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Methods for Assessing the Health of Lake Eyre Basin Rivers

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Lake Eyre Basin Rivers

Assessment Methods Development Project

Methods for Assessing the Health of Lake Eyre Basin Rivers

Final report to Land & Water Australia

Centre for Riverine Landscapes,
Griffith University,

January 2005

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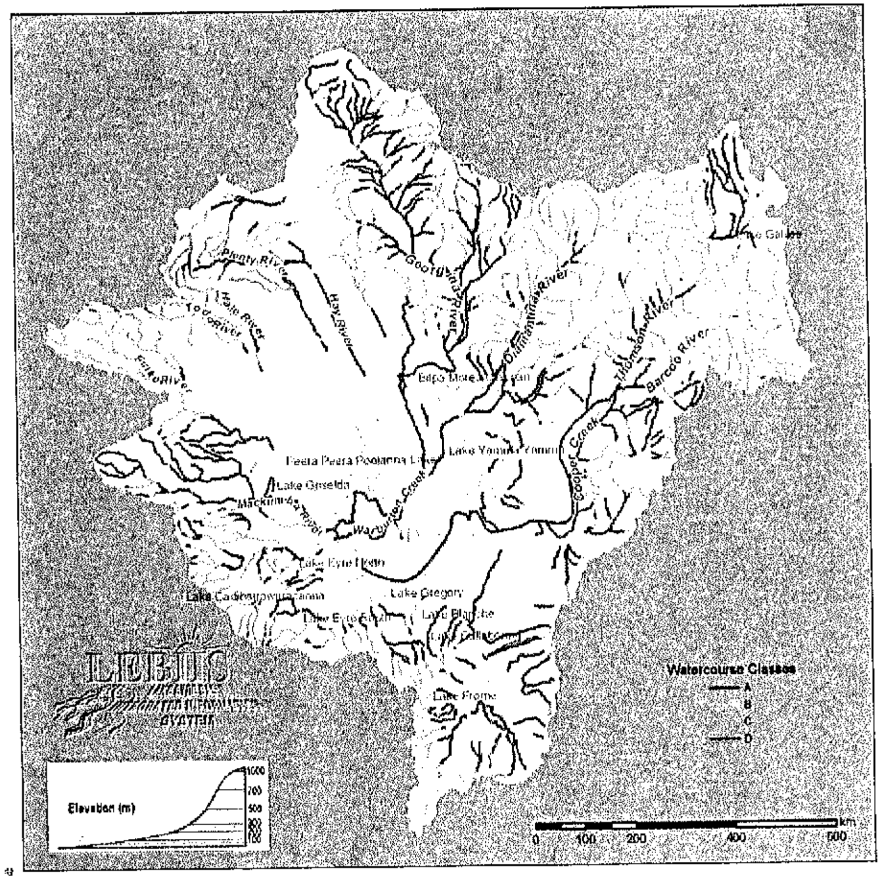

This report was prepared for Land and Water Australia by a group from the Centre for Riverine Landscapes, Griffith University with input from Vanessa Bailey from the Queensland Environment Protection Agency, Longreach, Alun Hoggett, LEBIIS Longreach and David Phelps from Queensland Department of Primary Industries.

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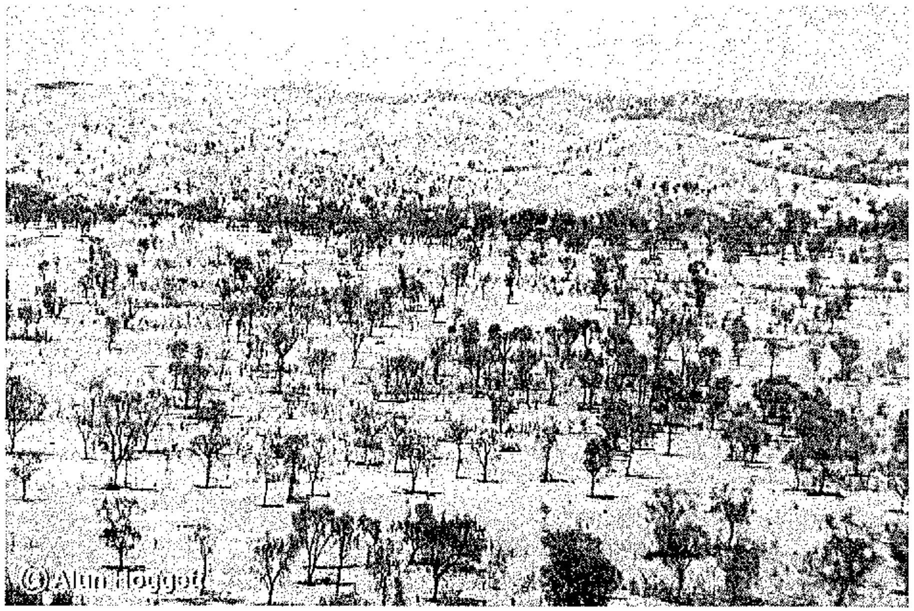

Photo by Alun Hoggett

The Selwyn Ranges, Lake Eyre Basin

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Executive Summary

Executive Summary

Preamble

The purpose of the Lake Eyre Basin Rivers Assessment Methodology Development project was to develop a scientifically based methodology for assessing the condition of river ecosystems and catchments in the Lake Eyre Basin. Community and government have articulated the values of, and threats to, the Basin watercourses; these have been used as a guide for the scope of this assessment methodology. The ongoing development and revision of the assessment methodology will be important to its success in assessing the condition of river ecosystems and catchments in the Basin. This report, *Methodology for Assessing the Health of Lake Eyre Basin Rivers* provides the required background resource material to enable proceeding to the implementation stage of an assessment of condition of river ecosystems and catchments in the Lake Eyre Basin.

Background

In this project we have used a subset of physical attributes to classify river systems throughout the Basin into three primary groups; *Headwaters*, *River Channels & Waterholes* and *Terminating Wetlands*. This classification has enabled us to conceptualise function of river ecosystems and to evaluate indicator applicability and comparability across the Basin. We have developed illustrative conceptual models to describe the physical and hydrological processes that underpin ecological function in the watercourses and floodplains of the Basin along with principal ecological processes at different spatial and temporal scales. Disturbance scenarios are also portrayed in order to facilitate understanding the rationale for inclusion of specific indicators and the recommendations given for the assessment approach. The limitations of these models are discussed. Metadata for relevant natural resource datasets and information have been collated and evaluated along with a comprehensive review of existing river health assessment schemes.

Indicators

Using these tools, existing knowledge, and reflecting the values and management issues, we have devised a list of suggested indicators for assessing the ecological health of rivers in the Basin. Each indicator is associated with one of four themes. The themes incorporate the ecosystem elements pertinent to the healthy functioning of the Lake Eyre Basin rivers, waterholes and wetlands; they recognise the intricate interrelationships of climate, hydrology, geomorphology, floodplains and aquatic ecosystems. These themes are *Flood & Flow*; *Physical Form*; *Riparian & Floodplain* and *Waterholes & Wetlands*. Under each theme are listed the specific attributes that are being addressed (*for example*: surface water use, riparian and floodplain biodiversity; waterhole water quality *etc.*), and associated with attributes are suggested indicators that can be measured in order to provide data for a condition assessment of the ecological health of Basin rivers and catchments. Techniques, or methods, for measuring each indicator have been provided; the indicators (and their measures) have been categorised according to their facility to be implemented "immediately", after a "pilot study" or with further "research and development". A table of suggested indicators is provided on page iii (Table E.1)

Assessment Scale

The scales required for an assessment of the ecological health of rivers are discussed in detail with a purposeful focus on the critical ecological issue of spatial and temporal scales that are unique to the Basin. Spatial scale divisions are addressed in the classification of watercourses throughout the Basin and further in the conceptual models. The classification suggests the principal units in the Lake Eyre Basin are *Headwaters*, *River Channels & Waterholes* and *Terminating Wetlands*. For each of these units the assessment scales, both spatial and temporal, for suggested indicators are considered. The implications of upstream and downstream impacts to site selection and indicator utility and assessment validity have been considered so that the Basin wide implications of a particular management strategy and/or, issues of information transference from a smaller spatial unit to a larger spatial unit, are recognised. The divisions of local, regional, catchment and basin are discussed in this context and tables of suggested indicators in the indicator methods section include a summary about which units (*i.e. Headwaters, River Channels & Waterholes* and *Terminating Wetlands*) relate to individual indicators.

Site Selection

The advised assessment approach for each unit; *Headwaters*, *River Channels & Waterholes* and *Terminating Wetlands* encompasses scale, frequency and development of specific assessment approaches. Sites that are associated with existing datasets or programs are used to illustrate the principles of site selection, which are referred to in the indicator methodology. The final group of indicators that is chosen for the assessment will be a foremost determinant of site selection.

Sampling Design

For each indicator a detailed account of its applicability and limitations and a provisional sampling protocol is provided in the indicator methodology. Decision tools have been included in order to proceed with an implementation framework that will support an ecological health assessment using the provided methodology. A specific decision tool is provided for indicator selection that starts at spatial and temporal scales and encompasses consideration of initial condition, indicator variability and required statistical power. The final protocol for sampling design will be developed depending on the actual group of indicators that are implemented in order to achieve the assessment of riverine ecological health.

Summary of Suggested Indicators

Table E.1 Summary Table of Suggested Indicators within each Theme for detecting the change in condition of different regions (Headwaters (HW), Channels & Waterholes (C&W), and Terminating Wetlands (TW)) of the Lake Eyre Basin. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there are existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique but its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Flow & Flood	Water Use	Volume of Water Held in Storage (% increase or decrease between assessment times)	Upstream water licensing information	**Immediate**			
			Upstream area (volume) of water stored calculated from satellite imagery	Pilot Study			
		Percent of Flow Diverted	Water licensing information	**Immediate**			
			Area (volume) of water diverted calculated from satellite imagery	Pilot Study			
	Hydrological Variability	Flow Variability at Gauging Stations	Long-term variability (& changes in variability) in amplitude, frequency and duration of floods	Pilot Study			
			Long-term changes in variability of multi-annual flows	Pilot Study			
			Predictability analyses	Pilot Study			
	Flood Extent	Flood Extent (current compared with modeled from past flood events)	Changes in the discharge vs. Flood extent relationship	**Immediate**			

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Riparian & Floodplain	Riparian and Floodplain Biodiversity	Riparian & Floodplain Biodiversity	Riparian & Floodplain vegetation taxa richness	Pilot Study			
			Riparian & Floodplain vegetation functional diversity	Pilot Study			
			Riparian & Waterbird assemblage composition & diversity	**Immediate**			
	Riparian Vegetation Condition	Riparian Composition & Extent	Riparian Cover Index	**Immediate**			
			Riparian SLATS – using TM and ETM+ images	Pilot Study			
		Riparian Recruitment & Regeneration	Riparian Regeneration Index	**Immediate**			
		Riparian Percent Exotics	Riparian NATIVES Index	**Immediate**			
	Floodplain[1] Vegetation Condition	Floodplain Composition & Extent	Floodplain Cover Index	**Immediate**			
			Floodplain SLATS – using TM and ETM+ images	Pilot Study			
		Floodplain Recruitment & Regeneration	Floodplain Regeneration Index	**Immediate**			
		Floodplain Percent Exotics	Floodplain NATIVES Index	**Immediate**			

[1] In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.

¹ In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.

BACKGROUND

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Aquatic Macroinvertebrate Assemblage Composition	Taxa richness	Pilot Study Existing Data			
			Modified SIGNAL Score				
			AUSRIVAS Scores				
		Fish Assemblage Diversity	Fish Assemblage O/E 50	**Immediate** Existing Data			
			% Exotic Individuals (abundance)				
			Recruitment				
	Waterhole & Wetland Water Quality	Water Quality	Conductivity (salinity)	**Immediate** Existing Data			
			pH				
			Turbidity				
			Diel range in dissolved oxygen				
			Diel range in water temperature				
			Nutrients (Total N and Total P)				
	Waterhole Process & Function	Ecosystem Processes	Benthic metabolism	Pilot Study			
			Algal Biomass & Composition				
			Carbon & Nitrogen Stable Isotope Analysis				

BACKGROUND

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Physical Form	Channel System Integrity	Channel System Integrity	Floodplain geomorphic complexity	R & D			
			Channel Complexity	Pilot Study			
			Within Waterhole complexity	Pilot study			
	Erosion Potential	Erosion Potential	Landscape Function Analysis	R & D			

Assessment Approach

Spatial Scale

The suggested indicators can be sampled and collected 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 (see Table E.2).

Local Scale Assessment

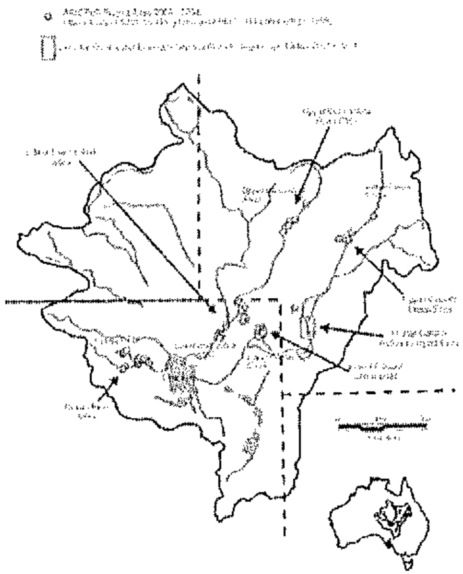
With assessment at the local scale both strategic and random sites should be used within the confines of budgets. Strategic sites will include Wetlands of National significance, Ramsar sites or other strategic conservation sites as well as established monitoring or research sites with existing data. Most measured ecological variables, however, will demonstrate considerable variation in space and time across many scales (Downes et al., 2002). To increase the power of any of the indicators to detect change over the large spatial scales evident within the Lake Eyre Basin it will be necessary to quantify the within location variability, as compared to the between location variability. To this end random sample sites should be positioned around strategic sites, such that several sites are sampled scattered over specific locations at each sampling time (see Downes et al., 2002; Page 129).

The number of sites recommended in Table E.2 will include both strategic and random sites. For example, the 20 recommended sites for the Headwater region may include 4 locations, with one strategic site in each location and 4 random sites. The positioning of random sites with strategic sites for the terminal wetlands will be difficult and thus 10 terminal wetlands should be monitored across the LEB with location grouping where possible.

For indicators measured at the "local" scale a site-based assessment of health will be generated, the condition assessment will be relevant only at a regional scale and little catchment condition will be inferred.

Table E.2 Example of sites that may be considered for Local Scale Assessment (see text for explanation)

Headwater	Rivers & Waterholes	Terminal Wetlands
Minimum of 20 sites Recommended	**Minimum of 50 sites Recommended**	**Minimum of 10 sites Recommended**
QNRM Water Quality Monitoring sites for the upper Cooper Creek system o Aramac Creek, o Reedy Creek o Sandy Creek o upper Thomson River at 'Camoola Park' o upper Barcoo River at Blackall. There are no existing sites in the headwater regions of the Diamantina or Georgina Rivers and these would need to be established. Wetlands of International Importance in the region include a number of spring sites: Aramac Springs, Cauckingburra Springs, Doogmabulla Springs.	QNRM Water Quality Monitoring sites for the middle and lower reaches of Cooper Creek, and the Diamantina and Georgina Rivers (see Bailey, 2001). Wetlands of International Importance in the region: o Birdsville – Durrie Waterholes Aggregation (QLD023), o Cooper Creek Overflow Swamps – Windorah (QLD025), o Cooper Creek Overflow Swamps- Nappa Merrie (QLD026), o Cooper Creek-Wilson River Junction (QLD027), o Diamantina Lakes Area (QLD028), o Diamantina Overflow Swamp-Durrie Station (QLD029), o Georgina River King Creek Floodout (QLD030), o Mulligan River-Wheeler Creek Junction (QLD039). Long-term research sites within the region (see figure): o ARIDFLO (Ecological-Flow relationships of Arid Rivers) o Cooperative Research Centre for Freshwater Ecology Dryland River Refugia Project.	Terminal Wetland sites should be distributed across the LEB and include terminal lakes in the Headwater Regions, such as Lake Galilee and Lake Buchanan. Other sites may include Lakes Frome and Blanche in South Australia as well as Lake Eyre. Other terminal wetland and lakes systems that should be considered include Lake Yamma Yamma in the Thomson River catchment, Lake Torquinie Area and Lake Phillipi in the Georgina River catchment.



Recommended position of locations in which sampling sites (strategic + associated random) for the river channels and waterholes zones of the Lake Eyre Basin should be chosen.

Headwaters: we recommend a minimum of 20 sites be established across the headwater zone of the Thompson, Barcoo, Georgina and Diamantina Rivers. These sites should be nested within locations or sub-atchments; for example, five locations each comprising four sites (one strategic site and three random sites).

Channels & Waterholes: we recommend a minimum of 50 sites be established across this vast section of the Lake Eyre Basin. Again sites should be nested within locations; locations should include the Cooper channel country and lower Cooper, Diamantina channel country and lower Diamantina and the western rivers including the Neales, a long-term sampling region for the ARIDFLO Project.

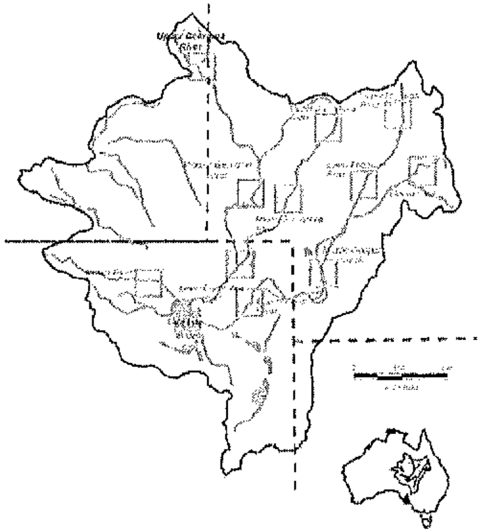
Terminal Wetlands: Terminal Wetlands and Lakes are distributed across the Lake Eyre Basin. We recommend a minimum of 10 terminal wetlands sites be established. These would include internally draining lakes such as Lake Galilee and Lake Buchanan in Queensland and Lakes Frome and Blanche in South Australia. Lake Eyre should be included as the terminus of the Lake Eyre Basin rivers system. It will be difficult to cluster groups of lakes for all locations, therefore, where groups of lakes do exist, a number of sites should be established so that within location variation can be quantified.

Project.

BACKGROUND

Regional Scale Assessment

Regional Scale Assessment has been recommended for the Physical Form indicators. These indicators are measured over larger distances and areas compared with many other indicators and will use remotely sensed data or large scale mapping. We have recommended at least eleven regions (or large scale reaches) for the assessment. These regions are essentially nested within river zone. Regions include the headwater of the Thomson, Barcoo, Diamantina and Georgina, middle and lower reaches of the Georgina and Diamantina River and Cooper Creek and at least one region on the western Neales River.



Recommended regions (or reaches) for undertaking regional assessment of some indicators within the Lake Eyre Basin.

Catchment Based Assessment

We have recommended Catchment Based assessment for the Flow Theme indicators. This data will be collected at the catchment scale and therefore allow reporting at the catchment level.

Summary of Spatial Approach

Overall we have recommended a "hybrid approach" for the assessment. This involves a network of locations across the basin. In each location both strategic sites and a number of randomly selected sites will be sampled for a "site-based" or local assessment. Including a number of sites for each location means that within location variability can be quantified. For those indicators recommended for site-based assessment to be up-scaled into catchment based assessment then a larger number of sites will be needed for each catchment. The Sustainable Rivers Audit of the Murray-Darling Basin suggested between 18 and 30 sites per river valley (sub-catchment) were needed for various indicators to make a catchment assessment of condition. With the large number of sub-catchments within the Lake Eyre Basin this would suggest a large number of sites are needed to undertake a full assessment of the Lake Eyre Basin. In conjunction with the network of strategic sites for site-based assessment we recommend a network of regions be assessed for landscape change and physical form indicators.

This, initial estimate of the number of sites required, has been made by assuming a nested sampling design, with five replicate sites sampled within different locations across the Lake Eyre Basin; giving broad geographic coverage, but also the ability to quantify the within-site variability. For example, in each of the four headwater regions across the LEB (Barcoo, Thomson, Diamantina and Georgina) five sampling sites would be chosen. These five should ideally include a strategic site where long-term data exists as well as four randomly placed sites.

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 each sub-catchment from continued analysis of assessment data combined with Pilot Studies.

BACKGROUND

Temporal Scale

Events Based Monitoring
Rainfall and flows in the headwater region are influenced by seasonal climatic conditions, including monsoonal phases and also by longer term climatic fluctuations such as El Nino and La Nina cycles. The biotic response to each event will differ depending on the timing, magnitude and duration of each event. Any assessment of trends in this region needs to consider the initial condition and variability associated with seasonal extremes.

Frequency of Assessment
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.

Summary of Temporal Approach
We recommend a standard assessment timeframe for each indicator combined with ad-hoc events based monitoring which will be required if a trend assessment approach is adopted.

Summary of Spatial and Temporal Sampling

Table E.2 **Summary Table of Suggested Indicators within each Theme including the suggested number of sites or regions for sampling and the temporal frequency of sampling.**

Theme	Attribute	Suggested Indicator	Suggested number of Sites or Regions	Suggested Sampling Approach	
				Spatial	Temporal
Flow & Flood	Water Use	Volume of Water Held in Storage	6	Catchment	Bi-annual
		Percent of Flow Diverted	6	Catchment	Bi-annual
	Hydrological Variability	Flow Variability	3	Catchment	Bi-annual
	Flood Extent	Flood Extent	6	Catchment	Bi-annual
Riparian & Floodplain	Riparian & Floodplain Biodiversity	Riparian & Floodplain Biodiversity	70	Local – site based	Annual + post event
	Riparian Vegetation Condition	Riparian Composition & Extent	70	Local – site based	Annual + post event
		Riparian Recruitment & Regeneration	70	Local – site based	Annual + post event
		Riparian Percent Exotics	70	Local – site based	Annual + post event
	Floodplain[2] Vegetation Condition	Floodplain Composition & Extent	70	Local – site based	Annual + post event
		Floodplain Recruitment & Regeneration	70	Local – site based	Annual + post event
		Floodplain Percent Exotics	70	Local – site based	Annual + post event
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Macroinvertebrate Assemblage Diversity	80	Local – site based	Autumn, Spring+ post event
		Fish Assemblage Diversity	80	Local – site based	Autumn, Spring+ post event
	Waterhole & Wetland Water Quality	Water Quality	80	Local – site based	Autumn, Spring+ post event
	Waterhole Processes & Function	Ecosystem Processes	50	Local – site based	Autumn, Spring+ post event
Physical Form	Channel System Integrity	Channel System Integrity	11	Regional	Five Years
	Erosion Potential	Landscape Function Analysis	11	Regional	Bi-annual

[2] In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.

Trend Based Assessment

One of the biggest challenges in selecting indicators, and more importantly in interpreting the data collected on any indicator, is to understand the large spatial and temporal variations in natural "condition" that are evident across the LEB. This large-scale variation means that at any one point in time, reflecting natural variations in flooding and rainfall, sections of the LEB will naturally be in "good" condition while others are in "poor" condition. As catchments and systems throughout the LEB move from wet into dry and back into wet or flood, the ephemerality of many watercourses (dry during the dry and wet after rain or flood) is an important aspect in their utilization as sites of high productivity, and breeding areas for waterbirds. The dynamic and changing nature of this ephemerality needs to be captured in the interpretation of the indicator assessment and from a management perspective should be protected in the "management of mosaics".

The approach we recommend is analogous to the "grazing gradient" approach used in the Australian rangelands to assess the health of pasture. The grazing gradient recognizes spatial changes in pasture cover a certain distance from a point water-source. Pasture in "good" condition will appear "poor" a short distance from the watering point but rapidly return to "good" condition. Pasture in "poor" condition will also appear "poor" a short distance from the watering point but will fail to return to "good" condition with increasing distance from the watering point. In this way the grazing gradient is measuring the "resilience" of the vegetation to the grazing disturbance.

A similar system should be incorporated for many of the indicators suggested. The indicator responses need to be 'scaled' so that a decline in condition with time since last flood or rainfall is expected, even in waterbodies in excellent condition, making the interpretation of "healthy" or "unhealthy" for a given waterbody more robust. Under this trend assessment scenario a site in poor condition would fail to respond or appear healthy even immediately after flooding or rainfall (display low reslience). In many instances the trends may be determined from existing data, in others Pilot Studies may need to be implemented to measure and document the trends. In this way declines in condition caused by human impact can be distinguished from natural variation.

Cost of the Assessment Program

The recommendations for spatial and temporal sampling within the assessment program have been made based on professional opinion as there has been no scope within this desk-top study to explore existing datasets to address the temporal and spatial variability within each indicator. We have included a feedback loop for existing and new data within the management framework to be used within the assessment, in line with a trend based approach and we recommend that the spatial and temporal frequency of the assessment be reviewed after the initial 10 year condition report to increase the power of the indicators to detect change. We have provided an estimate of the costings for a number of the indicators suggested as part of the assessment program (see Table E.3). These costings are based on being at the site and do not include the cost of travel to the often remote locations. For a number of indicators the final cost will need to be determined as part of a Pilot Study when the nature of the methodology for collecting data for the indicator is finalised.

Summary of Indicator Costing

Table E.3 Summary Table of Suggested Indicators within each Theme including the suggested number of sites or regions for sampling and the estimated cost of sampling at a given spatial scale and temporal frequency.

Theme	Attribute	Suggested Indicator	No of Sites, Regions	Cost per Site	Frequency – per year	Cost per Year
Flow & Flood	Water Use	Volume of Water Held in Storage	6	TBD[3]	0.5	TBD
		Percent of Flow Diverted	6		0.5	
	Hydrological Variability	Flow Variability	3		0.5	
	Flood Extent	Flood Extent	6		3	
Riparian & Floodplain	Riparian & Floodplain Biodiversity	Riparian & Floodplain Biodiversity	70	$400[4]	1	$28,000
	Riparian Vegetation Condition	Riparian Composition & Extent	70	$250	3	$52,500
		Riparian Recruitment & Regeneration				
		Riparian Percent Exotics				
	Floodplain[5] Vegetation Condition	Floodplain Composition & Extent	70	$250	3	$52,500
		Floodplain Recruitment & Regeneration				
		Floodplain Percent Exotics				
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Macroinvertebrate Assemblage Diversity	80	$400	3	$96,000
		Fish Assemblage Diversity	80	$400	3	$96,000
	Waterhole & Wetland Water Quality	Water Quality	80	$300	3	$72,000
	Waterhole Processes & Function	Ecosystem Processes	50	$200	3	$30,000
Physical Form	Channel System Integrity	Channel System Integrity	11	TBD[6]	0.5	TBD
	Erosion Potential	Landscape Function Analysis (LFA)	11	$400	0.5	$2200

[3] Indicators in this group involve the use of Landsat imagery and costs will need to be determined (TBD) after a Pilot Study phase and the final form of the imagery is decided.
[4] This costing does NOT include waterbird surveys, which would be undertaken at a regional scale and will need to be costed separately.
[5] In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.
[6] Again, this potentially involves the use of remotely sensed data and large scale mapping techniques. The costing would need to be reviewed when the final form of the indicator is decided.

Interpreting the Assessment

We have organised the indicators into five themes that recognise the intricate interrelationships of climate, hydrology, geomorphology, floodplains and aquatic ecosystems within the Lake Eyre Basin. While many existing assessment programs (such as in the Index of Stream Condition and the proposed Water Quality Indicator in the SRA) combine the information from the assessment into a single or overarching Indicator Score we do not recommend exploring this for the Lake Eyre Basin Assessment Program. As we have recommended a trend based assessment it would be short-sighted to reduce the information gained for each indicator into a single number. In a system as variable as the LEB the assessment will need to be undertaken by exploring changes over time for each indicator. For the purposes of graphically representing the health of regions within catchments or catchments themselves the approach used by the South East Queensland EHMP would be preferred. In this approach the minimum value for any indicator within a Theme is reported as a "traffic light" (red for poor condition and green for good condition).

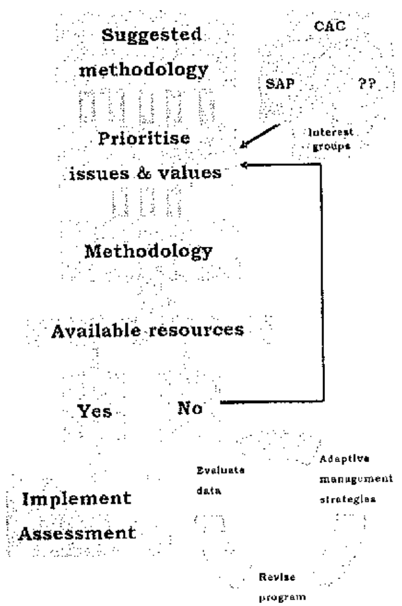
Different Assessments for Different Issues

As in the South-East Queensland EHMP (see Smith & Storey, 2001) we have recommended a background or ambient assessment program for the Lake Eyre Basin. Clearly, across the Lake Eyre Basin, monitoring may be required to assess the impact of town sewerage systems or industrial point source pollution. Such monitoring would require more rigorous use of nutrient sampling, biological and ecosystem process and perhaps less focus on physical form and flood and flow themes.

Management Framework

The management strategy incorporates elements from each section of the project and supports the provided methods. Feedback loops are structured to clearly acknowledge management issues and support the ongoing development of an assessment program that incorporates scientific input to underpin its implementation, addresses existing knowledge gaps and considers available resources. Interpretation and reporting are encompassed under data management within the assessment program with a feedback loop via program revision to address knowledge gaps. A data management strategy is given within the management framework that includes consideration of program authority, new and existing data. A geographic information system and Access database are recommended tools for data management.

The final form of the assessment will need to be refined by a number of 'steps'.
We have provided a list of suggested indicators and suggested methods for undertaking an assessment of condition of the Lake Eyre Basin rivers and wetlands. The LEB community, including the CAC and SAP will need to review this list in conjunction with a process of prioritising the issues and values for the LEB.



Methods for Assessing the Health of Lake Eyre Basin Rivers

Report Structure

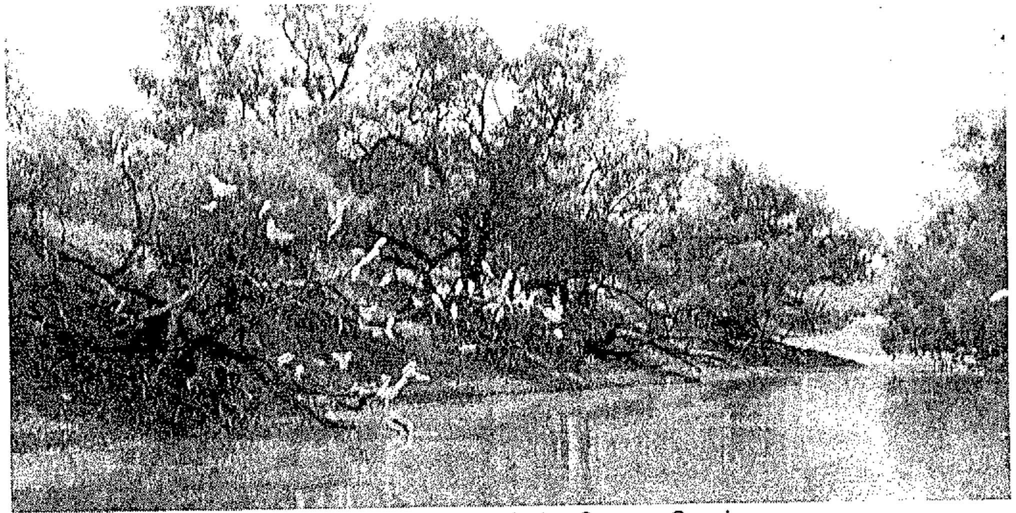
<u>Classification</u>: This report includes a summary of the Classification undertaken for the Lake Eyre Basin rivers (Section 2) – see also Backkground Document 2.

<u>Conceptual Models</u>: Conceptual models have been developed and presented for the three main functional zones of rivers and wetlands in the Lake Eyre Basin (Section 3)

- <u>Headwaters</u> (Section 3.2)
- <u>Rivers, Channels & Waterholes</u> (Section 3.3)
- <u>Terminal Wetlands</u> (Section 3.4)

<u>Indicator Methods</u>: A detailed methodology for those indicators recommended within the framework of the Conceptual Models is presented (Section 4)

<u>Management</u>: A framework for management of the assessment is presented (Section 5).



Glen Murken Waterhole, Cooper Creek
Photo by Jon Marshall, QNRM

The report includes four background documents:

Background Document 1: Conceptual Models for the Lake Eyre Basin Rivers Assessment Methodology Project – CDROM

Background Document 2: Classification of Lake Eyre Basin Rivers for the Lake Eyre Basin Rivers Assessment Methodology Development Project

Background Document 3: Review, Evaluation and Collation (metadata) of Relevant Natural Resource Information and Datasets for River Systems and Catchments in the Lake Eyre Basin Agreement Area for the Lake Eyre Basin Rivers Assessment Methodology Project.

Background Document 4: Review of Existing Assessment Schemes for the Lake Eyre Basin Rivers Assessment Methodology Project.

1. Introduction

1.1. Background

"Dryland" rivers typically occur where annual rainfall is less than 500 mm and the annual evaporation rate exceeds rainfall (Comin & Williams 1994). Australian dryland rivers have some of the most variable patterns of flow in the world (Puckridge et al. 1998). Both large floods, which breach the banks and cover vast tracts of land, and extensive droughts, where the water in the channel dries back to a few permanent waterholes, are features of Australian dryland rivers. Although the unreliable nature of flow in dryland rivers can cause human economic hardship, the animals and plants inhabiting the rivers and their floodplains are well adapted to the nature of this flood-drought variability (Boulton et al. 2000; Boulton et al. in press). In fact the ecological integrity of many dryland rivers, particularly in lowland areas, depends upon the periodic lateral movements of water onto the floodplain (period of flooding) and the converse drying out of the channel environment (period of drought) (Puckridge 1999).

The rivers of the Lake Eyre Basin (Figure 1.1) are dryland rivers, characterized by extremely variable and unpredictable flows, low gradients and complex flow paths. The rivers of the Lake Eyre Basin, the Thompson, Barcoo, Cooper Creek, Georgina, Diamantina and the Warburton and their tributaries change from chains of waterholes in dry times to slow moving 'inland seas' that are often many kilometres wide in big floods. These rivers are unregulated and largely unmodified by large-scale water resource developments.

The Lake Eyre Basin Agreement requires an initial assessment of the condition of the major river systems and catchments within the Lake Eyre Basin Agreement Area. This assessment will be repeated every 10 years and a program of monitoring is required to underpin the assessment. Over the past 10 years Australian governments have invested in national and State assessments of river health in order to evaluate current river conditions, monitor changes in river condition and determine priorities for management and rehabilitation. Much of the river health assessment to date has been conducted for rivers that have year-round flows or systems for which there is a significant amount of existing data. These tend to be in the catchments of eastern Australia and other catchments across Australia with intensive landuse.

This project provides a classification, conceptual models, indicators and a data management framework for the assessment of, and reporting on, the ecological condition of watercourses and catchments within the Lake Eyre Basin Agreement Area. Specifically the project has:

- Classified the rivers and streams of the Lake Eyre Basin so that like regions of the basin are compared with like;
- Developed conceptual models of river processes and functions that provide a scientific basis and rationale for the assessment and that clearly articulates current understandings of key processes as a basis for supporting management activities.
- Suggested a discrete set of indicators from attributes that, when collated and interpreted, provide measures of ecological condition.
- Linked indicators with values/threats identified for Lake Eyre Basin rivers (via conceptual models)
- Suggested an operational framework for the assessment that supports monitoring and reporting at regular intervals.
- Developed a method for the management framework for the assessment of and reporting on the ecological condition of watercourses and catchments within the Lake Eyre Basin Agreement Area.

1.2. Ecosystem Health

A more detailed description can be found in Background Document 4: Review of Existing Assessment Schemes for the Lake Eyre Basin Rivers Assessment Methodology Project.

Ecosystem health is most often measured by monitoring an ecosystem's response to disturbance through changes in key ecological patterns and processes. The biotic responses to disturbance can be summarized as (Downes et al., 2002):

- Resistance – the capacity to withstand a disturbance, and
- Resilience – the capacity to recover from disturbance

In many ecosystem health monitoring programs the indicator values of impact sites are compared with values obtained from reference sites (chosen to be as close as possible to the state of the environment undisturbed by human activity) or control sites (chosen to be as similar as possible in all respects to the impact location except for the presence of the impact) (Downes et al., 2002). However, disturbance gradient approaches that do not require reference sites, have also been used (Smith & Storey, 2001)

The use of biological patterns or organization (e.g. structure of fish and invertebrate communities), as indicators of ecological health is a popular approach for assessment (Hart et al. 1999). Biological communities integrate a range of disturbances over time and give a summary of environmental conditions for the preceding period (Williams, 1980). However, focusing health assessment purely on patterns will illustrate the effect of a disturbance but will not show how a system works (Bunn et al. 1999). Measuring ecosystem processes (i.e. gross primary production, nutrient cycling, denitrification) provides an integrated response to a broad range of catchment disturbances (i.e. nutrient inputs from diffuse sources, changes to the quantity/composition of organic carbon inputs, alteration to the light regime by riparian shading) and also contributes to understanding how a system works (Bunn et al. 1999).

1.3. The Lake Eyre Basin

1.3.1. Climate

The Lake Eyre basin lies in the arid zone which covers some 60% of Australia (Kotwicki 2003). Across the catchment average maximum winter temperatures range from 18°C to 24°C, and average summer temperatures range between 36°C and 39°C (Kotwicki 2003). However, the overall temperature range is large, with minima and maxima from the lower Cooper Creek area recorded at -2°C and 49°C respectively (Gibling et al. 1998). The annual average number of hours of bright sunshine is estimated at 3410 hr yr^{-1} (International Lake Environment Committee 2001).

Rainfall ranges from 400 to 500 mm y^{-1} in northern and eastern headwater regions to around 120 mm y^{-1} in the Simpson Desert (Gibling et al. 1998; Knighton & Nanson 1994b; Kotwicki 2003). Principally this pattern is attributed to the influence of the southern margin of the summer monsoon (Kotwicki 2003), which brings irregular but heavy rain causing floods to rivers in most years (Gibling et al. 1998).

Given the sparse canopy cover in the Basin, more than half of all precipitation (59%) falls directly on to the ground (Arora & Boer 2001). Evaporation rates exceed precipitation (Bailey 2001), with about 60% of all evaporation coming directly from the ground (Arora & Boer 2001). Humidity, though seasonally variable is low throughout the year (Bailey 2001).

also contributes to understanding how a system works (Bunn et al. 1999).

1.3.2. Geology & Geomorphology

(Adapted from Callen et al. 1986, Alley 1998 and Maroulis et al. 2000)

The Basin is a wide shallow Cainozoic structure overlaying the more extensive and pre-existing Eromanga Basin and early Tertiary Birdsville Basin. The Basin is bordered on the west by the Denison Range and the Dalhousie Dome, on the south by the Willouran, Flinders and Olary Ranges, and on the east by the Barrier Ranges. Domes of Mesozoic rock form the northern boundaries in Queensland, New South Wales and the Northern Territory. Sedimentation within the basin occurred in three main geological phases: 1) fluviolacustrine sand, silt, clay and carbonaceous horizons from the latest Paleocene to Middle Eocene; 2) dolomite and magnesium-rich clay and sand deposited in extensive shallow alkaline lakes suggested to be from the latest Oligocene-Miocene; and 3) red clay, silt and sand deposited in fluvial lacustrine and aeolian settings during the Pliocene and Quaternary.

The current channel system is formed mainly from aggradation between stable banks composed of floodplain muds. Their sediments are mud-dominated containing mixtures of quartzose sand, pedogenic sand-size mud aggregates and clay from suspension. Floods deposit mud across the wide alluvial floodplains.

The mud sheet is underlain by a sheet of sand and gravel that extends to below 35m depth and can be traced from headwater regions to Lake Eyre.

1.3.3. Landuse

Sheep and cattle pastoralism is the dominant land use within the Basin. Other land-uses include mining and petroleum, tourism, urban and conservation (Lake Eyre Basin Coordinating Group 2002).

The Basin has a long history of Aboriginal settlement and use, and large portions of it are subject to native title claims (Lake Eyre Basin Coordinating Group 2004). Important cultural sites within the Basin are being identified and preserved to allow Aboriginal people to maintain their traditional links to the land (Lake Eyre Basin Coordinating Group 2002).

Mining products include silver, opals, oil and gas (Lake Eyre Basin Coordinating Group 2002). The Basin houses Australia's largest onshore oil and gas reserve, and overall, mining provides the biggest economic contribution to the Basin (Bailey 2001).

Eco-tourism and cultural tourism in the Basin have risen in popularity in recent years contributing significantly to the regional economy, but also providing management challenges due to pollution, site degradation and movement of weed species (Treadlightly Australia 2005; Lake Eyre Basin Coordinating Group 2004).

Urban land-use is concentrated mainly to the north-east and the southern tip of the Basin and around Alice Springs, with smaller communities scattered throughout the Basin. Overall, the Basin is sparsely populated with about 57,000 people, 25,000 of which are in Alice Springs (Lake Eyre Basin Coordinating Group 2002).

The Basin is an area of high conservation significance with 37 listed parks and reserves covering a diverse array of habitat types including wetlands, grasslands and desert (Lake Eyre Basin Coordinating Group 2004). Within these areas there are many rare and endangered animal and plant species, and highly restricted endemic species that are supported by mound springs, wetland areas created by water seepage from the Great Artesian Basin (Lake Eyre Basin Coordinating Group 2004).

1.3.4. Hydrology

The Lake Eyre Basin is divided into five major catchment groups, partitioned according to the natural direction of surface water flow (Lake Eyre Basin Coordinating Group 2004) (Figure 1.2). The total catchment area of the Basin is 1,140,000 km^2 and it functions as the largest endoreic (internally draining) system in Australia (International Lake Environment Committee 2001). Average annual runoff for the entire catchment has been estimated by the Department of Primary Industries at 4,900,000 ML (Bailey 2001). Lake Eyre is fed mainly from its eastern tributaries Cooper Creek and the Diamantina and Georgina systems although significant run-off can originate from the western part of the Basin (Gibling et al. 1998; Kotwicki 2003). Both a shallow subsurface aquifer and deeper artesian water system exist within the Basin (Bailey 2001).

All watercourses are characterised by extreme flow variability in discharge volume and duration (Kotwicki 2003). For example, within the Diamantina River, flood discharge from a single week can exceed its annual discharge (Gibling et al. 1998). Creeks and rivers are ephemeral, with short periods of flow and long periods of no flow (Lake Eyre Basin Coordinating Group 2002).

The channel country of Cooper Creek and the Diamantina and Georgina Rivers are characterised by anastomosing channels (Morton et al. 1995; Rust & Nanson 1986). These watercourses transport sand in their main channels, but their principal load is mud which during flood phases is transported to the floodplain (Rust & Nanson 1986). During flood, the rivers can expand to exceptional widths with sheets of water up to 70km wide on the Cooper below Windorah and up to 500km wide on the Diamantina and adjacent channels above Birdsville (Gibling et al. 1998).

Low gradients within the Basin result in the slow movement of water throughout the system which may take several months to reach Lake Eyre (Bailey 2001; Gibling et al. 1998). Transmission losses can be very high. Flood volumes decrease systematically downstream due to evaporation and seepage to underlying sediments (Gibling et al. 1998). For example, over a 400km reach of Cooper Creek, transmission loss has been estimated at 75% (Knighton & Nanson 1994a). Flow ceases during dry periods, but water is retained within waterholes (Gibling et al. 1998).

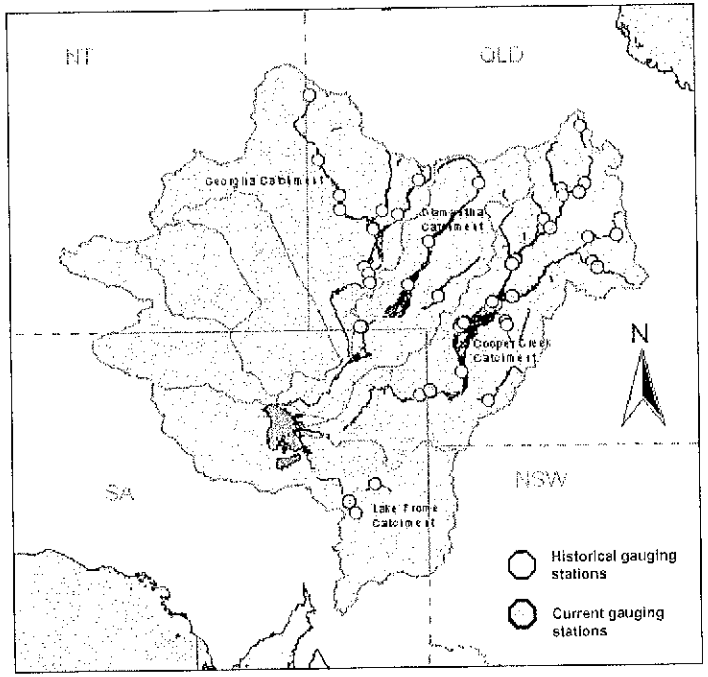


Figure 1.2. Map of the Lake Eyre Basin showing the position of gauging stations. Most of the gauges are now inactive – for a complete summary see Background document

decrease systematically downstream due to evaporation and seepage to

The major rivers of the Lake Eyre Basin (Cooper Creek and Diamantina River) are among the most variable rivers in the world (Puckridge et al., 1998). Gauging data exist from 1940 to 1987 for the Currareva Gauge, near Windorah in western Queensland. This period of record (Figure 1.3) shows a median annual discharge of 1648GL, a minimum in 1952 of 0GL and a maximum in 1974 of 23478GL (Puckridge et al., 2000). In further examining the hydrograph data from the Currareva gauge (1940 – 1987: 576 months) Puckridge et al. (2000) provide the following statistics:

- 248 months (43%) no discharge registered
- 289 months (50%) 0-1000GL recorded
- Maximum discharge February 1974 – 15890GL
- Median monthly discharge = 0.95GL
- Mean monthly discharge = 266.20GL

Despite this variability the Cooper hydrograph shows a distinct and predictable seasonal component in which summer and autumn flows are dominant (Puckridge et al., 2000).

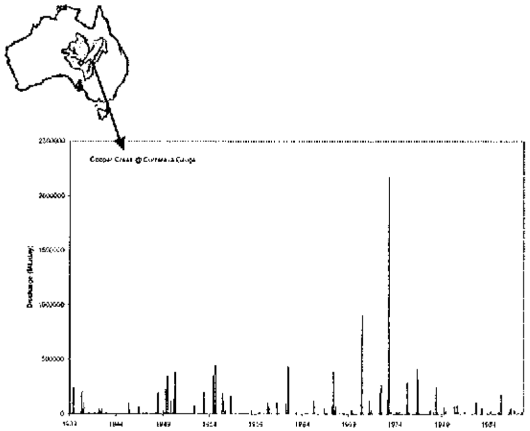


Figure 1.3 Hydrograph for Cooper Creek at the Currareva gauge.

The Diamantina River is also one of the most variable in the world (Puckridge et al., 1998). Gauging data for the Birdsville gauge for the period of 1953 to 1970 were used to compare with the Cooper Currareva gauge. For this period of record (Figure 1.4) the median annual discharge was 329GL, a minimum in 1969 of 13.4GL and a maximum of 6986GL in 1954. Further examination of the hydrograph (199 months) provides the following statistics:

- 65 months (33%) no discharge registered
- 29 months (1.5%) of 0-1000 GL recorded
- Maximum discharge March 1954 - 3712GL
- Median monthly discharge = 38GL
- Mean monthly discharge = 897GL

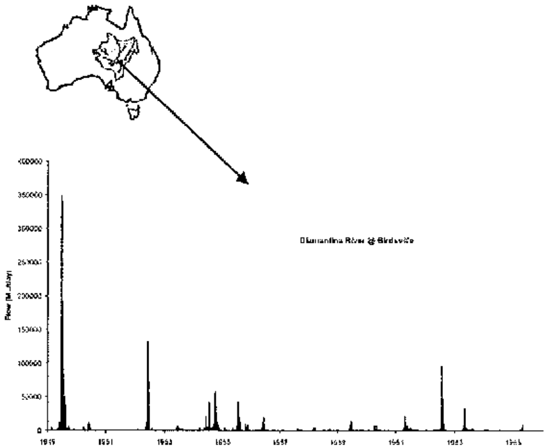


Figure 1.4 Hydrograph for the Diamantina River at the Birdsville gauge

1.3.5. Values of the Lake Eyre Basin

These are the environmental and social values in the Lake Eyre Basin, identified by community and government. This list of values was compiled by Bernice Cohen, Senior Policy Officer for the SA Department of Water Land & Biodiversity Conservation from discussions at the LEB Scientific Advisory Panel. This list of values has assisted in the derivation of the indicators for health of the rivers and catchments in the Lake Eyre Basin.

Values identified in the Lake Eyre Basin Agreement[7]

- 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 ecosystems 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[8]

- 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[9]

- 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

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[7] *Lake Eyre Basin Intergovernmental Agreement*, October 2000

[8] *Agreed policies* adopted by the Lake Eyre Basin Ministerial Forum 25 October 2002

[9] Lake Eyre Basin Coordinating Group, *Lake Eyre Basin Strategic Plan* October 2000

Georgina/Diamantina catchment[10]

- Healthy and diverse catchment
- Working together
- Vibrant and sustainable economy
- Catchment approach to management
- Surface and ground water for both ecological and production outcomes
- Improved pasture management particularly during drought
- Avoiding further pollution or degradation of land and water
- Alternative or multiple land use opportunities
- Control of feral animals and weeds
- Protection of aquatic and terrestrial ecosystems
- Protecting rich and unique diversity of plants and animals
- Economic viability and local employment opportunities

Cooper Creek[11]

- Up to date and accessible natural resource management information
- Sustainable, integrated management of natural resources for future environmental and development needs
- Viability of existing industries
- Development and growth of new industries based on environmental and economic sustainability
- Conservation of the natural environment to meet human and ecological requirements

[10] Lake Eyre Basin Coordinating Group *Georgina/Diamantina Catchment Strategic Plan*, October 2000

[11] Lake Eyre Basin Coordinating Group *Cooper's Creek Catchment Strategic Plan* October 2000

1.4. Approach

Our approach in undertaking this project has been:

- To develop conceptual models that illustrate how healthy dryland rivers such as those of the Lake Eyre Basin function and how they respond to threats (Section 3 and Background Document 1[12])
- To classify the rivers of the Lake Eyre Basin using data that are not subject to human disturbance (Section 2 and Background Document 2[13])
- To undertake a review of the existing data for the Lake Eyre Basin (Background Document 3[14])
- To review the available indicators for river health across the appropriate spatial and temporal scales applicable to the rivers of the Lake Eyre Basin (Background Document 4[15])
- To identify appropriate indicators of the ecological health of the rivers of the Lake Eyre Basin (Section 3 and Section 4)
- To suggest an operational management framework for the assessment (Section 5).

[12] **Background Document 1**: Conceptual Models for the Lake Eyre Basin Rivers Assessment Methodology Project – CDROM

[13] **Background Document 2**: Classification of Lake Eyre Basin Rivers for the Lake Eyre Basin Rivers Assessment Methodology Development Project

[14] **Background Document 3**: Review, Evaluation and Collation (metadata) of Relevant Natural Resource Information and Datasets for River Systems and Catchments in the Lake Eyre Basin Agreement Area for the Lake Eyre Basin Rivers Assessment Methodology Project.

[15] **Background Document 4**: Review of Existing Assessment Schemes for the Lake Eyre Basin Rivers Assessment Methodology Project.

1.5. Existing Schemes

There is a number of existing schemes in Australia for assessing the health of different rivers and their catchments. The major regional, or catchment, based schemes include:

- Ecological Health Monitoring Program for South East Queensland (EHMP)
- Sustainable Rivers Audit (SRA) for the Murray-Darling Basin
- Index of Stream Condition – catchments within Victoria

A range of broader (not catchment specific) approaches also exists – these have been incorporated into the catchment based schemes above. They include:

- Australian Rivers Assessment Scheme (AUSRIVAS)
- Stream Invertebrate Grade Number – Average Level (SIGNAL)
- Specific indicators from the Australian Rangelands Information system.

In suggesting a range of indicators for assessing the health of the Lake Eyre Basin rivers we have been mindful of those indicators already in use in these existing schemes and have attempted to "value add" to existing State and regional based monitoring and assessment programs.

2. Classification

2.1. Background

A full account of the classification, including detailed methods, can be found in Background Document 2: Classification of the Lake Eyre Basin Rivers for the Lake Eyre Basin Rivers Assessment Methodology Project

This section summarises the approach taken to classify the rivers and streams of the Lake Eyre Basin. Classification of rivers is important within an assessment program as comparisons of indicators are only relevant within similar rivers or reaches (i.e. apples are compared with apples). Another consideration in classifying rivers is that some indicators may prove more effective, or be more appropriate, for certain river and/or reach types. Classification could highlight this.

Classification of catchments into like rivers or reaches can be used for the following purposes in relation to river assessment:

1. inform the Conceptual Models, so appropriate models can be developed for different geomorphic reaches and regions.
2. inform the design for the assessment, so sampling sites and locations can be distributed across the different geomorphic regions
3. inform the outcome of assessment, so the results of any assessment, the values for indicators, can be compared within similar geomorphic regions.

For the Lake Eyre Basin project we initially used GIS to classify the rivers into like reaches. Available datasets were used to classify the rivers into four distinct groups (see GIS and Statistical Approach). Further separations of rivers and reaches into like groups acted to increase separation in the headwater regions so that more numerous (and less meaningful groups) were formed, but failed to distinguish differences in the lowland channel section. The channel country region of the majority of the Lake Eyre Basin differs geomorphologically in complexity and channel form. At this stage there are no GIS datasets of geomorphic complexity so this level of distinction was undertaken using an approach similar to the River Classification System (RCS) of Thoms (1998). The following is a summary of the Classification outcomes. .

2.2. GIS and Statistical Approach

Classification grouped those reaches that are similar based on physical attributes chosen. Only variables not directly affected by anthropogenic activity were considered in order to eliminate non-natural differences in stream type (see Smith & Storey, 2001).

Attributes were chosen to represent differences in streams and reaches based on climate, geology and geomorphology.

Attributes used were:
Stream Slope – measured as centimeters per kilometre
Annual Moisture Index – ranges between 0 and 1, where 1 is the wettest. This incorporates rainfall, evaporation and soil water retention (due to lack of soil information the model treated the area as a uniform clay loam)
Geology (era) – the following periods were chosen

CAINOZOIC
MESOPROTEROZOIC
MESOZOIC
NEOPROTEROZOIC
PALAEOPROTEROZOIC
PALAEOPROTEROZOIC - MESOPROTEROZOIC
PALAEOZOIC

Geology (lithology) – the following lithologies were used:
- amphibolite-facies metamorphics
- felsic volcanics
- granites
- granulite-facies metamorphics
- intrusive complexes
- mafic volcanics
- sedimentary rocks

Reaches were then discriminated on the basis of these physical attributes using a hierarchical clustering approach similar to that undertaken in Smith et al. (2001) and Whittington et al. (2001).

The size of the Lake Eyre Basin and the large number of reaches compared using the cluster technique meant that a large number of groups could potentially be derived. Taking into account the patterns seen in the data and the need for a meaningful classification, the discrimination of reaches was achieved using a four-group level of classification (each group is hereafter referred to as a "watercourse class") (Table 2.1; Figure 2.1).

Watercourse classes A and B are the most similar and include most of the lower slope channels (Figure 2.1). Watercourse class A has the lowest stream slope and predominantly traverses more recent sedimentary rocks. Watercourse class B includes the higher slope, headwater regions of the channel country rivers as well as many of the channels to the west of the LEB and they traverse mostly older sedimentary rocks. Watercourse class C channels occur mostly in the north and the west of the LEB, they have comparatively high stream slopes and traverse older granite and volcanic rocks. Watercourse class D channels also had a relatively high slope and again were restricted to the north and the west headwater regions traversing more recent granites and volcanic rocks. All watercourse groups had relatively low values for Moisture Index.

Table 2.1 Summary of mean values for the four attributes used in classifying the Lake Eyre Basin rivers into four major classes.

Class	Ave Stream Slope (±SE)	Most Common Lithology	Most Common Geological Era	Average Moisture Index (± SE)
A	100 (15)	Sedimentary	CAINOZOIC	0.122 (0.01)
B	571 (117)	Sedimentary	PROTEROZOIC - PALEOZOIC	0.106 (0.005)
C	568 (182)	Granites & Volcanics	PROTEROZOIC	0.100 (0.005)
D	400 (165)	Granites & Volcanics	NEOPROTEROZOIC	0.076 (0.005)

Watercourse classes A and B describe the majority of the Lake Eyre Basin rivers and are predominantly associated with the channel country. These watercourses differ in the degree to which they are anastomosing. These differences were consistent with moving from the upper headwater regions, where Watercourse class B dominated to the lower channel country where Watercourse A dominated.

There were insufficient data in GIS format to further distinguish channels within the lower reaches of the Basin. To formulate a meaningful distinction between regions of watercourse class A and B sections a further classification was undertaken using the River Classification System approach (adapted from Thoms, 1998), which focuses on smaller scale geomorphological features.

west headwater regions traversing more recent granites and volcanic rocks. All watercourse groups had relatively low values for Moisture Index.

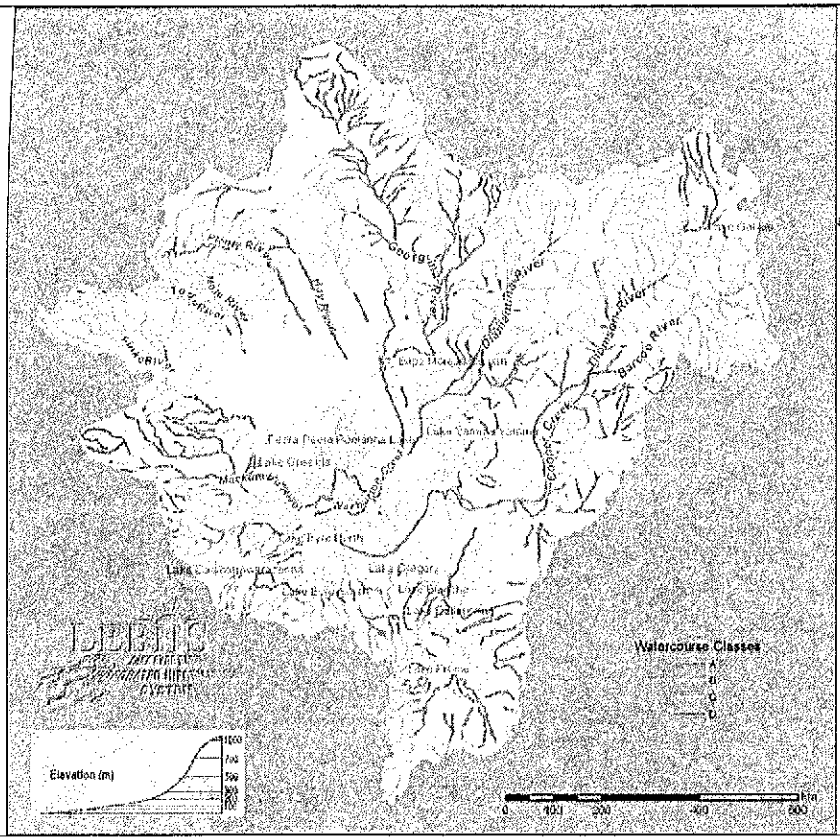


Figure 2.1 Map depicting the four group classification of the LEB rivers and streams. Lowland watercourses are shown in red (Watercourse Class A), headwater tributary regions of these watercourses are shown in yellow (Watercourse Class B). Watercourse classes C and D are upland regions draining granite and volcanic rocks of differing ages. The terminating wetlands of the basin (not included in the GIS classification) are shown in light blue.

2.3. RCS Approach for Classification of the Major Channels

An hierarchical classification similar to the RCS approach (Thoms, 1998) was used to divide watercourse class A and B rivers into reaches or zones with distinctive geomorphology. The RCS approach recognizes that fluvial systems are composed of several dominant functional zones. These zones include a zone of water and sediment supply near the headwaters, a zone of sediment transfer near the middle of the river profile and a zone of sediment storage near the lower end of terminus of the river system.

This classification was undertaken in a similar way to the Ecological and Geomorphological Assessment of the Georgina-Diamantina Catchment (Sheldon et al. 2003). The following tools were used in the assessment:

- GIS
- Satellite Imagery and Aerial Photography
- Topographic and Geological Maps
- Vegetation and Rainfall Maps
- Existing cross-sections and floodplain information

Each river reach was divided into zones of similar physical characteristics. Physical characteristics included river-floodplain geology, bioregion, river-floodplain morphology, mean annual rainfall and moisture index. The main channel regions were divided into the three functional zones (see Figure 2.2); a headwater zone (white), a mid channel-country zone (grey) and a lower channel-country zone (black). Terminal wetlands were considered a distinctive geomorphological unit and not included in this classification.

Upper Zone Summary: Upper zone channel systems were characterised by a large through flow of discharge and sediment in response to relatively high rainfall and the erosive breakdown of sedimentary rocks. Consequently, the morphology of most upper zone channels reflected these processes and displayed steep slopes and either a single channel planform or a low degree of anastomosing. Upper zones for the Georgina, Diamantina and Cooper catchments mainly occurred in the Mitchell Grass Downs bioregion.

Middle Zone Summary: Middle zone channels occurred mostly in the Channel Country bioregion and were characterised by a high degree of anastomosing in response to having extremely shallow slopes, cohesive clay banks and increased sediment deposition of mostly Cainozoic Alluvium. Large water holes, dunes, gorges and extensive floodplains are dominant features of the middle zone.

Lower Zone Summary: Lower zone channels were similar in planform to the upper zone systems characterised by either a single channel planform or a low degree of anastomosing and for Georgina, Diamantina and Cooper systems occurred mostly below the Channel Country within the Simpson-Strzelecki Dune Fields bioregion. The presence of extensive flood outs, wetlands and dunes, which play a big part in channel control, are dominant features of the lower zone.

Terminal Wetlands: these were considered distinctive geomorphological units and were classified separately to the channels.

For complete details of the reaches across the Basin see Background Document 2: Classification of the Lake Eyre Basin Rivers for the Lake Eyre Basin Rivers Assessment Methodology Project.

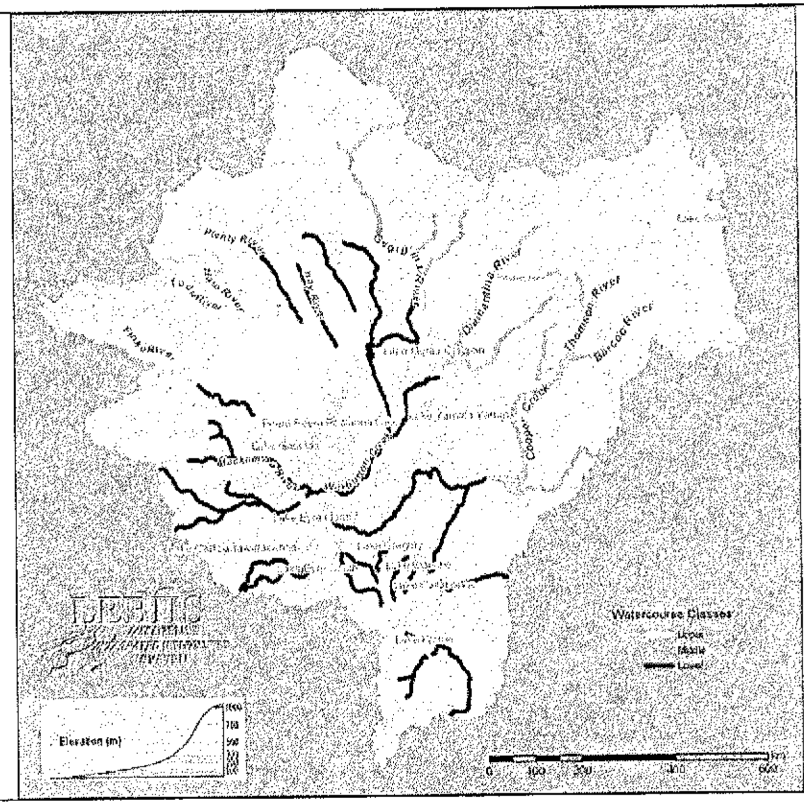


Figure 2.2 Map depicting the three sub-group RCS classification of the major watercourses in the Lake Eyre Basin based on satellite imagery, aerial photography, topographic and geological maps, vegetation and rainfall maps, existing cross-sections and floodplain information. Upper zones are shown in white, middle zones in grey and lower zones in black. The terminating wetlands of the basin (not included in the classification) are shown in light blue.

2.4. Summary of Classification

	GIS Classification	RSC Classification	Classification Used for Conceptual Models
Alluvial controlled streams and channels	Watercourse Class A Watercourse Class B	Headwater Zone Middle Zone Lower Zone	Headwater Channels and Waterholes
Bed-rock controlled headwater streams	Watercourse Class C Watercourse Class D	*Considered as part of the Ephemeral Rivers project*	
Terminal Wetlands	*Not included in GIS classification*		Terminal Wetlands

The classification of the rivers and streams of the Lake Eyre Basin separated the Basin into four watercourse classes and two major groups as well as the terminal wetlands.

- Watercourse Class C and D form a group of headwater streams that drain hard-rock regions in the north and west of the Lake Eyre Basin. The streams of these classes are better suited to the indicators being developed by the Land and Water Australia funded Project "Quantifying the Indicators of Health in Ephemeral Rivers" which is focusing on indicators for small ephemeral streams and rivers, many of which are bed-rock controlled.
- Watercourse Class A and B form a group of sediment based streams and channels that are the dominant form for rivers within the Lake Eyre Basin. Rivers in these classes were further divided, using a functional zone approach, into Upper, Middle and Lower process zones.
- Terminal wetlands are considered a distinct group on their own and were not included in the statistical classification.

2.5. Using the Classification

The Classification suggested three broad physical types of watercourses and aquatic habitats in the Lake Eyre Basin. These three types form the basis for the development of the Conceptual Models.

Conceptual Models have been developed for *Headwater*, *River Channels & Waterholes* and *Terminal Wetlands*. This forms the next section of the report.

As well as informing the Conceptual Model development, the Classification also assists in the selection and distribution of sites for assessment.

3. Conceptual Models

3.1. Background

3.1.1. Threats to the Lake Eyre Basin

The Lake Eyre Basin Scientific Advisory Panel identified a range of issues that pose challenges the management of the Lake Eyre Basin (see Cullen, 2004). These issues include:

- Abstraction of water for mining and irrigation development.
- Biodiversity of aquatic systems (including floodplains), which may be impacted by water decisions or contaminants.
- The possible existence of biodiversity 'hot-spots' that act as important refuges and as thus must be managed for in a particular way.
- Impacts of pastoral activities, tourism and mining.
- Management of waterholes – grazing, abstractions of water, groundwater linkages.
- Management of floodplains – levees, road/rail links and their impacts on water flow across the floodplain.
- Introduction of exotics and appropriate responses.
- Impacts of groundwater management on surface water resources.
- Management of mound springs.
- Health of the rivers and catchments.
- Salinity hazards and impacts of vegetation management on shallow groundwater.
- Impacts of climate change on surface water resources.

3.1.2. Development of Conceptual Models

These issues, along with the values identified by the Lake Eyre Basin community (see Section 1) provide a background for understanding the values of, and threats to, the Lake Eyre Basin rivers. Using these values and threats we formulated conceptual models to assist in selecting indicators for measuring ecosystem health.

The classification of the Lake Eyre Basin rivers (see Section 2) was used to develop conceptual models across the three major types of waterbodies within the Basin, namely the "headwaters", "channels & waterholes" and "terminal wetlands".

Conceptual models are graphical images that:

a. Show how undisturbed healthy ecosystems function,
b. Show how aquatic ecosystems respond to disturbance,
c. Indicate critical biotic components/processes in the system to target in an assessment program.

When formulating models they should not only be useful and instructive for scientists, they should also be informative and easily understood by managers and the community (Smith & Storey 2001). Our models were formulated to be readily understandable to the range of interest groups associated with the Lake Eyre Basin; scientists, the general community, water managers and landholders.

For this project conceptual models were developed to provide an explanation of the current understanding of the highly variable aquatic systems in the Basin. The models were developed to show:

a. hydrological and geomorphological processes operating at both spatial and temporal scales across the LEB,
b. biotic processes operating at each spatial region across Basin with the major temporal changes in biotic processes associated with hydrology summarized,
c. disturbance scenarios for each region.

The role of the conceptual models was twofold. Initially, hydrologic and geomorphic processes were described at different geographic levels within the catchment. Second, variation from a temporal perspective was described.

we formulated conceptual models to assist in selecting indicators for measuring ecosystem health.

catchment. Second, variation from a temporal perspective was described.

Accordingly, the models describe processes within headwater, channel, waterhole and terminating wetland areas, and during different broad hydrologic phases. These are described as 'dry', 'wet' or 'flood'.

Additionally, important hydrologic disturbance elements identified in workshop sessions were depicted and illustrated with a number of case studies.

To enhance the combination of figures with key textual descriptions, conceptual models have been presented using a wholly interactive navigable CDROM interface which forms a Background Document 1: Conceptual Models for the Lake Eyre Basin Rivers Assessment Methodology Project. Users are therefore able to view all or specific model elements.

Using the CDROM, the models are arranged across both spatial and temporal scales and can be viewed across either scale. Accompanying the models are a series of photographs of the Lake Eyre Basin specific for both spatial or temporal scales. The impacts of disturbance are included in a separate section that contains sequence animations of hydrological impacts across regions of the Basin.

3.1.3. The Role of Hydrology

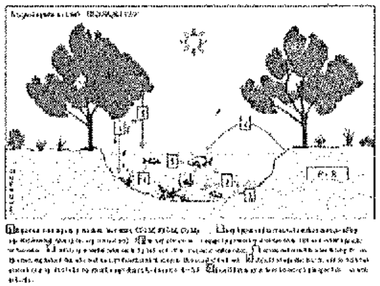
As outlined in Section 1, the rivers of the LEB are among the most variable in the world. It is impossible to capture the extent of this variability in graphical conceptual models. We have approached this variability by choosing the major hydrological phases to present graphically.

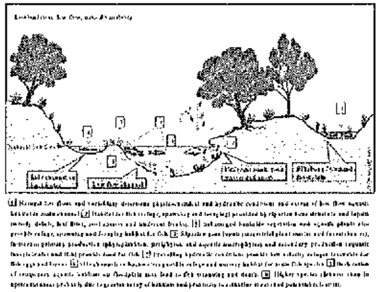
3.1.4. Model Development

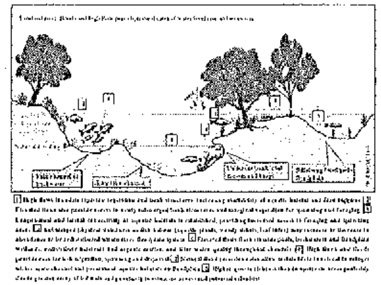
Conceptual Model content was developed by the project team and work-shopped at a two specific meetings.

- o Planning meeting Canberra, ACT, September 2003
- o Indicator Workshop, Griffith University, Qld, February 2004

General Conceptual Models of Stream & River Ecosystems







These general conceptual models of upland and lowland sections of a stream were used by the South East Queensland Regional Water Quality Management Strategy (SEQRWQMS) to graphically depict the biotic processes occurring within stream ecosystems.

For the Lake Eyre Basin rivers the extreme spatial and temporal variability associated with variable flooding, and the general lack of specific biotic process information, makes formulating such diagrams for this system difficult.

We have chosen to use icons and text to explain the changes in different biotic groups and ecological processes through differing aspects of the flood cycle.

3.1.5. Conceptual Model Structure

The conceptual models have been divided initially by region, so there is a section relating to "headwater", a section for "river channels and waterholes" and a section for the "terminal wetlands". Within each region the models relating to hydrologic and geomorphic processes are presented first followed by models describing biological processes. The models describing biological processes use a number of icons to describe the changes in biological communities and processes, both within the channel environment and on the floodplain, through major changes in flow. The major flow distinctions are "dry" and "wet" with the "wet" phase broken into "flow" and "flood" where appropriate.

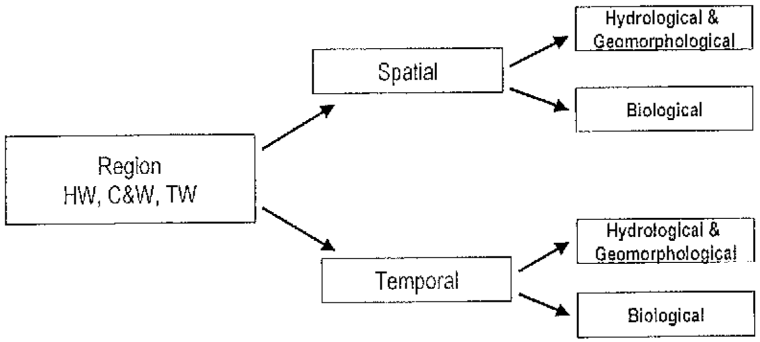
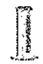


Figure 3.1 Organisation of the Conceptual Models

Icon	Description
	Water quality
	Ecosystem Processes
	Invertebrate assemblage
	Fish assemblage
	Waterbird assemblage
	Riparian vegetation
	Floodplain vegetation (or catchment vegetation for headwater regions)

3.2. Headwaters

3.2.1. Values and Threats

The headwaters include the tributary catchments, which occur mainly to the north and east in Queensland. In this region slopes are significant and flows are more channelised than in other regions of the LEB (Cullen, 2004). These headwater regions are the main source of much of the water that travels to downstream reaches. Land-use is currently dominated by pastoralism.

The major threats to the integrity of this region include:

- Tree clearing,
- Water resource development (dams and diversions),
- Weed infestation,
- Shifts from pastoralism to intensive farming (cropping).

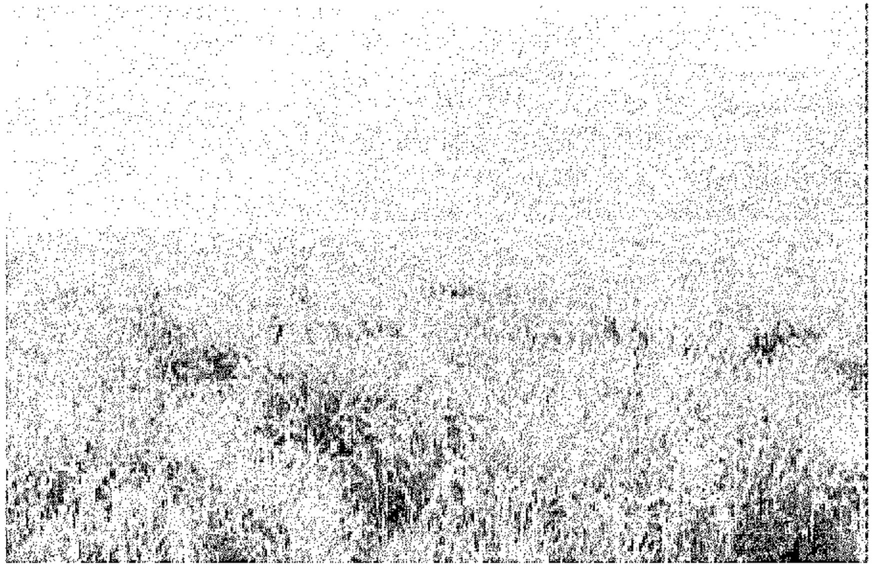
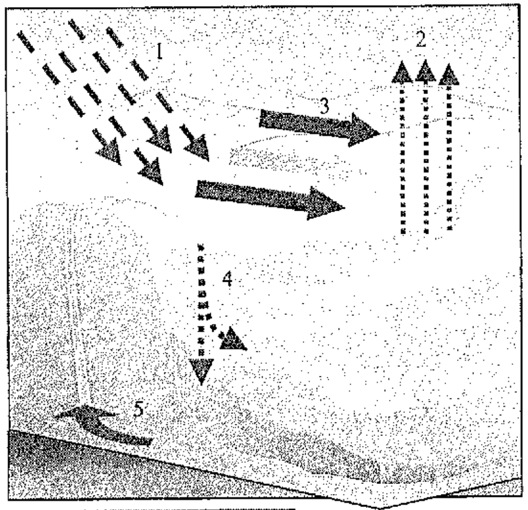


Photo by P. Sattler

Mitchell Grass Downs

3.2.2. Hydrologic and Geomorphic Processes

These images graphically describe the hydrologic and geomorphic processes operating in the headwater regions.



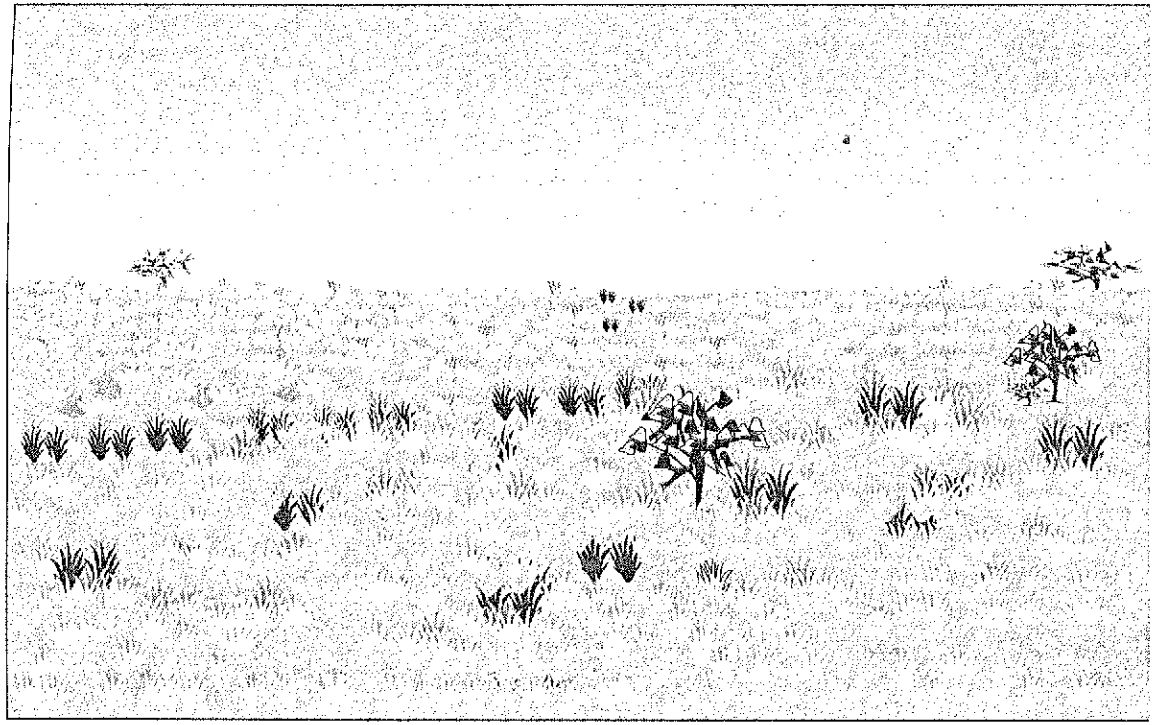
1. Rainfall
2. Evaporation
3. Overland movement of water and sediment to channels
4. Some surface water infiltration to alluvial and possible deeper groundwater
5. Movement of artesian groundwater to the surface via mound springs (patchy)

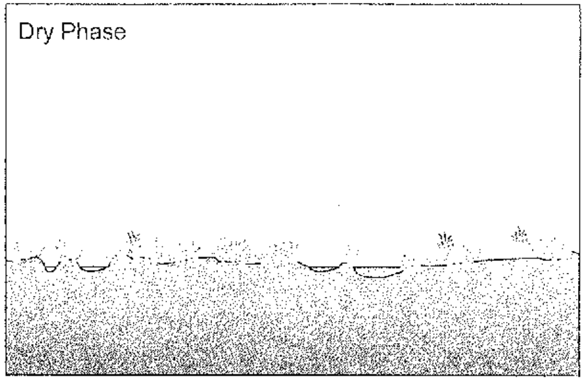
Headwater processes

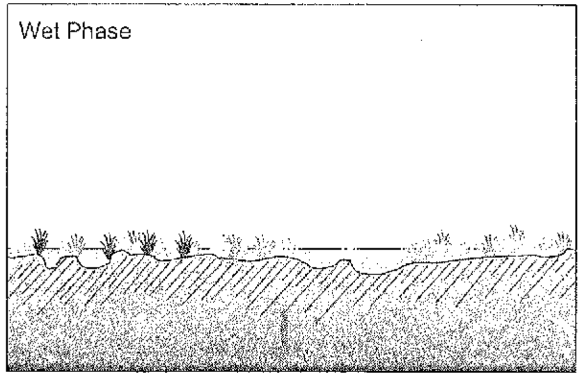
Rain in the headwater regions is rapidly converted to surface flow. Large downpours can produce significant surface flooding. Runoff from this flat landscape can produce significant flows downstream. There is considerable movement of water and sediment from the surrounding catchment to the channels.

In some regions of the LEB rainfall in the headwaters can infiltrate into both near surface and possibly deeper alluvial aquifers. This infiltration is patchy and determined by the underlying geology and geomorphology. Where this occurs it may be significant in maintaining permanent waterholes in the headwater regions during dry periods.

There are also groups of mound springs (surface expressions of the deep Great Artesian Basin (GAB) waters). These are significant ecosystems in their own right and have very little impact on the surface water system. Impacts from GAB waters on surface water systems occur mostly when there are uncapped bore drains releasing artesian water into surface water systems. In the headwater regions the presence of artesian springs is patchy.







Headwater Region

Headwater landscapes feature shallow channel definition.

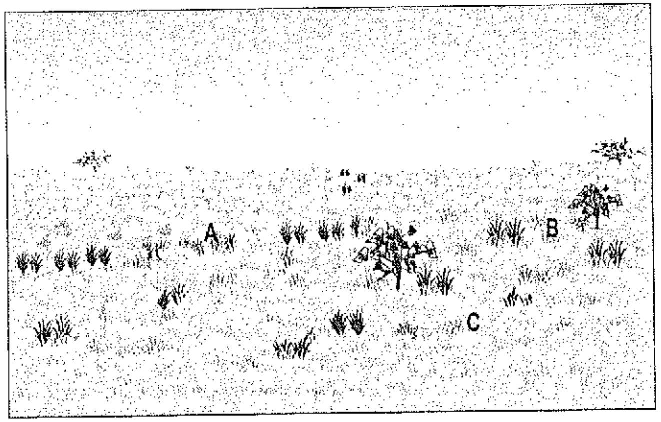
Dry Phase: Alluvium distinguishes the dry river and creek bed flats with few naturally occurring permanent waterholes.

Wet Phase: During wet periods rainfall is easily converted to runoff in the vast, low relief headwater landscapes.

3.2.3. Biotic Processes

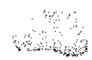
These images graphically describe the biotic processes of the headwater regions. These processes have been divided into the two major habitat types: ephemeral watercourses and permanent waterholes.

Ephemeral Headwater Watercourses



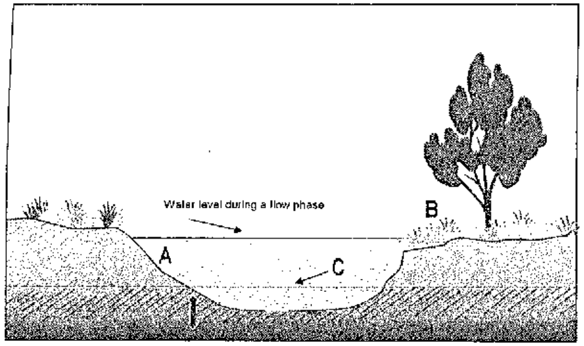
Headwater landscapes feature shallow channel definition during dry times. The headwater landscape includes

- Ephemeral channels that include a few permanent waterholes (A)
- Riparian zones that are sparse on ephemeral channels to substantial around permanent waterholes (B)
- Surrounding catchment areas of native pasture grass (C)

Dry		A	Most channels are dry, water only held within permanent waterholes – see next table
		A	Most channels are dry, water only held within permanent waterholes – see next table
		A	Desiccation resistant fauna may remain in the dry channels, less resistant taxa will perish or move to permanent waterhole – see next table.
		A	No fauna survive in ephemeral channels during the dry, all taxa seek refuge in permanent waterholes – see next table.
		B	Waterbirds concentrated around permanent waterholes.
		B	Leaf litter accumulates on dry ground around dry channels. Annual grasses may utilize this temporary dry habitat. Only substantial riparian zone around permanent waterholes.
		C	Terrestrial phase of production. Native pasture grasses.
Wet		A	As the water traverses the landscape, water quality may be modified by soil salinity, sediments and nutrients.
		A	Nutrient transfer from saturated soils to the riverine network
		A	Recruitment of desiccation tolerant taxa. Many endemic species.
		A	Seasonal expansion of habitat. See next table.
		B	This may be a critical ephemeral habitat for migratory species. It may also provide a crucial seasonal food supply of aquatic plants, zooplankton, macroinvertebrates and fish.
		B	Recharge to local alluvial groundwater which may sustain riparian communities during the dry.
		C	Sediment movement, transference of catchment nutrients to watercourses.

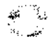
 C Sediment movement, transference of catchment nutrients to watercourses.

Permanent Waterholes



Permanent waterholes in the headwater region are significant refugia in an otherwise ephemeral aquatic environment. The local aquifer in headwater rivers and some terminating wetlands may help maintain their aquatic phase permanency during dry times. This surface-groundwater interaction may be specific to only some reaches of the alluvial channel, but where present may be significant in maintaining riverine ecosystem permanence.

- o Productive littoral zone (A)
- o Intact riparian zone (B)
- o Permanent water = aquatic refugia (C)

Dry		C	Increasing conductivity as water levels fall. Turbidity either reduced due to higher salinity or increased due to shallow water. Large variations in 24hr temperature and oxygen levels as water becomes shallow
		A, C	Increase in benthic production as more surface area reaches the light – increase in the bathtub algal ring. Possible increase in pelagic production as turbidity decreases with increasing salinity.
		A,C	Harsh physical and chemical conditions mean that few resilient fauna survive. The assemblage often includes highly mobile taxa that can move between isolated waterbodies, as well as taxa resistant to desiccation.
		A,C	Fish assemblage contains mostly tolerant taxa. Diversity held within large permanent refugia. At low waterlevels increased biotic interactions and competition. Increased incidence of disease and other stress related factors.
		B	Waterbirds concentrated around permanent waterholes. Nomadic and migratory species absent.
Wet		C	Flow reduces conductivity. Turbidity increases Smaller 24hr variations in measures of water temperature and oxygen.
		A,C	Change in light transmittance and vertical extraction reduced production. Pelagic production reduced by both flow and increased turbidity
		A,C	Greater proportion of 'riverine' taxa as waterbodies connect. Recolonisation to the river network from the permanent waterholes which acted as refugia during the dry. Desiccation resistant fauna can 'boom'.
		A,C	Fish communities increase in abundance.
		B	Flow connects waterbodies. Connected channels may not provide habitat for large numbers of species but will allow maintenance of populations.

3.2.4. Disturbance Scenarios

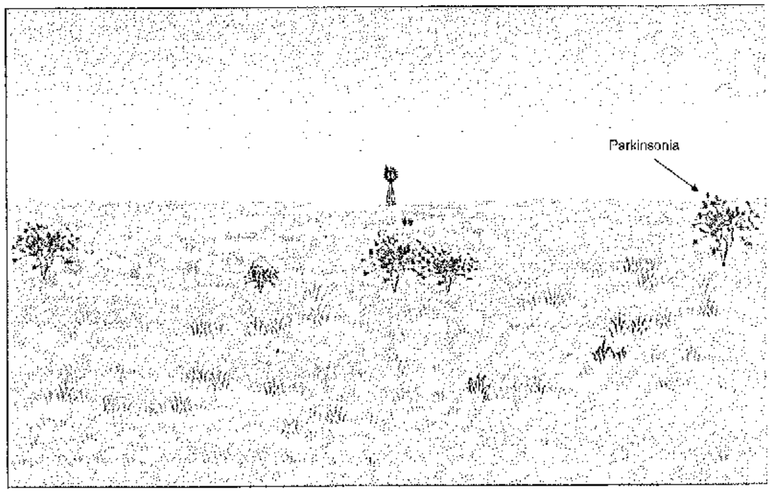
These images describe the major disturbance scenarios for the headwater region. These disturbances include increased water held within local storages (on and off-stream) and landuse changes from grazing to more intensive agriculture. At the waterhole scale the potential impacts include overuse of surface and alluvial water

Landuse Change

Farm Dams and Water Resource Development

The number of dams and water abstraction points may be an important factor in determining their impact on catchment hydrology. Increased water storage will reduce the magnitude and duration of small flood flows which will impact local and upstream floodplain processes through reduced inundation, and riverine processes through reduced connectivity.

- Increased water held in the catchment, reduction in the number and permanency of waterholes
- Reduction of downstream flows



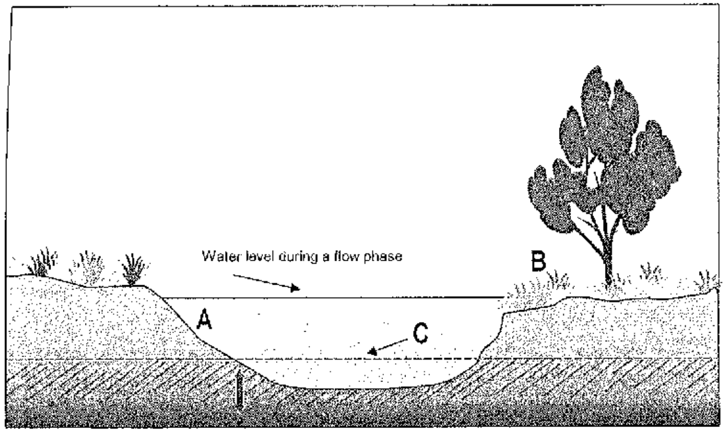
Land-Use Change

Reduction in native pastures can potentially lead to soil loss and weed invasion and reduced floodplain biodiversity.

The shift from grazing to more intensive agriculture increases catchment soil loss, as well as increases nutrients (fertilisers) and chemicals (pesticides) input to the river network

- Reduction of downstream flows

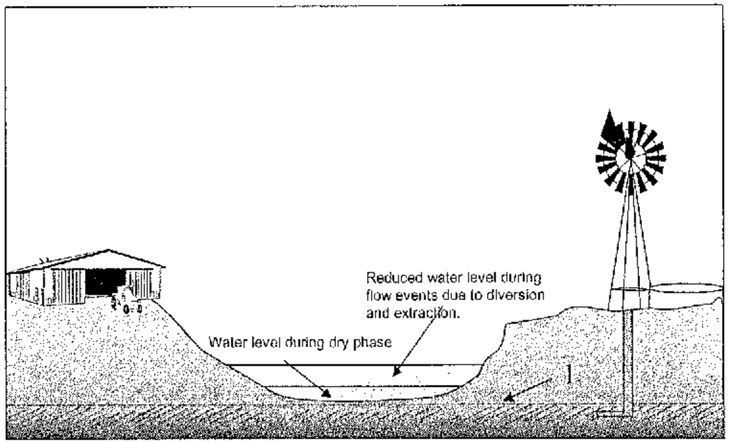
Groundwater Use



Local Aquifer – Undisturbed Conditions

The local aquifer in headwater rivers and some terminating wetlands may help maintain their aquatic phase permanency during dry times. This surface-groundwater interaction may be specific to only some reaches of the alluvial channel, but where present may be significant in maintaining riverine ecosystem permanence.

- Productive littoral zone (A)
- Intact riparian zone (B)
- Permanent water = aquatic refugia (C)



Local Aquifer – Disturbed Conditions

Pumping and extraction of water from the sub-surface aquifer can decrease or eliminate its interactions with riverine ecosystems. This can result in loss of water permanence and changes in water quality with impacts on those biological communities relying on the sub-surface aquifer for maintenance of water levels. Downstream flows are also reduced.

- Loss of productive littoral zone
- Loss of refugia
- Shift from permanent water (refugia) to semi-permanent or temporary habitat.

3.2.5. Summary

The conceptual models and associated disturbance scenarios have been reviewed in the context of LEB values and management issues. Below we describe the key threatening processes and link them to attributes relevant to management.

Landuse Change

- **Increased water storage and abstraction:** The conversion of rainfall to runoff is important in this region for maintaining local flows in channels as well as supplying flows to downstream channels and wetlands. Increases in damming, water extraction and water diversion will impact on both local flows as well as downstream flows.
- **Shifts from grazing to cropping:** The conversion of rainfall to runoff, as well as the movement of sediment and nutrients into the channel network is also important in this region for maintaining local ecosystems as well as supplying water, nutrients and sediments to downstream reaches. Changes in landuse (for example from grazing to cropping) may alter runoff patterns, increase nutrient supplies to the channel network, change sediment supply and thus channel and floodplain integrity (through increased erosion or siltation). These changes would also modify floodplain and riparian vegetation.

Groundwater Use

- **Changes in depth of alluvial groundwater**: In some parts of the headwaters (particularly the Upper Georgina region) localized alluvial groundwater is important in maintaining the permanence of some significant waterholes. Changes in the depth to groundwater via over-extraction could significantly impact the health and condition of permanent waterholes which act as refugia for invertebrates, fish and waterbirds during dry periods.

3.2.6. Indicators

The values, threats and conceptual models for the headwater region have identified a number of attributes that can be used to develop indicators for health assessment. The major threatening processes and possible attributes include:

Landuse change

Threat: *Increased water storage and abstraction*

Attributes that can be measured include Water Use and Riparian Vegetation Condition

Threat: *Shift from grazing to cropping*

Attributes that can be measured include Catchment Condition and Erosion Potential

Groundwater use

Threat: *Change in depth of alluvial groundwater*

Attributes that can be measured include Depth to Groundwater, Riparian Vegetation Condition, Waterhole Biodiversity and Waterhole Water Quality.

Indicators that would measure change in these key attributes are summarized in Table 3.1. An implementation approach for each measure of an indicator is highlighted. Where methodology exists and has been trialled in the Lake Eyre Basin, or elsewhere, to assess river and/or catchment health the indicator could be implemented immediately. This, however, does not mean that this measure is the best or most appropriate measure for that indicator. Other measures that have been highlighted 'Pilot Study' and 'Research and Development' (R&D) may actually be better but would require further development before implementation (see Section 4).

via over-extraction could significantly impact the health and condition of permanent waterholes which act as refugia for invertebrates, fish and waterbirds during dry periods.

Table 3.1. **Suggested indicators for detecting the change in condition of headwater regions of the Lake Eyre Basin associated with increased water storage and land-use change. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there is existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique but its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.**

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Water Use	Volume of Water Held in Storage	Water licensing information	Immediate Existing Data	Regional measurement & Catchment assessment	• Maintaining water transfer from surrounding catchment to channel network. • Maintaining flows to downstream channels
		Area (volume) of water stored calculated from satellite imagery	Pilot Study		
	Percent of Flow Diverted	Water licensing information	Immediate Existing Data	Regional measurement & Catchment assessment	
		Area (volume) of water diverted calculated from satellite imagery	Pilot Study		
Depth to Groundwater	Depth to Groundwater	Change in depth to groundwater	Immediate Existing Data (local and patchy)	Local measurement and Regional assessment	• Maintaining those permanent waterholes fed by groundwater. • Riparian vegetation condition in areas where groundwater is used
Riparian Vegetation Condition	Riparian Composition & Extent	Riparian Cover Index	Immediate	Local measurement and Regional assessment	• Shading, habitat and leaf litter input around permanent waterholes. • Roosting and nesting sites for some waterbird taxa. • Intact biodiversity
		Riparian SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Riparian Recruitment & Regeneration	Riparian Regeneration Index	Immediate	Local measurement and Regional assessment	
	Riparian Percent Exotics	Riparian NATIVES Index	Immediate	Local measurement and Regional assessment	

HW

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Catchment Vegetation Condition	Floodplain Composition & Extent	Floodplain Cover Index	Immediate	Local measurement and Regional assessment	• Regulates sediment and nutrient supply to the channel network during rainfall runoff. • Importance for pasture response after rainfall (industry) • Intact habitat
		Floodplain SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Floodplain Recruitment & Regeneration	Floodplain Regeneration Index	Immediate	Local measurement and Regional assessment	
	Floodplain Percent Exotics	Floodplain NATIVES Index	Immediate	Local measurement and Regional assessment	
Waterhole Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness Modified SIGNAL Score AUSRIVAS Scores	Pilot Study Existing Data	Local measurement and Regional assessment	• Specific to permanent waterholes. • Invertebrate desiccation resistant stages in ephemeral channels important for "boom" response on inundation. • Intact biodiversity, populations able to respond to inundation.
	Fish Assemblage Diversity	% Native Species % Exotic Individuals Fish Assemblage O/E	Immediate Existing Data	Local measurement and Regional assessment	
Waterhole Water Quality	Water Quality	Conductivity (salinity) pH Turbidity Diel range in dissolved oxygen Diel range in water temperature Nutrients (Total & available N and Total P)	Immediate Existing Data	Local measurement and Regional assessment	• Natural (expected) levels of salinity, nutrients and turbidity specific to stage in flood cycle.
Erosion Potential	Erosion Potential	Landscape Function Analysis	R & D	Regional measurement & Catchment assessment	• Regulates sediment and nutrient supply to the channel network during rainfall runoff.

3.2.7. Assessment Approach

Spatial Scale

The suggested indicators can be collected at either the local scale (site based measurements) or the regional scale (multiple site measurements, regional surveys or remotely sensed data).

The number of samples and sites required for an assessment will depend upon (modified from Whittington et al., 2001):

- Spatial reporting scale of the assessment
- Variability of the indicator
- Initial condition score of the indicator
- Aggregation and reporting statistics used
- Desired level of change to be detected
- Desired confidence in detecting that change.

Local Scale Assessment

With assessment at the local scale, we recommend a nested sampling design with a **minimum** of four locations across the "headwater" region (Upper Thomson, Barcoo, Diamantina and Georgina Rivers). Within each location five sampling sites should be established. With the large inherent natural variation evident within the Lake Eyre Basin it will be important to be able to distinguish between "within-location" variability and "between-location" variability. In each location one of the selected sites should ideally be a "strategic" sites that may be a Wetland of National significance, a Ramsar site or other significant conservation site, preferably with existing data, the remaining four sites in each location should be chosen randomly. This would provide a site based assessment of health, the condition assessment would be relevant only at a regional scale and limited information on catchment condition could be inferred.

For the headwater region existing monitoring sites could be captured in an assessment program, building on existing monitoring. These include the QNRM Water Quality Monitoring sites for the upper Cooper Creek system; Aramac Creek, Reedy Creek and Sandy Creek as well as the upper Thomson River at 'Camoola Park' and the upper Barcoo River at Blackall. There are no existing sites in the headwater regions of the Diamantina or Georgina Rivers and these would need to be established. Wetlands of International Importance in the region include a number of spring sites: Aramac Springs, Cauckingburra Springs, Doogmabulla Springs.

Catchment Based Assessment

If catchment based assessment is required then either a larger number of sites is needed for each catchment or remotely sensed data could be used over a larger area. The Sustainable Rivers Audit of the Murray-Darling Basin suggested between 18 and 30 sites per river valley (sub-catchment) were needed for various indicators to make a catchment assessment of condition. Although this will need to be tested for the Lake Eyre Basin it does suggest that with the large number of sub-catchments within the LEB a large number of sites would be needed to undertake a full catchment assessment.

Hybrid Approach

A hybrid approach may be to utilize a network of locations across the basin for which "site-based" or local assessment is undertaken (with a number of sites sampled in each location). In conjunction, a representative number of catchments within the headwater region, would be assessed using a catchment based assessment with a large number of sites per sub-catchment. The number of sites required to make an assessment of condition and detect possible change (power) for each indicator would need to be determined for each sub-catchment from Pilot Studies.

Recommended Spatial Approach

Given the scale and remoteness of much of the Lake Eyre Basin, we recommend the hybrid approach for selecting assessment sites with a minimum of 20 sites (5 sites within 4 separate locations) be established across the headwater region for the site based indicators and 4 regions for the reach and region scale indicators. For more detail see Section 4.9.

Temporal Scale

Frequency of Assessment
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.

Seasonal Sampling
Seasonal sampling would reflect the spring and autumn sampling used in other assessment programs. It would be undertaken on a subset of permanent waterholes.

Events Based Monitoring
Rainfall and flows in the headwater region are influenced by seasonal climatic conditions, including monsoonal phases and also by longer term climatic fluctuations such as El Nino and La Nina cycles. The biotic response to each event will differ depending on the timing, magnitude and duration. Any assessment of trends in this region will need to consider the initial condition and variability associated with seasonal extremes.

Recommended Temporal Scale

Although there is a seasonal component to rainfall in the headwater regions there is also a distinct unpredictable pulse in rainfall and thereby channel filling and subsequent flooding. We recommend that assessment be undertaken seasonally in the permanent waterholes and in response to flow events at these and other sites. The aim of temporal sampling will be to detect the response to the flow event and follow the subsequent change over a short temporal sequence.

Assessment Development
A number of suggested indicators have been highlighted as needing to be tested in a Pilot Study before they should be implemented in an assessment program (see Table 3.1). Others have been identified as useful and possibly cost-effective techniques, however, they would require a phase of research and development before they could reliably be used as indicators.

Attribute	Indicator	Type of measurement
Require Pilot Studies		
Water Use	Volume of water held in storage	Area (volume) of water stored calculated from satellite imagery
	Percent of flow diverted	Area (volume) of water diverted calculated from satellite imager
Riparian Vegetation Condition	Riparian composition & extent	Riparian SLATS using TM and ETM+ images
Floodplain Vegetation Condition	Floodplain composition & extent	Floodplain SLATS using TM and ETM+ images
Waterhole Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness, Modified SIGNAL score, AUSRIVAS score
Require Research and Development		
Erosion Potential	Erosion Potential	Landscape Function Analysis

2005 Implementation

The following indicators could be implemented as part of an assessment program immediately (2005). For full details on their specific methods see Section 4.

Attribute	Indicator	Type of measurement
Could be Implemented Immediately (2005)		
Water Use	Volume of water held in storage	Water licensing information
	Percent of flow diverted	Water licensing information
Depth to Alluvial Groundwater	Depth to Groundwater	Change in depth to groundwater
Riparian Vegetation Condition	Rip. Composition & extent	Riparian Cover Index
	Rip. Recruitment & Regeneration	Riparian Regeneration Index
	Riparian Percent Exotics	Riparian NATIVES Index
Floodplain Vegetation Condition	Fldpn. composition & extent	Floodplain Cover Index
	Fldpn. Recruitment & regeneration	Floodplain Regeneration Index
	Floodplain Percent Exotics	Floodplain NATIVES Index
Waterhole Biodiversity	Fish Assemblage Composition	% Native species, % exotic individuals, Fish assemblage O/E
Waterhole Water Quality	Water Quality	Conductivity, pH, Turbidity, Diel DO, Diel temp, Nutrients (Total & Available N and P).

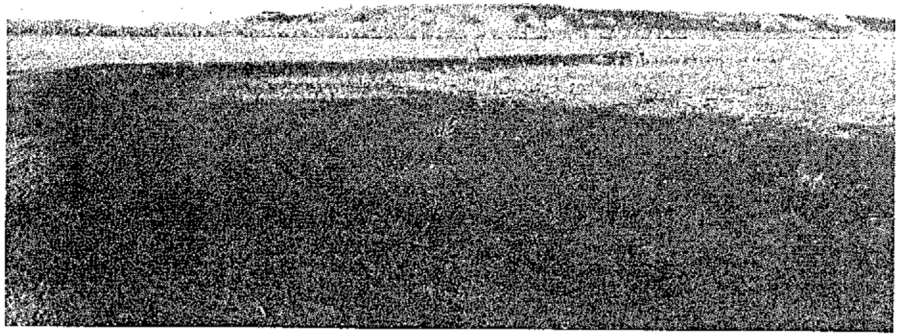


Photo by Fran Sheldon

Western River Catchment, Diamantina

3.3. River Channels and Waterholes

3.3.1. Background

River channels and waterholes dominate in the distributary floodplain regions of the Lake Eyre Basin. In this region there are two main habitat types:

- Ephemeral waterholes and channels that fill after rainfall or river flows but then dry – these can have a range of ephemeralities (from highly ephemeral and rarely flooded to semi-permanent)
- Permanent Waterholes that are topped up by river flows and rainfall but rarely dry completely, maintaining water and functioning as aquatic refugia during dry times.

The ephemeral waterholes and channels are hydrologically and biologically exceptionally variable. There are some aquatic plants and animals that can utilize them, especially those with resistant life stages or that are highly mobile, however, during dry times most aquatic fauna is restricted to the permanent waterholes (Bunn & McMahon, 2004).

The large floods characteristic of the Lake Eyre Basin connect the permanent and ephemeral habitats allowing dispersal of many organisms and giving rise to booms of aquatic production which filters through the food chain into fish production and massive waterbird breeding events (Bunn & McMahon, 2004).

3.3.2. Values and Threats

The river channels and waterholes of the Lake Eyre Basin are valued for their wild river status and their unique biodiversity. The combination of flow variability and geomorphic complexity within this region creates a distinctive boom and bust ecology, with characteristic episodes of intense reproduction and high productivity (Bunn & McMahon, 2004). The black soil floodplains in this region are also an important intermittent pastoral resource for the LEB pastoral

- Landscapes and watercourses that are valuable for production, 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 ecosystems processes

Threats to this region include:

- Upstream and local water storage and diversion that influence and alter water quality and both the frequency and magnitude of in-stream flows as well as the extent and duration of floodplain inundation.
- Degradation of riparian areas through overgrazing is a threat to waterholes
- Deliberate or accidental introduction of exotic and pest species
- Tourism & Infrastructure

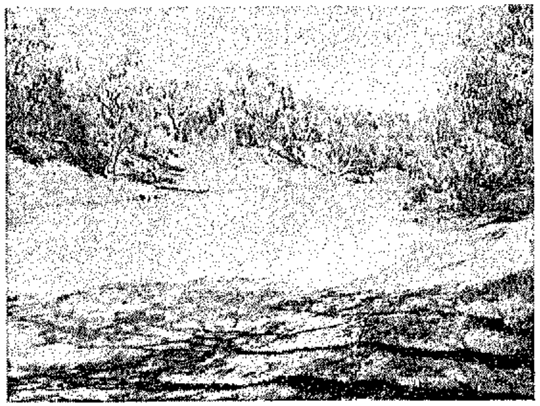


Photo by Jon Marshall

Murken Waterhole, Cooper Creek

productivity (Bunn & McMahon, 2004). The black soil floodplains in this region are also an important intermittent pastoral resource for the LEB pastoral industry. The values can be summarized as:

Photo by Jon Marshall

Murken Waterhole, Cooper Creek

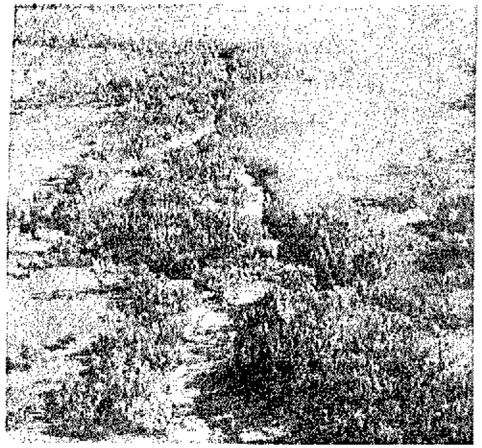


Photo by Stuart Bunn

Cooper Creek at Windorah

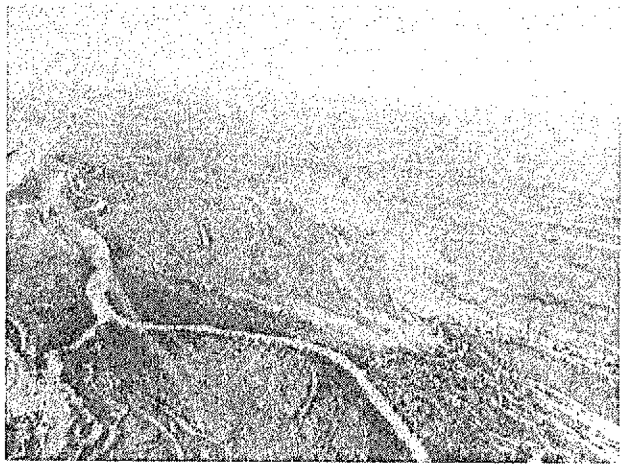


Photo by Peter Brunner

Channel Country under flow conditions

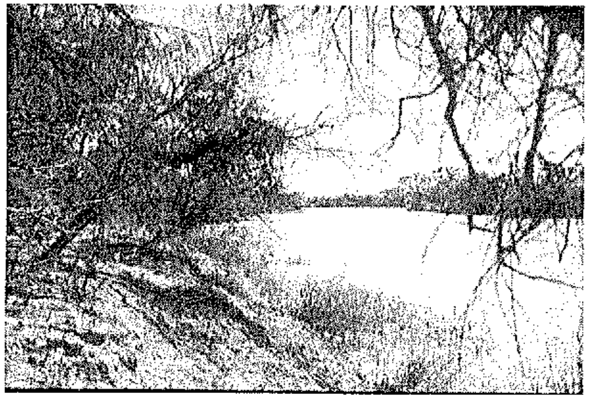


Photo by Fran Sheldon

Clifton Hills Waterhole, Diamantina River

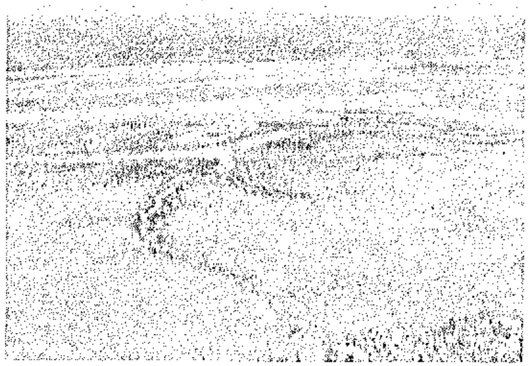
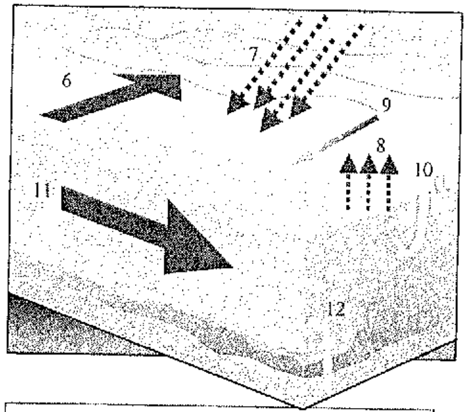


Photo by James Fawcett

Thomson River Flood at Longreach

3.3.3. Hydrologic and Geomorphic Processes

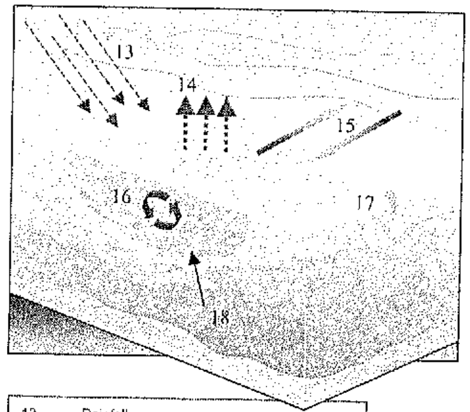
These images graphically describe the hydrologic and geomorphic processes operating in the river channels and waterholes regions.



6.	Movement of water on to the floodplain during flood
7.	Rainfall
8.	Evaporation
9.	Overland movement of water and sediment to channels
10.	Surface water infiltration to subsurface aquifers
11.	Water and sediment flow downstream via the channel
12.	Possible groundwater movement in to the river channel

Channel Processes

In the mid region of the Basin there are large river channels with networks of branching or anastomosing channels. Local rainfall can contribute to channel flows, however, the majority of water in this region comes from upstream. There are strong lateral connections between the river channel network and floodplain in this region. In some regions there may be alluvial aquifers close to the surface, however, there is little evidence of their influence on surface flows.



13.	Rainfall
14.	Evaporation
15.	Movement of water and sediment between the waterhole and floodplain during flood events
16.	In-situ cycling
17.	Possible surface infiltration to sand layer with movement of water back into waterhole
18.	Sediment deposition

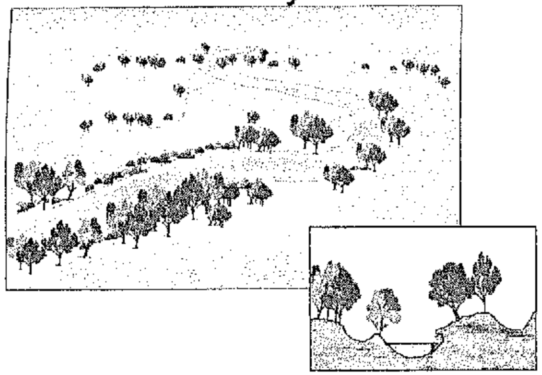
Waterhole Processes

In the mid region of the Basin there are large permanent waterholes. As with the river channel network in this region, rainfall contributes small amounts to surface flow, however, the majority of flow is from upstream or lateral movement across the floodplain during floods. When disconnected from the channel network waterholes function as separate mesocosms with in-situ cycling and production.

evidence of their influence on surface flows.

Floodplain

Dry

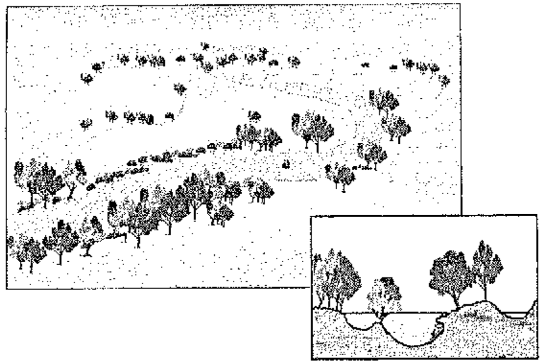


The rivers during dry times can contain naturally semi-permanent to permanent waterholes. The presence of more permanent surface water means riparian vegetation can be supported.

At a landscape perspective, 'dry' river channels are represented by isolated and disconnected waterholes. Waterholes will vary in their permanency, though few will remain after extended periods with no inflows.

The permanent waterholes tend to be fixed features in the landscape with little spatial reorganisation after floods (see Knighton & Nanson, 1994)

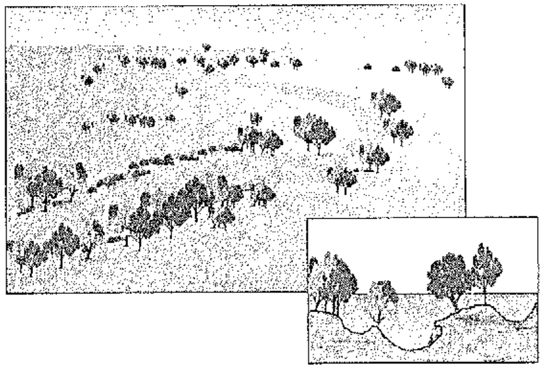
Flow



The rivers during the flow phase generally remain below bank level. Isolated and disconnected waterholes become connected.

The riverine landscape features flowing river channels. Many of the anastomosing channels fill and waterholes are reconnected.

Flood

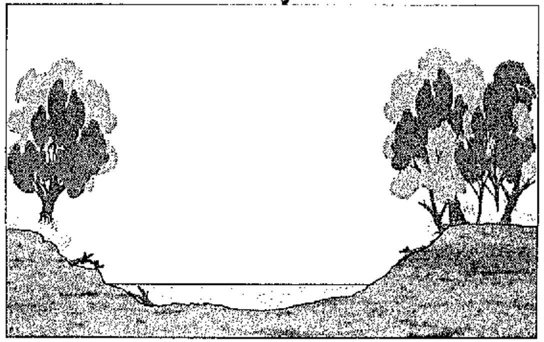


During a flood flow in the river channels increases and the vast floodplain can become inundated. Across the floodplain there are various zones corresponding to different flood extents.

During a flood the riverine landscape becomes inundated. The main channel network can be identified by lines of trees.

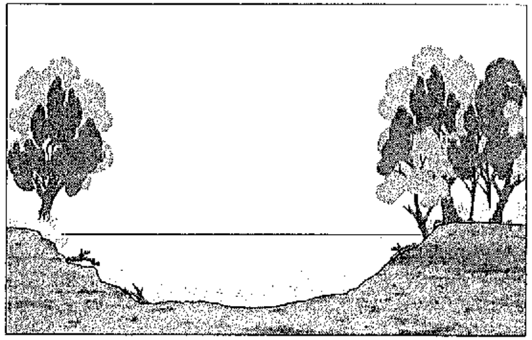
Waterholes

Dry



Waterholes during dry conditions are isolated; some are semi-permanent while others are permanent. During extended dry periods water levels in even the more permanent waterholes can become very low. During low flow periods water quality can decline substantially.

Flow



Waterholes during wet conditions can become topped up by rainfall and may become connected via channel flows. Connecting flows act to change or "reset" water quality conditions.

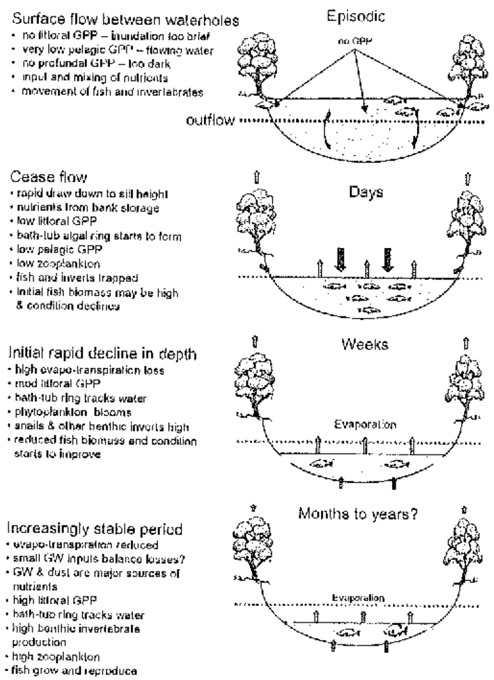
Flood

See landscape perspective of a flood where all waterholes are connected.

3.3.4. *Biotic Processes*

These images graphically describe the biotic processes of the river channel and waterhole region. The initial image graphically describes changes in ecological processes in dryland river waterholes as they move from connected and full through to disconnected and drying. The following images describe biotic processes in the two major habitat types: waterholes & channels and floodplain.

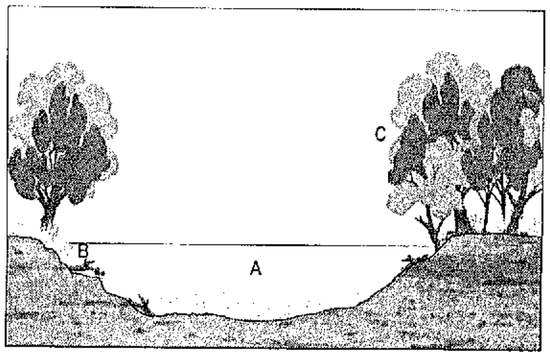
Waterhole dynamics



High turbidity is a natural feature of Lake Eyre Basin waterholes, with light penetration for photosynthesis often restricted to less than 30 cm. Despite this high turbidity, waterholes often have a productive band of algae restricted to the shallow littoral margins – this has been termed the bathtub ring (Bunn et al., 2003). This ring of algae appears to be a major source of energy for the aquatic food web, and sustains large populations of invertebrates and fish – and ultimately waterbirds.

This figure summarizes the general changes in production, food sources and invertebrate and fish assemblages as a hypothetical waterholes in the Cooper Channel Country dries after becoming disconnected (Bunn pers comm.).

Waterholes and Channels



Waterholes during dry conditions are isolated; some are semi-permanent while others are permanent. During extended dry periods water levels in even the more permanent waterholes can become very low.

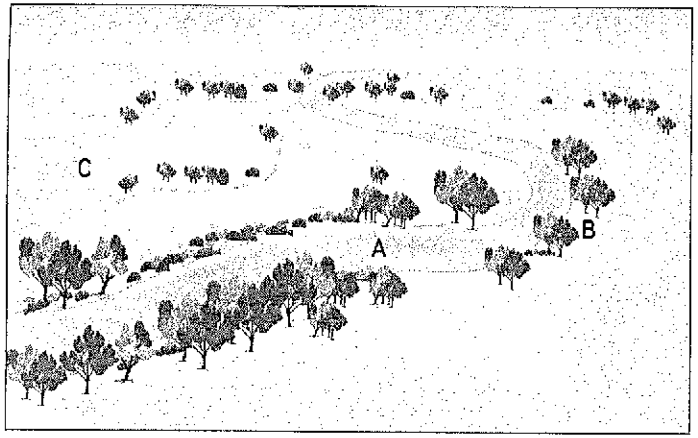
Waterholes during wet conditions can become topped up by rainfall and may become connected via channel flows.

- Permanent waterholes (A)
- Productive littoral region (B)
- Riparian zones that are substantial around permanent waterholes (C)

Dry	A	Increasing conductivity as water levels fall. Variable turbidity as in headwaters. Large variations in temperature, oxygen levels and available nutrients.
	B	Increased benthic production - bathtub algal ring. Possible increase in pelagic production as turbidity decreases with increasing salinity.
	A	In temporary waterholes only resilient taxa survive. Permanent waterholes contain higher biodiversity.
	A	Temporary waterholes contain mostly tolerant taxa, which will perish if waterholes dry. Diversity held within large permanent waterholes. At low water-levels increased biotic interactions and competition. Increased incidence of disease and other stress related factors.
	C	Waterbirds concentrated around permanent waterholes. Nomadic and migratory species absent.
Flow	A	Flow reduces conductivity. Turbidity increases Smaller 24hr variations in water temperature and oxygen.
	B	Reduced production as surface area and light transmittance is decreased. Pelagic production reduced by both flow and increased turbidity
	A	Greater proportion of 'riverine' taxa as waterbodies connect. Recolonisation to the river network from permanent waterholes - refugia during the dry.
	A	Fish increase in abundance with flow but may be food limited with little production while the river remains within its channel
	C	Flow connects waterholes and increases habitat for waterbirds. Connected channels may not provide habitat for large numbers of species but will allow maintenance of populations.
Flood	A	Low conductivity, high turbidity. Extensive flooding of terrestrial vegetation can cause massive reductions in water oxygen levels due to increased respiration via decomposition. Potential increase in nutrients in association with flooding.
	B	Extensive production with floodplain inundation – large amounts of both benthic and pelagic algal production.
	A	Extensive blooms of zooplankton and desiccation resistant taxa (eg. Notostraca).
	A	Massive breeding and recruitment of many native taxa occurs during flooding.
	C	Inundation provides critical habitat for waterbirds with many migratory species using flooded swamps and

C	Inundation provides critical habitat for waterbirds with many migratory species using flooded swamps and wetlands for breeding.

Floodplain



The river landscape features channel networks that during 'dry' phases are represented by isolated and disconnected waterholes. During a flow phase water levels generally remain below bank level, with isolated and disconnected waterholes becoming connected. During a flood the river channels are fast flowing and the vast floodplain can become inundated. Across the floodplain there are various zones corresponding to different flood extents

- Waterholes of varying degrees of ephemerality (ephemeral to permanent) (A)
- Riparian zone defines the channel network (B)
- Surrounding floodplain (C)

Dry	A	Most channels are dry, water only held within permanent waterholes – see waterhole table
	A	Most channels are dry, water only held within permanent waterholes – see waterhole table
	A	Desiccation resistant taxa may remain in the dry channels, less resistant taxa will perish or move to permanent waterholes – see waterhole table.
	A	No taxa survive in ephemeral channels during the dry, all taxa seek refuge in permanent waterholes – see waterhole table.
	B	Taxa concentrated around permanent waterholes. Nomadic & migratory species absent.
	B	Leaf litter accumulates around dry channels. Riparian zone around permanent waterholes, lining more frequently flooded channels, or following regions of sub-surface water.
	C	Terrestrial phase of production on floodplain. Native pasture grasses.
Flow	A	Flow reduces conductivity. Turbidity increases.
	A	Reduced production as surface area moves out of the light. Pelagic production reduced by both flow and increased turbidity
	A	Greater proportion of 'riverine' taxa as waterbodies connect. Recolonisation to the river network from the permanent waterholes which acted as refugia during the dry.
	A	Fish communities increase in abundance with flow but may be food limited with little production while the river remains within its channel
	B	Flow connects waterbodies and increases habitat for waterbirds. Connected channels may not provide habitat for large numbers of species but will allow maintenance of populations.
	B	Water supply for riparian areas, recharge of local alluvial aquifers
	C	Terrestrial phase of production on floodplain. Native pasture grasses.
Wet	A	Water quality modified by soil salinity, sediments and nutrient loads.
	A	Nutrient transfer from saturated soils to the riverine network
	A	Recruitment of desiccation tolerant taxa. Many endemic species.
	A	Massive breeding and recruitment of taxa occurs during flooding. Inundated floodplain acts as a "nursery" area for juveniles. Boom time
	B	A critical ephemeral habitat for migratory species, also provides a crucial food supply.
	B	Recharge to local alluvial aquifer which may sustain riparian communities during the dry.
	C	Sediment movement, transfer of nutrients between floodplain and watercourses.

3.3.5. Disturbance Scenarios

These images describe the major disturbance scenarios for the river channel & waterhole region. These disturbances include:

- catchment scale changes to waterhole permanence in the landscape through upstream water storage, extraction or diversion
- reach scale changes to the hydrological landscape through water extraction or diversion
- changes to waterhole diversity which may occur through overgrazing, riparian destruction, increased abundance of exotics, increased nutrient input as well as changes to local and catchment scale hydrology

Waterhole Permanence in the Landscape

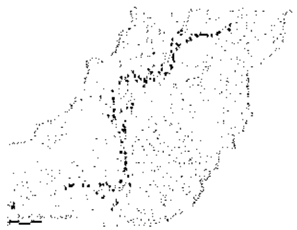
This case study can be used to show how changes to hydrology (via upstream and local dams, extraction and diversion) could affect the permanency and function of downstream ecosystems. A reduction in the frequency of connecting flows can render permanent waterholes semi-permanent and change the nature of waterhole distribution. The sequence below demonstrates what would happen to waterholes in a region of the Cooper floodplain if flows were now received for different periods of time.

1990 Flood -

All waterholes connected

Large floods such as the 1990 flood (depicted) in the Cooper Creek region inundate vast floodplains. Such floods connect all the major waterholes throughout the system.

After Flood



All waterholes filled, Waterhole >0.1km^2

After the floodwaters recede major waterholes those waterholes (>0.1km^2) as well as many smaller waterholes are full. Many are not permanent and if more water does not arrive waters will gradually evaporate.

Dry Spell < 2 years

Waterholes > 2km^2, ~80

After less than 2 years without flow the number of waterholes has been reduced to approximately 80, all > 2km^2.

Dry Spell > 2 years

Waterholes > 5km^2, ~40

After more than 2 years without flow the network was further reduced and only those waterholes > 5km^2 remain, approximately 40 in the entire area.

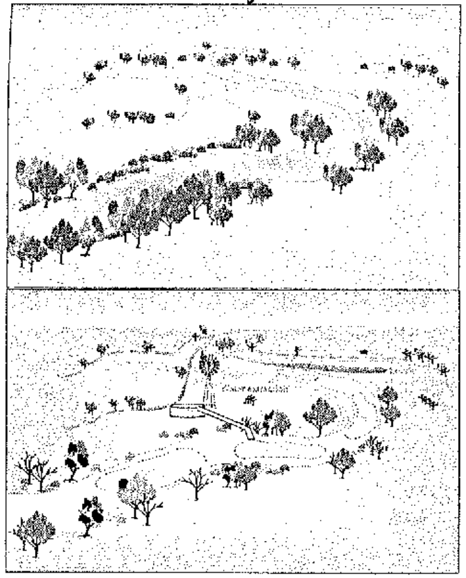
Dry Spell > 5 years

Waterholes >16km^2, only 5.

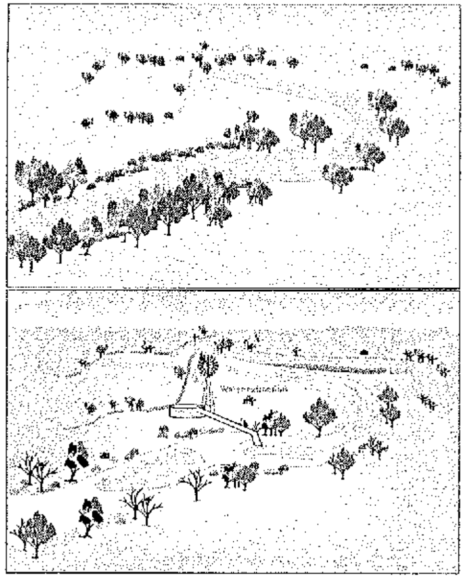
As the dry spell continued and no channel or flood flows were received for more than 5 years there were only 5 waterholes left in this region of the Cooper catchment Persistent waterholes had areas >16km^2.

Water Extraction

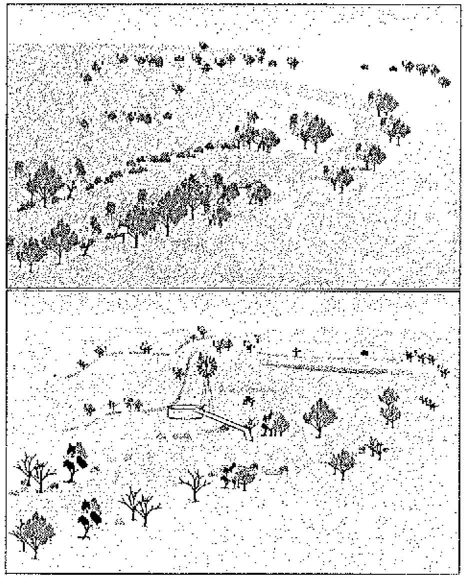
Dry



Flow



Flood



Undisturbed large river channels during dry conditions comprise a number of isolated and disconnected waterholes. Pumping, extraction and water diversion can reduce the permanence of waterholes such that river channel landscapes may become totally dry with few or no waterholes remaining during dry times. Heavy pressures on fewer permanent waterholes could impact aquatic and riparian communities and decrease the ground water depth to below the root zone of groundwater dependant species.

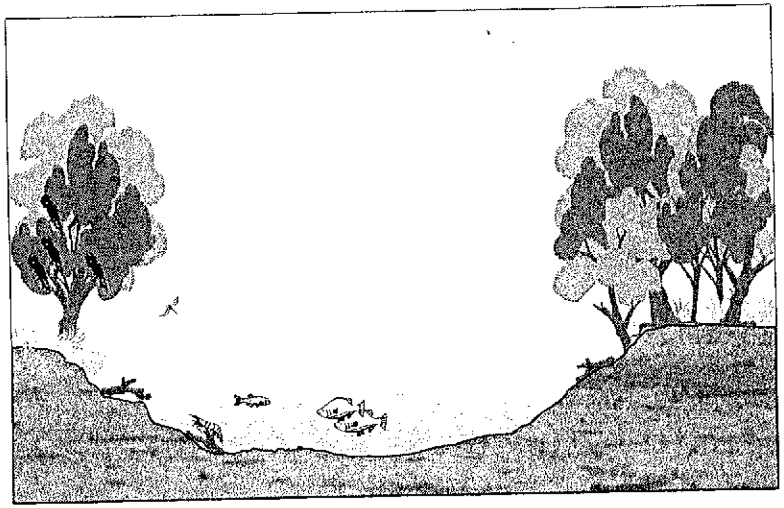
The undisturbed river channel during the wet phase comprises a number of connected waterholes. Pumping, extraction and water diversion locally, as well as dams and extraction in the headwaters, can reduce this connectivity. Waterholes may get minor 'top-up' flows but their frequency and duration is decreased. The permanence of many waterholes is reduced. The effect of flow alteration upon the ecosystem dynamics of these waterholes is unclear, but community and population changes would be predicted by changes to migration and connection pathways..

The undisturbed riverine landscape during a flood comprises flowing channels and a vast area of inundated floodplain. Floodwaters result in a 'boom' time for riverine biological communities and floodplain pasture. Pumping, extraction and water diversion locally, as well as dams and extraction in the headwaters can reduce the duration and extent of small to medium floods.

- Increased water held either locally or in upstream catchments reduces:
  - ⇨ the number and permanency of waterholes
  - ⇨ the frequency and duration of waterhole connection
  - ⇨ the frequency and duration of floodplain inundation

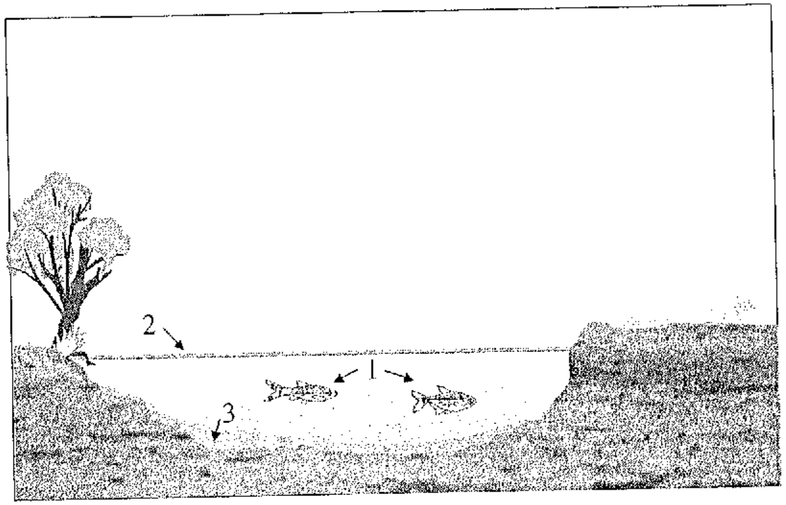
Waterhole Diversity

Undisturbed Condition



Undisturbed waterholes contain diverse biological communities including native fish and long-lived turtles endemic to the Lake Eyre Basin. These waterholes have complex bank structure and their littoral zones are areas of high primary production, they also play a critical role in supporting the terrestrial ecosystem.

Disturbed Condition



Disturbed waterholes can show increased proportions of exotic species (1) and a decline in the diversity and numbers of native species. Increased frequency and duration of toxic algal blooms (2) and other attributes of poor water quality may be evident along with loss of in-stream substrate complexity due to saltation (3). The riparian zone may have a reduced cover and diversity of native vegetation.

3.3.6. *Summary*

The conceptual models and associated disturbance scenarios have been reviewed in the context of LEB values and management issues. Below we describe the key threatening processes and link them to attributes relevant to management.

- Increased Water Storage and Abstraction
  - **Increased upstream and local water use:** The local conversion of rainfall to runoff as well as the supply of water from headwater regions is important for maintaining local flows in channels as well as supplying flows to downstream channels and wetlands. Increases in upstream damming, water extraction and water diversion as well as local water extraction and water diversion will impact on both local flows as well as downstream flows.
  - **Decreased connection between waterholes:** Waterhole connectivity during flow (not flood) phases is critical in maintaining waterholes as refugia during dry times. Often the time interval between large floods is long and within channel connecting flows provide vital maintenance functions.
  - **Reduced area of beneficial flooding:** Floodplain inundation plays a vital role in providing the flush of growth that is utilized by the pastoral industry to support their production.

- Reduced Channel and Floodplain Complexity
  - **River-Floodplain Interactions:** The vastness of floodwater inundation during flooding suggests a close relationship between the river and the floodplain for the Lake Eyre Basin rivers. Flooding provides a source of water for the floodplain and is a crucial factor in the use of the region as a grazing area. During flooding, the floodplain is a source of sediment and nutrients that can eventually end up in the river network. Changes in riparian and floodplain condition could greatly increase the supply of sediment and nutrients to the river with impacts on riverine processes.

- **Range of waterholes of varying complexity and flooding frequency.**
  - Not all the biota or diversity is held within the permanent waterholes. There are many taxa that require desiccation and drying as critical points in their life cycles. For these taxa a range of flooding and drying frequencies is required. The natural range of flooding and drying frequency of waterholes may be changed by increased water use upstream and/or changes for floodplain complexity such that waterholes are not connected under certain flows.

- Waterhole Integrity
  - **Permanent Waterholes:** Permanent waterholes are significant sites within the channel region for maintaining biodiversity during dry phases. They may provide refuge for populations with non desiccation resistant life stages that would otherwise disappear from the channel network during dry, "bust", times. They are the population source for the mass breeding and recruitment events, "boom" times associated with flooding.

3.3.7. Indicators

The values, threats and conceptual models for the river channel & waterhole region have identified a number of attributes that can be used to develop indicators for health assessment. The major threatening processes and possible attributes include:

Increased Water Storage and Abstraction

Threat: *Increased upstream and local water use*

Attributes that can be measured include: Water Use

Threat: *Decreased connection between waterholes*

Attributes that can be measured include: Hydrological Variability, Waterhole Biodiversity, Riparian Vegetation Condition

Threat: *Reduced area of beneficial flooding*

Attributes that can be measured include: Flood Extent, Floodplain Vegetation Condition

Reduced Channel and Floodplain Complexity

Threat: *Reduced Channel and Floodplain Complexity*

Attributes that can be measured include Channel System Integrity, Water Use

Threat: *Reduced River-Floodplain Interactions*

Attributes that can be measured include: Hydrological Variability, Riparian Vegetation Condition, Floodplain Vegetation Condition.

Threat: *Reduction in diversity of waterhole types.*

Attributes that can be measured include Channel System Integrity

Maintenance of Permanent Waterhole Health

Threat: *Upstream and local water use*

Attributes that can be measured include: Water Use, Hydrological Variability, Flood Extent.

Threat: *Increase in abundance of exotic taxa*

Attributes that can be measured include: Riparian Vegetation Condition, Waterhole Biodiversity.

Threat: *Increase in nutrient and sediment supply*

Attributes that can be measured include Waterhole Water Quality, Waterhole Processes, Channel System Integrity.

Suggested indicators that would measure change in these key components are summarized in Table 3.2. We have highlighted an implementation approach for each measure of an indicator. Where methodology exists and has been trialled in the Lake Eyre Basin or elsewhere to assess river and/or catchment health the indicator could be implemented immediately. This, however, does not mean that this measure is the best or most appropriate measure for that indicator. Other measures that have been highlighted 'Pilot Study' and 'Research and Development' (R&D) may actually be better but would require further development before implementation (see Section 4).

Table 3.2. **<u>Suggested</u> indicators for detecting the change in condition of channel and waterhole regions of the Lake Eyre Basin associated with increased water storage and land-use change. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there is existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique but its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.**

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Water Use	Volume of Water Held in upstream Storage	Upstream water licensing information	Immediate Existing data	Catchment measurement & Basin-wide assessment	• Maintaining water transfer from surrounding catchment to channel network. • Maintaining flows in channels and waterholes • Maintaining flow variability
		Upstream area (volume) of water stored calculated from satellite imagery	Pilot Study		
	Percent of local and upstream flow diverted	Water licensing information	Immediate Existing Data	Regional measurement & Catchment assessment	
		Area (volume) of water diverted calculated from satellite imagery	Pilot Study		
Hydrological Variability	Flow Variability	Long-term variability (and changes in long-term variability) in amplitude, frequency and duration of floods	Pilot Study Existing Data	Catchment measurement Basin-wide assessment	• Maintenance of "boom" and "bust" cycles. • Maintain periods of connection and disconnection of waterholes. • Maintain dynamic variability
		Long-term changes in variability of multi-annual flows	Pilot Study Existing Data		
		Predictability analyses	Pilot Study Existing Data		
Flood Extent	Flood Extent	Changes in the discharge vs. Flood extent relationship	Immediate Existing Data	Regional measurement and Catchment assessment	• Maintain diversity of flooding regimes and productive floodplain growth.
Riparian Vegetation Condition	Riparian Composition & Extent	Riparian Cover Index	Immediate	Local measurement and Regional assessment	• Shading, habitat and leaf litter input around permanent waterholes and channels • Roosting and nesting sites for some waterbird taxa • Intact biodiversity
		Riparian SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Riparian Recruitment & Regeneration	Riparian Regeneration Index	Immediate	Local measurement and Regional assessment	
	Riparian Percent Exotics	Riparian NATIVES Index	Immediate	Local measurement and Regional assessment	

Table 3.2. **Suggested indicators for detecting the change in condition of channel and waterhole regions of the Lake Eyre Basin associated with increased water storage and land-use change. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there is existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique but its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.**

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Water Use	Volume of Water Held in upstream Storage	Upstream water licensing information	Immediate Existing data	Catchment measurement & Basin-wide assessment	• Maintaining water transfer from surrounding catchment to channel network. • Maintaining flows in channels and waterholes • Maintaining flow variability
		Upstream area (volume) of water stored calculated from satellite imagery	Pilot Study		
	Percent of local and upstream flow diverted	Water licensing information	Immediate Existing Data	Regional measurement & Catchment assessment	
		Area (volume) of water diverted calculated from satellite imagery	Pilot Study		
Hydrological Variability	Flow Variability	Long-term variability (and changes in long-term variability) in amplitude, frequency and duration of floods	Pilot Study Existing Data	Catchment measurement Basin-wide assessment	• Maintenance of "boom" and "bust" cycles. • Maintain periods of connection and disconnection of waterholes. • Maintain dynamic variability
		Long-term changes in variability of multi-annual flows	Pilot Study Existing Data		
		Predictability analyses	Pilot Study Existing Data		
Flood Extent	Flood Extent	Changes in the discharge vs. Flood extent relationship	Immediate Existing Data	Regional measurement and Catchment assessment	• Maintain diversity of flooding regimes and productive floodplain growth.
Riparian Vegetation Condition	Riparian Composition & Extent	Riparian Cover Index	Immediate	Local measurement and Regional assessment	• Shading, habitat and leaf litter input around permanent waterholes and channels • Roosting and nesting sites for some waterbird taxa • Intact biodiversity
		Riparian SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Riparian Recruitment & Regeneration	Riparian Regeneration Index	Immediate	Local measurement and Regional assessment	
	Riparian Percent Exotics	Riparian NATIVES Index	Immediate	Local measurement and Regional assessment	

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Riparian Vegetation Condition	Floodplain Composition & Extent	Floodplain Cover Index	Immediate	Local measurement and Regional assessment	• Regulates sediment and nutrient supply to the channel network during flood inundation and rainfall runoff, • Importance for pasture response after both rainfall and flooding • Intact biodiversity
		Floodplain SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Floodplain Recruitment & Regeneration	Floodplain Regeneration Index	Immediate	Local measurement and Regional assessment	
	Floodplain Percent Exotics	Floodplain NATIVES Index	Immediate	Local measurement and Regional assessment	
Riparian and Floodplain Biodiversity	Riparian Diversity	Plant biodiversity measures (richness) Functional diversity	Pilot Study	Local measurement and Regional assessment	• Intact biodiversity within floodplains and riparian zones • Intact waterbird assemblages that can respond to flood events.
	Floodplain Diversity	Plant biodiversity measures (richness) Functional diversity	Pilot Study	Local measurement and Regional assessment	
	Waterbird Assemblage Diversity	Waterbird Diversity	Immediate	Regional measurement & Catchment assessment	
Waterhole Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness	Pilot Study Existing Data	Local measurement and Regional assessment	• Different expected diversity with waterholes of different permanency • Highest diversity and intact populations in permanent refugial waterholes • Invertebrate desiccation resistant stages on floodplain, respond to flooding as 'boom' response. • Intact biodiversity (both fish and invertebrates) able to respond to flooding
		Modified SIGNAL Score			
		AUSRIVAS Scores			
	Fish Assemblage Diversity	% Native Species	Immediate Existing Data	Local measurement and Regional assessment	
		% Exotic Individuals			
		Fish Assemblage O/E			
Waterhole Water Quality	Water Quality	Conductivity (salinity)	Immediate Existing Data	Local measurement and Regional Assessment	• Natural (expected) levels of salinity, nutrients and turbidity specific to stage in flood cycle.
		pH			
		Turbidity			
		Diel Range in dissolved oxygen			
		Diel range in water temperature			

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Waterhole Processes (Function)	Ecosystem Processes	Benthic metabolism Algal Biomass & composition Carbon & Nitrogen stable isotopes	Pilot Study	Local measurement and Regional Assessment	• High levels of benthic production during waterhole phase • Expected low levels during flow phase • High levels of floodplain production during flooding "boom" time.
Erosion Potential	Erosion Potential	Landscape Function Analysis	R & D	Regional measurement and Catchment Assessment	• Regulates sediment and nutrient supply to the channel network during flooding and ta
Channel System Integrity	Channel System Integrity	Floodplain geomorphic complexity	R & D	Local measurement and Regional Assessment	• Maintains variable channel network with full range of waterhole and floodplain types.
		Channel Complexity	Pilot Study		
		Within Waterhole complexity	Pilot study		

3.3.8. Assessment Approach

Spatial Scale

The suggested indicators can be collected at either the local scale (site based measurements) or the regional scale (multiple site measurements, regional surveys or remotely sensed data).

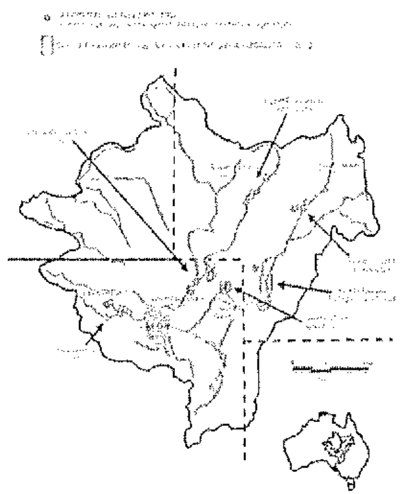
The number of samples and sites required for an assessment will depend upon (modified from Whittington et al., 2001):

- Spatial reporting scale of the assessment
- Variability of the indicator
- Initial condition score of the indicator
- Aggregation and reporting statistics used
- Desired level of change to be detected
- Desired confidence in detecting that change.

Local Scale Assessment

With assessment at the local scale we recommend, as outlined in the Headwaters Section, a nested sampling design with a **minimum** of ten locations across the "channels and waterholes" region. These locations should include middle and lower reaches of Cooper Creek (4 locations), middle and lower reaches of the Diamantina and Georgina Rivers (4 locations) and the western rivers (2 locations). Within each location five sampling sites should be established. With the large inherent natural variation evident within the Lake Eyre Basin it will be important to be able to distinguish between "within-location" variability and "between-location" variability. In each location one of the selected sites should ideally be a "strategic" sites that may be a Wetland of National significance, a Ramsar site or other significant conservation site, preferably with existing data, the remaining four sites in each location should be chosen randomly. This would provide a site based assessment of health, the condition assessment would be relevant only at a regional scale and limited information on catchment condition could be inferred.

For the channels and waterholes region existing monitoring sites could be captured in an assessment program, building on existing monitoring. These include the QNRM Water Quality Monitoring sites for the middle and lower reaches of Cooper Creek, and the Diamantina and Georgina Rivers (see Bailey, 2001). Wetlands of International Importance in the region include the Birdsville – Durrie Waterholes Aggregation (QLD023), Cooper Creek Overflow Swamps – Windorah (QLD025), Cooper Creek Overflow Swamps- Nappa Merrie (QLD026), Cooper Creek-Wilson River Junction (QLD027), Diamantina Lakes Area (QLD028), Diamantina Overflow Swamp-Durrie Station (QLD029), Georgina River King Creek Floodout (QLD030), Mulligan River-Wheeler Creek Junction (QLD039). Other important existing monitoring and research sites that should be built into any site based assessment program are those established sites of the ARIDFLO program and the CRC for Freshwater Ecology Dryland River Refugia Project. Sites for these projects are based on the channel and waterhole regions of the Cooper, Diamantina and Neales rivers and have existing databases that span a number of years.



Catchment Based Assessment

If catchment based assessment is required then either a larger number of sites are needed for each catchment or remotely sensed data could be used over a larger area. The Sustainable Rivers Audit of the Murray-Darling Basin (MDB) recommended between 18 and 30 sites per river valley (sub-catchment) were needed for various indicators to make a catchment assessment of condition. Although this still needs to be tested for the Lake Eyre Basin, with its higher natural variability compared to the MDB, it suggested that a large number of sites will be needed to undertake a full assessment of the Lake Eyre Basin.

Hybrid Approach

The same rationale for a hybrid approach as outlined in the "Headwaters" section would be appropriate for the "Channels & Waterholes". This approach would utilize a network of locations for which "site-based" or local assessment is undertaken (with a number of sites sampled in each location). In conjunction, a representative number of catchments within the channels and waterholes region, would be assessed using a catchment based assessment with a large number of sites per sub-catchment. The number of sites required to make an assessment of condition and detect possible change (power) for each indicator would need to be determined for each sub-catchment from Pilot Studies

Recommended Spatial Scale

Given the scale and remoteness of much of the Lake Eyre Basin, we recommend the hybrid approach for selecting assessment sites. We recommend a **minimum** of 50 sites divided among ten locations be established across the river channel & waterhole region for the site-based indicators and a minimum of 7 regions for the reach and region scale indicators.

Temporal Scale

Frequency of Assessment

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. Sampling should be divided between Seasonal Sampling and Events Based Sampling.

Seasonal Sampling

Seasonal sampling would reflect the spring and autumn sampling used in other assessment programs. It would be undertaken on a subset of permanent waterholes.

Events Based Sampling

Lake Eyre Basin rivers are characterized by floods of varying magnitudes and durations, from large floods that extend over vast floodplains and last for months to small in-channel flows that connect waterholes, perhaps only on a regional scale. The biotic response will differ depending on the size and duration of the flood

Recommended Temporal Scale

Although there is a seasonal component to rainfall in the headwater regions and therefore flows and flooding in the channel and waterhole network there is also a distinct unpredictable pulse in rainfall and thereby channel filling and subsequent flooding. We recommend that assessment be undertaken seasonally in subset of permanent waterholes (seasonal sampling) and, in response to flow events and flooding (event based sampling), at a larger suite of sites including temporary waterholes. The aim of temporal sampling will be to detect the response to the flow event and follow the subsequent change over a short temporal sequence.

Assessment Development

A number of suggested indicators has been flagged as needing to be tested in a Pilot Study before they should be implemented in an assessment program and others have been identified as useful and possibly cost-effective techniques, however, they would require a phase of research and development before they could reliably be used as indicators.

Attribute	Suggested Indicator	Type of measurement
Require Pilot Studies		
Water Use	Volume of water held in storage	Area (volume) of water stored calculated from satellite imagery
	Percent of flow diverted	Area (volume) of water diverted calculated from satellite imager
Riparian Vegetation Condition	Riparian composition & extent	Riparian SLATS using TM and ETM+ images
Floodplain Vegetation Condition	Floodplain composition & extent	Floodplain SLATS using TM and ETM+ images
Waterhole Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness, Modified SIGNAL score, AUSRIVAS score
Require Research and Development		
Erosion Potential	Erosion Potential	Landscape Function Analysis

2005 Implementation

The following suggested indicators could be implemented as part of an assessment program immediately (2005). For full details on their specific methodology, see Section 4.

Attribute	Suggested Indicator	Type of measurement
Could be Implemented Immediately (2005)		
Water Use	Volume of water held in storage	Water licensing information
	Percent of flow diverted	Water licensing information
Depth to Alluvial Groundwater	Depth to Groundwater	Change in depth to groundwater
Riparian Vegetation Condition	Rip. Composition & extent	Riparian Cover Index
	Rip. Recruitment & Regeneration	Riparian Regeneration Index
	Riparian Percent Exotics	Riparian NATIVES Index
Floodplain Vegetation Condition	Fpn. composition & extent	Floodplain Cover Index
	Fpn. Recruitment & regeneration	Floodplain Regeneration Index
	Floodplain Percent Exotics	Floodplain NATIVES Index
Waterhole Biodiversity	Fish Assemblage Composition	% Native species, % exotic individuals, Fish assemblage O/E
Waterhole Water Quality	Water Quality	Conductivity, pH, Turbidity, Diel DO, Diel temp, Nutrients (Total & available N and P).

3.4. Terminating Wetlands

3.4.1. Background

There are terminal wetland systems across the entire Lake Eyre Basin. Those in the headwater regions, such as Lake Galilee and Lake Buchanan drain very small endorheic catchments. Those in the river channel and waterhole region are essentially overflow lakes filled by both local rainfall and flooding and at the terminus of some portion of the distributary system. Many of the terminal ephemeral lakes, however, occur within northern South Australia. They can be filled by local rainfall but usually depend on major flushes down the entire system for their main fills (Cullen, 2004).

These wetlands are dynamic in space and time, changing in extent, depth, turbidity and salinity as they periodically fill and dry (Roshier & Rumbachs, 2004). Terminal wetlands are also sites of extreme productivity including the build-up of massive waterbird numbers during flooding (Kingsford et al., 1998).

3.4.2. Values and Threats

While Lake Eyre is the ultimate terminal wetland in the endorheic Lake Eyre Basin, smaller terminal wetlands are distributed throughout the basin subcatchments. They cover a broad range of sizes and are the terminus for a broad range of subcatchments. Each terminal wetland is the final sink for nutrients and sediments from their catchment Many wetlands are also the sites of enormous waterbird breeding and recruitment events when filled.

The major threats to the integrity of the terminal wetlands include:

- Upstream water resource development (farm dams and diversions)
- Landuse change (shifts from pastoralism to cropping)
- Tourism – through localized habitat destruction

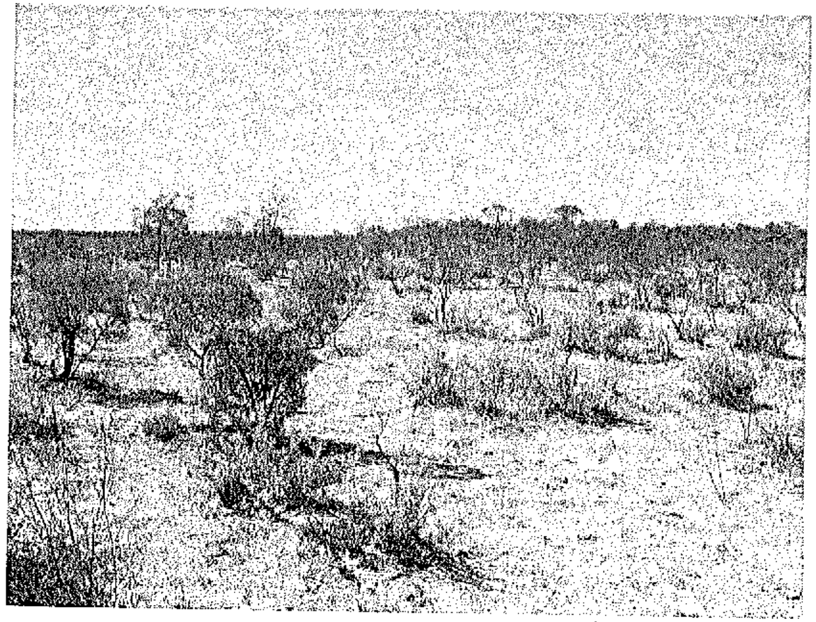
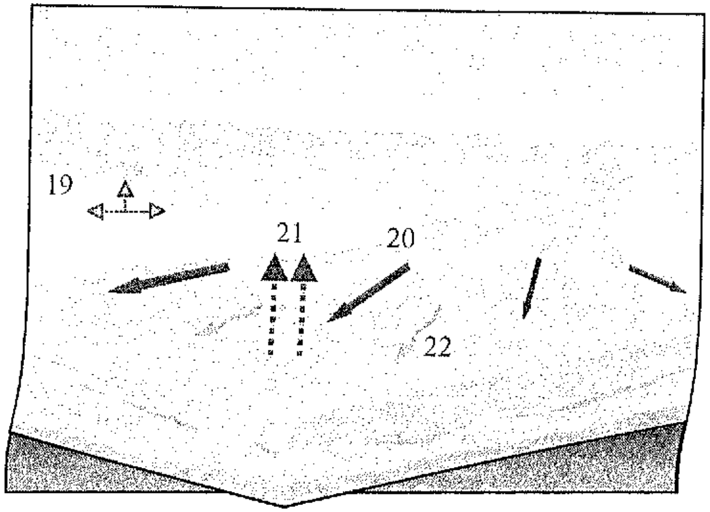


Photo by Paul Anderson

Lake Galilee

3.4.3. Hydrological and Geomorphological Processes

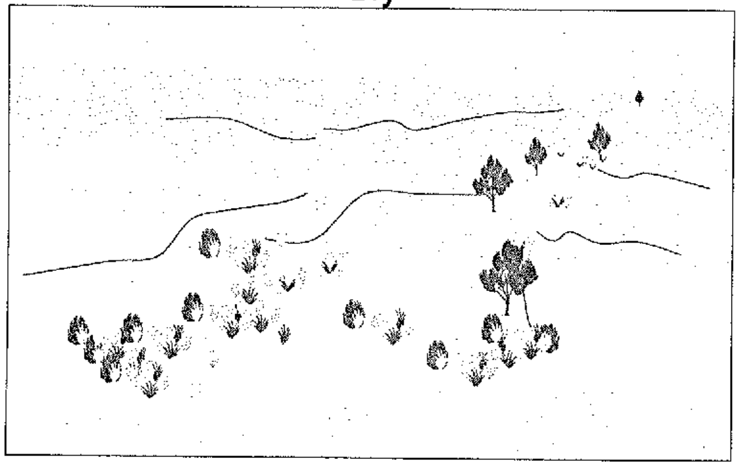
These images graphically describe the hydrologic and geomorphic processes operating in the terminal wetland regions.



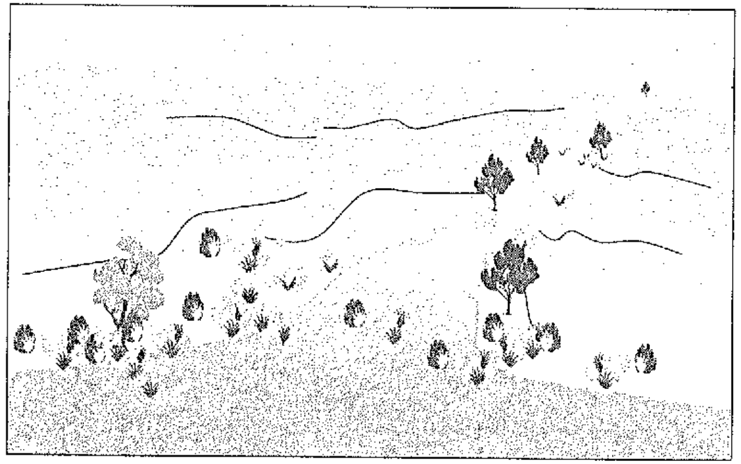
19.	Flow of groundwater to the surface via moundsprings
20.	Downstream flow
21.	Evaporation
22.	Sediment deposition

Terminating wetlands include swamps, marshes, waterholes, lakes and salt marshes. They may be static or flowing, fresh, brackish or saline. They will have dry and wet phases that may be critical habitats for some species.

Dry



Flood

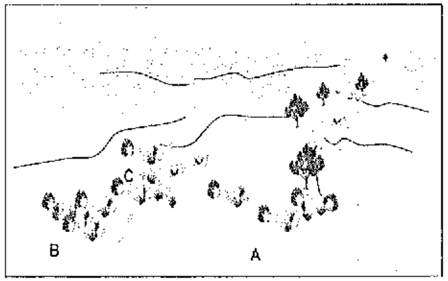


During dry times terminating wetlands are often also dry. Most of the terminating wetlands in the lower Basin are saline, the result of long periods of evaporation or seepage from salt impregnated alluvium. Riparian vegetation becomes scarce at this end of the system and is found only along the few permanent watercourses and waterholes.

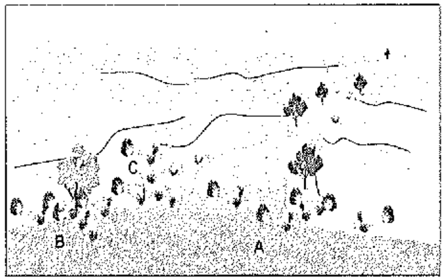
The flooding frequency and aquatic phase duration of the terminating wetlands varies depending on the hydrology of the sub-catchment. Floodwaters are the main source of water for the lower Basin terminating wetlands.

3.4.4. Biological Processes

These images graphically describe the biotic processes of the terminal wetland region.



When dry terminating wetlands provide habitat for terrestrial arthropods and reptiles. As they dry the environment can become harsh with extremes in water quality. Many of the terminating wetlands in the lower Basin are saline and harbor endemic and tolerant fauna and flora. Riparian vegetation becomes scarce at this end of the system and is found only along the few permanent watercourses and waterholes.



When wet the wetlands provide a substantial habitat for a range of flora and fauna depending on their salinity. When filled they are often sites for large populations of waterbirds feeding on large populations of aquatic organisms (fish, zooplankton and phytoplankton) – this typifies the "boom" times in this system.

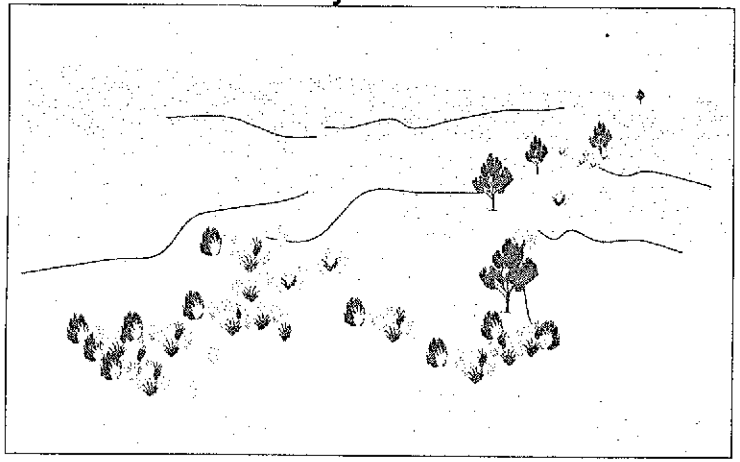
Dry		A	As terminal wetlands dry the water level decreases and the environment becomes harsh, water quality extremes are common in remnant pools. Remnant pools of water can remain between floods.
		A	Drying is often associated with phytoplankton and zooplankton blooms. These are further exacerbated through concentration. Large plankton biomass provide sources of N and P.
		A	Physiologically tolerant and desiccation resistant taxa may persist in remnant pools and sediments.
		A	No fauna survive during the dry, all taxa seek refuge in permanent waterholes within the channel network- see previous table.
		B	Waterbirds utilize drying habitat.
		B	Leaf litter and terrestrial grasses accumulate on dry ground during the dry.
		C	Physiologically tolerant plants can utilize the dry wetlands.
Wet		A	As the water traverses the landscape, water quality may be modified by soil salinity, sediments and nutrient loads.
		A	Extensive flooding is associated with high primary productivity and zooplankton blooms.
		A	Colonization from upstream and population recruitment. Aquatic phase for desiccation resistant taxa.
		A	Colonization from upstream and population recruitment.
		B	This may be a critical ephemeral feeding and breeding habitat for migratory species. It may also provide a crucial seasonal food supply (plankton, invertebrates, fish).
		B	Soil saturation and nutrient rich waters, seed propagules, recruitment.
		C	Sediment movement, transfer of catchment nutrients to wetland.

3.4.5. Disturbance Scenarios

These images describe the major disturbance scenarios for the terminal wetlands. These disturbances include:

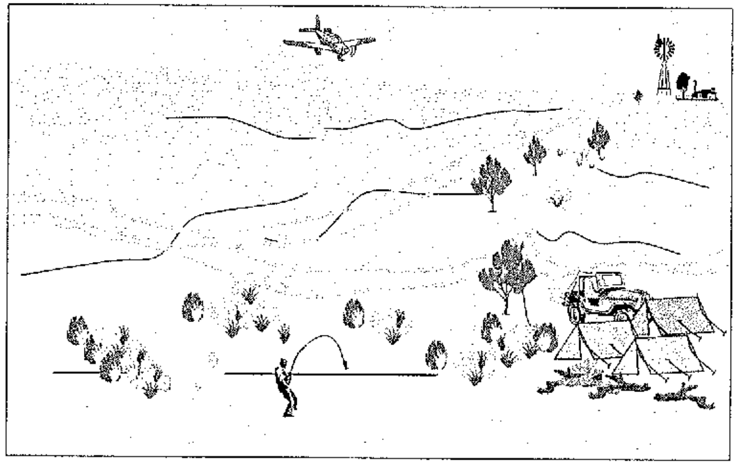
- catchment scale changes to wetland flooding frequency and duration in the landscape through upstream water storage, extraction or diversion
- localized changes to the hydrological landscape through regional water extraction or diversion
- changes to wetland diversity which may occur through overgrazing, riparian destruction, increased nutrient inputs, increased tourism impacts as well as changes to local and catchment scale hydrology

Healthy Conditions



Even when water is scarce, terminating wetlands remain associated with riverine ecosystems. They are a unique area within the landscape.

Disturbed Conditions



Disturbance to terminating wetlands may result from a wide range of pressures both localised and remote. Without their natural character and flow variability these ecosystems may no longer fulfil a key function in providing breeding habitat for large numbers of migratory bird species.

3.4.6. Summary

The conceptual models and associated disturbance scenarios suggest a number of key components of the terminal wetlands that can be incorporated into indicators:

- **Increased Water Storage and Abstraction**
  - **Increased upstream and local water use:** The local conversion of rainfall to runoff as well as the supply of water from headwater and channel regions is important for maintaining local flows into terminal wetlands. Increases in upstream damming, water extraction and water diversion as well as local water extraction and water diversion will impact on wetland flooding frequency and duration.

- **Range of wetlands of varying complexity and flooding frequency.**
  - Not all the biota or diversity is held within the permanent waterholes of the channel region. There are many taxa that require desiccation and drying as critical points in their life cycles and are restricted to the aquatic phase of the terminal wetlands, particularly the halobionts, found only in the saline terminal wetlands. For these taxa a range of flooding and drying frequencies and durations is required to complete their lifecycles. The natural range of flooding and drying frequency of wetlands may be changed by increased water use upstream and/or changes to local floodplain complexity such that wetlands are not filled under certain flows or rainfall events.

- **Wetland Integrity**
  - **Terminal Wetlands:** Terminal Wetlands are significant sites within the landscape scale of the Lake Eyre Basin for holding water for considerable periods after flooding flows. They are often the sites of incredible waterbird populations and breeding events. Their ephemeral nature means they are sites for populations of desiccation resistant, and often salinity resistant, fauna that do not survive within the channel network. They are the sites of mass breeding and recruitment events, "boom" times, associated with catchment flooding.

3.4.7. Suggested Indicators

The values, threats and conceptual models for the terminal wetlands have identified a number of attributes that can be used to develop indicators for health assessment. The major threatening processes and possible attributes include:

Increased Water Storage and Abstraction

Threat: *Increased upstream and local water use*

Attributes that can be measured include: Water Use and Flood Extent

Threat: *Decreased flooding frequency and duration of wetlands*

Attributes that can be measured include: Hydrological Variability, Wetland Biodiversity, Waterbird assemblage composition and diversity, Riparian Biodiversity.

Reduced Wetland Complexity

Threat: *Reduced Wetland Complexity*

Attributes that can be measured include Wetland complexity

Threat: *Reduction in diversity of wetland types.*

Attributes that can be measured include Wetland and Floodplain Biodiversity

Threat: *Landuse change causing increased erosion*

Attributes that can be measured include: Erosion potential, actual erosion, Floodplain Vegetation Condition.

Maintenance of Terminal Wetland Health

Threat: *Upstream and local water use*

Attributes that can be measured include: Water Use, Hydrological Variability, Flood Extent.

Threat: *Increase in abundance of exotic taxa*

Attributes that can be measured include: Riparian Biodiversity, Wertland Biodiversity.

Threat: *Increase in nutrient and sediment supply*

Attributes that can be measured include Wetland Complexity, Total and available N & P, changes in turbidity.

Threat: *Increased pressure from tourism*

Attributes that can be measured include Wetland Biodiversity

Suggested indicators that would measure change in these key components are summarized in Table 3.3. We have highlighted an implementation approach for each measure of an indicator. Where methodology exists and has been trialed in the Lake Eyre Basin or elsewhere to assess river and/or catchment health the indicator could be implemented immediately. This, however, does not mean that this measure is the best or most appropriate measure for that indicator. Other measures that have been highlighted 'Pilot Study' and 'Research and Development' (R&D) may actually be better but would require further development before implementation.

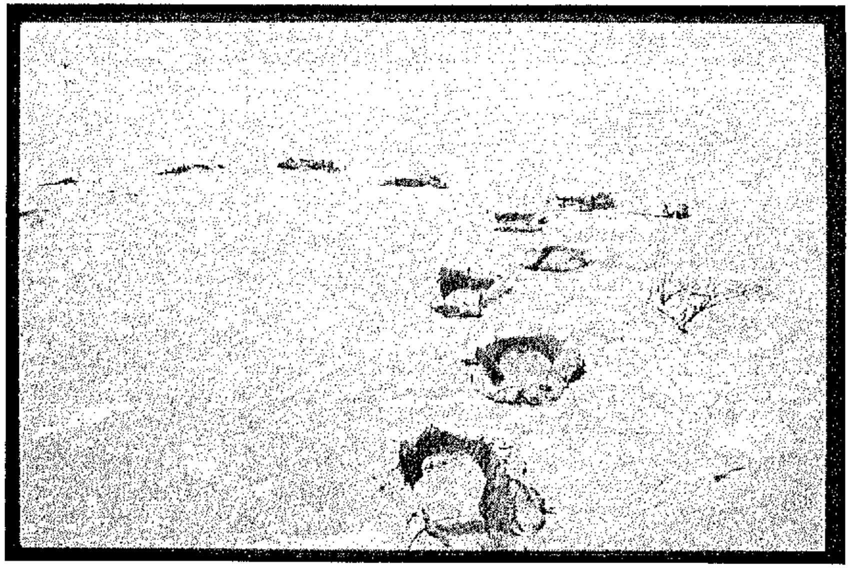


Photo by T.A. Jensen

Dry Lake Eyre

Table 3.3. **<u>Suggested</u> indicators for detecting the change in condition of terminal wetland regions of the Lake Eyre Basin associated with increased water storage and land-use change. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there is existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique but its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.**

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Water Use	Volume of Water Held in upstream Storage	Upstream water licensing information	Immediate Existing data	Catchment measurement & Basin-wide assessment	• Maintaining water transfer from surrounding catchment to channel network. • Maintaining flows in channels and waterholes which fill the wetlands • Maintaining flow variability
		Upstream area (volume) of water stored calculated from satellite imagery	Pilot Study		
	Percent of local and upstream flow diverted	Water licensing information	Immediate Existing Data	Regional measurement & Catchment assessment	
		Area (volume) of water diverted calculated from satellite imagery	Pilot Study		
Hydrological Variability	Flow Variability	Long-term variability (and changes in long-term variability) in amplitude, frequency and duration of floods	Pilot Study Existing Data	Catchment measurement Basin-wide assessment	• Maintenance of "boom" and "bust" cycles. • Maintain periods of connection and disconnection of wetlands with the channel network. • Maintain dynamic variability
		Long-term changes in variability of multi-annual flows	Pilot Study Existing Data		
		Predictability analyses	Pilot Study Existing Data		
Flood Extent	Flood Extent	Changes in the discharge vs. Flood extent relationship	Immediate Existing Data	Regional measurement and Catchment assessment	• Maintain diversity of flooding regimes and productive floodplain growth.
Catchment / Floodplain Vegetation Condition	Floodplain Composition & Extent	Floodplain Cover Index	Immediate	Local measurement and Regional assessment	• Regulates sediment and nutrient supply to the wetland during rainfall runoff, • Importance for pasture response after both rainfall and flooding • Intact biodiversity
		Floodplain SLATS – using TM and ETM+ images	Pilot Study	Regional measurement & Catchment assessment	
	Floodplain Recruitment & Regeneration	Floodplain Regeneration Index	Immediate	Local measurement and Regional assessment	
	Floodplain Percent Exotics	Floodplain NATIVES Index	Immediate	Local measurement and Regional assessment	

Attribute	Suggested Indicator	Types of measurement	Implementation	Scale of Measurement	Relationship to Conceptual Models
Catchment / Floodplain Biodiversity	Floodplain Diversity	Plant biodiversity measures (richness) Functional diversity	Pilot Study	Local measurement and Regional assessment	• Intact biodiversity within floodplains and riparian zones • Intact waterbird assemblages that can respond to flood events.
	Waterbird Assemblage Diversity	Waterbird Diversity	Immediate	Regional measurement & Catchment assessment	
Wetland Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness	Pilot Study Existing Data	Local measurement and Regional assessment	• Different expected diversity with wetlands of different permanency • Invertebrate desiccation resistant stages on floodplain, respond to flooding as 'boom' response. • Intact biodiversity (both fish and invertebrates) able to respond to flooding
		Modified SIGNAL Score			
		AUSRIVAS Scores			
	Fish Assemblage Diversity	% Native Species	Immediate Existing Data	Local measurement and Regional assessment	
		% Exotic Individuals			
		Fish Assemblage O/E			
Wetland Water Quality	Water Quality	pH	Immediate Existing Data	Local measurement and Regional assessment	• Natural (expected) levels of nutrients and turbidity, specific to the wetland type.
		Turbidity			
		Nutrients (Total & available N and Total P)			
Erosion Potential	Erosion Potential	Landscape Function Analysis	R & D	Regional measurement and Catchment Assessment	• Regulates sediment and nutrient supply to the wetland during flooding.

3.4.8. Assessment Approach

Spatial Scale

The suggested indicators can be collected at either the local scale (site based measurements) or the regional scale (multiple site measurements, regional surveys or remotely sensed data).

The number of samples and sites required for an assessment will depend upon (modified from Whittington et al., 2001):

- Spatial reporting scale of the assessment
- Variability of the indicator
- Initial condition score of the indicator
- Aggregation and reporting statistics used
- Desired level of change to be detected
- Desired confidence in detecting that change.

Local Scale Assessment

With assessment at the local scale we recommend a slightly different approach to that outlined in both the Headwaters Section and the Channels & Waterholes Section. We recommend the sampling of a **minimum** of ten terminal wetlands across the geographic extent of the Lake Eyre Basin. These wetlands, where possible, should be distributed across all the major subcatchments. Due to the position of terminal wetlands across the basin it will be impossible to use a nested design for this group. However, where possible a group of spatially close wetlands in a given location should be included within the design such that the degree of "within-location" variability can be quantifies.

For the terminal wetlands there is a number of Wetlands of International Importance in the region such as the Lake Galilee and Lake Buchanan in Queensland and Lakes Frome and Blanche in South Australia. Lake Eyre should be included as the ultimate terminus of the system; however, its infrequent filling will mean it can rarely be sampled for assessment. Other terminal wetland and lake systems that should be considered include Lake Yamma Yamma in the Thomson River catchment, the Lake Torquini Area and Lake Phillipi in the Georgina River Catchment.

Catchment Based Assessment

As the terminal wetlands are usually at the end of catchments then catchment based assessment is not required in this context. Presumably if there is a detectable change in the condition of a terminal wetland due to anthropogenic disturbance it could be assumed that there is catchment impact.

Recommended Spatial Scale

We recommend that terminal wetland sites be distributed across the LEB with representations in all major subcatchments where possible.

Temporal Scale

Events Based Monitoring

Lake Eyre Basin rivers are characterized by floods of varying magnitudes and durations, from large floods that extend over vast floodplains and last for months to small in-channel flows that connect waterholes, perhaps only on a regional scale. The biotic response will differ depending on the size and duration of the flood.

Many of the terminal wetlands are not filled seasonally or annually and then only with floods of certain magnitudes. The assessment of the terminal wetlands will need to be events based, with sampling occurring a number of times after filling and as the wetland moves into the drying phase. If a trend-based assessment is implemented it is the response and subsequent trajectory of indicators after filling that will inform their health assessment.

Assessment Development

A number of suggested indicators has been flagged as needing to be tested in a Pilot Study before they should be implemented in an assessment program and others have been identified as useful and possibly cost-effective techniques, however, they would require a phase of research and development before they could reliably be used as indicators.

Attribute	Suggested Indicator	Type of measurement
Require Pilot Studies		
Water Use	Volume of water held in storage	Area (volume) of water stored calculated from satellite imagery
	Percent of flow diverted	Area (volume) of water diverted calculated from satellite imager
Hydrological Variability	Flow variability	Calculated measures of long-term variability, changes in variability and predictability
Flood Extent	Flood Extent	Changes in discharge to flood extent relationship
Floodplain Vegetation Condition	Floodplain composition & extent	Floodplain SLATS using TM and ETM+ images
Wetland Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness, Modified SIGNAL score, AUSRIVAS score
Require Research and Development		
Erosion Potential	Erosion Potential	Landscape Function Analysis

2005 Implementation

The following suggested indicators could be implemented as part of an assessment program immediately (2005). For full details on their specific methodology, see Section 4.

Attribute	Suggested Indicator	Type of measurement
Could be Implemented Immediately (2005)		
Water Use	Volume of water held in storage	Water licensing information
	Percent of flow diverted	Water licensing information
Floodplain Vegetation Condition	Fpn. composition & extent	Floodplain Cover Index
	Fpn. Recruitment & regeneration	Floodplain Regeneration Index
	Floodplain Percent Exotics	Floodplain NATIVES Index
Wetland Biodiversity	Fish Assemblage Composition	% Native species, % exotic individuals, Fish assemblage O/E
Wetland Water Quality	Water Quality	pH, Turbidity, Diel DO, Diel temp, Nutrients (Total & available N and P).

4. Indicator Methodology

4.1. Background

Summarising from the conceptual models across the three regions the key processes recognized in the maintenance of function in the LEB rivers include:

- Maintenance of flood and flow variability
- Maintenance of spatial habitat complexity
- Interaction between river and floodplain
- Maintenance of integrity (bioidiversity, nutrient cycles, habitat complexity) of waterholes and wetlands, which may function as refugia during dry periods.

In recognizing these major functions we have summarized the Indicators into four separate themes (Figure 4.1; Table 4.1):

- Flood and Flow Theme
- Physical Form Theme
- Riparian and Floodplain Theme
- Waterhole & Wetland Theme

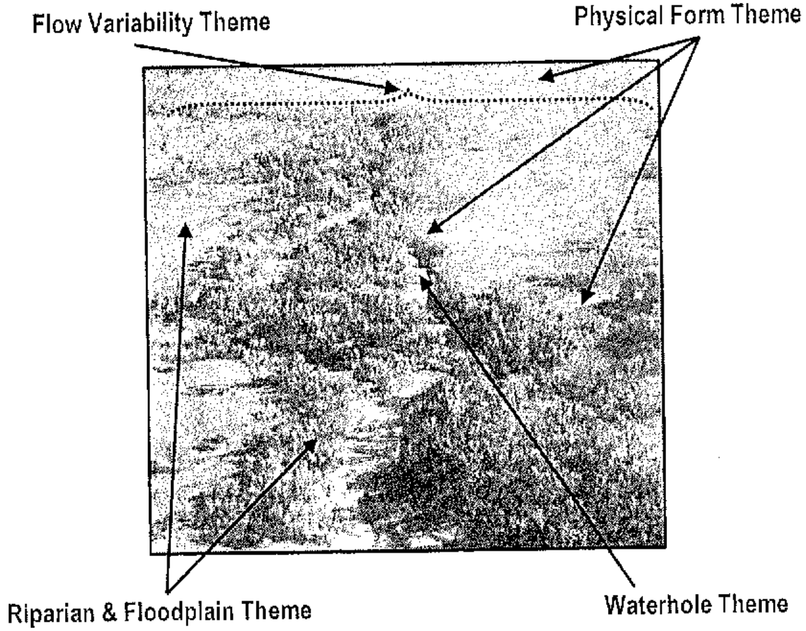


Figure 4.1 Themes summarizing the functioning of rivers and watercourses of the Lake Eyre Basin.

Table 4.1 **Summary of Themes and Attributes across the three regions identified by Classification (Section 2) and used to develop Conceptual Models (Section 3).**

Theme	Attribute	Region		
		HW	C&W	TW
Flood and Flow Theme	Surface Water use			
	Alluvial Groundwater Use			
	Hydrological Variability			
	Flood Extent			
Physical Form Theme	Erosion Potential			
	Channel System Integrity			
Riparian and Floodplain Theme	Riparian Vegetation Condition			
	Floodplain/ Catchment Vegetation Condition			
	Riparian and Floodplain Biodiversity			
Waterhole and Wetland Theme	Waterhole Biodiversity			
	Waterhole Water Quality			

Within each "theme" we outline a number of important attributes. Within each attribute are the indicators that could be measured at specific scales of both space and time (Figure 4.2).

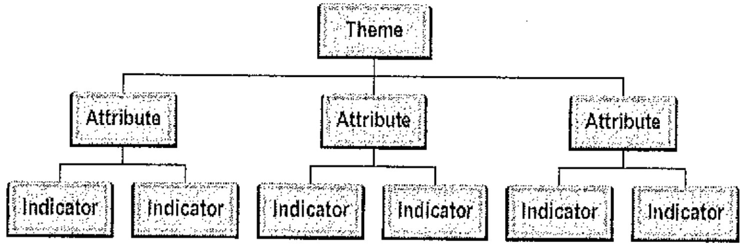


Figure 4.2. Arrangement of Indicators within Attributes and Themes.

4.2. Scale of Assessment

The scale and design of the final assessment will determine how the overall condition of the Lake Eyre Basin can be assessed. Condition assessments can be made across a number of scales with the final scale of the assessment depending on the number of sites included in the assessment. If only a few sites are assessed per catchment (sites nested within location) then the condition assessment can only be reported at the location scale.

Eg. these particular sites were healthy / unhealthy

Given the inherent spatial and temporal variability of the Lake Eyre Basin most measured ecological variables will demonstrate considerable variation in space and time across many scales (Downes et al., 2002). To increase the power of any of the indicators to detect change over the large spatial scales evident within the Lake Eyre Basin it will be necessary to quantify the within location variability, as compared to the between location variability. To this end random sample sites should be positioned around strategic sites, such that several sites are sampled scattered over specific locations at each sampling time (see Downes et al., 2002; Page 129). This provides a nested sampling design, where a number of spatially close sites are sampled from one location. We have suggested the minimum number of sites and locations required for the site-cased assessment within each river zone within the Lake Eyre Basin.

If complete sub-catchment assessments are required then the number of sites and locations will need to be increased. For example, the Sustainable Rivers Audit for the Murray-Darling Basin Commission, suggests the following number of sites for reporting at the river-valley scale (Whittington et al., 2001):

Macroinvertebrates: annually at 30 sites per river valley
Water Quality: 4-6 times per year at 18 sites per river valley
Physical Habitat: every 5 years at 20 sites per river valley.

The Murray-Darling Basin rivers display lower levels of spatial and temporal variability compared with the Lake Eyre Basin rivers (see Puckridge et al., 1998); thus, the exact number of sites per sub-catchment required for Lake Eyre Basin rivers is likely to be higher and would need to be determined through Pilot Studies.

We have recommended measurements be made at both the site scale (using field and automated techniques) and at the reach or regional scale (using remotely sensed data).

In this section for each indicator we suggest whether the measurement should be undertaken using field based site measures or remotely sensed data.

4.3. Data

4.3.1. Type of Data

We have selected indicators based on both field measurements and remotely sensed data. Many of the field-based measures are already operational and could be implemented within an assessment program immediately. Remote sensed data offers a comparatively cost effective methodology for assessing large areas, for a range of indicators at once. This is appealing for a catchment the size of the Lake Eyre Basin. Multispectral imaging (both airborne and satellite) may be useful at high resolutions to document attributes (and changes in attributes) such as riparian vegetation diversity, flood extent, waterhole connectivity and channel system geomorphology. These data may be used for a number of analyses relating to habitat, water quality, and watershed health. Although many of the remotely sensed techniques are operational, if selected for use in health assessment they will require at least validation through a Pilot Study phase and in some instances further R & D to make them operational.

4.3.2. Spatial and Temporal Issues with Indicators

The highly variable nature of the rivers and waterholes of the Lake Eyre Basin and the dynamic changes in assemblage composition of sites reflecting hydrological fluctuations provide a challenge in developing and interpreting measurements of ecosystem health. Most existing river health schemes measure ecosystem health spatially at one point in time (usually seasonal), results are compared either between reference sites using seasonal models (AUSRIVAS – Coysh et al., 2000) or across a disturbance gradient (Smith & Storey, 2001) – see also Background Document 4. These approaches work well if assemblage composition and changes in composition vary only seasonally, and if hydrological fluctuations are seasonally driven, which is the case for many river systems and regions. In Lake Eyre Basin rivers, however, assemblage composition is driven more by hydrological changes than seasonal shifts (Capon, 2003; Arthington et al. in press; Marshall et al. in press).

The overriding influence of hydrological regime in dryland rivers suggests the use of seasonal models for ecosystem health assessment may be open to misinterpretation. For example, the macroinvertebrate based AUSRIVAS observed vs. expected (O/E) score for sites on the Georgina-Diamantina River system in the Lake Eyre Basin Australia shows O/E scores as ranging from 0.28 (very few expected taxa – and thus assumed impacts) to 1.6 (more then expected taxa when compared to reference sites) (Sheldon et al., 2003). All sampled sites within the Georgina-Diamantina system are presumed to be 'healthy' with minimal anthropogenic disturbance. This range in O/E score is real and reflects the natural decline in condition associated with hydrological fluctuations, during dry times sites would naturally be in 'poor' condition and therefore score a low O/E. During dry times the majority of the fauna will comprise tolerant generalists (Sheldon et al., 2003).

The SIGNAL score (Chessman, 2003) gives an indication of the average sensitivity of individual taxa in terms of the water quality in the river from which the sample was collected. If the same data are analysed using SIGNAL the majority of samples from sites within the Georgina-Diamantina river system fall within quadrants 2 and 4, suggesting high levels of pollution, development, salinity and nutrients. The Georgina-Diamantina River system is one of the least developed and polluted rivers in Australia. Again, the range in SIGNAL reflects natural declines in condition associated with hydrological fluctuations. During dry times sites would naturally be in 'poor' condition and contain tolerant generalist taxa possibly also associated with polluted and degraded sites in other systems.

These examples highlight the limitations of a spatial assessment that does not include large natural temporal shifts in the interpretation of indicator scores. A critical component of ecosystem health is the ability of a system to rebound after a disturbance event (Whitford et al., 1999). Spatial assessments of ecosystem health in isolation of temporal interpretation do not incorporate this rebound ability. One approach that has utilised the 'rebound' ability of ecosystems as a measure of health is the 'grazing gradient' approach in rangeland pasture systems (Pickup, 1989; Pickup & Chewings, 1994).

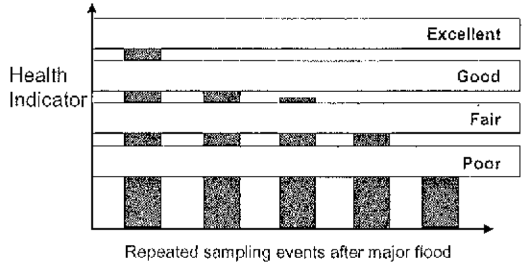
The "grazing gradient" approach has been used in the Australian rangelands to assess the health of pasture (Pickup, 1989; Pickup & Chewings, 1994). Degradation in the rangelands is considered as "grazing-induced long term reductions in the capacity of the land to produce forage for grazing animals in response to rainfall" (Pickup & Chewings, 1994). The grazing gradient recognizes spatial changes in pasture cover a certain distance from a point water-source. Pasture in "good" condition will appear "poor" a short distance from the watering point but rapidly return to "good" condition the greater distance you move from the watering point. Pasture in "poor" condition will also appear "poor" or "very poor" a short distance from the watering point but will fail to return to "good" condition with increasing distance from the watering point.

One of the biggest challenges in selecting indicators, and more importantly in interpreting the data collected on any indicator, in a variable river system is to understand the large spatial and temporal variations in natural "condition". This large-scale variation means that at any one point in time, reflecting natural variations in flooding and rainfall, some rivers and river reaches are likely to naturally be in "good" condition while others will naturally be in "poor" condition. Knowing where a site is on a natural trajectory between "good" and "poor" condition would increase the power of the indicator to assess the health of the site in relation to anthropogenic impacts and prevent misinterpretation.

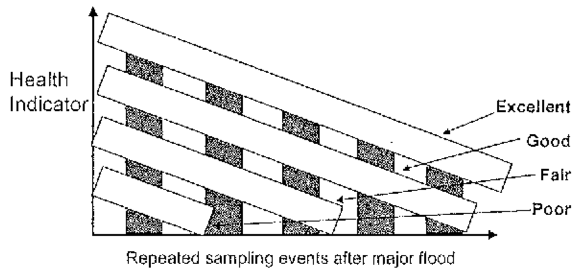
If the score, or output, of an indicator is recognised to vary in response to natural large scale fluctuations in hydrology then not only can the change in indicator associated with anthropogenic disturbance be measured but also the ability of the system to respond after the drying disturbance (resilience). As in the grazing gradient approach for rangelands, measuring ecosystem resistance to disturbance and resilience following disturbance in aquatic systems may provide an early warning of risk of degeneration of the ecosystem when exposed to stress (Whitford et al., 1999).

Temporal changes and resilience can be built into the use of many of the ecosystem health indicators currently in use (AUSRIVAS, SIGNAL etc). In highly variable rivers not subject to anthropogenic disturbance, sites that have only recently become disconnected after connecting flows or floods should present as healthy, with increasing time since flood or connection there will be a decline in the indicator score (Figure 4.3). This decline could be interpreted as a decline in the "condition" or health of the waterbody. Under a spatial assessment scenario a site disconnected for a substantial period of time would be misinterpreted as in "poor" condition, even though it might be the expected condition for that temporal phase of the hydrological cycle. If the indicator bars are modified so that a decline in condition with time since last flood or rainfall is expected, even in waterbodies in excellent condition, then the interpretation of "healthy" or "unhealthy" for a given waterbody will be more robust. Under this modified scenario (Figure 4.3) a site in poor condition would fail to respond or appear healthy even immediatey after flooding or rainfall.

In highly variable rivers, like those of the Lake Eyre Basin, the spatial variability in condition at any one point in time will be enormous and may well require relationships between condition and flooding history to be developed for a number of sites or regions across the basin.



(a) Normal positioning of health indicator "bars". They do not take into account natural declines in condition in relation to natural events such as flooding and drying.



(b) Modified positioning of health indicator "bars" that recognize natural declines in condition on a temporal scale after flooding or rainfall events. Sites in impacts poor condition would not be expected to respond after flooding in the same manner as sites in excellent condition.

Figure 4.3. Different approaches for positioning the 'health' bars in an assessment of condition. (a) the traditional approach. (b) approach modified for naturally variable systems.

These graphs (Figure 4.3) assume a linear response of declining health with increasing time since last flood. A linear response is not expected for all indicators and for some indicators the response may vary between waterbody type, natural flooding frequency and region. Some potential responses are outlined in Figure 4.4. For some indicators or waterbody types condition may not change for considerable time after flooding and then decline very rapidly over short time periods. For others the response may be stepped or various combinations of those described.

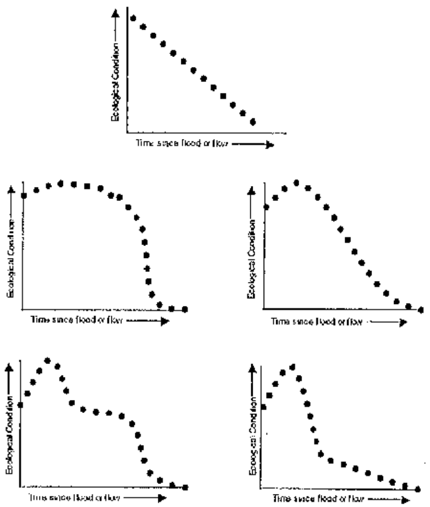


Figure 4.4 Possible shapes of ecological condition response to time since last flood. From Sheldon et al. (2000)

Very little of the data collected for Lake Eyre Basin rivers has been analysed (or the analysis published) to explore response curves to drying. Data collected Dr Jim Puckridge (University of Adelaide) for his PhD thesis as well as data collected as part of the ARIDFLO project (Department of Environment and Heritage) has the temporal replication to establish some of these responses for different taxonomic groups and waterbody types. Response curved would need to be generated via pilot studies for many of the other indicator types.

For many of the indicators suggested the use of a trend approach in interpretation will be necessary. As outlined above in many instances the trends may be determined from existing data, in others Pilot Studies may need to be implemented to measure and document the trends. In this way declines in condition caused by human impact can be distinguished from natural variation (power of the indicator).

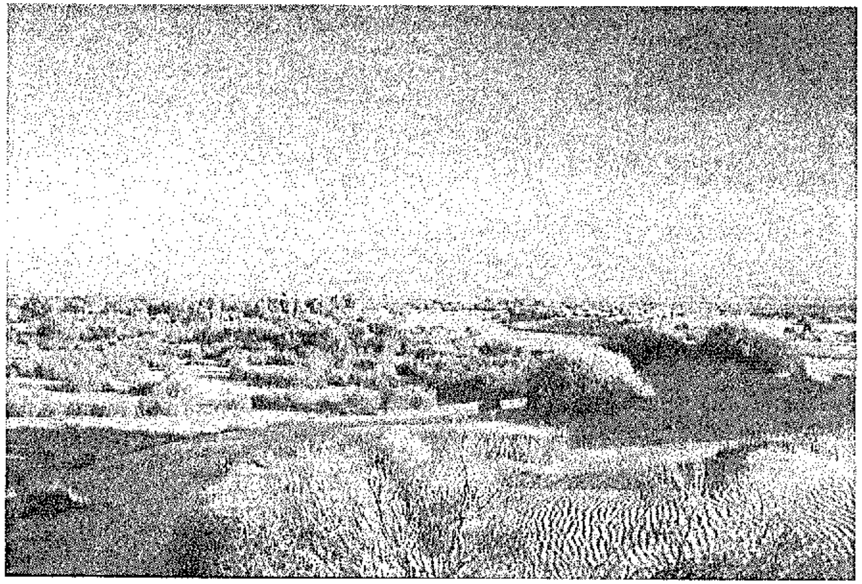


Photo by Fran Sheldon

Koonchera Waterhole, Lower Diamantina River

4.4. Flood & Flow Theme

4.4.1. Background

Flooding and flow variability are important facets of the ecology of the Lake Eyre Basin rivers and are evident in many aspects of their variable flow regime (volume, rate, seasonality, overall variability) (Puckridge et al., 1998; Puckridge et al., 2000). In many other assessment programs hydrological indices are based on flow deviation measures using modeled natural and current impacted hydrographs (White & Ladson, 1999; MDBC 2004a). As many rivers and catchments in which assessment is undertaken are developed and changed in ways that modify their flow regime, measuring change from natural is a good way to measure hydrological impact. The LEB rivers, however, are different from these in that large scale changes to their hydrology have not been made and the small scale hydrological changes associated with farm dam storage have not been successfully modeled in such a large catchment (Sheldon et al., 2003) but at the basin scale are expected to be small. However, upstream storage, even in small farm dams, may drastically decrease sub-catchment flows during the low flow period, so that impacts are local and felt in the headwater region rather than basin-wide and felt at Lake Eyre.

Outside of large scale water resource development projects (eg. Walker et al., 1997), most of the future hydrological impacts within the LEB are likely to occur in the headwaters regions and involve increases in the volume of water stored in farm dams and storages for stock and domestic use (Sheldon et al, 2003). Therefore the "Flow Variability Theme" will need to have several Attributes, which capture both the broad scale nature of flow variability within the basin, and the degree to which water is held in the headwaters.

The Flow Variability Theme is designed to capture changes, or changing trends, in long-term flow variability across the LEB, recognizing that short-term fluctuations in flow variability are normal with cycles of flood and drought.

4.4.2. Possible Indicators

Attributes	Possible Indicators for Measurement
Hydrological Variability	Measures of Flow Variability
Flood Extent	Flood Extent
Water Use	Volume of water held in storage Percent flow diverted
Alluvial Groundwater	Depth to groundwater, variance in groundwater depth

4.4.3. Hydrological Variability Attribute

In many assessment programs (Index of Stream Condition, and Sustainable Rivers Audit) the Hydrological Indicator focuses on the hydrological change associated with water resource development. For the Lake Eyre Basin Rivers the current level of development and lack of gauged and modeled flow data makes such calculations both meaningless and impossible. It may be more meaningful in detecting changes in flow variability in these rivers to undertake long-term trend analysis of the variability in amplitude, frequency and duration of floods and look for changes in these measures. Correlating these variability measures with rainfall may also enable the longer-term rainfall records to be used as substitutes for gauge data.

In the Pilot Sustainable Rivers Audit for the Murray-Darling Basin rivers (MDBC, 2004a) a number of measures were suggested to assess hydrological health. Although these measures were calculated using modeled data they theoretically could be adapted for use in the unregulated LEB Rivers.

Mean and Median Annual Flow Indicators

Mean Annual Flow Indicator (A) (modified from Whittington et al., 2001):

$$\text{if } \overline{Q_c} > \overline{Q_n} \text{ then } A = \frac{\overline{Q_n}}{\overline{Q_c}}, \text{ else } A = \frac{\overline{Q_c}}{\overline{Q_n}}$$

Where: Q_c = mean or median annual flow under current period of assessment
Q_n = mean or median annual flow under natural period of record.

Annual Variation Indicator

Annual Variation Indicator (AV) (modified from SKM, 2003 as cited in MDBC, 2004a) is the ratio of the coefficient of variation of annual flows under the natural period of record and the current assessment period, where the coefficient of variation is defined as the standard deviation divided by the mean.

$$AV = \frac{AVC_n}{AVC_c}$$

Where: AVC_c = Annual coefficient of variation for assessment period
AVC_n = Annual coefficient of variation for natural period of record.

High and Low Flow Spell Indicators

High flow event number indicator (HFEN) is calculated as the number of event exceedances above specific flow thresholds (biologically significant events – such as waterhole connections or the filling of terminal wetlands) under both natural period of record and current assessment conditions (MDBC, 2004a).

$$HFEN = \min(N_n, N_c)/\max(N_n, N_c)$$

Where: N_n = number of event exceedances for specific flow thresholds under natural period of record conditions
N_c = number of event exceedances for specific flow thresholds under current period of assessment conditions

Low flow event number (LFEN) was developed for the SRA (MDBC, 2004a) and relates to the 90th percentile of non-zero flows. If modified for LEB rivers the LFEN would assess the difference in the number of low flow events between natural period or record and current assessment conditions.

$$LFEN = \min(N_n, N_c)/\max(N_n, N_c)$$

Where: N_n = number of event exceedances < the natural 90th percentile of non-zero flows under natural period of record conditions
N_c = number of event exceedances < the natural 90th percentile of non-zero flows under current period of assessment conditions

The Low flow event duration (LFED) indicator was developed by the SRA to assess the difference in mean duration of low flow events between natural and current development conditions (MDBC, 2004a). If modified for the LEB rivers it would measure the LFED difference between the natural period of record and current assessment period.

$$LFED = \min(N_n, N_c)/\max(N_n, N_c)$$

Where: N_n = mean duration of event exceedances < the natural 90th percentile of non-zero flows under natural period of record conditions
N_c = mean duration of event exceedances < the natural 90th percentile of non-zero flows under current period of assessment conditions

Realities of using Hydrological Indicators for LEB Rivers

One impediment to undertaking complete hydrological analyses of the Lake Eyre Basin rivers is the lack of operating gauging stations. Figure 1.2 in Section 1 shows all the gauges within the Basin for which data are available. Despite the apparent wide coverage, most of these gauges are no longer operational and for many only very short periods of record exist. Operational gauges are shown in green on Figure 1.2, suggesting no current coverage over much of the LEB.

The other major impediment to using hydrological indices to assess health is the extreme variability of flow and the long periods of data required to detect change. With most of the water resource development planned for headwater regions, the limited number of gauges within these regions and the lack of long-term data records it may be difficult to use hydrological indices to detect low flow hydrological impact.

We recommend a Pilot Study phase for these Indicators, where aspects of flow variability for existing gauging station data can be assessed for the potential to detect change in flow variability. Their usefulness in an assessment program may not be on a catchment basis, but rather on a smaller sub-catchment basis to detect specific impacts of small and localized water resource development projects. For this to be feasible there would need to be a better coverage of gauging stations.

Scale

Hydrological data for existing gauging stations is already collected. The programming of formulae for calculating various indicators of variability, once undertaken, would allow annual computation of each variability index and reporting of the Attribute. Given the hydrological variability of the Lake Eyre Basin Rivers assessment of impact at the level of an Attribute would only be appropriate after a sustained change in the value of a number of variability measures and a concordant change in other Indicators from related and non-related Attributes.

Variability measures would need to be calculated for all existing hydrological data and then long-term running "averages" or trends (over different time periods) examined. The value of change in each Indicator would need to be reported within the Attribute.

There is a number of current gauges within the LEB (Section 1), however not all major subcatchments have gauges and even the major watercourses have only a couple of gauges separated by hundreds of kilometers. A larger number of gauges spread throughout the Basin would provide a more robust measure of flow variability change.

4.4.4. Flood Extent & Duration Attribute

Flood Extent Indicator

Relationships can be determined between discharge at a point and the area inundated by the given discharge. These relationships can be established using existing satellite images and discharge data. The flood extent Indicator would assess changes in the area inundated for a given discharge. The development of an interactive satellite and gauge station model is suggested.

We have recommended that this Indicator could be implemented immediately. There are existing satellite images and discharge data and the EA funded project ARIDLFO used a similar technique to estimate discharge and flows for ungauged rivers. This could be expanded to formulate a Flood Extent Indicator.

Scale

The variability evident in the spatial patterns of flooding means that this relationship would need to be determined for a number of points across the basin. It would be measured at the regional scale and so catchment based assessments could be made.

Flood extent would be measured for specific regions for both the Channels and Waterholes area and the Terminal Wetlands. Flood extents should be mapped for targeted regions (regional assessment areas) after each flood cycle.

4.4.5. Water Use Attribute

Volume of water held in storage Indicator

Licensing information could be collated from relevant licensing authorities to determine the volume of water held in storage, this could be categorized into urban / farm / and industrial. Trends and changes over time in the volume of water in storage could be assessed.

This information is available and this licensing measure for the Indicator could be implemented immediately. The data would need to be collated and impacts assessed as trends in license numbers over time.

As license information may not be a true record of the volume of water held in storage we also recommend that satellite imagery be used to estimate the volume of water held in storage after flood or rainfall events –this information would be analysed for trends over time. This measure for the Indicator would require a Pilot Study to determine the best techniques for measuring volume of water held in storage using satellite imagery.

Percent flow diverted Indicator

Again, licensing information could be collated from relevant licensing authorities to determine the volume of water diverted from the channel or floodplain environment. Trends and changes over time in the volume of water diverted could be assessed.

Again, this information is available and could be implemented immediately. The data would need to be collated and impacts assessed as trends in license numbers over time.

Again, as license information may not be a true record of the percent of flow diverted we also recommend that satellite imagery be used to estimate the percent of flow diverted during and after flood or rainfall events – again this information would be analysed for trends over time. This measure for the Indicator would require a Pilot Study to determine the best techniques for measuring percent of flow diverted using satellite imagery.

Scale

This Attribute and Indicators would be measured for all three major regions. Measurement would be made at the catchment scale. As they are huge differences in upstream area for the different regions the Indicator for Headwater regions would record local water held in storage and local water diverted while Indicators for Channel and Waterhole regions and the Terminal Wetlands would need to record local water held in storage and diverted as well as any upstream water.

4.4.6. Alluvial Groundwater Attribute

Depth of alluvial groundwater Indicator

The depth to alluvial groundwater could be measured at strategic sites across the LEB. A long-term record is required to relate natural changes in groundwater depth to natural changes in the hydrograph in relation to flood events. The interpretation of this indicator would require a gradient analysis approach where impact is determined by deviations in trends over time.

This Indicator could be implemented immediately.

Scale

This would be undertaken at strategic sites across the headwater region of the LEB. Interaction between surface flows and groundwater is likely to be patchy, so the assessment of this indicator would need to be region specific.

4.5. Physical Form Theme

4.5.1. Background

In large floodplain rivers, such as those of the LEB, fluvial complexity across a range of scales is important for both aquatic and terrestrial biota as it provides food resources as well as places for nesting and recruitment. The spatial habitat complexity evident in dryland rivers is a fundamental attribute of these systems. Assessments of the physical complexity of river systems can provide insights into available habitat condition, significant for flora and fauna diversity.

The Physical Form Theme is designed to assess the physical complexity of the channel and floodplain environment and to indicate changes in this complexity that may impact on aquatic condition. Such changes include loss of channel and floodplain complexity (channel system integrity), floodplain salinisation and catchment erosion potential (Figure 4.4).

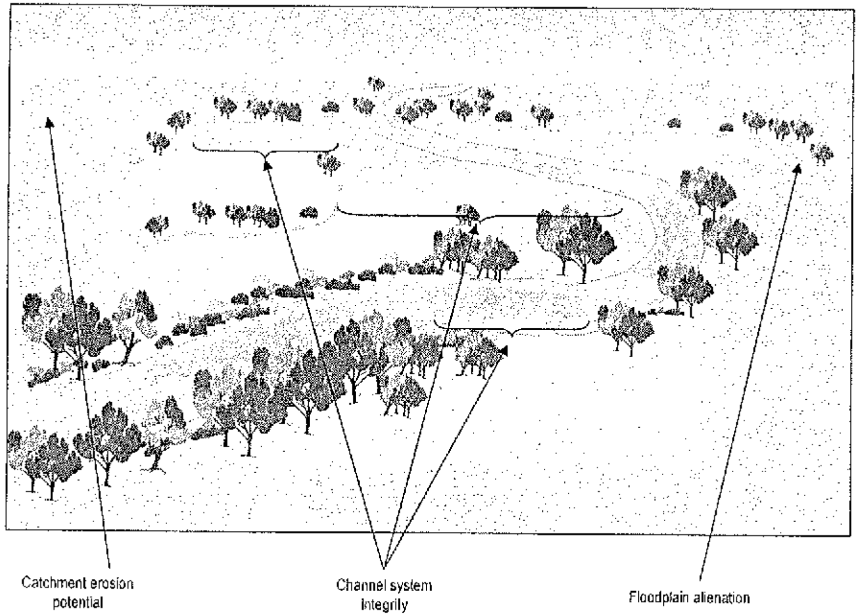


Figure 4.4. A typical arid river riparian and floodplain landscape. Key physical elements in this landscape are the braided and anastomosing channels, floodplains of various heights. Key indicators of physical form are the channel system integrity (waterhole connections and diversity), the potential for catchment erosion and alienation of the floodplain.

4.5.2. Possible Attributes

Attribute	Possible Indicators for Measurement
Channel System Integrity	Floodplain Complexity Channel Complexity Within-Waterhole Complexity
Erosion Potential	Landscape Function Analysis
	Floodplain salinisation

4.5.3. Channel System Integrity Attribute

The Channel System Integrity Indicator should attempt to summarize fluvial complexity at the scale of floodplain, reach and waterhole. These measures outlined below could be combined to form an overall assessment of channel system integrity.

Floodplain Complexity Indicator

Research as part of the Dryland River Refugia Project (CRC for Freshwater Ecology) has used a number of geomorphic measures (e.g. floodplain width, floodplain setting, bifurcation ratio) to provide an estimate of floodplain complexity (Thoms pers com). These measures should be explored further, using existing data, to formulate a measure of floodplain complexity that could be built into a Channel System Integrity Indicator. Much of these data could be accessed from remotely sensed images.

Major habitat types on the floodplain can be mapped using a range of remote sensing techniques that include airborne photography, airborne multi-spectral and hyper-spectral images as well as satellite based multi-spectral fine and medium resolution and hyper-spectral images (CSIRO, 2003). To make remotely sensed habitat mapping of the floodplain to form a floodplain complexity indicator a reality, transects would be required to develop "training sets" for the different habitat type identification (CSIRO, 2003). In this way this indicator would require an initial period of R & D, even though the technology is operational.

Channel Complexity Indicator

Again measures trialled as part of the Dryland River Refugia Project (CRC for Freshwater Ecology) have attempted to measure channel complexity including the degree and number of anastomosing channels and the braidedness of channels, as well as waterhole size and shape (Thoms pers com). These measures should be explored further, using existing data, to formulate a measure of channel complexity. This could be undertaken as a Pilot Study.

Much of this data could also be accessed from remotely sensed images with the potential to save in field costs over the long-term. As with floodplain habitats, channel complexity can be mapped using a range of remote sensing techniques that include airborne photography, airborne multi-spectral and hyper-spectral images as well as satellite based multi-spectral fine and medium resolution and hyper-spectral images (CSIRO, 2003). Aspects of channel complexity that could be measured using remote images include slope, shape, erosion extent, proportion of slumping and lateral scour of river banks (CSIRO, 2003). More detailed assessments of within channel complexity using remote images may be impeded due to the naturally high levels of turbidity in the water. The ability to measure channel complexity using remote images would need to be developed during an R & D phase.

Within-Waterhole Complexity Indicator

The use of remotely sensed images for assessing within-waterhole complexity woud be severely limited by the high levels of turbidity throughout the LEB (see CSIRO, 2003). For this indicator we recommend site-based field assessment.

Woody Debris

In Lake Eyre Basin rivers woody debris can provide a major habitat type. The presence – absence or complexity of woody debris at a site should be assessed using criteria outlined in the Index of Stream Condition (White & Ladson 1999). The following ratings and descriptions are used for assessing within channel woody debris (White & Ladson 1999). In the Lake Eyre Basin watercourses, where water levels can be extremely variable, the presence of woody debris would not need to be below the waterlevel at the time of assessment, rather at any position within the channel watercourse.

Woody Debris Assessment

Description	Rating
Excellent habitat. Typical features: abundant debris from indigenous species. Site probably never desnagged and riparian vegetation probably never cleared.	4
Good habitat: Typical features: numerous pieces of large woody debris from indigenous species. Perhaps limited large woody debris from exotic species present also. Limited impact of desnagging or riparian vegetation clearing.	3
Marginal habitat: Typical features: moderate visible pieces of large woody debris from indigenous species in the watercourse, or abundant pieces of exotic large woody debris in the channel; moderate impact of desnagging or riparian vegetation clearing.	2
Poor habitat: Typical features: few visible pieces of large woody debris in the channel (either from indigenous or exotic species)	1
Very poor habitat: Typical features: no large woody debris visible.	0

As these measures of floodplain, channel and waterhole complexity have not routinely been used within the context of dryland rivers, and given the enormous spatial variability of floodplains, channels and waterholes we recommend that this Indicator requires both a Pilot Study phase and possible some Research and Development before it could be implemented for assessment.

Other In-Channel Habitat Measures

The Australian River Assessment System: AusRivAS Physical Assessment Protocol (http://ausrivas.canberra.edu.au/Geoassessment/Physchem/) a number of within waterhole habitat complexity variables. Some of these were used in the CRC for Freshwater Ecology Dryland River Refugia project and explained more variation in macroinvertebrate community composition than broader geomorphological parameters or hydrology (Marshall et al. in press).

Within Habitat Assessment

Category	Variable
Substrate	Bed compaction
	Sediment angularity
	Bed stability rating
	Sediment matrix
	Substrate composition
	Presence of rocks
Bank Characteristics	Bank shape
	Bank slope
	Bank material
	Bedrock outcrops

Scale

Field based measures of floodplain, channel and within-waterhole complexity would need to be undertaken at the scale of "site". Where appropriate remotely sensed data could be used to assess complexity at the reach scale. Numerous reaches would need to be sampled to gain a regional or catchment scale assessment.

4.5.4. Erosion Potential Attribute

Erosion Potential Indicator

Conservation of soil, water and nutrients is encompassed by the term "landscape function". Loss, at a catchment scale, of perennial plants and nutrient patches can initiate and indicate landscape degradation. Degraded landscapes can contribute soil and nutrients to the associated aquatic system, they contribute to excessive run-off and decreases in rainfall runoff efficiency. Measuring landscape function at a catchment scale may inform the erosion potential of the catchment and be a useful indicator of physical processes at the catchment scale.

The Australian Rangelands Operational Manual (2000) describes the methodology for Landscape Function Analysis (LFA). Landsat TM (Thematic Mapper) and MSS (Mulit-Spectral Scanner) images have been trialled in some parts of Australia for use in LFA, further trials using NOAA data were suggested.

The Australian Rangelands Information System suggests the following large scale information products could be used to determine landscape function:

- Change in vegetation cover using Landsat satellite data (Product 1: ARIS, 2000)
- Change in minimum cover of perennial vegetation at broad scales using NOAA satellite data (Product 2: ARIS, 2000)
- Change in rainfall use efficiency at broad scales using NOAA satellite data (Product 3; ARIS, 2000).

Although LFA has been undertaken for some regions of Australia it has not been used within the Lake Eyre Basin. Although is appears a promising technique for assessing erosion potential across large areas it would need to undergo a phase of Research and Development before it could be implemented.

Scale

Ideally this could be undertaken at the catchment scale. Landscape Function Analysis is already undertaken in some regions of the country (see Australian Rangelands Operational Manual, 2000)

Product 1 is only operational in the Northern Territory and needs further development.

Product 2 is already undertaken across Australia – see Atlas

Product 3 is already undertaken across Australia – see Atlas

These LFA measures are trend measures – reporting at the catchment scale with changes measured over 3-year time periods.

4.5.5. Floodplain Salinisation Attribute

Salinity Scalding Indicator

Salinity scalds could be mapped using aerial photography and in some instances remotely sensed data. Salinity scalds could be reported as % area of the catchment and changes over time assessed as a pressure indicator.

Scale

The area affected by salinity scalding would need to be reported at the catchment scale.

4.6. Riparian & Floodplain Theme

4.6.1. Background

Riparian and floodplain habitats are important regions within catchments for supporting high levels of biodiversity. In large floodplain rivers, both the riparian zone and the floodplain play a significant role in the flux of materials between terrestrial and riverine environments (see Naiman & Decamps, 1997). Aspects of the condition and functioning of both the riparian zone and floodplain can therefore be used as indicators of catchment condition (see Rapport et al, 1998).

The riparian zone and the floodplain perform the following functions

- Act as filters for nutrients, mediate sediment inputs into the channel network
- Act as a source of organic matter to the channel network (eg. logs, twigs etc)
- Provide habitat (both terrestrial and aquatic)
- Provide shading
- Provide stability for the channel network
- Aesthetic values

Recognizing the intricate relationship between the river and floodplain in dryland rivers such as those of the LEB, the Riparian Zone and Floodplain Theme is designed to measure the condition of the riparian zone and floodplain environment (Figure 4.5). A riparian zone and floodplain in poor condition will have impacts on the aquatic environment through increased sediment input (erosion) and increased nutrients.

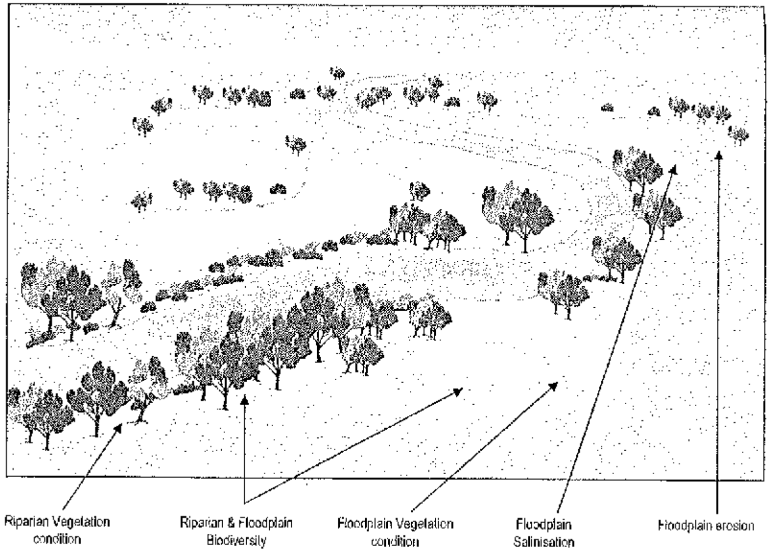


Figure 4.5. A typical arid river riparian zone and floodplain landscape. Key elements in this landscape are the riparian and floodplain vegetation communities. Key indicators for the health of these communities include richness and structure, spatial extent, extent and diversity of recruitment (different age classes) and the presence and dominance of exotic taxa. Impacting on these communities and subsequently in the health of the associated river environment is floodplain salinisation and erosion.

4.6.2. Possible Attributes

Attribute	Possible Indicators for Measurement
Riparian Vegetation Condition	Vegetation composition (richness & structure) Vegetation extent Recruitment Percent Exotics
Floodplain Vegetation Condition	Proportion of catchment cleared Vegetation composition (richness & structure) Vegetation extent Recruitment Percent exotics
Riparian and Floodplain Biodiversity	Plant biodiversity measures (richness) Functional diversity Waterbird Diversity

4.6.3. Riparian Vegetation Condition Attribute

Riparian Vegetation Composition and Extent Indicator

COVER RV Index (Jansen & Robertson, 2001) measures vegetation cover and structural complexity. The COVER Index would be measured at the site or waterhole scale. Measures that combine to form the cover index are shown below. For the Lake Eyre Basin rivers the Cover Index would need to be corrected for what would be expected in that region of the basin, given the extreme spatial and temporal variability. This field-based measure could be implemented immediately.

Measure	Range	Method of Scoring	No of measurements per site
Canopy Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60% cover	4
Understorey Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60%	4
Ground Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60%	4
Number of Layers	0-3	0= no vegetation layers to 3=ground cover, understorey and canopy layers	4

SLATS RV (Statewide Landcover and Trees Study: Goulevitch et al., 2002). SLATS maps and monitors Queensland's woody vegetation cover using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) satellite imagery. These techniques provide data on vegetation cover and cover change. SLATS could be used to estimate riparian cover at a reach to sub-catchment scale. Although operational, the use of SLATS for LEB riparian assessment would require a Pilot Study phase.

Other remotely sensed data, such as airborne laser, airborne hyper-spectral and satellite multi-spectral fine resolution have the potential to measure dominant tree and shrub species in the riparian zone and map vegetation associations within this zone (CSIRO, 2003). With the naturally low canopy cover and low species diversity of riparian trees in the LEB the use of remotely sensed data in this respect is feasible. To make these techniques operational for assessment field based ground-truthing of vegetation associations and species composition would be required. This would require a Pilot Study and R & D phase of development.

Riparian Recruitment / Regeneration Indicator

REGENERATION RV INDEX. Regeneration of native taxa in the riparian and floodplain zone is an important indicator of overall condition, as is a range of age classes in the different vegetation classes. The Index of Stream Condition (ISC) uses an index for regeneration (see below). This field-based measure could be implemented immediately.

Description	Rating
Abundant and Healthy (>5% cover of healthy native regeneration and typical features: range of heights, no obvious signs of stress or extensive predation from stock, rabbits or insects.	2
Present (between 1-5% cover of healthy native regeneration or >5% of unhealthy regeneration and typical features: few taxa present, most regeneration is about the same height, obvious signs of stress	1
Very limited regeneration – less than 1% cover of native regeneration	0

Given broad scale pastoralism across the LEB it may be necessary to establish a referential system here, where sites of low grazing pressure (cattle, other stock, rabbits, macropods etc) can be used as reference points.

Riparian Percent Exotics Indicator

NATIVES RV Index (Jansen & Robertson, 2001) measures the percent exotic contribution to the overall vegetation cover and structural complexity. The NATIVES Index would be measured at the site or waterholes scale. Measures that combine to form the NATIVES index are shown below. This field-based measure could be implemented immediately.

Measure	Range	Method of Scoring	No of measurements per site
Canopy	0-1	Cover score for natives divided by the cover score for all vegetation	4
Understorey	0-1	Cover score for natives divided by the cover score for all vegetation	4
Ground Cover	0-1	Cover score for natives divided by the cover score for all vegetation	4
Number of Layers	0-3	0= no vegetation layers to 3=ground cover, understorey and canopy layers	4

Scale

SLATS and other remotely sensed data systems could be used across the basin to monitor composition and extent of both riparian and floodplain vegetation. Natural changes in vegetation extent and cover would need to be understood and ground truthed. Remotely sensed assessments could be undertaken at the catchment scale.

The site based measures (COVER RV, REGENERATION RV, NATIVES RV) would all be undertaken at sites nested within locations across the basin.

4.6.4. Floodplain Vegetation Condition Attribute

Proportion of Catchment Cleared Indicator

SLATS FV (Statewide Landcover and Trees Study: Goulevitch et al., 2002). SLATS maps and monitors Queensland's woody vegetation cover using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) satellite imagery. These techniques provide data on vegetation cover and cover change. SLATS could be used to estimate cover of floodplain vegetation at a reach to sub-catchment scale, this could then be converted to the proportion of the catchment cleared. Although operational in Queensland, the use of SLATS in the assessment would require a Pilot Study phase.

Other remotely sensed data, such as airborne photography, airborne laser, airborne hyper-spectral, satellite multi-spectral fine resolution and satellite hyper-spectral have the potential to measure the percentage of the catchment cleared (CSIRO, 2003). Although all these techniques are operational, to detect changes in floodplain cover for use as an assessment tool the techniques would require a Pilot Study and R & D phase of development.

Floodplain Vegetation Composition and Extent Indicator

COVER FV Index (Jansen & Robertson, 2001) measures vegetation cover and structural complexity. The COVER Index would be measured at the site or reach scale. Measures that combine to form the cover index are shown below. For the Lake Eyre Basin rivers the Cover FV Index would need to be corrected for what would be expected in that region of the basin, given the extreme spatial and temporal variability. This field-based measure could be implemented immediately.

Measure	Range	Method of Scoring	No of measurements per site
Canopy Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60% cover	4
Understorey Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60%	4
Ground Cover	0-3	0=absent, 1=1-30%, 2=31-60%, 3=>60%	4
Number of Layers	0-3	0= no vegetation layers to 3=ground cover, understorey and canopy layers	4

Remotely sensed data, such as airborne laser, airborne hyper-spectral and satellite multi-spectral fine resolution have the potential to measure dominant tree and shrub species on the floodplain and map vegetation associations within this zone (CSIRO, 2003). With the naturally low canopy cover and low species diversity of floodplain vegetation in the LEB the use of remotely sensed data in this respect is feasible. To make these techniques operational for assessment field based ground-truthing of vegetation associations and species composition would be required. This would require a Pilot Study and R & D phase of development.

Floodplain Recruitment / Regeneration Indicator

REGENERATION FV INDEX. Regeneration of native taxa on the floodplain is an important indicator of overall condition, as is a range of age classes in the different vegetation classes. The Index of Stream Condition (ISC) uses an index for regeneration (see below). This field-based measure could be implemented immediately.

Description	Rating
Abundant and Healthy (>5% cover of healthy native regeneration and typical features: range of heights, no obvious signs of stress or extensive predation from stock, rabbits or insects.	2
Present (between 1-5% cover of healthy native regeneration or >5% of unhealthy regeneration and typical features: few taxa present, most regeneration is about the same height, obvious signs of stress	1
Very limited regeneration – less than 1% cover of native regeneration	0

Floodplain Vegetation Percent Exotics Indicator

NATIVES FV index (Jansen & Robertson, 2001) measures the percent exotic contribution to the overall vegetation cover and structural complexity. The NATIVES FV Index would be measured at the site or reach scale across the floodplainn. Measures that combine to form the NATIVES FV index are shown below. This field-based measure could be implemented immediately.

Measure	Range	Method of Scoring	No of measurements per site
Canopy	0-1	Cover score for natives divided by the cover score for all vegetation	4
Understorey	0-1	Cover score for natives divided by the cover score for all vegetation	4
Ground Cover	0-1	Cover score for natives divided by the cover score for all vegetation	4
Number of Layers	0-3	0= no vegetation layers to 3=ground cover, understorey and canopy layers	4

As remotely sensed data, such as airborne laser, airborne hyper-spectral and satellite multi-spectral fine resolution have the potential to measure dominant tree and shrub species on the floodplain (CSIRO, 2003) these remote techniques could be further developed to allow detection of the presence and extent of exotic taxa within the assemblage, particularly if differences between native and exotic taxa are spectrally distinguishable. To make these techniques operational for assessment, however, field based ground-truthing of species composition would be required. This would require a Pilot Study and R & D phase of development.

Scale

SLATS and other remotely sensed data systems could be used across the basin to monitor composition and extent of floodplain vegetation. Natural changes in vegetation extent and cover would need to be understood and ground truthed. Remotely sensed assessments could be undertaken at the catchment scale.

The site based measures (COVER FV, REGENERATION FV, NATIVES FV) would all be undertaken at sites nested within locations across the basin.

4.6.5. Riparian and Floodplain Biodiversity Attribute

Plant Biodiversity Indicators

Involves the identification of riparian and floodplain taxa in given quadrat areas. Biodiversity indicators would be reported as the number of taxa present or the functional diversity present. Using existing data and historical surveys current richness values could be compared with what is expected in any given region creating an O/E score for vegetation. This indicator would be subject to the same trend in change with natural declining condition (during droughts and dry phases).

Riparian and Wetland Bird Diversity

Kingsford et al. (1999) describe a methodology for using aerial surveys of waterbirds to assess the health of wetlands in the arid zone. The methodology can successfully be used to collect abundance data for up to 50 different waterbird species. The techniques are quick and inexpensive compared with ground counts and can potentially be used to survey large areas rapidly. Richard Kingsford (NSW National Parks) has successfully used aerial survey to assess waterbird populations on wetlands in both the Murray-Darling Basin and the Lake Eyre Basin and has a considerable long-term dataset. This methodology could be extended to cover more of the Lake Eyre Basin and could be implemented immediately.

Bryce et al. (2002) have developed a bird index of biotic integrity which could easily be adapted for use at different scales in the LEB. Given the dynamic and variable nature of bird assemblages in the LEB, a bird IBI will be subject to the same problems as other biotic indicators (See Section 6.2.4). A bird measure such as % exotics or some sort of rainfall adjusted abundance may be useful in detecting riparian vegetation health at a reach scale. The Bird IBI would require more R&D before it could be applied.

Scale

The ground-based measures would need to be undertaken at the site scale, with numerous sites per catchment be required to make catchment assessment. Aerial surveys of waterbirds would be undertaken at the scale of reach or wetland and allow assessment of a larger area.

4.7. Waterhole Theme

4.7.1. Background

The indicators suggested under the Waterhole Theme are all operational, having been used for a number of years as part of the South-East Queensland EHMP having been initially tried and tested across a land clearance catchment disturbance gradient (see Smith & Storey, 2001). Some of these indicators were also selected for trial in the Pilot Audit of the Murray-Darling Basin Commissions Sustainable Rivers Audit (Whittington et al. 2001).

The suggested indicators focus on waterhole condition and would ideally be measured during low-flow conditions. The range of potential attributes and their indicators are outlined below. The feasibility of any one indicator or attribute in assessing river health across the LEB can only be determined after investigations of a Pilot Study using existing data.

Recognising the importance of waterholes in the LEB watercourses, the Waterhole Theme is designed to measure both pattern and process response indicators in waterhole environments (Figure 4.6).

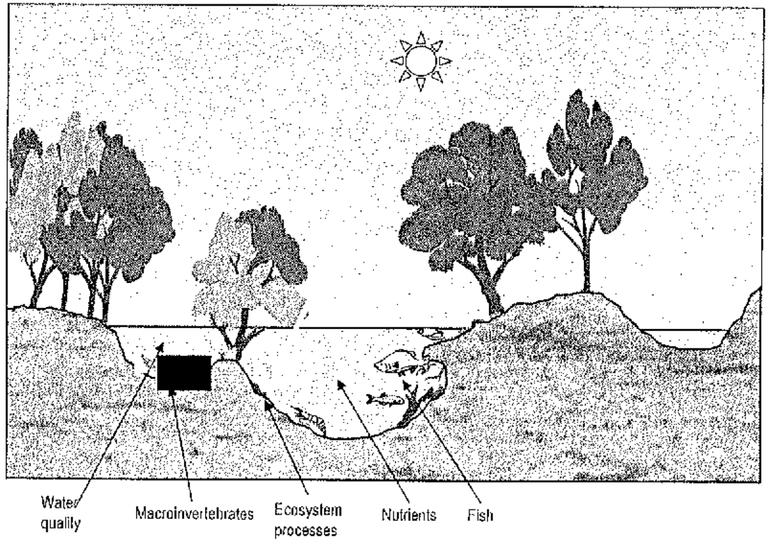


Figure 4.6. A typical riverine foodweb has inputs such as branches, leaf litter, organic matter (CPOM, FPOM & DOC) from the riparian zone. Periphyton and this terrestrial detritus is then consumed by aquatic invertebrates (primary consumers). In turn predatory invertebrates, fish and other aquatic vertebrates eat these primary consumers. The predatory invertebrates are eaten by fish and other aquatic vertebrates. Small fish may in turn be eaten by larger fish, as well as birds. Modified from SEQWRMS (1999).

4.7.2. Possible Attributes

Attributes	Possible Attributes for Measurement
Water Quality	Conductivity pH Diel range in dissolved oxygen Diel range in water temperature
Macroinvertebrate	Taxa Richness Modified SIGNAL Score AUSRIVAS scores Specific Indicator Taxa
Fish	% Native species % Exotic Individuals Fish Assemblage O/E
Ecosystem Processes	Benthic Metabolism Algal Biomass & Composition Carbon & Nitrogen Stable Isotopes
Nutrients	Nutrients (Total and Available N and P)

4.7.3. Water Quality Attribute

Indicators for measuring water quality have been included in a number of other assessment programs (see Chapter 2). The individual indicators suggested for each program differ and a Pilot Study would need to be undertaken using existing water quality data and new data to assess the usefulness of each indicator and attribute for informing health in the Lake Eyre Basin rivers.

As spot measurements of water quality taken once or twice a year offer little information on overall river health, especially in systems as physically and hydrologically variable as the LEB, it is often recommended that water quality sampling be undertaken more frequently. Whittington et al. (2001) suggested sampling at least six times per year for water quality as part of the SRA. Given the remoteness of much of the LEB we don't consider this level of frequency feasible unless it was built into a broader community based program such as Waterwatch. We suggest that the indicators within the Water Quality Attribute be collected at the same time as the other field-based measures, as they will inform the interpretation of the biodiversity and ecosystem process attributes. For some water quality measures the use of automated loggers is applicable.

Remotely sensed data is also being developed to assess a number of water quality parameters (CSIRO, 2003) and where appropriate we have highlighted its potential use. The use of such data, however, is still in the R & D phase of development.

Conductivity

Conductivity, which is the ability of water to conduct an electrical charge, can also be used as a measure of the salinity of a water body. Elevated salinity levels (>1500 $\mu S\ cm^{-1}$) are known to have negative effects on biotic diversity. Many Australian waters have naturally higher salinities than other parts of the world, these salinities are often highly variable in time and space, reflecting flooding and drying regimes or differing groundwater inputs throughout the hydrological cycle.

Conductivity can be measured by a hand held meter in the field, from a water sample in a laboratory or it may be assessed at remote locations using automated loggers.

pH

pH is a measure of the concentration of hydrogen ions in the water. It is measured on a reverse logarithmic scale of 1 (highly acidic) to 14 (highly alkaline) with 7 being neutral. Extreme pH values are known to have adverse effects on respiration and ionic balance in aquatic fauna.

pH can be measured with a handheld meter in the field it can also be measured at remote locations using automated loggers.

Diel range in dissolved oxygen

The oxygen concentration of the water is critically important for aquatic biota. More important is the diel range in dissolved oxygen concentration. Watercourses with a high pollution load may have relatively high levels of dissolved oxygen during the day (due to photosynthesis) but levels may drop to near zero during the evening, in the absence of photosynthesis, and owing to high levels of respiration.

The diel range in oxygen concentration can be measured over 24 hours with a probe and a logger.

Diel range in water temperature

As with oxygen, water temperature can be critically important for aquatic biota. Again, the diel range in temperature can be significant. Watercourses that are well shaded may have a small range of temperature change over 24 hours owing to protection by riparian vegetation whereas those with no riparian vegetation, or unhealthy vegetation may show extreme changes due to heating during the day and excessive cooling at night. In many of the LEB rivers riparian vegetation is naturally sparse and possibly has little effect on maintaining temperatures. The diel range in temperature may be naturally high.

The diel range in water temperature can be measured over 24 hours with a probe and a logger. Temperature can also be measured at remote locations using automated loggers.

Turbidity

Turbidity provides an indication of the amount of suspended solids in the water, or opaqueness of the water. Turbidity affects light penetration and therefore primary production. Both increases and decreases in natural turbidity levels can impact watercourses. Many of the LEB rivers have naturally high levels of turbidity. In this system any impact that caused a decrease in turbidity levels may inadvertently cause an increase in primary production.

Turbidity can be measured in the field using a multi-probe or in the lab from a collected water sample.

There is also potential for turbidity to be measured from remotely sensed airborne of satellite imagery (CSIRO, 2003), its use in the highly turbid Lake Eyre Basin rivers would need to be investigated through an R & D phase.

Scale

Field-based water quality parameters would be measured at the site scale and we recommend measurement at the same frequency as the biodiversity and ecosystem process indicators. If assessment programs in the LEB are developed for particular localized impacts, such as urbanization or large-scale upstream developments, then more frequent sampling of the water quality indicators may be required.

4.7.4. Macroinvertebrate Attribute

Macroinvertebrates are useful in river assessment for the reasons outlined by Rosenberg & Resh (1993) which include:

- Ubiquitous – found in nearly every aquatic environment
- Sedentary– providing indication of localized environmental conditions
- Large numbers of taxa with broad range of reasonably well known tolerances to disturbance and pollution.
- Integrate the effects of disturbance over time
- Ease of collection using existing protocols

Macroinvertebrate assemblages are routinely sampled in many river health assessment programs and there are established techniques for their sampling in the field and processing within the laboratory. A number of measures of macroinvertebrate diversity is routinely used. Once a sample has been taken and sorted the calculation of a number of these measures is simple. Although the use of macroinvertebrates as an indicator is operational and could be implemented immediately, the usefulness of any one measure for the LEB rivers would need to be assessed through a Pilot Study phase, as different programs have found different scores perform better in different catchments (Smith & Storey, 2001).

Total Richness

Total richness is the number of taxa at a particular taxonomic resolution (families, genera or species) found at each site. The use of "total richness" as an indicator is based on the idea that impact leads to a reduction in richness due to the loss of some taxa.

OET Richness

In many assessment programs the EPT (Ephemeroptera: mayflies, Plecoptera: stoneflies, Trichoptera: caddisflies) richness is used as an indicator of river health. This is because the EPT taxa are believed to be some of the most sensitive insect orders to disturbance. The use of the EPT richness indicator is made difficult in many arid and ephemeral areas of Australia as Plecoptera are naturally absent from the assemblage. Pilot studies of existing data could explore the use of Odonata (dragonflies) instead of Plecoptera, which are not found in LEB rivers. A similar suggestion has been made for the Murray-Darling Basin rivers (Swirepik pers comm.), suggesting an OET Richness Indicator may be useful.

SIGNAL – Stream Invertebrate Grade Number

Originally developed by Chessman (1995) and recently modified (Chessman 2003). SIGNAL gives scores to common aquatic invertebrate families based on their sensitivity to salinisation and pollution. SIGNAL was originally developed for eastern Australian streams, particularly those in the Sydney Water Board region. The more recent modification of SIGNAL has extended its use and provided a geographic framework for interpreting the SIGNAL score.

The calculated SIGNAL score, as an indicator of river health, should be explored initially on existing data. Another option is to reassign scores to taxa in the Lake Eyre Basin, to make SIGNAL more sensitive in these rivers. This option should be explored through Pilot Studies with existing data.

AUSRIVAS Score

AusRivAS (the Australian River Assessment Scheme) is an Australia wide river health assessment program using macroinvertebrates. AusRivAS models assess the condition, or "health", of a site by predicting the macroinvertebrate fauna expected (E) to occur at a site in the absence of disturbance. Predictions are derived from data collected from a set of minimally disturbed Reference sites. Sampled sites closest to reference condition will have an O/E score close to 1 but disturbed sites are suggested to have O/E scores of less than 1, with the lower the score suggesting the greater the impact.

If the AUSRIVAS Score is to be implemented and used within an assessment of LEB river health then robust regional models need to be developed for these rivers.

Scale

There are many different techniques available for collection of macroinvertebrate samples however, the most common technique used in river health assessment throughout Australia is that developed as part of the Monitoring River Health Initiative (MRHI). This sampling protocol now forms the basis of the AUSRIVAS sampling undertaken around the country. We recommend that macroinvertebrate sampling within any assessment of LEB river health be undertaken using the relevant AUSRIVAS sampling protocols (http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates).

Macroinvertebrate sampling would be undertaken at the site scale. Samples would need to be collected twice yearly and the AUSRIVAS protocol suggests autumn and spring collections. The Sustainable Rivers Audit (Whittington et al. 2001) recommends collecting samples from 30 sites per river valley to make a catchment assessment of health however, they recommend sampling only every two years (MDBC, 2004d). Given the spatial and temporal variability within the LEB we would suggest more frequent sampling (twice yearly) over fewer sites and the sites grouped by reach (minimum of 20 sites for headwater region, 50 for river channels & waterholes, 10 for terminal wetlands).

4.7.5. Fish Assemblage Attribute

Fish are useful in river assessment for the reasons outlined by Harris (1995) which include:

- Longevity – providing long-term indicators
- Mobility – providing broad spatial coverage
- Range of trophic levels – integrate broad aspects of the ecosystem
- Ease of collection
- Usually well known taxonomy and easy identification in the field
- Habitat and ecology usually well known

Fish assemblages are also routinely sampled in many river health assessment programs and there are established techniques for their sampling and assessment in the field. For river health assessment fish data from sampling sites are often composed into an Index of Biotic Integrity (IBI) where a number of different attributes of the fish assemblages are considered at once. Given the low diversity, high tolerance and generalistic nature of the fish assemblage of the LEB we suggest that a few specific measures of the fish assemblage may be a better assessment of the health than a more complicated IBI.

% Native species

The number of native species is commonly used to measure ecological condition of aquatic systems (see Harris, 1995; Kennard et al., 2001). The number of native species is expected to decline with increasing environmental stress. In the Lake Eyre Basin rivers the number of native species present in the fish assemblage is naturally low (Sheldon et al., 2003; Arthington et al., in press) and varies naturally between sub-catchments. The percentage of native species may be a better indicator in these systems, with percent native species decreasing with increasing anthropogenic impact.

% Exotic Individuals

This measure would need to be included with the above measure and only one exotic species may mean that 95% of all taxa are still native, however, this one exotic may comprise 70% of the abundance having a big impact on the assemblage. The presence and relative abundance of exotic species (% exotic individuals) has been suggested to reflect the general condition of the aquatic ecosystem (see Kennard et al., 2001). The value for % exotic individuals should increase with increasing environmental stress.

Fish Assemblage O/E

Over larger regions within the LEB (reach to sub-catchment) the ratio of observed number of species to expected number of species (O/E) could be used as a summary of regional condition. The LEB fish assemblage is rather species poor and species presence and absence varies considerably over very short distances. Comparing fish species presence and absence at the regional scale, rather than at the site scale, would be more meaningful within this system.

Scale

Fish sampling can be undertaken using a range of techniques. The SRA has recommended the use of electro-fishing and bait traps for fish assemblage assessment in the Murray-Darling Basin (MDBC, 2004e). However, electrofishing has not been routinely used in the LEB where combinations of fyke, gill and seine nets have been preferred (Puckridge, 1999; Bailey & Long, 2001; Arthington et al., in press). The sampling efficiency of electrofishing is greatly reduced in highly turbid waters such as those of the LEB (Pusey et al., 1998). If aspects of fish assemblage structure were to be used in the health assessment of Lake Eyre Basin rivers we suggest the use of tested equipment within these rivers (fyke and seine nets) see also Puckridge (1999b).

Fish sampling would be undertaken at the site scale. We have suggested that samples be collected twice yearly. The Sustainable Rivers Audit (Whittington et al. 2001) recommends collecting fish samples from between 20-40 sites per river valley to make a catchment assessment of health, however, the Pilot SRA Audit recommends sampling every site once every three years with one third of all valleys sampled every year (MDBC, 2004e). Given the spatial and temporal variability within the LEB we would suggest more frequent sampling (twice yearly) over fewer sites, and these sites grouped by reach (minimums of 20 sites for headwater region, 50 for river channels & waterholes, 10 for terminal wetlands).

4.7.6. Ecosystem Processes Attribute

Where the suggested macroinvertebrate and fish attributes focus on the diversity aspect of ecosystem health, this attribute focuses on ecosystem processes. Although the maintenance of ecosystem processes is integral in ecosystem health they have only recently been included in river health assessment programs (Bunn et al., 1999; Smith & Storey, 2001; MDBC, 2004b).

Community Metabolism Indicator

Measures of the gross amounts of both primary production (photosynthesis) and respiration (community metabolism) represent the amount of carbon produced and consumed in any given ecosystem (Smith & Storey, 2001). Community metabolism is therefore an integral part of ecosystem function. It influences the biomass and trophic structure of ecosystems.

Community metabolism can be determined by measuring the net change in dissolved oxygen within dome-shaped Perspex chambers over a 24 hour period (see Udy et al., 2001). Different components of benthic metabolism can be calculated by comparing the rate of O_2 change in the chambers at different times of the day. In the Pilot SRA Audit within the rivers of the Murray-Darling Basin (MDBC, 2004b) problems were encountered with the use of metabolism chambers, these included:

- Complexity of equipment and need for specialist training
- High failure rate of equipment and damage potential
- Chamber data cannot be integrated at the reach level, making comparisons between regions difficult. However, the use of the Classification of rivers within the LEB (Section 2 & Background Document) should alleviate this problem, with data only compared between like reaches.
- Difficulty in establishing reference condition.

The SRA suggested that the whole-stream method trialed as part of the Pilot Audit had the greatest potential as a routine monitoring tool in the large rivers of the MDB (MDBC, 2004b).

For the LEB rivers, the measurement of benthic metabolism in the littoral zone using benthic chambers has been successfully undertaken as part of the CRC for Freshwater Ecology, Dryland River Refugia Project (Fellows pers com). Although these measures have not been used to infer health they demonstrate that the techniques work in these rivers. In LEB rivers the alternate use of whole-stream metabolism may be limited due to issues with disconnection between sites and extreme hydrological variability.

Although the techniques and methodology exist for immediate implementation, we suggest that the use of metabolism chambers as a measure of community benthic metabolism and therefore an indicator of river health be explored in a Pilot Study phase. During the Pilot Study issues relating to specific habitat deployment and replication could be addressed.

Algal Biomass Indicator

Increases in benthic algal biomass often result from increases in nutrient and light availability. Littoral benthic algae have been shown to be fundamental drivers of the food web of Cooper Creek waterholes (Bunn et al., 2003) and measuring sustained changes (either increases or decreases) in benthic algal biomass may prove to be a useful indicator of health.

Benthic algal biomass can be measured using "bioassay pots" (small plastic pots covered with a 100 µm mesh lid), which can be deployed at a site and left for four weeks prior to sampling. On collection the mesh is removed, frozen until return to the laboratory where chlorophyll *a* analysis can be undertaken (see Udy et al., 2001).

Stable Isotopes Indicator

The $\delta^{13}C$ values of freshwater algae have been shown to be correlated with a GPP of benthic algae across a number of different catchments in Australia (Bunn et al. 1999). $\delta^{13}C$ values have been used successfully in ecosystem health monitoring in south-east Queensland (Smith & Storey, 2001).

The use of $\delta^{15}N$ values of aquatic plants as an indicator of nitrogen cycling in streams was recommended from the DIBM3 project (see Smith & Story, 2001) as it integrates factors that relate to the denitrification process and catchment landuse. The use of $\delta^{15}N$ is becoming more common in monitoring programs where there is an interest in the nitrogen cycle. As $\delta^{15}N$ analysis is also a relatively simple method it is also possible that this could be used at a large number of sites, with high $\delta^{15}N$ values being used as a mechanism to instigate further investigation of the nitrogen cycle at specific sites.

Although the measurement of $\delta^{13}C$ and $\delta^{15}N$ requires the use of a technically precise analytical instrument (mass spectrometer) it is relatively easy to collect the samples.

The use of stable isotopes of N and C as indicators of river health were explored as part of the Pilot Audit for the SRA. There were difficulties encountered and these related mostly for field collection (MDBC, 2004b). The recommendation from the SRA was that although the use of stable isotopes as indicators of river health was promising, their inclusion in the full SRA would require further R & D.

Given the relative ease of collection and processing of samples for stable isotope analysis we recommend that their use in the context of the LEB river health assessment be initially explored in a Pilot Study, taking into account the issues raised in the Pilot SRA.

Scale

Sampling for Ecosystem Process indicators would be undertaken at the site scale at the same time as the other Waterhole Theme indicators. Given the spatial and temporal variability within the LEB we recomment frequent sampling (twice yearly) for all indicators with event based sampling of specific indicators where appropriate. We recommend a hierarchical sampling design of sites nested within location with a minimum of 20 sites across 4 locations for the headwater region, 50 sites across 10 locations for the river channels & waterholes, and 10 for terminal wetlands.

4.7.7. Nutrients Attribute

Nutrient and light availability are important in determining the structure and health of aquatic ecosystems. When light does not limit plant growth, nutrient availability is the next most likely factor that will. Therefore measuring the health of key nutrient processes in an environment, and which nutrients if any are limiting algal growth, are important parameters in the management of river ecosystems.

Research and water quality samples undertaken as part of the CRC for Freshwater Ecology, Dryland River Refugia Project, suggest that nutrients are not limiting algal (benthic or pelagic) production in the Cooper system. Rather, the high turbidity levels, make light the most likely limiting factor. As benthic algae has been shown to be the basis for much of the food web in the Cooper Creek system (Bunn et al., 2003), we recommend measuring at least some nutrients at a site scale as an indicator of potential changes to the nutrient – light balance in the LEB rivers. Total nitrogen and phosphorous can be measured from water samples collected and frozen in the field, or estimated using field based nutrient kits.

Total Nitrogen and Phosphorous

Samples for total N and P can be collected on site using an appropriate sampling technique (see MDBC, 2004b). The scale and remoteness of much of the LEB means that frequent sampling for nutrients will not be feasible. We recommend that samples be collected along with the site based assessment sampling for other attributes within this theme, with more frequent spatial and temporal sampling implemented where potential impacts are thought likely (eg. downstream of urban centres etc). As the spatial and temporal variability of these nutrients has not been quantified for LEB rivers, we recommend a Pilot Study phase for these indicators in which existing data (see Bailey, 2001) could be used.

Soluble Nutrients

The soluble nutrients that should also be collected include:

- FRP: filtered reactive phosphorus
- Nitrate & Nitrite
- Ammonia

Details of sampling methods and laboratory processing for these soluble nutrients can be found in MDBC, (2004b). As the spatial and temporal variability of these nutrients has not been quantified for LEB rivers, we recommend a Pilot Study phase for these indicators in which existing data (see Bailey, 2001) could be used.

Scale

The sampling scale for nutrients would be the same as for water quality. A subset of sites would be sampled for seasonal assessment, while a larger suite would be sampled on an events basis.

4.8. Indicator Summary

Table 4.1 Summary Table of <u>Suggested</u> Indicators within each Theme for detecting the change in condition of different regions (Headwaters (HW), Channels & Waterholes (C&W), Terminating Wetlands (TW)) of the Lake Eyre Basin. Implementation categories: "Immediate" = could be implemented straight away, "Existing Data" = there is existing data which could be used to generate long-term trends, "Pilot Study" = the methodology exists but to be adequately used as an indicator in this context in the LEB would require a pilot study – and could be considered for implementation in the short-term, "R & D" = this would be a useful technique buts its use as an indicator would require some research and development and its implementation would need to be considered in the long-term.

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Flow and Flood	Water Use	Volume of Water Held in Storage	Upstream water licensing information	Immediate			
			Upstream area (volume) of water stored calculated from satellite imagery	Pilot Study			
		Percent of Flow Diverted	Water licensing information	Immediate			
			Area (volume) of water diverted calculated from satellite imagery	Pilot Study			
	Hydrological Variability	Flow Variability	Long-term variability (and changes in variability) in amplitude, frequency and duration of floods	Pilot Study			
			Long-term changes in variability of multi-annual flows	Pilot Study			
			Predictability analyses	Pilot Study			
	Flood Extent	Flood Extent	Changes in the discharge vs. Flood extent relationship	Immediate			

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Riparian and Floodplain	Riparian and Floodplain Biodiversity	Plant Vegetation Biodiversity	Riparian & Floodplain vegetation taxa richness	Pilot Study			
			Riparian & Floodplain vegetation functional diversity	Pilot Study			
			Riparian & Waterbird diversity	Immediate			
	Riparian Vegetation Condition	Riparian Composition & Extent	Riparian Cover Index	Immediate			
			Riparian SLATS – using TM and ETM+ images	Pilot Study			
		Riparian Recruitment & Regeneration	Riparian Regeneration Index	Immediate			
		Riparian Percent Exotics	Riparian NATIVES Index	Immediate			
	Floodplain Vegetation Condition	Floodplain Composition & Extent	Floodplain Cover Index	Immediate			
			Floodplain SLATS – using TM and ETM+ images	Pilot Study			
		Floodplain Recruitment & Regeneration	Floodplain Regeneration Index	Immediate			
		Floodplain Percent Exotics	Floodplain NATIVES Index	Immediate			

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Macroinvertebrate Assemblage Composition	Taxa richness	Pilot Study Existing Data			
			Modified SIGNAL Score				
			AUSRIVAS Scores				
		Fish Assemblage Diversity	% Native Species	Immediate Existing Data			
			% Exotic Individuals				
			Fish Assemblage O/E				
	Waterhole & Wetland Water Quality	Water Quality	Conductivity (salinity)	Immediate Existing Data			
			pH				
			Turbidity				
			Diel Range in dissolved oxygen				
			Diel range in water temperature				
			Nutrients (Total and available N and P)				
	Waterhole Process & Function	Ecosystem Processes	Benthic metabolism	Pilot Study			
			Algal Biomass & Composition				
			Carbon & Nitrogen Stable Isotope Analysis				

Theme	Attribute	Suggested Indicator	Types of measurement	Implementation	Region		
					HW	C&W	TW
Physical Form	Channel System Integrity	Channel System Integrity	Floodplain geomorphic complexity	R & D			
			Channel Complexity	Pilot Study			
			Within Waterhole complexity	Pilot study			
	Erosion Potential	Erosion Potential	Landscape Function Analysis	R & D			

4.9. Assessment Approach

Spatial Scale

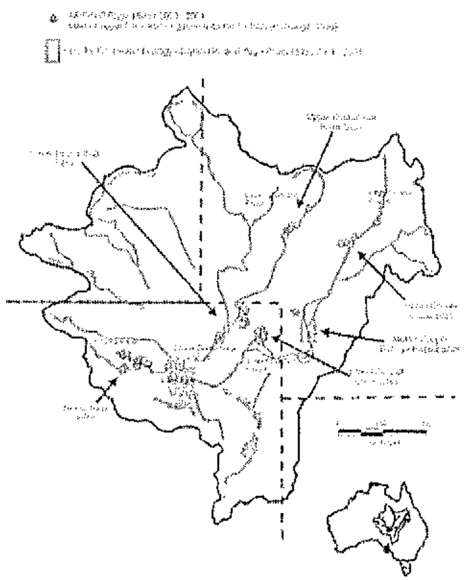
The suggested indicators can be sampled and collected at either a local scale (site based measurements), regional scale (multiple site measurements, regional surveys or remotely sensed data) or for the hydrological indicators at the catchment scale (see Table 4.2).

Local Scale Assessment

With assessment at the local scale both strategic and random sites should be used within the confines of budgets. Strategic sites will include Wetlands of National significance, Ramsar sites or other strategic conservation sites as well as established monitoring or research sites with existing data. Most measured ecological variables, however, will demonstrate considerable variation in space and time across many scales (Downes et al., 2002). To increase the power of any of the indicators to detect change over the large spatial scales evident within the Lake Eyre Basin it will be necessary to quantify the within location variability, as compared to the between location variability. To this end for both the Headwater zone and Channels & Waterhole zones random sample sites should be positioned around strategic sites, such that several sites will be sampled within specific locations at each sampling time (see Downes et al., 2002; Page 129).

The number of sites recommended in Table 4.2 will include both strategic and random sites. For example, the minimum of 20 recommended sites for the Headwater region may include 4 locations, with one strategic site in each location and 4 random sites. The minimum of 50 recommended sites for the Channels & Waterholes region may include 10 locations, with one strategic site in each location and 4 random sites. The positioning of random sites with strategic sites for the terminal wetlands will be difficult and thus a minimum of 10 terminal wetlands should be monitored across the LEB with location grouping where possible.

For indicators measured at the "local" scale a site-based assessment of health will be generated, the condition assessment will be relevant only at a regional scale and little catchment condition will be inferred unless a large number of sites were sampled.



Recommended position of sites for the river channels and waterholes zones of the Lake Eyre Basin.

Table 4.2 strategic sites that should be included in the local assessment. Strategically selected as well as randomly selected sites should be sampled.

Headwater Minimum of 20 sites Recommended	Rivers & Waterholes Minimum of 50 sites Recommended	Terminal Wetlands Minimum of 10 sites Recommended
QNRM Water Quality Monitoring sites for the upper Cooper Creek system o Aramac Creek, o Reedy Creek o Sandy Creek o upper Thomson River at 'Camoola Park' o upper Barcoo River at Blackall. There are no existing sites in the headwater regions of the Diamantina or Georgina Rivers and these would need to be established. Wetlands of International Importance in the region include a number of spring sites: Aramac Springs, Cauckingburra Springs, Doogmabulla Springs.	QNRM Water Quality Monitoring sites for the middle and lower reaches of Cooper Creek, and the Diamantina and Georgina Rivers (see Bailey, 2001). Wetlands of International Importance in the region: o Birdsville – Durrie Waterholes Aggregation (QLD023), o Cooper Creek Overflow Swamps – Windorah (QLD025), o Cooper Creek Overflow Swamps- Nappa Merrie (QLD026), o Cooper Creek-Wilson River Junction (QLD027), o Diamantina Lakes Area (QLD028), o Diamantina Overflow Swamp-Durrie Station (QLD029), o Georgina River King Creek Floodout (QLD030), o Mulligan River-Wheeler Creek Junction (QLD039). Long-term research sites within the region (see figure): o ARIDFLO o CRC for Freshwater Ecology Dryland River Refugia Project. o AUSRIVAS sites	Terminal Wetland sites should be distributed across the LEB and include terminal lakes in the Headwater Regions, such as Lake Galilee and Lake Buchanan. Other sites may include Lakes Frome and Blanche in South Australia as well as Lake Eyre. Other terminal wetland and lakes systems that should be considered include Lake Yamma Yamma in the Thomson River catchment, Lake Torquinie Area and Lake Phillipi in the Georgina River catchment.

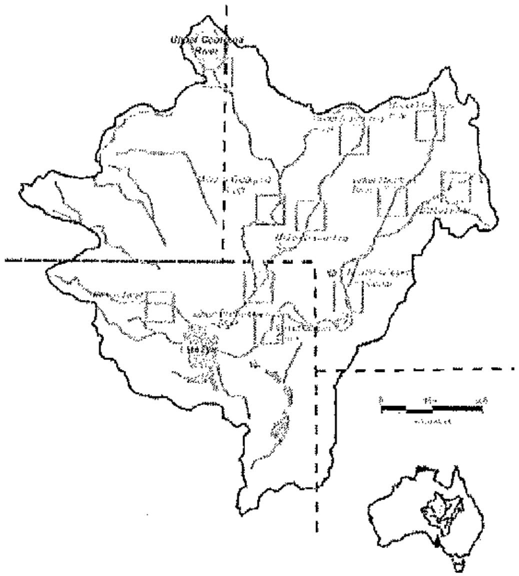
Headwaters: we recommend a minimum of at least 20 sites be established across the headwater zone of the Thompson, Barcoo, Georgina and Diamantina Rivers. These sites would ideally be distributed as five per catchment.

Channels & Waterholes: we recommend a minimum of at least 50 sites be established across this vast section of the Lake Eyre Basin. Sites should include the Cooper channel country and lower Cooper, Diamantina channel country and lower Diamantina and the western rivers including the Neales, a long-term sampling region for the ARIDFLO Project.

Terminal Wetlands: Terminal Wetlands and Lakes are distributed across the Lake Eyre Basin. We recommend a minimum of at least 10 terminal wetlands sites be established. These would include internally draining lakes such as Lake Galilee and Lake Buchanan in Queensland and Lakes Frome and Blanche in South Australia. Lake Eyre should be included as the terminus of the Lake Eyre Basin rivers system.

Regional Scale Assessment

Regional Scale Assessment has been recommended for the Physical Form indicators. These indicators are measured over larger distances and areas compared with many other indicators and will use remotely sensed data or large scale mapping. We have recommended at least eleven regions (or large scale reaches) for the assessment. These would include headwater regions in the Thomson, Barcoo, Diamantina and Georgina, middle and lower reaches of the Georgina and Diamantina River and Cooper Creek and at least one region on the western Neales River.



Recommended regions (or reaches) for undertaking regional assessment of some indicators within the Lake Eyre Basin.

Catchment Based Assessment
We have recommended Catchment Based assessment for the Flow Theme indicators. The nature of this data means it is collected at a catchment scale and allows reporting at the catchment level.

Summary of Spatial Approach
Overall we have recommended a "hybrid approach" for the assessment. This involves a network of locations within which groups of sites are nested. Sites within locations should include some strategic sites (sites with existing data or specific conservation significance) as well as randomly chosen sites. This will give a regional assessment of condition but will not provide detailed sub-catchment-based assessments. By having the locations and regions distributed across the Lake Eyre Basin, however, it will provide an assessment of Lake Eyre Basin condition.

If detailed sub-catchment assessments are required, then a larger number of sites than the recommended minimum, will be needed for each sub-catchment. The Sustainable Rivers Audit of the Murray-Darling Basin suggested between 18 and 30 sites per river valley (sub-catchment) were needed for various indicators to make a catchment assessment of condition. With the high degree of spatial and temporal variability in the Lake Eyre Basin, combined with the large number of sub-catchments, this would suggest a large number of sites are needed to undertake full sub-catchment assessments of the Lake Eyre Basin rivers. In conjunction with the network of strategic sites for site-based assessment we recommend a network of regions be assessed for landscape change and physical form indicators. 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 each sub-catchment from continued analysis of assessment data combined with Pilot Studies.

Temporal Scale

Frequency of Assessment
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 and can be divided into Seasonal Sampling and Events Based Sampling.

Seasonal Sampling
Seasonal sampling would reflect the spring and autumn sampling used in other assessment programs. It would be undertaken on a subset of permanent waterholes.

Events Based Sampling
Rainfall and flows in the headwater region are influenced by seasonal climatic conditions, including monsoonal phases and also by longer-term climatic fluctuations such as El Nino and La Nina cycles. The biotic response to each event will differ depending on the timing, magnitude and duration. Any assessment of trends in this region needs to consider the initial condition and variability associated with seasonal extremes.

Summary of Temporal Approach
Although there is a seasonal component to rainfall in the Lake Eyre Basin rivers and streams, and therefore flows and flooding in the channel and waterhole network there is also a distinct unpredictable pulse in rainfall and thereby channel filling and subsequent flooding. We recommend that assessment be undertaken seasonally in subset of permanent waterholes (seasonal sampling) and, in response to flow events and flooding (event based sampling), at a larger suite of sites including temporary waterholes. The aim of temporal sampling will be to detect the response to the flow event and follow the subsequent change over a short temporal sequence.

4.9.1. Summary of Spatial and Temporal Sampling

Table 4.2 Summary Table of Suggested Indicators within each Theme including the suggested number of sites or regions for sampling and the temporal frequency of sampling.

Theme	Attribute	Suggested Indicator	Suggested number of Sites or Regions	Suggested Sampling Approach	
				Spatial	Temporal
Flow & Flood	Water Use	Volume of Water Held in Storage[a]	6	Catchment	Bi-annual
		Percent of Flow Diverted	6	Catchment	Bi-annual
	Hydrological Variability	Flow Variability	3	Catchment	Bi-annual
	Flood Extent	Flood Extent	6	Catchment	Bi-annual
Riparian & Floodplain	Riparian & Floodplain Biodiversity	Riparian & Floodplain Biodiversity	70	Local – site based	Annual + post event
	Riparian Vegetation Condition	Riparian Composition & Extent	70	Local – site based	Annual + post event
		Riparian Recruitment & Regeneration	70	Local – site based	Annual + post event
		Riparian Percent Exotics	70	Local – site based	Annual + post event
	Floodplain[16] Vegetation Condition	Floodplain Composition & Extent	70	Local – site based	Annual + post event
		Floodplain Recruitment & Regeneration	70	Local – site based	Annual + post event
		Floodplain Percent Exotics	70	Local – site based	Annual + post event
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Macroinvertebrate Assemblage Diversity	80	Local – site based	Autumn, Spring+ post event
		Fish Assemblage Diversity	80	Local – site based	Autumn, Spring+ post event
	Waterhole & Wetland Water Quality	Water Quality	80	Local – site based	Autumn, Spring+ post event
	Waterhole Processes & Function	Ecosystem Processes	50	Local – site based	Autumn, Spring+ post event
Physical Form	Channel System Integrity	Channel System Integrity	11	Regional	Five Years
	Erosion Potential	Landscape Function Analysis	11	Regional	Bi-annual

[16] In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.

4.9.2. Summary of Indicator Costing

Table 4.3 Summary Table of Suggested Indicators within each Theme including the suggested number of sites or regions for sampling and the estimated cost of sampling at a given spatial scale and temporal frequency. Costings are "at the site" and do not include travel from office locations. Costings have been based on. Those outlined by the QLD Department of Natural Resources and Mines (www.nrm.gov.au/monitoring/indicators/river/attachmenta.html).

Theme	Attribute	Suggested Indicator	No of Sites, Regions	Cost per Site	Frequency – per year
Flow & Flood	Water Use	Volume of Water Held in Storage	6	TBD[17]	0.5
		Percent of Flow Diverted	6		0.5
	Hydrological Variability	Flow Variability	3		0.5
	Flood Extent	Flood Extent	6		3
Riparian & Floodplain	Riparian & Floodplain Biodiversity	Riparian & Floodplain Biodiversity	70	$800[18]	1
	Riparian Vegetation Condition	Riparian Composition & Extent	70	$800	3
		Riparian Recruitment & Regeneration			
		Riparian Percent Exotics			
	Floodplain[19] Vegetation Condition	Floodplain Composition & Extent	70	$800	3
		Floodplain Recruitment & Regeneration			
		Floodplain Percent Exotics			
Waterholes & Wetlands	Waterhole & Wetland Biodiversity	Macroinvertebrate Assemblage Diversity	80	$1000	3
		Fish Assemblage Diversity	80	$2000	3
	Waterhole & Wetland Water Quality	Water Quality	80	$300	3
	Waterhole Processes & Function	Ecosystem Processes	50	$500	3
Physical Form	Channel System Integrity	Channel System Integrity	11	TBD[20]	0.5
	Erosion Potential	Landscape Function Analysis (LFA)	11	$800	0.5

[17] Indicators in this group involve the use of Landsat imagery and costs will need to be determined (TBD) after a Pilot Study phase and the final form of the imagery is decided.
[18] This costing does NOT include waterbird surveys, which would be undertaken at a regional scale and will need to be costed separately.
[19] In the headwater region, where true floodplains do not exist, these measures would be undertaken on catchment vegetation.
[20] Again, this potentially involves the use of remotely sensed data and large scale mapping techniques. The costing would need to be reviewed when the final form of the indicator is decided.

4.10. Coping with High Levels of Natural Variability

4.10.1. Placing the Assessment Data on the Trajectory of Natural Change

See also Section 4.3

One of the biggest challenges in interpreting the data collected on these indicators for rivers and streams in the Lake Eyre Basin is to understand the large spatial and temporal variations in natural "condition". This large-scale variation means that at any one point in time, reflecting natural variations in flooding and rainfall, some rivers and river reaches are likely to naturally be in "good" condition while others will naturally be in "poor" condition. Knowing where a site is on a natural trajectory between "good" and "poor" condition will increase the power of the indicator to assess the health of the site in relation to anthropogenic impacts and prevent misinterpretation.

If the score, or output, of an indicator is recognised to vary in response to natural large scale fluctuations in hydrology then not only can the change in indicator associated with anthropogenic disturbance be measured but also the ability of the system to respond after the drying disturbance (resilience).

Temporal changes and resilience can be built into the use of many of the ecosystem health indicators suggested in the following way; sites that have only recently become disconnected after connecting flows or floods should present as healthy, with increasing time since flood or connection there will be a decline in the indicator score. This decline could be interpreted as a decline in the "condition" or health of the waterbody. However, If the indicator bars are modified so that a decline in condition with time since last flood or rainfall is expected, even in waterbodies in excellent condition, then the interpretation of "healthy" or "unhealthy" for a given waterbody will be more robust. Under this modified scenario a site in poor condition would fail to respond or appear healthy even immediatey after flooding or rainfall.

In highly variable rivers, like those of the Lake Eyre Basin, the spatial variability in condition at any one point in time will be enormous and may well require relationships between condition and flooding history to be developed for a number of sites or regions across the basin. We therefore recommend that these trajectories of change will need to be established for the indicators suggested, either through a Pilot Study phase, or by adaptive management and reinterpretation during the first phase of assessment.

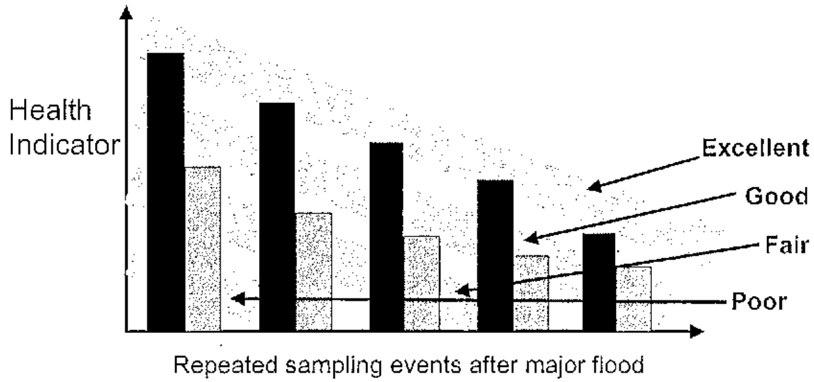


Figure The modified positioning of health indicator bars, such that a relationship between health and time since last flood is recognised: dark bars = site in "good" condition, light bars = site in "poor" condition. Modified from the Grazing Gradient Approach (Pickup & Chewings, (1994).

4.11. Combining Indicators into a River Health Index

The methodology for reporting the final outcome of river health assessment varies between programs. The Index of Stream Condition (ISC) and the Murray-Darling Basin Commission Sustainable Rivers Audit (SRA) provide a method for aggregating indicator values into an overall Index.

The Single Index Approach

The Sustainable Rivers Audit (MDBC, 2004a) uses an approach of "expert rules" for combining indicators in the recommended fish, macroinvertebrate and hydrology themes. The SRA describes the development of the expert rule system as "taking a set of *rules* specified by one or more *experts* and creating a decision surface". The decision surface provides a single curve that represents the 'expert' interpretation of the values of all the indicators.

The Index of Stream Condition (ISC: White & Ladson, 1999) measures key indicators within a number of categories. These indicators are then combined to form a sub-index, which is then further aggregated to form the overall ISC Score. To convert the indicator values to a dimensionless 'rating' a scale of 0-4 is used with each rating value responding to a different band value of the indicator. The overall ISC Score varies between 0 and 50.

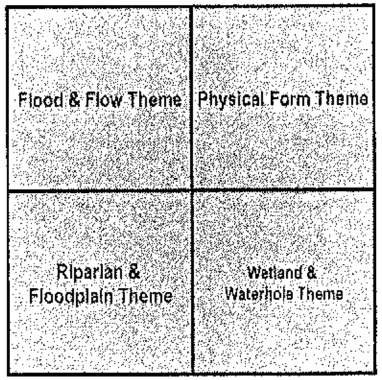
Multi-Indicator Approach

The Ecological Health Monitoring Program (EHMP) for South East Queensland uses a multi-indicator approach (Smith & Storey, 2001). Values for each of the five indicators used in the EHMP are presented as a pentagon, with each facet of the pentagon relating to one of the five indicators. Where indicators are comprised of a number of indices then the minimum value is reported within the indicator. The facets of the pentagon are coloured from red to green to depict impacted to healthy sites.

An Approach for the LEB Rivers

Given the high spatial and temporal variability in natural condition at the site scale in the Lake Eyre Basin it would be meaningless to aggregate the data into a single Indicator Score. Particularly given the trajectory approach (see above) for interpreting indicator values in line with changing natural condition. At any one site different indicators will be on different trajectories of change; for example many of the riparian vegetation indicators will not change in line with short term flow changes, whereas water quality and biodiversity indicators will.

We therefore recommend keeping the values for each of the recommended indicator Themes separate, as used in the EHMP. For each indicator theme the trajectory adjusted minimum value should be used to report the condition of that indicator.

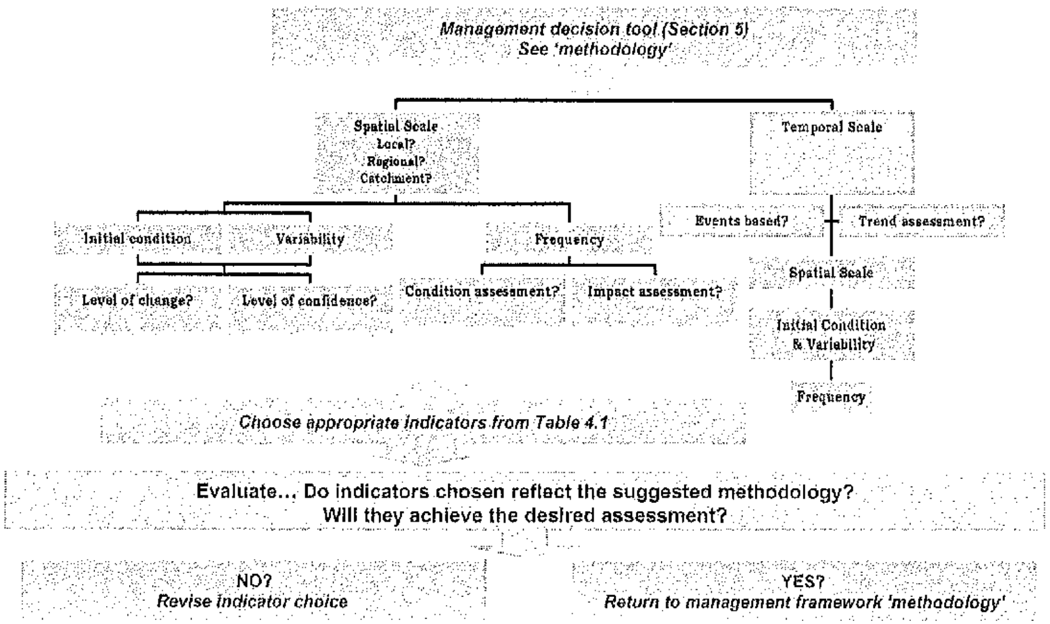


Example of four theme reporting graphic that could be used for site and reach health assessment in the Lake Eyre Basin.

4.12. Choosing Indicators for Assessment

We have suggested a number of key indicators built within four major themes for assessing the health of rivers, streams and wetlands of the Lake Eyre Basin. We have outlined a methodology (spatial and temporal) for their measurement and suggested a reporting framework. However, the final form of the assessment program, will need to be further developed in consultation with both the Lake Eyre Basin community, relevant management authorities and research agencies. We have aligned the suggested indicators with both the community identified values and threats to the Lake Eyre Basin and the Conceptual Models developed as part of this project.

Decision tool for choice of indicators in methodology



Decision tool that can be used to select and refine the indicators to be measured in the final assessment methodology.

5. Management Framework

We have recommended a set of proposed indicators for assessing the health of Lake Eyre Basin rivers (Table 4.1). A subset of these are recommended as "able to be implemented immediately", based on the availability of existing data and the development of methods for measurement – see *assessment approach* given for each watercourse classification (HW, RC & WH and TW) and Table 4.1.

Beyond this recommended indicators a process is outlined below, that provides a decision support mechanism for progressing with the assessment of health in the Lake Eyre Basin Rivers.

5.1. Framework for the Assessment

The assessment needs to have a management framework. One of the key next steps in the process is to establish a mechanism by which the Lake Eyer Basin assessment can be coordinated and implemented. This could be done through a management group comprising the relevant State agencies (Queensland, South Australia, Northern Territory as well as the Federal Government) that will allow cross-state planning and coordination or by sub-contracting the task to a single research organization or group.

In its initial stages the assessment needs to be driven from a central location, after successful implementation it may be possible to distribute assessment to regional groups, but this will only be successful after the basic process has been established and tested.

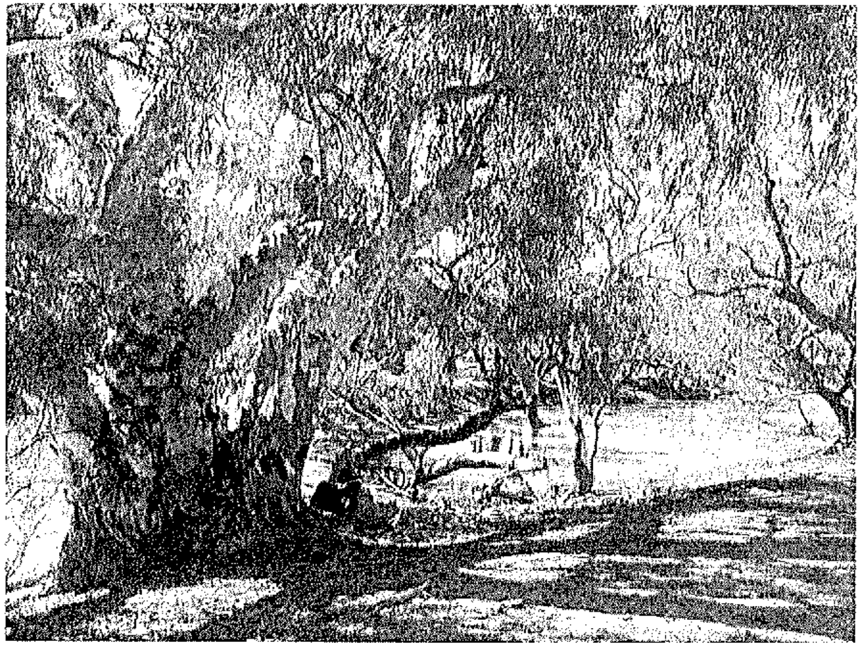


Photo by Steve Hamilton

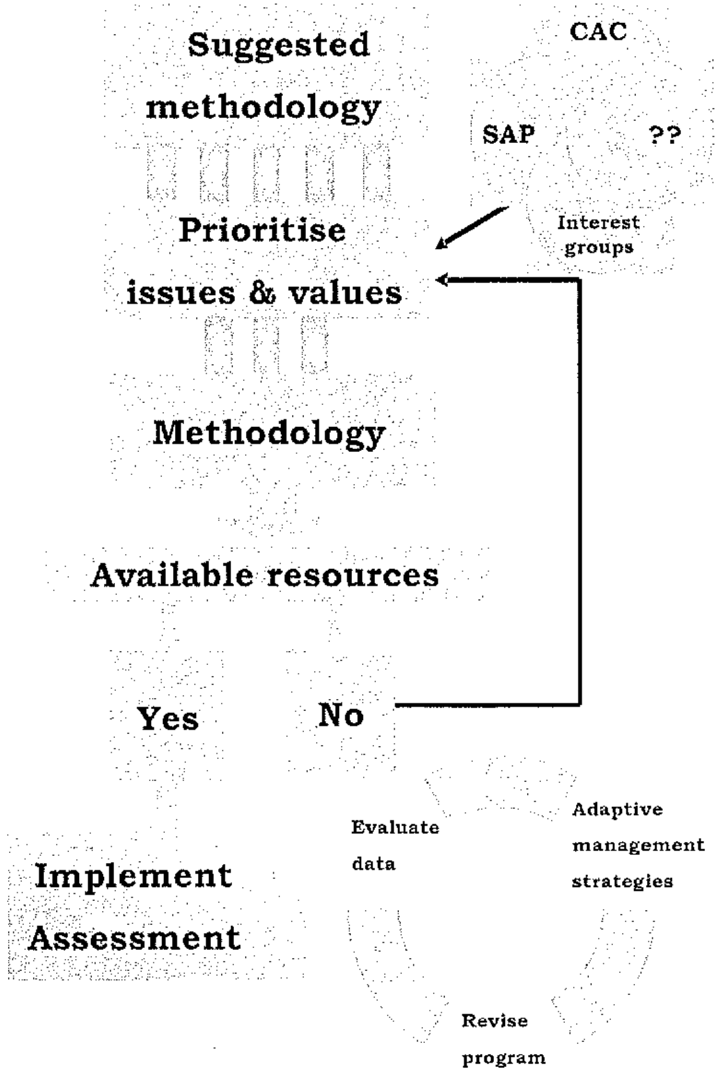
Cooper Creek Waterhole,

5.2. Decision tool (opposite)

We have identified three distinct overarching areas within the management framework, these are:

Administration structure & feedback
Scientific feedback and development structure
Data Management elements

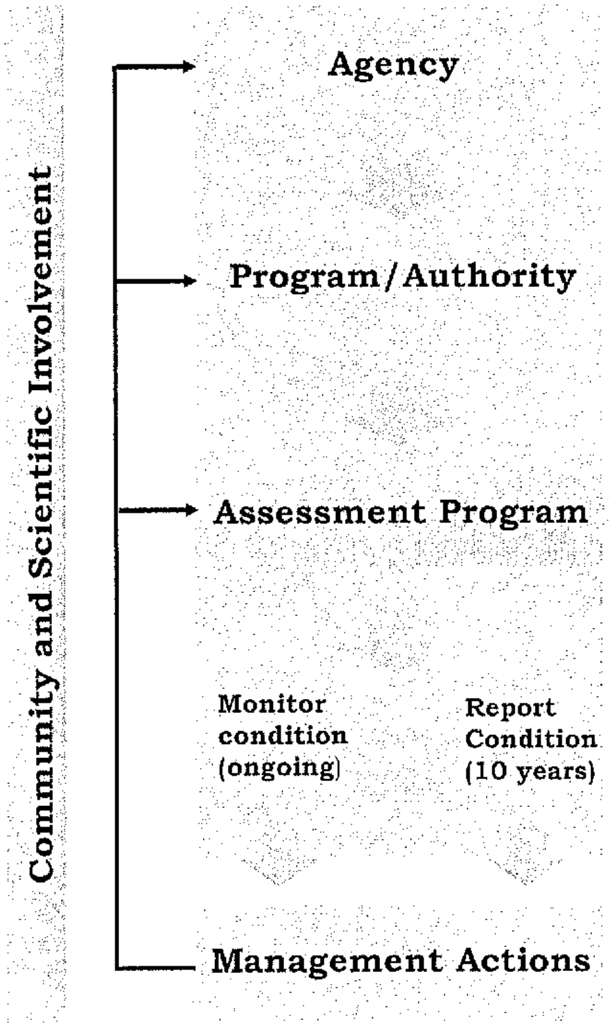
A description of these sections of the framework follows.



5.3. Administrative Structure (opposite)

The administration of the assessment will be clearly linked to the approach adopted (regional, catchment or basin-wide) and identify those responsible for implementation, evaluation and reporting. This structure will report river health to managers and the wider community. Provide guidance to regional committees about river health assessment monitoring based on setting targets that reflect community values and recognise identified management issues and inform policy development.

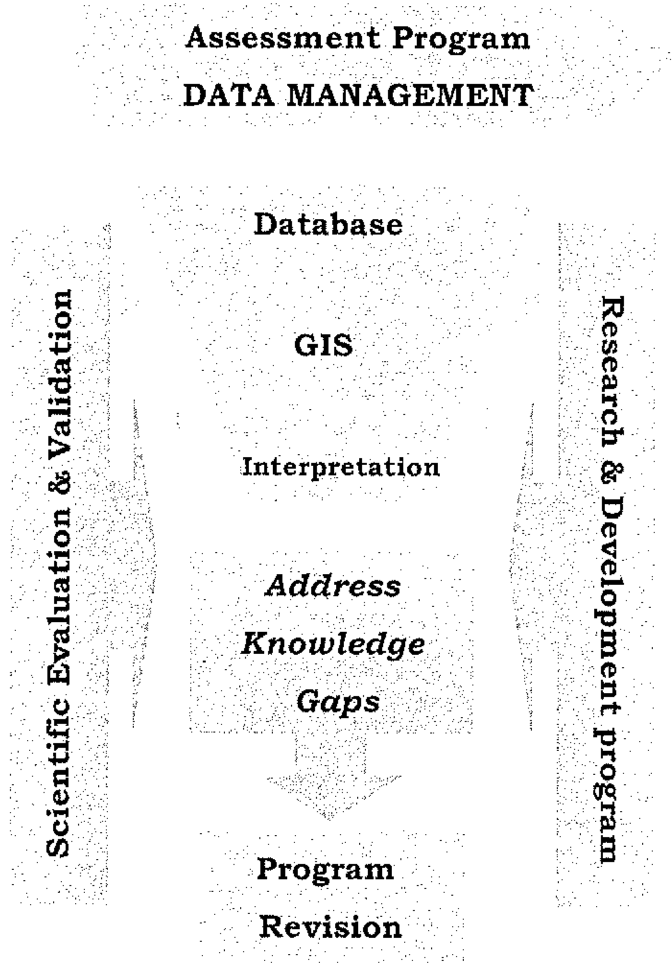
We have identified that there needs to be a central "Agency" or "group" for undertaking the overall coordination of the assessment, this central Agency could be an independent Commission such as the Murray-Darling Basin Commission, an office within Environment Australia, or a sub-contracted research or consultancy group. The Agency would delegate the task of the actual assessment to a designated Program or Authority. This Authority could operate at the Basin-wide level in a manner such as the Murray-Darling Basin Commission, could be a conglomerate of State Government Departments (building on existing structures) or regional bodies such as Desert Channels Queensland and the Arid Areas Water Resource Board.



5.4. Scientific feedback and development structure (diagram opposite)

The Lake Eyre Basin Rivers Assessment involves collecting data for the chosen indicators. The variable nature of the rivers of the Lake Eyre Basin means that for each iteration of the rivers assessment both new data and existing data will need to be used. Long-term trend analysis of the existing data may feed back into the Administrative Structure. Scientific tasks have been identified for the implementation of the suggested methodology including:

- Validation of data that will provide baseline information for a pilot program that assesses the proposed indicators (see also Database section).
- Undertaking power analyses to validate the usefulness of indicators for detecting impact.
- Final identification of location networks and regions for trend and assessment monitoring of waterbodies and wetlands.
- Trial of indicators (spatial variability only)
- Development of temporal and events based monitoring and sampling program at location and regional scales.
- Parallel research to address knowledge gaps in riverine ecosystem function within the wider landscape and within unique waterbodies.



5.5. Data Management elements (opposite)

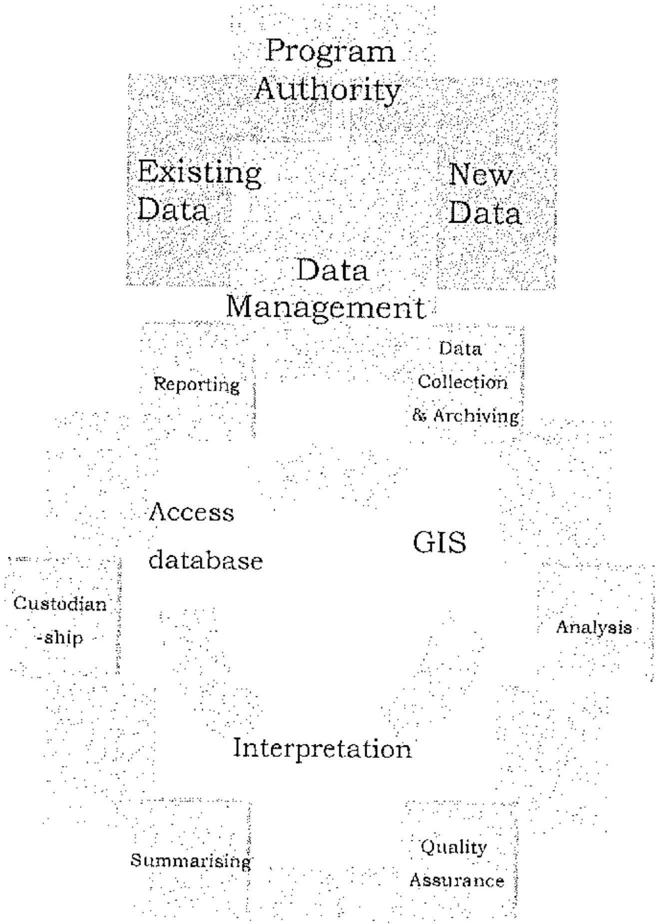
It is suggested that data management elements will largely be under the jurisdiction of the program authority that undertakes the assessment of condition including data interpretation, trend analysis and reporting. There are numerous models suitable for the suggested methods and the following elements are a sub-set of those included in standard operational frameworks and database management systems

- Data policy
- Data ownership
- Data documentation and metadata compilation
- Data quality, standardization, harmonization and audit
- Data lifecycle control
- Data custodianship

5.5.1. Database structure and use

A database management system, or DBMS, will need to be established for the assessment. A DBMS gives users access to data and helps them transform the data into information. Examples of database management systems include Microsoft Access, dBase, Paradox, IMS, and Oracle. These systems allow users to create, update, and extract information from a databases. Compared to a manual filing system, the biggest advantages to a computerized database system are speed, accuracy, and accessibility.

A database is a structured collection of data. Data refers to the characteristics of people, things, and events. A database stores each data item in its own *field*. The name of a field usually reflects its contents. Each DBMS has its own rules for naming the data fields. Each record is made up of a number of fields. No two fields in a record can have the same field name.



5.5.2. Relational Databases

Sometimes all the information of interest can be stored in one table. However, more often databases comprise different tables (eg. Water quality data, production data, macroinvertebrate data, physical habitat data) and the data in these multiple tables needs to be linked. This is a key feature of a relational database management system, or RDBMS. They store data in two or more tables and enable you to define relationships between the tables. The link between the tables is based on one or more field values common to both tables.

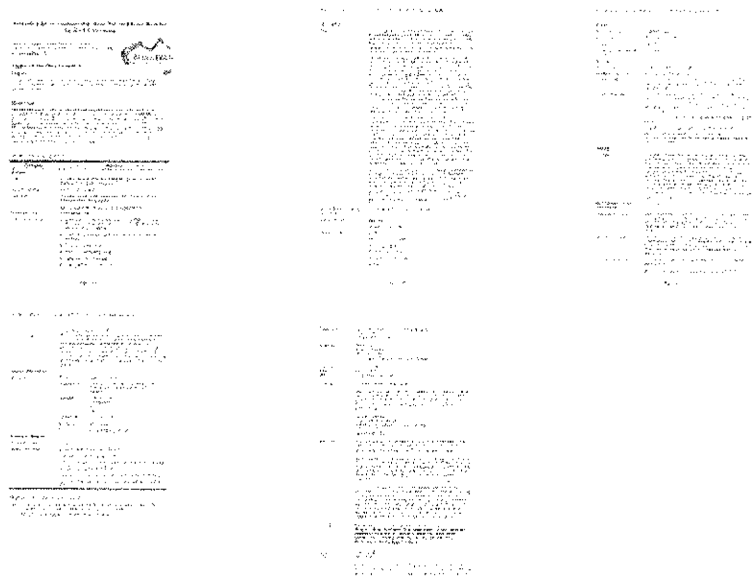
We recommend the establishment of a relational database for the LEB assessment. Such as relational database could be constructed in Oracle® or Microsoft® ACCESS. ACCESS is the database used for much of the MRH data across Australia, with Oracle used by the New South Wales and South Australian programs. Both database systems have advantages and disadvantages and the final choice of software should be made after finalizing the managing Agency or Authority for the assessment.

To ensure completeness of all field data in the database, all samples and information collected at a field site should be entered into a field master form within the database. Each site should have a unique sitecode and this should form the relational basis of all the tables in the database. As in the NSW MRHI (Waddell, 2000) electronic data entry forms should be generated to mimic the layout of the field and laboratory datasheets to minimize potential errors. Other aspects of the NSW MRHI database that would be minimize database errors include:

- Built-in range checks to highlight unusual or incorrect values for given variables
- Double-checking of entered data (electronic comparison with field sheets) by different operator
- Random checking of field measurements each collection period.

5.5.3. Metadata template

Once the relational database has been established a Metadata file or document will need to be generated. Metadata is Data about data. A dataset description that explains a spatial dataset (i.e. a metadata record). Dataset metadata can be searched through a common web interface known as the Australian Spatial Data Directory (ASDD). More information can be found at:
http://www.anzlic.org.au/infrastructure_metadata.html



Example Metadata Template for the Australian River Assessment System (AusRivAS). (Gray, 2004)

5.6. Quality Control Issues

Quality Control (QC) and Quality Assurance (QA) procedures will need to be built into the LEB Assessment. All of the State based National River Health Programs have QC/QA procedures (see Waddell, 2000) and all State government departments have Water Monitoring Data Collection Standards (see http://www.nrm.qld.gov.au/water/monitoring/pdf/wm_data_col_stds.pdf). The form of the QA/QC for the LEB Assessment will depending on the final structure of the assessment team. If the assessment is undertaken by an independent body (consultancy firm or research organization) then comprehensive QA/QC procedures will need to be established for all aspects of the assessment. If the assessment is undertaken via a collaboration of existing State government authorities existing QA/QC procedures within each respective State department could be used as a starting point for a generic QA/QC for the LEB assessment.

QA/QC procedures will need to be established for (after Waddell, 2000):

- Field Measurements
- Data handling and storage
- Sample identification
- Laboratory Analysis
- Data Screening

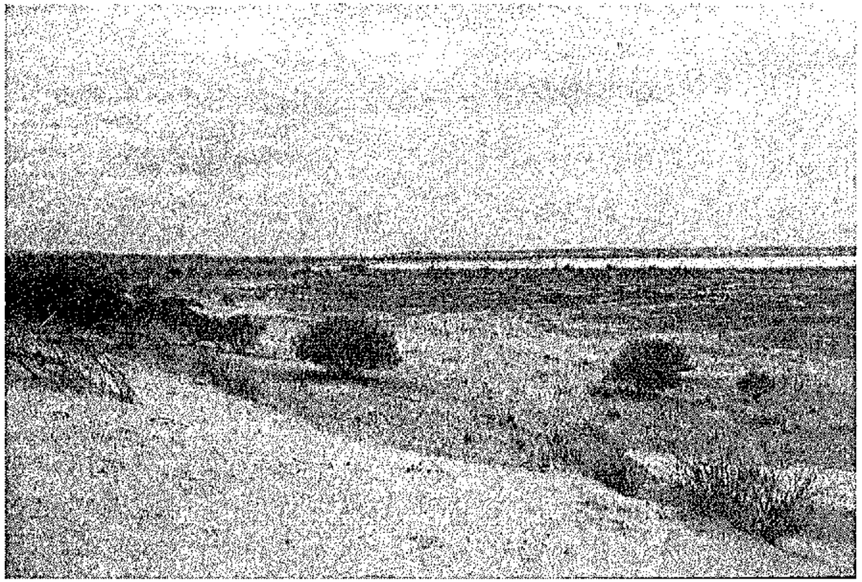


Photo by Fran Sheldon

Lake Maroopootanie, Coongie Lakes system, Cooper Creek

6. Recommendations

Recommendation 1: That a detailed Administrative Structure be established for undertaking any assessment of the Lake Eyre Basin rivers. This structure would need to be established by the Lake Eyre Basin Ministerial Council and be mindful of the funding arrangement for the Assessment.

Recommendation 2: That Pilot Studies, using either existing data or data collected on Pilot reaches, be implemented immediately to further explore the feasibility and power of each suggested indicator for assessing the health of the Lake Eyre Basin rivers and detected possible human impact.

Recommendation 3: That a project be implemented to further explore the use of the trajectory approach for assessing health using the suggested indicators. This project could be implemented using existing datasets.

Recommendation 4: That the Lake Eyre Basin management agencies combine with the Murray-Darling Basin Commission to fund joint research and development of the use of remotely sensed data for measuring a number of the indicators suggested. Techniques are available but they need testing and validating before implantation in assessment. As both the MDB and the LEB have similarities (mostly semi-arid to arid catchments, rivers of high flow variability) a joint project would benefit both the Sustainable Rivers Audit and the Lake Eyre Basin Assessment Program

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