are generated to define acceptable levels of change in riverine landscape form and function.
4. Research and observations of riverine landscape form and function are used to audit and understand river ecosystem condition in relation to TPCs.
5. Management interventions are an accepted part of ecosystem processes but only occur in context of TPCs.
6. Learning by doing is an essential part of SAM: knowledge of river ecosystems is constantly reviewed in order to update TPCs and management options.

The principles of Resilience Thinking, the ecosystem approach and Strategic Adaptive Management are here collated to form the components of a good practice framework for managing and monitoring resilience in the Lake Eyre Basin. Frameworks are used widely in many disciplines as a means to organise ideas, understand systems, identify direct cause and effect links and guide decision making about system management. Frameworks often fail in these functions, especially in complex systems, because of the lack of recognition of the hierarchical organisation of ideas, contexts and methods. The 'why', 'what' and 'how' components of any framework are often mixed together, resulting in confused logical levels of organisation and thinking.

The components of a best practice framework for managing and monitoring resilience in the Lake Eyre Basin form three levels of organisation representing the 'why', 'what' and 'how' of managing and monitoring riverine landscapes.

The first level places river ecosystem resilience as the highest component. Resilience forms the principle that guides the other levels of the framework. Without this anchor, other levels of the framework have no context. In short, it should be viewed as an aim. In this case, the context is that managing for the resilience of river ecosystems means maintaining the capacity of the system to absorb change or disturbance while remaining in essentially the same state that retains the same function, structure and feedbacks.

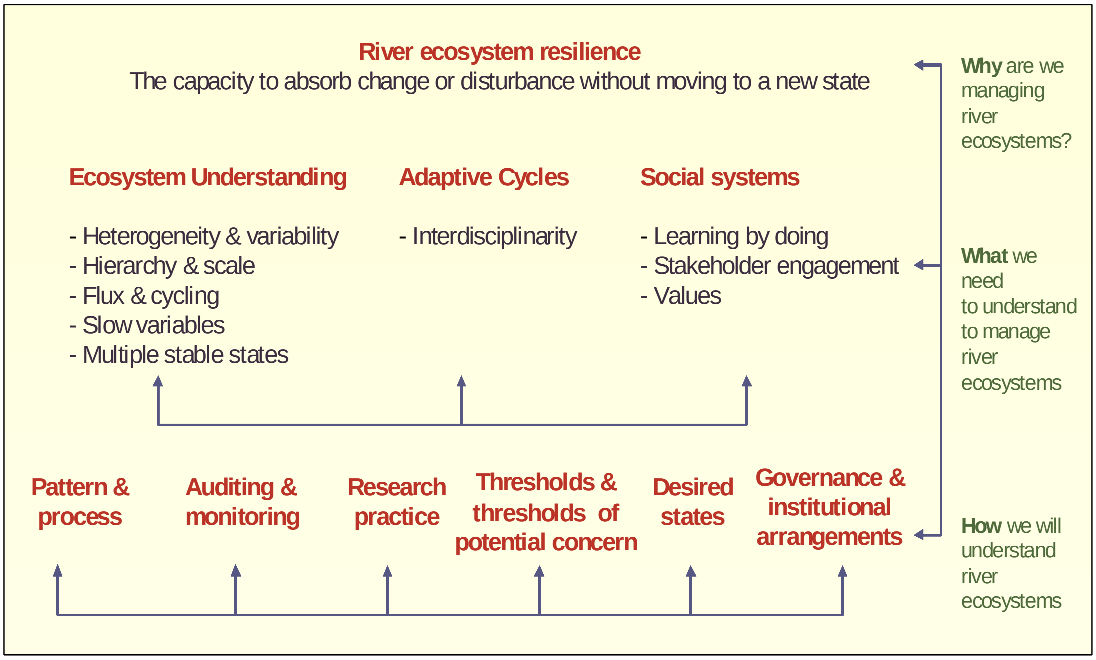

Figure 3: Components of a best practice framework for managing and monitoring resilience in the Lake Eyre Basin.

This second level defines the essential elements needed for an understanding of managing and monitoring for resilience in the riverine landscapes of the lake Eyre Basin. Each component of this level must be viewed in the context of the higher level to ensure that it maintains this focus. The second level of the framework is comprised of three components:

Ecosystem understanding is essentially about understanding the biophysical system. This component is characterized by paradigms and concepts that have been shown in the scientific literature to describe the properties inherent in the structure and functioning of riverine landscapes.

Adaptive cycles pertain to understanding riverine landscapes in terms of cycles of collapse and renewal. The position of the ecosystem within the adaptive loop influences the characteristics of the system, vulnerability to change and opportunity for change.

Social systems represent the social components of managing resilience in riverine landscapes, and pertain to communities, stakeholders, governance and institutions.

The third level describes how the components of understanding will be achieved. Components at this level are essentially methods and tools that can be used to operationalize the understanding about managing and monitoring resilience in the riverine landscapes of the Lake Eyre Basin that is the goal of the second level. The third level of the framework is comprised of six components:

Pattern and process expresses the need to include structural and functional elements of ecosystems that may be important in maintaining resilience.

Auditing and monitoring pertains to the ways that the state or condition of an ecosystem is assessed or measured, within the context of the overall aim to manage resilience.

Research practices highlight that the choice of paradigms, methods and scales of observation must be set within the context of managing resilience.

Thresholds and Thresholds of Potential Concern can be used in managing resilience to indicated demonstrated or actual tipping point between alternate stable states.

Desired states describe the states towards which the management of resilience should aim. Desired states are set with the input of all stakeholders.

Governance and institutional arrangements represent the policy, legislation and governance instruments to facilitate the implementation of an approach to managing the resilience of river ecosystems.

It is important to reiterate here that these components are not the framework itself, but rather, represent the underlying philosophy of an approach for managing resilience in the riverine landscapes of the Lake Eyre Basin. Development of components is essentially the first step in a three step process for introducing these ideas into the management arena of the Lake Eyre Basin. The remaining steps are:

Turning the components into a framework – this step will require the formation and ordering of components between and within the components of the framework. Essentially, a framework is a map outlining the various routes that can be taken to manage resilience in riverine landscapes.

Implementing the framework – this step involves developing the management, policy and governance structures and attitudes required to go about managing for resilience in the Lake Eyre Basin riverine landscapes. This step is not simple or easy. As Rogers (2006) points out, the real river management challenge lies in developing a collective understanding, and integration, within and between scientists, citizens and management agencies. However, the experiences of biodiversity management in the rivers of Kruger National Park suggest that this can be achieved though participatory and cooperative approaches and a commitment to long-term co-learning.

10. Recommendations

In progressing to the next stages of this project, which deal directly with the implementation plan and governance arrangements covering future assessments (Milestones 3 and 4), Kiri-ganai Research makes the following recommendations:

i. A revised LEB assessment method should be agreed to be based around whole-of-Basin condition, in line with the terms of the LEB Intergovernmental Agreement. An outline of such a method is provided in this report. Six components are considered to be able to monitored immediately; these being physical habitat, fish, water birds and riparian vegetation.

ii. It is the variability and complexity of environmental processes at multiple spatial and temporal scales in response to a range of disturbances that needs to be captured in any future development of a management and monitoring programme for the Lake Eyre Basin. A Strategic Adaptive Management system is recommended for an assessment of the Lake Eyre Basin with resilience of the natural resources of the basin being the ultimate aim of the programme. This provides the context for the selection of indicators, collection of data and establishment of Thresholds of Probable Concern.

iii. The timing of future assessments should be every 5 to 10 years, with ongoing monitoring reported annually, even where this is minimal monitroring.

iv. Governance arrangements in respect to future Assessments should be adopted that support a strategic adaptive management approach. Such arrangements should allow for continuous learning and improvement, and ensure that assessments inform stakeholders responses.

v. The workshop proposed for August 2009 should include discussion around the technical component of the assessment process as well as the governance and implementation components.

Appendix A: Terms of Reference

LEB Rivers Assessment Implementation Plan

The Department of Environment, Water, Heritage and the Arts requires the development of a Lake Eyre Basin Rivers Assessment Implementation Plan (Implementation Plan) to identify how regular on-going monitoring of key indicators of the condition of river ecosystems and catchments will be implemented within the Lake Eyre Basin Intergovernmental Agreement Area. The process of developing the Plan will involve:

1) **Review of achievements to date under the Lake Eyre Basin (LEB) Rivers Assessment (Milestone 1)**

a. A number of activities have been undertaken as part of the LEB Rivers Assessment to date. As part of developing the Implementation Plan, reports from these activities are to be reviewed and recommendations incorporated into the Plan for future on-going monitoring.

b. The Service Provider is to provide a draft report to the Department, for review and comment, indicating how the recommendations have been considered. The Service Provider will be required to address all comments received and provide a final document to the Department. The report should include, but is not limited to:

- the title of the report addressed;
- how the recommendations have been considered in developing the Methodology/Implementation Plan;
- any further action required.

2) **An agreed LEB Rivers Assessment Methodology (Milestone 2)**

As part of developing the Implementation Plan, the Service Provider is to finalise a methodology for monitoring that can be undertaken immediately, recognising that there will be a need for continued research and development of some indicators for future use.

This task will require the Service Provider to perform services including but not limited to:

a) identify the monitoring already being undertaken within the Lake Eyre Basin which will be included in the Implementation Plan;
b) identify the recommendations from previous LEBRA work that will be included in the Implementation Plan;
c) identify the indicators that were suggested in Method for Assessing the Health of Lake Eyre Basin Rivers that will be included in the Implementation Plan;
d) identify linkages with national monitoring, evaluation and reporting frameworks;
e) identify monitoring actions that can be undertaken immediately – summarise their methods and costs;
f) identify monitoring actions that require further research and development; and

g) advise on the appropriateness of reporting on a ten year basis or other timeframe.

3) Support development and documentation of governance arrangements (Milestone 3)

The Implementation Plan should briefly review the current responsibilities of the jurisdictions with the Agreement area and make recommendations on the options for governance associated with ongoing monitoring. The Service Provider is to provide a draft written report to the Department indicating suggested governance arrangements which includes but is not limited to:

a) reporting requirements;
b) the role of the Lake Eyre Basin Scientific Advisory Panel;
c) the role of Government officers;
d) the role of Regional Natural Resource Management groups;
e) links with Bureau of Meteorology;
f) scientific review of the program;
g) Quality assurance/quality control;
h) research and development issues independent of the assessment.

4) Development of a business model (Milestone 4)

The LEBRA Implementation Plan is to include an outline of how the monitoring activities will be funded or supported.

The Service Provider is to provide a draft report to the Department, for review and comment, indicating suggested governance arrangements. The Service Provider will be required to address all comments received and provide a final document to the Department. The report should include, but is not limited to:

a) the organisation committed to providing funding or support;
b) the funding or support to be provided;
c) the source of the funding or support; and
d) duration of commitment

5) LEB Rivers Assessment Implementation Plan (Milestone 5)

Using information from Milestone Reports 2, 3 and 4 the Service Provider will prepare a draft LEB Rivers Assessment Implementation Plan. The Service Provider will be required to address all comments received and provide a final document to the Department. Detail on what is to be included in the Implementation Plan is to be discussed with the Steering Committee.

6) Workshop (Milestone 6)

After completion of Milestone 5 the Service Provider is required to organise and participate at a workshop with relevant stakeholders. The location and duration of the workshop will be determined by the Steering Committee and the Service Provider together, and may include participation of some stakeholders by telephone. The services that will be required include, but are not limited to:

a) Organisation of the workshop (location to be agreed with the Steering Committee, will be a capital city).
b) Attendance and presentation at the workshop which will include:
   - outlining the approach undertaken to develop the Implementation Plan;
   - feedback received from stakeholders;
   - commitment to regular on-going monitoring of key indicators of the condition of river ecosystems and catchments.

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Appendix C: Stakeholders consulted to date

Place	Name	Organisation
Canberra	Derek White	Dept of Environment, Water, Heritage & Arts
	Don Blackmore	World Bank
	Craig James	Desert Knowledge CRC
	Tim Fisher	Minister Wong's Office
	Mark Sjolander	Parliamentary Sec. Kelly's Office
	Doug Watkins	Wetlands International
	Mark Stafford Smith	CSIRO Sustainable Ecosystems
Brisbane	Stuart Bunn	Griffith University
	Fran Sheldon*	
	Stephen Balcombe	
	Satish Choy	Dept of Environment & Resource Management
	Bill Reurich	
	Peter Old	
Longreach	Vol Norris	LEB Facilitator
	Angus Emmott	LEB Community Advisory C'tee
	David Phelps	Dept of Employment, Economic Development & Innovation (formerly DPIF)
	Luw Markey	
	Mike Chuk	Desert Channels Qld Inc
	Vanessa Bailey	
	Alun Hoggett	
Adelaide	Ben Fee	Dept of Water, Lands & Biodiversity Conservation
	Dale Lewis	
	Henry Manchini	
	Glynn Schulze	
	Jenny Cleary	South Australian Arid Lands (SAAL) NRM Board
	Kirrilie Rowe	
Alice Springs	Ian Fox	Dept of Natural Resources, Environment, the Arts and Sport
	John Wischusen	Geoscience Australia
	Richard Walsh	Centralian Land Management Assoc
	Hugh Pringle	Bush Heritage Australia
Darwin	Kate Andrews*	NT NRM Board
Sydney	John Porter	University of New South Wales

* Teleconference