Framework for prioritising waterways for management in Western Australia

Centre of Excellence in Natural Resource Management
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Front cover credit: Bremer River, Eastern South Coast bioregion in May 2006, looking downstream by Geraldine Janicke.

Disclaimer

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Summary

Background

Based on an asset-threat management approach, and taking into account state and national developments in waterway prioritisation, the Centre of Excellence in Natural Resource Management at the University of Western Australia on behalf of the Department of Water has developed a framework for prioritising waterways for management in Western Australia.

The framework provides a consistent and transparent approach to setting priorities for management. It ranks waterways in terms of their ecological, social and economic values and also according to their level of threat, and based on these rankings, classifies these waterways into broad categories. Appropriate management responses for each of these categories are proposed.

The framework can be used at scales ranging from whole catchments down to individual reaches of a waterway. It can be used in situations where data is limited or plentiful, and of both a qualitative or quantitative nature. It also recognises that some natural resource management regions already have processes for prioritising waterways for management, and is thus designed to incorporate and complement all previous and present waterway prioritisation and assessment initiatives undertaken by government agencies and regional bodies in Western Australia.

The assessment process

The assessment approach is based on a framework of values, criteria, indicators and measures. Three broad categories of values are proposed – ecological, social (including cultural) and economic. For each of these values, a number of criteria are defined. For example, ecological value is determined using the criteria of naturalness, representativeness, diversity, rarity and special features. For each of these criteria, a number of indicators are proposed, and for each indicator, a number of possible measures are suggested. All waterway units in an assessment are scored for each indicator and measure on a scale of 1 to 3, where a higher rating represents a greater contribution to the value of that waterway unit. Indicators with more than one measure are scored by taking the mean value of these measures. For each criterion, the indicator scores are added together to derive a total score for that criterion, and scores are then standardised by scaling to 100 or 1.0. The assessment process would proceed as follows:

- Identify the purpose of the assessment.
- Select an appropriate scale (choosing the size of the waterway units to be assessed, such as catchment, subcatchment or reach).
- Identify the values of the waterway units, and the criteria, indicators and measures to be used to assess them.
- Identify the threats to the waterway units and the indicators and measures to be used to assess them.

- Rank the waterway units according to their values and threats.
- Place the waterway units on a ‘values–threats’ prioritisation matrix and use their position on this to assign priorities.
- Identify the appropriate management responses.

The framework includes 10 threatening processes. These are:

- riparian zone degradation
- erosion and sedimentation
- eutrophication and deoxygenation
- inappropriate fire regimes
- pollution
- introduced animal and plant species
- salinisation and waterlogging
- acidification
- flow alteration
- In-stream habitat destruction and fragmentation.

A number of possible indicators and measures are proposed for each of these processes. The level of threat to waterway units is assessed by rating each threatening process on a scale of 1 to 3, where a rating of 3 represents a high level of threat, and a rating of 1 indicates a low level of threat.

Value scores are located against threat scores on the values–threats prioritisation matrix for each waterway unit (Figure 1). Values and threatening processes are classified as being ‘high’, ‘medium’ or ‘low’, resulting in nine possible categories in the matrix. Three of these categories were classified as requiring ‘Priority 1’ responses, two categories were classified as requiring Priority 2 responses, and the remaining four categories were classified as requiring Priority 3 management responses.

Threatening processes	Values: High	Values: Medium	Values: Low
High	High value, high threat (HV/HT) Priority 1	Medium value, high threat (MV/HT) Priority 2	Low value, high threat (LV/HT) Priority 3
Medium	High value, medium threat (HV/MT) Priority 1	Medium value, medium threat (MV/MT) Priority 2	Low value, medium threat (LV/MT) Priority 3
Low	High value, low threat (HV/LT) Priority 1	Medium value, low threat (MV/LT) Priority 3	Low value, low threat (LV/LT) Priority 3

Figure 1 Values–threats prioritisation matrix

Once priorities have been assigned to each waterway unit, the appropriate management response can be chosen. The framework proposes a choice of seven general management responses. Table 1 lists the responses appropriate to each combination of value and threat, and Table 2 gives the goals of these responses and a brief description of them.

Table 1 Generalised management responses for value–threat combinations

Primary priority level	Sub-priority level		Main management responses
1	1a	HV/HT	Secure, stabilise, restore
1	1b	HV/MT	Secure, maintain, restore
1	1c	HV/LT	Monitor, secure, maintain
2	2a	MV/HT	Stabilise, contain, restore
2	2b	MV/MT	Contain
3	3a	MV/LT	Stabilise, restore
3	3b	LV/HT	Stabilise, contain, adapt
3	3c	LV/MT	Contain, adapt
3	3d	LV/LT	Adapt

HV = high value, MV = medium value, LV = low value

HT = high threat, MT = medium threat, LT = low threat

Table 2 Goals and descriptions of management responses

Goal	Management response	
To fully protect waterways values	Secure	of such importance that action is needed to fully protect environmental, social and economic values
	Maintain	prevent deleterious alteration to existing waterway condition, practices and standards
To improve waterway health	Restore	reinstate specific values, conditions, standards or practices
To manage degradation	Stabilise	halt degradation processes
	Contain	limit degradation processes
To manage function	Adapt	accept that the waterway is highly degraded, identify the functions still operational and manage those functions
To identify possible future threats	Monitor	conduct regular assessments of water quality and riparian condition to identify emerging threats if and when they arise

Case studies

Four trials at different scales and with different quality data were carried out to assess the effectiveness of the framework over the range of situations it was intended to handle.

The four case studies were:

- a subcatchment scale trial of the Fortescue River in the Pilbara Region using secondary data from desktop sources available from the Internet and published documents (this considered ecological, social and economic values)
- at a catchment scale, an ecological assessment of the major waterways in the South Coast region using high-quality primary data (this only considered ecological values)
- at a catchment scale, an assessment of the Berkeley River in the north-east Kimberley exploring the potential for assessment where only minimal data was available (this considered ecological, social and economic values)
- a reach scale assessment of the Marbellup Brook involving high-quality primary ecological and social data (this also considered ecological, social and economic values).

The trials showed that the framework was able to be used successfully in all the situations for which it was intended.

1 Introduction

1.1 Background

The Department of Water has determined that there is insufficient data on water quality and riparian vegetation condition to make comprehensive, objective assessments of waterway health in Western Australia. Waterways are defined in this report as rivers (including creeks, brooks and streams) and their floodplains, estuaries, inlets, coastal lagoons, reservoirs and broad, flat and undefined systems that flow intermittently. Waterways may also include wetland systems that overflow into rivers (Department of Water 2008a). In many parts of the state, a comprehensive assessment of the values and condition of, and threats to, waterway ecosystems has not been undertaken (Department of Water 2004), although for some parts of the state, the *State-wide waterways needs assessment* has been trialled (Water and Rivers Commission 2002). Most information and management is centred on the South West land division and there is comparatively little knowledge of waterway systems in the remainder of the state. Even in parts of the South West there may be no data or only limited or inconsistent data.

Many regional natural resource management groups in Western Australia initiated Natural Heritage Trust and National Action Plan for Salinity and Water Quality projects which contain elements of mapping, classifying, evaluating or prioritising of waterways. For example, the South West Catchment Council, recognising the lack of a clear direction for research, monitoring and evaluation activities and restoration work in its region, funded the development of a draft framework for the evaluation and prioritisation of waterway assets in the South West region in 2005. South Coast Natural Resource Management Inc. also invested in similar projects. One of these projects is seeking to determine ecological values of waterways in the region, another prioritised waterways as part of a water resources regional planning exercise. Consequently, the Department of Water requested the development of a state-wide framework to ensure that there are comparable methodologies for the evaluation and prioritisation of waterways, to assist with projects being undertaken by these regional natural resource management (NRM) organisations.

Signatories to the National Water Initiative, including Western Australia, have committed to 'identify and acknowledge surface and groundwater systems of high conservation value, and manage these systems to protect and enhance those values'. In the case of Western Australia, identification of 'high conservation value aquatic ecosystems' falls into three broad categories: (i) wetlands, (ii) waterways, and (iii) threatened species. Presently, waterways are ranked as either 'high', 'medium' or 'low' for value, condition and pressures using the *State-wide waterways needs assessment: prioritising action for waterways management in Western Australia* (Water and Rivers Commission 2002) and the state assets report, *Agency statement of important natural resource management assets in Western Australia* (CONRACE 2006).

National frameworks are also in the early development stages. Although progress has been made on the development of guidelines for prioritising Australian waterways for protection (Bennett et al. 2002; Dunn 2000; Phillips *et al.* 2001), there is, as yet, no nationally agreed method for prioritising waterways. Bennett et al. (2002) did not advocate a 'single national method' because they recognised that political and technical constraints would make this endeavour very challenging – instead, they developed a framework that may be adapted to a variety of contexts. Identification, categorisation and criteria frameworks for Ramsar wetlands, the *Directory of important wetlands in Australia* (Environment Australia 2001), and assessment for National Heritage List nominations provide the only consistent frameworks for identification of high conservation value aquatic ecosystems across all states.

Recognising the need for a national approach, the Australian, state and territory governments are collaboratively developing draft guidelines for the identification and conservation management of high conservation value aquatic ecosystems. These guidelines are being developed by the national Aquatic Ecosystem Task Group. Six core biophysical criteria have been agreed upon as being appropriate for identifying high conservation value aquatic ecosystems and draft guidelines have been developed for applying the criteria. The core biophysical criteria are representativeness, diversity, distinctiveness (rarity), vital habitats, evolutionary history and naturalness. They have much in common with the determination of ecological values in the framework developed in this report. However, the national approach adopted for identifying high conservation value aquatic ecosystems does not take into account social and economic values.

Another national initiative that is presently being developed is the *Framework for assessment of river and wetland health* (FARWH) (National Water Commission 2007). This has been developed through consultation with state and territory jurisdictions, and is presently being trialled across Australia, including in Western Australia. The aim of FARWH is to provide assessments of the aggregate effects of resource use on rivers and wetlands as the basis for reporting on waterway condition at a national scale using the results of comparable state and territory-based assessments. It differs from the framework presented here in that it only considers ecological condition. However, indices used to assess waterway condition in FARWH may also be used in the present framework, as these indices could be used to score the 'naturalness' component of the ecological value of waterways.

The waterways framework described in this report is based on the *Catchment-based waterways management framework for Western Australia: classifying and evaluating waterways and prioritising management actions* (Department of Water 2004). It is also based on the matrix developed as part of the *Salinity investment framework (SIF) interim report – phase 1* (Department of Environment 2003) to prioritise investment. In the SIF model, assets were assessed in the values–threat matrix. The nine cells in the matrix were then grouped into management action tiers. The waterways framework process differs from the process in SIF in that all three high value categories are classed as equivalent to Tier 1, whereas in the SIF, only high value, high threat waterways are classed as equivalent to Tier 1 (Department of

Environment 2003). This adaptation has been suggested to ensure that there is a focus on maintaining high value waterways, before attention is given to managing medium or low value waterways.

This document presents a flexible state-wide framework that allows assessment of waterway attributes (values and threats) when comprehensive or adequate data are not available – where there is greater reliance on subjective rather than objective data. Such a prioritisation framework provides the evidence-based analysis called for by Pannell (2008) and Pannell and Roberts (2008) when considering investment in natural resource management. These authors have identified the need for more rigorous prioritisation of assets rather than relying on 'best judgement'. The report *Investment framework for environmental resources* (Pannell & Roberts 2008) has as one of its initial steps, the identification and characterisation of assets and the assessment of levels of threats.

1.2 Objectives of the framework

This framework describes a logical, consistent and transparent process that may be followed to enable the:

- rating or ranking of the ecological, social and economic values of waterways
- rating or ranking of the level of threats to waterways
- classification of waterways into broad categories based on the ranked values and threats
- classification of waterways into priority groups
- identification of options for management response.

1.3 Approach adopted for the framework

The approach used in developing this waterways assessment framework was to build on previous and current investments and expertise, to take into account the lack of comprehensive data for many systems, and meet the need to work at different scales. It was decided that the framework should:

- incorporate and complement all previous and present waterway prioritisation and assessment initiatives undertaken by government agencies and regional bodies in Western Australia
- be consistent with national developments in waterway prioritisation and assessment, yet recognise the need for modifying these approaches to accommodate the wide variety of Western Australian conditions
- support the asset–threat management approach adopted by the state
- be able to apply the framework at a variety of scales, including at the waterway reach, subcatchment and catchment levels
- be flexible so it may be applied when only limited quantitative and/or qualitative data is available.

1.4 Limitations

The framework is an effective, unbiased management tool for prioritising waterways. However, there are limitations, most of which are related to data availability. As a general rule, the more data used in an analysis, the more reliable will be the results. It has been assumed that most users of this framework will not be collecting data about waterways themselves, most will rely on existing data sources. The framework suggests the use of ecological, social and economic data to ensure that the analysis takes into account all the values that a waterway may have, but there are sometimes challenges in obtaining reliable spatial and temporal data. Quantitative data is lacking for many parts of Western Australia, therefore subjective and categorical data often need to be used. This is particularly the case for waterways in remote regions of the state. In spite of this, trials showed that the framework operates effectively at different scales using a variety of data types. The trials also confirmed that the framework may be used by anyone with a moderate level of scientific expertise.

The framework is intended to be a practical decision-making tool that is periodically updated following evaluation. Consequently, the methodological approach used in it will be developed and refined further as findings from real-world use are reported.

1.5 Structure of the report

The report contains six sections.

Section 1 provides the context to the development of the framework. It describes the objectives of the project and the principles adopted in developing the framework.

Section 2 explains the steps involved in using the framework.

Section 3 lists the waterway values used in the assessment process, and provides indicators and measures for each of these.

Section 4 lists the possible threats to waterways values, and provides indicators to enable quantification of these threats.

Section 5 provides descriptions of the case studies conducted to evaluate the framework methodology.

Section 6 gives general comments and conclusions arising from this project.

Appendix A provides a list of useful contact organisations.

Appendix B lists recommended GIS datasets and some additional sources of information.

2 Elements of the framework

The assessment framework uses the following seven-stage process described in Figure 2. This section explains each of these steps.

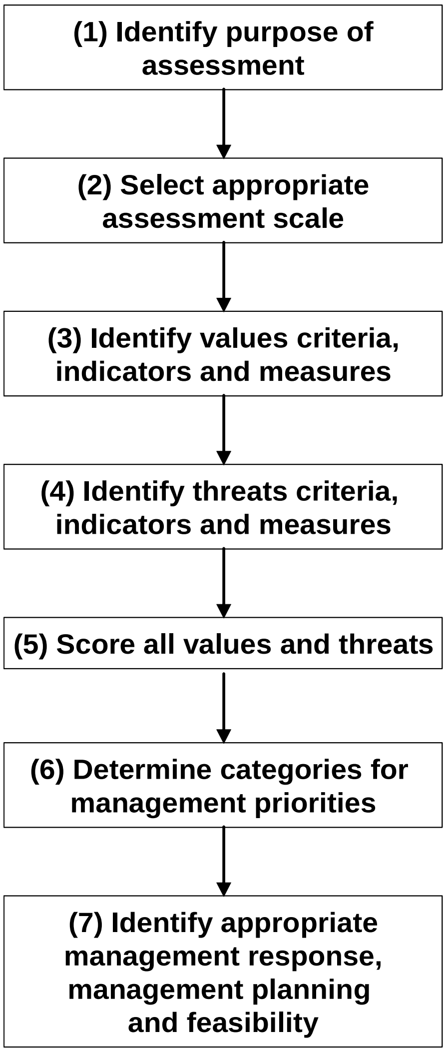

Figure 2 Seven-stage process for assessing waterways for management prioritisation

2.1 Identifying purpose of assessment

The purpose of the assessment will influence the selection of values, criteria and indicators to be used, as well as the scale of assessment. For example, broadscale planning could involve the selection of all three ‘value’ categories (ecological, social and economic), and the calculation of a single rating for the overall value of a waterway management unit. On the other hand, for a plan aimed at specifically protecting biodiversity, emphasis could be placed on ecological values.

2.2 Selecting an appropriate assessment scale

The framework may be applied at a variety of scales – at the reach level, the tributary or river level, the subcatchment level, the catchment level, and regional level. The choice of scale will depend on the purpose of the assessment. For example, a state-wide assessment of waterways would require assessment of all rivers at a subcatchment or catchment scale. A catchment-wide assessment would consider the main waterway along with its associated tributaries. A subcatchment-wide assessment would consider the individual reaches (stretches of waterway between confluences) of the waterway of concern. At the highest practical resolution, a reach assessment may involve dividing the reach into a number of sections of just one or two hundred metres, as has been done with some river action plans.

Specifically identifying the scale will prevent wasted effort searching for data that in the end may contribute very little to prioritising and assigning management activity. However, although scale selection should be based on management objectives, it is inevitable that data availability will also influence the scale of assessment.

2.3 Identifying values, criteria, indicators and measures

Values and criteria

The framework is based on three broad 'values' categories: ecological, social and economic. A number of 'criteria' are proposed to enable the assessment of these three categories of values, providing a systematic, comprehensive, simple and flexible method to describe the ecological, social (including cultural) and economic values of waterways in Western Australia (Table 3).

Table 3 Values criteria for assessing waterways management priorities

Criteria for ecological values	Criteria for social values	Criteria for economic values
Naturalness	Visual amenity	Water extraction
Representativeness	Recreational	Mineral extraction
Diversity or richness	Non-Indigenous heritage	Commercial
Rarity	Educational	Infrastructural
Special features	Indigenous heritage and native title	
	Spiritual and sense of place	
	Hunting/gathering	

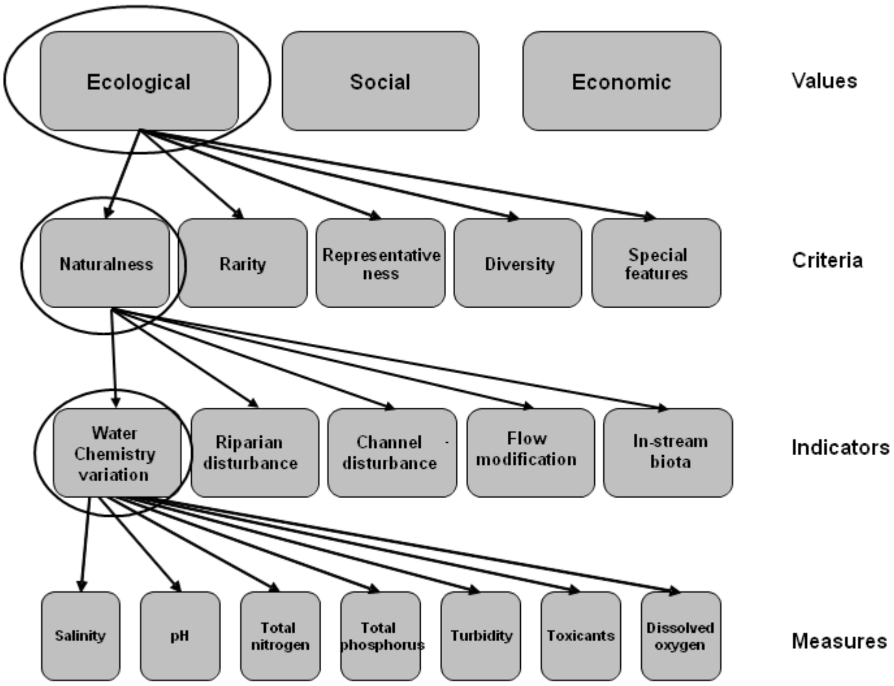

Figure 3 Hierarchy of values, criteria, indicators and measures used to assess the values of waterways in this framework.

Indicators

Having determined the values and criteria to be included in the assessment, appropriate indicators are then selected from the values tables given in Section 3, based on the available data and the purpose of the evaluation (Figure 3). For systems where the necessary data is available, it may be possible to use indicators that require directly measured data (e.g. water quality). For data-deficient systems, indicators which represent 'indirect' measures are likely to be more appropriate. Where there is no classification of the waterway units being assessed, it may not be possible to evaluate criteria such as 'representativeness'.

Measures

For each indicator, appropriate measures for which there are data available are then chosen (Figure 3). For extremely remote waterways it is conceivable that there may be no objective data. In such cases qualitative or even highly subjective data may be substituted so long as the uncertainty is reflected in the resulting scores.

2.4 Identifying threats, indicators and measures

For practical purposes, the threats affecting waterways are nearly always anthropogenic (caused by human activity). For example, excessive boating may cause bank erosion and sedimentation, camping may cause an accidental fire in the riparian zone, water extraction may alter natural flow regimes, and so on. These activities in themselves may not be problematic – it is only when they exceed ecological capacity that problems arise. Some of the threatening activities are capable of causing many threatening processes while others are likely only to cause one or two. For example, agriculture is capable of causing many of the threatening processes identified in Figure 4, whereas horse riding or cycling is likely only to cause minor erosion and sedimentation.

When identifying threats, there is a need to consider the assessment scale, as threatening processes may operate at different scales. For example, eutrophication and salinisation operate at the catchment scale.

Based on the identification of major threatening processes by various regional bodies and government agencies, and other authors across Western Australia (e.g. Pen 1999), 10 threatening processes have been identified as being useful criteria for assessing waterways (Figure 4). A number of indicators and examples of measures have been proposed for measuring the severity of each of these 10 threatening processes. It is important that the measures of threatening processes recognise the extent to which levels exceed historical levels or those of minimally affected ‘reference’ systems.

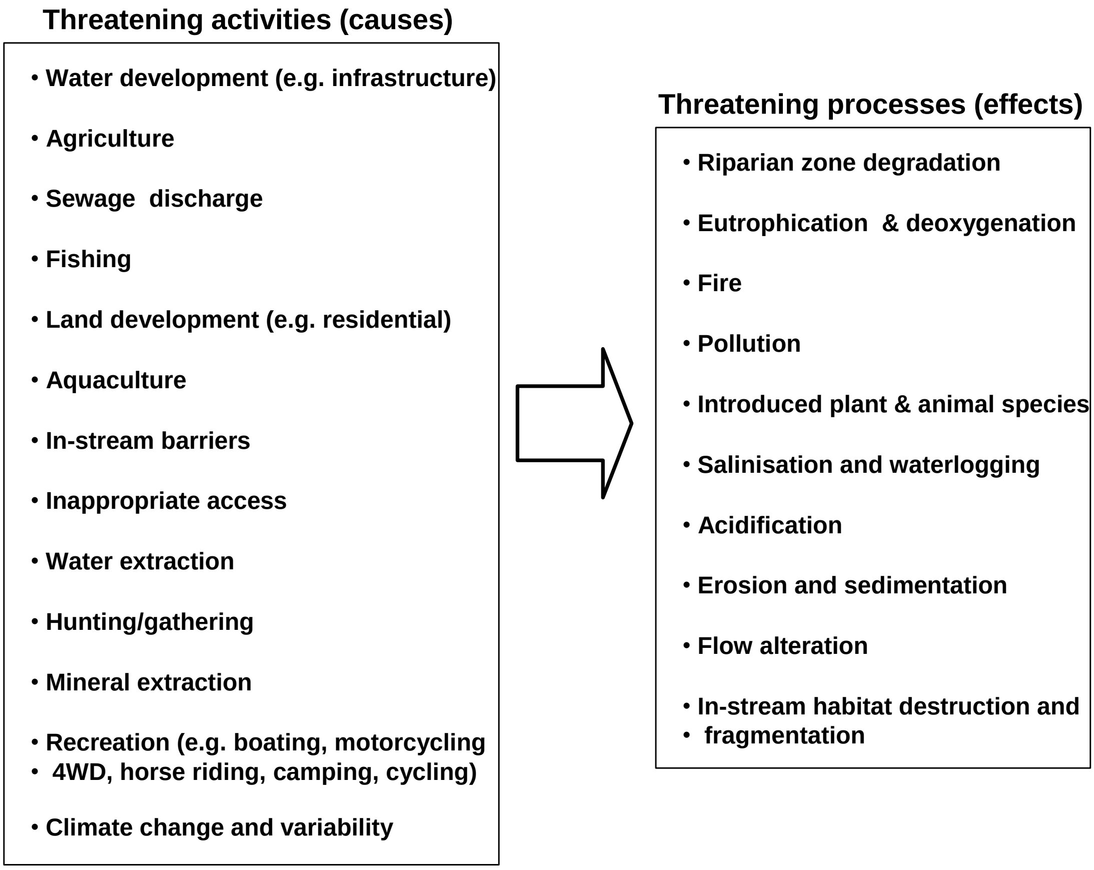

Figure 4 Threatening activities and processes affecting waterway values

Detailed descriptions of each of the threatening processes criteria and suggested indicators and measures are presented in Section 4.

2.5 Scoring values and threats

Scoring values and threats

In this framework, each waterway assessment unit is scored for each indicator and measure on a scale of 1 to 3, where a higher rating represents a greater (and more desirable) contribution to the ecological, social or economic value of the waterway, or a greater threat. Although three classes were recognised and scored here, it is not uncommon to see values defined on a five-point scale, ranging from relatively poor (score of 1) to best (score of 5) (e.g. Walker et al. 2006). Indicators with more than one measure are scored by taking the mean value of these measures. For each criterion, the indicator scores are added together to derive a total score for that criterion, and scores are then standardised by scaling to 100 or 1.0. Value scores at or near 100 or 1.0 indicate high value, while scores near 0 indicate low value. On the other hand, threat scores at or near 100 or 1.0 indicate a high level of threat.

The availability, quality and/or the reliability of data may vary considerably. These factors need to be taken into account when making decisions on how scores are to be treated. Standardising scores for criteria is appropriate to avoid skewing the result in favour of 'data-rich' criteria. Thus, each criterion that is included in the assessment is scored against the same scale (e.g. 0 to 1.0) regardless of how well represented it is by the data. If desired, scaled scores obtained for the criteria assessed can be added together to obtain an overall ecological, social or economic value or threat score for the waterway unit being assessed.

The general approach taken in this framework is in line with the recommendation that simplest aggregations should be used first, before embarking on the use of more complicated methodologies. Once the values of waterway assessment units are known, these can be ranked and managed according to their values and threats.

Missing data for scored measures can be accounted for by converting total value or threat scores to proportions based on the total possible score for each criterion. Proportions should be calculated as total value or threat score divided by the total possible score of scored criteria. For example, where indicators are scored on a scale of 1 to 3 the total possible score for scored criteria is given by the number of indicators scored multiplied by 3. An example of using proportions to account for missing data is shown in Section 5 in the Fortescue River trial.

Where data is limited or highly subjective it may be necessary to calculate confidence indices to determine the reliability of the assessment. Where an assessment is determined to be unreliable it may be desirable to weight data towards more quantitative data and re-analyse the results. Where data are limited, confidence indices should also be calculated to ensure the assessment has not been accidentally weighted in favour of data-rich criteria. This is especially important for waterways where ecological data is much more abundant than social or economic data. These steps are discussed in more detail below.

Confidence indices

The availability of data will influence the reliability of an assessment. Where there is sufficient data there should be a relatively high degree of confidence in the result. Conversely, inadequate data will generate a relatively low confidence result. A ‘confidence rating’ could be considered as another dimension within the framework and there may be a case for quantifying this dimension more explicitly by generating a meta-data score. An example of how to calculate confidence indices is presented in Section 5 in the Fortescue River trial.

Weighting

Equal ‘weight’ may be given to the ecological, social and economic values, and the criteria used to determine these values. However, it is possible that some criteria may be more important than others in some circumstances. For example, a waterway reach may contain a rare or threatened species (very important), or may be classified as a Ramsar wetland, while the social and economic values may be of little value by comparison. This is where a ‘weighting’ process can be used to make the final scoring reflect the importance of these factors. Weighting criteria or values can be a controversial approach, and thus this weighting process needs to be transparent. It is recommended that stakeholders be engaged in the decisions about how and when weighting should be applied. For example, although it is possible to preferentially weight quantitative data over subjective opinion, feedback from stakeholders suggests this approach may not be supported by them.

There does not appear to be any prescribed manner or standard system for applying weightings. It is likely that each case will have to be treated on its own merits. The involvement of stakeholders is likely to be necessary to determine the relative weights that should be assigned.

This weighting process was used in the case studies described in Section 5.

2.6 Choosing priorities and management responses

Identifying priorities using the values-threats prioritisation matrix

Once scores have been assigned to the values and threats for each waterway component under consideration, these can be plotted on the two-dimensional values–threats matrix (Figure 5).

A set of four guiding principles for prioritising waterways management is recommended (Department of Water 2004):

- The first priority should be to invest in waterways of high value or with multiple values (that is ecological, social and economic).
- The second priority is, for each value category, to invest in waterways that are in the best condition.
- The third priority is to invest in waterways that are subject to the highest pressure (greatest threats or combination of threats).

- Lastly, as appropriate to the identified goals:
  - invest in waterways where community interest is high
  - invest in waterways whose condition is deteriorating rather than in those where condition is stable or recovering
  - invest in waterways where there is a high likelihood of success and/or a technically feasible solution
  - invest in waterways where the cost/benefit ratio is lowest
  - invest in waterways where existing management effort or response is lowest.

The framework follows these principles and gives the highest priority to waterways with high value, high threat, and the lowest priority to the least valuable, least threatened. Figure 5 shows how the various combinations of values and threats combine to give the priorities.

The levels of high, medium and low are not intended to produce 'black and white' ('in' or 'out') results. This will be explained later using the trial case studies (see Section 5). Sometimes a borderline result suggests that other criteria (for instance management feasibility) may need to be considered before determining the final priority. Note that all the high value waterways are assigned Priority 1 regardless of threat level, and all low value waterways are assigned Priority 3 regardless of threat level. However, medium value waterways are given Priority 2 if they experience high or medium threat levels and Priority 3 if they experience only a low level of threat.

		Values		
		High	**Medium**	**Low**
Threatening processes	**High**	High value, high threat (HV/HT) Priority 1	Medium value, high threat (MV/HT) Priority 2	Low value, high threat (LV/HT) Priority 3
	Medium	High value, medium threat (HV/MT) Priority 1	Medium value, medium threat (MV/MT) Priority 2	Low value, medium threat (LV/MT) Priority 3
	Low	High value, low threat (HV/LT) Priority 1	Medium value, low threat (MV/LT) Priority 3	Low value, low threat (LV/LT) Priority 3

Figure 5 Values–threats prioritisation matrix

It should be noted that high value may not necessarily equate with good condition. For example, a waterway may be regarded as high value even when it is in poor ecological condition.

The matrix also indicates how management can be prioritised within each of the three primary categories. For Priority 1, there are three further ‘sub-priorities’: high-value, high-threat, high-value, medium-threat and, high-value, low-threat. Similarly, there are two sub-priorities for Priority 2 and four sub-priorities for Priority 3. By considering these sub-priority categories, further attention may be given to the institutional, social and economic constraints and limitations that are present in every NRM circumstance. For example, it is quite likely that management may be most effective if the less challenging threats are managed first.

Identifying appropriate management responses for these priorities

Once a waterway has been assigned to a priority category using the values–threats matrix, appropriate management responses are chosen in the priority order of Rutherfurd et al. (1999). These are:

- Save reaches that support valuable species or communities (rare or endangered) before you turn to less valuable reaches that support common species.
- Protect the streams that are in the best general condition, before trying to improve the ones that are in poor condition.
- Stop streams deteriorating, rather than waiting for them to stabilise and then trying to accelerate recovery.
- Improve the condition of reaches that are damaged, beginning with those that are easy to fix.
- While there are still reaches that need protecting or improving, don’t bother trying to fix reaches that are already extremely degraded.

Rutherfurd et al. (1999) were only concerned with ecological values whereas this framework is concerned with social and economic values as well.

The Department of Water (2004) suggests six management categories that could be considered. These have been modified and a seventh, related to monitoring, has been added. These are shown in Table 4.

Table 4 Management response options

Goal	Management response	
To fully protect waterways values	Secure	of such importance that action is needed to fully protect environmental, social and economic values
	Maintain	prevent deleterious alteration to existing waterway condition, practices and standards
To improve waterway health	Restore	reinstate specific values, conditions, standards or practices
To manage degradation	Stabilise	halt degradation processes
	Contain	limit degradation processes
To manage function	Adapt	accept that the waterway is highly degraded, identify the functions still operational and manage those functions
To identify possible future threats	Monitor	conduct regular assessments of water quality and riparian condition to identify emerging threats if and when they arise

Table 5 links these response options with the prioritisation matrix (Figure 5).

Table 5 Generalised management responses for value–threat combinations

Primary priority level	Sub-priority level		Main management responses
1	1a	HV/HT	Secure, stabilise, restore
1	1b	HV/MT	Secure, maintain, restore
1	1c	HV/LT	Monitor, secure, maintain
2	2a	MV/HT	Stabilise, contain, restore
2	2b	MV/MT	Contain
3	3a	MV/LT	Stabilise, restore
3	3b	LV/HT	Stabilise, contain, adapt
3	3c	LV/MT	Contain, adapt
3	3d	LV/LT	Adapt

The management responses in Table 5 are not prescriptive and there will be other, more appropriate management responses to particular situations. For example, in the trial of the South Coast region's waterways (see Section 5) the Goodga River was ranked relatively low on an overall score for ecological criteria (equal weighting applied) but this river should be regarded as having high ecological value because it is one of only two waterways known to be home to the critically endangered western trout minnow (*Galaxias truttaceus hesperius*). In such a circumstance it would be prudent to regard such a system as a 'top priority' regardless of the prioritisation category revealed by the framework. Alternatively, the rarity criterion could be given a much higher weighting than other criteria when assessing overall ecological value using a number of criteria (Cook et al. 2008).

By highlighting the most important responses in Table 5, the framework is seeking to make the most of limited resources. However, where resources are available, other management responses may be included. For example, the main management response for HV/LT could be expanded to include containment.

General descriptions of management for each priority

This section provides a brief explanation of the main management responses appropriate to the priority and sub-priority categories.

Priority 1

High-value waterways should be considered for management before waterways of medium or low value. This reflects the principle of always preserving or securing rare waterways, or waterways that are in good condition, first, before trying to deal with those that have more problems. It also acknowledges the practical problems involved with managing natural resources – especially cost-effectiveness. This approach should ensure managers obtain the highest return on investment, so that management will decrease the majority of threats at the lowest possible cost. Consequently, management efforts within Priority 1 will be predominantly those that secure and/or stabilise waterways from threats. Where waterways are not exposed to threats or threats are minimal, monitoring is likely to be the main management response. However, some efforts to secure or maintain may be required even if threats are minimal.

Sub-priority 1a (HV/HT)

Given the high-value, high-threat circumstance associated with waterways in this category, it is likely that these waterways will require the greatest proportion of management attention. Obviously it is important to secure the assets associated with such sites. For example, if the waterway is exposed to grazing then fencing off the waterways should ensure stock do not threaten the values. In situations where degradation is high it is important to consider any potential off-site effects – whether the degradation is being, or may be, passed on to other high-value reaches currently unaffected. For example, bank erosion is likely to create a sedimentation problem downstream. Where this is a possibility then the management efforts should first stabilise degradation. In most situations securing and maintaining assets will have priority over restoration, mainly because the cost of protection is typically about one-tenth the cost of restoration. Only after degradation has been stabilised should restoration strategies be considered.

Sub-priority 1b (HV/MT)

The high-value assets in this category are exposed to threats that are slightly less significant than in Sub-priority 1a. It is likely that degrading processes will also be less of a threat to high-value stretches of waterways downstream. There is not the sense of urgency apparent in Sub-priority 1a.

Management should still be concerned with securing assets where necessary but for waterways in this classification it is likely that some efforts may already have been made to secure. However, on-going maintenance may be necessary. For example, fencing that is already in place needs to be maintained, any weeds that are returning to riparian areas will need to be removed, and so on.

Sub-priority 1c (HV/LT)

Waterways that fall into this category are slightly different to the other two high-value sub-priorities. Since these waterways may be assumed to be in good condition and have little exposure to threats, there is likely to be little need to actively manage them – such waterways will 'manage themselves' so long as conditions remain stable, that is, no new development or degradation process is introduced. Consequently, all that waterways managers need be concerned with here is the potential for circumstances to change. This does not imply that waterways in this category may be ignored altogether. It would be prudent to consider establishing an appropriate monitoring program to ensure new threats do not emerge unnoticed.

Priority 2

Reaches or streams in this class are likely to have been damaged by human activity to some degree. There are two sub-priorities within this priority. Those classed as medium-value, high-threat (Sub-priority 2a) being prioritised before medium-value, medium-threat (Sub-priority 2b). Once again, recognising relative costs of protection compared to restoration, the most widespread benefit may be obtained by stabilising existing degradation before considering restoration. This reflects Rutherfurd et al.'s (1999) fourth principle – 'Improve the condition of reaches that are damaged, beginning with those that are easy to fix.'

Sub-priority 2a (MV/HT)

Typically, the most degraded examples of waterways or reaches in this category would be those that have been largely cleared of riparian and in-channel vegetation, with marginal water quality and some sediment deposition in the channel. Ideally, restoration is justified but as noted above, active degradation (erosion, weed spread and nutrient enrichment) should be stabilised or at least be contained first. Where restoration opportunities do arise, pragmatism should dictate the order of attack. For example, it is easier to improve a reach in relatively good condition than to restore an isolated reach. It may be possible to develop a project aimed at 'linking' two slightly higher value reaches. Where restoration may be employed, one should look for opportunities to improve the higher ecological values that are present. Consequently, the following order of management should be considered:

- improve degraded assets in reaches with some high quality values
- work on a poor quality reach that links two higher value reaches
- work on a poor quality reach connected at one end to a higher value reach.

Sub-priority 2b (MV/MT)

Management options for this and lower value waterways and reaches will inevitably be quite limited simply because the higher value systems may consume most of the resources available. Given the relatively high cost of restoration, it is likely that efforts may have to be directed more towards the containment of threatening processes. However, if opportunities do arise for restoration then the order of priorities identified for Sub-priority 2a would apply.

Priority 3

Due to the high costs associated with restoration, there is likely to be very limited opportunity to bring about dramatic improvements in the condition of Priority 3 waterways. However, waterways in poor condition may constitute a threat to other more valuable waterways or reaches downstream. For example, a reach that is infested with salvinia (*Salvinia molesta*, a highly invasive aquatic weed of national significance) may pose a serious threat to reaches downstream, some of which may be high value. In such cases, management efforts must seek to stabilise and contain the degradation. For waterways that pose little or no threat, resources may be more usefully directed to protecting or restoring higher value waterways – accepting that there may be nothing that can effectively be done (the 'adapt' management response).

Sub-priority 3a (MV/LT)

This is the only medium-value category with a Priority 3 rating. Management should mainly be concerned with stabilising degradation, with restoration where opportunities arise.

Sub-priority 3b (LV/HT)

Reaches and streams typical of this category would be in very poor condition with little or no chance of recovery without significant restoration efforts. These will be expensive and difficult. It is important to determine whether or not the degraded condition is likely to affect other higher value reaches or streams. Where this is unlikely there is a strong argument for doing nothing at all except perhaps protecting what ecosystem functions remain (adapt) but where highly degraded reaches have the potential to threaten reaches downstream it is appropriate to take action to stabilise or at least contain the degrading influences.

Sub-priority 3c (LV/MT)

Management for reaches in this category is mostly concerned with containment. The nature of threats will not be as much of a concern as for Sub-priority 3b but since these are low-value systems there is likely little to be gained by investing heavily in active restoration.

Sub-priority 3d (LV/LT)

Adaptation is most likely for waterways in this sub-priority category, where remaining ecosystem functions are managed to at least protect these.

Monitoring should be considered, to ensure that increases in threat levels do not go undetected.

2.7 Stakeholder engagement and feasibility

The framework leads to a choice of seven management responses. There are two other factors that need to be considered when choosing what action to take. These are stakeholder engagement and feasibility.

Waterway management projects are as much about people as they are about science and construction. From the beginning of the project it is important to identify the stakeholders and groups who may support or oppose the goals of the project.

There are a variety of techniques that may be employed to ensure stakeholder engagement is properly tailored to the project. The Victorian government’s Department of Sustainability and Environment website is a useful source of information on developing an engagement plan (visit <www.dse.vic.gov.au> and search for ‘Developing an engagement plan’). The Engagement Planning Tool can be downloaded from the website.

Resources inevitably play a central role in all management projects. The management response to the identified threats is constrained by the capacity of the organisation, community and land managers to undertake the required management.

Each of the objectives should be examined to determine whether or not they are feasible. Six questions related to feasibility may assist in this assessment:

- How much will each objective cost?
- How technically feasible is each objective?
- Will each objective effectively contribute to reducing the threats?
- How long will it take for the objectives to reduce the threats?
- Will the objectives be implemented and supported by relevant stakeholders?

Determining answers to each of these questions should make it possible to arrive at a final realistic list of objectives for inclusion in the project.

2.8 Designing the management response

In this stage a list of actions and detailed design should be developed. If detailed information is required, these could be in the form of a river action (or recovery) plan or waterway management plan.

River action plans establish priority on-ground works and actions to improve the health of a waterway (e.g. stabilisation, revegetation and fencing). They may also provide a record of waterway condition, values and threats, baseline information and hydrology for future comparison and technical advice. They may strengthen any commitments made by the local community to addressing the issues.

Waterway management plans describe values, objectives and actions to maintain agreed environmental, social and economic values; and improve management of waterways by ensuring efficient and effective application of statutory planning processes. These plans may include issues that need to be resolved at a catchment scale.

Every waterway management initiative should include an evaluation process to determine if it has met the intended objectives. Evaluation does not necessarily need to be detailed and expensive; however, wherever possible, the indicators should be specific, measurable, achievable, and relevant.

The plan should be implemented by developing a timeline, allocating responsibilities, finalising funding, carrying out the works and organising the evaluation schedule.

The final stage in the planning process is to maintain the work that has been done and to set a point in the future to formally assess the success of the project, using the information gathered during the evaluation stage.

The Department of Water and other agencies including NRM and catchment groups provide support for river restoration and for building the capacity of communities to undertake river restoration. The Department of Water’s role includes holding river restoration training workshops, coordinating a communication network for river managers called the ‘river restoration action team’ (River RATs), supporting foreshore condition assessments and development of river action plans and supporting funding incentives to encourage landowners to protect and manage waterways.

The river restoration manual, *A guide to the nature, protection, rehabilitation and long-term management of waterways in Western Australia* (Water and Rivers Commission 1999-2003) and the *Water note* series provide further guidance on river management and restoration. These are available on the Department of Water's website via <www.water.wa.gov.au> (select 'Waterways health', then 'Looking after our waterways', then 'Planning' or 'Restoration'). Advice is available on topics such as planning river restoration, river action plans, foreshore condition assessments, hydrology, stream channel analysis, ecology, fencing, crossings, livestock watering points, revegetation, riffle and fishway construction, sediment management and bank stabilisation.

3 Values, indicators and measures

This section looks in detail at the waterway values that are used as criteria for assessing priorities. It contains tables of suggested indicators and measures for each type of value.

3.1 Ecological values

Ecological values include aquatic and riparian biota, river habitats and geomorphology, physical and biological river processes, and the role that rivers may play in sustaining other systems such as karst, estuaries, floodplains and wetlands (Dunn 2000). Bennett et al. (2002) defined ecological values as ‘the natural significance of ecosystem structures and functions, expressed in terms of their quality, rarity and diversity. Significance may arise from individual biological, physical or chemical features or a combination of features.’ Based on broadscale support at both the national (Dunn 2000; Bennett et al. 2002) and state level, the framework proposes the following five criteria to identify ecological values:

- naturalness
- representativeness
- diversity or richness
- rarity
- special features.

These criteria are also in broad agreement with the ‘core criteria’ selected for the identification of high conservation value aquatic ecosystems in Australia. There are a number of indicators and measures that could be used to assess each criterion, the choice of which may depend on the availability of data.

Naturalness

Naturalness assesses to what extent the waterway structures and functions are similar to those that would exist without the presence of human-induced disturbance. Therefore this criterion measures waterway condition. Condition assessments provide a measure of how much a system has changed (due to disturbance or stress) relative to a nominated ‘benchmark’ or ‘reference’ condition. Reference condition may be determined using either sites that are ‘undisturbed’ or ‘least-disturbed’ waterways of a similar type, or synthesised pre-European condition based on literature, expert opinion or modelled condition.

This framework uses six broad indicators to assess waterway ‘naturalness’, relative to its’ natural state. These are:

- level of catchment disturbance
- level of riparian zone disturbance
- level of river channel disturbance
- level of flow modification

- variation from natural state of water chemistry
- variation from natural state of in-stream biota.

Table 6 contains details of indicators and measures for 'naturalness'. A comprehensive assessment would seek to rate the waterway unit for all of these indicators. Assessments based on limited data would seek to use as many of these indicators as is possible.

Where the national *Framework for the Assessment of River and Wetland Health* has been used to assess condition, indices from this assessment may be used to provide scores for the degree of 'naturalness' of a management unit.

Table 6 Proposed indicators and examples of measures for assessing the 'naturalness' value of a waterway unit

	Naturalness values
Indicator	**Examples of measures**
Level of catchment disturbance	% of natural vegetation cover remaining in a catchment
	% of selected land-use type in a catchment known to be detrimental to waterway structure and functioning
Level of riparian zone disturbance	Presence and continuity of intact, native riparian vegetation as a % of waterway unit length
	Width of intact, native riparian vegetation
	Canopy cover of native riparian vegetation
	Number of indigenous riparian plant species present relative to the number found at a reference waterway unit of the type represented by the waterway unit being assessed
	Presence and cover of weed plant species in riparian zone
	Presence and density of exotic animal species in riparian zone
Level of river channel disturbance	Presence and extent of erosion and sedimentation
Level of flow modification	% of annual flow diverted
	% of former floodplain no longer flooded
	Number of impoundments, weirs or other artificial barriers present

	Naturalness values
Indicator	**Examples of measures**
Variation from natural state of water chemistry	Extent to which salinity (or conductivity) of the water varies from that which would be expected of the river type represented by the waterway unit being assessed
	Extent to which the nutrient (nitrogen and phosphorus) status of the water varies from that which would be expected of the type represented by the waterway unit being assessed
	Extent to which turbidity of the water varies from that which would be expected of the river type represented by the waterway unit being assessed
	Presence of toxicants in the water
Variation from natural state of in-stream biota	Species richness, number of pollution sensitive or tolerant species, observed to expected ratios and/or community composition of invertebrate taxa found relative to that found at a reference waterway of the river type represented by the waterway unit
	Number of indigenous fish species found relative to the number found at a reference waterway of the river type represented by the waterway unit being assessed
	Number of water bird species found relative to the number found at a reference waterway of the river type represented by the waterway unit being assessed.
	Species richness, number of pollution tolerant or sensitive species, community composition and/or cover of aquatic submerged and emergent plant species found relative to that found at a reference waterway unit of the type represented by the waterway unit being assessed.
	Number (and cover) of exotic faunal and floral aquatic species found

Representativeness

'Representativeness' assesses to what extent a waterway has features typical of a type or class of waterways, and is critical to the 'comprehensive, adequate and representative' approach to conservation planning. This criterion can only be scored following a classification of waterways or waterway management units. For example, to what degree the waterway is representative of a type of waterway in a drainage division.

The terrestrial-based *Interim Biogeographical Regionalisation of Australia* (IBRA) has 'significant limitations for riverine biota because they are predominantly constrained by catchment processes' (Kingsford et al 2005, p.21). The national Aquatic Ecosystem Task Group is currently developing an alternative approach to aquatic bioregionalisation. In the interim, the Department of Water recommends using the drainage division as the management unit.

This framework proposes three broad indicators to assess the ‘representativeness’ of a waterway unit. These are:

- hydrological regime
- water quality characteristics
- biotic characteristics.

Table 7 contains details of indicators and measures for ‘representativeness’.

Table 7 Proposed indicators and examples of measures for assessing the ‘representativeness’ value of a waterway unit

Representativeness values	
Indicator	**Examples of measures**
Hydrological regime	Measure of how well hydrological regime conforms to that of a particular waterway type
Water quality characteristics	Measure of how well pH conforms to that expected for a particular waterway type
	Measure of how well salinity conforms to that expected of a particular waterway type
	Measure of how well a selected water chemistry parameter conforms to that of a particular waterway type
Biotic characteristics	Presence of a typical macroinvertebrate community for a particular waterway type
	Presence of a typical fish community for a particular type
	Presence of typical riparian vegetation for a particular type
	Presence of typical in-stream macrophytes for a particular river type

Diversity or richness

The ‘diversity or richness’ criterion assesses to what extent a waterway has a range of biota and geomorphic features. Although biotic diversity may be measured at a range of scales (e.g. genetic, species, community and regional levels), it is most commonly measured for species or communities. Levels of diversity need to be assessed relative to those which could be expected for a particular river type. This framework uses six broad indicators to assess the ‘diversity or richness’ of a waterway unit. These are:

- hydrological diversity
- channel heterogeneity
- in-stream habitat heterogeneity
- invertebrate diversity
- vertebrate diversity

- floral diversity.

Table 8 contains details of indicators and measures for ‘diversity of richness’.

Table 8 Proposed indicators and examples of measures for assessing the ‘diversity or richness ’values’ of a waterway unit

Diversity or richness values	
Indicator	**Examples of measures**
Hydrological diversity	Number of distinct hydrological regimes in a given catchment (e.g. spring-fed streams, ephemeral and perennial streams, wetlands, swamps, floodplains, riffle pool sequences) Number of distinct in-stream habitats in a given reach (e.g. riffles, fast, moderate and slow flow, rapids, pools)
Channel heterogeneity	Number of different substrata types or size classes (e.g. bedrock, boulders, cobbles, sand, mud) Number of distinct channel types
In-stream habitat heterogeneity	Presence and extent of small and large woody debris and leaf packs Presence and extent of submerged and emergent vegetation
Invertebrate diversity	Total macroinvertebrate species richness in a given area for each catchment or region Mean macroinvertebrate species richness per site or reach for each catchment or region Frequency of occurrence of selected species Relative abundance of selected species
Vertebrate diversity	Total fish species richness in a catchment or region Mean fish species richness per site or reach in a catchment Bird diversity Frog diversity
Floral diversity	Macrophyte species richness Riparian vegetation species richness Total number of distinct in-stream or riparian communities

Rarity

The ‘rarity’ criterion (sometimes termed ‘distinctiveness’) assesses to what extent a waterway has an uncommon feature, or combination of features, such as unusual natural water chemistry, hydrology, geology or landscape features, or the presence of rare and threatened species. Threatened species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are those species considered to be ‘vulnerable, ‘endangered’ or ‘critically endangered’. Waterways that are home to one or more threatened species would be considered to have a high rarity value. For poorly studied groups such as aquatic invertebrates, or where a species has not been listed under the EPBC Act, a rigorous application of the EPBC Act guidelines may be undertaken to assess if they meet national thresholds for listing under the Act. Sutcliffe (2003) followed this process for her assessment of the conservation status of dragonflies, caddisflies and stoneflies in south-western Australia, identifying several species that could be considered as potentially threatened.

This framework uses five broad indicators to assess the 'rarity' of a waterway unit. These are:

- unusual hydrological regimes
- unusual water quality types
- rare geomorphological and habitat features
- presence of threatened and priority-listed species and communities
- presence of rare or endemic species.

Table 9 contains details of indicators and measures for 'rarity'.

Table 9 Proposed indicators and examples of measures for assessing the 'rarity' values of a waterway unit

Rarity values	
Indicator	**Examples of measures**
Unusual hydrological regimes	Presence of particular 'rare' or threatened hydrological regimes (e.g. ephemeral or perennial flows, spring-fed tributaries)
Unusual water quality types	Presence of a particular, 'rare' or 'unusual' water chemistry type
Rare geomorphological and habitat features	Presence of rare or threatened habitat features Frequency of occurrence of unusual geomorphological features or processes
Presence of threatened and priority-listed species and communities	Presence of threatened and 'priority-listed' animal or plant species (listed and protected by legislation, treaties or conventions) Presence of threatened and 'priority-listed' communities (listed and protected by legislation, treaties or conventions) Presence of habitats classified as threatened or of concern Presence of potentially threatened species that meet the EPBC criteria, but are not yet listed
Presence of rare or endemic species	Presence of selected animal or plant species known to be rare or endemic to a specific region or area

Special features

The 'special features' criterion assesses to what extent a waterway has features which are uncommon within the landscape generally, or to what extent the waterway sustains other important ecosystems such as karst, estuary or floodplain wetlands, or to what extent the waterway may have other functions such as acting as a drought refuge, biodiversity corridor or environment for ‘keystone’ or ‘flagship’ species. The extent to which systems support species in critical life stages would also be assessed under this criterion. Systems which have been formally recognised to be of international importance (e.g. either through the Ramsar convention, the World Heritage List or the East Asian–Australasian shorebird network), would also score highly for this criterion.

This framework uses eight broad indicators to assess ‘special features’ of a waterway unit. These are:

- drought refuge
- maintenance of hydrological features
- special biotic features
- significant areas
- refuge habitats
- presence of ‘flagship’ species
- habitat for species of ‘special’ interest
- significant scientific sites
- evolutionary history.

Table 10 contains details of indicators and measures for ‘special features’.

Table 10 Proposed indicators and examples of measures for assessing the ‘special features’ values of a waterway unit

Special features values	
Indicator	**Examples of measures**
Drought refuge	Presence or extent of ‘permanent’ wetlands and other water bodies in naturally dry catchments Presence or extent of ‘permanent’ river pools in naturally ephemeral waterways
Maintenance of hydrological features	Maintenance of mound springs Maintenance of karst systems
Biotic special features	Extent of use by migratory species such as birds Extent of use as breeding or nursery grounds by birds, fish and other animals Degree to which riparian vegetation acts as a ‘corridor’ for dispersal of terrestrial species
State, national or international recognised significant areas	Presence or extent of wild rivers, wetlands listed in the *Directory of important wetlands in Australia* (Environment Australia 2001) , conservation category wetlands or Ramsar wetlands Presence or extent of national parks, nature reserves, conservation parks and other conservation estates Presence of Systems (Red book) areas[1], Register of the National Estate, National Heritage or Bush Forever areas

Special features values	
Indicator	**Examples of measures**
Refuge habitat	Extent to which the waterway unit is a refuge for biota in a largely altered landscape
Habitat for species of special interest	Presence of habitat suitable for maintaining populations of 'flagship', 'indicator' or 'keystone' species
	Presence of habitat for an unusually large number of a particular species of interest
Presence of 'flagship'[2] species	Presence of 'flagship' species (e.g. well known or 'charismatic'[3] fish species, frogs, freshwater crayfish etc.)
Significant scientific sites	Presence or extent of areas that have been well studied scientifically or have unusual characteristics of scientific importance
Evolutionary history	Presence or extent of features or processes and/or supports species or communities which demonstrate the evolution of Australia's landscape or biota

[1]Areas recommended for protection in the Systems (Red Book) reports (Department of Conservation and Environment, 1976–1983; and Environmental Protection Authority 1993) except in areas where recommendations are superseded by later proposals approved by government.

[2]A 'flagship' species is a species chosen to represent an environmental issue, such as an aquatic ecosystem in need of conservation. These species are chosen for their vulnerability, attractiveness or distinctiveness, to engender support and acknowledgement from the community.

[3]A 'charismatic' species is a species with widespread popular appeal that serves as symbols to stimulate conservation awareness and action.

3.2 Social values

For the purpose of this framework, cultural values are taken to be a component of social values. Seven criteria are used to represent social and cultural values together:

- visual amenity
- recreational
- non-Indigenous heritage and sense of place
- educational
- Indigenous heritage and native title
- Indigenous spirituality and sense of place
- hunting and gathering.

Visual amenity

Visual amenity is a highly qualitative criterion so quantification will always present challenges. Arguably, it is also very subjective although it would seem self-evident that waterways in good condition in scenic locations would appeal to most people. Most people would also agree that waterway features such as waterfalls, gorges and waterholes have aesthetic appeal. Conversely, waterways that are devoid of such features (in what may be described as uninteresting landscapes), that are in poor condition (degraded) with evidence of bank erosion, sedimentation, pollution, that have been cleared or are infested with weeds are unappealing. Therefore, in many respects, many of the indicators and measures of visual amenity have much in common with those identified for 'naturalness'. Consequently, some of the indicators and measures for naturalness should also apply for visual amenity. Table 11 contains details of indicators and measures for 'visual amenity'.

Table 11 Proposed indicators and examples of measures for assessing the 'visual amenity' of a waterway unit

Visual amenity values	
Indicator	**Examples of measures**
Appealing waterscape	Presence or number of appealing waterscapes (e.g. gorges, pools, waterholes, waterfalls) Presence or number of known scenic lookouts of waterway features Presence of intact riparian zone consisting of native flora Presence of known picnic areas (with or without facilities) Visual assessment based on photographic evidence
Wildlife observation	Presence of sites known for their bird-watching potential Number of visits by bird-watchers and/or faunal watchers per annum by locals and tourists Number of indigenous bird and animal species found relative to the number found at a reference waterway of the river type represented by the waterway unit being assessed
Public access	Existence of easily accessible vantage points Ease of pedestrian and vehicle access Presence of walking trails Proximity to residential areas Availability and value of river-front residential properties

Recreational

After coastal landscapes, rivers are the most popular landscapes for recreation (Land and Water Australia 2006). Specifically the recreational values of waterways are: boating, recreational fishing, swimming, bushwalking, cycling and camping. Although indicators presented in Table 12 present quantifiable measures, the quality of the recreational experience may also be used to score recreational value.

Table 12 Proposed indicators and examples of measures for assessing the recreational values of a waterway unit

	Recreational values
Indicator	**Examples of measures**
Boating	Number of people per annum using the waterway for boating Presence or number of pools suitable for watercraft Number of boats per annum accessing the waterway Presence or number of known canoeing and kayaking sites Presence or number of pools suitable for water skiing
Recreational fishing	Presence or number of fish species targeted by recreational fishers Presence or number of known fishing locations Number of people per annum using waterway for recreational fishing
Swimming	Presence or number of suitable pools (permanent or seasonal)
Bushwalking, cycling, horse riding	Presence or number of walking tracks and trails (e.g. Bibbulmun Track) Presence or number of known cycle paths (sealed or unsealed) e.g. Munda Biddi Number of people per annum using the river for walking, cycling or horse riding
Recreational driving	Presence or number of mapped 4WD tracks Presence or number of motorcycle tracks Number of people per annum using the river for 4-wheel driving or off-road motorcycling
Camping	Presence or number of known caravan and camp sites close to waterway (with facilities e.g. water, toilets, power) Presence or number of known caravan and camp sites close to waterway (without facilities) Number of people using caravan and camp sites close to waterway per annum Presence or number of fireplace or BBQ facilities close to waterway

Non-Indigenous heritage and sense of place

Waterways have a central role in non-Indigenous culture and they have played a central role in the early European settlement of Australia. They were the natural pathways for European explorers and subsequent colonists (Kingsford et al. 2005) and later they provided a transport network. Most towns were established on rivers or their estuaries for their ports, water supply and productive land (Land and Water Australia 2006).

Table 13 contains details of indicators and measures for ‘non-Indigenous heritage’.

Table 13 Proposed indicators and examples of measures for assessing the non-Indigenous heritage values of a waterway unit

Non-Indigenous heritage values	
Indicator	**Examples of measures**
Local identity	Degree to which waterway contributes to local identity and/or has a place in local folklore Waterway representation in local and regional art (paintings, literal works)
Historic or heritage buildings	Presence or number of historic buildings occupying river frontage or riparian zone Presence or number of historic or archaeological sites of significance to white settlement (e.g. homesteads, churches, cemeteries) Heritage listings (National Register)

Educational

Waterways may be regarded as 'repositories' or 'libraries' of scientific knowledge and natural history. This is well understood by many in the community and it is common for schools and other educational institutions to use waterway sites to educate students in environmental and natural resources sciences. Waterways therefore have an important role to play in education. Eco-tourism, which usually has a strong educative role, should be acknowledged in this context.

Table 14 contains details of indicators and measures for educational values.

Table 14 Proposed indicators and examples of measures for assessing the educational values of a waterway unit

Educational values	
Indicator	**Examples of measures**
Opportunities for learning	Degree to which the waterway improves or could improve local and regional natural and/or cultural knowledge Presence or amount of interpretive and information signage Local school or learning institution and/or community group accessing for learning and training purposes Presence or number of eco-tourism operators Presence or number of residential camps (e.g. YMCA, school, religious groups, scouts/guides)
Scientific	Presence or number of unique or rare indigenous flora species Presence or number of unique or rare indigenous fauna species Presence or number of long-standing research or monitoring programs

Indigenous heritage and native title

For Indigenous people, waterways and other landscape features have an important spiritual role. Water and waterways are central to many customs and spiritual beliefs and may identify territorial boundaries. Water is significant to Indigenous people as an essential resource for life and a key element that has moulded the landscape.

Table 15 contains details of indicators and measures for ‘Indigenous heritage and native title’ values.

Table 15 Proposed indicators and examples of measures for assessing the ‘Indigenous heritage and native title’ values of a waterway unit

Indigenous heritage and native title values	
Indicator	**Examples of measures**
Native title significance	Presence or number of native title claims Presence or number of river sites listed under the Western Australian *Aboriginal Heritage Act 1972*[1]
Culturally significant natural landscape features	Presence or number of landscape or waterscape features known to signify traditional owners’ place identification e.g. boundary demarcations

[1]*Note: registration under the* Aboriginal Heritage Act 1972 *does not change the legal status of Aboriginal heritage sites because the Act protects all Aboriginal heritage sites in Western Australia, whether they are known to the Department of Indigenous Affairs or not. The register operates primarily as a form of notice that sites may be of Aboriginal heritage significance, and hence fall under the ambit of the Act (DIA 2009).*

Indigenous spirituality and sense of place

It has been argued that the principal difference between the way Indigenous and non-Indigenous people view the natural world is the cultural and spiritual connection Indigenous people have with it. Windle and Rolfe (2003) identified the following spiritual components of waterways: ‘seeing’ the water, life in the water, meeting places, importance of water holes and pools, the Dreaming – Rainbow Serpent, knowledge about the river and water, songs and special sites.

Table 16 contains details of indicators and measures for ‘spiritual and sense of place’ values.

Table 16 Proposed indicators and examples of measures for assessing the ‘spiritual and sense of place’ values of a waterway unit

Spiritual and sense of place values	
Indicator	**Examples of measures**
Sites of cultural significance	Presence or number of registered and non-registered Aboriginal sites (e.g. sites containing archaeological artefacts, middens, fish traps, rock art)
Meeting places	Presence or number of sites that traditional owners use for cultural activities or ceremonies (e.g. corroborees)
Culturally significant waterholes and pools	Presence or number of sites known to be connected with Dreamtime or other culturally important stories

Spiritual and sense of place values	
Indicator	**Examples of measures**
Stories and songs	The extent to which the waterway features in traditional stories and songs

Hunting and gathering

Traditional owners utilise waterways and riparian lands to obtain food (fishing, hunting, collecting bush tucker). This also has economic benefits since it provides the traditional owners with some economic independence (Jackson 2005). This is especially true of the permanent pools which are an important focus for faunal resources and in some circumstances they also support a wide range and dense concentration of flora. These places are therefore relatively rich in food resources and consequently must be expected to be significant foci for Indigenous settlement and exploitation, especially during times of economic hardship (Brown 1987).

Table 17 contains details of indicators and measures for 'hunting and gathering' values.

Table 17 Proposed indicators and examples of measures for assessing the 'hunting and gathering' values of a waterway unit

Hunting and gathering values	
Indicator	**Examples of measures**
Abundance of bush foods	Presence or number of river sites (in river and riparian zone) used by traditional owners for gathering bush foods Diversity and abundance of known bush foods present Number of Indigenous people (traditional owners) actively engaged in collecting bush foods
Abundance of bush medicines	Presence or number of river sites (in river and riparian zone) used by traditional owners for gathering bush medicines Diversity and abundance of known bush medicines present Number of Indigenous people (traditional owners) actively engaged in collecting bush medicines
Abundance of hunted animals	Diversity and abundance of species fished by traditional owners Diversity and abundance of animals hunted by traditional owners Number of Indigenous people (traditional owners) actively engaged in hunting and fishing

3.3 Economic values

Most of the values of waterways considered so far may be described as 'non-market', that is, the benefits provided are not easily quantified or traded in the marketplace[1]. However, in many circumstances there are marketable features or uses that may and do provide measurable economic benefits. Economic criteria used in the framework are:

- water and mineral extraction
- commerce
- infrastructure.

Water and mineral extraction

The water found within waterways is perhaps the most obvious marketable component (for example, for domestic supply and irrigation). A wide variety of industries are also notable consumers of water (for example, mining). River beds are also used to extract minerals, principally sand and gravel for construction.

Table 18 contains lists the indicators and measures used for 'water and mineral extraction' values.

Table 18 Proposed indicators and examples of measures for assessing 'water and mineral extraction' values of a waterway unit

Water and mineral extraction values	
Indicator	**Examples of measures**
Potable water supply	Population or communities relying on water for drinking and household use
	Whether or not the waterway delivers water to a reservoir
	Quantity of water extracted for drinking and household use
	Quantity of water extracted for bottling
Irrigation	Number of extraction sites
	Quantity of water extracted for irrigation purposes
	Types of agricultural industry extracting for irrigation
	Water quality for crop, pasture and animal production (e.g. based on Department of Agriculture and Food recommendations)
	Area of land supplied by irrigated water
	Number of properties supplied by irrigated land

[1] There are economic valuation tools available to construct valuations for non-market goods such as environmental features (e.g. travel cost method, contingent valuation method and hedonic pricing method) but these are not reviewed here.

Water and mineral extraction values	
Indicator	**Examples of measures**
Water extraction for industry	Number and types of industries extracting water for processing purposes e.g. mining operations Quantity of water extracted by industry
Mineral extraction	Number and types of industries extracting minerals Quantity of minerals extracted

Commerce

Waterways provide many direct commercial but non-extractive economic benefits. These include transportation (boating) and fishing (including aquaculture). Waterways are also used by commercial tourist and leisure operators so they have a direct commercial value to such enterprises. Waterways also contribute directly or indirectly to the value of adjacent properties. The land capability (carrying capacity) is lifted because stock may graze on riparian vegetation, and waterways provide visual amenity that increases the commercial value of land.

Table 19 contains details of indicators and measures for 'commerce'.

Table 19 Proposed indicators and examples of measures for assessing the 'commerce' values of a waterway unit

Commerce values	
Indicator	**Examples of measures**
Commercial fishing	Presence or number of commercial fishing operators operating in the waterway Number of fishers licensed to fish in the waterway Presence or number of aquaculture operators in the waterway Annual species catch and effort rates
Transportation	Number and types of transportation activities (e.g. ferries, commercial boats) Number of people travelling by the waterway per annum
Water-based tourism	Presence or number of tourist operators using waterway Presence of river reaches and sites with tourism potential Number of tourist bookings per annum

Commerce values	
Indicator	**Examples of measures**
Land values	The margin between carrying capacity and/or agricultural capacity with and without the waterway The potential rise in land values as a consequence of proposed development
Indigenous tourism	Presence or number of river sites (in river and riparian zone) used by traditional owners for tourism activities Number of Indigenous people (traditional owners) actively engaged in tourism activities

Infrastructure

Considerable investment goes into infrastructure associated with waterways to make them available for commercial enterprises and for the public. These infrastructure features have capital value that should be acknowledged.

Table 20 contains details of indicators and measures for ‘infrastructure’.

Table 20 Proposed indicators and examples of measures for assessing the ‘infrastructure’ value of a waterway unit

Infrastructure values	
Indicator	**Examples of measures**
Waterway crossings	Presence or number of bridges (rail, road and foot), fords or other similar infrastructure Frequency of use
Water collection and storage	Presence or number of dams, weirs and diversions Quantity of water collected or stored
Boating facilities	Presence or number of jetties and associated infrastructure Number of boats and/or users Presence or number of boat ramps
Hydro-power	Presence or number of power generation facilities Annual power (megawatts) generated

4 Threats, indicators and measures

This section considers 10 threatening processes that are used for assessing priorities. It contains tables of suggested indicators and measures for each type of threat.

The emphasis here is on the threatening processes, not the causes.

4.1 Riparian zone degradation

The riparian zone plays a major role in determining the ecological health of streams and rivers. It is an important supplier of detritus to the system, and controls in-stream temperatures and regulates algal growth by providing shading. In addition, riparian vegetation is typically highly diverse and provides habitat and a corridor for terrestrial fauna. Consequently, degradation of the riparian zone may affect the structure and function of both the aquatic and terrestrial ecosystem. This framework proposes the use of intactness of riparian vegetation, livestock access, and degree of human disturbance for assessing the degree of riparian zone degradation (Table 21).

Table 21 Proposed indicators and examples of measures for assessing the 'riparian zone degradation' threat to a waterway unit

Riparian zone degradation threats	
Indicator	**Examples of measures**
Intactness of riparian vegetation	Pen and Scott foreshore condition (Water and Rivers Commission, 1999a, 1999b)
	Presence and extent of clearing of riparian vegetation
	Width of riparian zone
	Cover of native riparian vegetation in riparian zone
	Extent of riparian vegetation continuity
Livestock access	Evidence and extent of trampling by cattle, horses and other livestock
	Presence and extent of fencing of riparian zones
Human disturbance	Evidence and extent of trampling, man-made structures and other modifications of riparian zones

4.2 Erosion and sedimentation

Removal of vegetation from the catchment and riparian zones of waterways (land clearing) and certain other ground disturbing activities, such as construction, excavation, and logging of forests, may lead to severe channel modification and the depositing of sediment into river pools, estuaries and wetlands. Collapsing of riverbanks and the subsequent removal of riparian vegetation may also lead to the accumulation of significant organic debris in waterways. The framework has proposed three indicators for this threatening process – presence and extent of erosion, presence and extent of sedimentation, and occurrence of ground disturbing activities (Table 22). The extent to which turbidity of the water varies from that which would be expected of the river type represented by the waterway unit being assessed, may also be used as measures of erosion and sedimentation.

Table 22 Proposed indicators and examples of measures for assessing the 'erosion and sedimentation' threat to a waterway unit

Erosion and sedimentation threats	
Indicator	**Examples of measures**
Presence and extent of erosion	Presence and extent of bed incision and bank collapse Stripping Presence and extent of the formation of gullies, other deep lateral channels, washouts and floodplain Presence and extent of significant log jams and flood debris
Presence and extent of sedimentation	Presence and extent of sediment plumes or bars on the stream bed Presence and extent of in-filling of river pools Level of and trend in surface water turbidity
Ground disturbing activities	Presence and extent of construction, excavation or other ground disturbing activities in the catchment Presence and extent of trampling of riparian zones by humans or livestock

4.3 Eutrophication and deoxygenation

Eutrophication, or nutrient enrichment, results from the input of large quantities of nutrients such as nitrogen and phosphorus into waterways. This may result in algal, aquatic weed (such as azolla) and/or seagrass blooms (for example, *Ruppia megacarpa* in Wilson Inlet). Algal blooms produce oxygen during the day, but remove it through respiration at night, often leading to lower levels of oxygen than that needed to sustain animals such as fish and crayfish. This framework proposes that nutrient level, algal growth, macrophyte growth and oxygen availability be used to assess the threat of eutrophication to a system (Table 23).

Table 23 Proposed indicators and examples of measures for assessing the 'eutrophication and deoxygenation' threat to a waterway unit

Eutrophication and deoxygenation threats	
Indicator	**Examples of measures**
Nutrients	Extent to which present total nitrogen levels exceed historical values or those of minimally affected 'reference' systems Extent to which present total phosphorus levels exceed historical values or those of minimally affected 'reference' systems
Algal growth	Extent to which present chlorophyll a levels exceed historical values or those of minimally affected 'reference' systems Presence or extent, and duration of algal blooms

Eutrophication and deoxygenation threats	
Indicator	**Examples of measures**
Macrophyte growth	Presence and extent of excessive macrophyte cover
Oxygen availability	Frequency and duration of periods of unnaturally low levels of oxygen Frequency and extent of 'fish kills'

4.4 Inappropriate fire regimes

Fire in riparian zones may arise as a result of natural (such as lightning strike) or anthropogenic processes. Often, fires start accidentally (for instance, open fires at camp sites, litter or cigarettes) or by arson, but fires may be deliberately started for legitimate reasons (for example, as part of a prescribed burning program). Depending upon its nature, the amount of available fuel, temperature and wind, fire may cause serious damage to native flora and fauna even though it is a natural part of the Western Australian landscape. Where fire is intense and extensive it may affect local biodiversity. Severe loss of riparian vegetation may expose banks to erosion and the increased exposure of the waterway to sun may cause the temperature of the waterways to increase, introducing further threats to aquatic habitat. The framework proposes the area exposed to fire, intensity of fire, frequency of fire, and site recovery as the indicators for assessing the fire threat (Table 24).

Table 24 Proposed indicators and examples of measures for assessing the 'fire' threat to a waterway unit

Fire threats	
Indicator	**Examples of measures**
Area exposed to fire	Square kilometres burnt
Intensity of fire	Number of low intensity ('cool') fires in relation to high intensity ('hot') fires over a given period
Frequency of fire	Number of times over a given period of time the waterway's riparian zone is burnt
Site recovery (post-fire state)	Proportion of riparian species present 3 to 5 years after a fire Floristic and structural changes Post-fire fuel (phytomass) accumulation rate

4.5 Pollution

Toxic chemical pollution may occur through the application of herbicides and pesticides in agriculture or from urban sources. These chemicals may find their way into local waterways, where they may accumulate in the sediment and eventually enter the food chain. Heavy metal contamination may also occur through the application of trace elements and fertilisers to agriculture land, mining activities, industrial and urban sources and more recently, from the exposure of acidic groundwater by deep drains. Pen (1999) has also proposed that rivers in the South West may be subject to organic pollution, as large amounts of decaying, soft-leaved material are washed into waterways, leading to the build-up of oxygen depleting black 'ooze' in river pools. The framework proposes chemical pollutants, organic material, biotic mortality, and extent of bioaccumulation as the indicators for assessing the pollution threat (Table 25).

Table 25 contains details of indicators and measures for 'pollution'.

Table 25 Proposed indicators and examples of measures for assessing the 'pollution' threat to a waterway unit

Pollution threats	
Indicator	**Examples of measures**
Chemical pollutants	Presence and level of toxic chemicals in the water column relative to Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) guidelines for defined uses of waterways and estuaries
	Presence and level of toxic chemicals in the sediment relative to ANZECC guidelines for defined uses of waterways and estuaries
Organic material	Presence and level of decaying organic material in the stream channel
	Extent of black 'ooze' on the substratum
Biotic mortality	Occurrence of unnaturally high levels of mortality in animals and/or plants due to contaminants
Extent of bioaccumulation	Concentrations of selected contaminants (e.g. dieldrin, heptachlor) in tissues of animals

4.6 Introduced animal and plant species

Introduced plants displace local native species, contribute significantly to land degradation, and reduce farm and forest productivity. Introduced animals affect native fauna by predation, they compete with native animals for food and shelter, destroy habitat and spread diseases. Introduced plants and animals are often found in the riparian zone because the waterway naturally attracts and provides habitat for them. The waterways themselves may also be affected by aquatic weeds and introduced fish species. The framework proposes the presence of aquatic weeds, the presence of introduced in-stream animals, the presence of riparian weeds, and the presence of introduced riparian species as indicators for introduced species (Table 26).

Table 26 Proposed indicators and examples of measures for assessing the 'introduced animal and plant species' threat to a waterway unit

Introduced animal and plant species threats	
Indicator	**Examples of measures**
Presence of aquatic weed species	Presence and abundance of introduced algal species
	Presence and abundance of introduced aquatic macrophyte species

Introduced animal and plant species threats	
Indicator	**Examples of measures**
Presence of introduced in-stream animal species	Presence and abundance of introduced in-stream macroinvertebrate species such as introduced crayfish Presence and abundance of introduced fish species Presence and abundance of introduced amphibian species such as cane toads
Presence of riparian weed species	Presence and % cover of understorey weeds Presence and % cover of middle storey weeds Presence and % cover of upper storey weeds
Introduced riparian animal species	Presence and abundance of introduced animal species in riparian zones e.g. rabbits

4.7 Salinisation and waterlogging

While salinisation and waterlogging may be regarded as separate degradation processes, they are often related, especially where waterways are affected. As far as waterways are concerned, salinisation is the increase of levels of salt in a waterway or wetland. This is due mainly to increasing groundwater inflows leading to larger quantities of salt being carried directly to waterways, and to rising groundwater bringing salt stored in the soil to the land surface where it may be washed away and carried into waterways.

Rising groundwater levels have also resulted in increased flows in waterways and wetlands, both in terms of level and duration. This has caused many streambeds to be waterlogged for longer periods of time. The framework proposes that conductivity (or salinity) levels, the presence of deep drainage, and the occurrence of selected biotic components be used as indicators for salinisation (Table 27).

Table 27 Proposed indicators and examples of measures for assessing the 'salinisation' threat to a waterway unit

Salinisation and waterlogging threats	
Indicator	**Examples of measures**
Conductivity or salinity	Extent to which present salinity levels exceed historical values or those of minimally affected 'reference' systems Yearly increase of salinity
Biota	Evidence of increased presence and extent of salt-tolerant plant species Evidence of the disappearance or decline of salt-sensitive animal and plant species Evidence of increased presence and extent of salt-tolerant animal species

Salinisation and waterlogging threats	
Indicator	**Examples of measures**
Extent of inundation and waterlogging	Extent to which present flow rates exceed historical values or those of minimally affected 'reference' systems in terms of levels and duration Presence and extent of dead and dying native fringing vegetation Evidence of absence of, or reduced regeneration of, native riparian plants

4.8 Acidification

Most natural inland waterways in Western Australia are neutral (neither acidic nor alkaline). However, acidification of surface waters may be caused by either rising acidic groundwater being brought to the surface, or by the exposure of natural sulfides in rocks or soils which then become oxidised. This triggers chemical and microbiological reactions that generate significant amounts of sulfuric acid, which may damage riverine habitat and biodiversity and even sterilise the aquatic environment. Where acidity is severe, infrastructure (such as concrete pilings) may be damaged. This framework proposes the use of pH, presence of deep drainage, biota, and soils as indicators for assessing the degree of acidification of a waterway (Table 28).

Table 28 Proposed indicators and examples of measures for assessing the 'acidification' threat to a waterway unit

Acidification threats	
Indicator	**Examples of measures**
pH	Extent to which present pH levels are lower than historical values or those of minimally affected 'reference' systems Yearly decrease in pH levels
Biota	Evidence of increased presence and extent of plant species known to tolerate more acidic conditions Evidence of increased presence and extent of animal species known to tolerate more acidic conditions Evidence of the disappearance or decline of animal and plant species known to be intolerant of acidic conditions
Soils	Presence and extent of exposure and disturbance of acid sulfate soils in the catchment

4.9 Flow alteration

Alteration to flow is a major factor contributing to loss of biodiversity and ecological function in aquatic ecosystems. There are four principal anthropogenic processes that may alter flows in waterways: building dams and other flow control structures (including weirs and barrages), building crossings, flow diversion (e.g. off-river storages), or extraction of water or minerals, and alteration of flows on floodplains with levees and structures (including those on wetlands to allow water storage). Mine de-watering as a result of mining below the watertable, is an emerging problem in the north of the state. In extreme circumstances this may change what are normally seasonal streams into perennial streams, providing new habitats for introduced species.

Table 29 contains details of indicators and measures for 'flow alteration'.

Table 29 Proposed indicators and examples of measures for assessing the 'flow alteration' threat to a waterway unit

Flow alteration threats	
Indicator	**Examples of measures**
Water extraction	Extent of extraction for consumptive purposes through damming or direct piping
Floodplain connectivity	Extent of change in connectivity between waterways and floodplains and/or estuaries
Variations in runoff	Variation in runoff relative to what could be expected in a minimally affected waterway of similar type Increases in annual runoff Decreases in annual runoff
Extent of inundation and waterlogging	Extent to which present flow rates exceed historical values or those of minimally affected 'reference' systems in terms of levels and duration Presence and extent of dead and dying native fringing vegetation Evidence of absent or reduced regeneration of native riparian plants
Presence of barriers	Occurrence of obstructions such as road culverts, weirs, dams and other flow control structures to faunal passage and migration Number of dams and other flow control structures that 'break' the continuous flow of the river

4.10 In-stream habitat destruction and fragmentation

In the past, woody debris has been removed from waterways to control flooding, improve navigation, and facilitate easier fishing and swimming. This has been done with little regard for the importance of this debris as habitat or food in the system. Weirs and dams have also acted as barriers to the movement of fish and other animals, resulting in isolation of sub-populations, and consequently, reduced gene flow among these sub-populations within a waterway. In some cases, stream channels have also been modified by dredging and the removal of sand and rock bars.

Table 30 contains details of indicators and measures for 'habitat destruction and fragmentation'.

Table 30 Proposed indicators and examples of measures for assessing the 'habitat fragmentation' threat to a waterway unit

Habitat destruction and fragmentation threats	
Indicator	**Examples of measures**
Barriers	Presence and influence of barriers to fish migration
	Presence and influence of dams and other flow control structures on the continuous flow of the river
Occurrence of de-snagging and straightening	Extent of removal of woody debris from waterways
Gene flow	Degree of genetic differentiation of sub-populations of plants or animals

5 Case studies

This section provides worked examples of applying the framework. These trials aimed to demonstrate how the framework could be applied at different scales and to determine its effectiveness when data was limited. Any deviations from the framework process are highlighted in each trial, as are the difficulties encountered and how they were dealt with.

The four case studies are:

- a subcatchment scale trial of the Fortescue River in the Pilbara Region using secondary data from desktop sources available from the Internet and published documents (this considered ecological, social and economic values)
- at a catchment scale, an ecological assessment of the major waterways in the South Coast region using high-quality primary data
- at a reach scale, an assessment of the Berkeley River in the north-east Kimberley exploring the potential for assessment where only minimal data is available (this considered ecological, social and economic values)
- a reach scale assessment of the Marbellup Brook involving high-quality primary ecological and social data (this also only considered ecological, social and economic values).

The Fortescue River trial conducted at a subcatchment scale is presented first as it details each step in the framework process. These were:

- obtaining data
- scoring values and threats
- creating the values–threats prioritisation matrix
- determining management responses.

As this trial was completed using limited and largely subjective data, it also looked at data weighting and confidence indices.

5.1 Subcatchment scale: Fortescue River (low quality data)

Data for this case study were obtained from published sources, reports and the Wetland Base database (available online on Department of Environment and Conservation website). The Fortescue River includes a number of areas already recognised for their special ecological and social values, including:

- *Directory of important wetlands in Australia* (Environment Australia 2001) listings
- Fortescue Marshes (subcatchments 2921 and 2810)
- Millstream Ponds, including Deep Reach pool (subcatchment 2927) (Figure 6)
- Wetlands of sub-regional significance between Millstream and Goodiadarrie Hills (subcatchments 2921, 2920, 2923 and 2926)

- Karijini National Park (subcatchment 2921).

Figure 6 Fortescue River, Millstream National Park

Determine purpose of assessment

The Fortescue River is located in the Pilbara region of Western Australia. A comparative assessment of the ecological, social and economic values of this river system has yet to be undertaken. The overall objective of this trial was thus to conduct a comparative assessment of the ecological, social and economic values of, and threats faced by, subcatchments along the Fortescue River.

Select appropriate assessment scale

This trial has been undertaken at a 'subcatchment' scale. Subcatchments used in this study were restricted to those directly on the Fortescue River (Figure 7). All data collected were attributed to these subcatchments for analysis. Selection of the subcatchment scale in this trial reflects not only the spatial scale of many degrading processes in the Fortescue River, but also the availability of data.

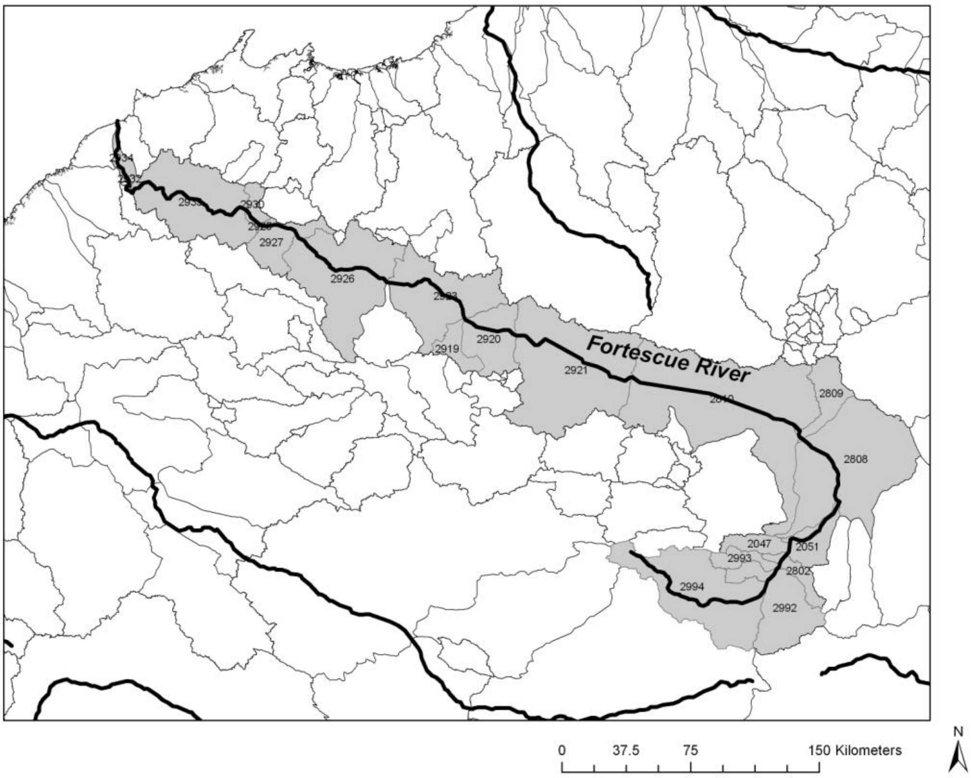

Figure 7 Fortescue River subcatchments. Grey subcatchments indicate those included in the trial.

Identify and score values criteria, indicators and measures

Ecological, social and economic criteria, indicators and measures were selected to assess the values of the 20 subcatchments along the Fortescue River system.

Ecological value was determined by 5 criteria (naturalness, representativeness, diversity, rarity, special features) using 13 indicators and 21 measures (Table 31). Social value was determined by 5 criteria (visual amenity, recreational, non-Indigenous heritage, educational, spiritual and Aboriginal heritage) using 6 indicators and 15 measures (Table 32). Economic value was determined by 3 indicators (water and mineral extraction, commerce, infrastructure) using 5 indicators and 6 measures (Table 32).

When more than one measure was used for a particular indicator, a mean score was obtained for that indicator, and all the mean indicator scores were summed to obtain a total criteria score. Criteria scores were then summed to obtain a total value score. Seasonal differences (wet and dry) were taken into account by averaging wet and dry season values separately for water quality parameters. All measures were scored on a scale of 3, where a score of 1 indicated the lowest ecological value, and a value of 3, the highest ecological value.

Values for naturalness and diversity were scored using mean values for subcatchment 2927 (Millstream) as a “pristine’ reference site.

Representativeness was scored using water quality parameters (turbidity, salinity, total nitrogen, total phosphorus and pH) compared with the ANZECC and ARMCANZ

(2000) guidelines for water quality thresholds in tropical rivers. Scores were based on the following classes:

- 3 less than or equal to the threshold or mean from the guidelines
- 2 between the threshold or mean and twice the threshold or mean
- 1 more than twice the threshold or mean.

Some measures, particularly to do with Ramsar listings or 'flagship' species were scored on the basis of 'presence'. For example, the presence of *Chelodina steindachneri* (flat-shelled turtle) automatically gives a score of 3.

All other measures were scored against the mean for each measure, with:

- 3 greater than or equal to the mean
- 2 between half the mean and the mean
- 1 less than half the mean.

An example of how to score against the mean value is shown graphically in Figure 8.

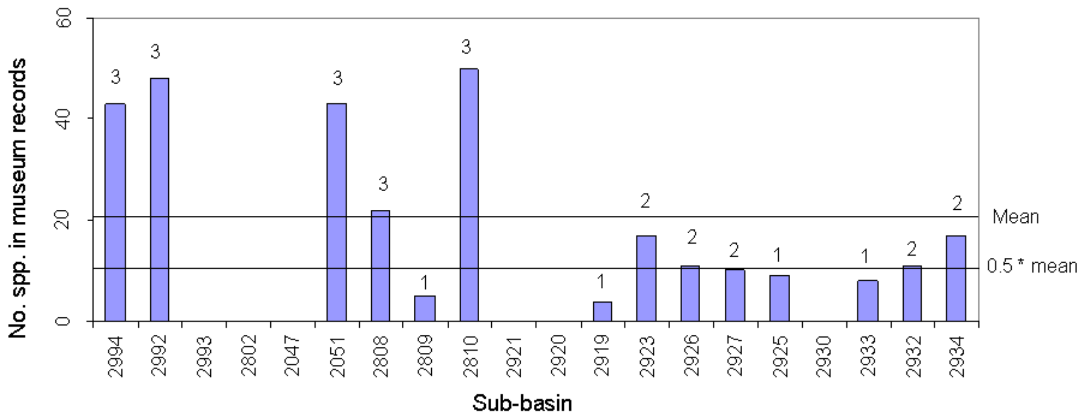

Figure 8 Example of scoring using the mean of each measure for subcatchments along the Fortescue River

Table 31 lists the ecological values and Table 32 lists the social and economic values assessed for the subcatchments along the Fortescue River, with the indicators and measures used and the way in which these were scored.

Table 31 Ecological values of subcatchments along the Fortescue River – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used	Units	Scoring*	
Naturalness	Channel disturbance	Presence and extent of sedimentation (turbidity)	NTU	Wet season 3 = ≤ 14.5 2 = 14.6–29.2 1 = > 29.2	Dry season 3 = ≤ 1.9 2 = 2–4 1 = > 4
	Variation from natural state of water chemistry	Extent to which salinity varies from natural	µS/cm	Wet season 3 = ≤ 1452 2 = 1453–2904 1 = > 2904	Dry season 3 = ≤ 2279 2 = 2280–4558 1 = > 4558
		Extent to which TN varies from natural	ppt	Wet season 3 = ≤ 482 2 = 483–964 1 = > 964	Dry season 3 = ≤ 520 2 = 520–1040 1 = > 1040
		Extent to which TP varies from natural	ppt	Wet season 3 = ≤ 60 2 = 60–120 1 = > 120	Dry season 3 = ≤ 30 2 = 31–60 1 = > 60
		Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (EPT)	Number of taxa	Wet season 3 = ≥ 3.66 2 = 1.83–3.65 1 = < 1.83	Dry season 3 = ≥ 5.25 2 = 2.6 -5.24 1 = < 2.6
	Invertebrate diversity	Total macroinvertebrate species richness	Number of taxa	3 = ≥ 23 2 = 11.5–23 1 = < 11.5	

Criteria	Indicator	Measures used	Units	Scoring*
	Vertebrate diversity	Total fish species richness (native freshwater species)	Number of species	3 = ≥ 2.9 2 = 1.45–2.8 1 = < 1.45
		Total frog species richness	Number of species	3 = > 1.2 2 = 0.6–1.2 1 = < 0.6
		Total number of vertebrate species in Western Australia museum records	Number of species	3 = ≥ 21 2 = 11.5–20 1 = < 11.5
Representativeness	Water quality characteristics	Measure of how well pH conforms to a tropical river (ANZECC & ARMCANZ guidelines (2000) – upper and lower thresholds)		3 = 6–8 2 = 8–9 or 5–6 1 = > 9 or < 5
Rarity	'Flagship' species	Presence of *Chelodina steindachneri* (flat-shelled turtle)		3 = present
	Endemic or rare species	Presence of *Livistonia alfredii* (Millstream fan palm), *Leioptherapon aheneus* (Fortescue grunter) and *Nosostica pilbara* (dragonfly)	Number of species	3 = ≥ 2 2 = 1 1 = 0
	Threatened and priority species	Number of listed faunal species	Number of species	3 = ≥ 1 1 = 0
Special features	Drought refuge	Number of permanent pools		3 = ≥ 2 2 = 1 1 = 0

Criteria	Indicator	Measures used	Units	Scoring*
	Biotic special features	Number of waterbird species breeding at the site	Number of species	3 = ≥ 6 2 = 3–5 1 = < 2
	Significant areas	Presence of national parks, wetlands listed in the *Directory of Important Wetlands in Australia* (Environment Australia, 2001) or wetlands of sub-regional significance		Presence = 3
	Significant scientific sites	Number of areas that have been well studied scientifically	Number of sites	3 = ≥ 7 sites 2 = 3.5–6 sites 1 = < 3 sites

**Scoring based on means or thresholds as outlined above.*

Table 32 Social and economic values of subcatchments along the Fortescue River – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used	Scoring
Visual amenity	Appealing waterscape[1,2]	Number of gorges present	3 = ≥ 2 2 = 1
		Number of permanent pools	3 = ≥ 2 2 = 1
		Number of scenic lookouts	3 = ≥ 2 2 = 1
		Number of picnic areas	3 = ≥ 2 2 = 1
		Photographs of pools and river sections scored visually for aesthetic appeal[2,3]	3 = highly appealing 2 =moderately appealing 1 = low or not appealing
Recreational	Swimming[1,2]	Number of pools suitable for swimming	3 = ≥ 2 2 = 1
	Bushwalking[1,2]	Number of walking tracks/trails	3 = ≥ 3 2 = ≤ 2
	Camping[1,2]	Number of known caravan and camp sites with facilities	3 = ≥ 2 2 = 1
	Canoeing[1,2]	Number of known canoeing locations	3 = ≥ 2 2 = 1
	Recreational fishing[1,2]	Number of known fishing locations	3 = ≥ 2 2 = 1
Non-Indigenous heritage	Historic/heritage buildings[1,2]	Presence of historic homesteads	3 = present
		Presence of heritage listed buildings	3 = present
Educational	Opportunities for learning[1,2]	Presence of information signage	3 = present and in national park 2 = present

Criteria	Indicator	Measures used	Scoring
Spiritual	Sites of cultural significance[4]	Number of Aboriginal sites near river	3 = ≥ 20 2 = 10 – 19 1 = ≤ 9
	Culturally significant waterholes or pools[2]	Presence of culturally significant waterholes or pools	3 = present
Water and mineral extraction	Potable water supply[5]	Presence of bores in well fields	3 = present
	Mineral extraction[1]	Number of mines	3 = ≥ 3 2 = 3 1 = 1
Commerce	Water-based tourism[2,3]	Number of photos found on the Internet of river reaches or pools	3 = highly photographed 2 =moderately photographed 1 = rarely photographed
		National parks	3 = present
Infrastructure	Waterway crossings[1]	Presence of bridges (road)	3 = present
	Water collection/storage[5]	Quantity of water collected or stored	3 = 32 GL

[1]*Roads and tracks Western Australia (Quality Publishing Australia 2008)*

[2]*DEC website (national parks information) and management plans*

[3]*Google image search on Internet for pools and Fortescue River, and images from published reports.*

[4]*Wetland Base database*

[5]*Department of Water reports*

Table 33 shows the calculated scores for ecological, social and economic values of the 20 Fortescue River subcatchments. Total scores of values (ecological, social and economic) were converted to proportions to account for missing values in the data set. Proportions were calculated as total score divided by total possible score of those criteria that had scores, where the total possible score of scored criteria = the number of indicators scored multiplied by 3.

Table 33   Subcatchment scores for ecological, social and economic values along the Fortescue River

Sub-catchment	Ecological					Social					Economic			Total (proportion)*
	Naturalness	Representativeness	Diversity	Rarity	Special features	Visual amenity	Recreational	Non-Indigenous heritage	Educational	Spiritual	Water and mineral extraction	Commerce	Infrastructure	
2994	8.0	2.3	5.3	5.0	2.0	3.0	4.0		2.0	3.0	1.0	1.0	3.0	0.69
2992	7.0	2.3	5.3	5.0	2.0	3.0	4.0			3.0	1.0	1.0	3.0	0.68
2993	8.3	3.0	4.0	1.0	1.0	2.0	0.0							0.73
2802	9.0	3.0	4.0	1.0	1.0		0.0			1.0				0.70
2047				0	0		2.0							0.67
2051			2.3	7.0	2.0		0.0			1.0				0.59
2808			3.0	3.0	2.0		0.0			1.0				0.50

Sub-catchment	Ecological					Social					Economic			Total (proportion)*
	Naturalness	Representativeness	Diversity	Rarity	Special features	Visual amenity	Recreational	Non-Indigenous heritage	Educational	Spiritual	Water and mineral extraction	Commerce	Infrastructure	
2809			1.5	5.0	1.0		0.0			1.0				0.47
2810	4.7	2.5	3.5	5.0	10.0	2.0	0.0			1.0	3.0	1.0		0.63
2921	9.0	2.3	6.0	2.0	10.0	2.8	9.0					3.0		0.93
2920				0.0	5.0	2.6	7.0		3.0			3.0		0.86
2919			2.0	6.0	1.0		0.0		3.0	1.0				0.48
2923	6.7	3.0	4.7	7.0	9.0	3.0	2.0			2.0				0.79
2926	4.6	3.0	3.5	5.0	7.0	2.0	0.0			3.0	3.0			0.69
2927	9.0	2.3	5.0	7.0	12.0	2.6	12.0	3		6.0	3.0	3.0		0.91
2925	7.2	2.0	3.5	5.0	4.0	2.0	0.0		3.0	3.0	3.0			0.76

Sub-catchment	Ecological					Social					Economic			Total (proportion)*
	Naturalness	Representativeness	Diversity	Rarity	Special features	Visual amenity	Recreational	Non-Indigenous heritage	Educational	Spiritual	Water and mineral extraction	Commerce	Infrastructure	
2930				0.0	3.0		0.0			1.0				0.44
2933		1.0	1.3	3.0	6.0	3.0	0.0			3.0	3.0			0.65
2932	9.0	2.25	5.0	7.0	5.0	2.3	2.0			3.0		1.0		0.77
2934	8.0	2.0	3.3	6.0	5.0	2.0	4.0		2.0	3.0				0.65

** Proportion calculated as total score divided by total possible score of scored criteria to account for missing data*

Identify and score threats criteria, indicators and measures

This section explains how the threats to the 20 subcatchments along the Fortescue River systems were scored.

Threatening processes were determined by four criteria (eutrophication, introduced plant and animal species, salinisation and riparian zone degradation) using four indicators and six measures (Table 34).

When more than one measure was used for a particular indicator, a mean score was obtained for that indicator, and all the mean indicator scores were summed to obtain a total threatening process score. All measures were scored on a scale of 3, where a score of 1 indicated the lowest threat, and a value of 3, the highest.

Threatening processes scored using water quality data (salinisation and eutrophication) were scored using ANZECC and ARMCANZ (2000) thresholds for water quality in tropical rivers.

An example of how to score threatening processes (in this case salinisation) against these thresholds is shown graphically in Figure 9. For this threatening process, the scores were assigned as follows:

- 1 less than or equal to 250 µS/cm
- 2 between 251 and 1200 µS/cm
- 3 greater than or equal to 1201 µS/cm.

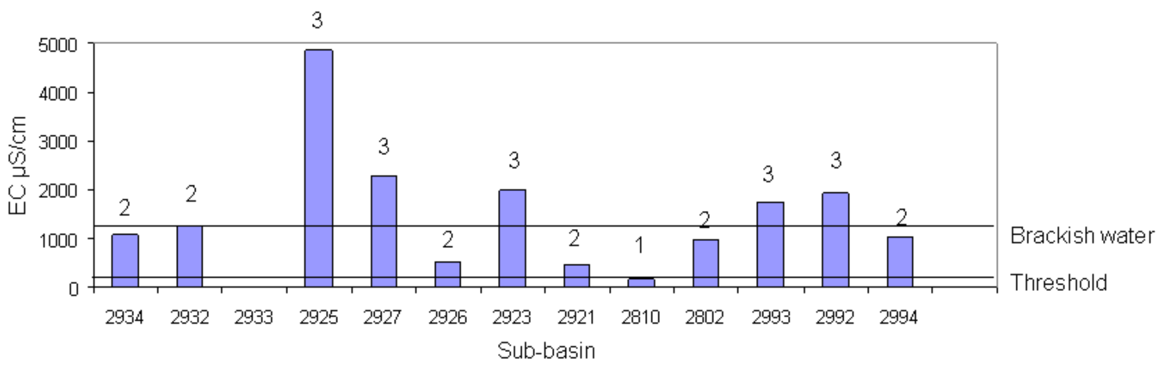

Figure 9 Example of scoring salinity using ANZECC & ARMCANZ (2000) water quality thresholds for tropical rivers for subcatchments along the Fortescue River

Table 34 Threats to subcatchments along the Fortescue River – criteria, indicators and measures used for assessment

Criteria	Indicator	Measure	Units	Scoring
Eutrophication	Nutrients	Extent to which total nitrogen levels exceed ANZECC and ARMCANZ (2000) thresholds for tropical rivers	µg/L	1 = ≤ 300 2 = 301–1000 3 = ≥ 1001
		Extent to which total phosphorus levels exceed ANZECC and ARMCANZ (2000) thresholds for tropical rivers	µg/L	1 = ≤ 10 2 = 11–50 3 = ≥ 51
Introduced animal and plant species	Presence of introduced plant and animal species	Presence of animal species		1 = none 3 = present
		Presence of introduced plant species		1 = none 2 = present (not including declared weeds) 3 = includes declared weeds e.g. *Parkinsonia*
Salinisation	Salinity	Extent to which salinity levels exceed ANZECC and ARMCANZ (2000) thresholds for tropical rivers	µS/cm	1 = ≤ 250 2 =251–1200 3 = ≥1201
Riparian zone degradation	Overgrazing	Presence of livestock and mention of overgrazing as a threat in literature		1 = livestock present, but no overgrazing 2 = moderate overgrazing 3 = highly overgrazed

Scores for threatening processes were totalled and converted to proportions to account for missing values in the data set (Table 35).

Table 35 Subcatchment threat scores along the Fortescue River

Subcatchment	Eutrophication	Introduced animal and plant species	Salinisation	Riparian zone degradation	Total (proportion)*
2994	1.00		1.5	3.0	0.61
2992	1.75		3.0	1.0	0.64
2993	0.50		3.0	1.0	0.61
2802	1.00		2.0	1.0	0.44
2047					

Subcatchment	Eutrophication	Introduced animal and plant species	Salinisation	Riparian zone degradation	Total (proportion)*
2051		3.0		3.0	1.00
2808		3.0		3.0	1.00
2809					
2810	3.00	3.0	1.0	3.0	0.83
2921	1.00	5.0	1.5	3.0	0.70
2920		2.0			0.67
2919					
2923	2.00	3.0	2.5		0.83
2926	2.50	3.0	1.5		0.78
2927	2.00	6.0	3.0	3.0	0.93
2925	1.25	6.0	3.0		0.85
2930					
2933		5.0	2.0		0.78
2932	1.25	5.0	2.0		0.69
2934	1.25	5.0	2.0		0.69

**Proportion calculated as total score divided by total possible score of scored criteria to account for missing data*

Choose categories for management priorities

Management prioritisation categories (1 = high priority, 2 = medium priority and 3 = low priority) were determined by plotting the total scores for threatening processes (as proportions) against total value scores (as proportions) for each subcatchment. Once plotted, the x and y axes were divided into 3 equal parts. The range of each part was determined by:

$$\frac{\text{Maximum value or threat total score - minimum value or threat total score}}{3}$$

The prioritisation matrix for the Fortescue river subcatchments is shown in Figure 10.

Due to the lack of data for threats for some subcatchments in this trial (subcatchments 2047, 2809, 2919 and 2930) these waterways were unable to be prioritised in the matrix. These subcatchments were distributed fairly evenly along the length of the Fortescue River.

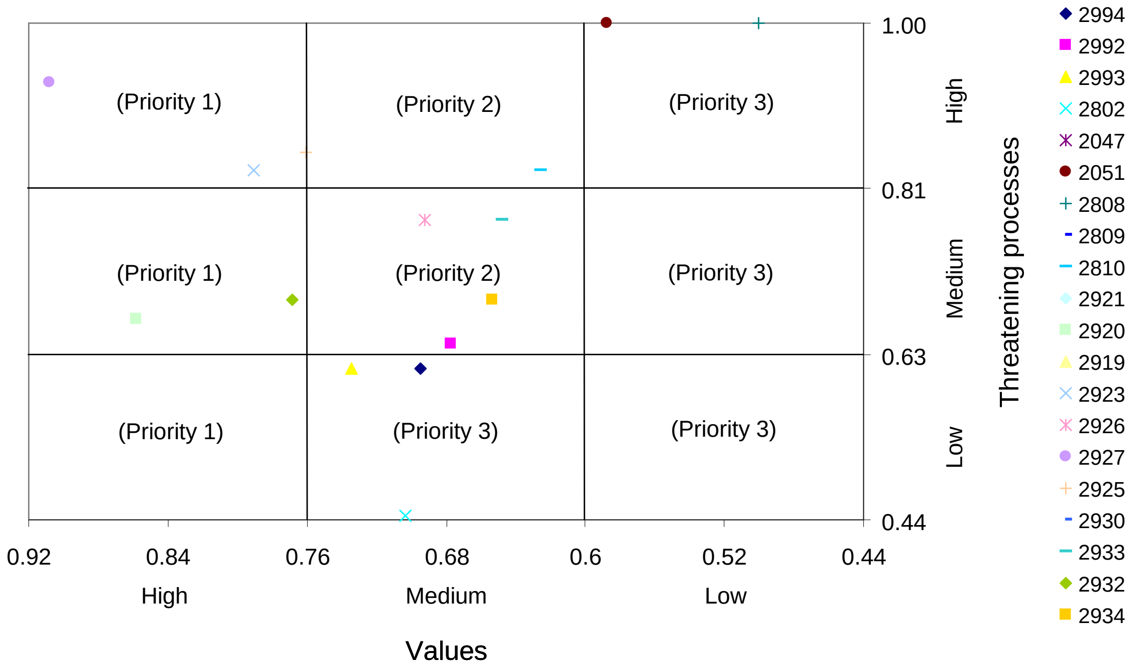

Figure 10 Summary matrix of values, threats and priorities for subcatchments on the Fortescue River

Before a final decision on priorities was made in this case, confidence indices were calculated because of the large amount of data missing, and weighting was carried out to reduce the influence of indicators scored by presence or absence or qualitative data and to give preference to more quantitative data.

Confidence indices

Confidence indices may prove useful where there is uncertainty in the management prioritisation framework outcomes or where further prioritisation within categories is needed. Confidence indices were calculated as:

$$\frac{\text{Total possible score of indicators scored}}{\text{Total possible score if all indicators were scored}}$$

Confidence indices were also plotted within the value and threat matrix. Figure 11 shows the summary matrix of confidence indices for values and threats for subcatchments on the Fortescue River.

Regressions of confidence indices against value or threat scores were also done to ensure that value and threat rankings were independent of the quantity of data scored (Figure 12). The low R^2 values indicate that there were no relationships between data quantity and value or threat rankings in this trial.

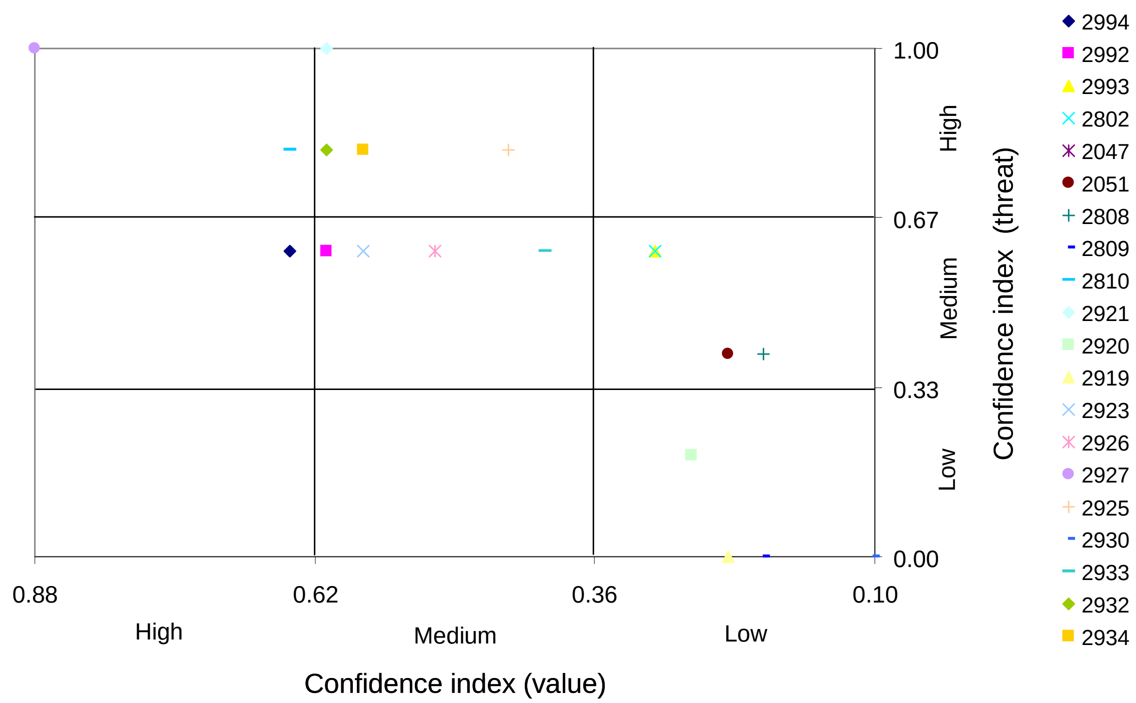

Figure 11 Summary matrix of confidence indices for values and threats for subcatchments on the Fortescue River

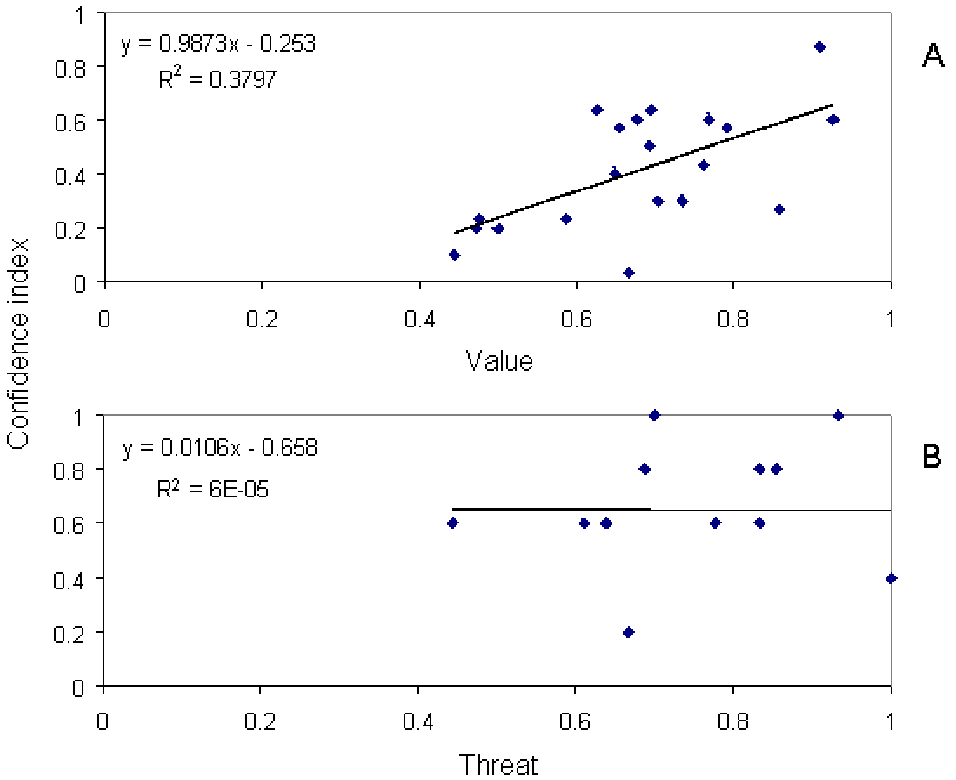

Figure 12 Relationships between confidence indices and values (A) and threats (B) for subcatchments on the Fortescue River, Pilbara Region

Weighting of values

To further explore the robustness of data in this trial, a data weighting exercise was carried out. Weighting was used to reduce the influence of indicators scored by presence or absence or qualitative data and to preferentially favour more quantitative data such as water quality.

Weighted scores were calculated as follows:

Weighted value score = (ecological score x 2) + (social score) + (economic score)

Weighted threatening processes score = ((salinity score + eutrophication score) x 2) + (introduced species score) + (overgrazing score)

The prioritisation matrix of weighted ecological values and threatened processes using water quality data is shown in Figure 13.

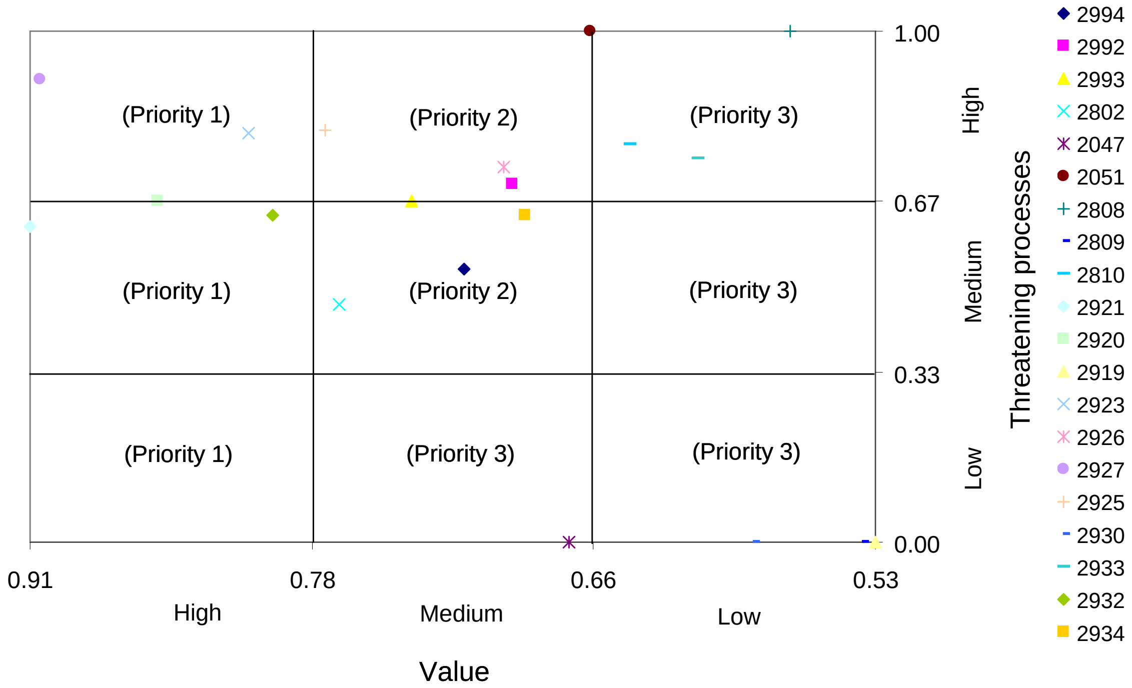

Figure 13 Summary matrix of weighted values and threats for subcatchments on the Fortescue River

A comparison of management prioritisation rankings using weighted versus non-weighted total scores for subcatchments is shown in Table 36. The weighting process did not affect subcatchments which had previously been ranked Priority 1. However, weighting changed the ranking of subcatchment 2925 which was borderline Priority 1 in the first analysis and became a Priority 2 subcatchment when weighted. Weighting also raised the ranking of Priority 3 subcatchments to become Priority 2. Obviously changes in ranking of Priority 2 and 3 subcatchments with weighting are only likely to become an issue where funding is available to support management activities at this level.

Table 36 Comparison of management prioritisation rankings using weighted and non-weighted total scores

Subcatchment	Management prioritisation	
	Non-weighted ranking	Weighted ranking
2994	3	2*
2992	2	2
2993	3	2*
2802	3	2*
2047	No data on threats	
2051	3	2*
2808	3	3
2809	No data on threats	
2810	2	3*
2921	1	1
2920	1	1
2919	No data on threats	
2923	1	1
2926	2	2
2927	1	1
2925	1	2*
2930	No data on threats	
2933	2	3*
2932	1	1
2934	2	2

** indicates changed rank due to weighting*

Figure 14 presents a map displaying the final priority categories for the subcatchments of the Fortescue River.

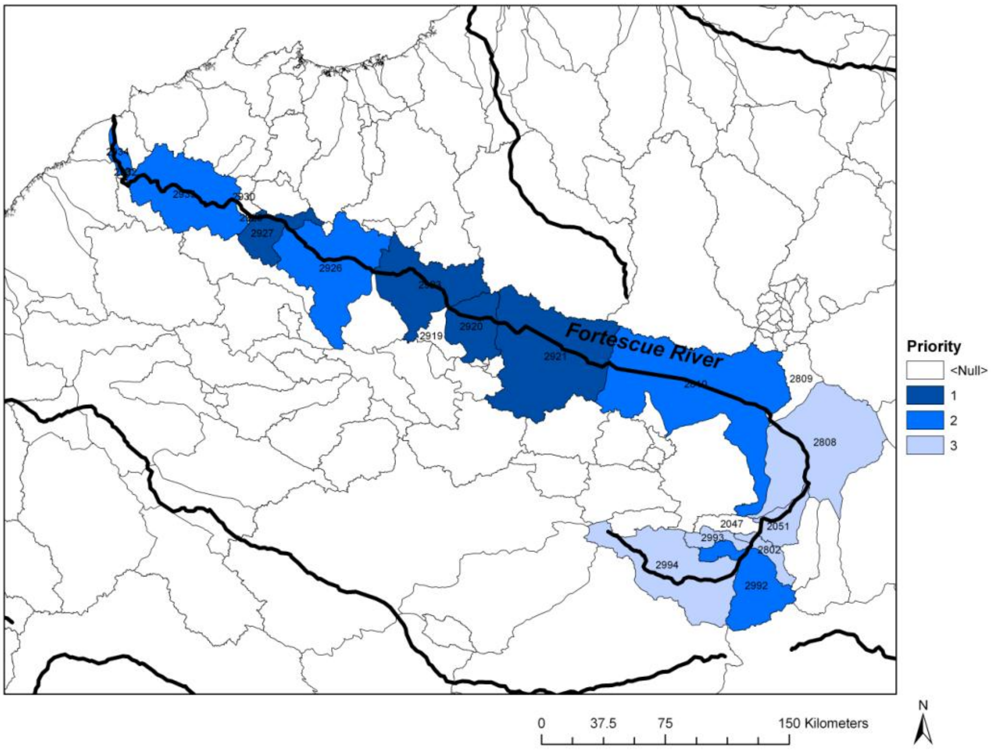

Figure 14 Waterway management priorities for subcatchments on the Fortescue River

Subcatchments which were ranked as Priority 1 waterways were 2921, 2920, 2923, 2927 and 2932. These included areas along the Fortescue River already recognised for their special ecological and social values, including:

- *Directory of important wetlands in Australia* (Environment Australia 2001) listings:
    - Fortescue Marshes (2921 and 2810)
    - Millstream Ponds, including Deep Reach pool (2927)
- Wetlands of sub-regional significance between Millstream and Goodiadarrie Hills (2921, 2920, 2923 and 2926)
- Karijini National Park (2921).

For inclusion in the *Directory of important wetlands in Australia* (Environment Australia 2001), wetlands are required to meet at least one of the following criteria, as agreed to by the ANZECC Wetlands Network. Fortescue Marshes and Millstream Ponds meet the first four criteria.

- It is a good example of a wetland type occurring within a biogeographic region in Australia.
- It is a wetland which plays an important ecological of hydrological role in the natural functioning of a major wetland system or complex.
- It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.

- The wetland is of outstanding historical or cultural significance.
- The wetland supports 1% or more of the national populations of any native plant or animal taxa.
- The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level.

Subcatchment 2925 was ranked Priority 1 before weighting. Subcatchment 2925 contains Dogger Gorge and is also listed as a wetland of sub-regional significance. Weighting downgraded this subcatchment to a Priority 2 waterway, highlighting the need to consider carefully any weighting or data manipulation applied during scoring. This is especially significant for waterways where data is lacking or is qualitative rather than quantitative.

The lack of data for less accessible areas along the Fortescue River was also likely to have caused the portion of the Fortescue Marshes (listed in the *Directory of important wetlands in Australia* (Environment Australia 2001)) located in subcatchment 2810 to be ranked as a Priority 2 waterway. Clearly, in this situation, prioritisation using the framework did not reflect the marsh's importance as a breeding ground for migratory birds or other important ecological values. This may indicate that the framework is more suitable for assessing permanent waterways and pools and is less able to score the values of ephemeral and less defined waterways such as floodplains. However, in the case of the Fortescue Marshes, this could be overcome by higher scoring of *Directory of important wetlands in Australia* (Environment Australia 2001) or Ramsar wetlands.

Data limitations may have also caused some subcatchments to score lower for threatening processes. Where data is limited, consultation with stakeholders may assist in rectifying these difficulties.

Importantly, this trial shows it is possible to prioritise management activities for waterways in northern Western Australia and where information is scarce or more qualitative.

Identify appropriate management response

The next step that would normally be undertaken at this stage involves identifying appropriate management responses for each of the subcatchments, based on the prioritisation revealed by the assessment. However, since the trials presented in this report are essentially test cases, where the purpose is to demonstrate and verify the prioritisation procedures, this final step was not undertaken.

Refer to sections 2.6 to 2.8 for further information on choosing priorities, identifying appropriate management responses, other factors that need to be considered and designing the management response.

5.2 Reach scale: Marbellup Brook (high quality data)

Determine purpose of assessment

This trial used data from a recent study, aimed at determining the effects of blue gum plantations and other land uses in the catchment, to assess the relative value of reaches along Marbellup Brook, with a view to informing the ecological water requirements process.

The Water Corporation has identified Marbellup Brook as a potential catchment for future drinking water supplies as demand for drinking water supplies for Albany increases. An ecological water requirements study and a social water requirements study have recently been commissioned. Both of these studies rely on understanding the values and threats in this system. This trial aims to assess the values and threats across reaches of Marbellup Brook.

Select appropriate assessment scale

This trial has been undertaken at a ‘reach’ scale. Data for 28 sites were assigned to one of 10 reaches falling into four subcatchments (Table 37).

Table 37 Reaches of Marbellup Brook assessed for values and threats

Reach	Subcatchment	Sites
1	Central Marbellup	6
2	West Marbellup	5,16,17,18
3	Central Marbellup	1, 2, 3, 4
4	Marbellup Down Road	12, 13
5	Marbellup Down Road	11
6	Marbellup Down Road	7, 8, 9, 10, 14, 15
7	North Marbellup	28
8	North Marbellup	23, 26, 27
9	North Marbellup	25
10	North Marbellup	19, 20, 21, 22, 24

Identify and score values criteria, indicators and measures

Three ecological value criteria (naturalness, diversity and rarity), one cultural value criterion (spiritual) and two economic value criteria (water consumption and infrastructure) were selected for assessing the overall value of each reach (Table 38).

Table 38 Ecological, social and economic values of subcatchments along Marbellup Brook – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used	Units	Scoring
Naturalness	Level of riparian zone disturbance	Width of intact, native riparian zone	m	1 = < 5 2 = 5–20 3 = > 20
		Canopy cover of native vegetation	%	1 = < 25 2 = 25–50 3 = > 50
		Presence of understorey weeds	% cover	1 = > 50 2 = 20–50 3 = < 20
	Channel disturbance	Presence and extent of bank erosion	%	1 = > 50 2 = 20–50 3 = < 20
		Presence and extent of sedimentation	%	1 = > 50 2 = 20–50 3 = < 20
	Variation from natural state of water chemistry	Extent to which salinity varies from natural	ppt	1 = > 5 2 = 2–5 3 = < 2
		Extent to which total phosphorus varies from natural	µg/L	1 = > 100 2 = 50–100 3 = < 50
	Biotic variation	Number of macroinvertebrate species	taxa	3 = ≥ 25 2 = 12.5–24 1 = < 12
		Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies)	Number of species	3 = ≥ 7.2 2 = 3.6–7.2 1 = < 3.5
Diversity	Macroinvertebrate species richness	Number of macroinvertebrate species	taxa	3 = ≥ 26 2 = 13–25 1 = < 12
	In-stream habitat heterogeneity	Index of in-stream habitat diversity based on total % cover of submerged, emergent and overhanging vegetation, leaf litter, woody debris and snags	points	1 = 0-7 2 = 8–14 3 = > 14

Criteria	Indicator	Measures used	Units	Scoring
	Channel heterogeneity	Index of substrata diversity based on total % cover of clay, mud, peat, sand, gravel, cobble and rock	points	1 = 1 2 = 2–3 3 = > 3
Rarity	'Flagship' species	Presence of decapods		3 = koonacs present 2 = shrimps but no koonacs 1 = no endemic decapods
	Endemic or rare species	Presence of endemic caddisfly and mayfly species	Number of species	Caddisfly 3 = ≥ 6 2 = 4–5 1 = 0–3 Mayfly 3 = ≥ 3 2 = 2 1 = 0–1
Spiritual	Sites of cultural significance	Presence of Aboriginal sites nearby river		3 = present 1 = 0 sites
Water and mineral extraction	Potable water supply	Potential sites for water abstraction		3 = present 1 = 0 sites
Infrastructure	Waterway crossings	Number of road crossings on reach		3 = 3 2 = 2 1 = 0–1

Naturalness was assessed by scoring four indicators: riparian disturbance, channel disturbance, water chemistry variation and biotic variation (Table 39). The reaches assessed had very similar levels of naturalness (range of 9.1 to 11.5).

Table 39 Scores of each reach assessed for the Marbellup Brook for four indicators of the degree of 'naturalness'

Reach	Riparian disturbance	Channel disturbance	Water chemistry variation	Biotic variation	Naturalness total
1	1.7	2.5	2.5	3.0	9.7
2	2.1	2.6	2.9	2.0	9.7
3	1.9	2.6	2.5	2.1	9.1
4	2.0	2.5	2.5	2.5	9.5
5	3.0	3.0	3.0	2.5	11.5
6	2.5	3.0	2.5	2.3	10.2
7	2.7	2.8	3.0	2.5	10.9

Reach	Riparian disturbance	Channel disturbance	Water chemistry variation	Biotic variation	Naturalness total
8	2.3	2.8	3.0	2.7	10.7
9	1.5	2.3	3.0	3.0	9.8
10	2.1	3.0	2.6	2.4	10.0

The degree of diversity was assessed using three indicators: channel diversity, habitat diversity and biotic diversity (Table 40). Values ranged from 5.0 to 6.5, suggesting that reaches were fairly similar in terms of their diversity when using the measures selected.

Table 40 Scores of each reach assessed for the Marbellup Brook for three indicators of the degree of 'diversity'

Reach	Channel diversity	Habitat diversity	Biotic diversity	Diversity total
1	1.5	1.0	3.0	5.5
2	1.4	1.5	2.3	5.1
3	1.5	1.5	2.5	5.5
4	2.5	1.5	2.5	6.5
5	1.0	2.0	2.0	5.0
6	1.8	1.5	2.5	5.8
7	1.5	1.0	3.0	5.5
8	1.6	1.2	2.8	5.6
9	2.0	1.0	3.0	6.0
10	1.7	1.9	2.5	6.1

The 'rarity' criterion was assessed using two indicators: presence of 'flagship' species (koonacs and shrimps), and the presence of endemic caddisfly and mayfly species (Table 41). Reach 5 scored highest (4.5) for the presence of 'flagship' and endemic species, while reaches 7 and 9 scored the lowest (2.5 for both).

Table 41 Scores of each reach assessed for the Marbellup Brook for three indicators of the degree of 'rarity'

Reach	'Flagship' species	Endemic species	Rarity total
1	3.0	2.0	5.0
2	1.5	1.1	2.6
3	2.0	1.3	3.3
4	3.0	1.3	4.3
5	3.0	1.5	4.5
6	1.8	1.5	3.3
7	1.0	1.5	2.5
8	2.0	1.5	3.5
9	1.0	1.5	2.5
10	2.5	1.6	4.1

When scores for naturalness, diversity and rarity were added together to obtain an overall score for ecological values (thus a weighting of 4:3:2 for naturalness:diversity:rarity), reach 5 was assessed as having the highest ecological value score (21.0), and reach 2, the lowest ecological value score (17.4) (Table 42).

Table 42 Scores of each reach assessed for the Marbellup Brook for overall ecological value

Reach	Naturalness	Diversity	Rarity	Total ecological value	Relative score on scale of 0–1
1	9.7	5.5	5.0	20.2	0.75
2	9.7	5.1	2.6	17.4	0.64
3	9.1	5.5	3.3	17.9	0.66
4	9.5	6.5	4.3	20.3	0.75
5	11.5	5.0	4.5	21.0	0.78
6	10.2	5.8	3.3	19.4	0.72
7	10.9	5.5	2.5	18.9	0.70
8	10.7	5.6	3.5	19.8	0.73
9	9.8	6.0	2.5	18.3	0.68
10	10.0	6.1	4.1	20.2	0.75

Social and economic values were assessed using three criteria (spiritual, water and mineral extraction, and infrastructure), with a maximum possible score of 9 (Table 43).

Table 43 Scores of each reach assessed for the Marbellup Brook for overall social and economic value

Reach	Spiritual	Extraction	Infrastructure	Total	Relative score on scale of 0-1
1	1	3	2	6	0.67
2	1	1	2	4	0.44
3	1	1	1	3	0.33
4	1	1	2	4	0.44
5	1	1	2	4	0.44
6	1	1	3	5	0.56
7	1	1	1	3	0.33
8	1	1	1	3	0.33
9	1	3	2	6	0.67
10	1	1	1	3	0.33

The total scores for ecological, social and economic values were added together to obtain a total value score for each reach.

Identify and score threats criteria, indicators and measures

Six threatening processes (erosion and sedimentation, eutrophication, introduced animal and plant species, salinisation, acidification and riparian zone degradation) were selected for assessing the level of threats to the reaches of the Marbellup Brook (Table 44).

Table 44 Criteria, indicators and measures used for scoring threats to 10 reaches of the Marbellup Brook

Criteria	Indicator	Measures used	Units	Scoring
Erosion and sedimentation	Presence and extent of erosion	Presence and extent of bed incision and bank collapse	%	1 = <20 2 = 20-50 3 = > 50
	Presence and extent of sedimentation	Presence and extent of sediment plumes and bars on the streambed	%	1 = <20 2 = 20–50 3 = > 50
Eutrophication	Nutrients	Extent to which total nitrogen levels exceed those of minimally affected sites	µg/L	1 = < 1000 2 = 1000–1500 3 = > 1500
		Extent to which total phosphorus levels exceed those of minimally affected sites	µg/L	1 = < 50 µg/L 2 = 50– 00 µg/L 3 = > 100 µg/L
Introduced animal and plant species	Presence of introduced in-stream animal species	Presence and abundance of introduced crayfish and fish		1 = none 2 = either yabby or mosquitofish or trout present 3 = two or more of these species present
Salinisation	Salinity	Extent to which salinity levels exceed those of minimally affected sites	ppt	Bioregion A 1 = < 25 2 = 25–35 3 = > 35 Bioregion B 1 = < 2 2 = 2–5 3 = > 5

Criteria	Indicator	Measures used	Units	Scoring
Acidification	pH	Extent to which pH levels are lower than those of minimally affected sites		1 = > 7 2 = 5–7 3 = < 5
Riparian zone degradation	Intactness of riparian vegetation	Width of riparian zone	m	1 = > 20 2 = 5–20 3 = < 5

Possible total scores for threatening processes ranged from 6 (low or no threats) to 18 (high levels of threats). For the reaches assessed, scores ranged from 8.0 (reach 5) to 12.5 (reach 1) (Table 45).

Table 45 Threatening process scores for each reach assessed.

Reach	Erosion	Eutrophication	Exotics	Salinisation	Acidification	Riparian degradation	Total
1	1.5	2.5	2.5	3.0	1.0	2.0	12.5
2	1.4	1.3	2.1	2.5	1.5	2.0	10.8
3	1.4	2.3	2.1	1.8	1.3	2.3	11.1
4	1.3	1.9	2.0	2.5	1.5	2.0	11.1
5	1.0	1.0	1.0	2.0	2.0	1.0	8.0
6	1.0	1.6	1.6	2.2	2.0	1.4	9.8
7	1.3	1.0	2.0	2.0	1.0	1.0	8.3
8	1.3	1.2	1.7	3.0	1.7	1.8	10.6
9	1.8	1.0	2.5	3.0	1.0	3.0	12.3
10	1.0	1.8	2.1	3.0	1.3	2.3	11.3

Determine management prioritisation categories

When plotted on a matrix of values versus threats, seven of the reaches fell into the MV/MT category, and three of the reaches fell into the MV/LT category (Figure 15, Table 46).

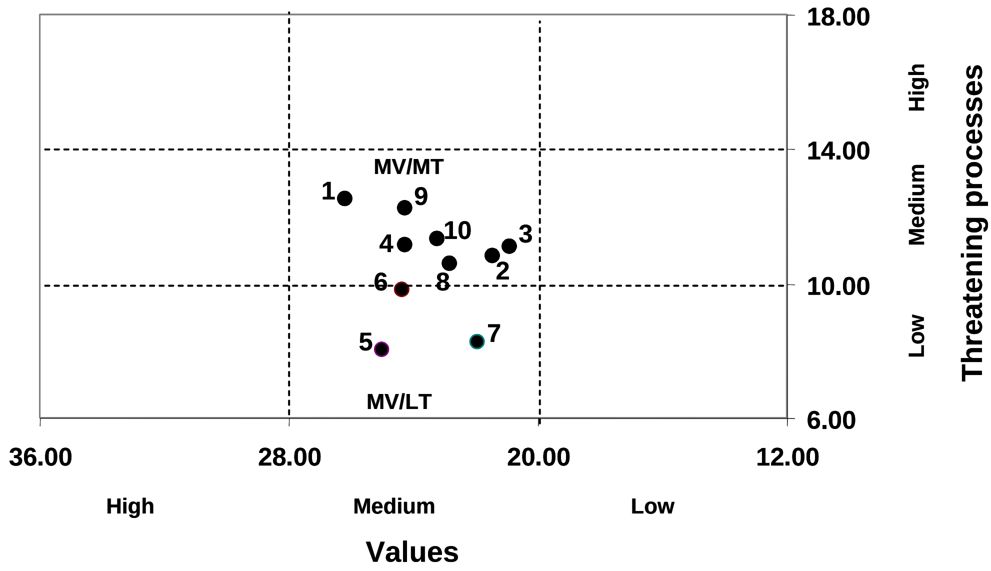

Figure 15 Summary matrix of values and threats for 10 reaches associated with the Marbellup Brook

Table 46 Classification of reaches of Marbellup Brook based on values and threats

Primary priority level	Sub-priority level	Reaches
2	2a: MV/MT	1, 2, 3, 4, 8, 9, 10
3	3a: MV/LT	5, 6, 7

Identify appropriate management responses

The lack of differentiation suggests that the measures selected for this trial, and the scoring system adopted (1, 2 or 3) did not provide sufficient resolution for classifying at the reach scale for Marbellup Brook. If reaches have similar values, are in similar condition and have comparable threatening processes operating, more detailed data would be required to separate them into more categories for management. An alternative approach would be to re-evaluate the scale of assessment, as a finer scale assessment may provide more valuable information and allow for clearer prioritisation of the waterway in this situation.

The next step that would normally be undertaken at this stage involves identifying appropriate management responses for each of the reaches, based on the prioritisation revealed by the assessment. However, since the trials presented in this report are essentially test cases, where the purpose is to demonstrate and verify the prioritisation procedures, this final step was not undertaken.

Refer to sections 2.6 to 2.8 for further information on choosing priorities, identifying appropriate management responses, other factors that need to be considered and designing the management response.

5.3 Reach scale: Berkeley River (low quality data)

The Berkeley River is located in the north-east Kimberley region of Western Australia. The river is approximately 190 km long and is highly regarded for its scenic beauty and recreational fishing. The vast majority of the river and its tributaries are located within the Oombulgurri Aboriginal Reserve and it has its headwaters in the Drysdale National Park (Figure 16).

The challenge of this assessment was that there was no readily available objective data. However, satellite imagery was available from online sources including NRM Info website, Google Earth and the Aboriginal Heritage Inquiry System of the Department of Indigenous Affairs. This data was supplemented by qualitative, subjective data provided by staff from the Department of Environment and Conservation who were familiar with the river. As all data in this trial was of a similar quality across the reaches, there was no need to preferentially weight quantitative data.

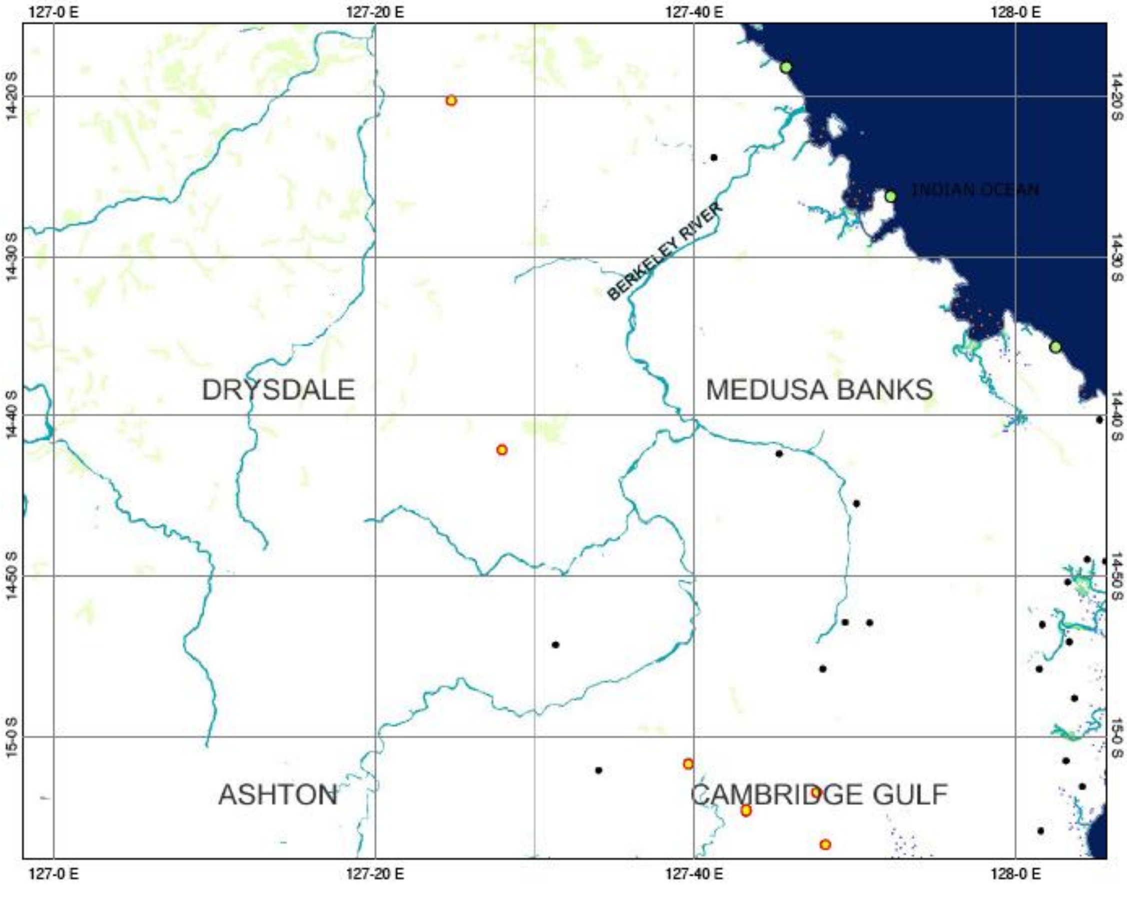

Figure 16 The Berkeley River, north-east Kimberley region

Source: MapConnect

The Berkeley River has been recognised as one of 48 'wild rivers'[2] in Western Australia, significant as a rare representative of a largely unchanged system (Figure 17).

Figure 17 Aerial photograph of the Berkeley River demonstrating 'wild river' status

Determine purpose of evaluation

As far as could be determined, a comparative assessment of the ecological, social and economic values of the Berkeley River has not been undertaken. Therefore the purpose of this trial was to conduct a brief desktop assessment of the well-known ecological, social and economic values of the river and its threats.

Select appropriate assessment scale

The Berkeley River was divided into 12 reaches ranging from 3.85 km to 35.94 km in length. No tributaries were included in the assessment.

Identify and score values criteria, indicators and measures

For this assessment one ecological and three social criteria were used to determine values (Table 47).

[2] Wild rivers are defined as 'those rivers which are undisturbed by the impacts of modern technological society. They remain undimmed, and exist in catchments where biological and hydrological processes continue without significant disturbance. They occur in a variety of landscapes, and may be permanent, seasonal or dry watercourses that flow or only flow occasionally' (Water and Rivers Commission 1999c).

Table 47 Ecological and social values for reaches of the Berkeley River – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used	Units	Scoring
Naturalness	Level of riparian zone disturbance	Presence and continuity of intact, native riparian vegetation as a % of waterway unit length	%	3 = >80.1 2 = 65.1–80 1 = <65%
Visual amenity	Appealing waterscape	Visual assessment based on photographic evidence Subjective and relative assessment based on visual impressions left by field visits		3 = high value 2 = medium 1 = low value
Recreational value	Recreational fishing	Subjective and relative assessment based on visual impressions and fishing experiences		3 = high 2 = medium 1 = low
Spiritual	Sites of cultural significance	Presence or number of registered Aboriginal sites from Register of Aboriginal Sites – Department of Indigenous Affairs)	Number of sites registered	3 = 4 or more 2 = 1 to 3 1 = none

All values criteria identified in Table 47 were regarded as being equally significant and weighting was not undertaken. Therefore the raw mean scores (Table 48) were used to generate the values–threats matrix (Figure 18).

Table 48 Berkeley River values scores

Reach ID	Reach length km	Riparian length (B1)	Riparian length (B2)	B1+B2	Proportion riparian %	Riparian value (score)	Registered Aboriginal sites (count)	Spiritual value (score)	Visual value (score)	Recreational fishing value (score)
R1	7.26	6.30	5.80	12.1	83.33	3	3	2	3	3
R2	14.88	11.10	8.40	19.5	65.52	2	2	2	3	3
R3	6.58	3.70	3.50	7.2	54.71	1	4	3	3	2
R4	13.45	12.20	11.50	23.7	88.10	3	0	1	2	1
R5	10.30	9.80	9.50	19.3	93.69	3	0	1	1	1
R6	13.55	13.47	13.36	26.8	98.89	3	0	1	1	1
R7	3.85	2.92	3.45	6.4	83.12	3	0	1	1	2
R8	29.02	23.15	25.82	48.9	84.25	3	0	1	1	2
R9	35.02	22.10	25.90	48.0	68.53	2	0	1	1	3
R10	12.34	9.40	8.10	17.5	70.91	2	0	1	1	3
R11	7.64	5.80	4.50	10.3	67.41	2	0	1	1	3
R12	35.94	21.00	23.90	44.9	62.47	1	0	1	1	3

Identify and score threats criteria, indicators and measures

Three surrogate threat indicators (tourism, boating access and fishing effort) were used to assess threats associated with the Berkeley River (Table 49).

Table 49 Threats associated with reaches of the Berkeley River – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used*	Scoring
Commerce	Tourism	Subjective assessment based on visual impressions of number of visitors (boats) and their impacts	3 = high impact 2 = medium impact 1 = low impact
Boating	Access	River only accessible by boat from sea (distance from mouth of river)	3 = mouth to 42.2 km upstream 2 = 42.3 to 55.9 km 1 = 60.0 km to 189.1 km
Fishing	Number of people fishing	Subjective assessment based on number of observed recreational fishers	3 = high impact 2 = medium impact 1 = low impact

**Note: These are surrogate measures for threatening processes and are based on threatening activities (causes)*

Table 50 Berkeley River threats scores

Reach Id	Access threat (score)	Tourist threat (score)	Recreational fishing threat (score)
R1	3	3	3
R2	3	3	3
R3	3	3	3
R4	3	2	2
R5	2	1	1
R6	2	1	1
R7	2	1	1
R8	2	1	1
R9	1	1	1
R10	1	1	1
R11	1	1	1
R12	1	1	1

All threats criteria identified in Table 49 were regarded as being equally significant and weighting was not undertaken. Therefore the raw mean scores (Table 50) were used to generate the values–threats matrix (Figure 18).

Determine management prioritisation categories

Figure 18 shows the values–threats matrix for the 12 reaches of the Berkeley River.

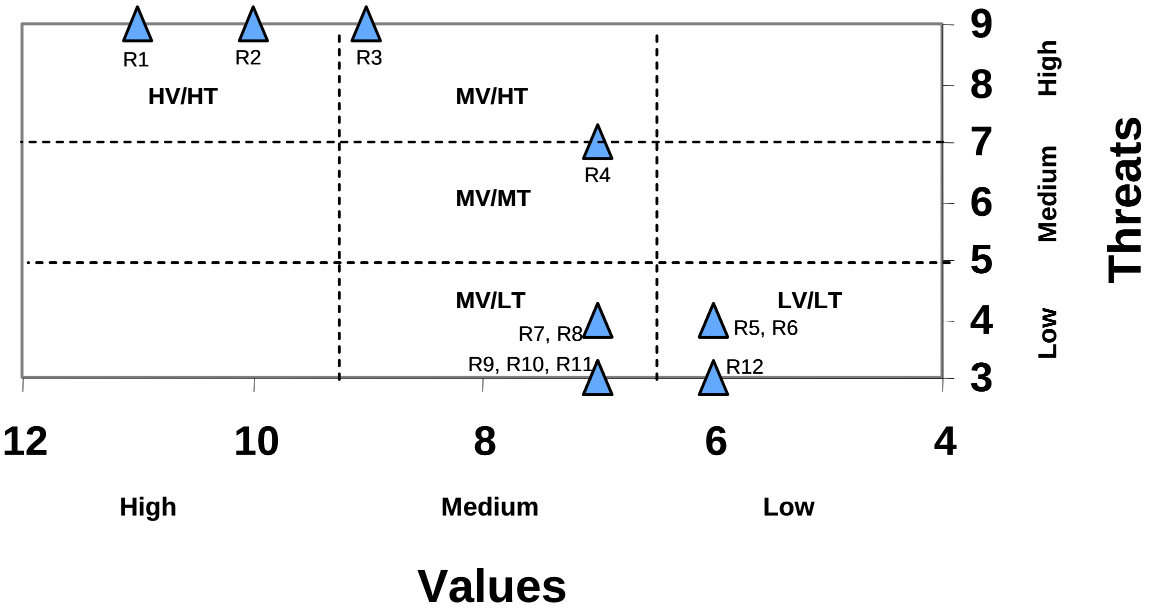

Figure 18 Summary matrix of values and threats for 12 reaches of the Berkeley River

Identify appropriate management response

From the results of the summary matrix (Figure 18) a table of management responses was developed (Table 51).

Table 51 Classification of reaches of Berkeley River based on values and threats

Primary priority level	Sub-priority level	Reaches
1	1a: HV/HT	R1, R2
2	2a: MV/HT	R3
	2b: MV/MT	R4
3	3a: MV/LT	R7, R8, R9, R10, R11
	3d: LV/LT	R5, R6, R12

The geographic arrangement of reaches in the above analysis starts at the mouth of the river (R1) and terminates at the headwaters (R12). Figure 18 demonstrates very clearly that the two reaches closest to the river's mouth (R1 and R2) are the high-value, high-threat reaches. The priority order of remaining reaches follows the river upstream fairly consistently, with the only exception to the pattern being R5. This result is almost entirely due to access. Nearly everyone who directly interacts with the river does so by boat, which must be done from the sea. Many of these people are tourists and recreational fishers and it is these people who both value the lower part of the river and, by their visitation, generate the threats. The conclusion that emerges for management is that tourism and fishing may need to be managed to ensure continued high-value status of the river mouth.

It is also worth noting that although reaches 5 and 6 have been identified as low-value, low-threat, these reaches should probably be given the same prioritisation as reaches 7, 8 and 9 as threatening processes in reaches 5 and 6 are likely to affect these downstream reaches.

It should be stated again that the Berkeley River is a ‘wild river’, and is widely acknowledged as being in very good ecological condition. It could be argued that the entire river should be classed as ‘high-value’. However, this would prevent any useful prioritisation. The results from this trial should be considered ‘relative’ as there is no reason to believe that reaches R1 and R2 are under any significant threat, but this trial does indicate that they are marginally more valued (and threatened) than more remote reaches upstream. Whether this means that specific management responses are required is difficult to determine without further investigation of the nature of the threats, but the data acquired during this brief assessment appear to suggest it would be unlikely at this time.

The next step that would normally be undertaken at this stage involves identifying appropriate management responses for each of the reaches, based on the prioritisation revealed by the assessment. However, since the trials presented in this report are essentially test cases, where the purpose is to demonstrate and verify the prioritisation procedures, this final step was not undertaken.

Refer to sections 2.6 to 2.8 for further information on choosing priorities, identifying appropriate management responses, other factors that need to be considered and designing the management response.

5.4 Catchment scale: South Coast region (high quality data)

The data for this case study was obtained from a recent 'ecological snapshot' conducted of selected rivers.

Determine purpose of assessment

The South Coast region contains approximately 107 rivers and major tributaries, ranging from larger, perennial systems, to smaller, often ephemeral, streams. A comparative assessment of the ecological values of these systems has yet to be undertaken. The overall objective of this trial was thus to conduct a comparative assessment of the ecological values of, and threats faced by, selected river systems in the South Coast region.

Select appropriate assessment scale

This trial has been undertaken at a catchment scale. Data for 188 sites in 33 separate catchments were obtained from a recent survey of these systems (Table 52).

Table 52 River systems and sites sampled in the South Coast region

River system	Number of sites sampled
Gardner River	5
Shannon River	5
Deep River	5
Walpole River	2
Frankland-Gordon River	11
Bow River	2
Kent River	5
Kordabup River	1
Denmark River	7
Hay-Mitchell River	22
Sleeman River	2
Marbellup Brook	28
Seven Mile Creek	1
Bluff Creek	1
Goodga River	2
Limeburners Creek	1
Kalgan River	11
Waychinicup River	3
Pallinup River	8
Bremer River	7
Gairdner River	5
Fitzgerald River	9

River system	Number of sites sampled
Phillips-West River	8
Steer River	1
Jerdacuttup River	4
Oldfield River	7
Young River	5
Coobidge Creek	2
Dalyup River	4
Bandy River	2
Coromup River	2
Dailey River	3
Thomas River	1

Identify and score values criteria, indicators and measures

The 33 river systems were ranked according to their ecological value, as determined by four criteria (naturalness, diversity, rarity and special features) using 12 indicators and 19 measures (Table 53). Five indicators (catchment disturbance, riparian disturbance, river channel disturbance, variation from natural state of water chemistry and variation from natural state of biota) were used to obtain a score for 'naturalness', thus resulting in a potential maximum score of 15 for systems in pristine condition. The 'diversity' criterion was scored using four indicators: in-stream habitat heterogeneity, channel heterogeneity, invertebrate diversity and vertebrate diversity, thus resulting in a potential maximum score of 12 prior to standardisation of the scoring. As the criterion 'rarity' was scored using only two indicators, the number of threatened species, and the presence of endemic or rare species, and the 'special features' criterion was scored using a single indicator, the presence of 'flagship' species, these two criteria were amalgamated to form a single criterion, 'rarity and special features'. Presence of native freshwater crayfish species were used as the measure for 'flagship' species. Because of their 'charismatic' appeal, flagship species serve to increase public awareness (Nickoll and Horwitz, 2000). These species usually have high public profile, and require conservation. After evaluating the use of marron as a flagship species, Nickoll and Horwitz (2000) concluded that this species was an appropriate flagship for the restoration of the Blackwood River in the South West region of Western Australia, and thus it is likely that crayfish would be appropriate to use as flagship species in other riverine systems in south-western Australia. The number of fish species listed as either threatened or rare by the IUCN was used as a measure of threatened species. Species of concern included the spotted minnow, *Galaxias truttaceus hesperius* (listed as 'critically endangered'), Balston's pygmy perch, *Nannatherina balstoni* ('vulnerable') and the salamanderfish, Lepidogalaxias *salamandroides* ('rare'). The mayflies and the caddisflies, two groups known to have high numbers of endemic species were used as measures of the indicator, 'endemic or rare species'.

When more than one measure was used for a particular indicator, a mean score was obtained for that indicator. All indicator scores were summed to obtain a score for each of the three criteria. Before adding these together to obtain an overall ecological value score, scores for each of the three criteria were standardised to give each an equal weighting in the calculation of the overall total score. All measures were scored on a scale of 3, where a score of 1 indicated a lower ecological value, and a value of 3, a higher ecological value.

Bioregional differences were taken into account by modifying the scoring to account for the river type being assessed. It was thus necessary to define aquatic bioregions for the South Coast region prior to scoring the indicators and measures. Previous testing of the *Interim Biogeographic Regionalisation of Australia* (IBRA) for representing aquatic ecosystems in Victoria found that this regionalisation was not effective in characterising macroinvertebrate assemblage distributions across that state (Marchant et al. 2000). Thus, an *a posteriori* (subsequent) approach was adopted to delineate interim aquatic bioregions for the South Coast region based on macroinvertebrate community composition. Such an approach defines empirically-based bioregions for use in managing (and assessing ecological values) of aquatic ecosystems, rather than highlighting the causal factors behind the regionalisation. Wells et al. (2002) used similar methodology to define aquatic bioregions for Victoria (see also Newall and Wells 2000). Macroinvertebrate and environmental data were obtained from the 'least affected' sites sampled for each waterway. These 'least affected' sites were selected based on scores calculated for the 'width of riparian vegetation' and the occurrence and extent of degradation processes such as erosion, sedimentation, and weed infestation. Data from all sites for each river system were combined, and converted to presence or absence data before analysis. Following the calculation of Bray-Curtis dissimilarity measures, a cluster analysis was conducted using unweighted pair groups with mean averaging, and the result plotted as a dendrogram. Based on this dendrogram, two broad bioregions were recognised for the South Coast region (Figure 19).

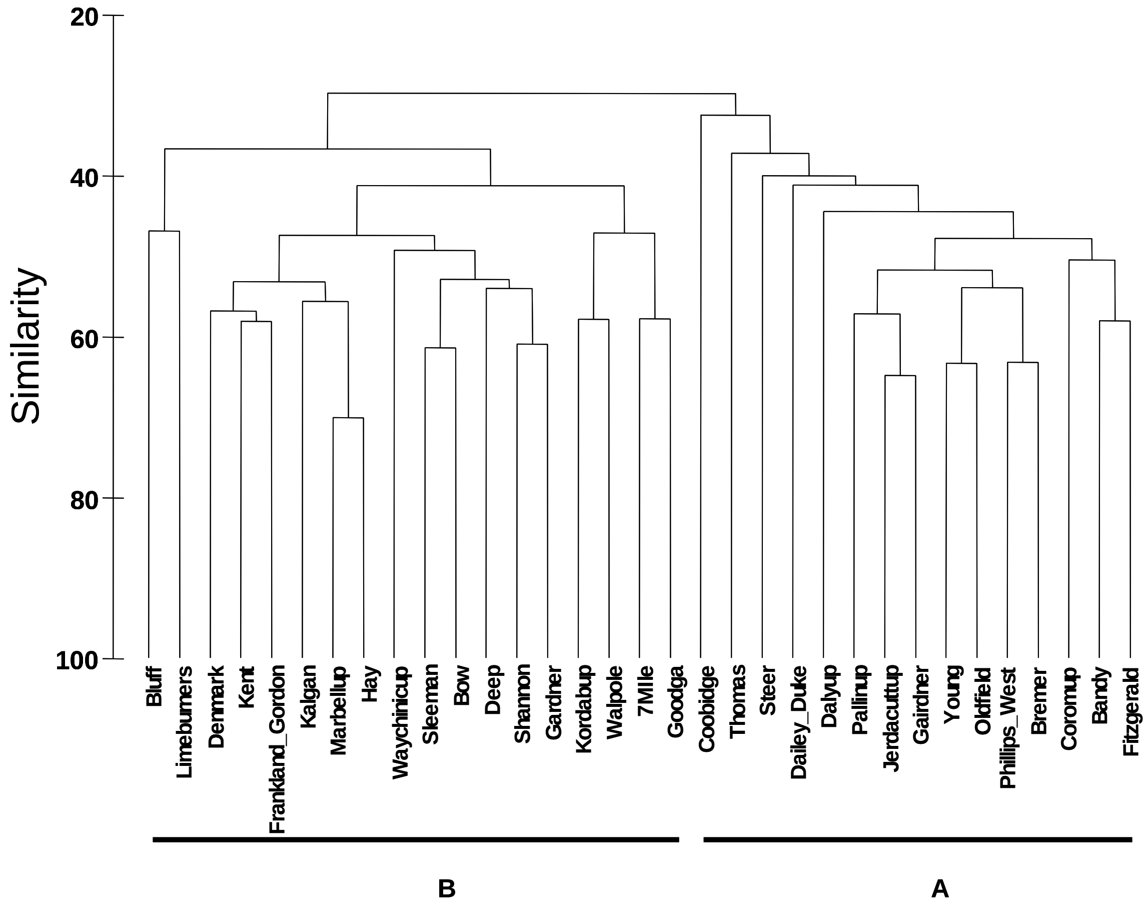

Figure 19 Dendrogram resulting from a hierarchical classification of rivers of the South Coast region using macroinvertebrate data, showing the existence of two broad aquatic bioregions, (A) Eastern South Coast and (B) Western South Coast

After delineating bioregions using macroinvertebrate data, environmental data were used to provide general descriptions of each bioregion.

The two aquatic bioregions defined are:

- Bioregion A Eastern South Coast
- Bioregion B Western South Coast.

Figure 20 shows these bioregions.

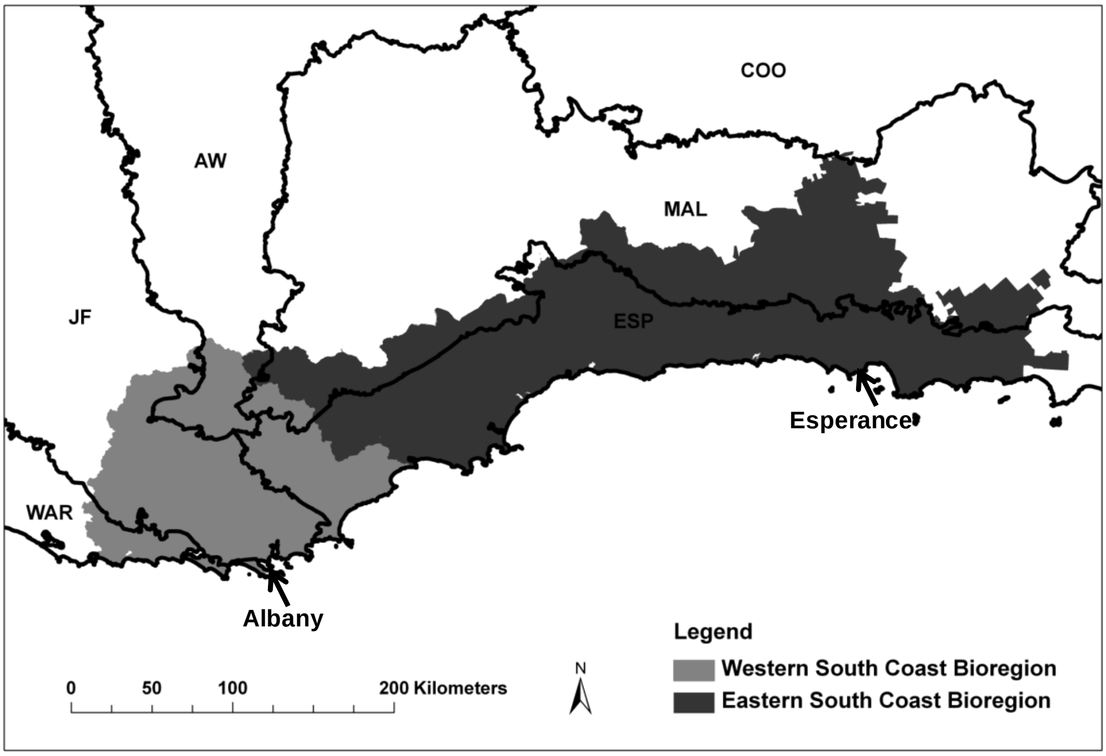

Figure 20 Map of South Coast region showing aquatic bioregions.

Table 53 Ecological values of river systems in the South Coast region – criteria, indicators and measures used for assessment

Criteria	Indicator	Measures used	Units	Scoring
Naturalness	Level of catchment disturbance	Proportion of natural vegetation cover remaining	%	1 = 0–32.99 2 = 33–66.99 3 = > 67
	Level of riparian zone disturbance	Width of intact, native riparian zone	m	1 = < 5 2 = 5–20 3 = > 20
		Canopy cover of native vegetation	% cover	1 = absent to < 25 2 = 25–50 3 = > 50
		Presence of understorey Weeds	% cover	1 = > 50 2 = 20–50 3 = < 20
	Level of river channel disturbance	Presence and extent of bank erosion	%	1 = > 50 2 = 20–50 3 = < 20
		Presence and extent of sedimentation	%	1 = > 50 2 = 20–50 3 = < 20

Criteria	Indicator	Measures used	Units	Scoring
	Variation from natural state of water chemistry	Extent to which salinity varies from natural	ppt	Bioregion A 1 = > 35 2 = 25–35 3 = < 25 Bioregion B 1 = > 5 2 = 2–5 3 = < 2
		Extent to which total phosphorus varies from natural	µg/L	1 = > 100 2 = 50–100 3 = < 50
		Extent to which total nitrogen varies from natural	µg/L	1 = > 1500 2 = 1000–1500 3 = < 1000
	Variation from natural state of biota	Species richness	Number of species	Bioregion A 1 = < 30 2 = 30–45 3 = >45 Bioregion B 1 = < 45 2 = 45–70 3 = > 70
		Number of Ephemeroptera-Plecoptera-Trichoptera taxa	Number of species	Bioregion A 1 = < 2 2 = 2–3 3 = > 3 Bioregion B 1 = < 8 2 = 8–12 3 = > 12
Diversity	In-stream habitat heterogeneity	Index of in-stream habitat diversity based on total % cover of submerged, emergent and overhanging vegetation, leaf litter, woody debris and snags	Index points	Bioregion A 1 = 0–4 2 = 5–8 3 = > 8 Bioregion B 1 = 0–7 2 = 8–14 3 = > 14
	Channel heterogeneity	Index of substrata diversity based on total % cover of clay, mud, peat, sand, gravel, cobble and rock	Index points	1 = 1 2 = 2–3 3 = > 3

Criteria	Indicator	Measures used	Units	Scoring
	Invertebrate diversity	Total macroinvertebrate species richness	Number of species	Bioregion A 1 = < 26 2 = 26–53 3 = > 53 Bioregion B 1 = <45 2 = 45–90 3 = >90
	Vertebrate diversity	Total fish species richness (Bioregion A: native freshwater and estuarine species. Bioregion B: native freshwater fish species only)	Number of species	Bioregion A 1 = 0–1 2 = 2–3 3 = > 3 Bioregion B 1 =0–2 2 =3–4 3 => 4
Rarity and special features	'Flagship' species	Number of endemic decapod species	Number of species	Bioregion A 1 = no endemic decapods 2 = shrimps, but no koonacs present 3 = koonacs present Bioregion B 1 = < 2 spp. of endemic crayfish 2 = 2–3 spp. of endemic crayfish 3 = 4 spp. of endemic crayfish
	Endemic or rare species	Number of endemic mayfly species (Bioregion B only)	Number of species	Bioregion B 1 = 0–1 2 = 2 3 = 3–4
		Number of caddisfly species (Bioregion A: all species; Bioregion B: species endemic to south–west Western Australia only)		Bioregion A 1 = < 2 spp 2 = 2-3 spp 3 = 4-6 spp Bioregion B 1 = 0–3 2 = 4 –7 3 = 8–12
	Threatened species	Number of listed fish species		1 = No threatened species 2 = Either *L. salamandroides* or *N. balstoni* present 3 = *G. truttaceus* present

Five indicators were used to obtain a score for ‘naturalness’ (Table 53), thus resulting in a possible maximum score of 15 for systems in pristine condition. The indicator, ‘level of catchment disturbance’ was scored using the measure ‘% natural vegetation cover remaining’. Three measures were used to represent the ‘level of riparian zone disturbance’: the width of the native riparian zone, the canopy cover of native vegetation in this zone, and the presence of understorey weeds.

Rivers with the highest ranking, and thus the ‘best condition’ in the Western South Coast bioregion (Bioregion B) were the Shannon River (14.80), the Deep River (14.43) and the Denmark River (14.25) (Table 54). All of these waterways drained relatively well vegetated catchments, riparian zones were in good condition, channel disturbance was minimal, and little or no variation from that which could be expected for rivers of this type was detected for water chemistry and biodiversity values. The lowest ranked waterway in this bioregion was the Sleeman River (score of 9.58). This waterway drained a poorly vegetated catchment, the riparian zone at both sites sampled was disturbed, and water quality sampling revealed nutrient enrichment, resulting in a decline in the more sensitive taxa such as mayflies (Order Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera).

Table 54 Scores obtained for degree of ‘naturalness’ for waterways of the South Coast region, ranked in descending order

Bioregion A eastern South Coast		**Bioregion B western South Coast**	
River	**Score**	**River**	**Score**
Oldfield	13.79	Shannon	14.80
Jerdacuttup	13.22	Deep	14.43
Gairdner	12.70	Denmark	14.25
Phillips-West	12.69	Gardner	13.93
Young	12.53	Walpole	13.50
Dailey	12.33	Kent	13.03
Steer	12.00	Limeburners	13.00
Bremer	11.79	Waychinicup	13.00
Bandy	11.58	Hay-Mitchell	12.73
Thomas	11.00	Frankland-Gordon	12.45
Fitzgerald	10.64	Bow	12.25
Coromup	10.58	Bluff	12.00
Dalyup	10.33	Marbellup	11.49
Pallinup	10.19	Goodga	11.00
Coobidge	8.17	Kalgan	11.00
		Seven Mile	10.83
		Kordabup	10.67
		Sleeman	9.58

The top three ranked rivers in the Eastern South Coast bioregion (Bioregion A) were the Oldfield River (13.79), the Jerdacuttup River (13.22) and the Gairdner River

(12.70). These rivers drained moderately to well-vegetated catchments, had riparian zones in generally good condition, had minimal channel disturbance at the sites sampled, and showed only moderate variation in the water chemistry variables and biodiversity values assessed. The lowest ranked waterway was Coobidge Creek (8.17), a relatively disturbed waterway draining a predominantly agricultural landscape west of Esperance.

The ‘diversity’ criterion was scored using four indicators: channel heterogeneity, in-stream habitat heterogeneity, invertebrate diversity and vertebrate diversity, resulting in a possible maximum score of 12 for highly diverse, ‘pristine’ systems (Table 53).

The most diverse of the waterways in the Eastern South Coast bioregion were the Oldfield (10.13), Bremer (9.27), Jerdacuttup (9.00) and Young (9.0) rivers, while Coobidge Creek (4.0) was found to be the least diverse of systems in this bioregion.

The most diverse of the waterways in the Western South Coast bioregion were the Shannon (10.40), the Frankland-Gordon (9.55) and the Gardner (9.40) rivers (Table 55). These systems were particularly diverse in terms of their biota, and all systems scored highly for macroinvertebrate and fish diversity. Seven Mile Creek, Bluff Creek and Goodga River were least diverse in terms of the substrata, in-stream habitat and faunal diversity found in these systems.

Table 55 Scores obtained for degree of ‘diversity’ for waterways of the South Coast region, ranked in descending order

Bioregion A Eastern South Coast		**Bioregion B Western South Coast**	
River	**Score**	**River**	**Score**
Oldfield	10.13	Shannon	10.40
Bremer	9.27	Frankland-Gordon	9.55
Jerdacuttup	9.00	Gardner	9.40
Young	9.00	Deep	9.00
Phillips-West	8.88	Kent	9.00
Fitzgerald	8.00	Marbellup	8.23
Coromup	8.00	Bow	7.50
Gairdner	7.60	Denmark	7.50
Pallinup	7.50	Waychinicup	7.33
Dalyup	7.50	Kalgan	7.33
Steer	7.00	Sleeman	7.00
Bandy	7.00	Hay-Mitchell	6.82
Thomas	7.00	Walpole	6.50
Dailey	6.67	Kordabup	6.00
Coobidge	4.00	Limeburners	6.00
		Seven Mile	5.00
		Bluff	5.00
		Goodga	5.00

The criterion 'rarity and special features' was scored using three indicators – the number of 'flagship' species, the number of threatened species, and the presence of endemic or rare species, resulting in a possible maximum score of 9 for 'pristine' systems with either threatened, rare, endemic or 'flagship' species (Table 53). Rivers in the Eastern South Coast bioregion that scored highest for 'rarity and special features' were the Bremer (7), Gairdner (7), Fitzgerald (6) and Phillips and West (6) rivers. The freshwater crayfish species, *Cherax preissii*, commonly known as the 'koonac' occurred in the Bremer and Gairdner rivers. These records represent a range extension, as this species was previously thought to occur only as far east as the Kalgan River. These systems also harboured between four to six species of caddisflies. River systems in the Western South Coast bioregion that ranked highest for 'rarity and special features' were the Shannon (8) and Deep (7) rivers, and Marbellup Brook (7) (Table 56). All three systems had high numbers of endemic mayflies and caddisflies, while two of the systems, Deep River and Marbellup Brook, were home to at least four species of freshwater crayfish. The Shannon and Deep rivers were also home to the threatened Balston's Pygmy Perch, *Nannatherina balstoni*.

Table 56 Scores obtained for degree of 'rarity and special features', for waterways of the South Coast region, ranked in descending order

Bioregion A Eastern South Coast		**Bioregion B Western South Coast**	
River	**Score**	**River**	**Score**
Bremer	7	Shannon	8.0
Gairdner	7	Deep	7.0
Fitzgerald	6	Marbellup	7.0
Phillips-West	6	Gardner	6.0
Jerdacuttup	6	Walpole	6.0
Oldfield	5	Bow	6.0
Bandy	5	Hay-Mitchell	6.0
Pallinup	4	Frankland-Gordon	5.5
Coromup	4	Kent	5.5
Dailey	4	Denmark	5.5
Steer	3	Goodga	5.0
Young	3	Waychinicup	4.5
Coobidge	3	Sleeman	4.0
Dalyup	3	Seven Mile	4.0
Thomas	3	Bluff	4.0
		Kordabup	3.5
		Kalgan	3.5
		Limeburners	3.0

When 'naturalness', 'diversity' and 'rarity and special features' were considered together to obtain an overall assessment of ecological value (Table 57), with the three criteria equally weighted, the top three ranked rivers in the Western South Coast bioregion were the Shannon, Deep and Gardner rivers. Similarly, the top three ranked rivers in the Eastern South Coast bioregion were the Bremer, Oldfield and Jerdacuttup rivers. Coobidge Creek scored the lowest for this bioregion. For the Western bioregion, rankings resulting from the 'diversity' criterion alone was the best predictor of overall rankings produced when all three criteria were considered (Spearman's rank correlation coefficient $r = 0.955$; $p < 0.001$) (Table 58). Rankings produced using only the 'rarity and special features' criterion best matched the overall rankings for the Eastern bioregion ($r = 0.854$; $p < 0.001$), and were also well matched to the overall rankings for the Western bioregion ($r = 0.838$; $p < 0.001$) (Table 58).

Table 57 Standardised scores obtained for ecological value of waterways of the South Coast region, ranked in descending order of overall ecological value for each bioregion

River system	Naturalness	Diversity	Rarity	Overall	Overall %
Western South Coast bioregion					
Shannon	98.7	86.7	88.9	274.2	91.4
Deep	96.2	75.0	77.8	249.0	83.0
Gardner	92.9	78.3	66.7	237.9	79.3
Frankland-Gordon	83.0	79.5	61.1	223.7	74.6
Hay-Mitchell	84.8	71.6	66.7	223.1	74.4
Kent	86.9	75.0	61.1	223.0	74.3
Marbellup	76.6	68.6	77.8	222.9	74.3
Denmark	95.0	62.5	61.1	218.6	72.9
Bow	81.7	62.5	66.7	210.8	70.3
Walpole	90.0	54.2	66.7	210.8	70.3
Waychinicup	86.7	61.1	50.0	197.8	65.9
Kalgan	73.3	61.1	38.9	173.3	57.8
Goodga	73.3	41.7	55.6	170.6	56.9
Limeburners	86.7	50.0	33.3	170.0	56.7
Sleeman	63.9	58.3	44.4	166.7	55.6
Bluff	80.0	41.7	44.4	166.1	55.4
Kordabup	71.1	50.0	38.9	160.0	53.3
Seven Mile	72.2	41.7	44.4	158.3	52.8
Eastern South Coast bioregion					
Bremer	78.6	77.3	77.8	233.6	77.9
Oldfield	91.9	84.4	55.6	231.9	77.3
Jerdacuttup	88.1	75.0	66.7	229.8	76.6
Gairdner	84.7	63.3	77.8	225.8	75.3

River system	Naturalness	Diversity	Rarity	Overall	Overall %
Phillips-West	84.6	74.0	66.7	225.2	75.1
Fitzgerald	70.9	66.7	66.7	204.3	68.1
Young	83.6	75.0	33.3	191.9	64.0
Bandy	77.2	58.3	55.6	191.1	63.7
Dailey	82.2	55.6	44.4	182.2	60.7
Coromup	70.6	66.7	44.4	181.7	60.6
Pallinup	67.9	62.5	44.4	174.9	58.3
Steer	80.0	58.3	33.3	171.7	57.2
Thomas	73.3	58.3	33.3	165.0	55.0
Dalyup	68.9	62.5	33.3	164.7	54.9
Coobidge	54.4	33.3	33.3	121.1	40.4

Table 58 Spearman's rank correlation coefficients for overall rankings calculated using all three criteria together versus rankings generated using each criterion alone. P < 0.001 for all comparisons.

Criteria	Western bioregion	Eastern bioregion
Naturalness	0.761	0.750
Diversity	0.955	0.839
Rarity and special features	0.838	0.854

Identify and score threats criteria, indicators and measures

The framework proposes 10 threatening processes for scoring, six of which were selected for this trial (Table 59). These were erosion and sedimentation, eutrophication, introduced animal and plant species, salinisation, acidification and riparian zone degradation. Each river system was scored for each indicator on a scale of 1 to 3, where a score of 3 represented a high level of threat and a score of 1, a low level of threat.

Table 59 Threats to waterways in the South Coast region – criteria, indicators and measures used for assessment

Criteria	Indicator	Measure	Units	Scoring
Erosion and sedimentation	Presence and extent of erosion	Presence and extent of bed incision and bank collapse	%	1 = <20 2 = 20–50 3 = > 50
	Presence and extent of sedimentation	Presence and extent of sediment plumes and bars on the streambed	%	1 = <20 2 = 20–50 3 = > 50
Eutrophication	Nutrients	Extent to which total nitrogen levels exceed those of minimally affected sites	µg/L	1 = < 1000 2 = 1000–1500 3 = > 1500

Criteria	Indicator	Measure	Units	Scoring
		Extent to which total phosphorus levels exceed those of minimally affected sites	µg/L	1 = < 50 2 = 50–100 3 = > 100
Introduced animal and plant species	Presence of introduced in–stream animal species	Presence and abundance of introduced crayfish and fish		1 = none 2 = either yabby or mosquitofish or trout present 3 = two or more of these species present
Salinisation	Salinity	Extent to which salinity levels exceed those of minimally affected sites	ppt	Bioregion A 1 = < 25 2 = 25–35 3 = > 35 Bioregion B 1 = < 2 2 = 2–5 3 = > 5
Acidification	pH	Extent to which pH levels are lower than those of minimally affected sites		1 = > 7 2 = 5–7 3 = < 5
Riparian zone degradation	Intactness of riparian vegetation	Width of riparian zone	m	1 = > 20 2 = 5–20 3 = < 5
		Pen and Scott (1999) foreshore condition scoring		1 = Score of A1, A2 or A3 2 = Score of B1, B2 or B3 3 = Scores of C1, C2, C3, D1, D2 or D3

Possible total scores for threatening processes ranged from 6 (low or no threats) to 18 (high levels of threats). For the rivers assessed, scores ranged from 6 (Limeburners, Steer and Thomas rivers) to 14 (Coobidge Creek) (Table 60).

Table 60 Rating for six indicators of threatening processes for waterways in the South Coast region

River system	Erosion	Eutrophication	Exotics	Salinisation	Acidification	Riparian degradation	Total
Gardner	1.5	1.5	1.0	1.0	2.0	1	8.0
Shannon	1.2	1.2	1.0	1.0	2.0	1	7.2
Deep	1.0	1.0	1.0	1.0	2.0	1	7.0
Walpole	1.0	1.0	1.0	1.0	3.0	1	8.0
Frankland-Gordon	1.1	1.1	2.0	3.0	1.0	1.5	10.1
Bow	1.3	1.3	1.0	1.0	3.0	1	9.3

River system	Erosion	Eutrophication	Exotics	Salinisation	Acidification	Riparian degradation	Total
Kent	1.0	1.0	1.0	2.0	2.0	1.0	8.0
Kordabup	1.0	1.0	1.0	1.0	2.0	2.0	10.0
Denmark	1.0	1.0	3.0	2.0	2.0	1.0	10.0
Hay-Mitchell	1.2	1.2	1.0	2.0	2.0	2.0	9.2
Sleeman	1.0	1.0	3.0	1.0	2.0	1.5	11.0
Marbellup	1.2	1.2	2.0	1.0	2.0	2.0	9.7
Seven Mile	1.0	1.0	1.0	1.0	2.0	2.5	10.5
Bluff	1.0	1.0	1.0	1.0	2.0	1.0	7.0
Goodga	1.3	1.3	1.0	1.0	2.0	1.0	8.8
Limeburners	1.0	1.0	1.0	1.0	1.0	1.0	6.0
Waychinicup	1.0	1.0	1.0	1.0	2.0	1.0	7.0
Kalgan	1.0	1.0	2.0	3.0	2.0	1.5	11.0
Pallinup	1.1	1.1	1.0	2.0	1.0	2	10.1
Bremer	1.3	1.3	3.0	1.0	1.0	1.5	10.8
Gairdner	1.2	1.2	1.0	1.0	1.0	2.0	8.2
Fitzgerald	1.2	1.2	1.0	3.0	1.0	1.5	8.7
Phillips-West	1.0	1.0	1.0	2.0	1.0	1.5	9.0
Steer	1.0	1.0	1.0	1.0	1.0	1.0	6.0
Jerdacuttup	1.0	1.0	1.0	2.0	1.0	2.0	8.5
Oldfield	1.0	1.0	1.0	2.0	1.0	1.0	8.0
Young	1.0	1.0	1.0	1.0	1.0	1.5	7.5
Coobidge	2.0	2.0	1.0	3.0	3.0	3.0	14.0
Dalyup	1.2	1.2	2.0	2.0	2.0	1.5	10.7
Bandy	1.0	1.0	1.0	1.0	1.0	2.0	7.0
Coromup	1.3	1.3	2.0	1.0	1.0	3.0	10.3
Dailey	1.2	1.2	2.0	1.0	1.0	1.0	7.2
Thomas	1.0	1.0	1.0	1.0	1.0	1.0	6.0

Determine management prioritisation categories

When values and threats were plotted for each river system, they fell into six categories (Figure 21). The Bremer, Oldfield and Jerdacuttup rivers in the Eastern South Coast bioregion and the Shannon, Deep and Gardner rivers in the Western South Coast bioregion were all categorised as Priority 1 (Table 61).

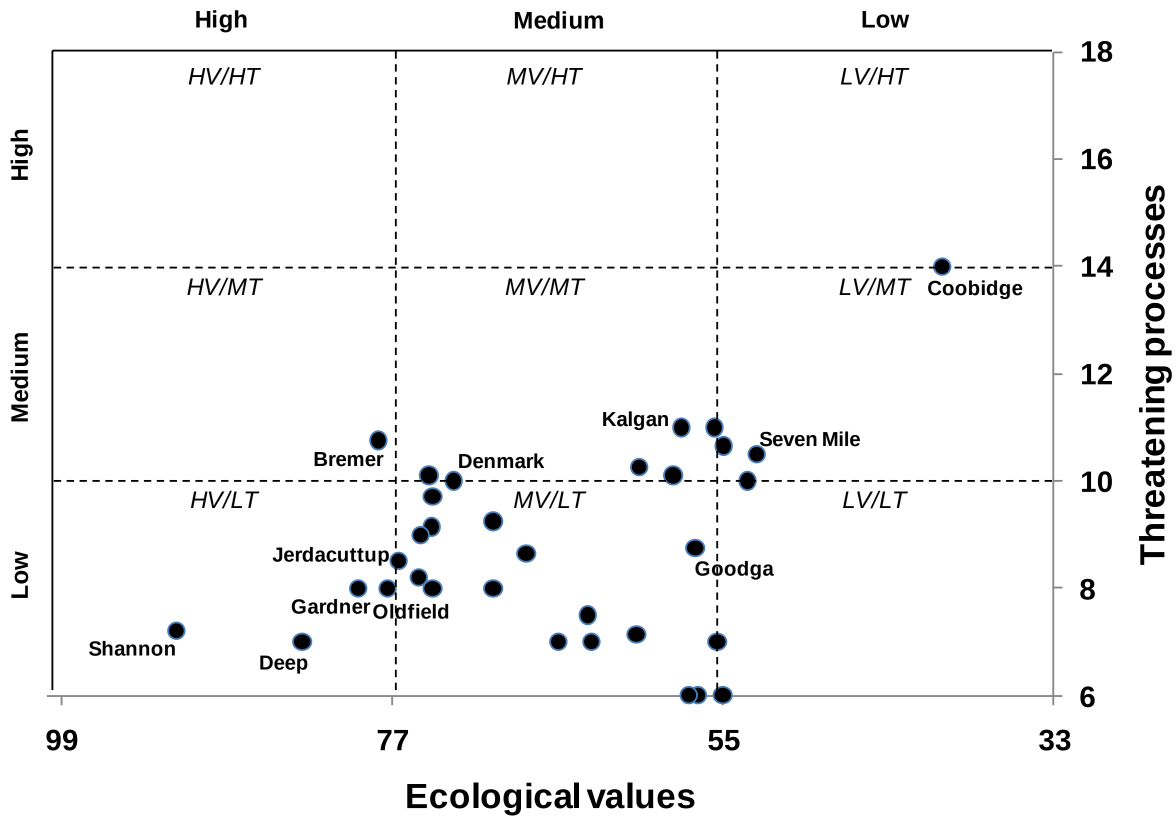

Figure 21 Summary matrix of waterways values and threats for South Coast waterways

Table 61 Classification of reaches of South Coast rivers based on values and threats

Primary priority level	Sub-priority level	Rivers
1	1b: HV/MT	Bremer
	1c: HV/LT	Shannon, Deep, Gardner, Oldfield
2	2b: MV/MT	Frankland-Gordon, , Denmark, Sleeman, Kalgan, Pallinup, , Coromup
	3a: MV/LT	Jerdacuttup, Kent, Marbellup, Walpole, Bow, Hay-Mitchell, Waychinicup, Limeburners, , Goodga, Phillips-West, Gairdner, Fitzgerald, Young, Bandy, Dailey, Steer,
3	3b: LV/HT	Coobidge
	3c: LV/MT	Seven Mile, Dalyup, Kordabup
	3d: LV/LT	Bluff, Thomas

Identify appropriate management responses

Table 61 shows that the Bremer River (classified as Sub-priority 1b) is the highest priority river in the Eastern South Coast bioregion, and so requires the greatest proportion of management attention in this bioregion. This system has been identified as a ‘strategic catchment’ by South Coast NRM Inc. The highest priority rivers for the Western South Coast bioregion (classified as Sub-priority 1c) were the Shannon, Deep and Gardner rivers. These systems, along with the Oldfield River in the Eastern South Coast bioregion (also classified as Sub-priority 1c) have not been the focus of attention to date. The results obtained here suggest that these systems need to be monitored regularly to ensure that ‘new’ threats do not emerge unnoticed for these rivers.

The next step that would normally be undertaken at this stage involves identifying appropriate management responses for each of the rivers, based on the prioritisation revealed by the assessment. However, since the trials presented in this report are essentially test cases, where the purpose is to demonstrate and verify the prioritisation procedures, this final step was not undertaken.

Refer to sections 2.6 to 2.8 for further information on choosing priorities, identifying appropriate management responses, other factors that need to be considered and designing the management response.

6 General comments and conclusions

The *Framework for prioritising waterways for management in Western Australia* was developed to assist regional natural resource management groups and state government agencies to choose management priorities for waterways.

The framework provides a relatively simple, quick, and objective approach. It is also transparent, enabling stakeholders to readily engage with the approach and provide input. In situations where there are already processes in place for setting priorities, it can be used to augment what has already been done. Where these types of decision-making processes are yet to be carried out, the framework can be used as the initial approach.

As part of the framework's development, four trials were carried out. The trials demonstrated the framework effectively operates at different scales (a catchment, subcatchment or reach) using a variety of data types. The trials also revealed the framework may be used by anyone with a moderate level of scientific expertise.

The trials also demonstrated that the framework is flexible enough to allow prioritisation assessments to be carried out even with very limited data using readily available web-based sources such as Google Earth and Wetland Base or subjective data such as stakeholder opinions. Where data are limited, outcomes from the prioritisation could be used as an initial scoping study or to highlight knowledge gaps.

The inclusion of stakeholder opinions not only enables scoring of data deficient criteria but also improves the transparency of the framework. Use of the framework as a community engagement tool could also increase support for management decisions.

Appendix A Contacts

Department of Water

Organisation	Address	Telephone number
Perth	The Atrium, 168 St Georges Terrace Perth 6000 PO Box K822, Perth Western Australia 6842	08 6364 7600
South Coast	5 Bevan Street, Albany 6330 PO Box 525, Albany 6331	08 9842 5760
South West	35-39 McCombe Road, Bunbury 6230 PO Box 261, Bunbury 6231	08 9726 4111
Mid-West Gascoyne	94 Sanford Street, Geraldton 6530 PO Box 73, Geraldton 6531	08 9965 7400
	211 Robinson Street, Carnarvon 6701 PO Box 81, Carnarvon 6701	08 9941 6100
Pilbara	Lot 4608 Cherratta Road, Karratha 6714 PO Box 836, Karratha 6714	08 9144 2000
Kimberley	27 Victoria Highway, Kununurra 6743 PO Box 625, Kununurra 6743	08 9166 4100
Kwinana Peel Region	Mandurah Ocean Marina, 107 Breakwater Parade, Mandurah 6210 PO Box 332, Mandurah 6210	08 9550 4222
Swan Avon Region	7 Ellam Street, Victoria Park 6100	08 6250 8000
	254 Fitzgerald Street, Northam 6401 PO Box 497, Northam 6401	08 9622 7055

Other state government agencies

Organisation	Address	Telephone number
Department of Environment and Conservation (DEC)	The Atrium, 4th floor, 168 St Georges Terrace, Perth, 6000 Locked Bag 104, Bentley Delivery Centre 6983	08 6467 5000
	17 Dick Perry Avenue, Western Precinct Technology Park, Kensington 6151 Locked Bag 104, Bentley Delivery Centre 6983	08 9334 0333
Department of Agriculture and Food Western Australia	3 Baron-Hay Court South Perth 6151 Locked Bag 4, Bentley Delivery Centre 6983	08 9368 3333
Department of Fisheries	The Atrium, 3rd Floor, 168-170 St Georges Terrace, Perth 6000 Locked Bag 39, Cloisters Square 6850	08 9482 7333
Swan River Trust	Level 1, Hyatt Business Centre, 20 Terrace Road, East Perth 6000 PO Box 6740 East Perth 6892	08 9278 0900

Regional NRM groups in Western Australia

Perth Region NRM	80 Great Northern Highway, Middle Swan 6056	08 9374 3333
Northern Agricultural Catchments Council	18 Chapman Road, Geraldton 6530 PO Box 7168, Geraldton 6530	08 9964 9776
	Lesser Hall, Perenjori 6620 PO Box 95, Perenjori 6620	08 9973 1444
South West Catchments Council	Department of Agriculture and Food office, Verschuer Place, Bunbury 6230 PO Box 5066, Bunbury Delivery Centre 6230	08 9780 6193
South Coast NRM Incorporated	39 Mercer Road, Albany 6330	08 9845 8537
Rangelands NRM Coordinating Group	Rangelands NRM Centre, PO Box 887, Carnarvon 6701 PO Box 887 Carnarvon 6701	08 9941 9743
Wheatbelt NRM Incorporated	Lot 12 York Road, Northam 6401 PO Box 311, Northam 6401	08 9690 2250

Other organisations

Western Australian Local Government Association	15 Altona St, West Perth 6005 PO Box 1544, West Perth 6872	08 9321 5055

Appendix B Recommended GIS datasets and other sources of information

The sources of data listed below comprise an overview of some existing datasets that may be used to characterise the environmental values and attributes of a site. The listed data sources are not comprehensive and are intended as a guide only. Additional information should be obtained elsewhere if required.

In addition to these datasets, *Guidance statement 33: environmental guidance for planning and development* (EPA 2008a) provides useful lists of the types of significant natural areas (Chapter B1.2.1) and high conservation value native terrestrial vegetation (Chapter B2.2.2), terrestrial fauna (Chapter B3.2.2), wetlands (Chapter B4.2.2), waterways (Chapter B5.2.2), public drinking water sources (Chapter B6), karst, subterranean wetlands and fauna (Chapter B9.2.2), landscapes and landforms (Chapter B8.2.1). Guidance statement 33 is available at <www.epa.wa.gov.au>.

Table B1 contains many websites to assist with locating information. However, it should be recognised that websites change frequently. If a website is no longer active, the organisation could be telephoned or a search engine could be used to find the latest website.

Table B1 GIS datasets for waterway values

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Aboriginal Heritage Inquiry System and Aboriginal sites of significance (Aboriginal sites register)	Information from the *Register of places and objects* (often known as the 'Sites register') established and maintained under the *Aboriginal Heritage Act 1972*	Department of Indigenous Affairs	State-wide	The Aboriginal Heritage Inquiry System is available from the Department of Indigenous Affairs website, <www.dia.wa.gov.au/AHIS>. The GIS dataset is available by contacting the Department of Indigenous Affairs by emailing <sites@dia.wa.gov.au> or telephoning 08 9235 8000 and requesting the Heritage GIS Registration Officer. Further information on Aboriginal heritage sites is available on the Department of Indigenous Affairs website, <www.dia.wa.gov.au> (select ‘Site search’, then ‘Aboriginal Heritage Inquiry System’ or ‘Download site information’; or select). Further information about Aboriginal heritage is also available from <www.dia.wa.gov.au> by selecting ‘Heritage and culture’.

[3] Based on the Department of Water’s regional boundaries. Refer to <www.water.wa.gov.au> (search for ‘Water regions’)>.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Australian heritage places (World Heritage, Register of the National Estate, Commonwealth Heritage List, National Heritage List and Western Australian Heritage Register)	Sites on the World Heritage list, Register of the National Estate, Commonwealth Heritage List, National Heritage List and Western Australian Heritage Register	Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) formerly Department of the Environment, Water, Heritage and the Arts (DEWHA)	State-wide	Search or browse for relevant national GIS datasets, view metadata and download GIS datasets on the federal Department of Sustainability, Environment, Water, Population and Communities' Discover Information Geographically (DIG) web page. From the home page, <www.environment.gov.au>, search for 'Discover information geographically'. These include sites on the World Heritage list, Register of the National Estate, Commonwealth Heritage List and National Heritage List. Further information on national datasets is available at <www.environment.gov.au/heritage/places/index.html> or by telephoning DSEWPC on 02 6274 1111. The Western Australian Heritage Register is available from the Heritage Council of Western Australia's Places Database at <http://register.heritage.wa.gov.au>.
Bush Forever (proposed and existing)	Identifies the location and boundary of areas of natural bushland	Western Australian Planning Commission (WAPC)	Swan Avon and Kwinana Peel Region	*Bush Forever, keeping the bush in the city* (WAPC 2000) is available at <www.planning.wa.gov.au>. The GIS dataset is available from the Department of Planning by emailing <mapping@planning.wa.gov.au> or telephoning 08 9264 7777. Further information about obtaining the GIS dataset is available at <www.planning.wa.gov.au> by searching for 'Digital data' from the home page.
Department of Environment and Conservation managed land and waters	DEC Estate (proposed and existing national parks, nature reserves, conservation parks, state forests, etc.	Department of Environment and Conservation	State-wide	The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>. Further information is available via the DEC website, <www.dec.wa.gov.au> (select 'Parks and recreation', then 'Park finder', 'Visitor information' or 'Key attractions').

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Directory of Important Wetlands in Australia	Identifies the location and wetland values of nationally important wetlands	Department of Sustainability, Environment, Water, Population and Communities	State-wide	*A directory of important wetlands in Australia, third edition* (Environment Australia 2001) is available via <www.environment.gov.au>. DSEWPC's Australian Wetlands Database is available at <www.environment.gov.au>. Further information about these wetlands is available on the DEC website, <www.dec.wa.gov.au> (select 'Management and protection', then 'Wetlands' and 'Nationally recognised wetlands').
Environmentally sensitive areas	Environmentally sensitive areas as declared in Regulation 6 in *Government Gazette No. 115 Environmental Protection (Clearing of Native Vegetation) Regulations 2004*	Department of Environment and Conservation	State-wide	This dataset is provided to assist landowners and managers to determine the location of environmentally sensitive areas under the *Environmental Protection Act 1986.* The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning (08) 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>.
Environmental Protection Policy (EPP) areas	Various datasets that identify the location, boundary and environmental values of EPP areas	Environmental Protection Authority (EPA)	Swan Coastal Plain (Swan Avon, Kwinana Peel and South West Region)	EPP publications are available at <www.epa.gov.au>, including the *Environmental protection (South West Agriculture Zone wetlands) policy 1998, Environmental protection (Swan Coastal Plain lakes) policy 1992, Environmental protection (Western Swamp Tortoise habitat) policy approval order 2002, Environmental protection (Gnangara Mound crown land) policy 1992* and *Environmental protection (Peel Inlet – Harvey Estuary) policy 1992.* The EPP GIS datasets are available from the EPA by telephoning 08 6467 5600 and requesting the Spatial Services Branch.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
EPA Systems (Red book) areas	The boundaries of areas recommended for conservation by the EPA, as set out in a series of maps and text in the publication *Red book status report* (EPA 1993). Also known as Systems 1–12 areas	Environmental Protection Authority	State-wide	The *Red Book status report (1993) on the implementation of conservation reserves for Western Australia as recommended by the Environmental Protection Authority (1976–1984)* (EPA 1993) is available from the DEC library in Perth. The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>.
Geomorphic Wetlands, Swan Coastal Plain (two datasets, one is for the management category and the other is for the classification)	Displays the location, boundary, geomorphic classification (wetland type) and management category of wetlands on the Swan Coastal Plain, between Wedge Island and Dunsborough	Department of Environment and Conservation	Swan Coastal Plain (Swan Avon, Kwinana Peel and South West Regions)	*Wetlands of the Swan Coastal Plain, volume 2B wetland mapping, classification and evaluation – wetlands atlas* (Hill et al. 1996) is available from the DEC website, <www.dec.wa.gov.au> (select 'Management and protection', then 'Wetlands' and 'Publications'). The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>. Further information about wetlands is available on the DEC website, <www.dec.wa.gov.au> (select 'Management and protection', then 'Wetlands').

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Geomorphic Wetlands, Augusta to Walpole (category and classification)	Displays the location, boundary and geomorphic classification (wetland type) of wetlands within three study areas between Augusta and Walpole. Absences in data occur for locations adjacent to study areas	Department of Environment and Conservation	South West and South Coast Region (Augusta to Walpole)	*Mapping and classification of wetlands from Augusta to Walpole in the south west of Western Australia* (V and C Semeniuk Research Group 1997) is available from the DEC website, <www.dec.wa.gov.au> (select ‘Management and protection’, then ‘Wetlands’ and ‘Publications’). The GIS dataset is available from Landgate’s Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>.
Hydrographic catchments (drainage divisions, basins, catchments or subcatchments)	These spatial datasets identify the boundaries of drainage divisions, drainage basins, catchments and subcatchments in Western Australia	Department of Water	State-wide	The GIS datasets can be used or downloaded at <www.water.wa.gov.au> (search for ‘geographic data atlas’). Select ‘Download’ or use the interactive web mapping tool online. Further information is available by emailing <spatial.data@water.wa.gov.au> or telephoning 08 6364 7600 and asking for the Spatial Data Exchange Officer.
Hydrography, linear (hierarchy)	The spatial dataset identifies the location and hierarchy of waterways in Western Australia	Department of Water	State-wide	The GIS dataset is available from the Department of Water by emailing <spatial.data@water.wa.gov.au> or telephoning 08 6364 7600 and asking for the Spatial Data Exchange Officer.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Imagery and base maps (Landgate orthomosaic index)	The Landgate orthomosaic index can be used to determine which aerial photo images are relevant	Landgate	State-wide	The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>. Further information about imagery is available at <www.landgate.wa.gov.au> (select 'Products and services', then 'Imagery' and 'Online aerial', 'Aerial prints', 'PanAIRama CD-ROM series', 'Satellite images' or 'customised images').
National biodiversity hotspots	Fifteen areas in Australia identified as examples of locations that contain particularly high levels of biodiversity under threat	Department of Sustainability, Environment, Water, Population and Communities	State-wide	Further information is available at <www.environment.gov.au> (search for 'Biodiversity hotspots' or '15 national biodiversity hotspots') or by telephoning DSEWPC on 02 6274 1111.
Proposed 2015 pastoral lease exclusions	Areas proposed for exclusion from pastoral leases when the current leases expire in 2015. These areas are proposed for inclusion in the conservation estate (e.g. national parks, nature reserves) managed by DEC.	Department of Environment and Conservation	State-wide (crown land)	The GIS dataset are available from the DEC by telephoning 08 9334 0333 and requesting the Spatial Database Administrator.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Public drinking water source areas (PDWSA) (proclaimed, unproclaimed but in use and proposed)	The spatial dataset identifies the location and boundary of PDWSA	Department of Water	State-wide	The GIS datasets can be used or downloaded at <www.water.wa.gov.au> (search for ‘Geographic data atlas’). Select ‘Download’ or use the interactive web mapping tool online. Further information is available by emailing <spatial.data@water.wa.gov.au> or telephoning 08 6364 7600 and asking for the Spatial Data Exchange Officer. Water quality protection note 108 *Public drinking water source areas of Western Australia* (DoW 2010) provides a register of drinking water catchments within each local government area. Water quality protection note 25 *Land use compatibility in public drinking water source areas* (DoW 2004) provides guidance on the compatibility of land uses within PDWSA. These publications are available on the Department of Water website, <www.water.wa.gov.au> (select ‘Publications’, then ‘Find a publication’ and click on ‘Series browse’ and ‘Water quality protection note’).
Ramsar list of wetlands of international importance	Identifies the location and wetland values of internationally important wetlands	Wetlands International	State-wide	The GIS dataset is available from Landgate’s Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>. Further information is available from the DEC at <www.dec.wa.gov.au> (select ‘Management and protection’, then ‘Wetlands’ and ‘Internationally recognised wetlands – Ramsar’) and Wetlands International at <http://ramsar.wetlands.org>. Information about Ramsar wetlands is also available on DSEWPC’s website at <www.environment.gov.au> (search for ‘Ramsar’ and ‘Australian Wetlands Database’).
South Coast significant wetlands (category and classification)	Spatial dataset representing regionally significant South Coast wetlands	Department of Environment and Conservation	South Coast	The GIS dataset is available from Landgate’s Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Species or communities with ecological significance (declared rare flora, threatened ecological communities, Priority flora and fauna species, threatened fauna and threatened fauna habitat	Database search that may be requested to determine the presence of identified significant flora or fauna within a search area	Department of Environment and Conservation	State-wide	Flora, fauna and community data searches are conducted by DEC’s Species and Communities Branch. The Species and Communities Branch can be contacted on 08 9334 0455. General information on species or communities with ecological significance is available at the DEC website <www.dec.wa.gov.au> (select ‘Management and protection’, then ‘Threatened species’). General information on particular species is available from DEC’s FloraBase website, <http://florabase.calm.wa.gov.au> and NatureMap website, <http://naturemap.dec.wa.gov.au/default.aspx>
United Nations Educational, Scientific and Cultural Organisation (UNESCO) biosphere reserves	There are two UNESCO biosphere reserves in Western Australia, Fitzgerald River and Prince Regent Nature Reserve	Department of Sustainability, Environment, Water, Population and Communities	State-wide (currently the Kimberley and South Coast Regions)	A biosphere reserve is a unique concept which includes one or more protected areas and surrounding lands that are managed to combine both conservation and sustainable use of natural resources. Further information on the Fitzgerald River and Prince Regent River Biosphere Reserves is available from DSEWPC’s website, <www.environment.gov.au> (search for ‘biosphere’) or by telephoning DSEWPC on 02 6274 1111.

Name of dataset	Description	Custodian	Region[3] or relevant area	Availability and further information
Water monitoring and data	Surface water levels, flows and quality, drinking water and groundwater levels and quality	Department of Water	State-wide	For information contact the water information officers by emailing <waterinfo@water.wa.gov.au> or telephoning 08 6364 6505. Further information is available at <www.water.wa.gov.au> (search for ‘Monitoring and data’). The Water Resources Information Catalogue (WRIC) is an index of water resources data, including water quality, rainfall, flows and water levels, collected from a variety of surface and groundwater monitoring sites throughout the State. Available at <www.water.wa.gov.au> (search for ‘Monitoring and data’ or ‘Water Resources Information Catalogue’). The Water Resources Information Data (WRDATA) has summary water resources data from surface water and rainfall monitoring sites throughout the state, including monthly and annual streamflow and rainfall information. Available at <www.water.wa.gov.au> (search for ‘Monitoring and data’).
Wetland Base	Displays the location of wetlands and describes the nature of wetland data collection throughout the state	Department of Environment and Conservation	State-wide	This dataset is available from Department of Environment and Conservation at <www.dec.wa.gov.au> (select ‘Management and protection’, then ‘Wetlands’, ‘Wetlands data’ and ‘Wetland Base’).
Wild rivers	Wild Rivers are unique, rare examples of waterways where biological and hydrological processes continue without significant disturbance	Department of Water	State-wide	The GIS dataset is available from the Department of Water by emailing <spatial.data@water.wa.gov.au> or telephoning 08 6364 7600 and asking for the Spatial Data Exchange Officer. *Water note 37: wild rivers* (DoW 2009) provides a broad overview of wild rivers in Western Australia. Available at <www.water.wa.gov.au> (select ‘Waterways health’, then ‘Looking after our waterways’ and click on ‘Water notes’ at the bottom of the page).

Table B2 GIS datasets for threats to waterways

Name of dataset	Description	Custodian	Region[4]	Availability and further information
Acid sulfate soils (ASS) risk maps	Various ASS risk maps	Department of Environment and Conservation and Western Australian Planning Commission	State-wide	ASS risk maps are available for the Swan Coastal Plain, Albany-Torbay, estuaries, Geraldton, Lower South West and the Pilbara coastline. Other maps may be developed in future. The GIS dataset is available from Landgate's Shared Land Information Platform (SLIP) <https://www2.landgate.wa.gov.au>. SLIP support is available by telephoning 08 9273 7832 or emailing <SlipEnabler@landgate.wa.gov.au>. Further information is available from the DEC website <www.dec.wa.gov.au> (select 'Management and protection', then 'Land' and 'Acid sulfate soils'). The acid sulfate soils planning guidelines are available from the Department of Planning website, via <www.planning.wa.gov.au/Publications>.
Contaminated sites	Spatial database identifies the location of known contaminated sites	Department of Environment and Conservation	State-wide	The contaminated sites database is available from the DEC website, <www.dec.wa.gov.au> (select 'Pollution prevention', then 'Contaminated sites' and 'Contaminated sites database').

[4] Based on the Department of Water's regional boundaries. Refer to <www.water.wa.gov.au/Water+regions/default.aspx>.

Name of dataset	Description	Custodian	Region[4]	Availability and further information
Water monitoring and data	Surface water levels, flows and quality, drinking water and groundwater levels and quality	Department of Water	State-wide	For information contact the water information officers by emailing <waterinfo@water.wa.gov.au> or telephoning 08 6364 6505. Further information is available at <www.water.wa.gov.au> (search for ‘Monitoring and data’). The Water Resources Information Catalogue (WRIC) is an index of water resources data, including water quality, rainfall, flows and water levels, collected from a variety of surface and groundwater monitoring sites throughout the state. Available at <www.water.wa.gov.au> (search for ‘Monitoring and data’ or ‘Water Resources Information Catalogue’). The Water Resources Information Data (WRDATA) has summary water resources data from surface water and rainfall monitoring sites throughout the state, including monthly and annual streamflow and rainfall information. Available at <www.water.wa.gov.au> (search for ‘Monitoring and data’).

Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASS	Acid sulfate soils
AWRC	Australian Water Resources Council
CENRM	Centre of Excellence in Natural Resource Management
DEC	Department of Environment and Conservation
DEWHA	Former federal Department of the Environment, Water, Heritage and the Arts
DSEWPC	Federal Department of Sustainability, Environment, Water, Population and Communities
DIWA	Directory of important wetlands in Australia
DoW	Department of Water
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPP	Environmental protection policies
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These are common bio-indicators of the naturalness of waterways
FARWH	National *Framework for the assessment of river and wetland health*
GIS	Geographic information system
GL	Gigalitres
HT	High threat
HV	High value
LT	Low threat
LV	Low value

μg/L	Micrograms per litre
μS/cm	Microsiemens per centimetre
MV	Medium value
NRM	Natural resource management
NTU	Nephelometric turbidity units, a measure of turbidity
NWQMS	National Water Quality Management Strategy
PDWSA	Public drinking water source areas
ppt	Parts per thousand
SIF	Salinity investment framework
SLIP	Shared land information platform (Landgate)
TN	Total nitrogen
TP	Total phosphorus
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WAPC	Western Australia Planning Commission
WRDATA	Water Resources Information Data
WRIC	Water Resources Information Catalogue

Glossary

Asset	Term used in the *Salinity investment framework* to indicate an item of value in a waterway
Bioregion	Areas of land or water which contain characteristic, geographically distinct assemblages of natural communities and species – also called ecoregions
Catchment	Area of land from which water drains
Criteria	Attributes used to assess values and threats – for example ‘naturalness’ and ‘representativeness’ could be a criteria for assessing ecological value
Ecoregion	*See* bioregion
Indicator	Attributes used to assess a criterion – for example, the indicators ‘channel disturbance’ and ‘invertebrate density’ could be used to measure the criterion ‘naturalness’
Management framework	System for prioritising management responses of waterways
Measure	Scored variables which are used to assess the relative importance of indicators used to assess criteria (which in turn are used to assess values)
Rating	Used to determine management prioritisation and response
Riparian zone	The interface between a waterway and land, where the vegetation and natural ecosystems benefit from and are influenced by the passage and storage of water.
River reach	Stretches of waterway, generally less than 20 km long and located between tributary inflows. Reaches have been termed ‘river links’ by some authors.
Stakeholder	Individuals, groups or organisations that affect or may be affected by waterway management responses
Subcatchment	Smaller catchments which make up catchments
Threat	Include changes in environmental conditions which have the potential to reduce the health or sustainability of a particular attribute and hence reduce its value

Value	The framework provides a systematic, comprehensive and flexible method to describe the ecological, social (including cultural) and economic values of waterways in Western Australia. In this context value refers to usefulness or importance.
Waterway	Waterways include all rivers (including creeks, brooks and streams) and their floodplains, estuaries, inlets, coastal lagoons, reservoirs and broad, flat and undefined systems that flow intermittently. Waterways may also include wetland systems that overflow into rivers.
Waterway unit	The component of the assessment area that has been chosen for the 'scale' of the project. Waterway units could be catchments, subcatchments or reaches.
Weighting	Used to reduce the influence of indicators scored by presence or absence or qualitative data and to preferentially favour or emphasise more quantitative data such as water quality

References and further reading

This section provides a list of literature and data references cited in the report. Some of these references are specific to the trial case studies but others are a useful source for all waterways in the state.

Recommended GIS datasets and some additional sources of information are given in Appendix B.

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