Barmah Wetland System Environmental Monitoring Program

Part B: Monitoring Program

Bernard McCarthy, Daryl Nielsen, Darren Baldwin, Shaun Meredith, Jane Roberts, Alison King, Julian Reid and Keith Ward.

Report to the Goulburn Broken Catchment Management Authority

Murray-Darling Freshwater Research Centre

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Barmah Wetland System Environmental Monitoring Program, Part B: Monitoring Program

Report to the Goulburn Broken Catchment Management Authority, P.O. Box 1752, Shepparton 3632

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Cover Photograph

Moira Grass (*Pseudoraphis spinescens*) at Barmah Forest during a flood event augmented by the release of the Barmah-Millewa environmental water allocation. Photograph: B. McCarthy, MDFRC, 16 November 2005.

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List of acronyms

ARp	Amphibious Responders with plastic growth form
BACI	Before-After-Control-Impact
BMF	Barmah-Millewa Forum
CAMBA	China-Australia Migratory Birds Agreement
CMS	Conservation of Migratory Species
CPOM	Coarse Particulate Organic Carbon
CPUE	Catch Per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCE	Department of Conservation and Environment
DEM	Digital Elevation Model
DNRE	Department of Natural Resources and Environment
DOC	Dissolved Organic Carbon
DSE	Department of Sustainability and Environment
EVC	Ecological Vegetation Class
EWA	Environmental Water Allocation
GBCMA	Goulburn Broken Catchment Management Authority
GL	Gigalitre (=1,000,000,000 or 1 billion litres)
GPS	Global Positioning System
GST	Goods and Services Tax
JAMBA	Japan-Australia Migratory Birds Agreement
LiDAR	Light Detection and Ranging
LWD	Large Woody Debris
MDBC	Murray-Darling Basin Commission
MDBMC	Murray-Darling Basin Ministerial Council
MDFRC	Murray-Darling Freshwater Research Centre
ML	Megalitre (= 1,000,000 or 1 million litres)
MLLE	Multiple Lines and Levels of Evidence
POC	Particulate Organic Carbon
RCS	Regional Catchment Strategy
SEA	Significant Ecological Asset (or “icon site”)
TLM	The Living Murray
VAC	Visual Assessment Checklist
WMA	Water Management Area

Introduction

Purpose, position and scope of this study

The purpose of this study is to develop a comprehensive and flexible environmental monitoring program for the Barmah wetland system that incorporates adaptive management principles and meets current policy and management requirements.

A broad range of policies, plans, strategies, agreements and legislation control or influence the management of Barmah Forest (McCarthy *et al*., 2005) and identify a requirement to monitor various aspects of the ecology of Barmah Forest. It is considered that current environmental monitoring at Barmah Forest does not adequately meet these requirements (Consultancy Brief).

Currently, the lack of long-term consistently collected data is the single greatest limitation in allowing the assessment of ecological objectives outlined in the various policies, plans, strategies, agreements and pieces of legislation that govern or influence the management of Barmah Forest. The overarching goal of this study is to develop a sound and consistent ongoing monitoring program that, when implemented, provides the information necessary to evaluate the ecological targets detailed in this report and potentially also the various objectives previously identified (McCarthy *et al*., 2005).

The Terms of Reference of the Consultancy Brief detail five tasks to develop the monitoring program (Appendix A).

This report is an advisory document to the Goulburn Broken Catchment Management Authority. It is intended to inform the Victorian Government's contribution to the development of an environmental monitoring program in future reviews of the Barmah-Millewa Significant Ecological Asset: Asset Environmental Management Plan (MDBC, 2005). It will also inform the development of an updated Water Management Plan for Barmah Forest.

The broad scope of the environmental monitoring program is to relate strongly to water management. The monitoring of activities such as logging is considered outside the scope of the monitoring program.

Report structure

The Barmah Wetland System Environmental Monitoring Program consists of two stand-alone documents. Part A provides background information relating to environmental objectives and targets determined for Barmah Forest through the various policies, plans, strategies, agreements and pieces of legislation that govern or influence its management. It also reviews past and current monitoring programs at Barmah Forest (McCarthy *et al*., 2005).

Part B (this document) builds upon the information of Part A and details an ongoing environmental monitoring program for the Barmah wetland system.

Nomenclature

Barmah Forest is subject to flooding from the River Murray and is considered a wetland system. Therefore, the term Barmah wetland system will be used interchangeably with Barmah Forest in this report, particularly when referring to the floodplain character of the site.

Much of the monitoring terminology used in this report is consistent with that used in the monitoring and evaluation framework currently being developed for The Living Murray (TLM) Initiative (MDBMC, 2003; MDBC, 2004). This reflects the importance of TLM process in the development of this monitoring program and the preference for consistency of monitoring terms where possible.

Barmah Forest

Barmah Forest is a Victorian River Red Gum (*Eucalyptus camaldulensis*) dominated floodplain covering 29,800 ha, located between the townships of Tocumwal in NSW and Echuca in Victoria. Together with the NSW Millewa Forest it forms the largest River Red Gum forest in Australia. Barmah Forest consists of State Forest (21,320 ha, or 72% of area), State Park (7,900 ha, or 26% of area that includes the Reference Areas Top Island (177 ha) and Top End (124 ha)) and Murray River Reserve (580 ha, or 2% of area). The State Park and Murray River Reserve are managed by Parks Victoria under the provisions of the Barmah Management Plan (DCE, 1992), whilst State Forest is managed by the Department of Sustainability and Environment (DSE) under the Mid-Murray Forest Management Plan (DNRE, 2002a) with consideration given to the principles and actions of the Barmah Management Plan (DCE, 1992). In addition to these localised plans, other policies, plans, strategies, agreements and pieces of legislation influence the management of Barmah Forest and are reviewed in McCarthy *et al*. (2005).

Effects of regulation at Barmah Forest

The effects of regulation on floodplain inundation were described in Roberts (draft). The key characteristics are that:

- regulation acts at two scales, landscape and localized; and
- regulation has an effect across the range of flows, but the effect is not uniform.

The two scales seek to separate effects on river flow from effects specific to this part of the River Murray where the channel capacity is progressively reduced, *i.e*. from Yarrawonga Weir downstream through the Barmah Choke. Broadly, landscape scale refers to the flow volume and timing down the River Murray, as determined by operations of Hume Dam and diversions upstream of Yarrawonga Weir. Localized refers to the scale of impact and management response, specifically referring to rain rejections and the installation and operation of regulators on effluent creeks going into Barmah Forest.

The differential effect of regulation for certain flow components across flows of different magnitudes was determined for 109-year time series of daily flows at Tocumwal, for simulated Current and simulated Natural conditions using the GetSpells software (version 1.1, issued February 1999), but considering the flow range from 12,000 ML d^{-1} to 50,000 ML d^{-1}. Results are summarized in Table 1, taken from Roberts (draft). This analysis should be treated as indicative rather than definitive, and refining and improving it is the subject of a recommendation in the Issues and Options report (Roberts, draft).

Table 1. Summary of effects of regulation: Current v Natural for six flow thresholds (ML d^{-1}). Effect of regulation at six flow thresholds on frequency, duration, variability and start time. Greatly decreased means when Current/Natural*100 is less than 60%, and greatly increased means when Current/Natural*100 is more than 150%. Copied from Roberts (draft).

	Flow thresholds (ML d^{-1})					
	≥12,000	≥15,000	≥20,000	≥30,000	≥40,000	≥50,000
Frequency	Increased	Similar	Decreased	Decreased	Decreased	Decreased
Length (mean duration)	Decreased	Decreased	Decreased	Similar	Similar	Similar
Variation (CV)	Increased	Increased	Increased	Similar	Increased	Increased
Small v large events (Skew)	Increased	Increased	Increased	Similar	Similar	Decreased
Number of floods starting in May-June	Decreased	Decreased	Decreased	Greatly Decreased	Greatly Decreased	Decreased
Number of floods starting in Sept-Nov	Greatly Increased	Greatly Increased	Decreased	Decreased	Decreased	Decreased

Although each flow threshold is distinctive, three flowbands can be clearly distinguished within this range:

- Flows ≥12,000 and ≥15,000 ML d^{-1}: increased or similar number of events of generally shorter duration mean that Current conditions are characterised by repeated wettings, with a seasonal bias due to loss of late autumn-early winter floods and a large increase in number of spring floods (columns 1 and 2).
- Flows ≥20,000 ML d^{-1}: fewer events and shorter duration with no strong seasonal bias (*i.e.* reduced frequency across all times) mean that Current conditions are drier in nearly all respects (column 3).
- Flows ≥30,000 and ≥50,000 ML d^{-1}: reduced frequency but similar mean duration and in particular loss of autumn-winter floods mean that Current conditions are characterised by a seasonal bias and increased dryness (columns 4, 5 and 6).

Current flow regime for flows below 12,000 ML d^{-1} is considerably changed from Natural due to landscape-scale effects of river regulation, namely high in-channel flows through spring-summer-early autumn with very short drawdown in autumn compared with Natural. There are also localized effects resulting from high in-channel flows and rain-rejection flows.

Sustained high in-channel flows means that hydrologic connectivity from river to effluent creeks and associated wetlands is maintained for most of the year, except for those creeks with regulators. Rain rejection flows downstream of Yarrawonga, arriving on top of high summer flows, can cause uncontrolled flooding, and to relieve this regulators are opened on effluent creeks.

The combined effects of these different aspects of regulation are summarized in Table 2 for wetlands and creeks, and Table 3 for part of the floodplain.

Table 2. Effects of regulating River Murray flow on wetlands and creeks of Barmah Forest. Differential effects of regulation on flow regime of the River Murray combined with local management results in most wetlands and creeks having a Current flow regime that is substantially different from Natural. Summary statements in blue are inferred from analyses and literature presented in Roberts (draft) but should be confirmed by targeted analyses.

Physiographic unit within Barmah Forest	Summary of hydrological change	Example
Wetlands directly connected to the river.	Period of inundation extended into autumn. Duration of drawdown now shorter and constrained to cooler months of autumn into early winter. Complete drying out unlikely. Receive sustained inflows from effluent creeks without regulators and river water quality (temperature, sediment) rather than floodplain water quality. Receive periodic inputs during summer from effluent creek with regulators (if opened). **From a seasonal wet and dry regime to a nearly permanently inundated or waterlogged state.**	Barmah Lake
Effluent Creeks with no regulators.	Flowing phase is extended into autumn. Duration of no or low-flow now considerably shorter and seasonally constrained to autumn. Velocity patterns altered: no analyses available. **From seasonally flowing with a wet and dry regime to nearly always flowing. Therefore, now characterised by long periods of persistently high velocity with little or no gradual receding phase.**	War Creek Cutting Creek
Effluent Creeks with regulators that are opened for rain rejection flows	Flowing phase in summer now spasmodic but unlikely to completely dry out. The annual average (based on River Murray in-channel flows only) is 4 pulses of 14 days each between December and April. Overall frequency of flow down effluent creeks is expected to be less as this is now likely only on alternate years due to an agreement between the Victorian and NSW state authorities on operating regulators. **Flow inversion? Probably had seasonal wet and dry phases as for Effluent Creeks with no regulators, but now has flow pulses through summer; combination of frequency x duration probably sufficient to irrigate plants and possibly maintain soil in moist conditions.**	
River Effluent Creeks with regulators that are not routinely opened for rain rejection flows.	Specific analysis needed to determine difference between Natural and Current; landscape-scale effect dominant, localized effects probably not significant. **Analysis needed**	

Table 3. Effects of regulating River Murray flow on the floodplain of Barmah Forest. Differential effects of regulation on the flow regime of the River Murray means that different parts of the floodplain are differentially affected. Flows are referenced to the gauge at Tocumwal and the affected vegetation is taken from work by Bren *et al.* (1988). Summary statements in blue are inferred from Table 1, but should be confirmed by specific analyses. The flow-inundated area relationship is the subject of a recommendation in Roberts (draft). The equivalent vegetation is approximate per flow-band and needs to be revised and updated once vegetation mapping and flow-inundated area have been revised.

Increasing elevations of floodplain within Barmah Forest	Summary of hydrological change	Equivalent vegetation
Area of the floodplain affected by flows in between 12,000 - 15,000 ML d^{-1} at Tocumwal.	Increased number of events of shorter average duration means that Current conditions are characterised by repeated wettings. There is a seasonal shift from late autumn-early winter floods to a large increase in the number of spring floods. **'Wetter' and a seasonal shift/seasonal loss**	Approximately 12-22% of forest flooded. **Giant Rush, Moira Grass, River Red Gum and Moira Grass and some regenerating River Red Gum on Moira Grass.**
Area of the floodplain affected by flows between 15,000 -20,000 ML d^{-1} at Tocumwal.	Similar number of floods but of shorter duration. There is a seasonal bias due to loss of late autumn-early winter floods and an increase in number of spring floods. **'Wetter' and a seasonal shift/seasonal loss**	Approximately 22-35% of forest flooded. **Some River Red Gum woodland with Terete Culm Sedge.**
Area of the floodplain affected by flows between 20,000 - 30,000 ML d^{-1} at Tocumwal.	Fewer events of shorter duration, but with no strong seasonal bias (*i.e.* reduced frequency across all times) means Current conditions are drier in nearly all respects. **Generally drier.**	Approximately 35-55% of forest flooded. **Nearly all River Red Gum woodland with Terete Culm Sedge understorey.**
Area of the floodplain inundated by flows between 30,000 - 50,000 ML d^{-1} at Tocumwal.	Reduced frequency but similar mean duration and in particular loss of autumn-winter floods mean Current conditions are characterised by a seasonal bias and increased dryness. **Generally drier and a seasonal shift / seasonal loss.**	Approximately 55-80% of forest flooded. **Nearly all River Red Gum woodland with Common Spike Rush or Warrego Summer Grass.**

Development of the environmental monitoring program

The Barmah Wetland System Environmental Monitoring Program follows a seven step adaptive management process modified from Scholz *et al.* (2005) (Table 4). The framework of the monitoring program is influenced by other monitoring and evaluation frameworks including Downes *et al.* (2002), Cottingham *et al*. (2005) and Crome (2004).

The process of Scholz *et al*. (2005) was also used to design environmental monitoring programs for the Hattah Lakes Significant Ecological Asset (SEA), the Lindsay and Wallpolla Islands SEA (Scholz *et al*., 2005) and for the monitoring of fish at the Gunbower Island SEA (Richardson *et al*., 2005). The seven step process is consistent with Nyberg's (1999) adaptive management framework (Figure 1).

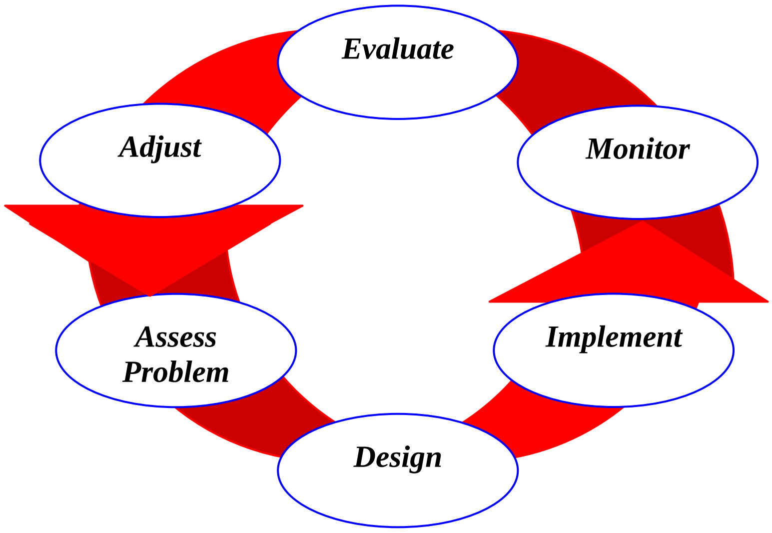

Figure 1. Contemporary adaptive management framework of Nyberg (1999).

Table 4. Seven step process for developing an environmental monitoring program at Barmah Forest (modified from Scholz *et al*., 2005).

Step	Further detail
1. Define management priorities, ecological objectives, and the scale of monitoring. Select ecological indicators.	Determine the spatial scale to be monitored, identify and prioritise management requirements for the area, list the key ecological objective(s) and define the key terms. Based on management priorities for the site, determine the ecological indicators (*e.g*. waterbirds, River Red Gum) for monitoring.
2. Develop a conceptual model for the system in question	Synthesise available knowledge of the relationships between various ecosystem components. Developing a conceptual model will help predict the ecological response from management actions and highlight knowledge gaps. For this monitoring program conceptual models were developed separately for each selected ecological indicator.
3. Define questions and testable ecological targets	Define testable ecological targets that are consistent with the ecological objective(s), and which are spatially and temporally explicit (and can be readily converted to testable hypotheses for formal statistical testing where appropriate). Ideally, these targets will be quantified rather than directional to allow their direct assessment (*e.g.* "4000 successfully fledged waterbirds" rather than "increase in waterbirds"). Within the adaptive management framework the assessment of targets informs our understanding of the system and facilitates refinement of the conceptual models.
4. Select the response variable(s) for measuring for each ecological indicator	From the ecological targets, identify the response variable(s) (*e.g.* abundance, diversity) for measuring.
5. Develop a study design	Determine the type of monitoring required to assess the ecological targets. Assessing some targets may require surveillance monitoring that does not necessarily examine cause and effect relationships. Other targets may require experimental monitoring where cause and effect relationships are investigated through more rigorous experimental designs and formal statistical testing. The scientific rigour of any monitoring program is influenced by what is achievable in terms of costs, whether suitable control, reference or replicate sites are available, and the management objectives for the site.
6. Optimise sampling effort and statistical power (including a Pilot study).	Sampling effort and statistical power need to be optimised to ensure an efficient use of resources. A pilot study (or use of data already collected if available) allows an assessment of the sampling error. For statistical testing, it also allows the calculation of the number of samples required to ensure that a pre-determined and biologically meaningful difference due to an intervention is detected statistically.
7. Implement monitoring program and evaluate results against ecological targets, and review monitoring program.	Implement the monitoring program and evaluate periodically (ideally annually by a review panel containing experienced ecologists) the data generated in the monitoring program to determine whether the ecological targets have been met. The data should inform the conceptual model for the system which will become increasingly refined over time through the adaptive management framework as our ecological knowledge of Barmah Forest improves. The review panel should review the monitoring program and set new ecological targets where applicable (and identify short-term intervention monitoring questions where applicable).

Environmental monitoring program

The Living Murray monitoring types

Four types of monitoring have been identified through TLM monitoring and evaluation framework (in development), and are summarised in Table 5. These monitoring types and terms have been adopted in this monitoring program for consistency given the importance of further environmental water allocations to Barmah Forest through TLM.

Table 5: The four monitoring and evaluation types proposed for The Living Murray.

Monitoring and evaluation Type	Details
River Murray System Monitoring	Results from **Surveillance monitoring** at the six Significant Ecological Assets are aggregated at the scale of the River Murray System to make a judgement on the effectiveness of environmental management actions in improving the health of the River Murray System. *Note that key ecological indicators for monitoring across each of the six SEAs are currently being defined and will be incorporated into the Barmah Wetland System Environmental Monitoring Program where applicable.*
Icon Site Condition Monitoring	**Surveillance monitoring** occurs at the scale of a single SEA to reveal the environmental condition of the site over time and permit ecological targets to be assessed. This type of monitoring does not necessarily establish cause and effect due to a lack of experimental control sites. As such, any improvement in the asset overall cannot be attributed solely to a management action (*e.g.* the application of environmental water) due to other factors (*e.g.* changed climatic conditions) not being controlled for.
Intervention Monitoring	**Intervention monitoring** seeks to assess how ecological responses to individual management actions (*e.g.* flow enhancement, pumping to wetlands) result in changes at the Asset scale. It provides scope for the examination of cause and effect relationships using formal statistical hypothesis testing, although the strength of inference will depend upon the experimental design and its use of experimental controls and replication. Interventions are considered event ready management experiments that will inform conceptual models and be extrapolated to other sites.
Compliance Monitoring	**Compliance monitoring** determines whether actions, works and measures are implemented in the manner intended (*e.g.* a wetland regulator operates in the manner intended). Compliance monitoring is also linked to water accounting.

Considerations for the monitoring program design

One of the most important decisions for a monitoring program is to determine the balance between providing information relating to the ecological condition of a site over time and the level of controlled experimentation (Crome, 2004). This balance will depend on management requirements and also require consideration of the feasibility, logistics and costs of undertaking experimental monitoring.

In the case of Barmah Forest, adopting controlled experimentation to answer questions at a large scale is problematic. Consider the question as to whether an environmental water allocation (EWA) will deliver ecological benefits to Barmah Forest. For an experimental design involving the sampling of control and impact sites both before and after the impact (BACI design) (see Cottingham *et al*. (2005) and Downes *et al*. (2002) for further details of the combinations of Before/After/Control/Impact/Reference designs and their relative strengths of inference), sites that have received a similar watering regime in the past would need to be identified and selected. Treatment and experimental controls would need to be allocated to these sites (ideally randomly), where experimental control sites receive flood waters without the EWA and treatment sites receive flood waters with the EWA. Without a detailed knowledge of how much water will be arriving at Barmah Forest (the EWA contribution may be small relative to natural flooding) and floodwater movement across the forest, managing flows effectively to allow disparate flooding of treatment and experimental control areas remains an exercise with inherently high risk.

A further complication is that Barmah Forest has received three environmental water allocations in the recent past including 1998, 2000 and late 2005 (Maunsell McIntyre Pty Ltd, 1999; BMF, 2001; Ward and O'Connor, 2006) making any "before EWA" comparison difficult.

One potential alternative to assess cause and effect relationships is to adopt a Multiple Levels and Lines of Evidence (MLLE) approach (Cottingham *et al*., 2005; Downes *et al*., 2002). This approach is not a substitute for a well designed and rigorous experiment but it allows less rigorous evidence from several sources to be collated in a logical way to allow greater inference of causality, and may be appropriate in situations where scientifically rigorous designs are not possible. Downes *et al.* (2002) lists nine causal criteria, including strength of association, consistency of association, biological gradient and biological plausibility that can, when considered together, increase the strength of causal inference. The current difficulty with the MLLE approach is in defining a method for integrating the different levels of evidence in a robust way (Downes *et al*., 2002). As noted by Cottingham *et al*. (2005), the use of MLLE in environmental assessment is relatively recent and may be a valuable tool in the future. The approach is highlighted here but not recommended as part of this monitoring program at this stage.

Environmental monitoring at Barmah Forest

This Barmah Wetland System Environmental Monitoring Program consists primarily of long-term monitoring. It uses monitoring that is consistent with three monitoring and evaluation types proposed under TLM, including surveillance monitoring at the Significant Ecological Asset scale, intervention monitoring and compliance monitoring (Table 5). The surveillance monitoring will allow an assessment of the ecological objectives and targets, inform the developed conceptual models, and permit an assessment of ecological change at

Barmah Forest over time. The intervention monitoring will allow an assessment of ecological response to management intervention (types are still being developed at the time of writing) and will focus on establishing cause and effect relationships where the strength of inference will depend upon the experimental design. Compliance monitoring will allow an evaluation of whether actions, works or measures occurred as intended (*e.g.* opening a regulator for a period of time resulted in flooding of a particular area). The area considered in the monitoring program includes the River Murray channel adjacent to Barmah Forest due to the importance of connectivity between the river channel and its floodplain.

Whilst the environmental monitoring program focuses on long-term monitoring, it also considers short-term intervention monitoring to be an important future component of the monitoring program. It is envisaged that in the future some identified knowledge gaps in the conceptual models may be better addressed through short-term, experimental monitoring at spatial scales smaller than Barmah Forest (*i.e.* sub-asset) to examine cause and effect relationships through rigorous experimental designs and formal hypothesis testing.

Adaptive management framework

The Barmah Wetland System Environmental Monitoring Program is embedded within an adaptive management framework (Figure 1).

This allows the identified ecological targets to be assessed whilst allowing for an improvement in our understanding of Barmah Forest over time. Hence, the monitoring program remains scientifically credible whilst allowing flexibility to strategically target knowledge gaps in the conceptual models developed for the system.

The adaptive management framework will incorporate an annual review of the monitoring program results by a 'review panel' consisting of ecological experts and natural resource managers. The identified ecological targets will be assessed to determine whether they were achieved in the specified period of time and will inform the conceptual models developed for different components of the system. These conceptual models should be updated by the review panel to better reflect the current understanding of the system and to highlight knowledge gaps for future monitoring.

This monitoring program has been developed to be ongoing. The long-term focus recognises the value of consistent and targeted monitoring so as to allow the detection of long-term trends at Barmah Forest. Given this focus, some ecological targets have been developed for periods of ten years to overcome some of the naturally high variability in flows between years. Developing the monitoring program within an adaptive management framework is crucial for permitting the program to remain flexible and adapt over time to changes in management and circumstances.

Ecological objective and targets

A considerable number of ecological objectives were identified through a review of the various policies, plans, strategies, agreements and pieces of legislation that influence the management of Barmah Forest (McCarthy *et al*., 2005). Given the importance of both TLM and the Victorian Bulk Water Entitlement Process in delivering EWAs to Barmah Forest to more closely mimic the natural flow regime, the ecological objective identified for these initiatives has been adopted here as the overarching ecological objective:

Enhance forest, fish and wildlife values.

This objective is considered a broad aspirational statement that encompasses many of the other stated objectives for Barmah Forest detailed in McCarthy *et al.* (2005). For example, the Ramsar objective, which is to maintain the ecological character at Barmah Forest at the time of its listing in 1982, is also considered an important objective, and one that is encompassed by TLM objective. However, it is also recognised that the TLM interim ecological objective may not be ideal (*e.g.* the term "fish" already comprises part of the "wildlife" term, and the term "forest" is not defined) and may warrant redefining in the future.

It could be argued that the ecological objective has been achieved at certain times during natural flooding or through the application of EWAs to Barmah Forest that result in successful bird or fish breeding. However, we consider the ecological objective to be an ongoing and long-term objective that should be evaluated through the assessment of specific ecological targets over the long-term.

Selected ecological indicators

The ecological indicators selected for monitoring are based on the prioritisation of current management requirements (Table 6 of McCarthy *et al*., 2005). Those considered most important for monitoring and included in this monitoring program are fish, waterbirds, vegetation, water quality, flood mapping and groundwater. Frogs have also been included in the monitoring program due to their responsiveness to flooding events. Ecological indicators not included in this list may be added to the monitoring program in the future (*e.g.* turtles and macroinvertebrates).

Workshop to develop conceptual models and ecological targets

A workshop was convened on 15th and 16th November 2005 to develop conceptual models and ecological targets that are consistent with the ecological objective "Enhance forest, fish and wildlife values". Experienced ecologists, managers and stakeholders with particular areas of ecological, remote sensing and management expertise attended the workshop. The primary outcome of this workshop and follow-up work was the development of conceptual models and ecological targets for the selected ecological indicators.

Testable and quantified ecological targets were developed that reflect a healthy ecosystem under current conditions when the site is managed well (based on best available information). The targets are spatially and temporally explicit where possible so as to allow their unambiguous assessment. In cases where baseline information was unavailable to set quantified targets, directional targets (*e.g.* increase/maintain/decrease) were set with the view to quantify the targets in the future where possible following a designated period of monitoring to establish a baseline.

Most of the ecological objectives and targets identified from the current policies, plans, agreements, strategies and pieces of legislation influencing the management of Barmah Forest (see McCarthy *et al*., 2005) are not quantified, making it a subjective exercise to assess whether a particular objective has been achieved. For example, it has been difficult to assess the Ramsar obligation “to maintain the ecological character of Barmah Forest” as ecological character has not been defined for the site until recently (see DSE, 2005). To overcome these deficiencies it was considered necessary to quantify (or set in train a process to allow targets to be quantified) the ecological responses through the establishment of directly assessable and quantified ecological targets. The ecological targets established here have not been addressed previously, and many require assessment over the long-term (*e.g.* ten years) to determine whether the target has been met.

Ecological Indicator 1: Fish

Background and limitations

The fish communities of Barmah Forest were once diverse and highly abundant, supporting a large commercial fishery and comprising an important food source for local Aboriginals (King, 2005). Today, although catches of native fish have declined substantially and introduced species are common (Table 6), Barmah Forest remains an important area for native fish. There have been no objectives or targets previously set for Barmah Forest fish populations, likely due to the limited long-term knowledge of fish in the region.

To date, there has been no long-term or consistent monitoring programs aimed at examining the ongoing status of fish communities in Barmah Forest. However, there has been a number of fish ecological research studies focussing on various activities relating to fish management in Barmah Forest (see McCarthy *et al.*, 2005) that have been used to enable informed target setting. Of particular interest are a number of more recent (some current) research programs investigating:

- the effect of water management on fish breeding and recruitment (King *et al*., 2004, 2005a&b, and current project);
- the effect of water management on native fish movement (Jones, 2004, 2005 and current project);
- the relative contribution of carp recruits to the River Murray population (Crook, 2004; Crook In press, and current project);
- the impact of regulators on fish stranding (Jones and Stuart, 2004); and
- the management of carp (Stuart and Jones, 2002).

Due to the limited amount of quantified data that exists:

- The presented conceptual model is based on our best understanding of how the system functions at this time using both local and general models of fish responses to water management interventions. Where applicable, key knowledge gaps have also been provided.
- The presented ecological targets have been established using the best available information and expert opinion.
- Most targets are generalised (*i.e.* directional) only at present.
- The monitoring program should conduct both:
    - Surveillance monitoring, aimed at informing about the trend in condition of the fish community at the Asset scale over the longer term (but does not necessarily inform about cause and effect).
    - Intervention monitoring, where specific hypotheses relating to the effect of specific management interventions are monitored. This is particularly important for fish management at Barmah Forest, as more information is required about the response of fish (native and exotic) to various water management activities (*e.g.* flow enhancement (EWA use) or regulator operations).
- The monitoring program should be implemented for a minimum of five years to obtain a baseline data set. After this time the interim targets should be thoroughly reviewed with the intent of refining and quantifying each target. More specific targets (*e.g.* for individual species) may also be set. Uncertainty modelling should also be explored at this time to aid in setting targets.

The fish fauna of the Murray-Darling Basin can be broadly categorised by their recruitment and early life history strategies (see King, 2002):

- flood specialists (*e.g.* golden and silver perch);
- flood opportunists (*e.g.* carp);
- low flow specialists (*e.g.* crimson-spotted rainbowfish, carp gudgeons and gambusia);
- generalists (*e.g.* Australian smelt and flathead gudgeon);
- main channel specialists (*e.g.* Murray cod, trout cod, river blackfish); and
- wetland specialists (*e.g.* carp gudgeons, Australian smelt, southern pygmy perch).

Whilst these strategies are based on limited evaluations at present and are under review, they provide a useful way to broadly describe and help predict fish responses to water management interventions. This is a key knowledge gap.

The native and exotic fish species recorded at Barmah Forest from past surveys (BMF, 2002; Jones, 2004; King *et al*., 2004, 2005a&b; McKinnon, 1997) are listed in Table 6 along with their relative abundance (from BMF, 2002; King, 2005).

Table 6. Fish species sampled at Barmah Forest (*exotic species, # translocated species).

Common name	Scientific name	Relative abundance
trout cod	*Maccullochella macquariensis*	Rare
Murray cod	*Maccullochella peeli peeli*	Common
golden perch	*Macquaria ambigua*	Common
silver perch	*Bidyanus bidyanus*	Common
crimson-spotted rainbowfish	*Melanotaenia fluviatilis*	Rare
Macquarie perch	*Macquaria australasica*	Probably locally extinct
freshwater catfish	*Tandanus tandanus*	Rare
carp gudgeons	*Hypseleotris spp.*	Abundant
Australian smelt	*Retropinna semoni*	Abundant
flathead gudgeon	*Philypnodon grandiceps*	Common
unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Rare
Murray hardyhead	*Craterocephalus fluviatilis*	Rare
Murray jollytail	*Galaxia rostratus*	Rare
southern pygmy perch	*Nannoperca australis*	Rare
river blackfish	*Gadopsis marmoratus*	Rare
short-headed lamprey	*Mordacia mordax*	Rare
southern purple-spotted gudgeon	*Mogurnda adspersa*	Probably locally extinct
bony herring	*Nematalosa erebi*	Rare
climbing galaxias#	*Galaxias brevipinnis*	Rare
common carp*	*Cyprinus carpio*	Abundant
goldfish*	*Carassius auratus*	Common
redfin perch*	*Perca fluviatilis*	Common
gambusia*	*Gambusia holbrooki*	Abundant
oriental weatherloach*	*Misgurnus anguillicaudatus*	Common
brown trout*	*Salmo trutta*	Rare
rainbow trout*	*Oncorhynchus mykiss*	Rare
tench*	*Tinca tinca*	Rare

Conceptual model

Changes to the River Murray's natural flow regime have reduced the frequency, duration and magnitude of flooding in Barmah Forest. Flooding (either managed or natural) and other related water management activities can both positively and negatively affect the various native fish groups (Figure 2).

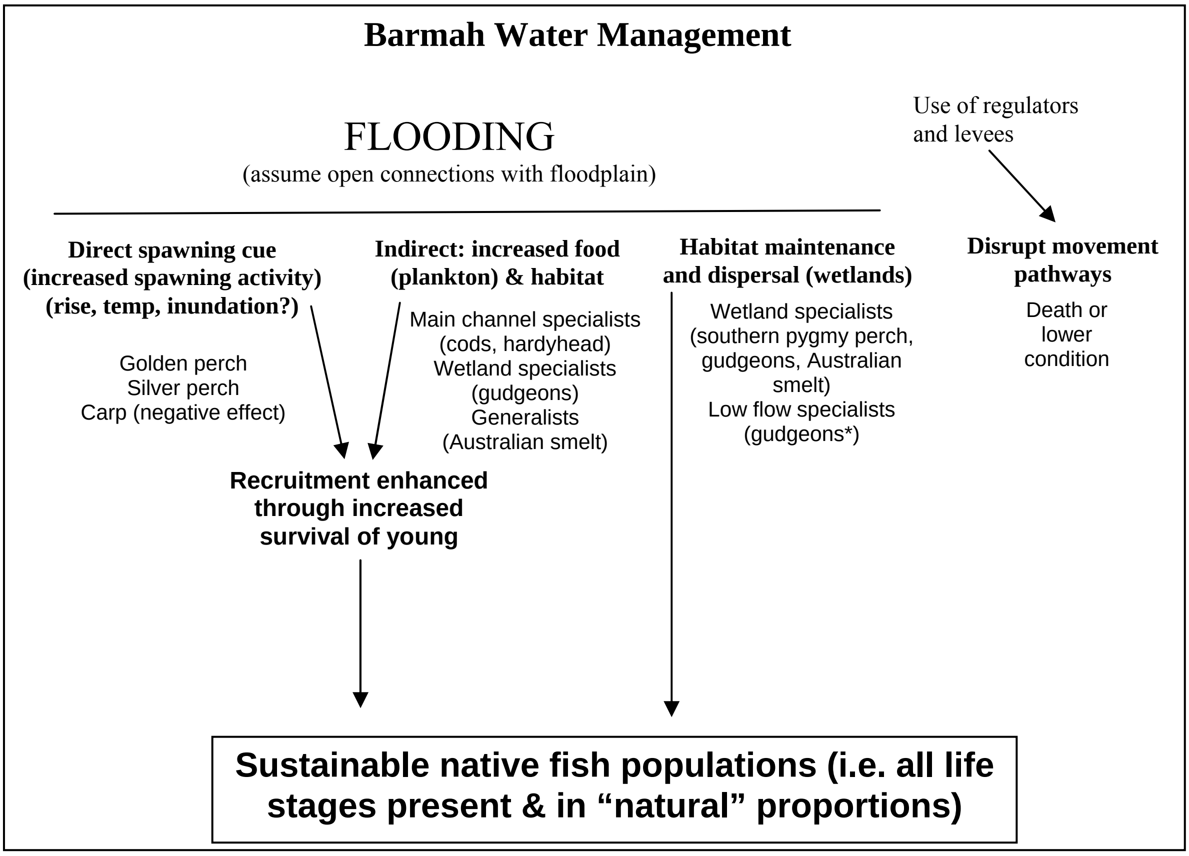

Figure 2. Conceptual model for fish populations at Barmah Forest.

Positive effects

Prolonged flooding (2-3 months) during spring resulting in both a rise in river level and inundation of Barmah Forest will:

1. Initiate a direct spawning cue and enhance breeding opportunities in some fish species including golden perch and silver perch.
2. Increase availability of suitable food and habitat for larval fish, thereby enhancing survival and recruitment. This could occur for all fish species in all strategies.

Key Knowledge Gap**:** This model has been largely drawn from our best understanding of expected responses and generalised fish recruitment models to flooding (Junk *et al*., 1989; Harris and Gehrke, 1994). Strong evidence supporting this component of the conceptual model is very limited for Australian species at present (see Humphries *et al*., 1999; King *et al*., 2003). However, this is largely due to a lack of understanding about the species responses to flooding. Responses to flooding are also likely to vary according to the timing and water temperature of the flood. Detailed investigations examining the response of fish to different types of floodplain inundation are required.

Flooding at any time of the year, when the flood inundates the floodplain and connects individual wetland components (creeks, wetlands swamps), will:

1. Allow refilling of wetlands to maintain habitat for wetland dwelling species. This is particularly important for those species reliant on wetlands either as key recruitment areas (*e.g.* carp gudgeons) or as specialised habitats (southern pygmy perch).
2. Maintain a diversity of habitat types within the floodplain. For example, permanently or infrequently inundated billabongs, swamps, creeks and floodplain.

3. Allow for dispersal of individuals between and within floodplain and in-channel habitat elements. This is likely to be particularly important for species that may be recruiting in floodplain areas and disperse into more permanent channel habitats (*e.g*. Australian smelt) and for dispersal of wetland dwelling species to other non-occupied wetlands.

Key Knowledge Gap: The importance of this component of the conceptual model for the maintenance of sustainable native fish populations at Barmah Forest is largely speculative (although intuitive) and requires further investigation.

Negative effects

Prolonged flooding (2-3 months) during spring, resulting in both a rise in river level and inundation of Barmah Forest, will enhance breeding opportunities and survival of young common carp (an exotic species).

Key Knowledge Gap: Common carp are known to successfully breed in a variety of conditions (non-flood and flood years, wetlands and rivers). However, little is known about the relative success of various breeding events into the adult population and also the relative contribution of carp sourced from Barmah Forest to the overall River Murray carp population. Both of these questions require further investigation at Barmah Forest.

Flooding at any time of the year, when the flood inundates the floodplain and connects individual wetland components, will enhance the dispersal of exotic species including carp and oriental weatherloach within and between channel and floodplain habitats.

Key Knowledge Gap: The importance of this component of the conceptual model is largely speculative (although intuitive) are requires further investigation.

Flooding, particularly in summer and where inundation has not occurred for a long period, increases the risk of severe blackwater and low dissolved oxygen events that may result in fish deaths or emergence from the water of Murray crayfish. However, a number of blackwater events have occurred in Barmah Forest that have not caused fish deaths, where fish are potentially able to move out of the affected areas and avoid the poor water quality.

Key Knowledge Gap: Although information is known about how blackwater events occur, there have been no investigations on the responses of native fish to varying types of blackwater events. For example, more natural shaped floods of prolonged durations and rate of rise may enable fish to avoid poor water quality conditions.

Regulators have been constructed on many creeks and flood paths throughout Barmah Forest to enable active management of floodplain inundation events into particular areas. However, the current operation of these structures can disrupt and hinder the movements of native fish utilising off-stream habitats with many small and large bodied fish potentially becoming stranded behind the regulators before they have an opportunity to reach more permanent waters (either in the forest or the river) (Jones and Stuart, 2004). Mortality and disease of fish stranded behind regulators also appears to be high (Jones and Stuart, 2004). This is likely to be a particular problem behind the larger Barmah Forest regulators constructed across major creeks (*e.g.* Gulf Creek).

Ecological targets

The ecological targets for fish are listed under three groups: (1) ecological targets for determining the abundance, diversity and distribution of fish communities at Barmah Forest (Table 7), ecological targets for determining spawning and recruitment at Barmah Forest (Table 8) and an ecological target for native fish stranded behind regulators (Table 9). Monitoring requirements and estimated monitoring costs are also presented separately for each group.

Status of fish communities at Barmah Forest

A targeted monitoring program examining the abundance, diversity and distribution of native fish at Barmah Forest has not been conducted previously. The proposed targets and monitoring program consider the status of the fish communities of both the River Murray channel and off-stream (particularly creek and wetland) habitats throughout Barmah Forest. This monitoring is consistent with the TLM surveillance monitoring at the Asset scale (Table 5).

Table 7. Ecological targets for fish communities at Barmah Forest (CPUE = catch per unit effort).

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Increase in abundance of key channel dwelling native fish.	Trout cod, Murray cod, silver perch, golden perch, Australian smelt, unspecked hardyhead	Abundance (CPUE)	Abundance data (measured as CPUE) collected for first 5 years of surveys to establish a quantified baseline (and permit refinement of target). Assess target by measuring mean abundance over past five years and comparing with baseline.
Increase in abundance of off-channel dwelling native fish.	Carp gudgeons, Australian smelt, southern pygmy perch	Abundance (CPUE)	Abundance data (measured as CPUE) collected for first 5 years of surveys to establish a quantified baseline (and permit refinement of target). Assess target by measuring mean abundance over past five years and comparing with baseline.
Maintain and/or increase the diversity of native fish species occurring in both off-channel and in-channel habitats.	Native fish	Diversity	Determine species diversity from first 5 years of monitoring to establish a quantified baseline for refinement of target. Assess target by measuring total diversity from past five years and comparing with baseline. Also need to evaluate composition and assess whether composition has changed.
Increase in the distribution and frequency of occurrence for all native fish species.	Native fish	Distribution / Frequency of occurrence	Assess the frequency of occurrence of all native fish species in a given year among all sampling locations. Determine baseline distribution over first 5 years of monitoring to establish baseline.
Young-of-year, sub-adults and adults present for all native species.	Native fish	Presence of fish per size class	Examination of length-frequency plots each year to ensure all life stages are represented. Evaluate over time.
Maintain or decrease the diversity of exotic fish species.	Exotic fish	Diversity	Determine species diversity from first 5 years of monitoring to establish a quantified baseline for refinement of target. Assess target by measuring total diversity from past five years and comparing with baseline. Also need to evaluate composition and assess whether composition has changed.
Maintain or decrease the abundance of exotic fish species.	Exotic fish	Abundance (CPUE)	Abundance data (measured as CPUE) collected for first 5 years of surveys to establish a quantified baseline (and permit refinement of target). Assess target by measuring mean abundance over past five years and comparing with baseline.
Decrease in abundance of carp in wetlands and River Murray channel.	Common carp	Abundance (CPUE)	Abundance data (measured as CPUE) collected for first 5 years of surveys to establish a quantified baseline (and permit refinement of target). Assess target by measuring mean abundance over past five years and comparing with baseline.

Monitoring requirements for determining status of fish communities

A range of channel and off-channel habitats should be surveyed intensively once each year for fish using standardised electrofishing protocols. Sampling sites should include a minimum of five river channel sites (to be sampled in early winter during low river levels), and three creek and three wetland sites (to be sampled during late summer before regulated flows decrease). Sampling should be repeated each year for a minimum of five years initially to establish a quantified baseline and allow population trends to be established. Given that there are targets to assess species diversity, sampling will occur across a range of habitats and with reasonable effort to improve detectability of less common species. Sampling sites should include sites sampled in previous surveys to enable some comparisons across a longer period of time at these specific sites. The methods and CPUE might be able to be consistent between surveys and this can be determined closer to the surveys being conducted.

Fish spawning and recruitment response to water management at Barmah Forest

The surveillance monitoring component proposed above will inform the trend in condition of the fish community at the Asset scale over the longer term (*i.e*. it will not determine cause and effect, but will provide an indication of the status of the fish community over time). Given the likely breeding and recruitment response of fish (both native and exotic) to managed or natural flooding events (see Conceptual Model), it is useful to consider additional ecological targets for Barmah Forest that specifically address spawning and recruitment of fish (Table 8). Whilst this type of monitoring could be considered as “intervention” monitoring (Table 5) due to management intervention of flow enhancement, the inherent lack of spatial controls and “before EWA” data means that causality needs to be inferred from comparisons between non-flood and flood years. This proposed monitoring would also build on three years of an existing and successful research program (King *et al*., 2004, 2005a&b).

Table 8. Ecological targets for fish spawning and recruitment at Barmah Forest.

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Successful spawning for flood specialists in at least three years in ten.	Flood specialists (silver and golden perch)	Spawning (Number of eggs and larvae)	Count the number of eggs and larvae for the two species during the spawning season in each year. Use information over a 5 year period to quantify a baseline for "successful spawning". Count the number of years in any ten year period to determine whether the target has been achieved. Also, compare spawning between both flood and non-flood years.
Successful spawning of main channel specialists in at least three years in ten.	Main channel specialists (Murray cod and trout cod)	Spawning (Number of larvae)	Count the number of larvae for the two species during the spawning season in each year. Use information over a 5 year period to quantify a baseline for "successful spawning". Count the number of years in any ten year period to determine whether the target has been achieved. Also, compare larval abundance between both flood and non-flood years.
Successful recruitment of flood specialists in at least three years in ten.	Flood specialists (silver and golden perch)	Recruitment (Number of young-of-year)	Count the number of young-of-year of the two species during targeted sampling in Autumn of each year. Use information over a 5 year period to quantify a baseline for "successful recruitment". Count the number of years in any ten year period to determine whether the target has been achieved. Also, compare recruitment between both flood and non-flood years.
Successful recruitment of main channel specialists in at least three years in ten.	Main channel specialists (Murray cod and trout cod)	Recruitment (Number of young-of-year)	Count the number of young-of-year of the two species during targeted sampling in Autumn of each year. Use information over a 5 year period to quantify a baseline for "successful recruitment". Count the number of years in any ten year period to determine whether the target has been achieved. Also, compare recruitment between both flood and non-flood years.
Maintain or decrease spawning and recruitment of exotic fish (particularly common carp).	Exotic fish	Spawning (number of larvae) and recruitment (number of juveniles)	Establish spawning and recruitment levels for first 5 years of surveys to establish a quantified baseline (and permit refinement of target). Assess target by measuring spawning and recruitment over past five years and comparing with baseline.
Successful spawning for generalists and wetland specialists fish groups every year, including three higher spawning and recruitment years every ten years.	Generalists and wetland specialists (Australian smelt, flathead gudgeon, carp gudgeons)	Spawning (Number of larvae)	Establish spawning levels each year during the spawning period. Use information over a 5 year period to quantify baselines for "successful spawning" and "higher spawning". Assess annually whether successful spawning occurred and count the number of years in any ten year period to assess whether "higher spawning" occurred to evaluate target.

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Successful recruitment for generalists and wetland specialists fish groups every year, including three higher spawning and recruitment years every ten years.	Generalists and wetland specialists (Australian smelt, flathead gudgeon, carp gudgeons)	Recruitment (Number of juveniles)	Establish recruitment levels each year during the recruitment period. Use information over a 5 year period to quantify baselines for "successful recruitment" and "higher recruitment". Assess annually whether successful recruitment occurred and count the number of years in any ten year period to assess whether "higher recruitment" occurred to evaluate target.

Monitoring requirements for determining fish spawning and recruitment

Targeted larval and juvenile sampling will be conducted intensively at a range habitat types throughout Barmah Forest, following the existing protocol and sites already in use in the existing monitoring program (King *et al*., 2004, 2005a&b). This will also enable comparisons to the existing three years of survey data. Sampling will be conducted during September to February each year, monthly at most Barmah Forest sites, and fortnightly for river drift sampling targeting spawning of key channel species. Specific gears for capturing early life stages of fish are required, including light traps, sweep net electrofishing, drift nets and hand trawl nets.

Targeted boat electrofishing surveys will be conducted following the protocol of King *et al*. (2005a&b) at three river channel sites to examine the recruitment success of key channel dwelling species. These surveys are more intensive than the standardised surveillance surveys and should be viewed separately, however they may occur at the same time in an effort to improve cost efficiency.

Sampling should occur every year, in both flood and non-flood years, and be maintained at least for five years. After this time, the targets and monitoring program should be reviewed.

Impact of regulator operation on native fish

One area highlighted for intervention monitoring is the assessment of fish stranded behind the Gulf Creek regulator. Following the closure of the regulator upon flood recession fish become stranded before they have an opportunity to move back to the main river channel (Jones and Stuart 2004). There are proposals to change the way the operator is closed (*i.e*. make it more gradual) or install a fishway on the regulator. It is proposed that monitoring of stranded fish continues to occur before and after this management change to determine the effect of regulator operation on the stranding of native fish and allow an assessment of the target of Table 9.

Table 9. Ecological target for native fish stranded behind regulators.

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Decrease the abundance of native fish stranded behind Gulf Creek regulators by 80%.	Native fish	Abundance	Monitor the number of fish stranded behind the Gulf Creek regulators and pool with previously collected data of Jones and Stuart (2004) and current surveys. Continue monitoring following a change in operation to the regulator or installation of fishway to assess whether target is being met.

Monitoring requirements for assessing native fish stranded behind regulators

For consistency with previous methodologies, water should be pumped out from behind the Gulf Creek regulators during Autumn to allow for the removal, identification and counting of the number of fish. Pre-intervention data is currently available (Jones and Stuart, 2004 and current project).

Estimated costs

Estimated costs are annual and based on the number of "people days". At this point in time it is estimated that one person day will cost $1,000. These costs are **exclusive** of accommodation charges, travel costs and GST and should be considered as indicative only.

Status of fish community monitoring	
11 sites (5 river, 3 creek, 3 wetland) sampled requiring 8d (including prep and travel time)	
Survey: 16 people days	$16,000
Electrofisher costs: 8d @ $400/d	$3,200
Annual report preparation: 8 people days	$8,000
TOTAL PER YEAR	**$27,200**

Fish spawning and recruitment monitoring	
12 sites sampled requiring 5d (including prep and travel time) **per survey**	
Survey: 10 people days per **monthly** survey x 6 surveys	$60,000
Survey: 4 people days per **fortnightly** survey x 5 surveys	$20,000
Sample processing: 8 people days (monthly surveys) x 6 surveys	$48,000
Sample processing: 3 people days (fortnightly surveys) x 5 surveys	$15,000
Annual report preparation: 10 additional people days	$10,000
TOTAL PER YEAR	**$153,000**

Impact of Gulf Creek regulator operation on fish	
Pump out area behind Gulf Ck regulators over 5d	
Survey: 10 people days	$10,000
Pump hire/running (6" pump)	$2,000 (estimate)
Annual report preparation: 2 people days	$2,000
TOTAL PER YEAR	**$14,000**

Skills and resources

Experienced fish ecologists with appropriate electrofishing training and identification skills for larval and juvenile fish are required to undertaken the fish monitoring. Victorian and NSW fishing permits and ethics approval are also needed. An electrofishing boat, backpack electrofisher and specialised larval sampling gear are also required.

Ecological Indicator 2: Waterbirds

Background and limitations

Colonially nesting waterbirds (hereafter colonial waterbirds) have been the iconic animal group at Barmah Forest. Here, the composition of this group is restricted to include all colonially nesting species of Australian inland waters in the taxonomic Orders Ciconiiformes (herons, spoonbills, ibis) and Pelecaniformes (pelicans and cormorants), and the terns and gulls (family Laridae). Colonial waterbirds known to have bred in the Barmah-Millewa Forest are listed in Table 10.

Table 10. Colonial waterbirds known to have bred in the Barmah-Millewa wetlands. (Source: modified from Table 1 in Leslie, 2001). Conservation status categories are from Victoria's Flora and Fauna Guarantee Act 1988 (after DSE, 2003a).

Common name	Scientific name	Status in Victoria
Darter	*Anhinga melanogaster*	
Little Pied Cormorant	*Phalacrocorax melanoleucos*	
Pied Cormorant	*Phalacrocorax varius*	Lower Risk – near Threatened
Little Black Cormorant	*Phalacrocorax sulcirostris*	
Great Cormorant	*Phalacrocorax carbo*	
Little Egret	*Egretta garzetta*	Endangered
White-necked Heron	*Ardea pacifica*	
Great Egret	*Ardea alba*	Vulnerable
Intermediate Egret	*Ardea intermedia*	Critically Endangered
Cattle Egret	*Ardea ibis*	
Nankeen Night Heron	*Nycticorax caledonicus*	Lower Risk – near Threatened
Australian White Ibis	*Threskiornis molucca*	
Straw-necked Ibis	*Threskiornis spinicollis*	
Royal Spoonbill	*Platalea regia*	Vulnerable
Whiskered Tern	*Chlidonias hybridus*	Lower Risk – near Threatened
Glossy Ibis	*Plegadis falcinellus*	Lower Risk – near Threatened

Existing conceptual models

A flow-based conceptual model that is explicit and quantitative exists for colonial waterbirds' breeding requirements in the Barmah-Millewa Forest. Maunsell McIntyre Pty Ltd (1999, Section 6.2, Table 6.2.1), based on the research of Leslie (2001, Figure 3), presented the prescription in Table 11 for 'excellent' breeding success using monthly discharge data measured at Yarrawonga. Note that the lower discharges for August and January approximate the median monthly discharge under current conditions (low in-channel flows with regulators closed).

Table 11. Monthly minimum flow (GL) required for 'Bird Floods' (after Maunsell McIntyre Pty Ltd, 1999) to result in 'excellent' colonial waterbird nesting success (Leslie, 2001).

Month	Prescription (GL month^{-1})	Equivalent ML d^{-1}
August	>240	>7,740
September	>550	>18,330
October	>550	>17,740
November	>480	>16,000
December	>480	>15,480
January	>230	>7,410
TOTAL	**>2,530**	

A conceptual water-based framework for successful colonial waterbird nesting in the Barmah-Millewa Forest has been described by Leslie (2001) and is of direct relevance to the conceptual model detailed below. The key points of this framework [with embellishments] are:

- suitable flood [size: see Table 11];
- [seasonal timing:] September to January inclusive [as in Table 11];
- [duration 1: high] floods are needed initially for 1.5 months for birds to settle, mate and build nests;
- [duration 2:] floods need to continue for 3.5 months after egg laying;
- the colony site needs to be flooded at a depth of ≥ 0.3 m for most of this 5 month period;
- [duration 3:] foraging areas [also] need to be inundated for 5 months;
- receding limb of the flood must be gradual to lessen risk of nest abandonment.

Conceptual model

The conceptual model for colonially nesting waterbirds applies to a single breeding event. Its temporal extent is one year and the breeding event may take place at multiple locations (colony sites) within Barmah Forest.

Five key components have been identified for the conceptual model of colonial waterbirds' nesting requirements at Barmah Forest from a water management perspective and will be elaborated upon below. The components are:

1. location and spatial extent of colony sites;
2. vegetation types and biophysical descriptions of regularly used colony sites;
3. inundation requirements at the colony sites including:
   - timing and duration
   - rate of water level recession
   - discharge requirements
4. inundation requirements of foraging habitat; and
5. management of human disturbance at colonies.

It is important to note that food resources are not included in the above list. It is assumed at this stage that if the requisite hydrological conditions are met, the food resources (plankton, macrophytes, invertebrates, fish and frogs) will be produced in sufficient quantities at appropriate rates to meet the colonial waterbirds' dietary needs. Should future nesting failures point to food being a limiting factor, then it would need to be incorporated into the conceptual model and targeted for further investigation.

Component 1: Location and spatial extent of colony sites

Knowledge Gap 1: The location and spatial extent of current and historical colony sites need to be mapped and described. Details such as the frequency with which these sites are used, and whether they have been used in recent times (past 35 years), need to be recorded. This is a collation exercise, potentially with a limited field survey component, undertaken in conjunction with filling Knowledge Gap 2. A subset of these sites – those regularly used over the past 35 years (see below) – becomes the focus for the remainder of the conceptual model.

Component 2: Vegetation types and biophysical descriptions of regularly used colony sites

Regularly used colony sites identified in the Barmah wetland system include Boals Deadwood, Top Island, Doctors Point, Bunyip Lagoon and Green Engine. These sites need to contain the following habitat types between them for most colonial waterbirds to breed, but not all elements need to occur at each site:

- Giant Rush and/or reed beds;
- emergent living River Red Gum; and
- dead emergent River Red Gum.

The provision of these three habitats is sufficient to allow all the colonial waterbirds at Barmah Forest (with the exception of the whiskered tern that requires floating vegetation) to nest provided other conditions are met (Leslie, 2001). Favoured breeding sites in River Red Gum have specific structural characteristics as described by Briggs and Thornton (1995).

Knowledge Gap 2: Detailed site descriptions of all current and historical colony sites are required. Floristic composition, vegetation structure and site-specific hydrological information (flow paths, inundation frequency and regime including depth and extent) are the main pieces of information to be gathered through a combination of field survey and flows modelling. The collection of this information will serve the dual purposes of an established baseline (for monitoring subsequent changes to colony sites) and descriptions of nest sites.

Component 3: Inundation requirements at the colony sites

The inundation requirements below apply particularly to colony sites on the floodplain. Some colony sites will be trees that overhang permanently inundated streams (*e.g.* River Murray) and in these cases it is the flood conditions on the floodplain that determine whether breeding will occur.

Timing and duration – minimum requirements

- Floods initiated in December-January need to inundate the colony sites for four months and maintain a minimum depth of 0.3 m (J. Reid, *pers. obs*.) throughout this period; birds commence nest building and egg laying without delay.

- Floods initiated in September-November need to inundate the colony sites for five months and maintain a minimum depth of 0.3 m throughout this period; birds take 4-6 weeks to settle and choose a nest site prior to laying.
- Floods initiated between April and August need to inundate the colony sites for an additional month for each month prior to September (*i.e.* six months if initiated in August, ten months if initiated in April) and maintain a minimum depth of 0.3 m throughout this period; birds delay their nest building and egg laying until spring.
- Floods initiated in February-March need to inundate the colony sites for 10 months and maintain a minimum depth of 0.3 m throughout this period; birds delay their nest building and egg laying until spring (clearly, management would need to consider the feasibility of this level of investment if EWAs are involved).

Rate of water level recession
A gradual rate of water level recession (function of discharge) on the receding limb of a flood is required over the last three months for each of the inundation duration conditions defined above to prevent abandonment of nests.

Both flood duration and depth of inundation are largely controlled by flood characteristics general to the entire Barmah Forest. However, engineering structures may allow some control at the site level to increase both duration and depth of inundation.

Knowledge Gap 3: The inundation figures presented are best guesses and generalisations (Scott, 1997; Briggs and Thornton, 1999; Leslie, 2001; MFAT; K. Ward *pers. comm.*). They assume that a winter hiatus in food production, largely controlled by water temperature, influences the nesting behaviour. The minimum inundation period is likely to vary between species, between years and between colony sites. Detailed nesting records from past events and results of future monitoring could be combined to refine these estimates and describe 'confidence limits' around them (*e.g.* "colony sites require 4-6 months inundation when flooding is initiated in October"). Similarly, required depth of inundation may vary across sites (see Leslie, 2001), and there may be a much greater depth (*e.g.* > 1 m) required initially as the proximate trigger to get waterbirds to settle at a colony. Quantifying the rate of water level recession on the receding limb of a flood (and discharge) is also required and can be based on past breeding events and hydrologic records and future monitoring.

Component 4: Inundation requirements of foraging habitat

It is assumed that breeding colonial waterbirds will regularly forage at distances up to 20 km from the colony which means that virtually all of the Barmah-Millewa floodplain is available as foraging habitat.

Peak River Murray flows of >40,000 ML d^{-1} are required to inundate more than 40% of the Barmah Forest floodplain (Overton *et al.,* 2006). This extent of flooding is considered sufficient to provide necessary foraging habitat provided that there is a minimum discharge of 2,000 GL over the **next four months** (approx. mean discharge 16,700 ML d^{-1}) after this peak discharge (assuming an August-October flood commencement).

Peak River Murray flows of >60,000 ML d^{-1} will inundate the majority of the Barmah Forest floodplain (Overton *et al.,* 2006). Provided a flood peak of this size is maintained for at least a week (≥420 GL), and then a further 2,000 GL discharge occurs over the next four months, and the minimum conditions around the colonies (Component 3) are met, a successful colonial waterbird breeding event should occur (these hydrological conditions were essentially those that occurred for the successful waterbird breeding in the 2000-01 event: BMF, 2001).

At the lower range of both peak flow size (<40,000 ML d^{-1}) and total discharge over the five-month flood period (<3,000 GL), maximisation of the **period of time** over which discrete wetlands and inundated floodplain components (together these are termed 'wetland units') remain inundated is expected to optimise waterbird breeding success. There is a general natural pattern in the order in which wetland units receive water on a rising flood – upstream units, units adjacent to the River Murray and major distributaries, and those lower in the floodplain will be filled first (in NSW the wetlands along Gulpa Creek fill later than the central-southern wetlands in the Barmah Forest). Regulators and levees can be used to vary this natural sequence. For these smaller floods, regulators should be used to delay the filling of some wetland units so as to maximise the staggering of the initial filling sequence. A necessary caveat to this is that wetlands, once inundated, should not be drained too rapidly so as to prevent any nest abandonment.

Also at the lower range of flood sizes, the area of inundated floodplain which has been dry in the previous six months should be maximised to increase the production of waterbird food resources (*i.e.* managers should aim to dry out as much of the floodplain each year as possible). A greater pulse of productivity is predicted from wetlands that have been allowed to dry.

<u>Knowledge Gap 4</u>:
(A) The inundation figures for foraging areas are generalisations. Consequently, the discharge to inundation relationships require careful examination with respect to past breeding events so that the essential discharge variables (daily peak, duration of peak above a certain threshold, total volumes over defined periods) can be identified to allow estimation of the minimum set to support successful waterbird breeding. Leslie (2001) has made an excellent start in this regard, but the more sophisticated DEMs and flow models now available for the Barmah-Millewa wetlands require this exercise to be undertaken again.

(B) An investigation of the degree to which Barmah Forest water managers can stagger the inundation sequences of discrete wetland units is required, and the Issues and Options report currently in development (Barmah Wetlands: Issues and Options, in prep.) may assist in this regard.

(C) An understanding of the customary and maximum distances that nesting colonial waterbirds will forage from the colony is required for different species.

(D) Minimum depths and periods of inundation for each wetland unit need to be defined, again based on modelling and past experiences.

(E) An experimental study of waterbird food production in wetlands is required, to study the effects of drying regime on food production.

Component 5: Management of human disturbance at colonies

Minimise visits to colonies when birds have eggs, as temporary departure of adults from the nest will leave the eggs vulnerable to predation by Australian Raven *Corvus coronoides*. This could be significant depending on the local abundance of Australian Raven. Rates of corvid predation should be noted. Juvenile cormorants are particularly sensitive to nest disturbance prior to fledging, as they will dive into the water if approached too closely and then risk not being able to get back to the nest or onto perches where safe from cat and fox predation. For colony sites accessible by boat and open to the general public, it may be necessary to monitor the effects of human disturbance and to consider closing public access.

Knowledge Gap 5: The effects of human visitation to and recreation at or near colonies on nesting success require study, so that safe protocols can be implemented.

Assumptions of the Conceptual Model

- Provision of the minimum conditions defined above will result in active colonies **forming** (regardless of colony size and number of species). However, conditions elsewhere in the Murray-Darling Basin may influence the magnitude of breeding response at Barmah Forest due to birds choosing to breed at other sites where environmental conditions may be more favourable.
- Colonial waterbirds customarily forage at distances up to 20 km from the nest (J. Reid *pers. obs.*) Therefore it is important to maintain a mosaic of wetlands at different stages of filling and drying across the entire Barmah-Millewa Forest to maximise nesting success.
- Food resources will not be limiting provided the minimum flooding and inundation conditions are met.

Ecological target

The interim TLM ecological target for colonially nesting waterbirds provided for the Barmah-Millewa Forest SEA ("Successful breeding of thousands of colonial waterbirds in at least three years in ten") is considered unsatisfactory in two respects for this monitoring program. First, it does not define the number of different species and second, it does not specify the number of each species that should be involved in successful breeding events. For example, if Australian White Ibis were to breed in their "thousands" in three years in ten, whilst all other species disappeared from Barmah Forest, then the target would still be met.

A single ecological target for colonial waterbirds that addresses these concerns has been devised (Table 12).

Table 12. Ecological target for colonial waterbirds at Barmah Forest.

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Successful breeding by at least 4000 pairs of colonial waterbirds in at least three years in ten, including 10 or more successful breeding pairs* of five or more species other than Australian White Ibis, Nankeen Night-Heron and Cattle Egret.	Colonially nesting waterbirds	Abundance, diversity, breeding	In each year where flooding of Barmah Forest occurs a combination of aerial and ground/water surveys will be undertaken to record colonial waterbird nests. Data from monitoring in each year will inform whether the target was met in that particular year. Evaluation of yearly results over a ten year period will determine whether the target has been met.

*A successful breeding pair is defined here as having a nest from which at least one fledgling is raised to flight and departure.

It is anticipated that colonial waterbird monitoring over time will allow separate targets to be devised and quantified for individual species or functional groups of species through the monitoring program review process.

Monitoring requirements

Colonial waterbird breeding success is relatively straightforward to measure or estimate provided that all breeding colonies are located and sampled. The main difficulty in its accurate measurement is that fledging occurs over an extended period, and so would require daily visits to all colonies once fledgling commences if completely accurate data were required. This is unpractical due to both disturbance of the colonies and monitoring costs. Instead, estimates of nest success and numbers of fledglings can be gathered from one or two visits to each colony in the latter stages of nesting, and weekly visits to colonies has proved successful in the past (K. Ward, *pers. comm.*). This method may underestimate waterbird breeding success but should be sufficient to evaluate whether the target has been met.

A combination of aerial surveys and ground/water based inspections have been used to good effect in the past to estimate waterbird breeding success in the Barmah-Millewa Forest (*e.g.* BMF, 2001; Leslie and Ward, 2002; O'Connor and Ward, 2003; Webster, 2004; Ward and O'Connor, 2006; K. Ward, *pers. comm.*), and this dual approach is adopted here.

Aerial surveys will occur about one month after flood initiation (assuming a flow threshold is met). Previously known colony sites will be inspected from the air using experienced observers to look for signs of colony formation and nesting. Aerial surveys should continue on a monthly basis as the flood event continues to look for previously undetected colonies and to assess nesting progress at known colonies. When nesting has been identified, ground and water surveys will be undertaken to appraise the species composition and effort (effort equals the number of active nests and breeding pairs without double-counting these items). Based on this initial appraisal, a second visit by ground/water will be scheduled to coincide with the time the first nestlings are expected to be one month old. Again, a thorough search and count of all nests, by species, will be undertaken and recorded within the following categories: (a) abandoned nest, (b) nest building, (c) eggs/incubating adult, (d) nestlings ≤ 2 weeks old, (e) nestlings 2-6 weeks old, (f) nestlings >6 weeks (*i.e.* large and feathered). A third inspection and count should be taken when most nests are predicted to have chicks in the 6-8 weeks old period. If there is evidence for further waves of nesting activity then further visits should be timed to coincide with the second and subsequent waves of chicks as they reach 6-8 weeks old.

Additional colony inspections may also be warranted. These were recommended by Leslie and Ward (2002) and O'Connor and Ward (2003), (*e.g.* on a weekly basis) to inform other management decisions such as the continued use of an environmental water allocation.

Information including colony size, location, and habitat descriptors for each species will be documented. When breeding has been completed, data will be collated to obtain estimates of nest success and number of fledglings for each species at each colony.

Future monitoring

This monitoring program for waterbirds has focused on colonial nesting waterbirds. Other groups of waterbird including waterfowl and waders may be deemed important for monitoring at Barmah Forest based on TLM requirements (to be determined). Also, waterbirds listed under JAMBA, CAMBA and CMS, and those considered vulnerable or endangered, may warrant monitoring when the monitoring program is reviewed in the future. The waterbirds in Table 13 have been identified as being important additional species for monitoring at Barmah Forest (DSE, 2003a).

Table 13. Other waterbirds identified at Barmah Forest for potential inclusion in the monitoring program in the future. Conservation status categories are from Victoria's Flora and Fauna Guarantee Act 1988 (after DSE, 2003a).

Common Name	Scientific Name	Status in Victoria
Blue-billed Duck*	*Oxyura australis*	Endangered
Musk Duck*	*Biziura lobata*	Vulnerable
White-bellied Sea-Eagle*	*Haliaeentus leucogaster*	Vulnerable
Latham's Snipe*	*Gallinago hardwickii*	Lower Risk – near Threatened
Azure Kingfisher*	*Alcedo azurea*	Lower Risk – near Threatened
Little Bittern*	*Ixobrychus minutes*	Endangered
Australasian Bittern*	*Botaurus poiciloptilus*	Endangered
Australasian Shoveler	*Anas rhynchotis*	Vulnerable
Brolga	*Grus rubicunda*	Vulnerable
Hardhead	*Aythya australis*	Vulnerable

*These species span a range of functional feeding and habitat types and may be good candidates for monitoring.

Estimated costs

Estimated costs are annual and based on the number of "people days". At this point in time it is estimated that one person day will cost $1,000. These costs are **exclusive** of accommodation charges, travel costs and GST and should be considered as indicative only.

Waterbird monitoring	
Estimated 4 flights per year @ $600 per aerial survey	$2,400
2 observers for 0.5d for 4 flights = 4 people days	$4,000
First ground visit: 2 people x 3d = 6 people days	$6,000
Second ground visit: 2 people x 5d = 10 people days	$10,000
Third ground visit: 2 people x 5d = 10 people days	$10,000
Further breeding: 2 people x 5d = 10 people days	$10,000
Annual report preparation: 8 people days	$8,000
TOTAL PER YEAR	**$50,400***

*Assumes annual flooding and waterbird breeding

Skills and resources

Scientists with expertise in identifying and surveying waterbirds are required. Access to a plane and pilot will be required to undertake aerial surveys. Car and boat are required to access colony sites. Ethics permits will be required in Victoria for ground surveys of colonies.

Ecological Indicator 3: Vegetation

The approach taken for vegetation monitoring differs to that of fish and waterbirds for two reasons. The stationary nature of vegetation and relatively slow changes to the population for some species means that the monitoring of vegetation is spatially explicit. Second, a number of the ecological objectives already determined for Barmah Forest emphasise returning the vegetation of Barmah Forest to an earlier condition, therefore a slightly different approach is warranted:

- The existing management objectives for vegetation monitoring at Barmah Forest are characterised and prioritised.
- Previous vegetation monitoring at Barmah Forest is reviewed to determine whether this could be continued in some form in the current monitoring program.
- A conceptual model for vegetation is presented that focuses on the spatially explicit nature of the effects of river regulation on flooding at Barmah Forest ("flowbands") and the consequent changes and threats to plant communities.
- Ecological targets are established for the Moira Grass, Giant Rush and River Red Gum communities.
- Monitoring requirements for each community are presented and estimated costs of monitoring are provided.

Background and limitations

Characteristics of existing vegetation objectives

A total of 16 ecological objectives were identified through a review of the policies, plans, strategies, agreements and pieces of legislation influencing the management of Barmah Forest (McCarthy *et al*., 2005). These 16 vegetation objectives, although they stem from just a few common concerns, are not necessarily mutually compatible. For example, increasing the area of Moira Grass plains (DSE and GBCMA, 2005) is not compatible with maintaining the extent of all native vegetation types at 1999 levels (GBCMA, 2003). Issues relating to clarity and compatibility of the objectives are discussed elsewhere (Roberts, draft).

Although these vegetation-related objectives and targets are not to be specifically developed further here, they can be considered typical in their content and range. They show that the focus of management concerns ranges across virtually all biological-ecological organisational levels, from individuals and species, to vegetation types (Table 14). The implication of having a wide ecological range in the objectives is that an equally wide range of metrics and methods will probably have to be used in monitoring.

Table 14. Biological / ecological levels.

Level	Ecological objective (and source)
Individual	To protect significant River Red Gum trees (DCE, 1992).
Species	To protect significant plant species (DCE, 1992). To protect plant species (*and communities*) that are threatened or of special significance (DCE, 1992). Reduce encroachment of giant rush and river red gum (*onto Moira grass plains*) (DSE and GBCMA, 2005).
Ecological groups: growth-forms	Maintain health of sedges, (*giant rush and wetland communities)* (DSE and GBCMA, 2005).
Ecological groups: functional types	Not used in objectives to date, but has potential and is recommended here.
Ecological groups: habitat-based	Maintain health of (*sedges, giant rush and)* wetland communities (DSE and GBCMA, 2005).
Community	To maintain and protect the structural and floristic diversity of natural plant communities (DCE, 1992). To protect (*plant species and*) communities that are threatened or of special significance (DCE, 1992).
Specific vegetation units, plant name used but a vegetation type implied	Assist maintenance of majority of Moira grass (DSE and GBCMA, 2005). Maintain health of (*sedges,*) giant rush (*and wetland communities*) (DSE and GBCMA, 2005).
Specific vegetation units, plant name and structure or plant name and place	To protect and encourage the re-establishment of mature River Red Gum woodland (DCE, 1992). Management will protect the health and viability of River Red Gum forest (DCE, 1992). Maintain up to half of river red gum forest (DSE and GBCMA, 2005). Protect and restore Moira grass plains (DSE and GBCMA, 2005).
General: Vegetation type and vegetation class including EVC	Maintain extent of all native vegetation types at 1999 levels in keeping with the goal of 'net gain' listed in Victoria's Biodiversity Strategy 1997 (GBCMA, 2003). Healthy vegetation in at least 55% of the area of the forest (MDBMC, 2003). Improve the quality of 90% of existing (2003) native vegetation by 10% by 2030 (GBCMA, 2003). Increase the cover of all endangered and applicable vulnerable EVCs to at least 15% of their pre-European vegetation cover by 2030 (GBCMA, 2003).

The level of organisation also has some bearing on what attributes are used and how they might be measured. For example, attributes such as 'quality' or 'healthy' can be applied at different levels and are correspondingly tailored to match that level. Thus, a healthy species might be one that has an appropriate age structure when surveyed across the forest (hence implying adequate recruitment) or could be one with no evidence of any physiological stresses or insect attack; whereas a healthy vegetation might be one that has the preceding characteristics but also has certain structural characteristics, few introduced species and a low level of parasitism. Then there are attributes specific to particular levels: species richness, for example, is used to describe vegetation types, communities or functional groups but is not applicable to levels such as species or individuals.

Neither functional groups nor indicator species were included in the range of ecological levels (Table 14) but these may well prove useful in monitoring. There are several functional types that are relevant:

- **Water regime and wetland plants:** the system of Brock and Casanova (1997) has been used effectively within Barmah Forest by Reid and Quinn (2004).
- **Grazing and other disturbances:** McIntyre and Lavorel (2001) and McIntyre *et al.* (1995) have developed and fine-tuned ways of selecting and working with functional types to describe system response to disturbance, especially grazing. The work is based on temperate and tropical grassy woodland and should have relevance to the understorey of River Red Gum forest and woodland at Barmah Forest.
- **Floodplain functional types:** in the absence of the extensive information on species, Higgins *et al.* (1997) used simple array of traits to develop functional types which then revealed a distribution pattern driven by soil moisture in the understorey of the Nyl River floodplain, South Africa.
- **Indicator species:** Reid and Quinn (2004) noted that increases in the abundance of species in the amphibious responder with plastic growth (ARp) functional groups (*Ludwigia peploides*, *Myriophyllum crispatum*) are more useful and reliable indicators of increased flooding and of water regime than are the more generalist species such as *Pseudoraphis spinescens, Juncus ingens*, *Eleocharis actua*, which are all in a different (Ate) group, *viz*. the amphibious, tolerant of water-level changes and emergent growth form.
- **Fire types:** fire-response functional types can also be identified. For example, Kevin Tolhurst proposed a system for the forest/woodland understorey at Barmah Forest (included in Bren *et al*., undated).

Prioritising the vegetation objectives

Legal obligation is one of the most effective means of setting priorities for the ecological objectives and was adopted in the review of the objectives relating to Barmah Forest (McCarthy *et al*., 2005). Three of the plans have been accepted by some tier of government, making their objectives legally binding. These are Ramsar (DSE, 2005), the Living Murray, and the Goulburn Broken Regional Catchment Strategy (RCS) (GBCMA, 2003). Of these, the Ramsar objectives for Barmah Forest can be presumed to have primacy, as it is subject to international agreement, followed by the Living Murray objectives and the Regional Catchment Strategy, both of which have been signed off at the ministerial level.

Objectives under Ramsar

The contracting party (*i.e.* the Australian Government) is obligated to maintain the ecological character of Barmah Forest, the designated Ramsar wetland. **Ecological character** should be considered as the sum of its components, of which vegetation is an important part and be based on vegetation mapping and description (DSE, 2005). The benchmark against which change is measured is the ecological character at the time of nomination. In the case of the Barmah Forest it was Ramsar listed on 15 December 1982.

Comments on this are:

- Although ideally the state (*i.e*. the components) of Barmah Forest in 1982 should be used as the temporal benchmark when developing monitoring targets, this may prove difficult to do, at least in the immediate future. This is because descriptions of the

Barmah-Millewa Forest are limited to descriptions given in Chesterfield *et al.* (1984) and to the vegetation map prepared by Chesterfield (1986), and neither of these is described in ways that can be readily expressed as quantitative ecological targets for monitoring. This is because the mapping has a fairly coarse resolution, is of uncertain precision, and is not supported by quantitative descriptions for the different vegetation types and mapping units. In time, no doubt, a set of ecological descriptions will be developed based on available information, modelling and local knowledge, but for the moment there are relatively few reliable quantitative descriptions of the vegetation that can be made that can be used to set ecological targets for monitoring (see p.41).

- There is the difficulty also of using a single point in time as a benchmark when Barmah Forest is probably still adjusting to past environmental changes. See Benchmarks (p.39).

Variables: Variables potentially useful for monitoring vegetation change against Ramsar objectives are:

- Extent (area, in ha) of particular vegetation type.
- Description (wetland ecological vegetation class (EVC), released March 2006).

Objectives under the Living Murray

The Living Murray has two interim objectives/targets for the Barmah-Millewa Forest SEA with the vegetation-related one (MDBMC, 2003) being:

"*Healthy vegetation in at least 55% of the area of the forest, including virtually all of the Giant Rush, Moira Grass, River Red Gum forest and some River Red Gum woodland*".

Comments on this are:

- This objective refers to 55% of the Barmah-Millewa Forest, and it is not certain whether this 55% is expressed equally, *i.e.* means 55% of Barmah and 55% of Millewa Forests, or an unequal partition of a flood peak. Flooding data given in reports documenting the application of the EWA (reported in Reid and Roberts, draft) suggest that a given flood does not cover an equal percentage of each forest, *i.e.* the floodplain is not topographically similar on both sides of the main river channel.
- The objective takes no account of the trajectories of ecological change as the forest adjusts. In particular, it takes no account of the invasive character of Giant Rush and its role as a threat to Moira Grass vegetation.
- The term 'healthy' is left undefined and open to interpretation. In relation to vegetation it could mean not only the physiological state of the dominant and characteristic species but its viability. In addition, 'healthy' considers other species, the understorey, and ecological processes.

Variables: Attributes considered to collectively describe the 'health' of vegetation are:

- Extent: considered as area (for mapping units).
- Integrity: dominance by native species.
- Resilience: capacity to recover, hence emphasis on regeneration.
- Vigour: growth, which may be measured as biomass, height, density or cover.
- Ecosystem functioning: the role(s) of the dominant species within the forest.

Variables that could be used to monitor these five attributes differ between the four vegetation types. This is because their dominant species are of diverse lifeforms: stoloniferous aquatic grass, tall emergent macrophyte, floodplain tree.

Objectives from the Goulburn Broken Regional Catchment Strategy

Vegetation objectives given in the RCS (GBCMA, 2003, p11) are:

"*Maintain extent of all native vegetation types at 1999 levels …*"
"*Improve the quality of 90% of existing native vegetation by 10% by 2030*"
"*Increase the cover of all endangered and applicable vulnerable EVCs to at least 15% of their pre-European vegetation cover by 2030*"

Comments on this are:

- Data describing the extent of native vegetation types in 1999 have not been located. Targets may be defined by drawing on mapping by Doug Frood (no reference), which has recently been made available (see Barmah Wetlands: Issues and Options, in prep.).
- Quality is an undefined term, broadly related to condition. Contemporary data describing the quality of native vegetation types have not been located, and it is not known if these exist.
- The Murray Fans bioregion (Web search 24 April 2006) has 19 wetland EVCs, of which eight are given as Endangered, five as Vulnerable, one as Rare, and four as Depleted. These designations are slightly at odds with the RCS objectives and general conservation concerns about plant communities, as this gives EVC #289 Moira Plains Wetland as Depleted (rather than Endangered or Vulnerable) and EVC #821 Tall Marsh (which includes areas dominated by *Juncus ingens* and *Typha* spp.) as Endangered. These descriptions and broad conservation assessments have only recently been completed by DSE. There has been no indication that there will be any modelling of their pre-European extent, as has been done for terrestrial EVCs.
- Setting quantitative targets for vegetation objectives given in the RCS is therefore challenging at present.

Variables relevant to the RCS objectives are:

- Extent: considered as area (ha, mapped units, vegetation types or EVCs).
- Integrity: as a surrogate for quality, pending clarification of quality.

Variables and design

There is enough similarity between these three sets of objectives, especially in relation to extent and integrity, to be able to use all or part of the same list of attributes.

The difference between the three sets of objectives will be evident in the choice of variables, which in plant ecology tend to be fairly similar, and in the direction of the target (*i.e*. whether to increase, maintain or decrease).

The key to monitoring will lie in the design and layout of the monitoring program rather than in the choice of variables, as this will be the real test of generating insight and answering necessary questions.

Additional issues when setting sensible objectives

Temporal benchmarks: Another difficulty in using a specific benchmark, whether 1982 as for Ramsar objectives or 1999 as for RCS objectives, is that it is unlikely that the floodplain vegetation, both forest and wetland, are at a (dynamic) equilibrium. It has been experiencing continuous environmental change (persistent changes in intensity and pattern of fires, flooding and surface water, grazing and stocking, timber and wood utilisation) for over 150 years.

Fallacy of the EWA: Change has occurred, and may not be reversible under contemporary social, economic and river management constraints, despite environmental water allocations (EWAs). In addition, EWAs may be having negative effects on wetland vegetation within low-lying areas within certain flowbands (Reid and Roberts, draft). Moreover, the EWAs are restricted and do not reach more elevated areas of the floodplain where they are needed, nor do they provide an autumn flood.

Previous vegetation monitoring and investigations at Barmah Forest

Previous vegetation monitoring projects, assessments and investigations at Barmah Forest were reviewed to determine whether these could be worth continuing in some form or whether they could prove useful ‘before’ data for the current monitoring program.

Monitoring: Bell and Whyte (2004)

There appears to have been only one monitoring program devised and initiated. “*The Monitoring Plan for the Barmah-Millewa Forest*” (Bren, 2001[1]) was implemented in a modified form by Bell and Whyte (2004) in 2003. Its purpose was to provide rapid feedback to managers on change within the forest, and to set up a long-term data set of physical and biological characteristics and hence of physical and biological changes. The program had six themes and an ambitious array of variables at comparatively frequent intervals: trees and tree growth; understorey; biodiversity; soils and groundwater; flood; fire and fuel load. A distinctive feature of this proposal was to monitor the understorey by walking established transects ranging in length from 4 to 8 km.

In their first progress report, Bell and Whyte (2004) described their extensive modifications to the Bren (2001) proposal, including: changing some sampling intervals; introducing new measurements (*e.g.* bark thickness); rejecting some methods (*e.g.* transects, xylem pressure potential; 12C/13C status) and using different techniques (diameter tape instead of dendrometer bands for tree growth). Only two parts of the monitoring program were actually initiated. The first was the Visual Appearance Checklist (VAC) comprising a set of observations for a 50 x 2 m transect, set out ‘left’ of each of the permanent plots; the VAC comprises six variables (seedlings of *E. camaldulensis*, mature *E. camaldulensis*, understorey, grazing, Gum-leaf Skeletoniser *Uraba lugens*, Goat Moth/bardy grub) each recorded in qualitative terms for their abundance (low, moderate or high) and condition (low, moderate or high). No data were presented, only verbal summaries. The second was soil moisture (three depths, all within the top 0.1 m) and data on the relationship between tree height, tree diameter and bark thickness from permanent plots; these data are plotted as

[1] **Bren (2001)**. This may not be the final version. Bell and Whyte (2004) refer to Bren (2002) however this later document was not available.

mean values which can be read from plots: raw data were not in the report and available for review. The sampling design was three permanent plots in forest areas of different site quality, resulting in nine plots in the Barmah Forest.

Finding: For a number of reasons, these data are unlikely to be useful as a set of 'before' data in another monitoring program. First, the number of plots and associated transects is comparatively small, so the coverage is sparse; more importantly, however, their location is not specifically linked to issues of surface water management. Second, the variables that have been recorded as part of the VAC are very broad and qualitative, making analysis of long-term trends difficult to do, and awkward to present.

Assessment: Leversha and Gowans (2003)

In August 2001, Leversha and Gowans (2003) assessed vegetation condition in Barmah State Park for Parks Victoria. They developed and used a protocol based on seven main attributes (called parameters), in a referential approach. Assessments were done on 30 x 30 m quadrats, with ten quadrats for each of four vegetation types. The four vegetation types were: Wet Plains, Riverine Swamp Forest (including Floodplain Regeneration Thicket), Floodplain Forest (including Riparian Tall Woodland), and Drier Woodlands. Within each vegetation type, the ten quadrats were distributed across several mapping units making up each vegetation type. Quadrat distribution in the field was thus determined by the distribution of the mapping units, as determined in hand-drawn maps prepared by Doug Frood. The report is carefully presented and compiled, and the appendix comprises a one-page summary for each of the quadrats assessed. The appendix is thus a useful compilation of vegetation structure, tree and shrub demography (age classes) and species cover-abundance and species richness for August 2001.

Finding: Despite its thoroughness, this data set is unlikely to be built on and the quadrats are unlikely to continue to be used. This is because the assessment protocol developed by Leversha and Gowans (2003) has now been superseded by habitat-hectares (*e.g.* Parkes *et al.,* 2003; DSE, 2004), the state-wide standard method for assessing vegetation condition with its clearly-defined Benchmarks. It is possible that the age class data could prove useful at some time in the future, especially as it is based on reasonable coverage of Barmah State Park.

Methods development: Reid and Quinn (2004)

An investigation into the development of sound protocols for monitoring the effects of EWAs to wetlands was funded by the MDBC (Reid *et al.,* 2001) and aspects published as a journal paper (Reid and Quinn, 2004). A literature review (Reid and Brooks, 2000) had earlier identified macrophytes as the most appropriate biota for monitoring ecological change in wetlands. The purpose of this project, referred to by its authors as a pilot study, was to refine monitoring approaches for wetland vegetation where the water regime was being changed.

The study is relevant to Barmah Forest as the pilot study comprised a two-year field program at nine depression wetlands, seven within Barmah Forest, and most of these being 'open plain wetlands, dominated by Moira grass, swamp wallaby grass and common spike rush'. Sampling was seasonal, for two years, and included macrophyte counts, water quality, and some biomass data (Reid *et al.,* 2001). Monitoring was done using a transect point-count method per wetland, which the authors found to be rapid, robust and effective for the more widespread and common species (Michael Reid, *pers. comm*. 17 February 2006). Analyses considered such questions as detecting responses, indicator species, functional groups and responses through time (Reid and Quinn, 2004).

Finding: Methods outlined and used are likely to prove useful for monitoring changes in macrophyte assemblages in wetlands generally, and hence also at Barmah Forest. Analyses done for this study contain useful information and advice on power and on suitability of certain functional groups and species as indicator species. The study refers to additional data on biomass and species richness.

Variability of wetland vegetation: Ward (1994)

The design of a successful monitoring program requires some understanding of spatial and temporal variability. Obtaining this understanding can be particularly challenging for wetlands and wetland vegetation, because the natural variability has been modified since European settlement through uneven effects such as river regulation, local operation of regulators, impact of forestry operations, grazing and trampling, and altered fire regimes. An issue in understanding temporal variability is that vegetation responses to temperature and day-length (*i.e*. seasonal drivers) and plant responses to different inundation phases (filling, full, receding, inter-flood) may have become off-set through river regulation. Similarly, an issue in understanding community distributions is that species abundances and occurrences in relation to soils or topographic gradients has probably been disturbed through 150 years of changing land use.

A two-year project tracking the wetland vegetation in Barmah Forest (Ward, 1994) provides some much-needed information on temporal and spatial variability within and between five wetlands, and links these to recent water regime. At each wetland, two transects were established, with each divided into 2 to 4 zones corresponding to major community differences. A permanent quadrat (400 m^2) was established at each transect within which ten random quadrats were sampled, initially monthly. A clear succession was noted on at least two wetlands, from *Myriophyllum*-dominated herblands during inundation to Spike-rush *Eleocharis acuta* sedgelands in recession, which then persisted until the next inundation.

In addition, the report tabulates flowering time and duration for over 20 species common in wetlands but generally not well covered in standard summaries (*e.g.* Roberts and Marston, 2000), and links these to water regime and specifically flood duration.

The report is in draft form and, given the value of the data (see following), would be worth investing in finalising.

Setting benchmarks for wetland vegetation

The studies of Reid and Quinn (2004) and Ward (1994) provide a valuable set of historical information on wetlands within Barmah Forest, under differing conditions, that could be relevant to different sets of objectives.

Ward (1994) provides monthly cover data (in first year) then seasonal cover data (in second year) for 33 zones in five wetlands, from July 1991 to April 1993. This data might be relevant to Ramsar objectives (time of listing some 10 years earlier).

Reid and Quinn (2004) provides seasonal frequency data along a topographic gradient at nine wetlands from November 1998 to March 2001, so could be related to RCS objectives (linked to 1999).

An additional point of interest is that the studies share three wetlands: Top Island, Top Lake and Little Rushy.

These datasets could help set quantitative benchmarks for wetlands within Barmah Forest, but would require some working. Original data are held by Keith Ward of the Goulburn Broken CMA, and Dr Michael Reid, currently at University of Canberra, respectively.

Conceptual model

Principles describing ecology-flow relationships

Describing how these different ecological levels (Table 14) are linked to river flow can be challenging, as each has its own scale of interaction. The simplest description is based on the natural paradigm and can be articulated in the form of generalizations or principles, as done for aquatic species and riparian plant communities (Bunn and Arthington, 2002; Nilsson and Svedmark, 2002), as follows:

- Flow regime is a major determinant of the distribution and abundance of species, through being a major determinant of physical habitat.
- Life history is linked to, in the sense of being co-evolved with, the natural flow regime.
- Population viability, which entails movement and dispersal of critical stages such as seed and propagules for plants, also organic material, depends on longitudinal and lateral connectivity.
- Altering the natural flow regime disrupts these first three sustaining mechanisms and so facilitates invasion, establishment and success of introduced species.
- Successional trajectory of riparian plant communities and their spatial patchiness is determined by flow regime with events of different sizes having specific effects.
- The riparian corridor is effectively a pathway.
- The riparian zone has complex spatial-temporal patterning and wet-dry states, reflecting its position between the aquatic and terrestrial environments and is disproportionately rich in species.

Conceptual models in this form are not quantitative and have no temporal or spatial resolution. However, they can be quantified by using simulated data (such as simulated flow time series) and linking this to vegetation as in flow-inundated area relationships, as described in Roberts (draft). It follows from these principles that if the flow regime is altered then floodplain ecology and floodplain vegetation are affected.

Effects of regulation

The effects of regulation on river flow were summarised in the Introduction (Table 1), with the effects of different aspects of regulation presented for wetlands and creeks (Table 2) and part of the floodplain (Table 3).

The threats from these hydrological changes to the vegetation at different parts of Barmah Forest are listed in Table 15.

Current knowledge about vegetation-flow relationships as it relates to plant species at Barmah Forest was considered rather dated in a review by Roberts (draft), and a number of recommendations were made about areas for further research (Roberts, draft).

Table 15: Threats to vegetation from hydrological changes to different parts of Barmah Forest.

Hydrological change	Threats (in relation to vegetation)	Monitoring the threats
[A] Wetlands directly connected to the river. **From a seasonal wet and dry regime to a nearly permanently inundated or waterlogged state.**	[A.1] Loss of vegetation and plant communities favoured by a seasonal wet-dry regime. [A.2] Lack of dry phase in summer-autumn and instead the presence of wet muds in autumn alters the regeneration niche, so that any species regenerating avoids summer desiccation so has greater likelihood of survival. Possibly this is favouring Giant Rush. [A.3] Persistently wet substrate and persistent anoxic conditions favour emergent macrophytes tolerant of waterlogged conditions and capable of growing in waterlogged and deep water conditions. These tend to be tall, high biomass species, such as Giant Rush *Juncus ingens* or Cumbungi *Typha* spp., with potential for developing mono-specific stands and hence excluding other species. [A.4] Receive near-continuous supply of river water via Effluent Creeks with no regulators, hence supply of cooler water. This may affect thermal regime in wetland, as the wetland no longer has the warm, shallow phase as flood water recede, and could affect macrophyte growth rates, especially of submerged species. Inflow from creeks with regulators that are opened has passed over the floodplain, and should have acquired floodplain characteristics in terms of temperature and colour.	[A.1] Monitor the extent (area) and position (boundaries) of Moira Grass stands (may be better done remotely). A historical analysis of changes to the extent and position of Moira Grass stands would provide useful comparative information and help refine the conceptual model.
[B] Effluent Creeks with no regulators **From seasonally flowing with a wet and dry regime to nearly always flowing. Therefore, now characterised by long periods of persistently high velocity with little or no gradual receding phase.**	[B.1] Fast-flowing channel with no slow-flowing phase during the growing season does not provide any opportunity for macrophytes to grow. [B.2] Channel unlikely to provide a regenerating or germinating / establishing opportunity for benthic macrophytes due to prevalence of fast-flowing conditions through most of the year. [B.3] Channel is conduit for transporting undesirable propagules into the centre of the wetland.	[B.3] Monitor species composition of littoral habitats in these creeks, and along relevant flowpaths in receiving waters, by GPS logging of target species.
[C] Effluent Creeks with regulators that are opened for rain rejection flows **Flow inversion? Probably had seasonal wet and dry phases as for Effluent Creeks with no regulators, but now has flow pulses through summer; combination of frequency x**	[C.1] Conditions downstream of regulators appear to have favoured Giant Rush in the past.	[C.1] Opportunity to compare growth (biomass, height or culm density) of Giant Rush under different flow management regimes. For example, comparing between WMAs with contrasting water

Hydrological change	Threats (in relation to vegetation)	Monitoring the threats
duration probably sufficient to irrigate plants and possibly maintain soil in moist conditions.		management.
[D] Effluent Creeks with regulators that are not routinely opened for rain rejection flows. **Analyses needed.**	Analyses required to compare Current with Natural, and so determine nature and extent of change in water regime. Creeks chosen for analysis should be selected to cover different issues (*e.g*. having different sill levels).	
[E] Area of the floodplain affected by flows in between 12,000 - 15,000 ML d^{-1} at Tocumwal. **'Wetter' and a seasonal shift/seasonal loss**	[E.1] Shift in understorey and wetland composition towards species favoured by prolonged moist and flooded conditions in warmer months, including invasive and non-native species, and loss of cooler-season species.	[E.1] Relative abundance, species richness and/or nativeness of functional groups determined by season of flooding.
[F] Area of the floodplain affected by flows in between 15,000 - 20,000 ML d^{-1} at Tocumwal. **'Wetter' and a seasonal shift/seasonal loss**	[F.1] Shift in understorey and wetland composition towards species favoured by brief or intermittently moist and flooded conditions in warmer months, including invasive and non-native species, and loss of cooler-season species.	[F.1] Relative abundance, species richness and/or nativeness of functional groups determined by season of flooding.
[G] Area of the floodplain affected by flows in between 20,000 - 30,000 ML d^{-1} at Tocumwal. **Generally drier.**	[G.1] Shift in understorey composition away from inundation-adapted species towards inundation-tolerant and terrestrial species.	[G.1] Relative abundance, species richness and/or nativeness of functional groups determined by frequency and duration of flooding.
[H] Area of the floodplain affected by flows in between 30,000 - 50,000 ML d^{-1} at Tocumwal. **Generally drier and a seasonal shift/seasonal loss.**	[H.1] Possibly a shift in understorey composition towards species more typical of drier conditions and away from species that respond to early flood.	[H.1] Relative abundance, extent, species richness and/or nativeness of functional groups typical of drier conditions versus functional groups indicative of an early-season flood.

Ecological targets

General points

Benchmark: Choice of benchmark or point of reference depends on which objective is being adhered to. Mapping is central to the Ramsar objective, important in the Living Murray objective and specific to the RCS objectives but each has a different benchmark or point of reference:

- Ramsar – Needed for 1982: recommendation is to use Chesterfield (1986) for forest, until alternatives developed; possibly Ward (1994) for composition of wetland communities and seasonal changes.
- Living Murray – Time-frame not stated: point of reference uncertain; suggest 2005-2006 DSE EVC wetland mapping for Barmah Forest.
- RCS – Needed for 1999: use mapping by Doug Frood (started 2000) when available; or 2005-2006 DSE EVC wetland mapping for Barmah Forest for extent; use Reid and Quinn (2004) for relative abundance of common species and seasonal changes.

Mapping methods: Use remote sensing imagery, GIS and ground-truthing. Describe vegetation using recently-released (March 2006) descriptions of 19 wetland EVCs that occur in the Murray Fans bioregion, preferably with more precision than is currently required; for example, with respect to the dominant species of Wetland EVC #821 Tall Marsh.

Evaluation: Vegetation monitoring is largely surveillance (Table 5), with the potential to test for trends. Opportunities for intervention monitoring are limited to comparing between water management areas (WMAs) and differences in regulator operation. The development of a statistical design requires spatial information (definitions of WMA, flood inundation levels) and iteration with client to set priorities. A statistical design may change the form of some variables from absolute to relative measures and hence require transformations prior to analysis.

Comparisons: Comparisons are feasible between WMAs and in some instances between wetlands. Given the recent changes in managing rain rejection flows, a comparison between WMAs with contrasting regulator operating rules would be highly desirable, especially for Giant Rush and Moira Grass vegetation.

Multiple objectives: The ecological targets for Barmah Forest have been developed to satisfy all three sets of objectives and these are:

- healthy Moira Grass vegetation
- healthy Giant Rush vegetation
- healthy River Red Gum forest and woodland

Healthy vegetation

Healthy vegetation is the principal vegetation-related objective for the Living Murray. Healthy vegetation can be defined in terms of the amount of vegetation (**extent)**, its **integrity**, **resilience** and **vigour**, and (in some instances) taking account of its role and function within the ecosystem (**ecosystem functioning**). Using this definition thus satisfies TLM objective and covers the other two legally-binding objectives.

As the term “healthy” when referring to vegetation is a suite of attributes, it is not assessable by a single response variable. Accordingly, ecological targets are here established for each vegetation type, influenced by its growth form.

Moreover, as there are only limited benchmark or historical data, only some of these targets can be quantified immediately. For those lacking data, directional targets can be established, where possible, using information from previous surveys (where they exist and are of an appropriate format). In cases where a consistent and comparable data set is not available, the benchmark will need to be determined from data collected during the first five years of the monitoring program.

Moira Grass vegetation

Health of Moira Grass (*Pseudoraphis spinescens*) grassland should be monitored using the following five attributes (measured variables are given in brackets). The ecological targets for each attribute and a summary of the attributes are provided in Table 16.

Extent (area, measured in absolute terms as hectares) of aquatic grasslands dominated by Moira Grass. This should be described and expressed as the area of Wetland EVC #809 Floodplain Grassy Wetland.

Integrity (presence and abundance as number or area of invasive species, indicator species, indicator functional groups). Current water regime is one of the major threats to the integrity of Moira Grass plains (Roberts, draft), and the risks associated with this are a gradual or punctuated colonisation by tall emergent macrophytes, notably Giant Rush *Juncus ingens* or Cumbungi *Typha* spp. and persistent colonisation by River Red Gum seedlings. An early warning of likely change to wetter conditions in the aquatic grasslands is the increase (abundance, cover, frequency) of macrophyte species such as *Ludwigia peploides* and *Myriophyllum crispatum* or of certain functional groups notably amphibious responders with plastic growth form (ARp) or *Paspalum distichum* (assess annually from fieldwork).

Resilience (reproductive status: counts of number of stems that are flowering at time of flood peak). Moira Grass is generally considered a perennial (*e.g.* Flora Victoria) which implies regeneration from rhizome propagules. The actual mode of regeneration for Moira Grass, whether from seed bank or from rhizome propagules, has not been established at Barmah Forest. In addition, nothing is known of seed longevity, seed bank viability and the effects of current management practices (water regime, stock impacts) on either of these. As a precautionary principle, therefore, it is desirable that Moira Grass grows until it reaches flowering. This is expected to provide the opportunity for seed set and therefore also for charging the seedbank and for re-charging rhizome storage, if that is the mechanism. As a response variable, reproductive status and effort should be considered temporary, in the expectation that it will be superseded by some other variable, should the investigations that are needed on reproductive and growth ecology of *Pseudoraphis spinescens* be completed in the near future.

Vigour (dry weight of live Moira Grass). The amount of aboveground growth in aquatic macrophytes is influenced by a number of factors, most notably water regime (time since flooding, water depth), soil conditions etc. Sampling will need to be carefully standardised so that comparisons between sites and through time can be made. The suggested time is at flood peak, *i.e.* coincident with flowering (above). Biomass data for Moira Grass (Spiny

Mudgrass elsewhere in eastern Australia) are very limited. Silvers (1993) using a very small quadrat of 0.3 m^2 recorded an average of 33 g m^{-2} in winter 1992 (before flooding) and 150 g m^{-2} in spring (after flooding) at Top Lake, Barmah Forest. These data should be adequate for setting an interim ecological target. The values are low when compared with the Northern Territory, where biomass peaks of 1,670 g m^{-2} have been recorded 2-3 months after the flood peak (Finlayson, 1991). A pilot study will be needed to determine standardised positions on topographic gradient across wetlands.

Ecosystem functioning (frequency counts to give persistence as percentage remaining of dead v live Moira Grass after flood recession). On flood recession, Moira Grass trails over the ground and the canopy senesces in response to desiccation and to frost. This dead material, if not damaged by stock trampling, becomes a source of soluble nutrients (dissolved organic carbon etc) on re-flooding, thus favouring microbial and zooplankton productivity. The presence of this dead material provides shelter habitat for small terrestrial fauna, and effectively excludes opportunistic weedy terrestrial species. Thus the retention of this dead material is desirable. In the Northern Territory, *Pseudoraphis spinescens* persists as a short but viable turf between inundation events (Finlayson, 1991). No persistence data are known for northern Victoria but a turf of dead grass is known to persist in wetlands with little to no grazing pressure within the Barmah Forest (Silvers, 1993; Ward, 1994) and along the Murrumbidgee River at McKenna's Lagoon (Jane Roberts, *pers. obs.*). Thus a provisional target for persistence is until the next flood.

Table 16: Ecological targets for healthy Moira Grass vegetation.

Target	Attribute	Taxa, guild or sub-group	Response variable	Evaluation of target
Maintain or increase the area of Moira Grass.	Extent	Wetland EVC #809 Floodplain Grassy Wetland, possibly others. (assess from remote imagery)	Area (ha) (Map at 4 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA.
Maintain or decrease area of invasive and threatening species in Moira Grass plains.	Integrity	Invasive & threatening species. (assess from remote imagery)	Number of detectable clumps (when clumps are small). Area per clump (when clumps are sufficiently large to measure on GIS). (Map at 4 year intervals)	Time trend for Barmah Forest and for individual WMAs, of number of clumps and their area. Comparison between specific WMAs, using regulator management as contrast is possible. These data will need to be standardised for comparing between wetlands, and between WMAs. Invasive emergent macrophytes to be detected from imagery are *Juncus ingens*, *Typha* spp. *Phragmites australis*.
Maintain or decrease occurrence of indicator species.	Integrity	Indicator species. (assess from fieldwork)	Frequency counts from randomly-placed fixed transects in sentinel wetlands. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparison between specific WMAs, using regulator management as contrast is possible. Indicator species (*Ludwigia peploides*, *Myriophyllum crispatum*).
Maintain or decrease occurrence of indicator functional groups.	Integrity	Indicator functional groups. (assess from fieldwork)	Frequency counts from randomly-placed fixed transects in sentinel wetlands. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparison between specific WMAs, using regulator management as contrast is possible. Indicator functional group is ARp
Maintain or increase in flowering of Moira Grass.	Resilience	Flowering (assess from fieldwork)	Counts of flowering stems per m^2, and mean percent flowering. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparison between specific WMAs, using regulator management as contrast is possible.

Target	Attribute	Taxa, guild or sub-group	Response variable	Evaluation of target
Maintain or increase live biomass of Moira Grass.	Vigour	Biomass (live) (assess from fieldwork)	Dry weight per m^2 (mean). (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparison between specific WMAs, using regulator management as contrast is possible.
Maintain or increase extent and persistence of Moira Grass dead turf following flood recession.	Ecosystem functioning	Dead material (assess from fieldwork)	Cover or frequency counts. (At least twice-yearly field visit in autumn and early winter)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparison between specific WMAs, using regulator management as contrast is possible. Comparisons between specific WMAs, using wetlands as replicates.

Monitoring requirements for Moira Grass

Extent and integrity (invasive and threatening species): Remote sensing imagery every 4 years (high resolution, preferably real colour with field truthing, that covers all areas of Moira Grass plains at Barmah Forest).

A once-off desktop study using available (historical) aerial photographs is also recommended to measure the recent historical expansion of River Red Gum and Giant Rush onto Moira Grass plains through time. As a minimum, sites should be selected that match those being used in the field work.

Integrity (indicator species and functional groups), resilience, vigour and ecosystem functioning: Field based method. Integrity, resilience and vigour can be measured at the same time (flood peak) once per year. The recommended approach for integrity is that of recording species frequency using the point method of Reid and Quinn (2004), using randomly placed permanent transects (notionally six per grassland) at ten aquatic grasslands distributed across the WMAs of Barmah Forest. The technique is fairly rapid, (Michael Reid, *pers. comm.*) and a team of two persons can do frequency counts for two (or more) wetlands/sites a day. Resilience and vigour are measured by harvesting five quadrats from ten grasslands for dry weight, stem length and flowering status. Ecosystem functioning as persistence of the dead Moira Grass turf is measured using the same design, layout and transects as used for measuring integrity, and records whether the ground is vegetated and whether this is by standing dead or senescent Moira Grass (*i.e.* not litter or debris where material has separated from the parent plant). A non-destructive technique is required as it uses the same sites and transects as for integrity. Ecosystem functioning is measured at fixed time intervals after wetland drying (*e.g.* 1 and 3 months). Alternatively, ecosystem functioning could be recorded at monthly intervals following flood recession and until the following flood. This may be suitable for a local community or school group, with appropriate guidance or supervision, assuming there was an interest in Moira Grass. Other information should also be gathered to increase interest.

Giant Rush vegetation

The health of Giant Rush (*Juncus ingens*) vegetation should be monitored using the following three attributes (measured variables are given in brackets). The ecological targets for each attribute and a summary of the attributes are provided in Table 17.

Extent (area, measured in absolute terms as hectares) of tall rushland dominated by Giant Rush, and described in terms of Wetland EVC #821 Tall Marsh.

Integrity (Giant Rush canopy cover, as percent of area): When emergent macrophytes such as *Juncus ingens* form dense stands they intercept most of the downward radiation resulting in the exclusion of other plants. A canopy cover of 100% implies a continuous stand with high integrity (for Giant Rush). This results in low plant species richness and low structural diversity. Conversely, a canopy cover of 50-70% (indicating lower integrity for Giant Rush) implies a stand with discontinuous cover and open areas where aquatic macrophytes, amphibious or terrestrial species can establish and persist, depending on prevailing water regime. This results in greater species richness and structural diversity.

Vigour (stand height): Field-based method. Normally the height of aboveground parts (culms, leaves) of emergent macrophytes varies across a water depth gradient, from deeper to shallower to drying. For this reason it will be necessary to establish points within the different wetlands and within Barmah Lake that have a similar 'water regime environment'. A pilot study will be needed to document height variability across expected water regime gradients and hence to recommend a specific part of the elevation gradient for recording height and returning to these using a GPS.

There are fewer attributes for Giant Rush than for Moira Grass. This is due to differences in knowledge about species ecology (even less is known about J*uncus ingens* than *Pseudoraphis spinescens*) and differences in their status and role within the Barmah Forest ecosystem. Giant Rush has a dual or ambiguous role in these wetlands. On the one hand it is an invasive emergent macrophyte that has expanded over the last 100 years threatening Moira Grass plains (see p.47): thus a target for the RCS objective might be expressed in terms of reduced extent, lower integrity and less vigour. On the other hand, Giant Rush is important in some wetland patches as a preferred nesting habitat for waterbirds, and as a native plant it is important in its own right; thus a more appropriate objective for the Living Murray might be to maintain vigour and integrity without expansion. Both of these traits are accommodated in the ecological targets for Giant Rush (Table 17).

Table 17: Ecological targets for healthy Giant Rush vegetation.

Target	Attribute	Taxa, guild or sub-group	Response variable	Evaluation of target
Maintain extent of Giant Rush.	Extent	Wetland EVC #821 Tall Marsh dominated by *Juncus ingens*. (assess from remote imagery)	Area (ha) or as percentage of WMA. (Map at 4 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between specific WMAs, using wetlands as replicates.
Maintain integrity of Giant Rush.	Integrity	Wetland EVC #821 Tall Marsh dominated by *Juncus ingens*. (assess from remote imagery)	Canopy cover of Giant Rush (% of area); presence and area of other tall emergent macrophytes within EVC #821. (Map at 4 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between specific WMAs, using wetlands as replicates. Other tall emergent macrophytes relevant to wetlands within Barmah Forest are Common Reed *Phragmites australis* and Cumbungi *Typha* spp.
Maintain vigour of Giant Rush.	Vigour	*Juncus ingens* (assess from fieldwork)	Mean height, per wetland. (Annual field visit) Biomass and stand density are alternatives but require more time to implement and process.	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between specific WMAs, using wetlands as replicates.

Monitoring requirements for Giant Rush

Extent and integrity: Remote sensing imagery every 4 years (low-level high resolution, preferably real colour with field truthing, that covers all areas of Giant Rush at Barmah Forest).

Vigour: Field based method. Vigour is measured once per year at the flood peak. Clump heights are recorded from 20 random points from within a pre-standardised environment from at least six rushlands.

River Red Gum forest and woodland

The health of River Red Gum forest and woodland should be monitored using the five attributes of extent, integrity, resilience, vigour and ecosystem functioning. The ecological targets for each attribute and a summary of the attributes are provided in Table 18.

For monitoring, River Red Gum forest and River Red Gum woodland have the same attributes and also the same variables, at least initially. It is envisaged that there will be some institutional investment in relevant studies over the next 5-10 years, so that this preliminary selection of variables, targets and sampling protocols can be revised, and made specific to forest or to woodland, where necessary. Forest and woodland is a coarse division and each should be further sub-divided or stratified, for example by flowbands. Although it is convenient to divide the range of flows into discrete even-sized flowbands for data analyses (Table 1), for ecological and mapping purposes uneven divisions may prove more appropriate. It is likely that the choice of which to use for monitoring will depend on hydraulic considerations including how large or generalised an area each flowband covers in the forest.

Extent: The vegetation map by Chesterfield (1986) recognises seven River Red Gum dominated vegetation types for Barmah Forest and has been considered too coarse in resolution. Subsequent EVC mapping (*e.g*. Interactive Mapping on DSE website) has even less discriminatory power, recognising just one River Red Gum forest type (EVC #255 Riverine Grassy Woodland / Sedgy Riverine Forest / Wetland Formation mosaic) and one River Red Gum woodland type (EVC #295 Riverine Grassy Woodland) for Barmah Forest. At the other extreme, preliminary mapping by Doug Frood (*e.g*. Frood and Ward, 2001) has recognised a large and rather unworkable number of mapping units (in excess of 80). In conjunction with DSE, this mapping is currently being revised and finalised, and should occupy an intermediate and useful position.

It is suggested that when this mapping becomes available, which may be sometime in 2006 to meet the requirements of Victorian Environmental Assessment Council, it should be adopted as the benchmark for the extent of River Red Gum forest types and River Red Gum woodland types. The variable of interest is the area (in hectares) of each EVC across Barmah Forest and within each WMA.

Mapping should then be repeated at 25 year intervals. Note that this mapping interval is considerably longer than for the non-woody vegetation types (Moira Grass and Giant Rush) because it is less dynamic and changeable (with the exception of Floodplain Regeneration Thickets) and because it is more expensive to map and field-truth woody vegetation by its dominant tree characteristics and understorey composition. If woody vegetation proves to be more changeable than anticipated here, and be relatively cheap to map, then a shorter interval would be preferable.

With each subsequent mapping, including the current revisions, a reference or look-up table will need to be developed that links associations used in earlier vegetation maps (notably Chesterfield, 1986) to latest EVCs.

Integrity (character of the understorey)**:** Any change to character of the understorey is a loss of integrity of the forest or woodland. It may also be an early warning of change in vigour. (Note that by this criterion, many parts of Barmah Forest are probably already changed in character).

Variables used to describe "character" can be species composition, species diversity and relative abundance of functional types, which can all be derived from same data sets. Following the experience of Reid and Quinn (2004) with aquatic macrophytes in wetlands, point data from multiple transects is recommended to monitor the character of the understorey.

Current threats to River Red Gum forest and woodland are given in Tables 14 and 15, and can be expected to shift understorey character away from:

- Flood Tolerant towards Flood Intolerant; and
- Flood Cued towards Opportunistic and Rainfall-cued.

Resilience: This includes the capacity of River Red Gum forest and woodland to replace themselves through regeneration from seed. This can be monitored in the following two ways:

- periodic mapping (co-incident with mapping above) of the number and location of so-called Floodplain Regeneration Thickets (recognised as an EVC); and
- through periodic site descriptions of forest age (stage) structure from saplings to senescents.

Neither the ideal targets for this nor the appropriate spatial scale for evaluating this are currently known. A combination of desktop analysis, consultation with foresters and ecologists, and quick field checks will be necessary to set preliminary targets and sampling criteria (quadrat size and locations and temporal characteristics). It will be necessary to revise the targets and their spatial characteristics after 5-10 years, becoming more explicit regarding the differences (if any) between River Red Gum forest and River Red Gum woodland in terms of their regeneration characteristics. This will give the opportunity to incorporate advances in knowledge that will have been generated in the meantime.

Table 18: Healthy River Red Gum forest (and to be applied separately to woodland).

Target	Attribute	Taxa, guild or sub-group	Response variable	Evaluation of target
Maintain extent of EVCs.	Extent	River Red Gum forest(s) River Red Gum woodland(s) (assess from remote imaging)	Number of EVCs and their area (as hectares), or area as percentage of WMA. (Map at 25 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum forest and woodland as separate analyses.
Increase in abundance of flood tolerant functional types.	Integrity	Understorey: Flood Tolerant Functional Types. (assess from fieldwork)	Number of species, and proportion of assemblage at site. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum forest and woodland as separate analyses. Expectation is that the response variables will increase through time, and with increasing elevation.
Decrease in abundance of flood intolerant functional types.	Integrity	Understorey: Flood Intolerant Functional Types. (assess from fieldwork)	Number of species, and proportion of assemblage at site. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses. Expectation is that the response variables will decrease through time, and with increasing elevation.

Target	Attribute	Taxa, guild or sub-group	Response variable	Evaluation of target
Decrease in abundance of opportunistic species.	Integrity	Opportunistic types of species. (assess from fieldwork)	Number of species, and proportion of assemblage at site. (Annual field visit)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses. Expectation is that the response variables will decrease through time, and with increasing elevation.
Maintain or increase the number of EVC patches.	Resilience	EVC Floodplain Regeneration Thickets. (assess from imagery and mapping)	Number and location (geo-reference) of these EVC patches. (assess at 7 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses.
Maintain or increase in canopy cover and tree density.	Vigour	Mature Trees (assess from remote imagery)	Canopy cover Tree Density (assess once each year)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses.
Increase in abundance of over-mature and senescent trees.	Ecosystem functioning	Over-mature and senescent trees. (assess if possible from remote sensing or use fieldwork)	Number and location (geo-referenced) (assess at 7 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses.
Increase in load of fallen large timber.	Ecosystem functioning	Fallen large timber (assess if possible from remote sensing or use fieldwork)	Load (assess at 7 year intervals)	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses.
Increase in load of small leaves and twigs.	Ecosystem functioning	Litter (small) *i.e.* leaves and twigs. (assess from fieldwork)	Load (assess quarterly and annual).	Evaluate as a time trend for Barmah Forest as a whole, and for each WMA. Comparisons between WMAs in same flowband, River Red Gum Forest and Woodland as separate analyses.

Monitoring requirements for River Red Gum forest and woodland

Extent: Remote sensing imagery every 25 years of whole of Barmah Forest.
Integrity: Within River Red Gum forest select two flowbands. Sample understorey once per year at one site for each flowband at five WMAs. Within River Red Gum woodland select one flowband. Sample understorey once per year at one site at five WMAs.
Resilience (Remote): Measure River Red Gum thickets every 7 years (feasibility of using remote sensing to measure this needs to be determined).
Ecosystem functioning (Field and Remote): Set litter traps at five forest and woodland sites and collect after designated period of time to measure biomass of small leaf and twig fall. Measure senescent hollow-bearing trees and fallen timber through remote sensing imagery every 7 years (feasibility of using remote sensing to measure this needs to be determined).
Vigour (Remote): Measure canopy cover and tree density with periodic field truthing once per year.

As a general principle, a flowband for monitoring should be selected on the basis that it is currently or likely threatened by current flow management. A fine-partitioning of flowbands was set out above (Table 1) but broader groupings (Table 3) should prove more realistic and retain ecological sense. The final choice of which flowbands to use will be determined by practical issues, namely the equivalent area of floodplain and its accessibility; this will become apparent after the vegetation mapping and the flow-inundation area relationships have both been revised. As far as possible, it would be sensible to select flowbands with contrasting ecological effects.

Remote sensing

Remote sensing offers potentially extensive and cost effective techniques for ecological monitoring. A feature of remote sensing is the compromise between image resolution and price. High resolution imagery provides detailed information but in turn is relatively costly. The two options available to obtain remote sensing imagery are via satellite and airborne sensors.

Satellite imagery

Panchromatic (0.6-1m resolution) or multispectral imagery (2.4-4m resolution) can be obtained from satellites (e.g. IKONOS or QuickBird sensors) and purchased on a per square km basis. For Barmah Forest (ca. 30,000 ha), images are estimated to cost $50,000-60,000 (Damian Barrett, *pers. comm.* 16/11/05). Alternatively, lower resolution satellite images can be purchased at a lower cost; panchromatic (2.5-10m) or multispectral imagery (10-20m resolution) can be obtained from satellites such as SPOT 5 and each purchased image covers ca. 3,600 square km. One or two images should cover Barmah Forest and are estimated to cost $8,000-$16,000 (Damian Barrett *pers. comm.* 16/11/05).

Satellite imagery has the advantage of covering large spatial areas but it may take several overpasses to obtain satisfactory images from cloudless skies. This makes it difficult to specify particular image dates.

Airborne imagery

Aerial imagery of Barmah Forest can be obtained by contracting an imagery service provider to fly over the site in an aircraft and capture the required data. The following discussion is based on services provided by Aerometrex Pty Ltd (South Australia) who have been contracted in the recent past to provide detailed aerial imagery of the Hattah Lakes and Lindsay-Walpolla Island SEAs.

Imagery obtained from a fixed-wing aircraft can be captured at considerably greater spatial resolution than satellite imagery (0.04-0.5m) and has the further advantages of having very high spatial accuracy (2 pixels horizontal accuracy).

Weather conditions need to be favourable and free of cloud cover on the day of image capture.

Aerometrex Pty Ltd has provided an estimated quote based upon obtaining orthorectified imagery for 300 square km (30,000ha) which covers Barmah Forest. The costs to obtain fully orthorectified natural colour (RGB) and near infrared imagery of Barmah Forest at several pixel resolutions are:

- 0.25m pixel resolution: $35,350 plus GST
- 0.30m pixel resolution: $27,450 plus GST
- 0.35m pixel resolution: $22,750 plus GST.

These costs are based on mobilising the aircraft from Canberra to undertake this task alone. Savings can be made when the aircraft is mobilised with multiple tasks in the region and this could be achieved through inter-agency cooperation. Aerometrex Pty Ltd also has available aerial imagery of Barmah Forest in 2002.

It is anticipated that the 0.30m resolution RGB & NIR option will allow all of the response variables to be measured, with the possible exceptions of those for Moira Grass integrity and River Red Gum ecosystem functioning (load). For Moira Grass integrity, the RGB & NIR imagery should ensure detection of the proposed invasive species such as the emergent macrophytes *Juncus ingens*, *Typha* spp. and *Phragmites australis*, but hyperspectral imagery may be needed for other invasive species, notably *Sagittaria*. If this becomes an issue then a pilot study may be required to determine whether hyperspectral imaging is required. Note that the costings below do not include hyperspectral imaging but it is anticipated that the cost of capturing hyperspectral imaging along with RGB & NIR would not be a major additional cost. For River Red Gum ecosystem functioning (load), LiDAR has the potential for recording the distribution of large woody debris (LWD), especially LWD log-jams, throughout the forest. The feasibility of using existing LiDAR data could be the subject of a dedicated small study or a student project.

Prior to committing resources to a particular remote sensing option, it is recommended that a pilot study be undertaken to resolve on the optimal remote sensing to assess the specific vegetation attributes. This will also provide a basis for a quote on the data processing and interpreting and field-truthing requirements (see p.70).

Estimated costs

Estimated costs are annual and based on the number of “people days”. At this point in time it is estimated that one person day will cost $1,000. These costs are **exclusive** of accommodation charges, travel costs and GST and should be considered as indicative only. Remote sensing costs do not include time for data processing, interpreting or field-truthing.

Moira Grass field monitoring	
(Integrity): 10d fieldwork, 2d analysis	$15,000
(Resilience and Vigour): 10d fieldwork and 5d processing per analysis	$15,000
(Ecosystem functioning): 10d fieldwork and 2d analysis x 2 field visits per year	$24,000*
Annual report preparation: 6d	$6,000
TOTAL PER YEAR	**$60,000**

*Ecosystem functioning monitoring could potentially be measured by trained volunteers

Giant Rush field monitoring	
(Vigour): 10d fieldwork and 5d processing per analysis	$15,000
Annual report preparation: 4d	$4,000
TOTAL PER YEAR	**$19,000**

River Red Gum field monitoring	
(Integrity): 20d fieldwork and 15d processing per analysis	$35,000
(Ecosystem functioning): 20d fieldwork and 5d processing / analysis	$25,000
Annual report preparation: 10d	$10,000
TOTAL PER YEAR	**$70,000**

Remote sensing monitoring needs	
Moira Grass (Historical Extent): 30d analysis of historical imagery	($30,000*)
Moira Grass (Extent and Integrity): Remote sensing imagery every 4 years	$27,500**
Giant Rush (Extent and Integrity): Remote sensing imagery every 4 years	
River Red Gum (Vigour): Remote sensing once per year	
River Red Gum (Extent): Remote sensing imagery every 25 years	
River Red Gum (Resilience and Ecosystem Functioning): Remote sensing every 7 years	
TOTAL PER YEAR	**$27,500****

*Once-off cost involving review of past imagery to document vegetation change
**Annual cost to obtain RGB & NIR 0.30m resolution imagery for 30,000ha to cover Barmah Forest based on an estimated quote from Aerometrex Pty Ltd.

Skills and resources

Experienced field workers required, preferably ecologists with botanical and analytical skills. Drying ovens required to estimate biomass from collected samples. Car and boat required to access sites. Workers with skills and experience in processing and analysing remote sensing imagery are required.

Ecological Indicator 4: Frogs

Background and limitations

Floodplain wetland systems such as Barmah Forest provide important habitats for the sustainability of frog populations. Frogs are considered to be important indicators of the quality of aquatic habitat (Fairweather and Napier, 1998) due partly to their permeable skin and use of both aquatic and terrestrial habitats. Frogs are also important to monitor because populations in Australia are following the worldwide trend of reductions in their range and abundance (EA, 1999).

We do not know which frog species persisted at Barmah Forest prior to river regulation. However, frogs identified at Barmah Forest in the recent past (Brown, 1981; Ward, 2001, 2002, 2003, 2004 and 2006, Loyn *et al*., 2002) are listed in Table 19.

Table 19. Frogs identified at Barmah Forest and their conservation status in Victoria (DSE, 2003b).

Common name	Scientific name	Conservation status in Victoria
Peron's Tree Frog	*Litoria peroni*	
Eastern Banjo Frog	*Limnodynastes dumerili*	
Spotted Marsh Frog	*Limnodynastes tasmaniensis*	
Common Eastern Froglet	*Crinia signifera*	
Barking Marsh Frog	*Limnodynastes fletcheri*	Data Deficient
Eastern Sign-bearing Froglet	*Crinia parinsignifera*	
Sloane's Froglet	*Crinia sloanei*	
Common Spadefoot Toad	*Neobatrachus sudelli*	
Bibron's Toadlet	*Pseudophryne bibroni*	Endangered

Additional Notes: The Giant Banjo Frog (*Limnodynastes interioris*) has been recorded in farmland nearby but outside of Barmah Forest (Loyn *et al*., 2002) and was not recorded in the surveys by Ward from 2000-2006. It is listed as Critically Endangered in Victoria (DSE, 2003b). The Southern Bell Frog (*Litoria raniformis*) has been listed as being present in Barmah Forest on one occasion but this reporting is now considered erroneous (see Loyn *et al*., 2002).

Conceptual model

Flow regime

Frogs of the Barmah wetland system (Table 19) are dependent upon surface waters for tadpole development and metamorphosis to the adult stage (Hero *et al*., 1991). Floodplain inundation from riverine flooding is an important mechanism to stimulate frog breeding activity at Barmah Forest (Ward, 2001, 2004) although rainfall may also be sufficient for pool formation and successful breeding in some species (*e.g.* the burrowing Common Spadefoot Toad). Prior to regulation of the River Murray, flooding of Barmah Forest would have resulted in the regular inundation of a mosaic of habitat types for various durations. The presence of surface water for a sufficient period and at the appropriate time of year to match the species-specific breeding requirements is important for the persistence of frog species at Barmah Forest.

Since European settlement there have been progressive changes to the flow regime of the River Murray that have resulted in alterations to the flow regime (see Table 1) that may have influenced the populations of frogs at Barmah Forest. Less frequent large flooding of Barmah Forest (>20,000 ML d^{-1} in the River Murray at Tocumwal) results in the more elevated areas of the floodplain receiving less inundation. The greater period of dry conditions would be predicted to result in fewer opportunities for frog breeding in these areas. Similarly, a decrease in the duration of flooding from pre-regulatory conditions results in wetland areas being inundated for shorter periods of time and may alter frog community structure. These changes may influence the breeding success of some species if the period of inundation is not sufficient to allow tadpoles to metamorphose to adults.

The timing of flooding is important to determine whether frogs will breed. The greater frequency of floods commencing in spring (Table 1) may benefit most species of frogs of Table 19 with the exception of the endangered Bibron's Toadlet that breeds from March-June (Frogs of Australia website, accessed 5 April 2006). This species likely has fewer breeding opportunities due to less frequent floods commencing in the months of May and June. Bibron's Toadlet differs from the other frogs of Table 19 in that it spawns on land and its eggs require inundation from rain or floodwater for aquatic tadpole development (Hero *et al*., 1991).

An increase in small floods (12,000 – 15,000 ML d^{-1}) as a result of rain rejection flows results in some low-lying areas of Barmah Forest being inundated more often than natural during the warmer months. This could potentially provide increased breeding opportunities for some frog species, and also provide an increase in particular habitat (*e.g.* Giant Rush) from pre-regulation conditions. However, the decrease or loss of drying periods in these areas may impact on wetland productivity and influence frog populations indirectly such as through the provision of appropriate food.

Water quality

The quality of surface water has the potential to decrease the survivorship of tadpoles and eggs, particularly during blackwater events where high tannin and low dissolved oxygen conditions occur. Water quality at Barmah Forest has in the recent past been of a reasonable standard for the survival of tadpoles and frogs (Ward, 2000-2004, 2006). Its frequent monitoring provides managers with the potential ability to mitigate poor water quality conditions.

Habitat for shelter

Structural complexity within wetlands is important for providing shelter to tadpoles to avoid predation from fish, birds and other animals. Appropriate vegetative habitat, logs, bark and leaf litter are also required in fringing areas of the wetlands to provide adequate shelter for adult frogs. Cracks in the soil also provide necessary habitat for some species to survive dry periods. Shallow, vegetation rich and recently inundated ephemeral wetlands at Barmah Forest were noted to contain more frogs than steep sided, vegetation poor and permanent wetlands (Ward, 2004).

Other threats to frogs of Barmah Forest

Grazing by stock occurs in sections of Barmah Forest and has the potential to impact upon frog populations through trampling and consumption of vegetation that may provide important habitat for frogs. Grazing at wetlands along the Murrumbidgee River, for example, has altered frog communities where increased grazing pressure has decreased frog species richness (Jansen and Healey, 2003).

A chytrid fungus of the genus *Batrachochytrium* has been implicated in the decline in range and abundance of many frog species in both Australia and overseas (Berger *et al*., 1999). This fungus has not been recorded at Barmah Forest (Speare and Berger, 2005) but is a potential threat to its frog populations.

Direct predation from a range of exotic fauna, predominately foxes, Common Carp and Gambusia, also pose significant threats to the frog populations of Barmah Forest. The relatively high numbers of these pest species in the forest, combined with their known ability to predate on various stages of the frogs life cycle, can be expected to exert a significant downward influence on the frog populations. Rarer frog species are particularly at risk of local extinction.

Future monitoring

- Investigation of the effects of grazing on frog populations at Barmah Forest through stock exclusion experiments.
- Investigations of the tolerances of different frog species and their stages of development to various water qualities (particularly low dissolved oxygen and high tannin concentrations).
- Study of frequency of flooding on wetland productivity and its influence on frog productivity at Barmah Forest.
- Examination of the effects of exotic fish on frog populations of Barmah Forest through their consumption of eggs, tadpoles and frogs.

Ecological target

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
The nine species of frog of Table 19 will be recorded at Barmah Forest in any five year period.	Frogs	Diversity, abundance	List of species and relative abundance obtained at designated sites across Barmah Forest. Evaluate target by comparing any consecutive five years of data. Suitable data available for the 2000/01, 2001/02, 2002/03, 2003/04 and 2005/06 seasons.

Monitoring requirements

Surveys of the male breeding calls is recommended here as the preferred technique for monitoring frog populations, as consistent with Baldwin *et al*. (2005). Whilst this approach has limitations due to temporal variability in calling by male frogs, it has the important advantage of being non-invasive compared to other techniques. However, supplementary survey techniques of sweep-netting for tadpoles and active spotlight searching for frogs are usually also required to compile a full species list, in addition to providing other useful data on breeding status and activity (*e.g.* Ward, 2006).

Monthly surveys from September to February should occur at two sites in each of the 11 WMAs of Barmah Forest as consistent with previous monitoring by Ward (2004). Surveys of frog calls need to occur at night, beginning at least 30 minutes after sunset and concluding at least 30 minutes before sunrise. Listening to the vocalisations of breeding male frogs (with concurrent recording with a high quality digital tape recorder) should occur for 15 minute duration at each site, regardless of the degree of flooding, noting species and estimating numbers that can be heard. The male advertising calls of the less common species of Sloane's Froglet *Crinia sloanei*, Common Spadefoot Toad *Neobatrachus sudelli*, Bibron's Toadlet *Pseudophryne bibroni*, Giant Banjo Frog *Limnodynastes interioris* and Southern Bell Frog *Litoria raniformis* should be played back (1 minute each) in an attempt to elicit calling responses and any return calls noted.

Tadpole sampling should be undertaken by sweeping a fine meshed, flat-bottomed dip-net a standardised number of times for a known distance or time duration (*e.g.* 10 sweeps each of 10 m distance or 15 s duration) at each site. Strict hygiene protocols should be adopted in the handling of tadpoles and frogs and in the cleaning of equipment to minimise the potential spread of pathogens such as the chytrid fungus between wetlands. Spotlighting should occur for 10 minute duration at each site, regardless of the degree of flooding, to actively search for frogs to make visual identification and frequency counts.

Basic water quality parameters and notes on habitat condition should also be obtained. Site photographs are an ideal accompaniment, though can only be taken if part of the survey is conducted during daylight hours. However, this has the disadvantage of increasing travel distance and time in having to visit all sites twice (*i.e.* night-time surveying remains of primary importance to obtain frog activity data), though may have the advantage of decreasing the night-time sampling hours by allowing water quality, habitat descriptions and sweep-net sampling to be undertaken during the day.

Estimated costs

Estimated costs are annual and based on the number of "people days". At this point in time it is estimated that one person day will cost $1,000. These costs are **exclusive** of accommodation charges, travel costs and GST and should be considered as indicative only. Furthermore, night-time sampling does present additional challenges (safety, mosquitoes, etc) that may increase the "people days" rate.

Frog monitoring	
Monthly sampling over 6 months requiring 6 people days per survey (2 people required in the field over three nights)	
36 people days per year	$36,000
Annual report preparation: 4 people days	$4,000
TOTAL PER YEAR	**$40,000**

Skills and resources

Car, boat and/or bicycle transport will be required to access sites. Experience in the identification of tadpoles, frogs and frog calls is required. Any capturing and handling of tadpoles and frogs will require the appropriate ethics and permit permissions. A sub-sample of the recorded frog calls should be verified by an independent person experienced in frog call identification.

Ecological Indicator 5: Water Quality

Conceptual model

Floodplains are both net sinks and sources for particulate and dissolved material.

Inflow: As incoming floodwaters leave the main channel and enter the floodplain, the velocity of flow decreases and consequently entrained inorganic material (*e.g.* silt) can settle out. As nutrients, particularly phosphorus (P), are associated with these particles this should lead to a decrease in both turbidity (total suspended solids) and total P in the floodwater. The actual effect for Barmah Forest may be reduced relative to other floodplains. Yarrawonga weir, upstream of the forest, can act as a sedimentation basin, reducing the amount of fine inorganic material reaching the forest than normally would have occurred. Thus, the rate of sedimentation in the forest may have decreased since the construction of the weir.

Coarse particulate organic matter (CPOM) entrained in the floodwater is important for productivity and may or may not fall out on the floodplain. It will depend in part on the density of the CPOM and the 'roughness' of the floodplain (*i.e.* the ability to physically restrain particles). A preliminary estimate based on CPOM upstream and downstream of Barmah Forest suggests that it will act as a net trap for CPOM entrained in floodwaters (Ben Gawne *pers. comm.*).

Outflow: Floodwaters will leach carbon and nutrients from organic litter on the floodplain (Baldwin, 1999). In addition, on rewetting, dried soils will release a pulse of dissolved P and nitrogen (N) into the water column (Baldwin and Mitchell, 2000). The pulses of nutrients and carbon will promote both primary and secondary production both on the floodplain and downstream of the forest. This in turn will effect dissolved oxygen concentrations in the returning water. The actual levels of dissolved oxygen downstream of Barmah Forest will depend on many inter-related factors (Howitt *et al.*, 2005). Probably the most important parameter is temperature, which in turn is related to seasonality. For example, imposition of floods during summer should result in a marked decrease in dissolved oxygen downstream of Barmah Forest.

Aquatic organisms such as fish and crayfish have particular tolerances to low dissolved oxygen which differ between species. Studies of fish deaths at Broken Creek (McKinnon and Shepheard, 1995) and documented emergence from the water of Murray crayfish (*Euastacus armatus*) (McKinnon, 1995) indicate that a dissolved oxygen concentration below 3 mg L^{-1} is considered unfavourable to native fish and crayfish species in the Barmah Forest region.

Increased dissolved organic carbon by itself, but coupled to increased secondary productivity (increased production of carbon dioxide), as well as potential exchange with acidic soils and sediments, will also lead to a decrease in pH in the return water. The actual extent of the effect on pH will depend in part on the buffering capacity of the receiving water.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

Floodwaters may also release any salt that has built up in the floodplain soils or wetlands, rasing the electrical conductivity in the receiving water. However, this is probably not an important issue for Barmah Forest (see Ecological Indicator: Groundwater, p69).

Based on this simple model we would expect that the returning floodwater in comparison to incoming floodwater would be:

- lower in total suspended solids (less turbid) and total phosphorus;
- higher in dissolved phosphorus and nitrogen (nitrate and ammonia);
- higher in dissolved organic matter (more coloured);
- lower dissolved oxygen; and
- lower pH.

Ecological targets

The ecological targets for water quality are presented in Table 20.

Table 20. Ecological targets for water quality.

Target	Taxa, guild or sub-group	Response variable	Evaluation of target
Maintain over 3 mg L^{-1} of dissolved oxygen in surface waters of the River Murray.	Surface water quality	Dissolved oxygen	Measure dissolved oxygen concentrations at River Murray sites during flood and non-flood periods to assess target.
Maintain pH within range of 6.5-8.0	Surface water quality	pH	Measure pH at River Murray sites during flood and non-flood periods to assess target. Note that the pH range is consistent with the ANZECC and ARMCANZ (2000) trigger thresholds that apply to slightly disturbed lowland river and freshwater lake ecosystems.
Maintain or increase loads of dissolved organic carbon entering the River Murray from Barmah Forest during flooding.	Surface water quality	Dissolved organic carbon	Measure dissolved organic carbon (DOC) at River Murray and Broken Ck sites each week during flood events over five years. Match with MDBC discharge data to determine DOC load from Barmah Forest for each flood event. Refine target to quantify loads if appropriate.
Maintain or increase loads of particulate organic carbon entering the River Murray from Barmah Forest during flooding.	Surface water quality	Particulate organic carbon	Measure particulate organic carbon (POC) at River Murray and Broken Creek sites each week during flooding events over five years. Match with MDBC discharge data to determine POC load from Barmah Forest for each flood event. Refine target to quantify loads if appropriate.
Decrease load of total suspended solids downstream of Barmah Forest compared to upstream during flood periods.	Surface water quality	Total suspended solids	Measure total suspended solids at River Murray and Broken Creek sites each week during flood times. (Indicates sedimentation at Barmah Forest)
Maintain or decrease salt loads entering River Murray from Barmah Forest during flooding.	Surface water quality	Electrical conductivity	Measure electrical conductivity at River Murray and Broken Ck sites during flood events over five years. Match with MDBC discharge data to determine salt load from Barmah Forest for each flood event. Refine target to quantify loads if appropriate.

Monitoring requirements for water quality

To determine the effects of Barmah Forest on water quality it is necessary to estimate loads entering and leaving the forest. Therefore it is necessary to know both the flow (discharge) and concentrations of materials in the incoming water and the return water. Also because the outflow from the forest (Barmah Lake) is so close to the junction of Broken Creek and the River Murray, it will be necessary to determine contributions from Broken Creek to avoid confounding of the results. It is assumed that water moving onto the Millewa Forest floodplain will leave the system via the Edwards River so as to allow for the calculation of loads specific to Barmah Forest.

Therefore it is suggested that sampling sites be established at:

- a River Murray site downstream of Tocumwal but upstream of Barmah Forest (upstream site);
- on inflowing flood runners at the western and northern edge of the forest;
- in the Cutting;
- at the junction of Barmah Lake and the River Murray
- in the Broken Creek, upstream of the junction with the River Murray; and
- on the River Murray approximately 2-3 km downstream of the Broken Creek junction (downstream site).

All sites should be monitored weekly during flood events. Boat sampling will be required to collect vertically integrated samples across the river channel. This technique is considered important so as to accurately measure water quality across the whole river channel to take account of potential vertical and horizontal stratification due to tributary inputs.

Three sites (River Murray upstream and downstream, and Broken Creek) should also be monitored every two weeks outside of flood periods to allow a measure of the yearly loads along the River Murray.

Determinants would include:

- flow (discharge) (from MDBC monitoring stations and at regulators);
- temperature, dissolved oxygen, pH, electrical conductivity and turbidity;
- total suspended solids; and
- dissolved and particulate carbon.

Estimated costs

Estimated costs are annual and based on the number of "people days". At this point in time it is estimated that one person day will cost $1,000. These costs are **exclusive** of accommodation charges, travel costs and GST and should be considered as indicative only.

Water quality monitoring (flood periods)	
Field visits: 18 day visits per year[1] (2 people days per field trip)	$36,000
Sample processing: (216 samples per year[2] @ $50 per sample)	$10,800
Annual report preparation: 6 days	$6,000
TOTAL PER YEAR	**$52,800**

[1]Assumes weekly field surveys over a four month flooding event
[2]Based on collection of two samples per six sites

Water quality monitoring (non-flood periods)	
Field visits: 18 day visits per year[1] (2 people days per field trip)	$36,000
Sample processing: (108 samples per year[2] @ $50 per sample)	$5,400
Annual report preparation: 2 days	$2,000
TOTAL PER YEAR	**$43,400**

[1]Assumes field surveys each two weeks over eight month non-flood period
[2]Based on collection of two samples per three sites

Skills and resources

Personnel with appropriate equipment (vertically integrated sampler/water quality meter) and expertise in sampling water quality will be required due to the importance of collecting vertically integrated water samples (see methodology) by boat. Car and boat required to access sampling sites. Appropriate consumables and equipment required for field storage of samples and processing.

Ecological Indicator 6: Flood Mapping

Background

A detailed understanding of water movement across the Barmah wetland system under different levels of flooding and regulator operation is important for the effective management of Barmah Forest. This is particularly the case for the applications of EWAs to specific areas of the forest to achieve environmental outcomes and for the management of rain rejection flows into the forest. An accurate knowledge of water movement also assists in the interpretation of other data arising from monitoring activities at Barmah Forest given that flooding is a primary driver of ecological response.

A hydrodynamic model utilising MIKE FLOOD software has been completed for the Barmah and Millewa Forests (Water Technology, 2005) based on a digital elevation model (DEM) derived from Light Detection and Ranging (LiDAR) airborne remote sensing data collected by the Murray-Darling Basin Commission. Water Technology (2005, p.10) notes several data gaps in the model and that "when addition data does become available in the future it can be readily incorporated into the hydraulic model as part of the ongoing refinement and improvement of the model". This additional data refers to cross-section surveys of some streams, feature surveys of regulatory structures (since completed) and further hydrologic data measurements. Only some of the hydrologic data measurements are considered to be within the scope of this monitoring program, including (a) surface water level measurements throughout Barmah Forest including the river and main regulators (but not the flow (discharge) measures at the regulators), and (b) flood extent mapping (potentially using remote sensing). The hydraulic stations located throughout Barmah Forest currently monitor surface water levels (monitored by Thiess Environmental) and the MDBC gauging stations currently monitor riverine hydraulic and hydrologic parameters.

Recommendation

That the current collection of surface water level data at the hydraulic stations within the Barmah Forest continues, and that regulator operations continue to be recorded. This monitoring program assumes that updates of the current hydrodynamic flood model (Water Technology, 2005) will occur in the future (outside of this monitoring program) so that the collected data will inform the refinement of the model. Should the current hydraulic monitoring within Barmah Forest change then these changes should be reviewed and event-based surface water level monitoring incorporated into this monitoring program if necessary.

Ecological Indicator 7: Groundwater

Background

Elevated groundwater tables and high groundwater salinity are considered a potential threat to the ecosystem health of the Barmah wetland system due to an altered flow regime and land management changes in the surrounding region (*e.g.* irrigation) (HydroTechnology, 1995; Ife, 1988; SKM, 2005). Groundwater has been monitored at Barmah Forest since 1984 and a recent review suggests that groundwater levels are influenced by rainfall and potentially surface water features (particularly in areas close to the River Murray) (SKM, 2005).

A network of 98 bores monitors the Upper Shepparton Formation, Lower Shepparton Formation and Deep Lead aquifer systems underlying Barmah Forest. These bores are monitored for groundwater levels on a monthly basis where possible, and for salinity (and maintenance) annually in April by Goulburn-Murray Water. A recent independent review of the groundwater monitoring program states that the bore network and its monitoring frequency is adequate and the current threat of groundwater on Barmah Forest is low (SKM, 2005).

Recommendation

That the current monitoring program continues. Should the monitoring program change then these changes should be reviewed and groundwater monitoring incorporated into this monitoring program if necessary.

Pilot study to optimise effort

Fieldwork

A pilot study is recommended prior to the commencement of the monitoring program where appropriate sampling data is not already available. A pilot study is considered essential for the vegetation component of the monitoring program, for example, to determine the number of Moira Grass sites, the number of WMAs to include in the sampling, to assess how many quadrats are required and the locations of quadrats. Evaluation of the pilot study data allows for the optimisation of sampling to ensure an efficient use of resources. If too few samples are collected, time and money may be wasted. If too many samples are collected one could have obtained the same result for less time, money and effort. Data collected at the appropriate spatial scale permits the calculation of the number of samples required to ensure a pre-determined level of precision.

For statistical testing, a prospective power analysis can also be used to help determine the number of samples required to ensure a high probability that a pre-determined and biologically meaningful effect is detected statistically. This ensures that sampling effort is optimised so that a sufficient number of samples is collected to avoid the situation that a null hypothesis is accepted (*i.e.* no different between treatments) when a difference did exist (*i.e.* avoiding a Type II error) (Manly, 1992).

Remote sensing

A pilot study is recommended to resolve on the optimal remote sensing to assess specific vegetation attributes. Further liaison is strongly recommended with those groups currently undertaking similar work (*e.g.* Water for a Healthy Country program of CSIRO and monitoring programs at other SEAs). This will allow for information and knowledge transfer and for a consistent and successful approach between SEAs.

Implement, evaluate and adjust the monitoring program

The monitoring program will be implemented and results collected over each one year period will be collated, analysed and evaluated against the ecological targets. Note that the yearly period is defined here as July-June rather than a calendar year given the natural flooding pattern for this site. Data will be presented in an annual report by each group undertaking the monitoring.

Management of the monitoring program

A management structure will need to be defined to coordinate the monitoring program. The structure will necessarily be developed by management but it is envisaged that it will incorporate a quality assurance and quality control program (Baldwin *et al*., 2005) that will, among other things, specify ‘rules’ relating to the monitoring program and any modifications. It is also envisaged that it will include the establishment of a ‘review panel’ (or equivalent) consisting of experienced ecologists and natural resource managers. The review panel should meet annually to appraise the yearly monitoring data and to consider it with data from previous years to allow the evaluation of the ecological targets. This is an essential component of the adaptive management cycle.

Other roles for the review panel are foreseen to be:

- To redefine the directional ecological targets at appropriate times and convert to quantified targets based on the acquired baseline monitoring data.
- To identify new ecological targets based on the current monitoring program. As an example, ecological targets may be developed for individual waterbird species as our knowledge of their breeding activities improves. This role may also be necessary as part of the requirements for specific monitoring of particular species or guilds as part of TLM monitoring.
- To refine the established conceptual models as knowledge of the ecology of Barmah Forest improves.
- To add new ecological indicators to the monitoring program with newly defined ecological targets.
- To review and adjust the frequency of monitoring of a particular ecological indicator if required.
- To highlight new knowledge gaps in the conceptual models.
- To determine whether these knowledge gaps should be addressed with long-term monitoring where new ecological targets or ecological indicators may be added to the monitoring program.
- To make recommendations for funding of short-term intervention monitoring.
- To make recommendations on the prioritisation of monitoring activities.

The review panel could potentially be incorporated into the current TLM structure for the Barmah-Millewa Forest involving a Coordinating Committee and Technical Advisory Committee (MDBC, 2005).

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Appendices

Appendix A. Tasks of the consultant brief for the Barmah Wetland System Environmental Monitoring Program.

In consultation with GBCMA staff, the consultant is to undertake and report on the following tasks:

Task 1

(i) Conduct a search of available literature to determine current policy and management requirements for environmental monitoring in Barmah Wetland and:

- list any identified ecological objectives and targets;
- identify data needs for reporting; and
- identify any commonalities.

(ii) Rank the importance of the current policy and management requirements for environmental monitoring in Barmah Wetland at local, regional, state and national scales.

Task 2

(i) Assess and document the scientific rigour, relevance to policy and management needs identified in Task 1 and effectiveness of past and current environmental monitoring programs in Barmah Wetland.

(ii) Identify any important physical or biological parameters that are not currently monitored in Barmah Wetland as part of an environmental monitoring program.

(iii) Review current and proposed environmental monitoring programs at Millewa Forest (the New South Wales component of the Barmah-Millewa Forest) and the other five Significant Ecological Assets (Gunbower, including Pericoota-Kondrook Forest; Hattah Lakes; Chowilla Floodplain, including Lindsay and Walpolla Islands; Murray Mouth, Coorong and Lower Lakes; and the River Murray Channel) to identify their transferability and applicability to Barmah Wetland.

Task 3

(i) In line with the State Government's vision for Barmah Wetland and the priority policy and management requirements for environmental monitoring in Barmah Wetland identified in Task 1, define the scope of the Barmah Wetland environmental monitoring program and its ecological objectives and targets.

(ii) Compare the suitability of different scientifically accepted monitoring options to determine whether the ecological objectives and targets identified above have been met.

Task 4

(i) Convene a scientific panel comprising experts in floodplain ecology and environmental monitoring to review the Barmah Wetland environmental monitoring program.

Task 5

(i) Develop an ongoing environmental monitoring program for Barmah Wetland that:

- incorporates adaptive management principles;
- meets current policy and management requirements (Task 1);
- builds on or is consistent with existing monitoring programs where applicable (Task 2);
- uses scientifically accepted methods;
- is flexible so that new variables can be incorporated as our understanding of the ecosystem improves; and is cost and time efficient.