Barmah Forest: a review of its values, management objectives, and knowledge base

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Abstract

The aims of this report are to support the development of the Asset Environmental Watering Plan for Barmah Forest, and assess research needs and management aims. In the report we review the values generated by Barmah Forest and evaluate the objectives of vegetation, waterbird and water management. We also evaluate the classification systems of vegetation relative to its management, and the status of the knowledge on which management of Barmah Forest is now based. We comment on the reporting of the consequences of two earlier Environmental Water Allocations, and we explore the options for getting water to Barmah Forest and allocating it within. We draw conclusions in the report which we summarise below.

Values: Barmah Forest generates values to multiple stakeholders at scales from local to international. Some the values are marketed and can be expressed in dollars, others are not. There is a pressing need to estimate the values of the un-marketed uses, in particular Indigenous cultural and biodiversity conservation values, and the values of recreation and tourism.

Objectives: the objectives under which Barmah Forest is currently managed through the Asset Environmental Management Plan (DSE and GBCMA 2005) confuse means and ends, and focus on particular vegetation communities or faunal groups to the neglect of others. Some contain mixed purposes in the one objective, and some are subsumed within other objectives in the set.

Vegetation management objectives in the Plan under-emphasis the importance of spatial heterogeneity and the need to maintain it. They also need to take account of grazing and fire, and shift the focus away from a few species and towards the maintenance of ecological communities.

Waterbird management objectives in the Plan need to emphasise a wider range of species, the provision of maintenance habitat outside the breeding season, and the spatial and temporal distributions of water. The water regimes specified for birds do not give guidance on where the water should be applied, so it is difficult both to assess the need for changes in the control structures, and to relate waterbird management to the proposed new Water Management Units.

We propose the development of new objectives for Barmah Forest of two kinds – value delivery, and system maintenance. We propose the Goulburn Broken Catchment Management Authority develops these based on the concept of 'Thresholds of Potential Concern' which define the acceptable upper and lower limits within which Barmah Forest should be maintained. Management would then be about keeping the Forest within this envelope of acceptability. The framework encourages adaptive management but maintains long term goals.

The knowledge base: the vegetation and hydrological knowledge base for managing Barmah Forest is small for such an important asset, out of date, its accuracy uncertain, and vegetation classifications not yet appropriate. We propose new research on hydrological-vegetation relationships, the causes of changes in vegetation patterns, and the effects of grazing.

The waterbird knowledge base is also slim, but the authors of the Asset Environmental Management Plan have made insufficient use of the scientific information on waterbird ecology collected outside Barmah-Millewa Forest. Even so there are many gaps in the information, and we propose new research on trade-offs at local and regional scales, the

regional role of Barmah-Millewa in supporting waterbird populations, the status and trends of waterbird species, the status and needs of threatened species, and the effects on waterbirds of flood duration and unseasonal flooding.

The authors of the Asset Environmental Management Plan (DSE and GBCMA 2005) have made very effective use of available vegetation and hydrological information, including expert knowledge, and there has been substantial learning by doing and adaptive management within Barmah Forest. The adaptive management approach taken to waterbird management is likewise endorsed by us, but there is a need to conduct it within a better-defined framework that enables priorities to be redetermined as circumstances change, and to change the focus of particular watering events without losing sight of longer term goals. Given the scarcity and unreliability of scientific information, water management will necessarily continue to be based in the short term upon the 'natural paradigm' and on correlations between patterns of inundation and the distribution and observed responses of species and ecological communities. However, the limitations of these approaches should be acknowledged, investments made in experimental manipulations supported by modelling, and a better-designed adaptive management program pursued.

Past Environmental Water Allocations: in evaluating the 1998 and 2000 Environmental Water Allocations we concluded that because of the small amounts of water involved and the multiple constraints on using it, EWAs are best seen as a series of events that in total drive Barmah Forest towards the long term goals. Each on its own may produce no more than a modest gain towards specific objectives. Clear objectives for the EWA need to be set beforehand, and vary between years according to the attributes of the flood, and because it will be necessary to 'rotate' priorities among the competing objectives. It is important the long term goals are not lost in this process. A systematic monitoring and reporting system is needed for future EWAs.

Allocating Water Within Barmah Forest: there is a need to manage water allocations and surpluses better in time and space within Barmah Forest and evaluate spatio-temporal trade-offs. Quantification of the flows through the control structures, possible reconfiguration of the control structures, and new Water Management Units are needed for this. Prior steps are high precision hydrological modelling and better vegetation mapping. Trade-offs among the water management units can be evaluated using an approach we propose in the report.

Getting Water to Barmah Forest: there is also a need to secure water allocations to Barmah Forest. The frequency, duration and inundation area of winter-spring floods are all insufficient. Options already being addressed are acquiring easements between Hume and Yarrawonga, and back-flows from the Goulburn River. Unseasonal flooding of Barmah Forest from high channel flows is a further problem for water managers. Reducing flow through Barmah Choke, changing the height of Yarrawonga Weir and/or reducing storage levels there are options.

Regulation of the Ovens River is major potential threat. The negative impact of a reservoir within its catchment would exceed the positive contribution of The Living Murray Initiative. On the other hand, the current EWA may be just a first step towards higher allocations. Whether the availability of water for Barmah-Millewa Forest increases, decreases, remains at the current low level or changes in seasonality will depend upon the political pressures on governments, as well as climatic change. Realisation of beneficial ecological responses, and increased benefits from tourism and recreation would strengthen the case for larger EWAs.

Managers' Summary

1. Purpose and scope of this report

In this report we review the values generated by Barmah Forest and evaluate the objectives of vegetation, waterbird and water management, and the status of the knowledge on which management of Barmah Forest is now based. The report includes knowledge from elsewhere that is applicable to Barmah Forest. The chapters analyse management objectives and propose changes. They then capture the main research that has been done, evaluate it, identify knowledge gaps and propose what needs to be done to fill these gaps. The report will be used in the development of the Asset Environmental Watering Plan for Barmah Forest.

Figure 1 reflects the structure of this executive summary, and of the report as a whole. The next section in this summary sets Barmah Forest in its historical and regional context. Section 3 identifies and classifies the values generated by Barmah Forest. Section 4 is a critical analysis of ecological objectives for Barmah Forest. In Section 5 we evaluate the potential for management purposes of the various vegetation classifications. Section 6 analyses the evidence on vegetation responses to water and other factors affecting vegetation management. Section 7 is about the responses of waterbirds to water regimes and flood events, and Section 8 evaluates the use of the Environmental Water Allocations in 1998 and 2000. Section 9 examines water management options, and Section 10 is our conclusions and recommendations.

2. Barmah Forest in its Regional and Historical setting

Before the country was colonised Barmah Forest was part of an extensive floodplain and wetland system that flooded in winter and dried in summer. Following settlement much of the floodplain land was taken for agriculture, and the water was stored and diverted for irrigation. Barmah Forest is now a remnant River Red Gum dominated floodplain covering approximately 29500 ha, located between the townships of Tocumwal and Echuca. It is reserved as State Forest (72% of the area), State Park (26%) and Murray River Reserve (2%).

Barmah Forest has great conservation, heritage and amenity value. Barmah-Millewa Forest is part of the traditional country of the Yorta Yorta people. It is part of the Barmah–Millewa Forest which the Murray Darling Basin Commission (MDBC) has identified as a Significant Ecological Asset. It has a total area of over 66,000 ha, which extends into NSW and is listed as a Wetland of International Importance under the Ramsar Convention. It is also valued by pastoralists and the broader community, and it is a popular recreational destination.

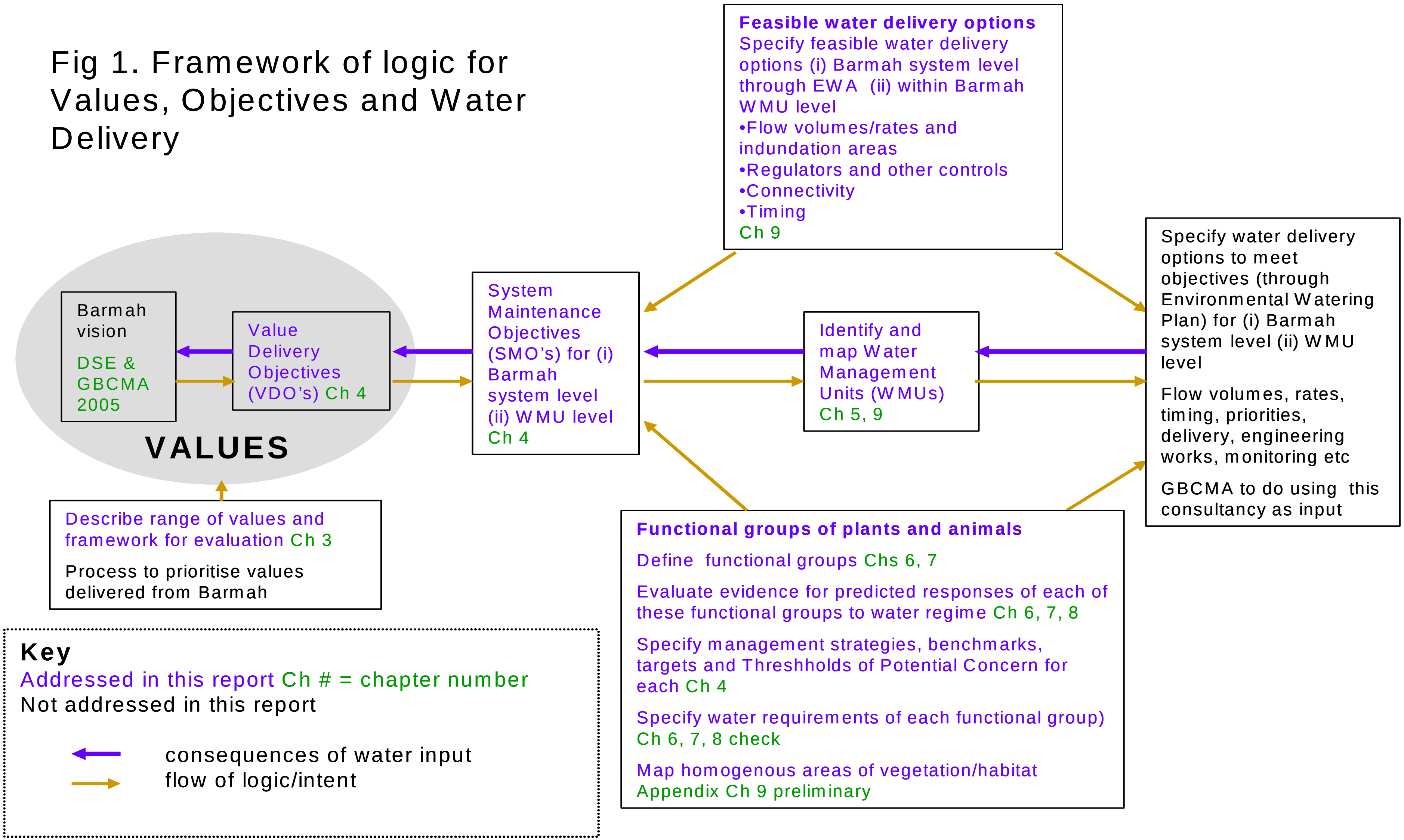

Figure 1: Framework of logic for values, objectives and water delivery

3. Values from Barmah Forest

We have classified the conservation, cultural heritage, amenity and other values of Barmah Forest at scales from local to international in Figure 2 and Table 1. Non-use and the non-market use values of Barmah Forest are poorly understood and there is insufficient information to compare the benefits Barmah Forest realises from its use of Environmental Water Allocations compared with the use of that water for irrigation. Nor can the relative importance of some values that are in conflict within Barmah Forest be compared convincingly. In these circumstances it is difficult but still necessary to maintain and realise what are assumed to be the main values. This is critically dependent on the ability of the managers of Barmah Forest to maintain the area as a functioning floodplain and wetland system using Environmental Water Allocations (EWAs) and other sources of water, the exclusion of unseasonal floods, and the management of a rising water table. Grazing, wildfires and recreational pressures are also management issues.

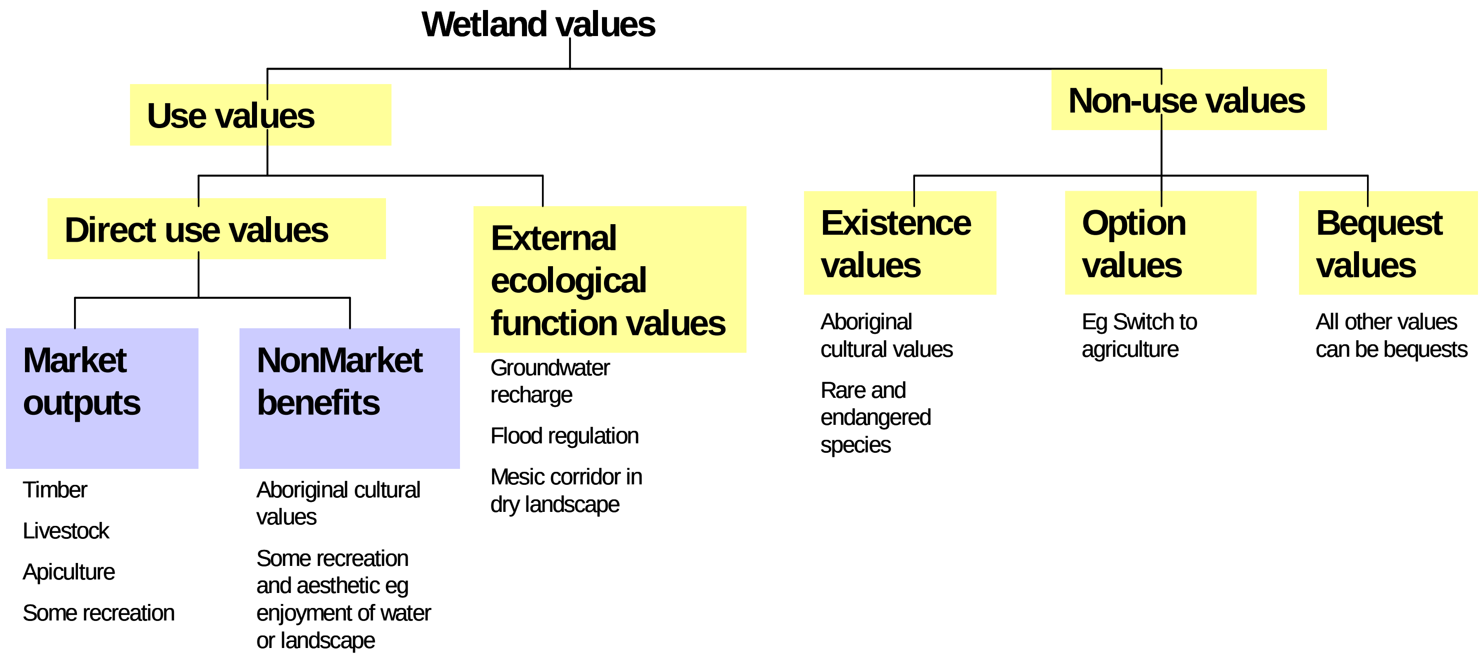

Figure 2: Classification of floodplain and wetland values.

Table 1: Values attributed to Barmah Forest vegetation communities at local, regional, State, Murray Darling Basin, National and international scales:

We recorded values against Chestefield's (1984) vegetation community categories. Empty cells means we judged the activity that generates a particular value was uncommon or absent from that category. 'Vegetation community not distinguished' means the source of the information did not identify the vegetation community in which the activity occurs, or it is thought to occur in all vegetation communities. Scale at which the value is significant: L = Local; R = regional; V = Victoria; M = Murray Darling Basin; N = National; I = International

Vegetation community (adapted from Chesterfield 1984).	Values of Barmah (Victorians' willingness to pay once to keep Barmah Forest as it was in 1991 estimated by contingent valuation survey at between $111 and 141m (2004 values) (Stone 1992).					
	Use values: estimated 8% of values of Barmah Forest (Stone 1992)			Non-use values: estimated 92% of values of Barmah Forest (Stone 1992)		
	Direct use values		External ecological function values	Existence values	Option values	Bequest values
	Marketed outputs	Un-marketed outputs				
River, lakes & billabongs	Boat tours, neighbouring caravan parks and camp sites, boat hire, fishing tours. LR	Recreational fishing and boating, bait collection, picnicking, duck hunting [IN BARMAH?] LR	Organic carbon storage V Groundwater recharge L Flow regulation and flood control LR Mesic corridor through dry landscape providing links between remnants LRV Critical role as part of larger network of wetlands (RAMSAR) LRVMNI Provide a source of propagules, organic carbon and other environmental services to surrounding or downstream area LRV	Native fish LRVMN Waterbirds LRVMNI	Option to manage only for tourism and recreation LR Option to take more water for agriculture elsewhere LR Unknown options	All values are potential bequest values at a scale depending on the particular value
Swamps & marshes		Duck hunting [IN LR BARMAH?]		Vegetation community depleted LRVMNI Waterbirds LRVMNI	Option to manage only for duck hunting LR Option to take more water for agriculture elsewhere LR Unknown options	
Rush beds		Scenic driving, 4WD driving trail bike riding, cycling, horse riding, bush walking, orienteering, picnicking, camping,		Vegetation community depleted LRVMN Waterbirds LRVMNI	Unknown options Option to take more water for agriculture elsewhere LR	

Open grassland plains	Cattle grazing L Beekeeping L	hunting feral animals, bird watching, nature study. LR		Vegetation community depleted LRVMN Waterbirds LRVMNI	Option to manage only for agriculture LR Option to take more water for agriculture elsewhere LR Unknown options	
Red gum forest and woodland (to be split)	Cattle grazing L Timber and firewood LR Beekeeping L			Vegetation community depleted LRVMN	Option to clear and manage for agriculture only LR Option to manage only for forestry LR Unknown options	
Blackbox woodland	Cattle grazing L Beekeeping L			Vegetation community depleted LRVMN	Option to clear and manage for agriculture only LR Option to manage for forestry only LR Unknown options	
Grey & yellow box woodland				Vegetation community depleted LRVMN		
Vegetation community not distinguished		Indigenous cultural values LRVN Post-settlement cultural values LRV		Rare and endangered flora and fauna LRVMN		

4. Objectives for environmental water use

The vision for Barmah stated by DSE and GBCMA (2005) is to:

Restore and maintain a mosaic of healthy wetland communities throughout the floodplain environment representing pre-regulation communities.

Objectives for achieving this vision derive from other plans and strategies (Figure 3).

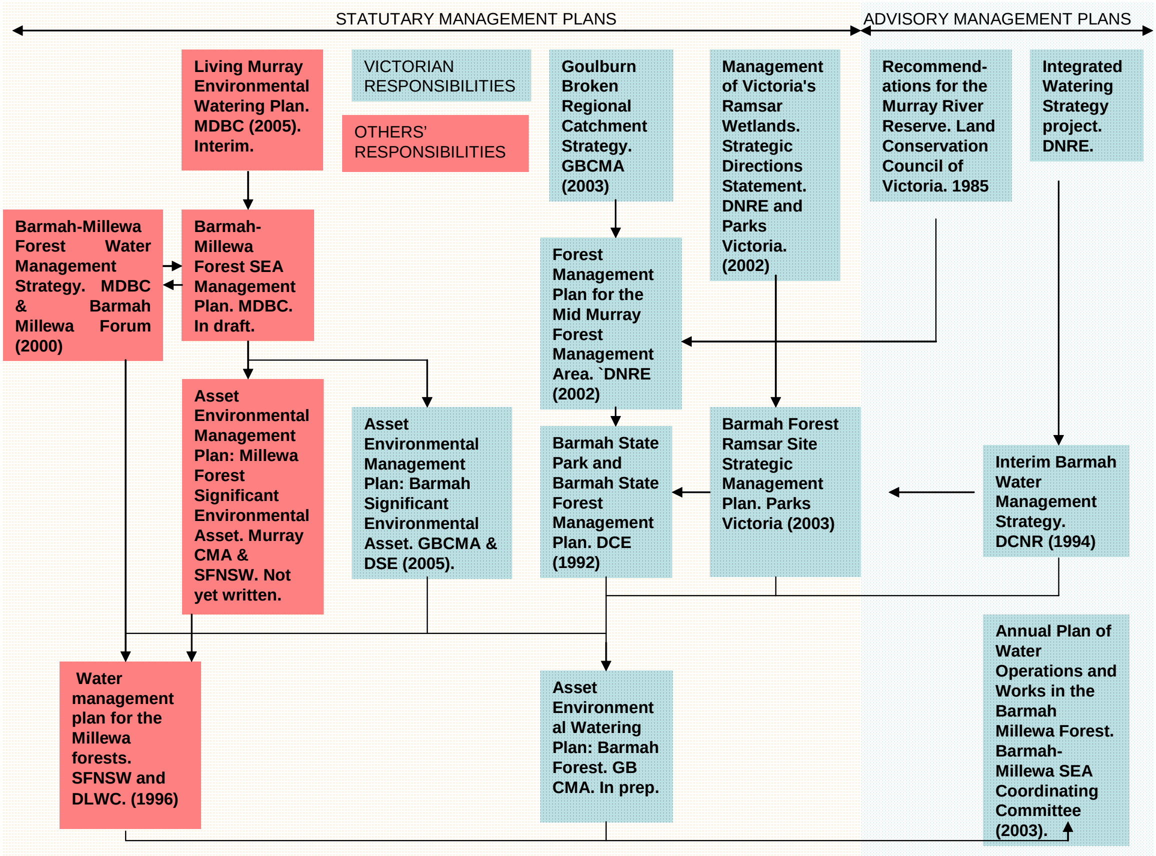

Figure 3. Influences of the management strategies and plans upon each other
(Based on DSE and GBCMA 2005).

The objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005) are repetitive, they confuse means and ends, and they do not link clearly to either the delivery of values or the maintenance of the wetland ecosystem. We propose an approach for developing better objectives based on these principles:

- Clear distinction of System Maintenance Objectives (SMOs) and Value Delivery Objectives (VDOs).
- Each objective should address a single, well defined purpose.
- Objectives need to be ranked and prioritised.
- Particular objectives should be applied either at the whole system (Barmah Forest or Barmah-Millewa Forest) scale OR to Water Management Units (Section 9).
- Objectives should address 'Thresholds of Potential Concern' and be cast in an adaptive management framework.

A large network of agencies and stakeholders has interests in the management of Barmah and neighbouring Millewa Forest, and there are conflicts and synergies among their objectives, including those within the Asset Environmental Management Plan (DSE and GBCMA 2005). Conflicts could be resolved, reduced or managed through: making the relative importance of value delivery objectives explicit; engagement of agencies and stakeholders in participative planning; and zonation in time and space using Water Management Units. All are already employed, but could be done better, in particular through the better definition of Water Management Units (WMUs). In the next section we evaluate current and proposed classifications of vegetation as a foundation for redefinition of WMUs.

5. Classification of Floodplain Vegetation Communities

Six vegetation classification and mapping exercises cover all or parts of Barmah-Millewa Forest. None in their present form provides appropriate Water Management Units, though Frood's detailed mapping is likely to play an important role. It is envisaged that the new improved Ecological Vegetation Class map that is in preparation will be appropriate. The vegetation classification should represent the heterogeneity of the vegetation species composition and structure at a resolution relevant to management. Given that the vegetation patterning and dynamics are strongly influenced by water regime, a functional responses classification that groups species in terms of their water regime requirements holds promise (Section 9).

6. Floodplain Vegetation Responses to Water Regime, Grazing and Fire

6.1 River flows and floodplain inundation

Changes in river flow are due to upstream storages and releases, and local scale manipulation of regulators collectively affect floodplain inundation. Analyses have identified (DSE & GB CMA 2005) reduced frequency, duration and inundation area of winter-spring floods; altered timing of floods; increased frequency of small summer floods; and reduced variability in flood flows.

Their effects on floodplain inundation are different at different river flow levels. Table 2 summarises a spells analysis for 109 years of simulated daily flow (Current and Natural) at Tocumwal[1]. Lower lying areas of Barmah Forest have become wetter because of the increased frequency of small summer floods as the river conveys water to irrigators downstream. Areas of River Red Gum woodlands and the Box communities which are on higher ground have become drier because of the decrease in large winter and spring floods due to the storage of water. To counter the effects of both excessive inundation and dryness on vegetation it is necessary to set vegetation management objectives. We evaluate the current objectives next.

[1] Simulated flow data (ML per day) for Tocumwal was provided by the Murray-Darling Basin Commission, using their flow model BigMod; natural conditions was run on 31/05/2005, Run 6781000 and benchmark 0505 was run on 31/05/05, Run 6785000. GetSpell – program developed by Rory Nathan of Sinclair Knight Merz for the Department of Natural Resources & Environment, Victoria. Version 1.1. February 1999.

Table 2: Summary of effects of regulation: Current v Natural for six flow thresholds.

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%.

	Flow thresholds at Tocumwal, ML/d					
	=>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

6.2 Evaluating the vegetation objectives in management plans

The vegetation-specific objectives from the Barmah-Millewa Forest Significant Ecological Asset report (MDBC 2005, from MDBMC 2003) and the Goulburn Broken CMA's Regional Catchment Strategy (GB CMA 2003) have these limitations

- it is unclear what jurisdictional or management area is meant by "Barmah Forest";
- the diagram used to define areas to be maintained or improved by flooding (Figure 6 in DSE & GBCMA 2005) is not consistent with Bren *et al.* (1988), nor with Figure 4 in DSE & GBCMA (2005);
- words such as 'health' and 'wetland' are undefined ;
- targets are not consistent between plans;
- the scientific foundation of the objectives is weak, and this should be taken into account in setting specified targets.

A process for setting better objectives was discussed in section 4 of this summary, but new objectives would need to take into account the scientific uncertainty on which management is currently based. We turn to this next.

6.3 Plants and Water Regime

A water regime for plants on floodplains is the temporal pattern and specific sequences of timing, depth, duration of inundation, frequency of flooding, rate of change, and duration of dry phase. Prescribing with confidence an appropriate water regime for a wetland plant requires specific knowledge of its response at each stage of its life-cycle to flooding and drying at different temporal scales. Moreover, response needs to be understood in terms of what is optimum, adequate, stressful or even fatal for each species. Ideally, managing the water regime of a wetland with several plant communities requires an understanding of species, of phenology and of competitive interactions under different flooding conditions. This is rarely achieved or achievable. Instead, attention is given to a few dominant (or keystone) species; failing this, the "natural paradigm" is used.

The natural paradigm is the widely-accepted assumption that the natural vegetation pattern of a floodplain is a direct response to its natural flow regime, and that any change towards a more natural flow regime will in the long term result in a more natural vegetation pattern. In fact the potential range of plants can be greatly reduced by other factors. Zonation of plants, for example, may be the visible outcome of inter-specific competition interacting with water regime (Grace and Wetzel 1981). Unfortunately there are no general rules for estimating the discrepancy between observed and potential distributions or for determining its ecological significance, other than by experimentation or modelling. It is likely that this discrepancy is more important for herbaceous plants than for the woody species.

The inclusion of objectives for managing rare and threatened species compounds problems arising from the natural paradigm. It is incorrect to automatically link rarity with river regulation. Species may be rare because of habitat change and threatening processes, but may also be rare *despite* human activities. The inclusion in a monitoring program of rare and threatened species whose habitat preferences are not well understood may not be a good use of resources (Dyer and Roberts 2006).

6.3.1 The scientific basis for water-related objectives

Just six publications of variable quality and relevance are the scientific basis for defining what flows are needed to meet the water requirements of the plant communities in Barmah Forest (Table 3). Just one satisfies criteria of scientific rigour and relevance - Bren *et al.* (1988). The work is at least fifteen years old.

The water regimes identified for Barmah (Table 1 in DSE & GBCMA 2005) are effectively based on just the natural paradigm, and Leitch (1989). His approach shows the range and distribution of inundation duration and length of dry period for rushlands; and monthly pattern of flooding frequency for Moira Grass plains. Unfortunately, the methods for deriving these data are not given. It is uncertain whether relationships for natural water regime refer to all patches of Giant Rush or Moira Grass, or to a subset; and if to a subset, then it is uncertain how typical or where it is. The simulated natural flows used monthly rather than a daily time-step. Finally, omitting ponding time flood duration is under-estimated in low-lying areas (as in other flow-inundation estimates).

Leitch used the flow-inundation area relationship for Barmah Forest developed by Bren and Gibbs (1986) and Bren *et al.* (1987) in which:

- regulators into the Forest were assumed to be open;
- the area modelled may have excluded Barmah State Park or Yielima;
- the flood maps were prepared during a wet phase which affects flood extent;
- flood maps were prepared from observations of flood-level marks on trees and local knowledge;
- permanent waterbodies and Barmah Lake were not included;
- the short duration of floods originating in the Ovens River results in over-estimation of the area flooded (p49, Maunsell McIntyre 1999).

Although its authors say that "Clearly the model can be regarded as only a first approximation" (p138, Bren and Gibbs 1986), this flow-inundation area relationship is now a foundation for water management.

Table 3: State of knowledge

Publication	Source (peer review)	Study Area	Type of Evidence
Sharley & Huggan (1995)	Agency report	Riverina (Chowilla floodplain)	Scientific Investigation: Flow-inundation relationships. Errors acknowledged, no calibration reported.
Ward (1991)	Agency report	Barmah	Scientific Investigation: Experiment: but treatments confounded by overtopping flood.
Roberts & Marston (2000)	Research institution report	Murray-Darling Basin	Not primary data. This is a synthesis of existing information.
Bren *et al.* (1988)	Scientific journal	Barmah	Scientific Investigation: Flow-inundation relationships.
Leitch (1989)	Agency report	Barmah	Scientific Investigation: Flow-inundation relationships. Method not given.
Dexter (1978)	Scientific report	Barmah	Scientific Investigation: Observations and long experience of forest trees.

6.4. The effects of grazing and fire

Hydrology is not the sole driver of floodplain vegetation. The effect on the Forest of between 800-2000 head of cattle (Silvers 1993) has been much debated (eg Orthia 2002), but the case for or against grazing has virtually no hard information.

Information on fire in Barmah Forest is also sparse. The detrimental effects of fire on River Red Gum were described by Eyles (2004) who was convinced that fire was a significant ecological factor, but other than this, the consequences for forest ecology and fauna are largely ignored.

7. Waterbird Responses to Water Regimes

7.1. Evaluating waterbird management objectives

Waterbird ecological objectives as adapted from DSE and GBCMA (2005) are:
<u>General Ecological Objectives</u>

- Enhance breeding and recruitment of waterbirds
- Provide suitable habitat for waterbirds
- Ensure breeding success of colonial waterbirds

<u>Overriding Ecological Objective</u>

- Provide successful recruitment of large colonies of colonial waterbirds

We propose these objectives are modified to emphasise a wider range of species and the provision of maintenance habitat outside the breeding season, as follows:
General Ecological Objectives

- Enhance breeding and recruitment of a wide range of waterbirds
- Provide breeding and maintenance habitat for a wide range of waterbirds
- Ensure breeding success of a wide range of colonial waterbirds

Overriding Ecological Objective

- Ensure successful recruitment at large colonies of a wide range of colonial waterbirds

The water regimes needed to meet the waterbird ecological objectives are (summarised from DSE and GBCMA 2005:19):

1. Annual summer-autumn drying phase (most years).
2. Small floods maintained for four months in spring in 50% of years, and the return time between such events not to exceed five years.
3. Small-medium floods, delivered as at least one month of large flow with flooding maintained for four months, in 40% of years.
4. Medium-large floods, delivered as at least one month of very large flow (but with no requirement for flooding to be maintained for four months), in 30% of years.

The benefits to waterbirds of 1 is supported by the scientific evidence, but there is substantial scientific uncertainty over 2. Time of year is likely to be one determinant of the length of time required to complete breeding, likely being longer in cooler months.

The water regime requirements do not specify where in Barmah Forest the water is required. It is necessary to know this, and to judge whether more control structures are needed, or if relocation is necessary. Along with the capital costs there are ecological disadvantages to an engineering approach (section 8). This consideration should be linked to the determination of new Water Management Units (section 9). There will need to be trade-offs, spatially and temporally, and between species, ecological communities and functions.

It may take many years and a series of Environmental Water Allocations to achieve objectives. While it is critically important to identify and stick to the long term goals, priorities should be reviewed and altered if necessary after each significant flow event. Such a sophisticated prioritisation framework can only be successful if a well designed monitoring program is in place.

7.2. The Scientific Basis for Waterbird Management

Scant literature was cited in the waterbird material within DSE and GBCMA (2005). Leslie & Ward (2002), MFAT (the Murray Flow Assessment Tool), Blanch (1999), and O'Connor & Ward (2003) were the main sources. O'Connor & Ward (2003), not a peer-reviewed scientific paper, is sound management-oriented research that used appropriate survey techniques, and used the results to guide subsequent management. As with the interventions described by Leslie & Ward (2002), these are good examples of adaptive management. Only one primary, peer-reviewed, journal paper was found in a literature search on the response of waterbirds to flooding in the Barmah Forest (Leslie 2001). This was not referred to by DSE and GBCMA (2005). Peer-reviewed papers on waterbird research in the Murray Darling basin by Kingsford and colleagues, and Briggs and colleagues ought to be considered in the management of Barmah Forest.

Kingsford has generalised his understanding of waterbird ecology in MFAT, documented in Young *et al.* (2003). Wetland sites within the Barmah were used for MFAT modelling. If feasible these sites ought to be used for subsequent monitoring, so that the model can be tested and improved. These models need to be made spatially explicit for the management of Barmah-Millewa Forest.

Webster (2004a) studied waterbird ecology in Barmah-Millewa wetlands between 1999 and 2003. Though the design is simple with low replication, this unpublished report contains a valuable body of systematic observations.

Tables 4 and 5. evaluates the literature of direct relevance to wetland management in Barmah Forest.

Table 4: State of knowledge: References cited in AEMP to support waterbird ecological objectives and required hydrological conditions

Publication	Source (peer review)	Study Area	Type of Evidence	Value to Managers
Leslie & Ward (2002)	Journal article **(but difficult to be sure that peer review is required)**	Barmah-Millewa Forest	*Scientific Commentary*: partly based on Leslie (2001) which was a Scientific Investigation of hydrology waterbird breeding relationships. Sound modelling, with calibration used.	*High Value*: adaptive management in action
MFAT (2003)	Agency report	Murray River generally	*Conceptual Models.* Distillation of authoritative ecological understanding of waterbird maintenance and breeding habitat requirements into simple, effective hydrological-waterbird response models.	*Moderate Value*: needs to be developed and made spatially explicit at the asset scale
Blanch (1999)	Conference presentation published on an NGO website	Murray-Darling Basin	*Scientific Commentary*	*Limited Value*
O'Connor & Ward (2003)	Agency report	Barmah Forest	*Observations*. Waterbird breeding response to EWA, with adaptive management to ensure greater breeding success. Sound.	*High Value*: adaptive management in action

Table 5. State of knowledge: References not cited in AEMP that could be used to support waterbird ecological objectives and required hydrological conditions

Publication	Source (peer review)	Study Area	Type of Evidence	Value to Managers
Leslie (2001)	Journal article	Barmah-Millewa Forest	*Scientific Investigation* of hydrology waterbird breeding relationships. Sound modelling, with calibration used.	*High Value*
Kingsford & Johnson (1998); Kingsford & Thomas (2004); Kingsford & Auld (2005)	Journal articles	Murray Darling Basin rivers generally	*Scientific Investigation* of hydrology waterbird breeding relationships. Sound modelling, with some calibration.	*Limited Value*: not relevant to asset-scale management
Briggs (1988)*; Briggs & Maher (1985); Briggs & Thornton (1995, 1999); Briggs *et al.* (1997)	Journal articles peer reviewed (*except unsure about peer review of status of this one)	Murray-Darling Basin, particularly middle Murrumbidgee	*Observations*. Careful observational design with measurement of environmental variables (water level, period and extent of inundation) allows for strong conclusions.	*High Value*: targets wetland managers directly
Crome (1986).	Journal article	Murray-Darling Basin	*Observations*. Careful observational design with measurement of environmental variables (duck food) allows for strong conclusions.	*Moderate Value*: emphasises need to dry out wetlands
Webster (2004a)	Agency report	Barmah	*Observations*. Waterbird breeding response to annual variations in flow magnitude.	*Moderate Value*

Two reports by Leslie (1988, 1998) cited in DSE (2003: *Barmah Forest Ramsar Site: Strategic Management Plan*, the SMP) could not be traced.

8. Evaluation of the 1998 and 2000 Environmental Water Allocations

Here we evaluate the effects of the Environmental Water Allocations (EWAs) of 1998 and 2000 on the vegetation of Barmah Forest, and on waterbirds of Barmah-Millewa Forest, a compromise made necessary by the information available. This was sourced from Maunsell McIntyre (1999, 2001) with additional information provided by Keith Ward in personal communications.

The major objectives considered in this evaluation are (from Table 4.1, Chapter 4 in this report):

- Restore and maintain a mosaic of vegetation communities representing the relative areas and attributes of pre-regulation communities in Barmah Forest.
- Maintain or enhance important functional groups of fauna [waterbirds in this context].
- Maintain or enhance specified vegetation communities within each Water Management Unit, in terms of composition, diversity, structure and area.
- Maintain or enhance populations of selected rare or endangered species of flora and fauna.

To counter the effects of river regulation it is necessary to increase the flooding frequency for plant communities on the floodplain lying higher than areas reached by 25,000 ML day at Tocumwal, and supply water for ecosystem processes dependent on autumn-early winter floods. The EWA is constrained in what it can achieve because:

- The volume available is relatively small and cannot be supplied with sufficient frequency
- It often cannot be used effectively in winter because upstream storage in winter keeps channel flows too low
- Maximum flow is constrained by the channel capacity between Hume and Yarrawonga to 25,000 ML day.

The interim rules (Appendix C, MDBC 2005) governing the release of the EWA can address the effects of river regulation on duration and frequency, but not for all parts of the Forest; they do not address timing. The emphasis on duration and on guaranteeing a summer flood appears to be based on modelling. Neither the outcomes of this modelling nor the criteria used to evaluate it were available.

Assessments of the ecological benefits of EWA by Maunsell McIntyre (1999, 2001), appear to have been based on incidental observations of vegetation during both EWA events, and birds in 1998; but used more systematic observations of waterbird colonies in the 2000/01 EWA. The 1998 and 2000 EWAs and the lessons learnt from them, (DSE and GBCMA 2005), are a cogent example of adaptive management through which knowledge was gained, but because of the lack of a formal sampling strategy it has not been possible to determine with clarity the effects of flooding. Our main findings are that:

1. Ecological objectives were not clearly specified therefore the success of the EWAs could not be clearly evaluated.
2. The volume released in the 1998 EWA (100 GL) was insufficient, as acknowledged by the Forest managers.
3. Systematic monitoring was not used adopted.
4. Anecdotal observations of ecological responses to flooding were not compiled and documented.
5. trade-offs were not explicitly recognised.
6. Constraints to the delivery of EWAs were not examined sufficiently.
7. The impacts of the EWAs on Rare and Threatened plants and animals, and on pests and weeds, were not paid sufficient attention.

Many of these shortcomings have since been or are being addressed (DSE AND GBCMA 2005).

The most obvious dilemma in using an EWA is whether to deliver a 'larger' flood of limited duration that inundates a greater proportion of the floodplain or to extend the duration of a natural flood (current practice). There are spatial, trophic, biotic, and functional (system maintenance) trade-offs to be made. An ill-judged choice in favour of the former option may result in blackwater events, water losses, or inundation that is too brief.

In the Ecological Objectives in the AEMP (Table 2 in DSE & GBCMA 2005), there is a heavy emphasis on using EWAs for red gum management, while past and current use of EWAs has focused on promoting/extending colonial waterbird breeding. It is important that other species and trophic groups become the primary targets in some future EWAs. Not all ecological benefits can be realised within each flood event, and so it will be necessary to vary goals through time and successive EWAs, bearing in mind synergies and trade-offs between objectives.

9. Water Management Options

9.1. Managing Water Within Barmah Forest

9.1.1 Improving the precision of water management

River flows to Barmah-Millewa Forest is in some times and places scarce, at other times and places excessive (section 6). The availability of high precision topographic models, remote sensing, hydrodynamic and flood inundation modelling can now replace outdated and low precision flow-inundation relationships on which management has been over-reliant. In particular they could be used to define Water Management Units (WMUs).

While Barmah-Millewa Forest must be managed as a whole system as far as possible, the need to make trade-offs within Barmah Forest, together with the need to allocate scarce water effectively requires that the area is divided into units that can be managed autonomously to some extent. Maunsell (1992) developed 11 water management areas for this purpose. Ward *et al.*, 1994 modified these and identified specific management objectives for each.

Achievement of objectives and management of conflicts among them requires a better alignment between vegetation communities and Water Management Areas than is now possible, and more precise allocation of water to vegetation communities in time and space. We therefore recommend redefinition of the Water Management Areas, and distinguishing them by renaming them Water Management Units (WMU).

Vegetation mapping needs to be precise enough for defining the WMUs. We identified three potential approaches – a functional response classification relying on Frood and Ward's (2000) high resolution map; using Moira Grass (*Pseudoraphis spinescens*) and River Red Gum (*Eucalyptus camaldulensis*) as indicator species; and matching Frood's and Ward's map to the Ecological Vegetation Class (EVC) classification. These should be explored more thoroughly using flow inundation and hydrodynamic modelling when the EVC mapping is ready.

Sections 6,7 and 8 of this summary have discussed the improvement of the spatial and temporal precision of water allocations by using control structures. The current structures have only recently been rated so their influence under various flow regimes can now be estimated accurately. Water Technology's MIKE FLOOD hydrodynamic model is now available for making these estimates, so enabling more refined use of the control structures, and their reconfiguration to complement the proposed Water Management Units if necessary.

9.1.2 Trade-offs in the allocation of water

Widespread inundation versus precise spatio-temporal allocation is only one of many trade-offs managers consider. Chapter 8 identifies spatial, trophic, biotic and functional (system maintenance) trade-offs. Temporal trade-offs can be made within each of these categories.

Clearly not all system maintenance and value delivery objectives can be met with every flood, and at times it may be necessary to sacrifice some areas by inundating them in summer in order to conserve other areas (section 8). We propose the units of spatial trade-off within Barmah Forest will be Water Management Units.

MDBC (2005) describes a process for making spatio-temporal trade-offs among Water Management Areas based on river flow-inundation thresholds. This approach has limited benefit for assessing management options where outcomes are not dependant on the same flooding thresholds. A preferred approach would be to determine an annual flood score on each objective that relates to each Water Management Unit and then rank the operating regime on the basis of achieving high scores for all objectives in a particular WMU.

In section 8 we recommend that watering or flood-avoidance priorities should shift over time. If allocation priorities are rotated rather than fixed a higher proportion of system maintenance and value delivery objectives can be met.

9.1.3 Getting water to higher elevations

DSE and GBCMA (2005) report that drought stressed Red Gum which occupies most of the higher elevations can usually only be watered from large natural flood events, which have become rarer (section 6). Management of rain-rejection events depends upon their volume and timing, but it tends to be prioritised towards higher drought-stressed Red Gum areas away from wetland basins. These high areas will need to be inundated periodically to sustain the Red Gum communities, and should be designated as separate WMUs.

9.1.4 Groundwater

Little is known about the interaction of groundwater and vegetation in Barmah Forest. Red Gum and Black Box woodland communities do utilise groundwater aquifers (Bacon *et al.,* 1993; Roberts, 2001). However, groundwater levels are rising and salinisation may follow. Black Box tolerates salt (Roberts 2001), but many other species do not. It may be necessary to lower the water table in some areas. Pumping is an option, subject to costs and disposal sites.

9.1.5 Water Quality

Decreased velocity can lead to blackwater and anabaena events. The period between wetland flooding events has increased compared with pre-regulation conditions. Flooding flushes organic matter, so the potential for deleterious events has increased. This has been exacerbated by the increase in Eucalypt density (DSE and GBCMA, May 2005). There is a trade-off between the use of control structures to increase the precision of allocations, which tends to increase the risks, and the use of unrestricted flows to flush the system.

9.1.6 Erosion rate

Riverbank slumping and flow path erosion result from increased duration of summer flows. Wash from boats, burrowing activities of carp and unrestricted stock access also contribute (DSE and GBCMA, May 2005). The increased sediment load reduces water quality and modifies micro-topography. Erosion can in some circumstances be reduced by modifying flows.

9.2. Availability of water and threats to supply

So far we have focussed mainly on the allocation of water within Barmah and Millewa Forests. We turn now to the availability of water from the river.

The volumes and timing of water received depend on releases from Lake Hume, Lake Mulwalla and inflow from the Ovens River. Allocations to Barmah-Millewa Forest comprise Environmental Water Allocations supplemented by contributions from NSW and Victoria. The EWA is not always available. In dry conditions both States are likely to re-borrow it. Repayment would occur in subsequent wetter years. Section 8 analyses other limitations of the EWA: the small volume, the infrequency with which it can be applied, and seasonal and channel capacity constraints on its use.

Regulation of the Ovens River is major potential threat. The river is extremely important in providing seasonal flows to the Barmah wetlands. The negative impact of a reservoir within its catchment would exceed the positive contribution of The Living Murray Initiative (DSE and GBCMA, May 2005).

9.2.1 Options for getting water to Barmah Forest and managing and adapting to adverse river flows

Unseasonal Summer-Autumn Flooding

Unseasonal flooding is primarily caused by rain rejection events in the latter half of the irrigation season or by high flows from summer storms. Thoms *et al.* (2000) recommended that during the period December to end of the irrigation season, Barmah Choke should be run below channel capacity (i.e. < 10,600 ML/day at Tocumwal) to prevent this. Chong (2003) found that the frequency of unseasonal flooding of the Barmah-Millewa Forest could be reduced substantially by raising Yarrawonga Weir and not filling the storage, or limiting the maximum flow at Tocumwal. A significant decrease would be achieved just lowering storage level without raising the Weir. There has also been an investigation of options for reduction of rain rejections by DIPNR Deniliquin (Ward pers. com., 2005) to mitigate the rain rejection flows that currently pass through Lake Mulwala. Lake Mulwala rain rejection management has been identified for funding under the Environmental Water Management Plan.

Insufficient Winter-Spring Flooding

Forest flooding during June to December is usually the result of rainfall in the Ovens and Kiewa catchments, whose flows enter the Murray below Hume Dam. The size and timing of the flow influences the triggering of an Environmental Water Allocation (EWA) (Barmah-Millewa Forum Website, 2005)., but lack of easements in the Hume to Yarrawonga reach reduces the ability to deliver the EWA. Options for acquiring easements are being investigated. Other options that have been explored include improved flooding of the lower Goulburn land and the decommissioning of Lake Mokoan. Thoms *et al.* (2000) recommended a review should be undertaken of the River Murray in this river zone (Zone 3 – Tocumwal to Torrumbarry Weir) to identify opportunities.

The lack of variability of flows

Barmah Forest would benefit from the re-introduction of some variability in the flow pattern to reduce the risk of erosion and to introduce some wetting and drying of in-stream habitats. Thoms *et al.* (2000) recommended this providing it does not increase the risk of summer flooding of wetlands. It would require fluctuating the flows through Tocumwal and regulating the control structures in Barmah at low flows to create gradual rises and falls in the river and creeks.

10. Conclusions and Recommendations

10.1 Values

We advocate the framework in Figure 2 to classify values as it is useful for categorising the values of Barmah Forest in a way which can be directly linked to the objectives for management. It is also useful when choosing between alternative management strategies, as the options can be compared in terms of the net changes in values. Such comparisons require the systematic identification of the particular values affected, and an explicit means to guard against double-counting or omission of significant values which this framework offers.

Key issues relating to the values of Barmah Forest include:

1. Barmah Forest generates multiple values at several scales. We propose that a social process be used to rank the values and reduce the conflicts between them. Management measures for addressing conflicts among objectives are discussed below.
2. There is a pressing need for research on the use and non-use values which are not reflected in the market, about which we have little understanding or information. These include Indigenous cultural values, biodiversity conservation values and tourism and recreation (which do have some flow-on market values to the local region). The CSIRO Flagship Water for a Healthy Country project 'Water Benefits in the River Murray Region' is estimating some of these values in Barmah Forest and the Coorong.

10.2. Objectives for Environmental Water Use

The current set of ecological objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005) confuse means and ends, and focus on particular vegetation communities or faunal groups to the neglect of others. Some contain mixed purposes in the one objective, and some are subsumed within other objectives in the set. We propose the development of new objectives following the framework in Figure 1, and applying these principles:

- a clear chain of reason linking realisation of vision and values to inputs of water
- Distinction of System Maintenance Objectives (SMOs) and Value Delivery Objectives (VDOs). Each objective should address a single, well defined purpose.
- The relative importance of values which the system should deliver needs to be made explicit. A social process is needed for this
- SMOs are based on the concept of maintaining structure, function and composition of geomorphic, flora and fauna elements within specified limits based on 'Thresholds of Potential Concern'
- Water and other management strategies are specified for each objective in terms of Thresholds of Potential Concern;
- Particular objectives would be applied either at the whole system (Barmah Forest) scale, or the Water Management Unit (WMU) scale, or the same objective may be applied to a sub-set of WMUs.

10.3 Classification of floodplain vegetation communities

In their present form, none of the classifications are appropriate bases for the proposed new Water Management Units. A classification that groups plant species in terms of their water requirements is advocated.

10.4 Floodplain Vegetation Responses to Water Regime, Grazing and Fire

10.4.1 Objectives for Vegetation Management

In considering the vegetation management objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005), we propose that future management plans need to:

- address the importance of spatial heterogeneity in ecological processes within Barmah Forest and the need to maintain it;
- take account of the roles of other factors such as grazing and fire in determining species composition and dominance;
- shift the focus away from a few species and towards the maintenance of ecological communities.

10.4.2 Improving the Vegetation Management and Hydrological Knowledge Base

The Asset Environmental Management Plan authors (DSE and GBCMA 2005) have made very effective use of available information, including expert knowledge. However the knowledge base for managing Barmah Forest is small for such an important asset, out of date, and its accuracy uncertain. Research needs include:

- a detailed hydrological analysis to characterise, natural, historical, current and future flow regimes in the River Murray as it affects inundation of the Barmah floodplain
- linking the above to a new high precision flow-inundation model to then identify areas of change, and the extent of change;
- a set of studies to understand what, if any, is the difference in the effects on ecosystem processes of cooler season and warmer season, and whether there is a suite of species disadvantaged if cooler season floods occur only very infrequently;
- an understanding of the past and current roles of effluent creeks within the Barmah floodplain in maintaining floodplain functions;
- an ecological history of Barmah Forest to help understanding of the causes of vegetation changes, and to assist in site selection for monitoring or research;
- revisitation of the Red Gum encroachment analysis. It used a 15-year time step, finishing in 1985. Now is the time to test the trends predicted by the model 1985-2000;
- analysis of existing descriptions of understorey vegetation (Frood unpublished, MPPL 1990) to describe spatial patterns and identify functional groups (currently being undertaken by CSIRO's Ecological Outcomes project);
- ecological Studies of Moira Grass (*Pseudoraphis spinescens*) and Giant Rush (*Juncus ingens*) should be initiated;
- conduct opportunistic searches for rare and threatened species covering a range of seasons, conditions, and flood phases;

- conduct research on the spatial and temporal impact of cattle grazing in Barmah Forest, their roles in fire suppression and in the spread of Giant Rush (*Juncus ingens*);

10.5 Waterbird Responses to Water Regimes

10.5.1 Objectives and Water Regimes

The waterbird management objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005) need modification to emphasise a wider range of species and the provision of maintenance habitat outside the breeding season.

The water regimes specified for birds do not give guidance on where the water should be applied, so it is difficult to assess the need for changes in the control structures, and to relate waterbird management to the proposed new Water Management Units.

The adaptive management approach taken to waterbird management is endorsed by us, but there is a need to conduct it within a better-defined framework that enables priorities to be redetermined as circumstances change, and to change the focus of particular watering events without losing sight of longer term goals.

10.5.2 Improving The Waterbird Management Knowledge Base

Research priorities are to:

- explore trade-offs, at the scale of Barmah Forest and Barmah-Millewa Forest, among species, functional groups, and vegetation communities, between the maintenance of ecological processes and the maintenance of species, and between immediate and longer term objectives;
- evaluate trade-offs between the various Assets of the Murray River;
- review the status and trends of all waterbird species both within the Barmah Millewa Forest and in the Murray basin
- conduct research on non-colonial species listed as 'Threatened', the Australasian Bittern (*Botaurus poiciloptilus*) is a high priority;
- understand the relative importance to colonially nesting waterbirds of Barmah Forest at local, regional, and broader scales to enable better prioritisation of EWAs;
- study the effects on waterbirds of long-duration and unseasonal flooding on lower-lying areas of Barmah Forest with a view to returning some to a pre-regulation flow regime
- explore the need and potential for providing permanent maintenance and drought refuge habitat for waterbirds within Barmah Forest;
- examine the duration, extent and season of flooding during previous colonial breeding events in Barmah Millewa Forest and relate these to what is known of the breeding event;
- understand the duration of flooding needed for colonial waterbirds to complete their breeding.

10.6 Evaluation of the 1998 and 2000 Environmental Water Allocations

EWAs are best seen as a series of events that in total drive Barmah Forest towards the long term goals. Each on its own may produce no more than a modest gain towards specific value delivery or system maintenance objectives.

Objectives for the EWA need to be set beforehand, once the timing and volume of the event can be estimated. Objectives should vary between years according to the attributes of the flood, and because it will be necessary to 'rotate' priorities among the competing value delivery and system maintenance objectives. Objectives for the EWA may change during the event too if conditions alter, but throughout this adaptive process it is important the long term goals are not lost.

A more systematic and flexible monitoring system is needed, possibly drawing on volunteer skills, and including capacity to record information other than the standard icons of colonial water birds and Moira grass program. The compiling and documenting of anecdotal information needs to be made more thorough, and the reporting reflect the more systematic monitoring system we advocate. Future waterbird monitoring documentation should include an annotated list of all waterbird species detailing distribution and abundance, habitat preferences, and nesting attempts/results/habitat. This information should be compiled retrospectively for the 2000 EWA.

The potential and actual contribution to the status and trends of rare and endangered biota needs to be evaluated.

10.7 Water management options

10.7.1 Allocating Water Within Barmah Forest

1. Water management should be set within the framework used in this report, described in section 1.
2. Water management will necessarily be based in the short term upon the 'natural paradigm' and on correlations between patterns of inundation and the distribution and observed responses of species and ecological communities. However, the limitations of these approaches should be acknowledged in management recommendations, investments made in experimental manipulations supported by modelling, and a stronger adaptive management program pursued.
3. This report advocates a rethinking of ecological objectives. Options for delivering water to and managing it within Barmah Forest will need to be developed to support those new ecological objectives. Meanwhile research should proceed on known problems of getting water to and distributing it within Barmah Forest (4-15 below).
4. *Better modelling and mapping of river flow and floodplain inundation* - despite the limitations of using correlations between flow regimes and plant distribution there is still much to be learned through this approach if information is collected at high resolution on temporal pattern and specific sequences of timing, depth, duration of inundation, frequency of flooding, rate of change, and duration of dry phase. MIKE FLOOD and RIM-FIM are now available for this.
5. *Improved definition of water management units* – better spatio-temporal modelling of flow-inundation relationships will provide the basis for redefining water management units using MIKE FLOOD and RIM-FIM.

6. *The potential for improving management through changes to control structures* - the effectiveness of the structures, and the potential for removing or adding structures should be evaluated using MIKE FLOOD
7. *Trade-offs* - we also propose that MIKE FLOOD should also be used to explore trade-offs in time and space among the WMUs. We suggested a new approach for evaluating these trade-offs.
8. *The need for groundwater management* – pumping may be necessary to lower the water table in some higher value conservation areas where the species at risk from salt and high water table are considered more valuable than those dependent on access to the water table.
9. *Getting water to areas of higher elevation in the floodplain* - identifying the Red Gum communities that are under stress due to lack of water availability from their high elevation will define one of the water management units. This WMU can then be targeted to achieve flow thresholds required by the Red Gums in this area.
10. *Managing water quality* - it is recommended that the blackwater risk model is used to assess the risk in the Barmah-Millewa forest and ensure that flushing flows occur to remove detritus and stagnant water.
11. *Managing erosion* – it is desirable to increase the variability of low flows to reduce the risk of bank erosion and introduce some wetting and drying of in-stream habitats, subject to the impacts of this on other parts of the system.

10.7.2 Getting water to Barmah-Millewa Forest and Managing Unseasonal Flows

1. *Unseasonal Summer-Autumn Flooding* – new options to remedy this include: lowering the water level at Yarrawonga; increasing the weir level at Yarrawonga but not raising the water level; reducing the flow through Barmah Choke through the irrigation season; sending water to sacrificial areas; building a bypass channel; en-route storages.
2. *Insufficient Winter-Spring Flooding* - the easements needed between Hume Dam and Yarrawonga are already being planned. MIKE FLOOD can be used to explore the usefulness of engineering works in the Yarrawonga to Tocumwal reach, and of using backflows from the Goulburn River to flood Barmah-Millewa Forest.
3. *Lack of variability of flows* - options could include manipulating the weir height at Tocumwal or manipulation of the control structures in Barmah and Millewa forests.
4. *Impact of damming the Ovens River on reduced flows* – the impact on river flow at Tocumwal can be estimated, then MIKE FLOOD or RiM-FIM can model the consequences for inundation of Barmah Forest.

10.8 Water and the Future of Barmah Forest

Current levels of water supply are unlikely to remain unchanged. Regulation of the Ovens River is major potential threat. The negative impact of a reservoir within its catchment would exceed the positive contribution of The Living Murray Initiative. On the other hand, the current EWA may be just a just a first step towards higher allocations. Whether the availability of water for Barmah-Millewa Forest increases, decreases, remains at the current low level or changes in seasonality will depend upon the political pressures on governments, as well as climatic change. Effective use of the current allocation, realisation of beneficial ecological responses, and increased benefits from tourism and recreation would strengthen the case for larger EWAs

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1. Purpose and Scope of this Report

The immediate purpose of this report is to support the development of the Asset Environmental Watering Plan for Barmah Forest. In the report we review the values generated by Barmah Forest and evaluate the objectives of vegetation, waterbird and water management. We also evaluate the classification systems of vegetation relative to its management, and the status of the knowledge on which management of Barmah Forest is now based. We comment on the reporting of the consequences of two earlier Environmental Water Allocations, and we explore the options for getting water to Barmah Forest and allocating it within.

The original purpose of this report was to provide independent expert advice to the Goulburn Broken Catchment Management Authority (GBCMA) on the efficacy of different water management approaches to sustain the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions and values. It became apparent, however, that the high resolution temporal and spatial scale information on flow regimes within Barmah Forest were not available and could not be generated in time to include in this report. With the agreement of the Goulburn Broken CMA (GBCMA) the purpose of this report was therefore changed so as to provide a benchmark that summarises the key literature and places it in context for Barmah Forest managers and researchers. Meanwhile a supplementary research initiative is being developed by the GBCMA, Water Technologies and CSIRO to provide some of the high spatial resolution information on flood extent needed to support the Asset Environmental Watering Plan for Barmah Forest.

Figure 1.1 summarises our understanding of the flow of logic required to produce the Asset Environmental Watering Plan, and also reflects the structure of this report. The figure links the vision and values for Barmah Forest (provided in the Asset Environmental Management Plan, DSE and GBCMA 2005) to objectives that support the vision and values, and to 'Water Management Units'. Water for these units is supplied in accordance with the forthcoming Asset Environmental Watering Plan for Barmah Forest. Many of the steps in Figure 1.1 are covered in this report (shown in purple). Some are only partially covered because of the scope of the consultancy or because the work is being done by other agencies.

In figure 1.1 and in later chapters we distinguish between 'Value Delivery Objectives' and 'System Maintenance Objectives'. The values that Barmah actually or potentially delivers to society (Chapter 3) should logically influence the vision for Barmah, and therefore its 'Value Delivery Objectives'. These are the objectives that, if achieved, will realise the values and the vision. This in turn determines what the ecosystem should be managed for – i.e. which 'System Maintenance Objectives' are important over the long term. An ecosystem can be managed in many different ways, with different functions maintained depending on the values to be delivered from it. The Value Delivery and System Maintenance Objectives are discussed in Chapter 4.

We view the objectives at two levels – those which are applicable at the scale of the Barmah system as a whole, and those which are applicable at the scale of the Water Management Unit (WMU). The WMUs are needed so that water can be targeted towards specific objectives at particular locations and times. The logic underlying the development of the Water Management Units is shown in Figure 1.1 and discussed in Chapter 9. We did not define Water Management Units as part of this report, but we did explore ways of doing so in Chapter 9.

Two additional steps must be made before the information needs of the Water Management Plan for Barmah Forest can be met satisfactorily:

1. Description of functional groups of flora and fauna

- defining the functional groups is discussed in Chapters 6,7 and 9 in relation to vegetation and waterbirds, and the limitations of the functional group approach is expressed in Chapter 7;
- evaluating the evidence for responses of vegetation and waterbirds to water regimes and flood events is in Chapters 6, 7 and 8
- specifying objectives and management strategies and "thresholds of potential concern" (Biggs and Rogers, 2003) for each functional group is outside the consultancy terms of reference but the logic is given and illustrated in Chapter 4;
- mapping homogenous vegetation units that take account of functional vegetation responses – this is being done by the Department of Sustainability and Environment.

2. Identification of feasible water delivery options

- defined for water delivered (i) to the Barmah system as a whole and (ii) to each WMU
- expressed in terms of seasonality, flow volumes and rates, areas inundated, depth and duration, and configuration of regulators (Chapter 9)

These steps will inform not only the delineation of the Water Management Units, but also the specification of water delivery strategies to meet the objectives. This will be undertaken in the Asset Environmental Watering Plan for Barmah Forest to be developed by the GBCMA.

An additional step is to specify the criteria for achievement of objectives. The Thresholds of Potential Concern are intended to provide these criteria. Again, developing the criteria is outside the scope of this consultancy.

In summary, then, this report brings together and evaluates the knowledge base for managing Barmah Forest, and proposes a framework that, if the content were developed, would enable management activities and environmental water allocations to be used more effectively in realising values and vision in the long term.

We are aware of the importance of the institutional environment of in which Barmah Forest is managed. Management occurs within a framework of Local, State and Federal legislation, and the organisations that implement it. This report does not address these frameworks. Though we hypothesise that significant gains could be made through some institutional changes, we do not analyse them nor explore opportunities for change, this also being outside the scope of our consultancy.

The next chapter in this report describes Barmah Forest in its regional and historical setting. Following that we identify and classify the values generated by Barmah Forest. This is followed by a critical analysis of ecological objectives for Barmah Forest, after which we evaluate the potential for management purposes of the various vegetation classifications. Chapter 6 then analyses the evidence on vegetation responses to water and other factors affecting vegetation management. Chapter 7 is about the responses of water birds to water regimes and events, and Chapter 8 evaluates the use of the Environmental Water Allocations in 1998 and 2000. Chapter 9 examines water management options, and Chapter 10 brings together the conclusions and the knowledge gaps identified in the chapters.

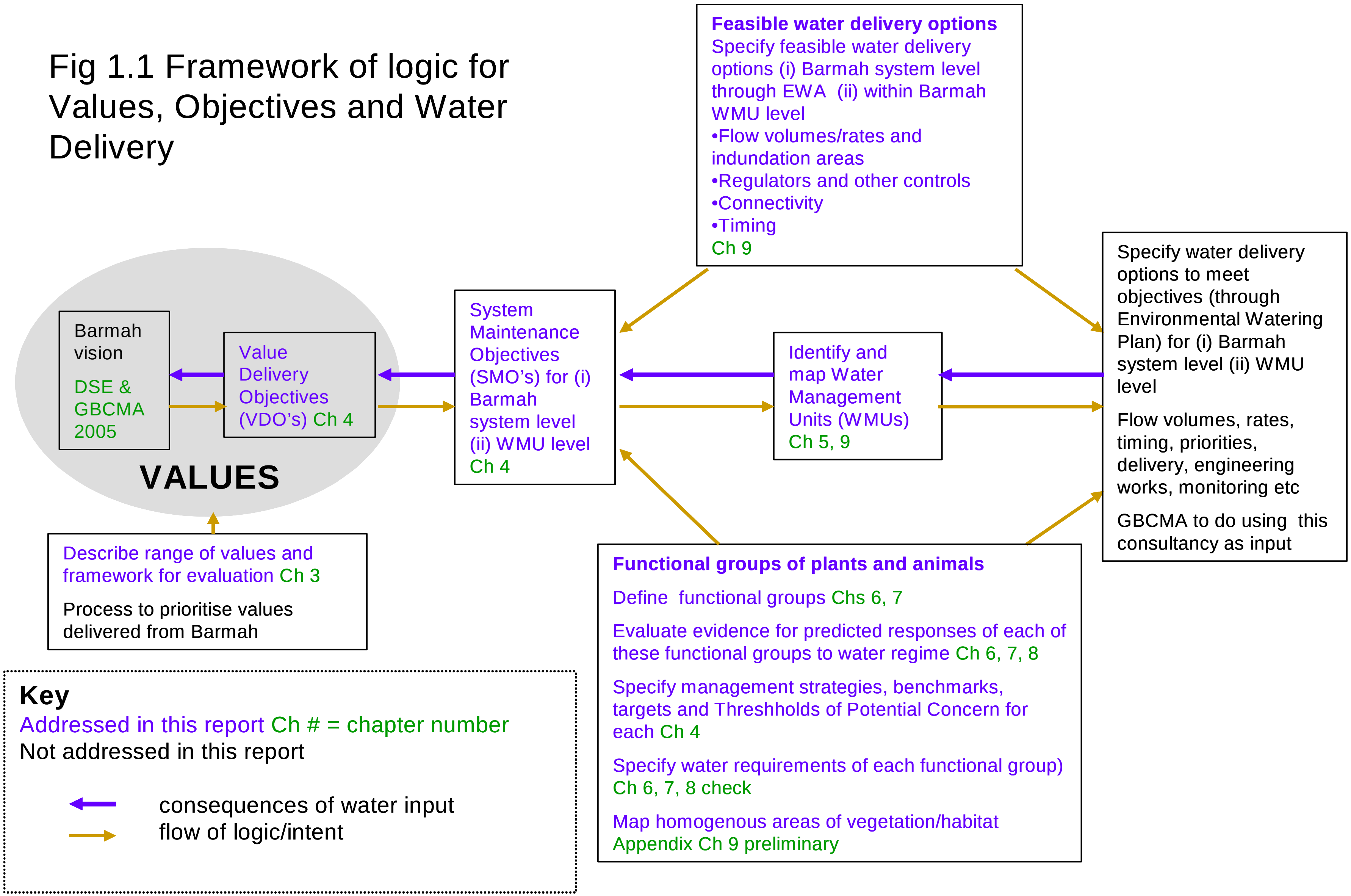

Figure 1.1: Framework of logic for values, objectives and water delivery

Table 1.1: Terms of Reference for Consultancy as Modified by September 2005 Meeting

Task 1	i.	Identify ecological objectives for environmental water use in Barmah Wetland in line with the State Government's vision for Barmah Wetland and with the key environmental management plans or directives for the site.
	ii.	Broadly define the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions.
	iii.	Rank the importance of these vegetation communities and their ecological, social, cultural and economic functions at local, regional, state and national scales.
Outputs	i.	Documented ecological objectives for environmental water use in Barmah Wetland.
	ii.	Documented definitions of the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions.
	iii.	A matrix indicating the local, regional, state and national importance of the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions.
Task 2	i.	Within the context of current water resource constraints, conduct a wide search of available literature to determine the flow and/or water regimes required to sustain the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions.
	ii.	Assess and document the scientific rigour of the literature reviewed.
Outputs	i.	Documented flow and/or water regimes required to sustain the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions.
	ii.	Database of relevant literature indicating its level of scientific rigour and level of relevance in water management planning.
Task 3	i.	Flag the issues, questions and information needs for appraising the water delivery options to: - provide flow and/or water regimes required to sustain the floodplain vegetation communities supported by Barmah Wetland and their ecological, social, cultural and economic functions; and - meet the ecological objectives for environmental water use in Barmah Wetland identified in Task 1.
	ii.	Evaluate the current Water Management Units and demonstrate how new ones could be derived.
Outputs	i.	Documented discussion of the issues, questions and information needs for appraising the water delivery options
	ii.	Documented evaluation of the current Water Management Units and demonstration of how better ones could be derived.
Task 4	i.	Evaluate the results of the Barmah Wetland environmental water allocation (EWA) releases in 1998 and 2000 in relation to: - the flow and/or water regimes identified in Task 2 required to sustain the floodplain vegetation communities supported by Barmah Wetland and their ecological, socia, cultural and economic functions; and - the efficacy of different water delivery options considered in Task 3.
Outputs	i.	Documented evaluation of the results of the Barmah Wetland EWA releases in 1998 and 2000, including recommendations for future use and planning.
Task 5	i.	Identify recommendations for further research where tasks have insufficient information.
Outputs	i.	Documented recommendations for further research where tasks have insufficient information.

2. Barmah Forest in its Regional and Historical Setting

Judith Harvey

2.1 Location

Before Victoria was colonised Barmah Forest was part of an extensive floodplain and wetland system that flooded in winter, dried in summer, and was manipulated by the fires of the Yorta Yorta people. Following settlement regular burning ceased, much of the floodplain land was taken for agriculture, and water was stored and diverted for irrigation.

Barmah Forest is now a remnant River Red Gum dominated floodplain covering approximately 29500 ha, located between the Victorian townships of Tocumwal and Echuca (Figure 2.1.). It is reserved as State Forest (73% of the area), State Park (26%) and Murray River Reserve (2%). The Significant Ecological Asset Plan has the total area stated as 28 500 ha (GBCMA & DSE May 2005). An area covering 29516 ha (Source: RAMSAR_100layer in DSE GIS Corporate Library (DSE 2005)), but excluding the Ulupna Island part of the State Park, is considered as the Barmah Forest Ramsar Site. Or 28515 (DSE 2003)]

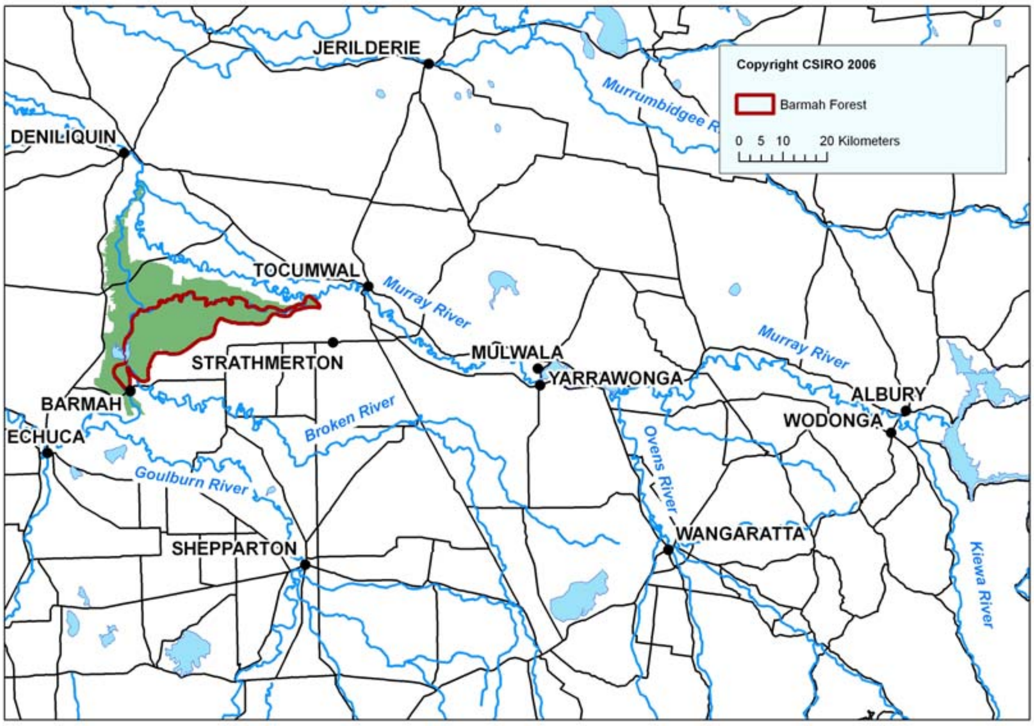

Figure 2.1 Regional location of Barmah forest

Barmah Forest has great conservation, heritage and amenity value. Barmah-Millewa Forest is part of the traditional country of the Yorta Yorta people. It is part of the Barmah–Millewa Forest which the Murray Darling Basin Commission (MDBC) has identified as a Significant Ecological Asset. It has a total area of over 66,000 ha, which extends into NSW and is listed as a Wetland of International Importance under the Ramsar Convention. It is also valued by pastoralists and the broader community, and it is a popular recreational destination. Its future as a functioning wetland depends on Environmental Water Allocations and other sources of water, the exclusion of unseasonal floods, and the management of a rising water table. Grazing, wildfires and recreational pressures are also management issues.

Barmah forest falls into the Riverina IBRA, a national bioregional classification and is described as an ancient riverine plain and alluvial fans composed of unconsolidated sediments with evidence of former stream channels. The Murray and Murrumbidgee Rivers and their major tributaries, the Lachlan and Goulburn Rivers flow westwards across this plain. Vegetation consists of river red gum and black box forests, box woodlands, saltbush shrublands, extensive grasslands and swamp communities.
http://www.deh.gov.au/parks/nrs/ibra/version5-1/summary-report/index.html

The Barmah Forest lies within the Barmah Landscape Zone typical of the Victorian Murray Fans Bioregion (Ahern *et al.,* 2003). The Murray Fans Bioregion extends from Yarrawonga in the east, downstream to Boundary Bend (just downstream of where the Murrumbidgee river enters to Murray River) It covers 421,000 hectares of the northern Victorian riverine plain is characterised by alluvial fans produced when streams from the hill country flow over the floodplain.

Geomorphologically Barmah Forest is within the Riverine Plains Physical Division of Southeast Australia (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/landform_geomorphology) .

2.2 Drainage

Smiths Creek distributes floodwaters through Barmah Forest. It is part of a complex system of anabranches fed from and draining back into the Murray River. The extent and duration of flooding is influenced naturally by the Barmah Choke, a constriction in the Murray River near Barmah Lakes, and artificially by releases from Hume Dam and by a series of regulators strategically established on effluent anabranches.

2.3 Vegetation

The vegetation was mapped by Chesterfield (1984). Table 2.1 summarises the landscape position, Hydrology, flora and fauna associated with the broad vegetation communities.

Later some of these classes were incorporated into the state-wide mapping of Ecological Vegetation Classes (EVCs). Ten EVCs have been mapped within Barmah Forest:

- Black Box Chenopod Woodland;
- Drainage Line Complex;
- Lagoon Wetland;
- Moira Plain Wetland;
- Reed Swamp;
- Lunette Woodland;
- Riverine Grassy Woodland;
- Plains Woodland;
- Riverine Grassy Woodland/Riverine Plains Grassy Woodland/Wetland mosaic; and
- Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic.

Most of the forest is mapped as the mosaic of Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation, which covers Chesterfield's Red Gum Units. Significant changes have been noted since Chesterfield's work (GBCMA & DSE May 2005). Since 2001 Doug

Frood has been mapping the vegetation of Barmah at a much finer scale, endeavouring to review the classifications of Chesterfield and the EVCs. This work will be used to refine the EVCs for Barmah and the Murray Fans Bioregion.

The plains grassy woodland is considered an endangered EVC (Ahern *et al.,* 2003).

The Barmah–Millewa Forest provides habitat for numerous threatened plant and animal species, including birds, fish and reptiles, and supports colonies of breeding waterbirds (See Appendix 3 and 4 in DSE 2003).

Further information on flora and fauna is given in GBCMA & DSE (May 2005), DCE (1992), DSE (2005) and in Appendix 3 & 4 of DSE (2003)

2.4 Surface Hydrology

The quantity of water diverted from the River Murray for irrigation development has increased substantially since the 1950s, augmented by inter-basin transfers from the Snowy River via the Snowy Mountains Scheme. The natural regime of river flow in the Murray has been progressively modified since construction of diversion channels between to the River Murray and Lake Victoria started in the late 1920s. Filling of the Hume Reservoir above Albury (Figure 2.1.) commenced in 1929 and was completed in 1934, with capacity augmented in 1949, 1958 and 1961. Dartmouth Reservoir was completed in 1979.

2.5 Groundwater

Geological characteristics include (Maunsell 1992a; Chong 2003):

- a shallow system dominated by silty and clayey sediments having low hydraulic conductivities;
- channelised sand bodies interspersed within this low hydraulic conductivity system. They have higher hydraulic conductivities, are partially or fully saturated, they may be confined or unconfined and may supply water to forest trees. It has been estimated that 30% of Barmah Forest has access to groundwater in shallow discontinuous aquifers (Maunsell, 1992). The aquifers have some potential for upward leakage of groundwater to the shallower aquifers

Table 2.1: Floodplain vegetation communities in Barmah-Millewa Forest

Vegetation community[2]	Landscape position	hydrology	fauna	Flora[2,4]	Comments[3]
Swamps and marshes Sedgelands, rushlands and grasslands to 3m EVC 300[1]	Low lying areas	Frequently flooded areas where water can pond to 1m deep. 75-100% of years inundated for 7-10 months during Winter to mid summer [6]	These provide nesting and feeding habitat for ibis, waterfowl and frogs	Giant rush (*Juncus ingens*), Cumbungi (*Typha spp*)Floating aquatics	These habitats are increasing in extent due to greater frequency of small summer floods, expanding at the expense of Moira Grass Plains 3
Open grassland plains, including large plains of Moira grass. EVC 289[1]	Low lying	Five month continuous flooding from mid winter to early summer.[5] 65-100% of years inundated for 5-9 months during Winter to mid summer[6]	When flooded, these are highly significant as breeding and feeding habitat for colonial breeding waterbirds like egrets, herons, spoonbills and marsh terns	Moira Grass(*Psuedoraphis spinescens* Common Spike Sedge (*Eleocharis acuta)* Rush Sedge (*Carex Tereticaulis*)	Originally treeless. Over two-thirds of the open grassland plains have disappeared since the 1930s, due to Giant Rush and Red Gum encroachment 3
Red gum forest over various sedges and /or grasses	Lower elevated areas supporting larger and denser red gum forest	40-92% of years inundated for 5 months during Winter and Spring[6]		Red Gum (*Eucalyptus camaldulensis*) Warrego Summer grass (*Paspalidium jubiflorum*)	Grazing and timber harvesting
Red Gum Riverine grassy woodlands	Higher areas	33-46% of years inundated for 1-2 months during Spring [6]		Red Gum Wallaby grasses (*Austrodanthonia spp)*	
Blackbox woodland	High Drier areas	14-33% of years inundated for 1-4 months during Winter-Spring [6]		Black Box (*E. largiflorens*) Wallaby Grasses, Saloop (*Einadia hastata),* Prickly Salwort *(Salsola tragus)*	
Box woodland (Grey/Yellow)	Sandhill complexes	Never inundated		Yellow box, (*E. melliodira*) Grey Box (*E. macrocarpa*)	

Vegetation community[2]	**Landscape position**	**hydrology**	**fauna**	**Flora**[2,4]	**Comments**[3]
Watercourses	Throughout the wetland system	regulated		Floating aquatics, Sedged and reed beds	important for connectivity, distribution of water, fish movement, aquatic plants and in sustaining large red gums along the banks which are important for bird roosting and nesting
Lakes and billabongs	generally deeper water environments		Habitat for biota such as fish and macro-invertebrates These are also very important in providing feeding areas for large colonial bird breeding events	Sedges and reed beds, Floating aquatics	
Main river channel (Murray)		regulated	Fish	Phragmites on the banks	

1. EVC codes are defined in Chapter 5 - Classification of Floodplain Communities
2. Chesterfield *et al.* (1984)
3. Chesterfield *et al.* (1986)
4. 4. DSE (2005)
5. Ward 1991
6. MDBC (2005b) Barmah-Millewa SEA Plan draft

3. Values from Barmah Forest

Nick Abel and Deborah O'Connell

In Chapter 1 and Figure 1.1 we discussed the hierarchical relationships and flow of logic between inputs of water and the realisation of values and the vision for Barmah Forest. The Victorian state vision for Barmah Forest is to:

Restore and maintain a mosaic of healthy wetland communities throughout the floodplain environment representing pre-regulation communities (DSE & GB CMA 2005).

DSE and GBCMA (2005) and contributing reports (Figure 4.1) list aesthetic, cultural, economic and environmental values for Barmah. Knowing these values is critical to the management of Barmah Forest because management objectives should be aimed at realising and maintaining these values (Chapter 1 and Figure 1.1).

We propose that values for wetlands fit well into the scheme in Figure 3.1, adapted from Whitten and Bennett (2005).

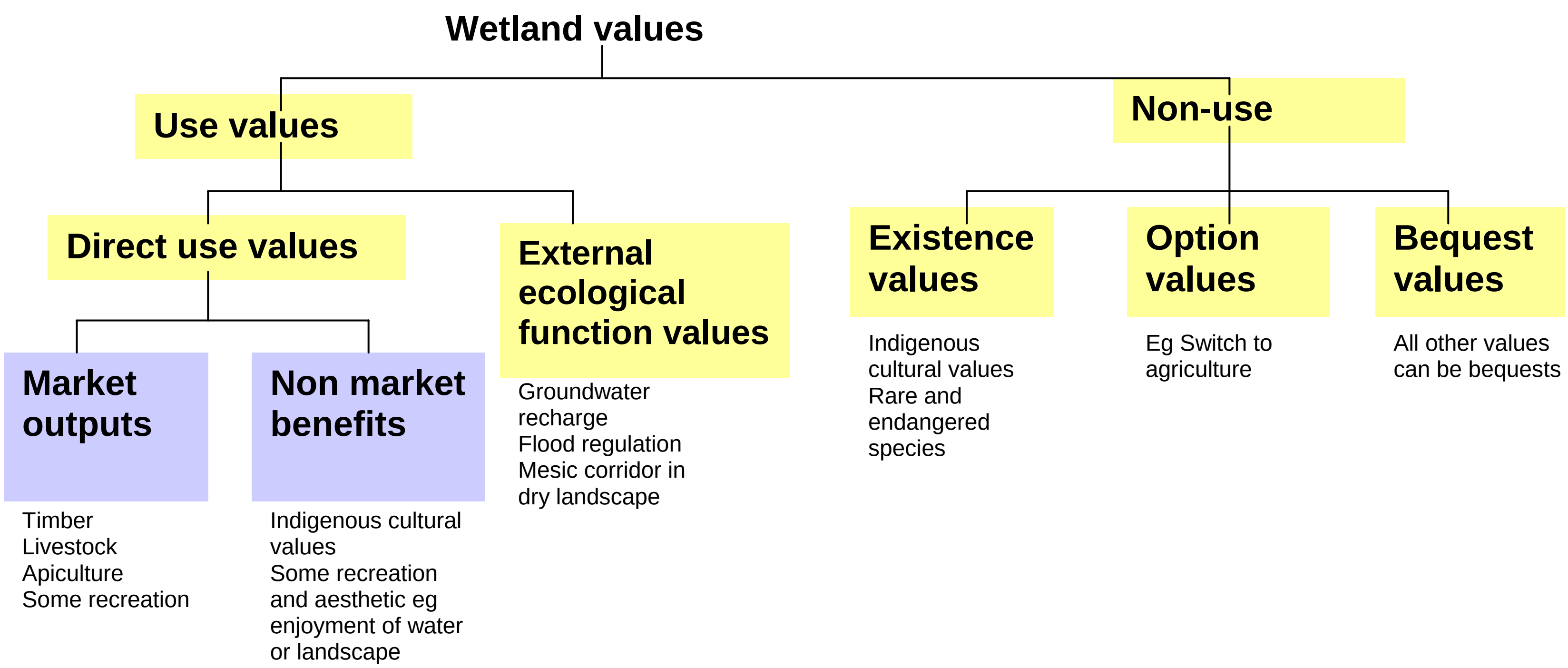

Figure 3.1. Classification of floodplain and wetland values

Table 3.1: Values attributed to Barmah Forest vegetation communities at local, regional, State, Murray Darling Basin, National and international scales:

We recorded values against Chestefield's (1984) vegetation community categories. Empty cells means we judged the activity that generates a particular value was uncommon or absent from that category. Vegetation community not distinguished' means the source of the information did not identify the vegetation community in which the activity occurs, or it is thought to occur in all vegetation communities.

The Chesterfield system is used as an interim classification. Ideally 'water management units' (discussed in Chapter 8) should be used.

Scale at which the value is significant: L = Local; R = regional; V = Victoria; M = Murray Darling Basin; N = National; I = International

Vegetation community (adapted from Chesterfield 1984).	Values of Barmah (Victorians' willingness to pay once to keep Barmah Forest as it was in 1991 estimated by contingent valuation survey at between $111 and 141m (2004 values) (Stone 1992).					
	Use values: estimated 8% of values of Barmah Forest (Stone 1992)			Non-use values: estimated 92% of values of Barmah Forest (Stone 1992)		
	Direct use values		External ecological function values	Existence values	Option values	Bequest values
	Marketed outputs	Un-marketed outputs				
River, lakes & billabongs	Boat tours, neighbouring caravan parks and camp sites, boat hire, fishing tours. LR	Recreational fishing and boating, bait collection, picnicking, duck hunting LR	Organic carbon storage V Groundwater recharge L Flow regulation and flood control LR Mesic corridor through dry landscape providing links between remnants LRV Critical role as part of larger network of wetlands (RAMSAR) LRVMNI Provide a source of propagules, organic carbon and other environmental services to surrounding or downstream area LRV	Native fish LRVMN Waterbirds LRVMNI	Option to manage only for tourism and recreation LR Option to take more water for agriculture elsewhere LR Unknown options	All values are potential bequest values at a scale depending on the particular value
Swamps & marshes	Cattle grazing L	Duck hunting LR		Vegetation community depleted LRVMNI Waterbirds LRVMNI	Option to manage only for duck hunting LR Option to take more water for agriculture elsewhere LR Unknown options	

Rush beds	Cattle Grazing L	Scenic driving, 4WD driving trail bike riding, cycling, horse riding, bush walking, orienteering, picnicking, camping, hunting feral animals, bird watching, nature study. LR		Vegetation community depleted LRVMN Waterbirds LRVMNI	Unknown options Option to take more water for agriculture elsewhere LR	
Open grassland plains	Cattle grazing L Beekeeping L			Vegetation community depleted LRVMN Waterbirds LRVMNI	Option to manage only for agriculture LR Option to take more water for agriculture elsewhere LR Unknown options	
Red gum forest and woodland (to be split)	Cattle grazing L Timber and firewood LR Beekeeping L			Vegetation community depleted LRVMN	Option to clear and manage for agriculture only LR Option to manage only for forestry LR Unknown options	
Blackbox woodland	Cattle grazing L Beekeeping L			Vegetation community depleted LRVMN	Option to clear and manage for agriculture only LR Option to manage for forestry only LR Unknown options	
Grey & yellow box woodland				Vegetation community depleted LRVMN		
Vegetation community not distinguished		Indigenous cultural values LRVN Post-settlement cultural values LRV		Rare and endangered flora and fauna LRVMN		

The values of Barmah Forest divide into **Use** and **Non-use** values. Use values are further split into the value components of **Direct use** (with marketed and unmarketed outputs) and **External ecological functions**. Non-use values are split into value components of **Existence, Bequest and Option** values. Some examples are provided in Figure 3.1, and are further described in Sections 3.1 and 3.2. There is a distinction between value components (yellow boxes) and outputs (purple boxes) in this scheme, and the reasons for this are discussed below, after we define the various values.

Use values are those that derive from physically using the resource – producing fish or timber for consumption, for example, or from using land or water for recreation, or Indigenous peoples deriving cultural value from being physically in a forest or beside a river. Some use values of a wetland benefit the users directly, and of these, some are bought and sold, and some are enjoyed without charge – Indigenous cultural heritage, for example. Other use values generate benefits indirectly outside the wetland – by regulating floods, for example.

Non-use values are those that generate benefits without being used physically. An existence value, for example, is the value some people get from just knowing a wetland is there, whether they visit it or not. A bequest value derives from a generation being able to pass on a functioning wetland to future generations. An option value of a wetland is its unknown potential to be valued for some purpose in the future. That purpose may be a use or a non-use-value, but an option value is classified as a non-use value now because it is not currently being realised.

Though the values identified for Barmah Forest in DSE and GBCMA 2005, and described in this chapter, fit within the framework of Figure 3.1, the boundaries between the value components are sometimes debatable. For example: marketed recreation uses many of the same flora, fauna water and landscapes that support un-marketed recreation values, existence values, option and bequest values; existence and option values are also bequest values in many cases; and option values can become use values, for example if a protected forest is turned over to commercial forestry. In addition to these potential overlaps, there will be differences between people in the way that they ascribe values to each value component. Nevertheless, the scheme is useful for categorising the values of Barmah Forest in a way which can be directly linked to the objectives for management.

There is an additional reason why this values framework is useful. When choosing between alternative management strategies, the options should be compared in terms of the net changes in values. Such comparisons require systematic identification of the particular values affected, and an explicit means to guard against double-counting or omission of significant values. This framework helps that task, and provides a good basis for environmental policy choices (Whitten and Bennett 2005).

3.1 Use Values

Wetland values can be estimated from peoples' willingness to pay for the maintenance of the wetland. Stone (1992) used a contingent valuation (CV) survey to estimate the willingness of Victorians to make a one-off payment into a trust fund to save Barmah Forest if a plan arose to drain it. Respondents apportioned about 8% to use values, with a range of $7.7- $9.9m (2004 value), and the other 92% to non-use values (section 3.2). Aggregated use values included hunting, scenic viewing, walking, boating, camping, fishing, bird-watching, grazing, salt and sewage absorption, timber, scientific research and Indigenous cultural uses.

An upward bias in willingnesses to pay identified by Stone probably resulted from the fact that respondents did not actually have to pay, so could feel good without cost. An additional source of upward bias not noted by Stone may have been that individuals used Barmah Forest as a proxy for conservation in general. Upward bias was also likely to result from strategic behaviour in which respondents claimed a high willingness to pay in order to add value to Barmah Forest therefore make it more secure. Other respondents may have offered a low payment on the expectation that other citizens would be more generous and save their personal costs – a source of downward bias (Stone 1992). Of these biases only the last was estimated using a follow up question. The r^2 value of the regression analysis was a low 17%, so the explanatory power of the statistical model was weak. The survey design was sound, the survey was clearly focussed on Barmah, and interviewees were briefed about the nature of the wetland. The report was re-published in a proceedings, therefore not reviewed presumably, with the same rigour as it would receive as a journal article. Although a 'choice modelling' approach (Whitten and Bennett 2005) would probably give more defensible results, we nevertheless classify it as a scientific investigation.

3.1.1 Direct use Values

We have already said that direct use values comprise outputs from the system, such as a commercial product or the enjoyment of a place by being in or near it. In the case of marketed outputs the benefits accrue to sellers as well as users. Buying and selling products, and travelling and using services in the course of enjoying the outputs also has a multiplier effect on the economy which increases gross regional product and employment. We do not consider multiplier effects further here, although they are being estimated in the CSIRO project Water for a Healthy Country.

Marketed Outputs

The dollar values of some marketed outputs along the Murray River near Barmah Forest have been estimated.

Tourism and recreation

Hassall & Associates and Gillespie Economics (2004) have estimated the present value of some paddleboats and boat tours between Hume Dam and Euston Weir Pool at $6.2 m, and camping and caravan parks at $283.3m (capitalised value at a 5% discount rate). A proportion of this is attributable to Barmah, where rivers, lakes and billabongs are important for interpretive cruises through Barmah-Millewa (DSE and GBCMA 2005). Barmah-Millewa also supports commercial caravan parks and camp sites, canoe hire, guided fishing tours & boat cruises. Their work was a desk-top study supplemented by consultations with the real estate and houseboat industries, and state tourism and fisheries organisations. As such it does not claim to be more than an unvalidated preliminary study.

Grazing

Hassall and Associates and Gillespie Economics (2004) have estimated the present value of floodplain grazing between Hume Dam and Euston Weir Pool at $1.1m (capitalised value at a 5% discount rate). Only a small proportion of this is attributable to Barmah, but open grassland plains, Red Gum forest, Blackbox woodland, Grey and Yellowbox woodland are used for cattle grazing in Barmah. In the summer of 2004/05 1400 cattle were licensed, and the previous winter 820 cattle (source Bruce Wehner Parks Victoria). Whitten and Bennett estimated the producer's surplus for floodplain cattle in upper southeast South Australia at $6.36/DSE. Assuming 8 DSE/ head, and a mean annual stocking rate of 1110 cattle, the annual value to cattle producers in Barmah Forest is around $56,500.

Forestry

The Mid Murray Forest Management Area, within which Barmah Forest lies, produces about 80% of Victoria's red gum timber in 2000/01 (DNRE 2002). This was harvested from Barmah Forest from within the area designated as State Forest, plus some from Barmah State Park (The licence for harvesting in Barmah State park expired in 2003 (Murray Thorson, Forester in charge Cohuna DSE). The volume of red gum from Barmah Forest was 44% of the volume from the Mid Murray Forest Management Area in 2000/2001, and 0.4% of the volume of Victoria's hardwood production in 2000/01 (DNRE Annual Report 2000/01). The revenue from forest products from Barmah Forest in 2000/2001 was about $232,000, or about 0.3% of the Victorian revenue from forest products ($78,335,000 in 1999/2000, DNRE 2001)

Table 3.2: Volume of timber, revenues and costs
(Sources: DNRE 2002; DNRE Annual Report 200/01)

Product	Victoria volume, m^3	Barmah Forest volume, m^3	Barmah Forest as % Victorian volume	Barmah Forest average unit stumpage, $\$/m^3$	Barmah Forest revenue
sawlogs all grades	742400	2973	0.4	47.83	142199
residual logs	1101135	1056	0.09	9.12	9631
sleepers	931?	1008		54.87	55309
firewood	97130	4516	0.05	5.48	24748
Totals		9553			231886

One cubic metre of unsawn log (gross volume) yields approximately 4.02 sleepers.

Un-marketed Outputs

Direct use values are not marketed but for some it is possible through surveys to estimate willingnesses of users to pay for them.

Un-marketed tourism and recreation

Hassall & Associates and Gillespie Economics (2004) have estimated the present value of recreational fishing at $41.6m, and recreational boating at $14.0m, between Hume Dam and Euston Weir Pool (capitalised value at a 5% discount rate). A portion of this is attributable to Barmah. Approximately 100,000 visitor days per year are reported for Barmah Forest and a high proportion are involved in non-market tourism and recreation. Rivers, lakes & billabongs swamps and marshes are important for boating & fishing, bait collection, picnicking, canoeing and duck hunting. Rush beds, open grassland plains, Red Gum forest, Blackbox woodland, Grey and Yellow Box woodland are important for scenic driving, 4WD driving, trail bike riding, cycling, horse riding, bushwalking, orienteering, picnicking, camping, hunting feral animals, bird-watching and nature study (Department of natural Resources and Environment 2002; DSE and GBCMA 2005). Hassall & Associates and Gillespie Economics (2003) estimated the present value (consumers' surplus) of camping at $33m (5% discount rate, and a 50 year time horizon). In terms of scientific soundness this was a scoping study that necessarily made untested assumptions. A reference cited relevant to Barmah Forest was Goodison 1992, a departmental report that we have not evaluated. Stone (1992) was not cited.

Indigenous cultural values

Barmah Forest is within the country of the Yorta Yorta indigenous nation. They expressed their strong connection to Barmah Forest through a Native Title Claim that was unsuccessful. The Indigenous response to the Living Murray Initiative (Anon 2003) stressed that the River Murray is a 'cultural economy' that includes all natural resources, a spiritual source, and a cultural heritage, and integral to song-lines and creation stories. Indigenous occupation of Barmah Forest is revealed in the burial grounds, mounds, middens, scarred trees, stone artefacts, shell deposits, scarred trees and artefacts. There is one registered Indigenous Cultural Place, and 2 Indigenous Post-contact Places (DSE and GBCMA 2005). It remains a source of bush foods, medicinal plants and artefact material (Yorta Yorta Clans Group 2001, cited in Orthia 2002).

Post-settlement cultural values

Pastoralists first used Barmah Forest in the 1840s, initially as squatters and later as leaseholders of Crown land (Fahey 1986). They continue to graze it under licence for the income from grazing (section 3.1.1) and for cultural reasons. The Red Gum forests were harvested for construction timber as settlers moved into the area, and became important for building and fuelling paddle-steamers. Barmah Forest is listed on the Register of National Estate as part of Australia's heritage and because of its outstanding natural values.

3.1.2 External Ecological Function Values

This value is about the services Barmah provides to humans <u>outside</u> its spatial boundaries. They can be estimated from the contribution they make to the production of other values outside Barmah. This has not been done by any authors that we know of.

As a large and important floodplain wetland, Barmah Forest affects the water quality and overall ecological condition of the river and floodplain areas downstream of its borders. It produces, traps, filters and transforms organic matter such as leaf litter, which it then exports as repackaged carbon, nutrients and other material of all sizes (Brinson *et al.,* 1981; Brinson *et al.,* 1983; Bretschko and Moser 1993; Hillman 1995; Glazebrook and Robertson 1999; Robertson *et al.,* 1999; Tockner *et al.,* 1999; Tockner *et al.,* 2000; Hein *et al.,* 2003). These become food and habitat for downstream organisms, supporting primary and secondary production during and after flooding (Elwood *et al.,* 1983; Junk *et al.,* 1989; Thorp and Delong 1994; Kingsford 2000)Junk *et al*. 1989; Thorp and Delong 1994; Kingsford 2000). Slow-flowing forest and wetland systems also act as traps for sediment, excess nutrients, and pollutants, reducing turbidity and improving water quality downstream (Brinson *et al.,* 1984; Haycock and Burt 1993; Gehrke *et al.,* 1995; Sparks 1995). Floodplain wetlands can act as 'egg banks' for the resting stages of many aquatic invertebrates, which when they emerge become food sources for consumers such as waterbirds and fish in and outside Barmah Forest (Boulton and Lloyd 1992; Jenkins and Boulton 1998). Fish productivity has been linked to increases in primary and secondary production following flooding of floodplain wetlands like the Barmah Forest (Gehrke *et al.,* 1995; Sparks 1995). [2]

A further external ecological function of the Barmah Forest and wetland systems is to increase groundwater recharge, and it helps regulate flow regimes and control floods (DSE and GBCMA 2005; Dexter 1979; FCV 1983; MDBC 1998. Barmah Forest forms a natural flood retardation basin with an estimated holding capacity of 32100ML (DSE 2003 p 11).

Barmah Forest is a large wetland remnant in a largely cleared landscape in which many wetlands have been inundated or drained. As such, it provides an external ecological service

[2] This paragraph contributed by Heather McGinness, CSE

to the region. It is a refuge, breeding ground and staging post for the conservation of waterbirds. It is an important part of a network of internationally significant wetlands, containing 4 of the 8 listed types of wetlands in Victoria (DSE 2003).

A further important function of Barmah is to provide a mesic corridor through the surrounding dry landscape. Barmah is the largest remnant patch of woodland in the region, and thus provides… (need further words here about patch size and connectivity it provides in a largely cleared and very dry landscape)

3.2 Non-use Values

Stone (1992) estimated that Victorians put the non-use values of Barmah Forest in 1991 at between $103m and 131m (in 2004 prices). This amount was 92% of the total value of Barmah Forest ($121m-153m in 2004 prices). This was for a one-off payment (the rigor of the method is discussed in section 3.1.).

3.2.1 Existence Values

Wetlands are productive ecosystems that are readily converted to agricultural and other uses. Therefore, they have been depleted globally (Ramsar n.d.), in Australia (Commonwealth Government of Australia 1997), NSW and Victoria. Barmah Forest contains about 13% of remaining shallow freshwater marsh in Victoria, about 15% of remaining freshwater meadow, and the largest areas of Moira Grass plains, around 5.5% of the area of Barmah, but this area is declining. It also contains Blackbox woodland which has a high priority conservation status in Victoria. Barmah-Millewa wetland is the largest River Red Gum wetland system in Australia and therefore the World (DSE &GBCMA 2005).

Barmah Forest is one of Victoria's largest waterbird breeding areas. It supports breeding colonies of Sacred and Straw Necked Ibis (*Threskiornis aethiopica*, and *T. spinicollis*) Royal and Yellow-billed Spoonbill (*Platalea regia*, and *P. flavipes*), Great & Little Pied Cormorant (*Phalacrocorax carbo* and *P. melanoleucos*), Darter (*Anhinga melanogaster*), and Rufous Night Heron (*Nycticorax caledonicus*). It provides habitat and drought refuge for many species. Barmah Forest hosts three bird species listed under the Japan-Australia Migratory birds agreement, including Latham's Snipe, and six listed under the China-Australia Migratory Birds Agreement. Twenty three species are listed under the Bonn Convention. Seven plant and 28 animal species listed under the Flora & Fauna Guarantee Act 1988 occur in Barmah. Thirty two plant and 49 animal species that occur there are rated 'threatened' . It is the only location in Victoria where the Superb Parrot (*Polytelis swainsonii*)) is known to breed (DSE &GBCMA 2005). Squirrel Gliders (*Petaurus norfolcensis*), Brush Tailed Phascogales (*Phascogale tapoatafa*), and Large Footed Myotis (*Myotis macropus*), threatened in Victoria, occur in the forest (Environment Australia 2001; Law and Anderson 1999), and native fish breed there (McKinnon 1993).

3.2.2 Option Values

Option values are the comparative values in using the area for alternative uses. For example, the options include the potential to change land use to commercial forestry or tourism and recreation. Their values can be estimated from the use values identified above. Other options would be to clear the area for agriculture; or to divert more of the water from the area into agriculture upstream and downstream. Another option would be to prioritise conservation values and make the area a National Park. There are a range of other options not yet identified.

3.2.3 Bequest Values

These can be a component of any of the other values.

3.3 Assessment of the Values at Different Scales

Table 3.1 summarises our understanding of the relative values of Barmah Forest at scales from international to local. At international, national and Murray Darling Basin scales Barmah Forest is predominantly important for its non-use values. We propose that the relative importance of use values declines as the scale broadens. This is supported by the evidence from Stone (1992) which - despite the methodological limitations acknowledged by the author - showed the strong preference of Victorians towards the non-use values. We also propose this because the scarcity value of the flora, fauna and vegetation communities becomes more apparent as scale broadens. In contrast, the marketed and un-marketed outputs from Barmah Forest shrink in significance as we move to State, Murray Darling Basin, national and international scales. Thus, while arguments for realising some of the marketed options might be relatively strong at local scale, at the broader scales the monetary values are outweighed by a powerful case for maintaining the existence, option and bequest values. This is supported by findings from the United States of America, Canada, Europe and Africa as synthesised by Heimlich *et al.* (1998, tabulated in Whitten & Bennett 2005).

3.4 Key gaps in value assessments

Key gaps relating to the values of Barmah Forest include:

1. **Conflicting values**. Barmah Forest generates multiple values at several scales. If objectives are developed to support the delivery of values as we recommend, then there will also be conflicting objectives. We discuss these in Section 4.2.10, and in Table 4.3. We are unable to address the conflicting values (and proposed objectives) in this report because it is beyond the consultancy terms of reference . We do, however, propose that a social process be used to rank the values and reduce the conflicts between them. Conflicts would also be reduced by allocating water to proposed new Water Management Units, and by better understanding of trade-offs and synergies among objectives in time and space.
2. **Non-market values**. There are use and non-use values which are not reflected in the market, about which we have little understanding or information. These include Indigenous cultural values, and tourism and recreation (which do have some flow-on market values to the local region),

The CSIRO Flagship Water for a Healthy Country project ‘Water Benefits in the River Murray Region’ is focussing on Barmah Forest and the Coorong as case study areas. The aim is to fill some of these knowledge gaps. The project is currently doing a small economic scoping study to gauge the values of tourism and recreation in the Barmah Forest.

4. Objectives for environmental water use

Nick Abel and Deborah O'Connell

4.1 Purpose and background

In this chapter we evaluate the objectives from the plans and strategies that guide the management of Barmah Forest and Millewa Forest, propose a set of new objectives that capture the intent of those plans and strategies, and highlight the conflicts among some objectives. We also discuss the great uncertainties in knowledge, and the intrinsic unpredictability of the Barmah-Millewa wetland. We consequently propose that management strategies are designed with an understanding of critical thresholds in the responses of vegetation to water and other factors ('Thresholds of Potential Concern'). Learning about those thresholds through adaptive management (MDBC 2005) and experimentation will be critical in maintaining Barmah –Millewa Forest within a desired envelope of spatial and temporal heterogeneity. The strategic use of environmental water allocations to achieve clear and measurable objectives will be the main means of maintaining Barmah-Millewa Forest between the ranges of these critical thresholds (Chapters 6, 7 and 8).

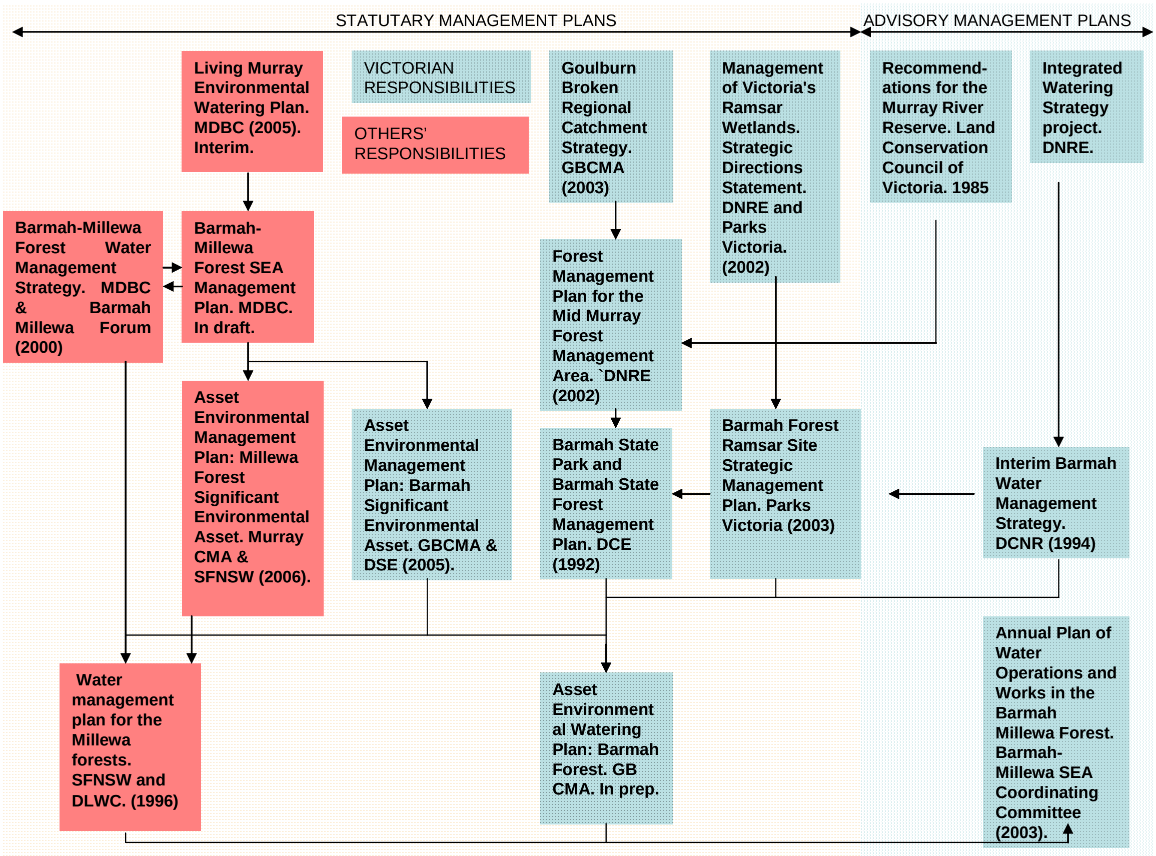

Figure 4.1. Influences of the management strategies and plans upon each other
(Based on DSE and GBCMA 2005. The statutory plans are required to address the specific requirements of their various acts).

DSE and GBCMA (2005) state the Victorian vision for the Barmah wetlands, and set out ecological objectives for the use of environmental water. Complementary objectives are being developed for Millewa. When finalised, the combined set will guide the management of the Barmah-Millewa system. The objectives will be 'developed, endorsed and delivered through the Barmah wetlands Environmental Water Management Program' (DSE and GBCMA 2005, p. 17) under a multi-agency coordinating committee. A process for developing objectives is in MDBC (2005. Barmah-Millewa Forest Significant Ecological Asset: Asset Environmental Management Plan 2005-2006. Draft 22nd July).

The water management plans are (or will be) designed to realise the objectives for Barmah wetland. The objectives are in turn intended to realise the values and vision (Chapters 1 and 3, and Figure 1.1) through water, fire and cattle management strategies, subject to high uncertainty about the response of the system to interventions (Chapters 6, 7 8 and 9). In this chapter we evaluate the ecological characterisation of Barmah as a Ramsar wetland (DSE 2005). We then evaluate the objectives in DSE and GBCMA (2005), and track the links between objectives, values and vision. We conclude that there is currently significant overlap and inconsistency among the objectives, and that some values are not supported by any objectives. We therefore propose an alternative approach to setting objectives in section 4.4, and illustrate the approach with a set of draft objectives. When developed this set is designed to:

- realise the vision for Barmah Forest;
- ensure system maintenance and value delivery; and
- capture the intent of the main existing plans and strategies (Figure 4.1)

We acknowledge that the statutory plans affecting Barmah Forest are designed to meet the requirements of various State and Commonwealth acts. While these must be addressed in the short term, in the longer term few laws are immutable, and if the management of Barmah Forest could be improved through legislative change, then securing that change can be a management objective. Unifying the management of Barmah Forest under one agency would seem to be a worthwhile aim, for example.

Not wishing to be constrained by current legislation, we therefore framed our objectives with a view to realising the vision for Barmah Forest in the long term, and without attempting to meet the requirements of the legislation. We map our proposed new objectives to the values they are intended to support, and the range of objectives in the main existing plans and strategies so that their lineage and relationships can be tracked (Appendix).

The vision for Barmah stated by DSE and GBCMA 2005 is to:

Restore and maintain a mosaic of healthy wetland communities throughout the floodplain environment representing pre-regulation communities.

This vision expresses both system function (healthy wetland communities) and value delivery intentions (the desirability of pre-regulation wetland communities). This dual meaning is also apparent in the ecological objectives in DSE and GBCMA 2005. The first meaning relates to the ability of the Barmah ecosystem to self-organise and maintain itself. Maintaining critical functions is necessary for the persistence of the system. The other meaning relates to delivering values from the system. Depending on the value set specified, the system can persist even if value delivery objectives are not achieved. The reverse may not be true. For example, if tourism and recreation were to be excluded, the system would persist but would not deliver this value component. A more complex illustration of this principle could be in protection of a rare species. A particular species may be valued for its own sake (existence value), without having a significant functional role in the maintenance of the ecosystem – it is debatable whether the functioning of the system and the delivery of values (other than the existence value associated with rare and endangered species) would be affected noticeably by the disappearance of one scarce species.

4.3 Evaluation of current objectives for Barmah Forest.

We list and comment on in sections 4.3.1 to 4.3.7 below the ‘general ecological objectives’ for the use of environmental water in Barmah Forest (DSE and GBCMA 2005). Section 4.3.8 deals with the ‘overall ecological objective’ for Barmah-Millewa Forest (DSE and GBCMA 2005).

4.3.1 Protect the ‘ecological character’ of the floodplain, as required under the Ramsar Convention.

The Barmah Forest Ramsar Site Strategic Management Plan (DSE 2003) is the most influential and binding of the plans and strategies that contribute to the ecological objectives in DSE and GBCMA (2005) (Keith Ward, pers. comm.). It falls under an international agreement, and is supported by the Living Murray Initiative (MDBC 2005) and the Goulburn Broken CMA Regional Catchment Strategy (2003), both of which have ministerial signature. Australia has obligations as a Contracting Party to the Convention on Wetlands (Ramsar, Iran, 1971). The Contracting Parties are obliged to document and maintain the ‘ecological character’ of listed Ramsar sites, and be informed of any changes to this (Ramsar convention 1987 cited in DSE 2005).

The Ramsar plan (DSE 2003) lists these objectives:

1. increase the scientific understanding of wetland ecosystems and their management requirements;
2. maintain or seek to restore appropriate water regimes;
3. address adverse processes and activities;
4. manage Ramsar sites within an integrated catchment management framework;
5. manage resource utilisation on a sustainable basis;
6. protect, and where appropriate enhance, ecosystem processes, habitats and species;
7. encourage strong partnerships between management agencies;
8. promote community awareness and understanding and provide opportunities for involvement in management;
9. ensure recreational use is consistent with the protection of natural and cultural values;
10. develop ongoing consistent programs to monitor ecological character.

As expressed, these are a *means* of achieving objectives, and are not objectives in themselves. In addition, the protection and enhancement of ecosystem processes, habitats and species advocated in these objectives is also captured by 4.3.2. Objective 6 does relate, however, to the concept of ‘ecological character’ (objective 10) and we therefore comment on the process for defining ecological character, and the management regimes specified for its maintenance. A framework for describing the ecological character of Ramsar wetlands is applied to Barmah wetland in DSE (2005).

The Ramsar framework and process has provided a systematic basis to define objectives to maintain critical system maintenance processes. It does however emphasise Ramsar wetland values at the expense of those other use values for which Barmah Forest is managed (Chapter 3), though these other values are noted as ecosystem services in DSE 2005. Identifying and addressing conflicts, synergies and trade-offs in water allocations and other management interventions is made more difficult by not including the full range of values and their supporting objectives. The ecosystem services framework can be made compatible with the classification of values that we employ (Figure 3.1; and Hein *et al* 2006). We considered an ecosystem services approach but did not use it because in our view it does not make the useful distinctions between values and objectives, and between system maintenance and value delivery objectives that the framework we propose in Chapter 1 and Fig 1.1 achieves. Nor does it link value delivery objectives to their values (Table 4.1).

4.3.2 Enhance the ecological functions and diversity of the floodplain by re-instating a more natural flood regime

It is clearly not likely that the ‘natural’ flood regime can be reinstated. Allocations of scarce water and measures to reduce unseasonal flooding are necessarily prioritised, with system maintenance as the primary aim, and trade-offs made in time and space. The need to prioritise and make trade-offs should be reflected in the management objectives. DSE (2005) goes some way towards this (4.3.1), and the issues of natural flooding, prioritisation and trade-offs are discussed in Chapters 6 to 8.

The renaming proposed in Chapter 3 to assist clarity and communication applies here. We applied the term ‘external ecological service’ to values, such as flood control, delivered *outside* the wetland (Figure 3.1). In DSE and GBCMA (2005) ‘ecological function’ refers to functions within Barmah that maintain its integrity. We have proposed in this chapter and in chapter 1 that objectives intended to maintain these internal functions be called ‘system maintenance objectives’ (Figure 1). An adequate set of system maintenance objectives should ensure internal functioning of the system and thus automatically deliver the external ecological services of flood control and aquifer recharge.

The diversity component of objective 4.3.2 could include heterogeneity of vegetation structure, and diversity of ecological communities and species, and its dimensions may be temporal, spatial or both. Diversity can contribute to existence, option and bequest values (Chapter 3), as well as contributing to system maintenance objectives.

4.3.3 Enhance breeding and recruitment of indigenous floodplain fauna and germination and regeneration of indigenous flora

We propose that this objective be disaggregated into new objectives, each mapped to a value or identified as a system maintenance objective. A functional classification of biota would enable the water requirements of functional response classes to be specified and prioritised. Although the knowledge for doing this is limited (Chapter 6), the approach should be adopted because it is fundamental, in our view, to the effective use of water for delivering Barmah’s values and maintaining the system. Understanding will increase both through learning-by-doing and research.

4.3.4 Provide suitable habitat conditions for indigenous flora and fauna

Like the others, this objective is not linked to the delivery of values. Moreover, it gives no priority nor guidance on what or where to manage. It could be seen as subsuming 4.3.3.

4.3.5 Ensure that all natural, flow related ecological functions can occur

This seems to be a restatement of 4.3.2, and as such is redundant.

4.3.6 Protect and restore Moira Grass plains

The Moira Grass plains have their own management objective because the Ramsar 'ecological character' definition focuses on those components likely to be lost – and the Moira Grass currently experiences spread of Red Gum and Giant Rush into or within this under-represented ecological community. The contribution of the Moira Grass plains to values or system maintenance functions would be made more explicit in the approach we are advocating.

4.3.7 Ensure breeding success of colonial water birds.

It is important that that objective is not over-emphasised, as an overly strong focus on specific components (such as waterbirds, tortoises, frogs or Moira grass) can be problematic, because we cannot assume that managing a system for a single species, or a limited range of them, will enable the system to continue to function and deliver other values. As with any of the objectives, there will be trade-offs and synergies with other objectives. We note that this objective is subsumed by 4.3.3 and 4.3.1.

4.3.8 'Overall ecological objective' for the Barmah-Millewa wetland system

The DSE and GBCMA 2005 also states that the overall ecological objective for the Barmah-Millewa wetland system is to enhance forest, fish and wildlife values by:

4.3.8.1. providing successful recruitment of large colonies of colonial water birds at least 3 years in 10;
4.3.8.2. increasing the area and quality of Moira grass plains;
4.3.8.3. providing breeding opportunities for floodplain fish, frogs and tortoises;
4.3.8.4.2. providing winter-spring floods to 50% of red gum forest; and
4.3.8.5. providing winter-spring floods to a proportion of all Barmah-Millewa wetland communities.

Objective 4.3.8.1 is subsumed by 4.3.7, objective 4.3.8.2 by 4.3.6, and objective 4.3.8.3 by 4.3.3. Objectives 4.3.8.4 and 4.3.8.5 probably fall under objective 4.3.5. Other objectives identified in DSE and GBCMA (2005) for the management of Barmah (rather than Barmah-Millewa) are not covered by 4.3.8.1 to 4.3.8.5. The need for interstate collaboration to make the management objectives for the two parts of the same ecosystem the same is well understood by managers, and expressed in MDBC 2005. The Asset Environmental Management Plan for Barmah-Millewa Forest sets out a process for developing objectives and targets for the Barmah-Millewa system, and this report is intended to contribute to that process. We propose a new statement of this objective below.

4.3 The need for a new set of objectives

The DSE and GBCMA (2005) objectives have been synthesised from other plans and strategies (Figure 4.1), whose objectives were derived through committee and participative processes. The resulting objectives are unlikely to guide managers towards actions that maintain the system. Nor do the objectives in DSE and GBCMA (2005) map well to the values identified in Chapter 3. Though the forestry plans do provide some additional objectives, many values remain unsupported by objectives in any of the plans.

Developing and gaining acceptance of new objectives requires a participative process, and it should not happen through a consultancy such as ours. However, given our comments on the current objectives for Barmah Forest in an early draft of this report, we were asked by the GBCMA to propose new ones. While we offer suggestions below, we recognise that Barmah

Forest will continue to be managed for a while under its current objectives. Incremental changes to these are therefore proposed in Chapters 6 to 9.

In Table 4.2 we propose new objectives and supporting strategies, and relate them to vegetation types (an interim proxy for the proposed new Water Management Units). We advocate these principles in developing these preliminary proposals:

- The relative importance of values which the system should deliver needs to be made explicit. We propose the GBCMA and DSE use existing social processes for the ranking. We have used the DSE &GBCMA (2005) vision as an overarching statement of values
- A clear chain of reason (as well as information flow) linking realisation of vision and values, to the inputs of water and other management strategies required to deliver these
- Distinction of System Maintenance Objectives (SMOs) and Value Delivery Objectives (VDOs). Each objective should address a single, well defined purpose.
- SMOs are based on the concept of maintaining structure, function and composition of geomorphic, flora and fauna elements within specified limits based on 'Thresholds of Potential Concern'
- Water and other management strategies are specified for each objective in terms of Thresholds of Potential Concern;
- Particular objectives would be applied either at the whole system (Barmah Forest) scale, or the Water Management Unit (WMU) scale, or the same objective may be applied to a sub-set of WMUs.
- Pre-existing objectives from the various strategies and plans affecting Barmah Forest (Appendix) should be re-evaluated in the light of the proposed ranking of values and consideration of trade-offs.

Table 4.1. System Maintenance and Value Delivery Objectives, and the Values they Support

A-D: Objectives that maintain the system and also deliver values
E-O: Objectives that deliver values

Proposed New Objectives	Values (from table 3.1.) Addressed by Proposed New Objectives
A. Restore and maintain a mosaic of vegetation communities representing the relative areas and attributes of pre-regulation communities in Barmah Forest as a whole (SMO and VDO)	Existence values; option values; bequest values: communities depleted at State scale
B. Maintain or enhance water quality within Barmah floodplain and channel (SMO)	Existence values; option values; bequest values: communities depleted at State scale
C. Maintain or enhance important functional groups of fauna - specify which ones, and have a separate sub-objective for each (SMO and VDO – maintaining or enhancing existence values)	Direct use values: duck hunting Existence values; option values; bequest values: water bird populations
D. Maintain or enhance specified vegetation community within each proposed WMU	Existence values; option values; bequest values: communities depleted at State scale
E. Manage identified areas to preserve Indigenous cultural values	Direct use values: Indigenous cultural values
F. Manage identified areas to preserve post-settlement cultural values	Direct use values: post-settlement cultural values
G. Develop and maintain provision for a range of recreational and educational opportunities, with specific strategies to manage conflicts between these values Subject to achievement of system maintenance objectives	Direct use values
H. Maintain opportunities for commercial use (subject to achievement of system maintenance objectives)	Direct use value: cattle production
I. Provide scientific research opportunities (subject to achievement of system maintenance objectives)	Indirect use value (the only IUV identified that is not an external ecological function value): research outputs
J. Maintain role as part of mesic corridor through a drier landscape – provides linkages between a number of remnants	External ecological function value
K. Minimise impacts of salt flushing events (from Forest to river/channels) – check if salt storage in floodplain is an issue	External ecological function value
L. Maintain or enhance role as part of regional, national and international wetland system.	External ecological function value
M. Maintain or enhance flow regulation capacity (subject to achievement of system maintenance objectives)	External ecological function value
N. Maintain or enhance flood mitigation capacity (subject to achievement of system maintenance objectives)	External ecological function value
O. Maintain or enhance populations of selected rare or endangered species (flora and fauna)	Existence, option and bequest values

4.4 Towards improved objectives

4.4.1 Uncertainty, thresholds and adaptive management

As the Asset managers already know, and as Chapters 6, 7 and 8 confirm, there are large gaps in our understanding of how the Barmah-Millewa system responds to changes in the water regime or other factors. The problem is compounded by the unpredictability of a system that is characterised by multiple interacting thresholds. Potential thresholds include water table depth and salt concentration, fuel loads and the probability of fire, upstream regulation of water, pest plant and animal densities, and state changes in vegetation, such as the spread of Giant Rush and River Red Gum. Each of these factors in isolation may change in a way which will change but not destroy the ability of the system to function. When a critical threshold is reached for one or many of these factors, however, the system may change its state irreversibly and no longer be able to maintain function and deliver values. The complexity is compounded by the interactions between the thresholds, which are poorly understood.

MDBC (2005) and DSE and GBCMA (2005) have stressed the importance of adaptive management in these circumstances. DSE 2005, state that “Managers ….need to know the range of variation for ecosystem services and their related components and processes that occur without the ecological character changing. This information can then be used to identify indicators for monitoring, and set targets for management” (p 9), and to specify “limits of acceptable change” (p 8). The concept of ‘Thresholds of Potential Concern’ (TPC) (Biggs and Rogers, 2003) is useful here. TPCs are targets that together define the spatio-temporal heterogeneity for which an ecological system is managed. They are defined as empirical or hypothetical upper and lower levels along a continuum of change in selected indicators - for example, the area of Moira Grassland, or the density of shrubs in a River Red Gum Forest. When a TPC is being approached (as indicated by measured or modelled rate of change), then the past and present management strategies and other drivers of change are identified and analysed, and management strategies changed accordingly. The levels of the TCPs are modified as understandings increase or drivers change. The set of TPCs is therefore a multi-dimensional envelope within which change in time and space is monitored and managed.

4.4.2 Addressing conflicts among objectives

There is a large network of stakeholders involved in the Water Management Strategy of the Barmah Forest including:

- the Murray-Darling Basin Ministerial Council;
- Commonwealth and State Government agencies with natural resource and water resource management responsibilities within the Barmah-Millewa Forests and the Murray catchment, including the MDBC;
- local government agencies;
- joint community-government resource management entities in the region — such as the Murray Catchment Management Committee, Cadell Land and Water Management Board, and Goulburn-Broken Catchment Management Authority;
- community groups with interests in natural resource management and the regional and local economy;
- communities in the region, including Indigenous communities, with strong cultural ties to the Forest environment;
- industries and users supported (directly and indirectly) by commercial, tourist and recreational activities pursued within the Forest; and

- downstream users of River Murray water.

Potential and actual conflicts among objectives within Barmah-Millewa Forest, and Barmah Forest itself originate from:

- multiple values desired by many stakeholders (Table 3.1), and the incompatibility of some values and the objectives and strategies that support them
- splitting a single wetland system by a state border and managing it as two systems, each with its own set of plans, strategies and management practices
- management by multiple agencies following plans, strategies and objectives and using management methods that are not mutually compatible (Figure 4.1). Thus Barmah Forest itself is divided into Murray River Reserve, State Park and State Forest, and contains reference areas, Ramsar Sites, Special Management Zones, and Special Protection Zones.

Any set of objectives designed to capture the intentions of the multiple contributing plans and strategies (Figure 4.1) will contain in-built conflicts. Table 4.3 is a preliminary identification of conflicts. They could be resolved, reduced or managed through: making the relative importance of value delivery objectives explicit; zonation in time and space, including use of the proposed new Water Management Units; engagement of agencies and stakeholders in participative planning, but with clear allocation of roles and responsibilities. All the measures for addressing conflict are already employed, but we submit that conflicts, trade-offs and synergies among objectives could be addressed better, so we comment on them below.

4.4.3 The relative importance of values and supporting objectives

The Victorian state vision for Barmah Forest (Section 4.2.) is unequivocally about the realisation of existence values. Clearly there is a conflict between these values and the broader societal value of providing water for irrigation. The Living Murray initiative is addressing conflict at this scale.

Conflicts also emerge at the more local scale between the values of conservation, grazing, forestry, and recreation, because there are some intrinsic incompatibilities among these values. Decisions are needed about the relative importance of the values associated with these types of use. Many of the current values being delivered from Barmah clash with those of the Yorta Yorta people. Even within one value set, there are serious conflicts in values between users – for example those who value the experience of powerful boats, wakeboards and jetskis, compared to those who may value hunting, or four-wheel driving, or others who may wish to have a wilderness experience.

The vision statement says clearly that conservation of existence values is pre-eminent, and use values are not mentioned. As the managers of Barmah Forest already know, a process is required to make decisions about the relative importance of a wider range of values if conflict is to be reduced. This should enhance the probability of the major objectives being achieved. Currently we believe that success in achieving some major objectives is jeopardised by concurrent attempts to achieve what should be less important objectives. The problem is compounded by joint management by several agencies, but we do not evaluate the consequences of this beyond this observation.

4.4.4 Zonation in time and space

Once values and objectives have been ranked, they can be mapped to the proposed Water Management Units. Zoning in time and space based on WMUs will help separate further those uses and management strategies (pest control and recreation, for example) that are more-or-less incompatible (Table 4.3), so that water management is integrated with system-wide pest and weed control and fire management, and the management of tourism, recreation, forestry and grazing.

Table 4.2. Objectives for System Maintenance and Value Delivery and Possible Management Strategies in relation to Vegetation Types/ Water Management Units

Water Management Units and Vegetation types: *we use a modification of the Chesterfield (1984) classification as a temporary proxy for proposed new water management units (WMUs).*

Water regime attributes: *as far as possible the water regimes should be specified in terms of duration of wet; frequency of flooding; rate of water level rise or recession; depth of flooding; time of year of flooding*

Proposed New Objectives	Proposed New Strategy	Whole Barmah System	Rivers lakes and Billabongs	Streams and channels	Swamps and marshes	Rush beds	Open grassland plains	River red gum forest/ woodlands	Blackbox woodland	Grey and Yellowbox woodland	Flood ecotones
Objectives that maintain the system (System Maintenance Objectives, SMOs), and also deliver values (Value Delivery Objectives, VDOs)											
A. Restore and maintain a mosaic of vegetation communities representing the relative areas and attributes of pre-regulation communities in Barmah Forest as a whole	A.1 Manage the trade-offs among the water requirements of each Proposed WMU at the scale of Barmah Forest by: - prioritising objectives across WMUs - specifying Thresholds of Potential Concern for each proposed WMU - specifying a water regime for each Proposed WMU	X									
	A.2 Maintain hydraulic connectivity as required for Barmah Forest to function as a whole by: - specifying Thresholds of Potential Concern for each proposed WMU (see text section 4.9) - specifying a water regime for Barmah floodplain as a whole - developing and maintaining engineering works to deliver water to each Proposed WMU while maintaining connectivity - maintaining or enhancing channel and pool fluvio-morphic characteristics	X	X	X	X	X	X	X	X		X
B. Maintain or enhance water quality within Barmah floodplain (SMO)	B.1 – B.n specify Thresholds of Potential Concern for each proposed WMU		X	X	X						
C. Maintain or enhance important functional groups of fauna	C.1 native waterbird populations - specify water regimes - specify pest control strategy –pigs, cats, foxes - specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X					
	C.2 native fish populations - specify water regimes - specify carp control strategy - specify Thresholds of Potential Concern for each proposed WMU		X	X	X						
	C.3 native frog populations - specify water regimes - specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X	X	X	X	X	X
	C.4 native tortoise populations - specify water regimes - specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X	X				

Proposed New Objectives	Proposed New Strategy	Whole Barmah System	Rivers lakes and Billabongs	Streams and channels	Swamps and marshes	Rush beds	Open grassland plains	River red gum forest/ woodlands	Blackbox woodland	Grey and Yellowbox woodland	Flood ecotones
	C.5 - n) Need to specify other functional groups and their water regimes		X	X	X	X	X	X	X	X	X
D.0 Maintain or enhance specified vegetation community within proposed WMU in terms of : - species composition - vegetation structure - function (what do you do to achieve this? If you get the other three can we expect function to follow?) - area	D.1-D.n. Implement a specific water regime for each vegetation community within each proposed WMU, and specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X	X	X	X		X
	D.o Control weeds - specify species and controls - specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X	X	X	X	X	X
	D.p Exclude, or specify controls on grazing by cattle, and specify Thresholds of Potential Concern for each proposed WMU					X	X	X	X	X	X
	D.q Fire management - specify strategy for each Proposed WMU - specify Thresholds of Potential Concern for each proposed WMU							X	X	X	X
	D.r Control logging and firewood collection - specify controls (refer Value Delivery Objectives below) - specify Thresholds of Potential Concern for each proposed WMU							X	X	X	X
	D.s Manage recreation impacts on vegetation community - specify controls (Refer Value Delivery objectives below) - specify Thresholds of Potential Concern for each proposed WMU		X	X	X	X	X	X	X	X	X
Objectives that deliver values (Value Delivery Objectives, VDOs)											
E.0 Manage identified areas to preserve Indigenous cultural values	E.1. Specify strategies including: - interpretation - conservation of sites - access - fire protection - Thresholds of Potential Concern	X									
F.0. Manage identified areas to preserve post-settlement cultural values	F1. Specify strategies including: - interpretation - conservation of sites - access - fire protection - Thresholds of Potential Concern	X									
G.0. Develop and maintain provision for a range of recreational and educational opportunities (subject to achievement of system maintenance objectives)	G.1. Support nature study – specify strategy, including: - interpretation - access	X									

Proposed New Objectives	Proposed New Strategy	Whole Barmah System	Rivers lakes and Billabongs	Streams and channels	Swamps and marshes	Rush beds	Open grassland plains	River red gum forest/ woodlands	Blackbox woodland	Grey and Yellowbox woodland	Flood ecotones
	G.2. Manage fishing and bait collection: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern others?	x	x	x	x						
	G.3. Manage boating (speed boating, waterskiing, kayaking, sightseeing, house boating): - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern others?	x	x								
	G.4. Manage picnicking and camping: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern others?	x	x					x	x	x	x
	G.5. Manage bushwalking, orienteering: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern others?	x						x	x	x	x
	G.6. Manage 4WD driving, trail bikes and cycling: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	x					?	?	?	?	?
	G.7. Manage pig, duck and fox hunting (specify strategy for each): - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	x	x	x	x	x	x	x	x	x	x
	G.8. Manage horse-riding: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	x				?	?	?	?	?	?
H.0. Maintain opportunities for commercial use (subject to achievement of system maintenance objectives)	H.1. Manage cattle grazing: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	x				?	?	?	?	?	?

Proposed New Objectives	Proposed New Strategy	Whole Barmah System	Rivers lakes and Billabongs	Streams and channels	Swamps and marshes	Rush beds	Open grassland plains	River red gum forest/ woodlands	Blackbox woodland	Grey and Yellowbox woodland	Flood ecotones
	H.2. Commercial boat tours: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern - others?	X	X								
	H.3. Beekeeping: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern - others?	X				X	X	X	X	X	X
	H.4. Timber harvesting: - controlled, sustainable forest utilisation where consistent with other objectives - Maximise utilisation of sawlogs from timber harvesting operations while continuing to provide other timber products through integrated and silvicultural operations - Apply silvicultural treatments and prescriptions that are environmentally and economically sound and which improve the overall productivity of the forest	X						X			
	H.5. Firewood collection: strategy to be specified	X						X			
	H.6. Manage exploration and mining within the constraints of those laws: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern - others?	X									
I.0. Provide scientific research opportunities (subject to achievement of system maintenance objectives)	I.1. Code of practice	X									
J. Maintain role as part of mesic corridor through a drier landscape – provides linkages between a number of remnants	J.. Is there a need to specify a strategy?	X						X	X	X	X
K. Minimise impacts of salt flushing events (from Forest to river/channels) – check if salt storage in floodplain is an issue	K1. Specify strategy and Thresholds of Potential Concern	X	X	X							
L. Maintain or enhance role as part of regional, national and international wetland system.	L.1. Strategy specified by RAMSAR	X	X	X	X	X					
M. Maintain or enhance flow regulation capacity (subject to achievement of system maintenance objectives)	M.1. Is there a need to specify a strategy?	X	X	X							

Proposed New Objectives	Proposed New Strategy	Whole Barmah System	Rivers lakes and Billabongs	Streams and channels	Swamps and marshes	Rush beds	Open grassland plains	River red gum forest/ woodlands	Blackbox woodland	Grey and Yellowbox woodland	Flood ecotones
N. Maintain or enhance flood mitigation capacity (subject to achievement of system maintenance objectives)	N.1. Is there a need to specify a strategy?	x	x	x							
O. Maintain or enhance populations of selected rare or endangered species (flora and fauna)	O.1-n. Specify separate strategies for each rare or endangered species. Specify Thresholds of Potential Concern	x	x	x	x	x	x	x	x	x	x

Table 4.3. Interactions among management strategies

How to use the table: e.g. to see the interaction between the strategy “Exclude, or specify controls on grazing by cattle in each WMU”, and “Control weeds – specific strategy for each proposed WMU”, first locate the former in the left column, and read across the row it is in until you are in the cell under the “Control weeds –“ strategy. That cell describes the interaction as “Cattle likely to be a source of weed seeds”.

	A.1 Manage the trade-offs among the water requirements of each Proposed WMU			
A.2 Maintain hydraulic connectivity as required for Barmah Forest to function as a whole	Specific water requirements of some WMUs may mean reduced system connectivity	A.2 Maintain hydraulic connectivity as required for Barmah Forest to function as a whole		
B.1 – B.n Maintain or enhance water quality within Barmah floodplain	Water requirements of different WMUs my be incompatible with management of salinity and black-water	Maintaining connectivity probably enhances water quality?	B.1 – B.n Maintain or enhance water quality within Barmah floodplain	
C.1 ; C.2 ; C.3 ; C.4 ; Maintain or enhance native waterbird , fish, frog and tortoise populations; J.1. Maintain or enhance role as part of regional, national and international wetland system	Potential incompatibility among vegetation, water-bird , frog and tortoise water requirements. Predation among these groups is a potential problem.	Mainly compatible?	Potential incompatibility between a water regime that maintains water quality and one that maintains or enhances these animal populations	C.1 ; C.2 ; C.3 ; C.4 ; Maintain or enhance native waterbird , fish, frog and tortoise populations; J.1. Maintain or enhance role as part of regional, national and international wetland system

D.1-D.n. Implement a specific water regime for each vegetation community within each proposed WMU	Water requirements of different WMUs may conflict	Conflict between connectivity and WMU water requirements likely to arise	Potential incompatibility between a water regime that maintains water quality and one that maintains or enhances vegetation communities	Potential incompatibility among vegetation, water-bird , frog and tortoise water requirements	D.1-D.n. Implement a specific water regime for each vegetation community within each proposed WMU				
D.o Control weeds – specific strategy for each proposed WMU	Potential conflict between weed control strategy and water regime			Potential incompatibility between weed control and water regime	Potential incompatibility between weed control and water regime	D.o Control weeds – specific strategy for each proposed WMU			
D.p; H.1. Exclude, or specify controls on grazing by cattle in each WMU	Interactions of grazing and water regime largely unknown (Chapter 6)		Conflict between stream bank erosion and water quality		Water regime may hamper access	Cattle likely to be a source of weed seeds	D.p; H.1. Exclude, or specify controls on grazing by cattle in each WMU		
D.q Fire management for each proposed WMUs	Interactions of fire and water regime largely unknown (Chapter 6)					Synergies likely	Fire management needs likely to conflict with stock management	D.q Fire management for each proposed WMUs	
D.r ; H.3. H8.4. .Timber harvesting Control logging and firewood collection	Water regime may hamper forestry access	Hydraulic connectivity may hamper access			Water regime may hamper access	Harvesting may promote spread of weeds		Potential conflicts	D.r ; H.3. H.4. .Timber harvesting Control logging and firewood collection

D.s ; G.1- G. 8. ; H.2 ; Manage recreation impacts and provide recreation facilities	Water regime will hamper recreation access in some WMUs	Hydraulic connectivity may hamper access	Any conflict?	Water regime will hamper recreation access in some WMUs	Water regime may hamper access	Recreation likely to spread weeds	Fencing and access for cattle management likely to clash with recreation needs	Potential conflicts	Potential conflicts	D.s ; G.1- 7. 8. ; H.2 ; Manage recreation impacts and provide recreation facilities		
E.1. Manage Indigenous cultural heritage	Water regime potentially incompatible with cultural conservation needs			Water regime potentially incompatible with cultural conservation needs			Indigenous cultural heritage likely to benefit from controls on grazing		Conflicts	Conflicts	E.1. Manage Indigenous cultural heritage	
F.1. Manage post-settlement cultural heritage	Water regime potentially incompatible with cultural conservation needs			Water regime potentially incompatible with cultural conservation needs			Conflicts likely between controls and cultural heritage				Potential conflicts	F.1. Manage post-settlement cultural heritage
O. Maintain or enhance populations of selected rare or endangered species (flora and fauna)				Potential conflicts between water requirements of functional groups and those of rare and endangered species	Potential incompatibility between water requirements of rare and endangered species and vegetation communities		Rare and endangered species likely to benefit from controls on grazing	Conflicts and synergies both possible	Conflicts	Conflicts		Conflicts

Chapter 4 APPENDIX: Proposed Objectives and Strategies, and Current Objectives

Key to plans and strategies referred to in column 4 of the table below: 1.n. Department of Sustainability and Environment & Goulburn Broken CMA 2005. Asset Environmental Management Plan: Barmah Significant Environmental Asset Plan – 11 May 2005 2.n. Goulburn Broken CMA. 2003. Goulburn Broken Regional Catchment Management Strategy 3.n. Parks Victoria (2003). Barmah Forest Ramsar Site Strategic Management Plan	4.n. Department of Conservation and Environment (1992) Barmah Management Plan - Barmah State Park & Barmah State Forest. DCE, Victoria. 6.n. Department of Natural Resources and Environment (2002) Forest Management Plan for the Mid Murray Forest Management Area. DNRE , Melbourne, Victoria. 8.n. Barmah-Millewa Forum (2000). Barmah-Millewa Forest Water Management Strategy. Murray Darling Basin Commission.	**Use of the key** i). Numbers 1-8 in this key relate to codes for objectives in column 4 of the table. These codes were used in our consultancy to track the objectives. Code numbers are not all consecutive because some plans have been superseded. ii). The second element in the code number (generalised as 'n' in this key) refers to a specific objective e.g. 1.1. is our code for the first objective in DSE & GBCMA (2005).

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
Objectives that maintain the Barmah Forest System (System Maintenance Objectives, SMOs) as well as delivering values (Value Delivery Objectives, VDOs)			
A. Restore and maintain a mosaic of vegetation communities representing the relative areas and attributes of pre-regulation communities in Barmah Forest as a whole (SMO and VDO)	A1 Manage Barmah as part of the larger Murray River system The Living Murray initiative	Existence values; option values; bequest values: communities depleted at State scale	In The Living Murray etc documents need to check
	A2 Manage the trade-offs among the water requirements of each Proposed WMU at the scale of Barmah Forest by: - prioritising objectives across WMUs - specifying Thresholds of Potential Concern for each proposed WMU - specifying a water regime for each Proposed WMU	Existence values; option values; bequest values: communities depleted at State scale	1. Victorian vision for Barmah Forest: Restore and maintain a mosaic of healthy wetland communities throughout the floodplain environment representing pre-regulation communities 4.17 minimise the impact of surrounding land and water uses on the forest 1.1 protect the ecological character of the floodplain, as required under the Ramsar convention 6.1 Biodiversity. Ensure that indigenous plant and animal species and communities survive and flourish throughout the Mid Murray forest planning area 8. Mission – Maintain or enhance the ecological health of the BM Forest by managing water regime in a manner which - Recognises the Forest as a single ecosystem - Recognises the appropriate economic, environmental and social factors and Adapts to advances in knowledge

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
	A3 Maintain hydraulic connectivity, morphology and VARIABILITY as required for Barmah Forest to function as a whole by: - specifying Thresholds of Potential Concern for each proposed WMU - specifying a water regime for Barmah floodplain as a whole - developing and maintaining engineering works to deliver water to each Proposed WMU while maintaining connectivity - maintaining or enhancing channel and pool fluvio-morphic characteristics by managing flow volumes and rates through effluent channels and wetlands	Existence values; option values; bequest values: communities depleted at State scale	6.8 Ensure that in stream water quality is not adversely affected by management activities. Ensure that available water is used to restore and maintain the health and vitality of the floodplain ecosystem. Ensure that the management strategies in the Forest Management Plan and the Water Management strategies are complementary. Integrated watering strategies 3.2 Maintain or seek to restore appropriate water regimes 1.2 Enhance the ecological functions and diversity of the floodplain by re-instating a more natural flood regime 8.2. To optimise use of river flows to enhance water management of the environment (2.1 – 2.6 strategies listed within this)
B. Maintain or enhance water quality within Barmah floodplain and channel (SMO)	B.1 – B.n - manage recreational impacts on water quality through sedimentation (road tracks and channel wash or stream bank erosion) - managing grazing impacts on water quality through pugging, channel sedimentation - manage blackwater events - fertilisers and nutrients in/out of channel(s) - specify Thresholds of Potential Concern for each proposed WMU	Existence values; option values; bequest values: communities depleted at State scale	6.8 Ensure that in stream water quality is not adversely affected by management activities. Ensure that available water is used to restore and maintain the health and vitality of the floodplain ecosystem. Ensure that the management strategies in the Forest Management Plan and the Water Management strategies are complementary. Integrated watering strategies
C. Maintain or enhance important functional groups of fauna - specify which ones, and have a separate sub-objective for each (SMO and VDO – maintaining or enhancing existence values)	C.1 native waterbird populations - ensure successful recruitment of large colonies of a wide range lf colonial waterbirds - enhance breeding and recruitment of a wide range of waterbirds - provide breeding and maintenance of habitat for a wide range of waterbirds - ensure breeding success of a wide range of colonial waterbirds Specify - water regimes	Direct use values: duck hunting Existence values; option values; bequest values: water bird populations	1.8 Provide successful recruitment of large colonies of colonial water birds at least 3 years in 10 1.7 Ensure breeding success of colonial water birds 11.1. Successful breeding of thousands of colonial waterbirds in at least three years in ten 1.14 Maintain health of sedges, giant rush and wetland communities; assist maintenance of majority of Moira grass; maintain up to half river red gum forest; provide events suitable for successful waterbird breeding; 55% of wetlands inundated 6.9 Minimise the impact of pest plants, animals, insects and diseases on the ecological, economic and cultural values of State Forest. Prevent the introduction of new pests and the spread of pests into sensitive areas 7.2. To maintain and where possible improve the abundance and diversity of wetland dependent flora and fauna.

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
	- pest controls – cats, pigs, foxes - Thresholds of Potential Concern for each proposed WMU		
	C.2 native fish populations Specify - water regimes - carp controls - Thresholds of Potential Concern for each proposed WMU (see text section 4.9)	Direct use values: recreational fishing Existence values; option values; bequest values: native fish populations	1.10 Provide breeding opportunities for floodplain fish, frogs and tortoises 6.9 Minimise the impact of pest plants, animals, insects and diseases on the ecological, economic and cultural values of State Forest. Prevent the introduction of new pests and the spread of pests into sensitive areas 7.2. To maintain and where possible improve the abundance and diversity of wetland dependent flora and fauna.
	C.3 native frog populations Specify - water regimes - pest controls - Thresholds of Potential Concern for each proposed WMU	Existence values; bequest values: native frog populations	1.10 Provide breeding opportunities for floodplain fish, frogs and tortoises 6.9 Minimise the impact of pest plants, animals, insects and diseases on the ecological, economic and cultural values of State Forest. Prevent the introduction of new pests and the spread of pests into sensitive areas 7.2. To maintain and where possible improve the abundance and diversity of wetland dependent flora and fauna.
	C.4 native tortoise populations Specify - water regimes - Thresholds of Potential Concern for each proposed WMU	Existence values; bequest values: native tortoise populations	1.10 Provide breeding opportunities for floodplain fish, frogs and tortoises 7.2. To maintain and where possible improve the abundance and diversity of wetland dependent flora and fauna.
	C.5 - n) Need to specify other functional groups - Function - Benchmarks and targets - Water regimes - Thresholds of Potential Concern		
D. Maintain or enhance specified vegetation community within each proposed WMU in terms of : - species composition - vegetation structure - function - area (SMO and VDO)	D.1-D.n. Specify - water regime for each vegetation community within each proposed WMU - Thresholds of Potential Concern for each proposed WMU	Existence values; option values; bequest values: communities depleted at State scale	1.14 Maintain health of sedges, giant rush and wetland communities; assist maintenance of majority of Moira grass; maintain up to half river red gum forest; provide events suitable for successful waterbird breeding; 55% of wetlands inundated 1.6 Protect and restore Moira grass plains 1.13 Reduce encroachment of giant rush and River Red Gum onto Moira Grass plains 1.9 Increase the area of Moira grass plains 1.11 provide winter-spring floods to 50% of Red Gum Forest 1.15 maintain health of majority of River Red Gum wetland system ; maintain some river red gum woodland; 66% of wetland system inundated 1.16 Maintain up to one half of river red gum woodland communities o 75% of wetland system inundated

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
			4.5 protect the health and viability of the River Red Gum Forest 11.2. 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 Woodlands
	D.o. Control weeds Specify - species and controls for each - Thresholds of Potential Concern for each proposed WMU		6.9 Minimise the impact of pest plants, animals, insects and diseases on the ecological, economic and cultural values of State Forest. Prevent the introduction of new pests and the spread of pests into sensitive areas
	D.p Grazing Specify - Thresholds of Potential Concern for each proposed WMU - Exclusion or controls on grazing by cattle		Check plans
	D.q Control logging and firewood collection Specify - controls (refer Value Delivery Objectives below) - Thresholds of Potential Concern for each proposed WMU		4.12 Protect the forest, life and property from Fire 6.8 Ensure that the management strategies established in this Plan and respective fire protection plans covering the FMA are complementary. Ensure that the fire protection strategies consider ecological values in conjunction with the requirement to provide adequate protection of adjacent landholders and forest assets
	D.r. Manage human recreation impacts on vegetation community Specify - controls (Refer Value Delivery objectives below) - specify Thresholds of Potential Concern for each proposed WMU		
Objectives that deliver values (VDOs)			
E. Manage identified areas to preserve Indigenous cultural values	E.1. Specify strategies including: - conservation of sites - access - interpretation if appropriate - fire protection - Thresholds of Potential Concern	Direct use values: Indigenous cultural values	2.2 Social goal To manage natural assets and their supporting infrastructure in a way that is responsive to the visions and values of communities of interest, is what the community wants to achieve socially, and that recognises the opportunities for management presented by existing and evolving social networks. 4.8 protect sites and areas of Indigenous and European cultural significance 4.16 facilitate the involvement of the Yorta Yorta Indigenous, local and state-wide interest groups and the general public in the management of the forest 6.10 Protect and maintain the cultural and historic values of State Forest. Encourage sensitive use of selected historic places for the education and enjoyment of the public. Establish and maintain relationships with local Indigenous communities and provide for their greater involvement in forest

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
			management 4.15 promote public awareness, appreciation and understanding of the natural and cultural environment through appropriate interpretative and education programs
F. Manage identified areas to preserve post-settlement cultural values	F.1. Specify strategies including: - interpretation - conservation of sites - access - fire protection - Thresholds of Potential Concern	Direct use values: post-settlement cultural values	2.2 Social goal To manage natural assets and their supporting infrastructure in a way that is responsive to the visions and values of communities of interest, is what the community wants to achieve socially, and that recognises the opportunities for management presented by existing and evolving social networks. 4.15 promote public awareness, appreciation and understanding of the natural and cultural environment through appropriate interpretative and education programs 6.10 Protect and maintain the cultural and historic values of State forest. Encourage sensitive use of selected historic places for the education and enjoyment of the public. Establish and maintain relationships with local Indigenous communities and provide for their greater involvement in forest management
G. Develop and maintain provision for a range of recreational and educational opportunities, with specific strategies to manage conflicts between these values Subject to achievement of system maintenance objectives	G.1. Support nature study – specify strategy, including: - interpretation - access	Direct use value : nature study	2.2 Social goal To manage natural assets and their supporting infrastructure in a way that is responsive to the visions and values of communities of interest, is what the community wants to achieve socially, and that recognises the opportunities for management presented by existing and evolving social networks. 3.9 Ensure recreational use is consistent with the protection of natural and cultural values 6.11 Provide public land recreation and tourism opportunities that are of high quality, diverse in their nature and setting, satisfying and safe. They should also be environmentally sustainable, economically viable and offer equity of access 4.7 develop existing opportunities and provide additional opportunities for visitors to participate in recreational activities, where consistent with other objectives 4.9 protect landscape values 4.13 take adequate precautions for the safety of visitors 4.15 promote public awareness, appreciation and understanding of the natural and cultural environment through appropriate interpretative and education programs 6.13 Improve knowledge about forest ecosystems and management activities and their interaction. Improve community understanding and awareness of the role of State forests and of forest management.
	G.2. Manage fishing and bait collection: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern - others?	Direct use value: recreational fishing Existence, option and bequest values: maintenance of native fish populations	As above
	G.3. Manage boating (speed boating, waterskiing, kayaking, sightseeing, house	Direct use value: recreational boating	As above

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
	boating): - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern - others?		
	G.4. Manage picnicking and camping: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	Direct use value: picnicking	As above
	G.5. Manage bushwalking, orienteering: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern - others?	Direct use values: bushwalking and orienteering	As above
	G.6. Manage 4WD driving, trail biking and cycling: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use values: 4WD driving, trail biking and cycling	As above
	G.7. Manage pig, duck and fox hunting (specify strategy for each): - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use values	As above

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
	G.8. Manage horse riding: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use value	As above
H. Maintain opportunities for commercial use (subject to achievement of system maintenance objectives)	H.1. Manage cattle grazing: - zoning (time and space) - access - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use value: cattle production	2.2 Social goal To manage natural assets and their supporting infrastructure in a way that is responsive to the visions and values of communities of interest, is what the community wants to achieve socially, and that recognises the opportunities for management presented by existing and evolving social networks. 2.3 Economic goal To manage natural assets and their supporting infrastructure in a way that is responsive to what the community wants and can afford to achieve economically and that recognises the opportunities for the further sustainable development of those assets. 6.4 Provide grazing access consistent with the conservation of biodiversity and cultural management goals for State forest.
	H.2. Commercial boat tours: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use value	As above
	H.3. Beekeeping: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use value	4.6 allow controlled, sustainable forest utilisation for products such as timber, grazing and honey, where consistent with other objectives 6.5 Continue to provide access to State forest for bee keeping while minimising any adverse impact on other forest values 7.1. To maintain and where possible improve existing forest values.
	H.4. Timber harvesting: - controlled, sustainable forest utilisation where consistent with other objectives - Maximise utilisation of sawlogs from timber harvesting operations while continuing to provide other timber	Direct use value	4.6 allow controlled, sustainable forest utilisation for products such as timber, grazing and honey, where consistent with other objectives 6.3 Provide a long-term sustainable supply of hardwood sawlogs to the timber industry. Maximise utilisation of sawlogs from timber harvesting operations while continuing to provide other timber products through integrated and silvicultural operations. Apply silvicultural treatments and prescriptions that are environmentally and economically sound and which improve the overall

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
	products through integrated and silvicultural operations - Apply silvicultural treatments and prescriptions that are environmentally and economically sound and which improve the overall productivity of the forest		productivity of the forest 6.12 Provide and maintain a forest road network suitable for forecast levels of forest utilisation, recreation and fire management and to standards adequate for intended uses, safety and minimal environmental impact 7.1. To maintain and where possible improve existing forest values. 7.5. Sustain and where possible improve forest growth and yield levels.
	H.5. Firewood collection: GET FROM PLANS	Direct use value	
	H.6. Manage exploration and mining within the constraints of those laws: - zoning (time and space) - code of practice - communication and education - Thresholds of Potential Concern (see text section 4.9) - others?	Direct use value	6.6 Provide for mining and exploration in State forest in accordance with the Minerals Resources Development Act 1990. Provide for the controlled use of other non-renewable resources such as sand and gravel in accordance with the Extractive Industries Development Act 1995. Minimise the impact of exploration, mining or extraction activities on State forest values
I.0. Provide scientific research opportunities (subject to achievement of system maintenance objectives)	I.1. Code of practice	Indirect use value (the only IUV identified that is not an external ecological function value): research outputs	3.1 Increase the scientific understanding of wetland ecosystems and their management requirements. 3.10 Develop ongoing consistent programs to monitor ecological character 4.14 provide appropriate opportunities for scientific research, especially that which will provide information of value for future management 6.13 Improve knowledge about forest ecosystems and management activities and their interaction. Improve community understanding and awareness of the role of State forests and of forest management. 8.5 5: To record and evaluate information on the Forest's history and past and on_going management practices, and apply that information to water management and to assessment of the water Management Strategy's performance. 8.5.1. Document present and past water management practices. 8.5.2. Record, collate and document Forest experience and knowledge from all sources: Indigenous and non_ Indigenous people, agency records, government archives, historical societies, anecdotal information etc. 8.5.3. Establish and maintain an information system for this - information. 8.6: To monitor, record and evaluate scientific information required to manage water flow operations efficiently, and to use that information in assessing the Water Management Strategy's performance and in managing adaptively. 8.6.1. Develop ecosystem indicators, and inventory and monitoring systems for flora, fauna and ecological processes. 8.6.2. Measure, record and evaluate information required to effectively manage the Barmah-Millewa

Proposed New Objectives	Proposed New Strategy	Values (from table 3.1.) Addressed by Proposed New Objectives and Strategies	Related Objectives from Other Plans and Strategies
			Forest ecosystem, and report it against specified performance criteria. 8.6.3. Evaluate remote sensing of Forest flooding and vegetation health to complement field observations. 8.6.4. Develop a database containing a Geographic Information System and other information. 8.6.5. Specify performance criteria and develop optimum water management options for each water management area, based on information collected. 8.6.6. Continue to model flows through regulators, Forest runners and the River Murray)', to provide hydraulic knowledge for operating Forest regulators. 8.6.7. In response to information acquired, assess the Water Management Strategy's performance and modify actions progressively in accordance with adaptive management
J. Maintain role as part of mesic corridor through a drier landscape – provides linkages between a number of remnants	J.1. Is there a need to specify a strategy?	External ecological function value	3.4 Manage Ramsar sites within an integrated catchment management framework.
K. Minimise impacts of salt flushing events (from Forest to river/channels) – check if salt storage in floodplain is an issue	K.1. Specify strategy and Thresholds of Potential Concern (see text section 4.9)	External ecological function value	3.4 Manage Ramsar sites within an integrated catchment management framework.
L. Maintain or enhance role as part of regional, national and international wetland system.	L.1. Strategy specified by RAMSAR	External ecological function value	1.1 Protect the ecological character of the floodplain, as required under the Ramsar convention
M. Maintain or enhance flow regulation capacity (subject to achievement of system maintenance objectives)	M.1. Is there a need to specify a strategy?	External ecological function value	
N. Maintain or enhance flood mitigation capacity (subject to achievement of system maintenance objectives)	N.1. Is there a need to specify a strategy?	External ecological function value	4.11 Provide for flood mitigation
O. Maintain or enhance populations of selected rare or endangered species (flora and fauna)	O.1-n. Specify separate strategies for each rare or endangered species. Specify Thresholds of Potential Concern (see text section 4.9)	Existence, option and bequest values	

5. Classification of floodplain vegetation communities

Judith Harvey and Sophie Bickford

5.1 Background and approach

The Barmah Asset Environmental Management Plan (AEMP) (DSE and GBCMA 2005) aims to achieve a suite of ecological objectives, reflecting a range of values, primarily through the manipulation of hydrological conditions and water regimes (Figure 1.1.) An appropriate vegetation classification and map are fundamental to this. This chapter documents the vegetation classification and mapping exercises in Barmah-Millewa wetland, and evaluates the suitability of the classifications and maps for management of Barmah.

Vegetation may be classified using many structural/physiognomic and floristic, ecological, environmental and other derived features (such as potential for a particular land use). The usefulness of a classification should be judged in relation to its purpose. Here we make an assessment of the utility of the current vegetation classifications for delivering the values through the management for ecological objectives (system maintenance and value delivery) of Barmah.

5.2 Vegetation classifications

The following six vegetation classification and mapping exercises cover all or parts of Barmah-Millewa:

- Barmah State Forest, Vegetation, Birds and Mammals Summer (Chesterfield);
- Murray Riparian Vegetation Mapping 1986 (Margules & Partners);
- Ecological Vegetation Communities, Murray Fans Bioregion (EVC);
- NSW DIPNR Deniliquin survey; Mathoura, Tuppal and Echuca 1:50 000 Map Sheets;
- Forestry Quality mapping;
- New South Wales Vegetation Classification, Benson; and
- Mapping of the Understorey Vegetation in Barmah Forest, Victoria - (Frood and Ward 2001).

They present communities defined using different attributes, over different extents, at different scales and at different points in time (Table 5.1).

The mapping exercises and the communities they delineated are described are discussed below.

Table 5.2 documents the communities, associated species and, where denoted, land forms.

Table 5.1: Summary of Vegetation Classifications for Barmah-Millewa.

Title	Year		Extent	Attribute information	NVIS Components (Level) See table 5.3)	No. of units in Barmah Millewa	Spatial scale	Custodian
	Survey	*Map*						
Barmah State Forest, Vegetation, Birds and Mammals Summer 1979 (Chesterfield)	1979	1983	Floodplains from Barmah township to Ulupna Island on Victorian side	Dominant species ascribed by their frequency and or life-form appearing to exert a controlling influence over their associates	Dominant growth forms (multiple),,implied cover, height of up to 3 strata and dominant species (Level V)	13	1:125 000	Forests Commission Victoria
Murray Riparian Vegetation Mapping (Margules & Partners)	1987-1988	1986 - 1991	Floodplain of River Murray: Hume Dam to upper end of lake Alexandrina	Height structure	Dominant growth form for dominant stratum (Level I)	3	1:100,000 Auslig topo maps for base work	MDBC
EVC, Murray Fans Bioregion	1992 - ongoin g	Circa 2002	Murray Fans Bioregion, but Victoria wide	Structure and floristics. Plus information on landscape position, soils hydrological requirements and conservation status.	Structure (height & cover) of dominant strata including dominant species (Level IV or V)	11	1:100 000	Vic DSE
Forestry Quality Mapping (New South Wales & Victoria)			Barmah – Millewa forests	Height structure	Dominant growth form (Level I)	3		Forests Commission Victoria
DIPNR Deniliquin survey; Mathoura, Tuppal and Echuca 1:50 000 Map Sheets	2003 - 2004	2003 - 2004	Mathoura, Tuppal and Echuca 1:250 000 Map Sheets	PATN classification of communities. Principal species in tree, shrub, Sedge/rushes/grasses and groundcover layers	Dominant growth forms (sometimes multiple) cover, height and Common species (Level VI)	13	1: 50,000	DIPNR NSW
NSW Vegetation Classification (Benson)	Circa 2002	-	Western Plains New South Wales	Dominant species in each strata, characteristic species, and structure	Dominant growth form for dominant stratum (Level I)	9/10	Not spatial	
Mapping of the Understorey Vegetation in Barmah Forest, Victoria (Frood)	2001 - 2006	-	Barmah	Vegetation class (complex), common species and hydrological influence. Many mosaics of 2 or more classes.	Dominant growth forms (sometimes multiple) cover, height and Common species (Level VI)?	88 + complexe s	1:10,000	GBCMA

Table 5.2: Documentation of floodplain vegetation communities defined by past mapping exercises in Barmah – Millewa

Chesterfield	EVC	Frood Vegetation Type-Main	Frood Vegetation Type-Secondary	Margules	DIPNR (Millewa forest)	John Benson, NSW Riverina classification
Formation /Community /Associated species					**Principal species**	**Class**
Rushland #1 Giant Rush Beds (< 2.5 m) Myriophyllum propinguum, Ludwigia peploides, Azeolla filiculoides, Polygunum hydropiper	**Reed Swamp (300):** Closed to open grassland/sedgeland to 3 m tall, dominated by Common Reed and Cumbungi. Small aquatic and semi-aquatic species occur amongst the reeds. Occurs on Quaternary sedimentary geology of mainly estuarine sands, soils are peaty, silty clays and average annual rainfall is approximately 600mm. It requires shallow water to 1 m deep and low current-scour and can only tolerate very low levels of salinity	**B Rushland/ tall sedgeland**: Juncus, Common reed, Cumbungi Marshland		Open areas	**Very Tall Rushland**. FLP012 Juncus ingens, Typha orientalis, Phragmites australis. Azolla pinnata, Amphibromus fluitans, Persicaria lapathifolia, Alternanthera denticulata, Persicaria prostrata, Centipeda cunninghamii, Pseudognaphalium luteo-album, Centipeda minima, Stellaria angustifolia, Pseudoraphis spinescens, *Ranunculus sceleratus, *Rorippa palustris, Triglochin sp., Ludwigia peploides subsp. montevidensis. Minor occurrences: RRG	Not denoted
Grassland #2 Moira grass 0.5 m. 14.3%	**Moira Plain Wetland (289):** Wetland dominated by floating aquatic grasses (which persist as turf during some of the drier periods), occurring in the most flood-prone riverine areas. Typically treeless but sometimes with thickets of saplings or scattered more mature specimens of E. camaldulensis. Occupies temporary shallow lakes in the most flood prone riverine areas, also as a narrow intermediate band around some floodway ponds.	**D Wetplains: Moira Grass**, Upright Milfoil, Common Spike rush Seasonal wetlands in flood prone areas- persistent inundation	P Dry grassy plains: Treeless; Spike rush in depressions amongst wallaby grasses and introduced annuals Subject to only incidental inundation from the highest level flooding/or seasonal waterlogging small	Open areas	Moira grass Grassland not delineated in Millewa. Does it occur? Pseudoraphis mapped as u/s occuring with Eleocharis acuta under RRG and in Rushlands with Juncus, Typha and Phragmites.	12. Shallow marsh of regularly flooded depressions on floodplains

Chesterfield	EVC	Frood Vegetation Type-Main	Frood Vegetation Type-Secondary	Margules	DIPNR (Millewa forest)	John Benson, NSW Riverina classification
Open forest – woodland #3 Red Gum over moira grass (33 m.) Understorey diversity low	**Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic (255)** – No description. Riverine grassy woodland (295): occurs on floodplains of major rivers in a slightly elevated position where floods are rare on deposited silts and sands, forming fertile alluvial soils. River Red Gum wood plant at 20 m tall with a groundlayer dominated by graminoids and sometimes lightly shrubby or with chenopod shrubs.	**F Riverine Swamp Forest Series 1**: River Red Gum; Moira grass, Common Spike-rush Prone to deep (>1m) regular flooding		Red Gum forest	If occurring in Milewa it is probably classed in FLP013: RRG over Eleocharis acuta, Pseudoraphis spinescens, Tall open forest to sedgeland with isolated trees.	#2 River Red Gum-sedge dominated tall open forest in frequently flooded sites of the semi-arid warm climate zone
Open forest – woodland #3 Red Gum over moira grass (33 m.)	**Billabong Wetland (344):** Herbland of permanent to semi-permanent wetland, dominated by sedges and/or aquatic herbs. Occurs on old anabranches of riversystems on the floodplains of major rivers, which may include deep permanent water and shallow seasonal water	**C Floodway ponds**: Moira Grass, Fern sedge Seasonally dry ponds		Red Gum forest		
Open forest – woodland #4 Red Gum over Amphibromus neesii (Swamp wallaby grass) and new introductions (31 m) 2% Mapped fringing river channel)	**Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic (255)**	**Q Wet Riparian Verges an Creeks:** River Red Gum; Common Blown-grass and love - grasses Associated with major drainage lines including sandy beaches		Red Gum forest	If occurring in Milewa it is probably contained in FLP013 and FLP009.	

Chesterfield	EVC	Frood Vegetation Type-Main	Frood Vegetation Type-Secondary	Margules	DIPNR (Millewa forest)	John Benson, NSW Riverina classification
Open forest – woodland #5 Red Gum over Carex tereticaulis (terete culm sedge) in association and mosaic with swamp wallaby and warrego summer grass (28m) with #6, #7, #8 52%	**Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic (255)**	**K Floodpalin Forest, Series 1:** River Red Gum; Common Spike rush, usually with Swamp wallaby grass & some Terete-culm sedge or Warrego Summer grass Prone to regular shallow <1m) flooding low lying areas within less flood prone areas	241: River Red Gum; Terete-culm sedge, Warrego Summer-grass Prone to seasonal water logging and shallow inundation from higher level flooding but less prone to persistent shallow inundation		Tall Open Forest to Woodland. FLP009 RRG. Exocarpos strictus. Carex tereticaulis, Juncus amabilis, Paspalidium jubiflorum, Carex appressa.Groundcover: Ranunculus sessiliflorus, Calotis scapigera, Arthropodium minus, Cotula australis, Eleocharis pusilla, Carex inversa, Brachyscome basaltica var. gracilis, Wahlenbergia fluminalis, Eryngium ovinum, Leptorhynchos squamatus, Triglochin procerum, Ranunculus inundatus, Xerochrysum bracteatum, Cynodon dactylon.	#2 River Red Gum-sedge dominated tall open forest in frequently flooded sites of the semi-arid warm climate zone
Open forest – woodland #6 Red Gum over Carex tereticaulis (terete culm sedge) (28m)	**Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic (255)**	**L Floodpalin Forest, Series 2:** River Red Gum; Terete-culm sedge, Warrego Summer-grass Prone to seasonal water logging and shallow inundation from higher level flooding but less prone to persistent shallow inundation	R Riparian Tall Woodland: River Red Gum over Silver Wattle and Common Tussock GrassSandy terraces along the Murray	Red Gum forest	FLP009 - as above	#2 River Red Gum-sedge dominated tall open forest in frequently flooded sites of the semi-arid warm climate zone

Note; The correlation between vegetation descriptions are not direct. This table was constructed as part of a process to identify difference definitions of communities in Barmah

5.2.1 Barmah State Forest, Vegetation, Birds and Mammals Summer 1979

The most cited classification for Barmah is the 'Barmah State Forest, Vegetation, Birds and Mammals Summer 1979', published by Chesterfield *et al*. (1984) for the Victorian Forests Commission. It was based on the dominant species and their structural characteristics. It distinguished 13 community types: *Juncus ingens* Rushland; *Pseudoraphis spinescens* Grassland; nine *Eucalyptus camaldulensis* Open Forest to Woodland classes of varying heights and over different cyperaceous or grassy understoreys; *Eucalyptus melliodora – Eucalyptus microcarpa* Woodland to Open Woodland and *Eucalyptus largiflorens* Woodland to Open Woodland. Dominant species were defined as those species by which their frequency and/or life form appeared to exert a controlling influence over their associates (Chesterfield *et al.,* 1984). Average tree height was determined from the Barmah Forest Assessment carried out seventeen years prior to the mapping exercise (Forests Commission Victoria, 1962). Tree height was used as a measure of site quality and assumed to reflect flooding characteristics of the forest. The vegetation was surveyed in the summer of 1979 and maps drafted in 1983 at 1:125000. Boundaries were determined from field mapping without aerial photographs (Chesterfield *et al.*, 1984).

5.2.2 Forestry site quality mapping

Smith (1983) classified Red Gum forests of Barmah according to 'site quality' based on mature red gum height. Classes were as follows; Site Quality I > 30 m, Site Quality II 21-30 m, Site Quality III < 21 m. Ref New South Wales Forestry map

5.2.3 Margules and Partners

In 1987 – 1989 Margules and Partners (MPPL 1990) surveyed and mapped the floodplain vegetation of the Murray and Edward Rivers and their anabranches between the Hume Dam and Lake Alexandrina, including Barmah and Millewa forests. It involved a floristic survey of 335 plots at 112 sites in September- November 1987, towards the end of a period in the mid 1980s of no large floods (Roberts, 2003). Plots of 400 m^2 recorded species cover-abundance. Floristic analysis was by numerical classification, defining groupings on species presence and abundance scores. Numerical classifications were assessed subjectively, with classes being retained if they reflected an 'obvious difference' in the vegetation. Thirty seven floristic communities were recognised. Twenty structural vegetation classes were then determined from aerial photographs. Maps at 1: 50000 scale were produced using aerial photographs, NATMAP 1:100,000 scale topographic maps and pre-existing vegetation maps. The reliability of the mapping varies between reaches of the river (MPPL 1990), depending on the scale, year of origin of the aerial photography and the nature of pre-existing mapping data, if it was used. Margules (1990) lists the Chesterfield map as an input data source, so it is likely that the vegetation classes and their boundaries were taking by simplifying Chesterfield's map. Congruence between Margules and Chesterfield boundaries suggest this was so. Aerial photography for the region may also have been drawn upon using the Echuca and Mathoura map sheets (Echuca 1:25 000 and compiled between 1977 – 1981; Mathoura 1: 45000, compiled in 1976). Most of Barmah forest is mapped as forest. Rush beds and Moira Grass plains are mapped as Open Areas. The *E. melliodora – E. microcarpa* Woodlands and *E. largiflorens* Woodlands delineated by Chesterfield are mapped as Mixed Woodland.

5.2.4 Ecological vegetation classes (EVCs)

Ecological vegetation classes (EVCs) were determined for Barmah forest in the mapping of the Murray Fans Bioregion at a 1:100 000 scale. EVCs are defined by the Commonwealth of Australia and Natural Resources and Environment (1996) as units "…consisting of one or a number of floristic communities that appear to be associated with a recognisable environmental niche, and which can be characterised by a number of their adaptive responses to ecological processes that operate at the landscape scale. Each ecological vegetation class is described through a combination of its floristic life form and reproductive strategy profiles, and through an inferred fidelity to particular environmental attributes". They were originally designed to be tools for regional and state-wide vegetation mapping and analysis as part of the East Gippsland Regional Forest Agreement. They aim to represent broadly similar environmental conditions and natural communities.

A criticism of the EVCs utility as a working tool has been that the concept has not been applied consistently by field workers due mainly to the lack of an explicit definition (ARIER, 2003). The Barmah area was mapped as part of the North East region of Victoria for which metadata and reports of methods and classification attributes were not found. The metadata describing state-wide EVCs as a whole (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/veg_evc) records that in cases EVC units are based on pre-existing vegetation maps. It appears as though some EVC boundaries and classes in the Barmah forest have been based on Chesterfield. Eleven EVCs are recorded for the Barmah Forest:

Dominant Classes:

- EVC300 Reed Swamp, which is comparable to Chesterfield's *Juncus ingens* Rushland in distribution;
- EVC289 Moira Plain Wetland, which encompasses some of Chesterfield's Moira grass Grassland, however some of Chesterfield's Moira Grass Grassland has been mapped as EVC255.
- EVC255 constitutes the greater part of Barmah Forest, it being a complex of Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Formation Mosaic. EVC255 encompasses Chesterfield's *E. camaldulensis* communities #4, #5, #6, #7, #8 and part of #10.

Classes with more restricted occurrences through EVC255 are:

- EVC652 Lunette Woodland, an open Eucalypt woodland to 15 m tall;
- EVC 295 Riverine Grassy Woodland (extant comparable with Chesterfield's *E. camaldulensis* over swamp wallaby, brown black wallaby with common spike rush #10);
- EVC 103 Riverine Chenopod woodland (Chesterfield's # 13 *E. largiflorens* Woodland);
- EVC803 Plains Woodland (Chesterfield's #12 *E. melliodora – E. microcarpa* Woodland);
- EVC872 Riverine Grassy Woodland/Plains Woodland/Riverine Chenopod Woodland complex (Chesterfield's # 13 *E. largiflorens* Woodland);
- EVC104 Lignum wetland (very small amount, not within the Living Murray Boundary for Barmah);
- EVC 168 Drainage Line Woodland (off Chesterfield's map extent)
- EVC334 Billabong Wetland (Chesterfield's #3 RRG over Moira Grass).

5.2.5 New South Wales DIPNR 'Deniliquin' mapping

New South Wales DIPNR (DIPNR 2004) mapped the vegetation of Millewa forest using structural and floristic qualities at 1:50,000 scale as part of six 1:100,000 map sheets for the Deniliquin region. Boundaries were determined using environmentally stratified floristic surveys. Data were evaluated using numerical clustering (PATN, PCORD) to generate floristic groups. Spatial distribution of classes was derived from 1:50 000 scale, colour aerial photography (January 2003) supplemented by geo-rectified Landsat TM false colour satellite imagery (10/10/2002). The minimum polygon size was 25 ha although the meta-data states that in some cases areas smaller than this were delineated if a community was deemed to be of significance. The estimated accuracy of the vegetation boundary data are between 12.5 and 75 m, dependent on the intensity of pre-existing location reference data. Some checking of polygon attributes was done after the mapping process.

Most of Millewa forest is mapped as FLP009 *Eucalyptus camaldulensis* Tall Open Forest to Woodland over *Exocarpus strictus, Carex teretecaulis, Juncus amabilis, Paspalidium jubiflorum, Carex appressa, Ranunclulus sessiflorus* and others. It is interspersed with patches of:

- FLP 013 *E. camaldulensis* Tall Open Forest to Sedgeland with Isolated Trees over *Eleocharis acuta, Pseudoraphis spinescens Persicaria lapathifolia* and others;
- FLP012 *Juncus ingens, Typha orientalis* and *Phragmites australis* Very Tall Rushland;
- FLP 008 *Callitris gracilis subsp murrayensis* Tall Woodland to Open Woodland over *Ajuga australis* and others;
- ALP018 *Erodium crinitum - Paspalidium constrictum* Grassland;
- ALP022 *Eucalyptus largiflorens* Mid-high Open Forest to Open Woodland over *Muehlenbeckia florulenta* and chenopods;
- ALP 024 *Eucalyptus melliodora* Tall Open Forest to Open Woodland; ALP025 *Eucalyptus microcarpa* Tall Open Forest to Open Woodland;
- ALP026 *E. microcarpa – E. melliodora, E. largiflorens* Tall Open Forest to Open Woodland
- minor occurrences of other Grassland communities.

5.2.6 Classification and Assessment of the Vegetation of NSW

A classification of the native vegetation of the western plains of NSW has been conducted for the NSW Biodiversity Strategy program (Benson, in review a& b). The classification was based on a compilation and literature review, mapping and survey documentation. Each vegetation community is described according to dominant species in each strata, characteristic species, structure and the equivalent classes of other authors. The classification has not mapped community boundaries, although record of Conservation Reserves, Botanical Divisions, Local Government Areas, Catchment Management Areas, IBRA Regions and IBRA Provinces for each community provide some spatial context. An assessment of the degree of modification and the conservation status of each community is included, along with estimates or measurements of pre-European extent, current extent and the area protected within specified formal conservation reserves, secure property agreements and voluntary conservation agreements as well as ongoing threatening processes. Typical land use, substrates, soil texture and landforms are also recorded for each community. The mapping project is available as a Microsoft Access 2002 database. It contains a field assigning a confidence level to the community classification. The adequacy of formal plot surveys of the community is also recorded. Descriptions of the database will be published in *Cunninghamia* (The Royal Botanic Gardens Journal of Plant Ecology) and placed on the Internet.

5.2.7 Mapping of the Understorey Vegetation in Barmah Forest, Victoria

The project Baseline Vegetation Mapping of Barmah Forest was undertaken with financial assistance from the MDBC via the Barmah-Millewa Forum. Frood and Ward (2001) state that the objective of the study was to produce a revised vegetation map of Barmah forest to assist ecological understanding and management. An initial task was to determine suitable floristic units and characterise these as subsets of the units of Chesterfield. Initial mapping was conducted at a scale of 1:10,000 with a minimum polygon size of 1 ha. Mapping began in 2000 and is due for completion in 2006. The methodology is not clear from the report. Initial field inspection revealed a 'high variation in the reliability of the existing mapping'.

Sixty six map units were recognised in 2001. Description of these includes structural, floristic and hydrological descriptions as well as comments on the correlation with Chesterfield's units. These can be grouped into 20 vegetation types (see table 5.3, below) according to The draft mapping (dated 19/7/05) includes nearly 500 different combinations of mosaics of the initial 66 units totalling contained over 8,000 polygons.

Table 5.3: Vegetation types derived from Units mapped by Frood

	Vegetation type	Species present	Hydrology	Frood vegetation Units
A	Lakes and Ponds:		Semi permanent and permanent Wetland	101,02
B	Rushland/ tall sedgeland:	Juncus, Common reed, Cumbungi	Marshland	011, 012, 013, 021, 031, 032
C	Floodway ponds:	Moira Grass, Fern sedge	Seasonally dry ponds	041, 042, 043
D	Wetplains:	Moira Grass, Upright Milfoil, Common Spike rush	Seasonal wetlands in flood prone areas- persistent inundation	051, 052, 061, 062, 071, 081, 082
E	Ephemeral wetland:	Floating Club-sedge	Ephemeral wetland	091
F	Riverine Swamp Forest Series 1:	River Red Gum; Moira grass, Common Spike-rush	Prone to deep (>1m) regular flooding	101, 102, 103, 104, 105, 106
G	Riverine Swamp Forest Series 2:	River Red Gum; Giant rush, Common reed	Low-lying sites	111, 112,
H	Riverine Swamp Forest Series 3:	River Red Gum; Fern Sedge or small Spike-rush	Flood prone, Sustained flooding	113, 114
I	Riverine Swamp Forest/woodland Series 4:	River Red Gum; Moira, Warrego Summer grass & Terete-culm grass, with some Common Spike- rush and Swamp wallaby-grass	Prone to regular shallow <1m) flooding Dryer than L	121, 122, 123, 124
J	Floodplain Regeneration Thickets:	River Red Gum; variable understorey		131, 132
K	Floodplain Forest, Series 1:	River Red Gum; Common Spike rush, usually with Swamp wallaby grass & some Terete-culm sedge or Warrego Summer grass	Prone to regular shallow <1m) flooding low lying areas within less flood prone areas	0211, 212, 213, 214
L	Floodplain Forest, Series 2:	River Red Gum; Terete-culm sedge, Warrego Summer-grass	Prone to seasonal water logging and shallow inundation from higher level flooding but less prone to persistent shallow inundation	221, 222
M	Floodplain Forest, Series 3:	River Red Gum; Warrego Summer grass, Terete-culm Sedge	Prone to brief inundation during major flooding events	231, 232,
N	Floodplain Swampy Woodland:	Open River Red Gum; Swamp wallaby grass, Common Spike rush and Brown back wallaby grass	Subject to shallow inundation from higher level flooding with extended dry periods.	241, 242, 243, 244
O	Riverine Grassy Woodland:	Open River Red Gum; Wallaby Grasses and introduced annuals	Subject to only superficial flooding from the highest level of flooding	311, 312, 313, 314, 315,

	Vegetation type	Species present	Hydrology	Frood vegetation Units
P	Dry grassy plains:	Treeless; Spike rush in depressions amongst wallaby grasses and introduced annuals	Subject to only incidental inundation from the highest level flooding/or seasonal waterlogging small	411
Q	Wet Riparian Verges and Creeks:	River Red Gum; Common Blown-grass and love -grasses	Associated with major drainage lines including sandy beaches	511, 521, 531, 541
R	Riparian Tall Woodland:	River Red Gum over Silver Wattle and Common Tussock Grass	Sandy terraces along the Murray	551, 552
S	Drier Woodland:	Yellow and Grey Boxes or Black Box	Above the influence of flooding	611, 612,711, 811,
T	Altered:	River Red Gum; introduced species	In areas heavily grazed or campsites.	911, 912, 921

5.3 Evaluation of the classifications

The biotic diversity of a floodplain is primarily related to environmental gradients and disturbance regimes (Ward *et al* . 1999). Important gradients in the Barmah floodplain are the spatial and temporal distribution of flood waters, with flood waters providing the primary source of moisture in this region. The natural spatial and temporal hydrological gradients in Barmah forest are primarily a function of local geomorphology, connectivity and climate patterns. Geomorphic heterogeneity in the alluvial Murray system is largely a consequence of the river re-working channels within an older floodplain and of geomorphic events such as avulsions and uplifts (Roberts, 2003).

Ecological theory suggests that species respond individually to environmental gradients, disturbance and competition (Birks, 1986; Franklin, 1995). Nevertheless assemblages of co-occurring species with similar responses to these variables can be recognised for management purposes. A classification that represents a minimum number of attributes associated with recognisably different functional responses to these variables by vegetation communities is required for management of Barmah. Chapter 6 discusses these. We envisage a classification that subdivides Barmah into Water Management Units (WMUs) that takes into account the vegetation communities, their functional response classes and hydrological patterns. This definition builds on the concept of water management units described in the Barmah SEA Management Plan pg6 (DSE & GBCMA 2005). Their water management units are identified as areas which can receive similar watering events.

Prior to the development of the Frood (2005) map, Chesterfield's (1979) map provided the most classificatory resolution of the diversity in vegetation patterns in Barmah forest. River Red Gum height is a function of site productivity (Chesterfield, 1986), which in large part is a function of water regime. However there are limitations with the Chesterfield map. Spatial accuracy is not recorded and as boundaries were determined by 'field mapping', without aerial photography, suggests their accuracy may not be high. Additionally, since the map was River Red Gum has encroached on *Moira grass* Grassland (Frood and Ward 2001) and the extent of Giant Rush, *Juncus ingens,* has increased also at the expense of *Moira grass* (Frood and Ward 2001) Grassland. Figure 5.1 compares the main vegetation maps. These layers are all in the same projection, however the Chesterfields map was digitised from a scanned image, and Frood's maps were digitised from originals and referenced to the road network. So the EVC mapping is probably the most accurate referenced to roads and river with Frood's vegetation boundaries the most accurate (pers com. Richard Maxwell DSE).

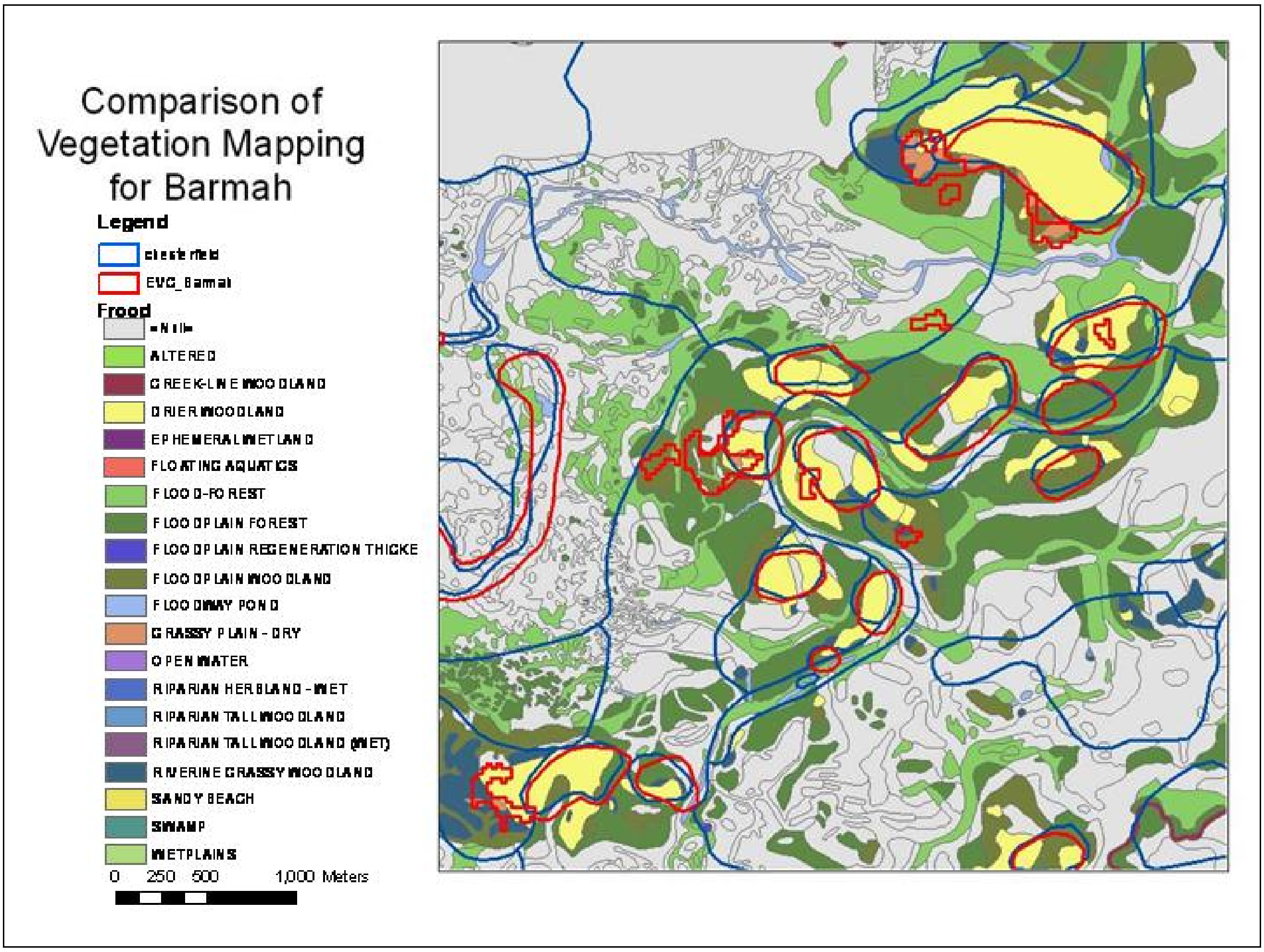

Figure 5.1 Comparison of Chesterfields, Frood and the EVC mapping

The Chesterfield map was the basis for the Margules maps for the Barmah region. Margules has grouped Chesterfield Red Gum community types, precluding this maps use for the management of the structural and floristic diversity of Red Gum forest in Barmah. Given its derivation from the Chesterfield map it is likely to be subject to the same problems of spatial accuracy as the Chesterfield map.

The EVC vegetation mapping approach, using environmental response attributes to define communities representing an 'environmental niche' or particular disturbance regime would seem to be well suited to further defining Water Management Units (WMU). However the scale at which EVCs have been determined in Barmah does not reflect the scale at which different water regimes operate and affect vegetation distribution, particularly with in the Red Gum forests. Most of Barmah Forest is mapped as EVC 255 which encompasses 5 Chesterfield Red Gum classes separated on overstorey height and dominant understorey species. While congruence between communities and their spatial extents suggests the EVC mapping exercise drew from the Chesterfield map, additional units were distinguished (EVC334 Billabong Wetland, EVC168 Drainage line woodland; EVC104 Lignum wetland) and some boundaries of comparable vegetation classes shifted.

A more detailed EVC mapping of the Murray River upstream of Echuca (excluding Barmah) and the lower reaches of the Goulburn, Ovens, King and Kiewa Rivers is currently being undertaken as part of the Victorian Environmental Assessment Council's River Red Gum Investigation (Alison Oats, DSE, Melbourne pers. com.) The mapping will concentrate on

EVC 255 Riverine Grassy Woodland/Sedgy Riverine Forest/Wetland Forest Mosaic (mapped in the original RFA mapping by Sue Berwick DSE Wodonga) and is based on the revised wetland typology of Doug Frood. For this project, Doug will be converting many of his mapping units for Barmah into EVCs and the resulting EVC map of Barmah based on his units. This map is due for completion by March 2005.

There are strong institutional reasons for using EVCs as the basis for setting objective. The GBCMA is required to use EVCs as a basis for reporting on the extent and condition of native vegetation across the catchment. The limitations in the earlier mapping outcome for Barmah stem largely from issues with implementation of the method, not from the experience elsewhere in the State (eg for forest management in East Gippsland) suggest that while there are limitations to EVC mapping, as with all classification methods, EVCs are a suitable system for management. The new EVC map for Barmah should provide a good basis for developing Water Management units (See chapter 8)

The DIPNR – Millewa mapping is up-to-date, is based on environmentally stratified surveys, separates vegetation on both structural and floristic attributes and its accuracy is quantified. However, the environmental stratification did not use hydrological gradients most affecting vegetation diversity in Millewa. Most of the region is mapped as FLP009 *E. camaldulensis*, *Exocarpos strictus* over *Carex tereticaulis*, *Juncus amabilis*, *Paspalidium jubilflorum, Carex appressa.* Direct comparison of the DIPNR vegetation classes with those delineated in Barmah is difficult with classes not easily being inter-relatable based on their descriptions.

Frood's classification has many classes which will be mapped to the new EVCs. There is a considerable improvement in the boundary detail of classes but this would probably be too fine for the delineation of general WMUs. Aspects of this detailed mapping, where it can be grouped and related to the digital elevation model, flood patterns and aerial photography, should contribute to the definition of WMUs.

5.4 Conclusions

The classifications of the vegetation of Barmah forest have used different attributes to distinguish classes, and have been undertaken at different classificatory and spatial scales and accuracies. Assessment of the interrelations and transferability of information between classifications was limited by non-comparable attribute data. In their present form, none of the classifications and mapping exercises provide appropriate Water Management Units for the management of the diversity and function of the Barmah forest. It is envisaged that a new improved EVC map will be appropriate. Ideally a vegetation classification for Barmah forest should represent the heterogeneity of the vegetation (both species compositional and structural) of the floodplain at a resolution relevant to management. Given that the vegetation patterning and dynamics in the area is most likely to be primarily a function of water regimes a functional responses classification that groups species in terms of their water regime requirements for establishment and growth would be most appropriate. A functional classification derived by grouping species according to their water regime requirements is presented in Section 8.4. This and the new EVCs can be compared to geomorphic patterns and a refined DEM. Some species distribution maps were established from Frood's maps and further mapping of species distributions can be made from the revised EVCs which will incorporate Frood's classification. A list of possible indicator species to map is also included in Section 8.4 together with the input of the functional response classification and flow inundation modelling effective Water Management Units can be derived.

6. Floodplain vegetation responses to water regime, grazing and fire

Jane Roberts

6.1 Preamble

A distinctive feature of floodplains – and a truism, also - is that they are an ecotone between terrestrial and aquatic systems; in the case of Barmah Forest, between the adjacent dryland of north-central Victoria and the River Murray. Thus although floods are indeed the primary driver of floodplain ecology, they are not the only influence; the alternate conditions of wet and dry mean that issues facing dryland managers elsewhere in Australia, such as grazing, resource utilisation and other human activities are relevant also on the floodplain.

Perceptions of floodplains are relevant to their management. Recognising hydrology as the driver of floodplain ecology makes it easy to think of the floodplain as a simple gradient in flood frequency, ranging from very frequently flooded to rarely flooded. This simple model is useful in terms of making sense of the particular combination of sameness and heterogeneity that seems to characterise floodplains. However, this model may be too simple: a recent study on the Sabie River, South Africa (van Coller *et al.,* 2000) found that it was most effective to use both environmental gradients and patch hierarchies to describe vegetation distribution and patterning.

Other perceptions of floodplain vegetation that are relevant are that plant communities are resilient and tough; contrasting with that is the perception that they are fragile. Underlying these is a knowledge limitation; that very little is known (and even less is documented) of temporal changes whether at time-scales such as seasonal, yearly or episodic yet it is accepted that floodplains are dynamic. This gap makes it hard to set meaningful objectives – especially those that look forward in time by incorporating the word sustainable or viable – for Barmah Forest; and it makes it doubly hard to place the kinds of changes the Forest appears to be undergoing since European settlement into a realist context.

6.2 River flows and floodplain inundation

Changes to the flow regime of the River Murray are significant for floodplain vegetation as these directly affect the inundation patterns (i.e. inundation regime or water regime) of Barmah Forest. In turn, inundation patterns are a major driver of the vigour and composition of plant communities on the floodplain. Understanding the nature of these changes is a critical first step in determining the issues relating to the vegetation of Barmah Forest.

Changes can be described from many perspectives. Spatial scale is used here as this links directly to distinct parts of the Forest, and to flow management, and hence potentially to Options. At the "catchment" scale, there are changes resulting from the construction and operation of Hume Dam and Yarrawonga Weir: these are the control, diversion and release of water from upland storages and from Yarrawonga Weir, and discussed below under River regulation. At the more "local" scale, there are changes resulting from the installation and operation of regulators on effluent creeks and separating the river channel from the floodplain: this includes on-floodplain management of "rain rejection" flows.

6.2.1 River regulation

Changes in surface hydrology are generally seen as a risk to environmental values (e.g. DSE 2003, DSE & GB CMA 2005) of the highest priority. A reach-scale description of these changes is given in Thoms *et al.* (2000) and an historical perspective is given by Maheshwari *et al.* (1995) and by Gippel and Lucas (2002). These changes affect floodplain inundation in the following ways (DSE & GB CMA, 2005):

- reduced frequency, duration and inundation area of winter-spring floods;
- altered timing of floods (sometimes referred to as seasonality);
- increased frequency of small summer floods;
- reduced variability in flood flows;

Although generally true, the dot-point summary (above) glosses over an aspect of river regulation that is particularly important for floodplain ecology, namely that regulation has a differential effect across different flow magnitudes. This means that flood events of a particular magnitude are more impacted than events of a different magnitude or threshold. In other words, a floodplain is not uniformly affected by river regulation. This is not always well-recognised, and is sometimes unintentionally glossed over and simplified. An example of glossing over is the 'confetti' diagram (Figure 4 in DSE & GB CMA 2005, and Fig 6 in MDBC, 2005). This powerful visualisation of the effects of regulation is shown for three flow thresholds; but it suffers from using flow bands that are very broad (eg equivalent to 0 to 55% flooded, 55-65% flooded) and so returns a coarse answer. Moreover it is difficult to relate this diagram to just Barmah Forest, as needed here, for it shows the effects on the combined Barmah-Millewa Forest, and the few comparative data suggest that flow-inundation area relationships for Barmah and for Millewa are not always the same, see below (Chapter 6.3.4).

To explore in more detail the effects of river regulation on floodplain inundation, a spells analysis was done for 109 years of simulated daily flow (Current and Natural) at Tocumwal[3], for six flow thresholds (greater than 12,000, 15,000, 20,000, 30,000, 40,000 and 50,000 ML day). The lowest flow threshold of 12,000 ML day was chosen to minimise overlap with the effects of unseasonal flooding and rain rejections, as these have been thoroughly analysed by Chong (2003) and Chong and Ladson (2003). Results are plotted in Figure 6.1 (spell frequency, duration characteristics) and in Figure 6.2 (timing effects). Trends for each flow threshold are summarised in Table 6.1, indicating whether Current is an increase, similar to, or a decrease, relative to Natural.

The spells analyses show changes in frequency, duration, duration variability and timing (when threshold begins to be exceeded) of floods.

Frequency – the number of times that Current river flow exceeds a threshold (relative to Natural conditions) is greatly increased at 12,000 ML day, probably a consequence of rain rejection events. however, this effect changes as flow magnitude increases. Thus the number of times that Current river flow exceeds a threshold (relative to Natural conditions) is similar at 15,000 ML day and is generally reduced by about half for flow thresholds of 20,000 ML day and above.

Mean Duration – the length of time that river flows stay above a flow threshold is considerably shortened under Current conditions for flows of 12,000 ML day, from about 2 months to about 1 month; this gradually attenuates, and mean duration is unaffected for flows of 30,000 ML day and above.

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[3] Simulated flow data (ML day) for Tocumwal was provided by the Murray-Darling Basin Commission, using their flow model BigMod; natural conditions was run on 31/05/2005, Run 6781000 and benchmark 0505 was run on 31/05/05, Run 6785000. GetSpell – program developed by Rory Nathan of Sinclair Knight Merz for the Department of Natural Resources & Environment, Victoria. Version 1.1. February 1999.

Maximum Duration – this is not much affected by regulation, and under Current conditions is consistently slightly less than under Natural for all flow thresholds analysed.

Variability – here meaning variability of the duration of flooding, is actually increased. This is consistent with historic comparison, pre- and post-Hume Dam (eg Figure 5 in Bren and Gibbs, 1986, Figure 12 in Bren *et al.,* 1987) using Box-and-Whisker plots, which showed that post-Hume flooding was more variable than pre-Hume flooding. This finding tends to be overlooked. Instead, it is sometimes stated that variability has been reduced by regulation (eg DSE & GBCMA, 2005, p9) meaning that a specific component (not specified) has been affected: usually this refers to loss of seasonal range.

Timing - flows exceeding 12,000 ML day are now more likely and more numerous in early autumn (April) and from late winter to early summer (August to December). Regulation has affected a seasonal shift with a net loss of late autumn-early winter floods evident for flow thresholds from 12,000 to 30,000 ML day, and loss of winter floods for flow events of 30-40,000 ML day.

Specific consequences of changes in frequency, duration, duration variability and timing are that:

- a reduction in mean duration results in less time for the river to flow onto the floodplain hence the extent of flooding is reduced. Also, the time that water stays on the floodplain is shorter, so time to penetrate the soil and re-charge soil moisture is also reduced. Water is retained for a shorter time in wetlands and depressions before evaporating away, hence there is less time for plants to germinate (or re-grow), flower and set seed (and/or replenish reserves), especially for submerged and floating-leafed plants. The ecological consequences are potentially quite severe if accumulated through time.
- a reduction in maximum duration probably has little ecological consequence.
- an increase in variability of duration means the duration of a flood is less ‘reliable’ with possibly quite serious effects on composition of plant communities as this is likely to favour species with wide tolerances, or opportunists.
- a shift in the timing of when floods begin away, from autumn-winter and towards winter-spring, means: a gradual alteration in the species composition of wetland plant communities, especially annual herbs, as species that are cool-season growers, possibly *Callitriche,* are disadvantaged.

Other characteristics not specifically considered in this type of spells analysis but also important ecologically are:

Recession - the timing of recession.

Interval between flood events - although sometimes dismissed as simply a statistic that is derived from frequency, it is worth articulating the interval and how it has changed in units of time, whether days, weeks or years, as this connects directly to species capacity to survive, whether as a seed, perennating organ (turion, bud or rhizome) or under conditions of water stress and storage depletion.

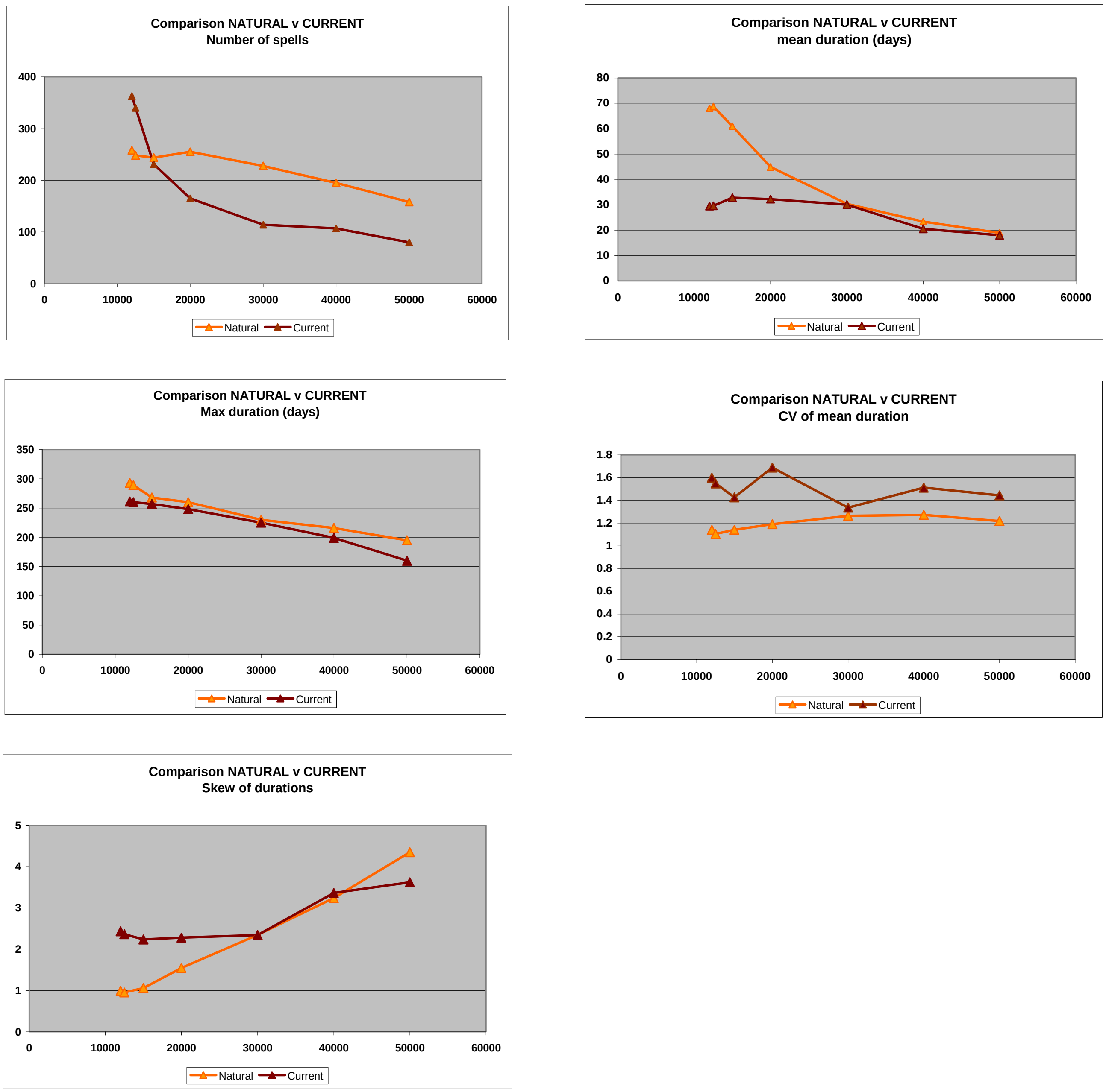


Figure 6.1 Effect of regulation on river flow at Tocumwal.
Horizontal axes are river flow in ML/d. Figures show the number of times in 109 years that each of six flow thresholds is exceeded for five statistics: number (frequency); mean duration; maximum duration; coefficient of variation of duration (%); skew of duration. Also shown is 12,500 ML day but this is not discussed in the text.

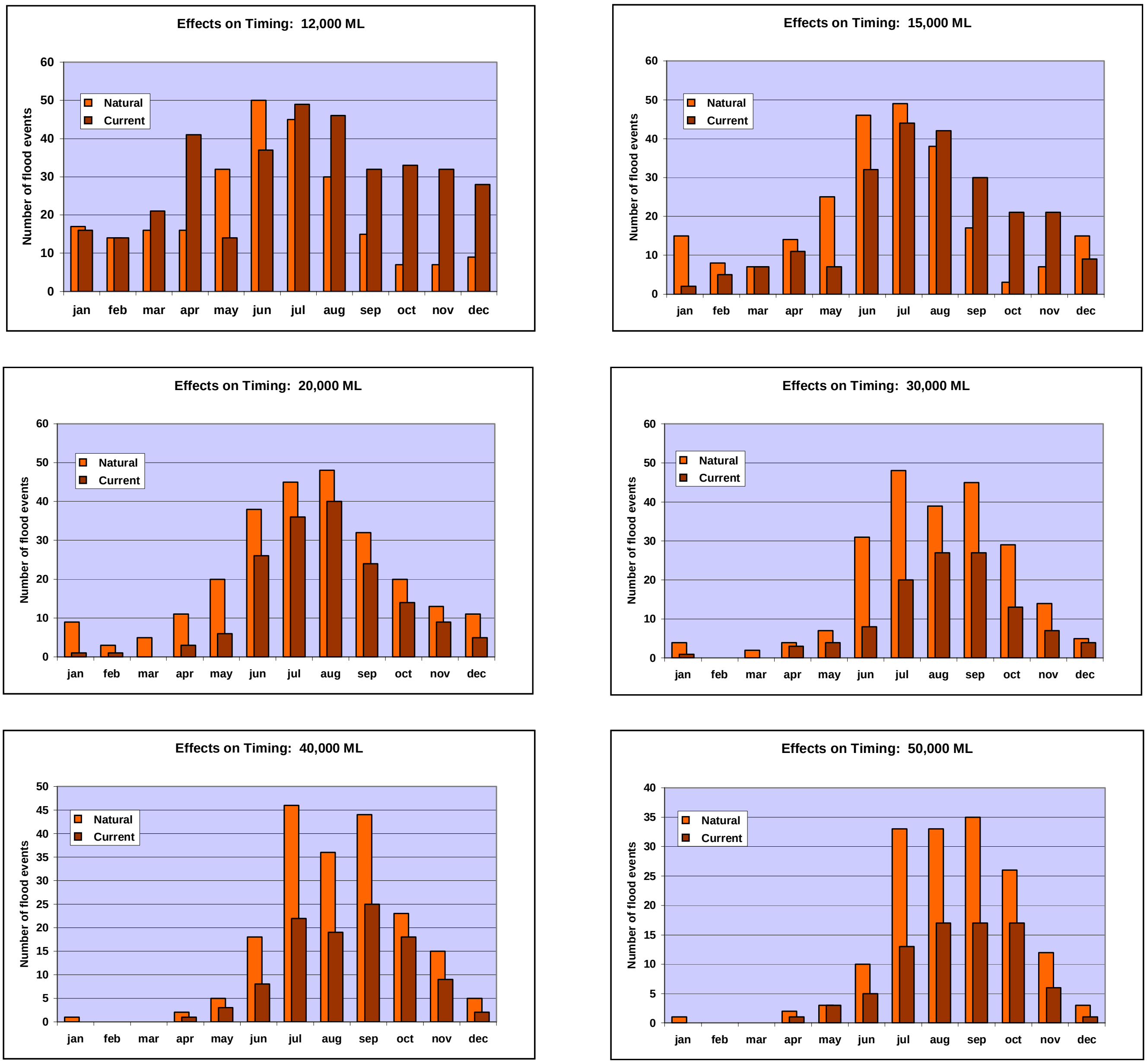


Figure 6.2: Effects of regulation on time of year when threshold exceeded.
Number of times a flow threshold is exceeded per month for Current and for Natural conditions, for six flow thresholds from 12,000 to 50,000 ML day.

The trends presented graphically in Figures 6.1 and 6.2 are summarised below in Table 6.1. What this shows is that, consistent with the idea of a differential effect across flows of different magnitudes, each flow threshold is distinctively affected relative to other flow thresholds. Six flow thresholds is probably too much to work with, so six is here reduced to just three. These can be identified as:

- flows => 12,000 and => 15,000 ML day - increased or similar events of shorter duration mean 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.
- flows => 20,000 ML day - fewer events and shorter duration with no strong seasonal bias (i.e. reduced frequency across all times) means Current conditions are drier in nearly all respects.
- flows > 30,000 up to => 50,000 ML day - 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.

Table 6.1. Summary of effects of regulation: Current v Natural for six flow thresholds:

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%.

	Flow thresholds at Tocumwal, ML/d					
	=>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**

This spells analysis sets out the effects of river regulation on flows likely to affect Barmah Forest, however it is only a guide and for two reasons, it could be better (Section 6.7). First, it is based on the idea of exceeding a flow threshold, similar to a commence-to-flow. For completeness, it should also consider the effects of falling below a flow threshold. Second, it uses peak daily flow at Tocumwal as this can be related to extent of flooding (Bren *et al.,* 1987); however, this is only indicative of what parts of the Forest are affected and in what way, as the flow-inundation area relationship needs to be updated: see comments in Section 6.3.4, item [d] and Recommendations in Section 6.7.1 below.

Note also, that this analysis uses daily flow data, so it is not directly comparable to the confetti diagram (Figure 4 in DSE & GBCMA, 2005, or Figure 6 in MDBC, 2005) which uses average daily flow for a month, or the 4-axes representation (Figure 6 in DSE & GBCMA 2005, or Figure 5 in MDBC 2005) which uses peak daily flow.

6.2.2 Rain rejection and high in-channel flows (localised effects)

Regulated effluent creeks

Rain rejection and high in-channel flows, although a consequence of river regulation, are here distinguished from "catchment" scale effects, partly for convenience and partly on account of the localised scale of impact and the management response. Within Barmah Forest, the areas of floodplain that are affected are effluent creeks and low-lying wetlands that are connected to the main river channel by in-channel flows; there are equivalent areas in the Millewa Forest. The characteristics of river flows at Tocumwal for the months of December-May, and of rain rejection flows have been described by Chong (2003) and Chong and Ladson (2003), and the effects of river regulation on in-channel flows during December-February by Gippel and Lucas (2002).

With the construction and completion of Hume Dam in 1934-1936, it became possible to deliver flows during summer to users down the River Murray. The effect of these sustained high in-channel flows where channel capacity was constrained, i.e. downstream of Bullatale Creek to the Barmah Choke, was that flows spilled into the Barmah and Millewa Forests. This resulted in areas where water ponded and persisted, sometimes without completely drying out; regeneration was inhibited, some trees died of root anoxia, and sometimes cumbungi (*Typha*) established. To rectify this, over a 20-year period between 1939 and 1959 (Dexter *et al.,* 1986), regulators were installed on the major effluents into the forests to prevent or at least minimise forest degradation. Although they largely excluded high in-channel flows, the regulators were only partly successful in preventing further problems in the forest, as there still remained the problem of rain-rejection flows which require that regulators be opened.

Rain rejection flows occur when in-channel flows are already high i.e. in January-April (Chong 2003, Chong and Ladson 2005). Prior to regulation, spills into the forest were unlikely during summer, occurring less than 10% of the time in February, March and April. March is the month showing the greatest change since regulation began, as flows exceeding 10,600 ML/d (indicative of the capacity of Barmah Choke) have increased nine-fold from 6.7% of the time to 59.8%. Since 1980, rain rejection events have occurred on average 4.1 times per year (i.e. within December-April timeframe) and lasted on average 14.1 days (median = 10 days) (Chong and Ladson, 2003); such frequency in summer-autumn would do much to keep parts of the floodways and effluents water-logged. The areas affected by rain rejection flows are effluent creeks downstream of major regulators in the middle and western parts of the Forest, such as downstream of Boals and the Gulf in Boals Deadwood and Gulf Creek Water Management Areas (Figure 9.3).

Under a recent agreement with New South Wales, the frequency of these enforced releases into Barmah and Millewa Forests is to be reduced, by approximately half. Prior to this agreement, rain refection events occurred about every year and on both sides of the river. Under the agreement, the two states have agreed to open the regulators for rain rejection flows in alternate years.. At this stage, it is not known how much effect this will have on water regime and hence plant communities along these effluents. No specific monitoring has been initiated.

In summary, the low-lying areas along these regulated effluent creeks have experienced the following since European settlement:

- a largely natural flow regime, up to the mid 1930s, for all effluents creeks;
- persistent and sustained in-flows from high in-channel flows during summer from the 1930s to when each regulator was constructed. The length of time is variable, 5 to 20

years depending on when a regulator was constructed, and hence parts of the floodplain and their associated low-lying wetlands have had different flooding histories;

- a change from persistent and sustained in-flows to frequent but short flooding, due to the opening regulators to allow passage of rain rejection flows, from approximately 1950s to present, i.e. for about fifty years. For some regulators, for the last 20 years, 1980 to about 2000, the flow pattern was an average of 14 days about 4 times per year in the December-April period; this may be indicative of all regulators but local and operational knowledge would confirm this;
- frequent and short floods one year alternating with a year of no rain rejection floods. This is very recent and affects only some regulators.

Unregulated effluent creeks and low-lying wetlands

Sustained high in-channel flows during the irrigation season also affect those effluent creeks and low-lying wetlands connected to the main river channel which do not have a regulator, principally Cutting Creek and War Creek, which flow into Barmah Lake, and Barmah Lake itself. Flow into and down these is in direct response to levels in the main river channel.

Before the construction of Hume Weir, the flow regime of these effluent creeks would have been seasonal i.e. drying back in summer and autumn in most years. This was true also for Barmah Lake which had a seasonal water regime, drying down long enough over summer and into early autumn for the substrate to harden before it was re-flooded (Cadwallader 1977). Nowadays the substrate is persistently soft and waterlogged even when river levels are low at the end of the irrigation season (Keith Ward, pers. comm. 2005).

Ecological character and ecosystem functioning

The combination of these different effects of river regulation mean that the character of a large part of the floodplain ecosystem has been changed, and some has been lost; specifically the areas that had a seasonal water regime of drying back in most years in summer-autumn; specifically Barmah Lake and effluent creeks. Together these represent a substantial part of the Forest. It is important to acknowledge that this change in character has implications for floodplain functioning, nutrient processing, carbon flux, connectivity and habitat for plant species such as Wavy Marshwort *Nymphoides crenata* and winter-growing species such as *Callitriche* sp.

6.2.3 Wetter and Drier Areas

Successive floodplains down the River Murray are similar in that they share features and species; nonetheless, each floodplain would have been distinctive because of differences in its underlying geomorphic template, such as the presence and abundance of effluent creeks, terraces, and basins. Regulation changes the hydrology, but without changing the template. Whether this will increase habitat diversity or re-arrange it is a point of speculation, and one which floodplain ecologists need to address.

Within a wetland, the number of flow-regime-by-geomorphic-template combinations is quite large and complex to manage, becoming more so when Barmah and Millewa Forests are considered together. For the moment, the combinations are best simplified into a binary system of 'wetter' and 'drier' areas of the Forest.

- The areas 'wetter' than before are effluent creeks and the wetlands and associated plant communities (Table 8.1, and Barmah Lake).

- The areas 'drier' than before are inundated by flows of about 20,000 ML/d and higher, equivalent to most of the River Red Gum woodlands and the Box communities (Table 8.1).

The flow analyses on which 'wetter' and 'drier' are based is the subject of a recommendation (Section 6.7.1).

6.3 Plants and Water Regime

The basis for delivering flows to Barmah Forest to provide an appropriate water regime for wetland and floodplain plant communities is work done by Leon Bren and colleagues, then developed by Colin Leitch (1989), some fifteen years ago. The main results from the two bodies of work were:

- Relationship between peak discharge in the river and extent of flooding; and
- Relationship between inundation of the floodplain (as flooding frequency) and major plant communities in Barmah Forest.

These relationships, with no known updating, are the undisputed 'building blocks' that now underpin most water-related objectives written into management plans since the early 1990s. As the following discussion will detail, these relationships were developed using technology that was much less sophisticated than is currently available. Although the overall approaches used by Bren and Leitch are now part of the standard repertoire, they were working without the benefits of considerable technical advances in GIS analysis, remote imagery, high resolution topographic modelling and hydrological simulations, so their work was pioneering rather than definitive.

This section gives a general overview of how water regime and water requirements for plants can be determined, the work of Bren and Leitch and the objectives relating to surface water and vegetation are reviewed; and gaps and knowledge deficiencies are highlighted.

6.3.1 Determining water regime

A water regime, as it relates to plants on floodplains and in wetlands, comprises the temporal pattern and specific sequences of timing, depth, duration of inundation, frequency of flooding, rate of change, and duration of dry phase. These affect each of the life-cycle stages: dispersal, germination, establishment and growth. Predictability is also important but less widely used.

Thus, prescribing with confidence an appropriate water regime for a wetland plant requires quite specific knowledge of its response at each stage of its life-cycle to flooding and drying at different temporal scales. Moreover, response needs to be understood in terms of what is optimum, adequate, stressful or even fatal for a particular species, even though these are elusive concepts. Because species vary in their attributes and adaptations, this understanding is needed for each species. Except in a very few cases of closely-related and morphologically similar species, such as *Typha orientalis* and *Typha domingensis*, it is generally inappropriate to extrapolate from one species to another. Ideally, managing the water regime of a wetland with several plant communities requires an understanding of species, of phenology and of their competitive interactions under different flooding conditions. This is a reductionist approach with such a considerable knowledge investment, that it is rarely achieved or even achievable. Instead, for pragmatic reasons, attention is given to a few dominant (or keystone) species. Failing this, the natural paradigm, which is sometimes a knowledge default (see below) is activated.

As the water regime provides growing conditions that may range from optimum through to fatal, the vigour and fate of an individual plant has follow-on effects for the population, the community and ultimately the local ecosystem. Survival and mortality influences population structure and demography, and the vigour and growth of a species can influence community ecology and, for keystone or dominant or widespread species, can affect ecosystem functioning over whole floodplains. One example of a species with a major influential ecological role on the Barmah floodplain is River Red Gum, *Eucalyptus camaldulensis.* It is widespread and influences other species through space occupancy, shading and litter fall. Giant Rush *Juncus ingens,* is another example as it is an invasive, displacing species and also a nesting habitat for birds.

If the number of species to consider is overwhelming, grouping species by their functional attributes, by life form or growth form are an alternative way of identifying water requirements (Chapter 9). However, a limitation on some approaches to functional groups (Boulton and Brock 1999) lis that they do not separate regeneration from maintenance phases in the life-cycle of plants. Typically these are quite different.

Information on species response to water regime can be obtained in different ways, for example:

- **Experiments – Contrasts & Manipulations:** Field contrasts (such as flooded v unflooded) or pot, mesocosm or transplant experiments where water regime is manipulated are useful for determining response to particular components of water regime. An example is an investigation into the onset of flooding on Moira Grass (Ward 1991). Field experiments are useful for tracking responses of all species in a community and the raw data can be interpreted in terms of species or functional groups, as done by Reid and Quinn (2004). Planting and manipulative experiments, typically with just one or two species, are useful for defining thresholds, for exploring consequences of varying one or more components of water regime and for establishing competitive ability or likely outcome of competition under stable or changing water levels. Examples are determining the relative importance of frequency, duration and depth of flooding for establishment of wetland plants (Casanova and Brock 2000), and competition between *Glyceria australis* and *Juncus articulatus* (Smith and Brock 1996). Depending on the number of treatments and number of interactions tested, manipulative experiments can sketch out a 1-dimensional or 2-dimensional response surface, where plant 'response' is a measure of growth, of reproduction, or of establishment. Using pot experiments or physiological studies to build up an understanding of the effect of water regime is powerful but costly. Such experiments are therefore, best used to tease out interactions between species or define response trends, such as whether increasing or decreasing biomass.
- **Simulation Modelling:** A response surface can also (and more efficiently) be described by modelling, using physiological field studies and experiments to provide parameters and calibration data, as has been done for Black Box *Eucalyptus largiflorens* on the lower Murray (eg Jolly 1996, Slavich *et al.,* 1999). There is a perception that much greater effort is involved in obtaining growth data and then validating the model and, because of this, such models have only rarely been built for species of ecological significance. However, this is changing as more and more growth models are being developed that can be modified and parameterised for a range of growth forms such as emergent macrophytes eg *Phragmites australis* (Asaeda and Karunaratne 2000), submerged macrophytes eg *Potamogeton pectinatus* (Asaeda *et al.,* 2000) and *Myriophyllum spicatum* (Best *et al.,* 2001).
- **Correlations with Observed Distributions:** Species water requirements can be inferred by correlating their spatial distribution with inundation patterns. Although this is possible at small and large scales, it is most frequently done at the landscape scale using floodplain inundation maps and vegetation maps (Chapter 9). The advantage of

working at the landscape-scale is that several dominant species and/or plant communities can be determined in one exercise. The disadvantage is lack of resolution, failure to accommodate transient species, and answers that are focus on the dominant species. The floodplain inundation maps can then be linked to river flow, and flow scenarios, giving a statistical relationship over time. This assumes no change in the spatial distribution of the plant community. A pre-requisite for this is a sound vegetation map at an appropriate level of detail. A disadvantage is that it may not pick up changes to vegetation structure or understorey composition in response to recent changes in water regime, as discussed further below.

- **Spot information:** Observations and records, both recent and historical, give spot information, which refers to particular points in space or time. These can be used to build a qualitative understanding and be interpolated and extrapolated, based on experience, judgement or by reference to the literature. Roberts and Marston (2000) is a compendium of information generated by all the above approaches, including spot information which can be useful in defining end points, which are otherwise difficult to obtain. An example of this is observations of time for Red Gums to die once water-logged behind Hay Weir (Roberts and Marston 2000).

Each of these offers different types of information and insights. In practice, no single method is used. Instead statements about what water regime is required are based on what information is available. As this is rarely complete, these tend to be supplemented by reference to the natural paradigm.

6.3.2 Natural Paradigm

The natural paradigm assumes that in the absence of actual data or demonstrable effects, the natural flow regime is valid and appropriate to use as a model for making recommendations regarding water regime.

- **Natural paradigm**: This is based on widely-accepted assumption that the natural ecological condition of a floodplain is a direct response to its natural flow regime. This is a long-term view, based on the idea that hydrology is the driver of floodplain ecology, affecting processes such as dispersal and nutrient processing as well as plant growth. In highly regulated rivers, the link between natural ecological condition (eg prior to settlement) and natural flow regime is fractured. Descriptions of the (simulated) natural flow regime can be used to make or support an aspect of the flow regime, for example timing or frequency.

The natural paradigm was conceived in relation to rivers, and has been articulated as four principles (Bunn and Arthington 2002) that apply equally to floodplains:

- flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition;
- aquatic species have evolved life history strategies primarily in direct response to natural flow regimes;
- maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of many riverine species; and
- the invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

The value of the natural paradigm is its emphasis on relationships between the physical environment and on ecological responses through co-evolution.

6.3.3 Water Regime, Water Requirements and Zonations

Within the context of wetland management, the terms ‘water regime’ and ‘water requirements’ are being used as if the two were equivalent, which is not the case.

Water regime is a suite of characteristics that describe the temporal hydrology of a wetland or the part of a wetland where a wetland plant or community occurs. It may be described statistically, for example as a range or mean value. It does not specify if conditions are optimal or stressful for a plant, as determined by (for example) carbohydrate depletion or physiological stress resulting in reduced vigour or even death. Water requirements are what the plant needs to grow and reproduce, and for populations to remain viable. Water requirements may also be expressed statistically, but almost never are.

Because much of our knowledge about water regime comes from inundation area-flow correlations and spot information, rather than from experiments or growth simulation models, the sub-optimal conditions such as competitive stress, physiological stress, chronic and fatal conditions, are not identified. Consequently water requirements that are based on a water regime are based on the false assumption that the observed distribution (of a species or community) is an optimum. Hence observations and correlations linking inundation patterns through time are a fair representation. This is not necessarily true, as the potential range for plants can be greatly reduced by other factors, for example by competition with other species.

Zonation patterns around wetlands are a fine example of the importance of competition in defining the species distribution. Zones are sometimes (incorrectly) treated as defining the boundaries of a species distribution, mapping units also imply that the observed boundaries imply actual boundaries. This is quite misleading, as co-occurring wetland plants may have quite similar water regimes, or be separated by differences that are hard to detect. Zones may not necessarily signify intrinsic differences between species but instead may be the visible outcome of inter-specific competition, mitigated by quite subtle differences between adjoining species in traits (eg leaf area, phenology, height, architecture) and in how these interact with water regime. The classic example is the demonstration by Grace and Wetzel (1981) in the USA that when grown in isolation, the vertical range of two species of *Typha* is quite similar. However when grown together broad-leafed *Typha* effectively displaces narrow-leafed *Typha* from wetland edges (from 20 cm above to nearly 60 cm below water line). The result is a zonation pattern that looks like species differences rather than similarities.

There is another view on species zonations. The littoral zone of wetlands is a steep environmental gradient from wet to dry over a relatively small vertical range. The change from anaerobic to aerobic soils, and from deep to shallow to exposed conditions, affects root oxygenation and carbon acquisition, and so determines which species can potentially become dominant. Experimental studies have shown that physical conditions may be more of a constraint over the lower part of a zone and biotic interactions in the upper part (Lenssen *et al.,* 1999). From this it is apparent that zonation patterns are a dynamic balance between species, and hence that changing water regime will affect species growth and competition, and that changes in community distribution will occur.

Unfortunately there are currently no general rules for estimating the discrepancy between observed and potential distributions or for determining its ecological significance, other than by experimentation or modelling. In the context of inferring water requirements from observed distributions, it is likely that this discrepancy is more important for herbaceous and non-woody plants than for the woody species. In the context of the Barmah Forest, herbaceous and non-woody plants are the understorey and ground cover that defines the extent of different forests and woodlands, and also defines the boundaries and zones in the wetland areas such as billabongs, lakes and Moira Grass plains.

6.3.4 Technical basis to water-related objectives

This section considers five aspects of the quality of the ecological and hydrological information underpinning water-related objectives for the Barmah Forest.

[a] Scientific Rigour & Relevance: The sources used to define what flows are needed to meet the water requirements of the plant communities at Barmah (Table 6.1) are limited to just six publications of variable quality and relevance. Two are journal papers; four relate directly to the Barmah forest; five can be described as scientific investigations, but the reliability and usefulness of results for three of these is considerably lessened due to inadequate reporting or unforeseen circumstances. Overall, just one of these six publications satisfies criteria of scientific rigour and relevance, namely Bren *et al.* (1988).

[b] Up to Date: The work by Bren and colleagues was done between the 1970s and early 1990s, thus is at least fifteen years old. It appears not to have been added to or refined since. A search of the scientific literature (June 2005) reveals no papers have been published on water regime, inundation history or on physiological tolerances of dominant species in Barmah such as Giant Rush *Juncus ingens* or Moira Grass *Pseudoraphis spinescens* other than work already referred to (Table 6.2).

By contrast, there has been a considerable amount of work done and published on River Red Gum, mostly on its role and function as a keystone species for lowland floodplains, for example: litter processing, the habitat value of trees with hollows, distribution and importance of debris piles, feasibility of monitoring by remote sensing, estimates of current vs historic loads of coarse woody debris on floodplains, and dendrochronology. Only two pieces of work over the last few years have the potential to inform water management, yet these could be pivotal. One is the development of a River Red Gum growth model equivalent to that produced for Black Box on the Chowilla floodplain (Slavic *et al.,* 1999). The other is a study of River Red Gum regeneration in the Lower Murray (George 2004).

Several plant ecology studies have been done on the floodplains of the lower Murray (eg Siebentritt *et al.,* 2004). Due to salinity on these floodplains and differences in species, these do not relate well to Barmah.

Table 6.2: State of knowledge

Publication	Source (peer review)	Study Area	Type of Evidence
Sharley & Huggan (1995)	Agency report	Riverina (Chowilla floodplain)	Scientific Investigation: Flow-inundation relationships. Errors acknowledged, no calibration reported.
Ward (1991)	Agency report	Barmah	Scientific Investigation: Experiment, but treatments confounded by overtopping flood.
Roberts & Marston (2000)	Research institution report	Murray-Darling Basin	Not primary data. This is a synthesis of existing information.
Bren *et al*. (1988)	Scientific journal	Barmah	Scientific Investigation: Flow-inundation relationships.
Leitch (1989)	Agency report	Barmah	Scientific Investigation: Flow-inundation relationships. Method not given.
Dexter (1978)	Scientific report	Barmah	Scientific Investigation: Observations and long experience of forest trees.

[c] Underlying Knowledge & Assumptions: The water regimes identified as appropriate targets for five vegetation types at Barmah (Table 1 in DSE & GBCMA 2005) are effectively based on just two sources, the natural paradigm (see above) and quantitative statements in Leitch (1989).

In his report "*Towards a strategy for managing the flooding of Barmah Forest*", Leitch (1989) determined the water requirements of rushlands of Giant Rush *Juncus ingens*, of grasslands, and of two categories of River Red Gum forest by reference to the natural water regime. This in turn was derived by correlating observed distribution of plant communities with inundation and simulated flow series for the River Murray. This was an application of the natural paradigm.

Sources used by Leitch (1989) were: observed distribution of plant communities using vegetation mapping of Chesterfield (1986) (for rushlands and grasslands) and a forest assessment (Smith 1983, *not located for this review*) for River Red Gum Site Quality I and Site Quality III; inundation mapping prepared by Bren *et al.* (1988); and 94-year long time series of river flows provided by MDBC. The inundation area-flow relationship developed by Bren and Gibbs (1986) and Bren *et al*. (1987) was part of this and is discussed separately below.

The great value of Leitch's approach is that it does not simply report a single measure of central tendency (mean or median), but shows the range and distribution, at least for two water regime components. These water regime components are inundation duration and duration of dry period (i.e. no in-flow period) for rushlands, and monthly pattern of flooding frequency for Moira Grass plains. Unfortunately, the methods for deriving these data are not given. The histograms are shown as percentages rather than total counts and sample sizes are not shown. Therefore, it is uncertain whether plots for natural water regime (e.g. Figures 3, 4, 5, 6 and 7 in Leitch 1989) refer to all patches of Giant Rush and Moira Grass respectively, or to a subset; and if to a subset, then it is uncertain how typical or where that subset is. The latter (a subset) seems more likely, given that most of these values were derived by manually compiling the inundation data (Leon Bren, pers. comm., July 2005). Either way, it is a reminder about the floristic heterogeneity of the open areas referred to as Moira Grass plains. Recent field studies have re-emphasised the floristic diversity within the Moira Grass plains, showing these support other grass species of similar form, notably River Swamp Wallaby Grass *Amphibromus fluitans* (Reid and Quinn 2004).

There are two further issues with the water regimes presented by Leitch (1989), especially for non-woody species such as Giant Rush and Moira Grass. One is the resolution of the hydrological data. The simulated natural flows for Tocumwal were estimated using MSM, an earlier model of River Murray flows, which operated on a monthly time-step. BigMod, the river flow model currently used by River Murray Water, operates on a daily time-step and uses a longer time-series. It is not clear how well water regime derived from a monthly time-step actually relates to a daily one. In broad terms, the differences are not likely to be significant, for example, the start and end times of in-flows should be similar, plus-or-minus 10 days or so (Andy Close, MDBC, pers. comm., July 2005).

The other is the difficulty in incorporating ponding time, which is also an issue with flow-inundation relationships. Floodplains being topographically diverse, means floodplains are a mix of areas that shed water freely and areas that retain it after flood recession, with the retention time varying between seasons. Water regimes based on mapping flood extent and related to river flows probably underestimate duration for low-lying areas.

[d] Flow – inundation area relationship: The flow-inundation area relationship for Barmah Forest, as developed by Leon Bren and colleagues some fifteen years ago, has certain characteristics that need to be appreciated in order to work with the relationship. These are:

- Regulators into the Forest were open: "*In all floods considered, the regulators were substantially open*." (p.136, Bren *et al.,* 1987).
- The area referred to as Barmah Forest was not specifically defined. However, the flood maps prepared every time the forest flooded were done by Forests Commission staff, suggesting perhaps that the area may have been limited to Barmah Forest and possibly not including Barmah State Park or Yielima.
- Wet Phase: the flood maps were prepared during a wet phase, thus whilst the forest would have been dry before each flood, it probably did not reach the level of being 'bone dry' associated with several years of drought and only low level flooding. In this wet phase, more than 20% of the Forest was inundated in 19 years out of 23, and there were 7 floods that covered more than 90% of the forest. Antecedent conditions, whether wet or dry, are known to affect flood extent.
- Flood maps were prepared by staff in the Department of Conservation, Forests and Lands "*from observations of flood-level marks on trees and local knowledge*" (p.360, Bren and Gibbs 1986).
- Permanent waterbodies and Barmah Lake were not included.

The procedure for developing the flow – inundation area was as follows: A series of possible predictors of flood extent (such as local rainfall) were trialled but peak flow for the River Murray at Tocumwal was chosen as the most appropriate. A model was derived that predicted the percentage (P) of the forest flooded from peak flow at Tocumwal (p138 in Bren and Gibbs 1986):

$$P = -435 + 47.6 \ln Q_p, \text{ for flows less than 68,500 ML day}$$

At 68,500 ML day, Barmah Forest is effectively fully flooded and additional flow does not increase extent, only depth. The authors were well aware of the coarseness of the data used to construct their model, saying cautiously that:

- "Clearly the model can be regarded as only a first approximation" (p138, Bren and Gibbs 1986), followed by:
- "In particular, as it is derived from data collected between 1963 and the present, it implicitly includes the effects of effluent regulation structures, and may be conservative if applied to situations in which effluent regulators were not present (eg pre-1939 data)."

This flow-inundation area relationship has been in use since its development and has become entrenched through being used in diagrams (eg MDBC 2005, p26) and probably also to set ecological objectives based on area flooded (see above: Chapter 6.1). It believed to be robust for smaller floods but for larger floods, where the shape of the hydrograph is variable and therefore also the flood volume, the relationship is less reliable (p49, Maunsell McIntyre 1999). Recently, floods originating in the Ovens River have been characteristically narrowly-peaked (i.e. shorter duration) so have much less volume than a flood of equivalent peak originating from the River Murray and hence are less effective at flooding the forest; in these instances, the relationship over-estimates the flooded area.

Points made include:

- Comparison of model prediction versus actual extent of flooding for a flow at Tocumwal of 70,000 ML/d at Tocumwal from the Ovens River in 1999 shows over-estimating by about half: 96% of Barmah Forest was predicted versus only 47% actually was (Maunsell McIntyre 1999).
- Comparison of model prediction versus actual extent of flooding for a flow at Tocumwal of 17,000 ML day shows good consistency, with 28% of Barmah Forest predicted to be inundated versus 25% actual (Maunsell McIntyre 1999).
- Comparison of model prediction versus measured extent of flooding for a flow at Tocumwal of 92,200 ML day from the Murray River shows good consistency with 94% versus 85% (Maunsell McIntyre 2001, p.82).

It is clear from the few data points available that Bren's work does not describe the flow-inundated area relationship for the Millewa Forest, and hence does not apply well to the combined Barmah-Millewa Forests.

- The Ovens flood of September 1998 flooded 47% of Barmah Forest and 80% of the Millewa Forest (p47, Maunsell McIntyre 1999).
- The EWA of October 1998 flooded 25% of Barmah Forest and 21% of Millewa Forest (p47, Maunsell McIntyre 1999).
- The flood peak in November 2000 flooded 85% of Barmah Forest and 91% of Millewa Forest (p82, Maunsell McIntyre 2001).
- During flood recession, and during the use of EWA in January 2001, the flooded area in Barmah Forest was 6% and in Millewa Forest was 9% (p82, Maunsell McIntyre 2001).

[e] Zonation patterns again: The derivation of flood frequency for plant communities at Barmah raises, again, some questions about zonation patterns. The procedure used by Bren and Gibbs (1986) for obtaining flood frequency data for each plant community was as follows: Chesterfield's (1986) map of vegetation types was overlaid onto a series of flood maps. Using 1250 grid cells each 0.5 km it was then possible to determine for each cell how much it was flooded and how frequently. This became part of the information describing the water regime (as flood frequency only) for each of the plant communities.

The value of this analysis was that it gave more than a single estimate of water regime for each community, and instead presented a range of values. Their skewed distribution is very evident in the box-and-whisker plots, which show the 25%, 50% and 75% with outliers and visually show the range and distributions for each of the plant communities (Figure 5, in Bren and Gibbs 1986). These data were based on historical flows (rather than simulated Current and Natural) at a daily time-step, making them a valuable historical insight. They have been little used, however, having been replaced by the coarser (in terms of time-step) analysis of Leitch (1989). They do have a unique value however, related to the topic of zonation.

These 13 communities are presented in descending order of wetness, and arranged in four groups. Although the groups are distinct, in terms of their flood frequency, there is little separation between communities within groups which have very similar and overlapping flood frequency distributions. Thus, as with zonation (above), the implications are that these communities are not segregated by flood frequency, but by another factor. It is now known that Group 2, which is the Moira Grass plains, Red Gum with Moira Grass understorey and Red Gum regeneration, are sensitive to other aspects of water regime (Bren 1992). It is not known what segregates the plant communities in Group 3, which are River Red Gum open forest-woodland with a variable understorey, the dominants being Terete Culm Sedge, Common Spike Rush and Warrego Summer Grass.

6.3.5 Issues with Rare and Threatened Species

The inclusion of rare and threatened species in floodplain management plans is well-meaning. Generally, it serves as a timely reminder that there are individual species requiring special attention, and whose management may not fall within the broad-brush approach being proposed. However the inclusion of lists of these species in rehabilitation plans which are targeting just one part of the physical environment, such as water or flows, is potentially misleading, as it carries the implication that there is a direct causal link between flow and the status of the species. Clearly causality needs to be established, before including rare and threatened species in monitoring plans.

There are three reasons why it is incorrect to automatically link rarity with river regulation and potentially inappropriate to make rare species the focus of a flow monitoring plan.

First, species may be rare for a number of reasons to do with habitat change and threatening processes, but may also be “naturally” rare. The conceptual approach to abundance patterns developed by Rabinowitz *et al*. (1986) as presented in Scarlett and Parsons (1993) is a little simplistic but nonetheless is useful as a reminder that some species are rare *despite* anthropogenic activities and that these species are likely to have a narrow geographic range, have quite specific habitat or regeneration requirements and occur in small populations. Rehabilitation is not appropriate for these species.

Second, the occurrence of species on a floodplain or within a riverine system does not mean that its life-cycle is dependent on or cued to floods. For example, the habitat descriptions of the 62 VROT species listed for the Lindsay-Walpolla system showed that only 10 could be positively identified as having a life-cycle that could be linked to flow or surface water management (SKM and Roberts 2003). When considered as ecological groups, these ten species were: aquatic macrophytes (1 species), shallow-water tolerant herbs, grasses and sedges (5 species) and flood recession herbs (4 species). The other 52 VROT species comprised: rainfall opportunists (3 species); floodplain soil species (29 species); non-alluvial soils (10 species); seven were undetermined. In the case of Barmah Forest, it is likely that the box ridges are the habitat requiring special attention, as these are disproportionately species-rich and are where extinctions are believed to have occurred (Chesterfield *et al.,* 1984). An early estimate is that box ridges comprise only 3.5% of the forest by area but have approximately one third of the plant species (Chesterfield *et al*., 1984), and grazing history is implicated. However, as the box ridges are well above the range of manageable floods, the species occurring there are unlikely to be dependent on floods; so for these species, rehabilitation by flood management is not appropriate.

Third, the inclusion of species that are rare, whose habitat preferences are not well understood and for which there is very little (probably no reliable) ecological information as part of a routine flow-monitoring program presents some quite serous design challenges, and may not be a good use of resources (eg Dyer and Roberts 2006).

These points apply to rare and threatened species for Barmah. Only about 9 of the 32 plant species given in Appendix 3 “Threatened status of flora” in the Ramsar Plan (DSE 2003) have life-cycles or habitat preferences that imply a dependence on or linkage to some aspect of flow regime or water. Some of these nine are examples of a particular aspect of ‘naturally rare’ that occurs on several of the River Murray floodplains. This is when a species occurs in Victoria but has a much wider distribution extending into New South Wales or inland Australia, i.e. the species is at the edge of its range. This was recognised by Chesterfield *et al*. (1984) who saw the Forest as important for some 14 species that were otherwise rare and uncommon in Victoria. Some may be species that are ephemeral and opportunistic in character, rather than flow-dependent. An example is recording three rare species after an exceptionally heavy rainfall in March 1978 (p26, Chesterfield *et al.,* 1984): slender sunray *Helipterum strictum*, fairy spectacles *Menkea crassa* and wild violet *Swainsona microcalyx ssp. adenophylla* (names as per original).

Because these species are rare, they tend not be included in the broadscale studies of wetland vegetation. None of the listed species featured in the 2-year monitoring (1991-1992) at eleven sites undertaken by Ward (1994) or the 2+ year study (1998-2001) done by Reid and Quinn (2004). Establishing some useful field-based information on rare and threatened species requires a specific and dedicated effort and a degree of opportunism to take advantage of temporal variations, which is a recommendation below (Section 6.7).

6.4 Vegetation Dynamics

The previous sections have focused on river flow, addressing technical issues of assembling information to improve floodplain management, and especially in relation to floodplain rehabilitation by water management. However, hydrology is not the sole driver of floodplain vegetation. The others are land management practices and resource use such as forestry and grazing, utilisation by people for recreation and camping, and fire. This section, boldly entitled Vegetation Dynamics, attempts to address just two of these, grazing and fire.

6.4.1 A Recent Historical Perspective

Barmah Forest has experienced considerable change since European settlement including the loss of the indigenous people and their practices, particularly in relation to fire; over 150+ years of livestock grazing, initially sheep but principally cattle; presence of other feral animals, notably rabbits; over 120 years of timber utilisation; over 70 years of river regulation; and changed fire patterns. All these can be expected to affect vegetation throughout the Forest, but as yet no environmental history of the Forest has been collated.

Changing land use and some environmental changes have been documented for the Barmah Forest (eg Fahy 1986). Typically, however, the perspective is chronological thus the aim is to describe sequences of change rather than their spatial characteristics, and the emphasis is on social history and management, rather than on the vegetation. Environmental changes, where these are noted, rarely say what happened where. To date there has been just one attempt (Chesterfield *et al.,* 1984, Chesterfield 1986) to place environmental changes in a historical perspective and link these to vegetation changes within Barmah Forest. Talking to workers with longer experience and knowledge of the Forest than their own, Chesterfield *et al*. (1984) were able to document a number of stories that 'explained' some of the oddities in vegetation patterns in the Forest. These 'stories' were generally events that then resulted in a localised change, for example:

- **Gulf Creek**: This was breached in the 1890 floods, and rapidly became established as a major effluent creek; this would have changed the forest along its path, and may explain the prevalence of dead trees.

Another example of a significant ecological event occurred at Top Island as described in "Barmah Chronicles" (Hibbins 1994):

- **Top Island:** According to Hibbins (1994), Top Island formerly known as Kinnear's Island, was made a common grazing area for selectors as early as 1877-8. In the 1914 drought, starving stock that had been turned into the Forest "*ate all the reeds, tussocks and small trees as well as the leaves from the big trees as high as they could reach*". By the following year, stock at Barmah Common had starved to death and their bodies had to be removed from the water.

As well as identifying events that cause ecological change, historical sources can point to gaps or missing components. This can be particularly useful for ecological systems such as the floodplain at Barmah as (like most of Australia) there are no historical surveys. Thus Leslie (1995), when seeking to establish a chronology of ecological change in the abundance of waterbirds at Moira Lake, the sister lake to Lake Barmah, noted that: "*For grebes and Whiskered Terns which nest on floating aquatic vegetation, the total loss of extensive beds of Wavy Marshwort and Water Primrose from the plains and fringes of Moira Lake has further contributed to their decline*." (Leslie 1995). This thesis convincingly showed a history of declining biodiversity and abundance from the late 19^{th} century onwards, and painted an image of abundance that are hard to reconcile with contemporary conditions.

In the last 15 years, there has been a surge of interest in environmental history, and also considerable output of reports and papers that contribute to our understanding of ecological change, in general and in relation to the River Murray and to the Barmah-Millewa Forests in particular. Examples are:

- A history of the Barmah Forests (Fahy 1986). A more general history, but provides a social background.
- An ecological history of Moira Lake in New South Wales (Leslie 1995). This could provide an interesting analogue for Barmah Lake.
- A history of the Millewa forests (Donovan 1997). The emphasis is on forestry and its effects on the forest.
- Palynology (eg Kenyon and Rutherfurd 1999) has potential for contributing to a pre-European vision of the forest.
- The use of historical and surveyors books to assess the question of tree density and forest openness (Parkinson and Mac Nally 2000).

Chesterfield's (1986) paper is an accessible resource hence is much used and quoted. However as a history of the Forest, it has limitations, such as incomplete coverage and incomplete chronology. An expanded update is timely, and if incorporated as a specialist layer in a GIS could prove to be immensely valuable in structuring sampling programs etc.

6.4.2 Grazing

Grazing is and has been, a significant land use over much of Australia (Wilson 1990) and it is a land use that affects both vegetation and soil. With vegetation, grazing reduces plant biomass, alters competitive interactions between plants, affects regeneration and hence populations, and results in mechanical damage through trampling. The consequences are far-reaching and not always reversible. They include altered species composition and vegetation structure through the removal of preferred species and through the consequent expansion of unpalatable species; and altered age structure including failure to recruit through loss of regenerating cohorts. Regeneration success of some riparian tree species appears to be favoured by light grazing but not dependent on it (eg Miller and Wells 2003), presumably because of reduced competition. For soils, grazing means loss of protective surface cover and development of bare linear areas as tracks. The consequences of this include altered seed banks, loss of native seed banks, establishment of weedy species and erosion. The severity of these effects is determined by a range of factors including the traits of the vegetation itself, pattern of grazing history, stocking density and which stock were present, whether sheep, cattle, horses or buffalo. The continuing presence and behaviour of introduced grazing animals, including rabbits, is recognised as a major agent of change in the vegetation and landscape across Australia (Kirkpatrick 1994).

Grazing in Australian Wetlands & Floodplains:

The effect of grazing is best understood and has been most intensively studied, where pastoralism is the dominant or significant land use, such as the rangelands of the semi-arid and arid zones, followed by grassy woodlands in the temperate zone and tropics. The number of studies of grazing in wetlands and floodplains is much fewer and cover three areas: impact studies done in the field, manipulative experiments to determine specific effects, and gradient studies linking grazing with impact. Three examples are presented here, all relevant to the Barmah Forest.

- **Floodplains of the Northern Territory:** Through a combination of herbivory and soil disturbance buffalo are credited with changing floodplain and wetland vegetation notably the loss of floating grass mats, reduction in extent of *Phragmites karka* and shifts in species dominance (Finlayson *et al.,* 1988, Corbett *et al.,* 1996); they have also degraded floodplains through forming swim channels, pugging and foraging tracks, some of which have facilitated salt water intrusions into formerly freshwater areas.
- **Alpine and sub-alpine wetlands:** the sub-alpine wetlands of the Bogong High Plains have been used by cattle for water since the 1850s because their convenient location on a main stock route. They showed the following symptoms of degradation compared with other wetlands: a higher cover of introduced herbs, more bare ground, more exposed rocks, tussocks of *Sphagnum* that were small and isolated rather than extensive, reduced cover of water-loving shrubs and stream channels that were entrenched. In contrast, a wetland site where cattle have been excluded for 50 years had very little bare ground and exposed rocks and was the only area with free-standing pools (Wahren *et al.,* 1999).
- **Riparian River Red Gum woodland:** In the riparian zone of the Murrumbidgee River, the differences between grazed and currently ungrazed (i.e. grazing has ceased) sites in River Red Gum woodland included a range of effects which when combined, pointed to reduced riparian functioning (Robertson and Rowling 2000). Ungrazed sites were characterised by higher biomass of ground cover, much greater densities of saplings and seedlings of the dominant tree species and much greater abundance of litter and organic material on the ground. Arising from this, RARC (rapid appraisal of riparian condition) was developed and successfully calibrated with stocking density (Jansen *et al.,* 2005).

The negative effect of stock and stocking history on native fauna such as woodland birds and frogs was determined using RARC and a measure of wetland condition (Jansen and Healey 2003). Effects of grazing may not be easily reversed (Jansen and Robertson, in press).

What emerges indirectly from the first two examples is the importance of surface water and hence water regime, i.e. whether surface water is present or not and for how long etc, in determining patterns of stock impact on floodplains. The third example emphasises that although the primary effect of grazing is on vegetation structure, the consequences of this are reduced habitat quality for some species, and reduced functioning, and that these effects are carried forward in time.

Water regime: The interaction between grazing and water regime is evident in three ways: spatial, substrate, and growth form.

- **Spatial:** The presence of surface water effectively concentrates stock to within walking range of water, consequently the effects of stock are concentrated around a water-body. This effect can be quite strongly developed for small isolated water-bodies in hot dry climates, such as mound springs, bores and permanent tanks in the Australian arid zone where the availability of permanent water and the movement of cattle to water results in a sharp gradient of degradation emanating outwards (eg James *et al.,* 1999). Unlike sheep, cattle and horses move into water so their impact is felt not just around a wetland but within it. In the Barmah Forest, this means that under non-flood conditions, such as summer and autumn, stock impact will probably be greatest close to permanent water or where there is still green forage, such as beside the River Murray or around near-permanent wetlands such as Barmah Lake, or around Moira Grass plains, if still green. Flood waters may also affect the spatial distribution of cattle in the forest, and if not removed, animals may be isolated on high ground, and thus re-locating the concentrated effect.
- **Substrate:** Surface water predisposes the substrate to impact. The presence of water makes the soil soft and not resistant to pressure, thus heavy stock with relatively small hoofs, such as cattle and buffalo, penetrate the soil surface and pug the soil. The consequences are that soil structure is broken or lost, seed banks turned over and plant propagules such as rhizomes and turions are damaged.
- **Plant growth form:** Plants differ in where their buds or meristems are located. Grazing may therefore remove just foliage or may remove buds. In the case of wetland plans, this is complicated by the presence of water, as this affects the plant's capacity to recover from grazing. Clipping experiments to simulate grazing (eg Blanch and Brock 1999, Clary 1995, Crossle and Brock 2002, Middleton 1999), show that how and whether a plant responds and the extent to which its reproductive potential is affected. Responses and sensitivities differ between species and appear to be influenced by growth form, and by water depth relative to the plant (in some of these experiments, plants were clipped under water to simulate cattle grazing behaviour). It has been suggested (Middleton 1999) that, in the aquatic grasslands of India and the Northern Territory of Australia, the feeding activities of cattle and buffalo arrest the post-flooding plant succession by maintaining open water patches and that these in turn facilitate the establishment of invasive species.

What this means, therefore, is that there is an interactive effect between grazing and wetted areas and hence where the wetted area alternately expands or shrinks to nothing, the floodplain can be expected to experience – and show – considerable spatial and temporal variation in the effects of cattle. Barmah Forest, with its diverse vegetation types and flooding conditions ranging from emergent macrophytes and aquatic/amphibious grasses on heavy clays and organic soils, through to sparse herbaceous understorey of a dry woodland on sandy soils, will experience considerable variation in impact from free-ranging cattle. This spatial heterogeneity needs to be considered if seeking to evaluate the effect of grazing on the Forest.

Grazing at Barmah: Despite a 150 year+ history of stock grazing on the floodplain, there is remarkably little information on the effects of grazing – whether historical or current – on the plant communities of Barmah Forest. There is an acceptance and vague understanding that the understorey in the Forest has changed since European settlement, based on the often-quoted observations made by Edmund Curr of the changes seen since his first arrival (Curr 2001). Also widely accepted (in the sense that they are repeated and not challenged) are observations regarding cattle preferences and assumed palatability. Moira Grass, Warrego Summer Grass are palatable, whereas Terete Culm Sedge and Giant Rush are unpalatable (Chesterfield *et al.,* 1984). The implications of these are not built on yet throughout the Forest there are instances where grazing may well be an explanatory or contributory factor and therefore worth understanding:

- The expansion of Giant Rush *Juncus ingens* (an unpalatable species) into the grasslands.
- The contraction of the Moira Grass-dominated grasslands (a palatable species).
- Understorey patterns and zonations: Terete Culm Sedge may have expanded into areas dominated by Warrego Summer Grass (Chesterfield *et al.,* 1984, p.13).
- Species richness and vulnerability of Box ridges.
- Distances from Moira Grass areas may have afforded understorey some protection from grazing impact (Chesterfield *et al.,* 1984, p.13).

The effect on the Forest of somewhere between 800-2000 head of cattle (Table 1 in Silvers 1993) has been an issue much debated (eg Orthia 2002). As commonly is the case with contentious issues, the experiences from elsewhere in Australia (above) are not enough to address local concerns or to defend a change. Due to lack of appropriate studies, the case either for or against grazing in the Forest has virtually no hard information. The few studies (Silvers 1993, Ward 1991, Watson 1992) assessing grazing impact at Barmah have suffered from poor design or inadequate replication, making it inappropriate to generalise findings across the Forest. More modern approaches using functional attributes (eg Jansen and Robertson, in press; McIntyre and Lavorel 2001) rather than species-based analyses are needed.

There is an acute need for a long-term perspective on grazing, and there is an acute lack of long-term data. Exclosures that were set up in the early 1990s as part of the investigations into grazing have been either dismantled or not rigorously maintained. Unfortunately the Reference Areas that were set up in the 1990s are not a substitute as maintenance of the fences has been sporadic.

A priority area for investigation is the need to establish whether cattle grazing is contributing to or the cause of the decline in Moira Grass. There are at least two separate questions: whether grazing facilitates the establishment and persistence of Giant Rush; whether cattle wading into water are affecting the seed and propagule bank of Moira Grass, and other wetland species. Grazing is the subject of some Recommendations in Section 6.7.

6.4.3 Fire

Information on fire in Barmah Forest is as sparse as on cattle grazing. Information on incidents and severity may be available but appears not to have been collated, and its ecological effects, if assessed, have not been reported on.

The history of fires in the forest has been scoped by Eyles (2004). Important phases include the burning practices of Aboriginal peoples, as observed by Edmund Curr (2001) and reported by Chesterfield (1986), lasting until Aboriginal peoples were displaced by Europeans in the middle-late 19th century. The second phase is the phase of resource utilisation by Europeans, for timber and stock grazing, when there would have been potential for escaped fires wherever workers were camped. Because of the importance of the resource, this may have been partly balanced by fire minimisation. The third phase is the most modern, characterised by the occurrence of fires from campfires and recreationists. Wildfires resulting from lightning strikes would have occurred at all times. These three phases could probably be characterised by likely intensities, time of year, and location.

The detrimental effects of fire on River Red Gum was explored and described by Eyles (2004) who was convinced that fire was a significant ecological factor, but other than this, the consequences for forest ecology and dependent fauna are largely ignored. The use of fire as a means to control (i.e. kill off) dense stand of River Red Gums (Bren and Acenolaza 2002) was found to be effective but not perfectly so, as it did not result in 100% kill.

6.5 Vegetation Objectives in Management Plans: a brief comment

As each agency and authority has formally faced its responsibilities, it has developed a management plan and a set of objectives relating to Barmah Forest that reflects its particular arena of authority. The result is, that since the early 1990s, a series of plans has been written and a multitude of objectives stated (Chapter 3). Currently the most influential and binding of these are the Ramsar Plan (DSE 2003), as this is subject to international agreement, followed by the Living Murray (MDBC 2005) and the Regional Catchment Strategy, as these have ministerial signature (Keith Ward, pers. comm., December 2005). Vegetation-related objectives for Barmah under these three most influential plans are as follows:

Ramsar: The Contracting party is under obligation to maintain the ecological character of the designated Ramsar site (DSE 2004). Guidance is given as to the meaning and intent of "ecological character" (DSE 2005) which is the sum of components, of which vegetation is one. Characterisation is discussed in Chapter 3. The benchmark against which change is measured is the ecological character at the time of its nomination as a Ramsar site; in the case of Barmah, this was 15 December 1982.

Living Murray: The vegetation-specific objective for the Barmah-Millewa Forest Significant Ecological Asset (MDBC 2005, from MDBMC 2003):

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.

Regional Catchment Strategy: The vegetation-specific objectives in the Goulburn Broken CMA's Regional Catchment Strategy (GB CMA 2003) are:

- 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.
- Improve the quality of 90% of existing (2003) 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.

Success is contingent on meeting the objectives, hence objectives need to be clearly and unambiguously stated. In a general sense, objectives set by these three plans and their predecessors address similar concerns about vegetation in Barmah Forest, namely the state and/or extent of plant communities, particularly the Moira Grass Plains and encroachment of Giant Rush and River Red Gum, which in turn is generally linked to river regulation. Because overbank flooding is recognised as a main driver of plant community composition and distribution in wetlands and floodplains, and because the flow regime of this part of the River Murray has changed since the construction of Hume Weir began in 1934, many plans have objectives emphasising river flows.

A problem with objectives is that the context in which they are drafted – which may be against a deadline or infused by a spirit of compromise between interests - is not the same as the context in which they are used or against which performance will be assessed – which may be precise, legalistic and occasionally hostile. For these reasons, objectives and rationale underpinning objectives, need to reflect their intent and are expressed adequately (Chapter 3).

This section addresses the content of objectives. Four problems were noticed during the course of background work for this chapter: clarity; benchmarks; unstated assumptions; inter-plan compatibility: examples of the first two are given below. The soundness of objectives is a different issue, one covered through the review of the technical basis in Sections 6.2 to 6.4 above. Points made here are opportunistic, arising out of other work, and should not be viewed as comprehensive.

6.5.1 Clarity

Clarity, as used here, refers to the following specific points where the meaning is ambiguous:

- **Forest and percentage of forest:** Compliance and monitoring targets are being set using percentage of the forest inundated as a target. However, Barmah Forest can be defined in different ways, ecologically for example, or administratively: as Barmah Forest, as the Ramsar site, as including or excluding freehold areas (Yielima) and including or excluding areas that do not get flooded, such as the sandhills. Given this, it is understandable and not surprising that the area of Barmah is variously reported as 29,500 and 28,600 ha.
  These differences become important when referring to the forest in relative terms, as percentages. Management objectives such as the Regional Catchment Strategy and The Living Murray are expressed as percentages of the forest (McCarthy *et al.,* 2006).
- **Inundation-area relationships on 4 axes:** The diagram in question (Figure 6 in DSE & GBCMA 2005) shows a relationship between river flow, area and percentage of forest inundated. Although this is a neat and useful representation, two points need to be attended to, to avoid generating confusion and misinformation.:
  - The text and arrows inside the box in Figure 6 imply that Open Water / Giant Rush begins to be inundated at flows of about 8000 ML day, that Moira Grass Plains begin to be inundated by flows of 12,000 ML day, and that River Red Gum Forest begins to be inundated by flows of about 25,000 ML day. Reading these Commence-To-Flow values off the right vertical axis suggests that Moira Grass Plains occupy about 38% of the forest (from 12% to 48%). This is inconsistent with areas and percentages of forest given in Bren *et al.* (1988).
  - Similarly, the axes need to be made compatible with flow threshold data given in Barmah Significant Asset Plan or *vice versa* (Figure 4 DSE & GBCMA 2005) that flows up to 18,330 ML day inundate up to 55% of the Barmah-Millewa Forest, etc.

Terminology: Words are used in setting objectives that although broadly understandable are imprecise, and hence ambiguous. If retained without revision, these are likely to generate problems in terms of assessing whether objectives have been met etc. Two examples are given below.

First example: "Maintain health of sedges, giant rush, and wetland communities" (eg Table 2 in DSE & GBCMA 2005).

- Sedge usually means a species in the family Cyperaceae, although common names used in Victoria mean that species from other families are also called or referred to as sedges, including sometimes *Typha*. Equally sedges could mean 'sedgeland'.
- There is no consistent use of 'wetland' in the various plans. Sometimes 'wetland' could mean a system mapped in the Wetlands_1994 layer of the DSE interactive Mapping layer; according to the Ramsar definitions, it means the entire floodplain.
- Health is open to interpretation and the use of such an ambiguous term could be a useful and deliberate option.

Second example: "Improve the quality of 90% of existing (2003) native vegetation by 10% by 2030 (GB CMA 2003).

- Quality in relation to vegetation can refer to its use as forage. Probably what is intended here is vigour of certain species, condition of certain communities and vegetation types, although this is not clear.

Benchmarks: Benchmarks may be variable between plans, thus giving multiple targets, or sometimes non-existent. Between them, two of the three most influential reports carry at least three benchmarks: 1982 for Ramsar character, 1999 for native vegetation types, and 2003 for quality (see above). This is discussed further in McCarthy *et al*. (2006).

6.6 Findings

The objectives and requirements as given in the various management plans are reliant on the natural paradigm, on data in Leitch (1989), on the vegetation mapping of Chesterfield (described in 1986), and on the flow-inundation relationship of Bren *et al*. (1988). From the above it is clear that all these have limitations. All data and relationships have some limitations. The issue here, however, is that the limitations are not well acknowledged and are of uncertain magnitude.

6.6.1 Monitoring environmental water allocations

In relation to the Moira Grass Plains, the following points need to be considered in the design and implementation of the program for monitoring environmental water allocations to the Barmah Forest: They arise out of the above critique and analysis.

- Hydrological variability between 'basins' in inundation patterns, connectivity to river and water retention.
- Floristic variability between areas mapped as Moira Grass plains or Wetlands, particularly as Moira Grass is not always the dominant species.
- Water regime requirements of species other than Moira Grass and Giant Rush need to be considered.
- Interactive effects of biomass removal and pugging on the growth, persistence and vigour of Moira Grass and the possible consequences for survival of River Red Gum seedlings.

6.6.2 Opportunities for Future work

The encroachment analysis fortuitously used a 15-year time step, finishing in 1985 which is 20 years ago. There is opportunity now to test the trends predicted by the model using the next 15-year timeframe, 1985-2000.

Recent technological advances in the areas of GIS and hydraulic modelling, vertical resolution of DEMs, horizontal and temporal resolution of remotely sensed imagery, and the relative ease of running flow series and different management scenarios, make it appropriate to develop a flow-inundation relationship *de novo* (Chapter 9).

6.6.3 Conclusions

The approach taken in developing recent management plans is, in general terms, appropriate and most of the information used is as up to date as it can be. However, there are areas of concern:

- the knowledge base is somewhat dated, through no fault of the Asset Environmental Management Plan authors (DSE and GBCMA 2005);
- it is not clear what the accuracy (or conversely the errors) in the key sources are;
- the importance of spatial heterogeneity within the Forest is underplayed;
- hydrology certainly is the key driver, but the roles of other factors in determining species composition and dominance are also under-emphasised e.g. grazing;
- the focus is rather narrow, with important elements within the forest being overlooked in favour of just a few species; and
- given that Barmah Wetland is recognised as significant at international, national and state levels, and is one of six icon sites on the River Murray floodplain, it deserves a better information base than is currently available.

6.7 Recommendations and Knowledge Gaps

Knowledge gaps and recommendations arising from these that were identified during the course of this review are arranged below by theme:

6.7.1 Hydrology

Wetter and Drier: The spells analyse (Section 6.2) is only a guide to the effects of river regulation, and needs to be refined, the interpretations and trends need to be confirmed by more sophisticated analyses, and the suggested threshold between wetter and drier (of approx 15,000 to 20,000 ML day at Tocumwal) needs also to be confirmed.

Recommendation

Hydrological analysis to characterise, ecologically, natural, historical, current and future flow regime in the River Murray as it affects inundation of the Barmah floodplain. These will need to be linked to an updated flow-inundation model to then identify areas of change, and the extent of change.

Flow-Inundated Area Relationship: The flow-inundated area of Barmah Forest relationship established by Bren *et al.* (1988) has been useful but it is becoming apparent that it has limitations, notably that it severely overestimates the extent of flooding in Barmah Forest for larger floods that are peaky, such as recent ones down the Ovens River.

Recommendation

The flow-inundated area relationship for Barmah Forest needs to be revised to accommodate variations in flood hydrograph shapes and volumes for similar peak at Tocumwal or other reference point.

In addition, an up-to-date relationship is also needed for the Millewa Forest and for the Barmah-Millewa Forest together. This last is particularly important given the need to manage the Barmah-Millewa Forests as a single ecological entity in the future.

6.7.2 Flow-Ecology Relationships

Flood Timing: replicated experiments such as field studies in Gulpa Forest (Robertson *et al.,* 2001) and mesocosm experiments (Nielsen and Chick 1997) have consistently shown the importance of inundation timing (sometimes referred to as season) in determining vegetation attributes such as species richness and net production. However, treatments used in field studies, such as Robertson *et al.* (2001), tend to be tied to river flows which although effective in investigating the typical current situation does not explore beyond actual so is limited to spring and summer flooding, and fails to include autumn or winter. Hydrological analyses show that timing is a significant effect of regulations, with the loss of most early winter floods (Chapter 6.1 above) and hence the delay in the onset of winter flooding to lower-lying parts of the forest (equivalent to 0 to 20% forest inundation). It is surprising that the ecological significance of winter (start June) flooding – as opposed to spring (start September-October) or summer flooding – has had so little attention and is so poorly understood.

Recommendation

There is a strong need to understand what, if any, is the difference between cooler season and warmer season floods in terms of species diversity, floodplain responses and ecosystem processes, and whether there is a suite of species currently disadvantaged if these floods occur only very infrequently. One investigation is unlikely to be adequate and a suite of parallel studies will be needed.

This is the subject of a priority recommendation in Chapter 9.

6.7.3 Floodplain as an ecosystem

Effluent Creeks: Floodplains further down the Murray system, such as on the Lindsay-Wallpolla Islands, have been viewed in a more holistic approach than at Barmah where there tends to be a focus on specific components such as Moira Grass or carp. Consequently, despite a less intensive research history, these other floodplains have a greater awareness of ecosystem functioning and of the components of these floodplains including effluent creeks.

Effluent creeks within Barmah have undergone significant ecological, hydrological and possibly also geomorphological changes since river regulation began, so it is to be expected that their functional significance in relation to the floodplain will also have changed. Whole of system management will require an understanding of these effluent creeks.

Recommendation

Develop an understanding of the range and diversity of effluent creeks with the Barmah floodplain, as physical and as ecological systems, their current ecological values and how these may have changed since European settlement, and their changing role in relation to the floodplain.

6.7.4. Ecological History

History of ecological change:

Recommendation

An ecological history of Barmah forest should be prepared, to record and describe changes in the condition of floodplain and wetland vegetation. As the purpose of such a history is to inform current understanding about patchiness in floodplain overstorey and understorey vegetation and to assist in site selection eg for monitoring or research, the changes will need to be described with both a spatial and a temporal context. The information will ultimately become a historical layer in a GIS, hence the history will need to be properly referenced.

6.7.5 Vegetation, Plant communities & Individual Species

Forest understorey: As evident in the various descriptions of River Red Gum forest and woodland, formations and alliances, given in descriptions and mapping such as Chesterfield (1986), MPPL (1990), there is considerable range and diversity in the understorey and ground cover. Ecological understanding of these understorey species and communities, in particular their flooding tolerances, and the relative importance of hydrology versus other factors in determining species composition, such as grazing, history or substrate, is almost completely lacking; none of the previous mapping projects appear to have collected quantitative data suitable for analysis. This is a serious gap in managing water in the forest, and in meeting vegetation objectives.

Recommendation

Existing descriptions of understorey communities (eg Frood, MPPL 1990) or, if not suitable, new data purpose-collected, should be analysed for patterns in species, functional groups and spatial patterns. This would be an important benchmark for Barmah Forest.

This project is particularly suitable for a PhD.

Moira Grass *Pseudoraphis spinescens* and equivalent species: The stoloniferous floating grass locally known as Moira Grass, though more correctly known as Spiny Mud Grass (Walsh and Entwistle 1994), is effectively an icon species for the Barmah Forest. Surprisingly, considering its prominence at Barmah Forest, neither the species nor its EVC (Ecological Vegetation Class) are listed as threatened.

Spiny Mud Grass occurs in all mainland states. Knowledge of this species within Barmah Forest is minimal, being limited to one study (Ward 1991) whose findings regarding growth and reproduction have been the only means for assessing the 1998 EWA (Chapter 9.2.2). Although the grasslands are shrinking (eg Chesterfield 1986, Bren 1992) due, largely to niche contraction and encroachment by Giant Rush *Juncus ingens* and by River Red Gum *Eucalyptus camaldulensis* (Bren 1992), they have not been formally listed as Endangered or Vulnerable, being instead considered Depleted and Naturally Restricted (Web search: 27

December 2005). It is known that the grass itself is highly palatable, being preferred forage for cattle in the Forest (Keith Ward, pers. comm.. 2005). Current management strategy emphasises duration, thus following a precautionary principle of trying to achieve flowering in the hope of maintaining a seedbank, even though it I not certain what the status of the seedbank is or how the species regenerates. Chesterfield *et al*. (1984) reporting on their experiences in the Forest 1977-1980 commented on the lack of flowering in Moira Grass, and believed it regenerated from vegetated parts.

Elsewhere in Australia, grasslands of Spiny Mud Grass are known to be important in nutrient cycling on the floodplains of the Northern Territory (Finlayson 1991) and as a highly productive shallow-water habitat used by waterbirds and fish at Coongie Lakes (Julian Reid, pers. comm.. December 2005). Observations from the Northern Territory suggest successful and extensive re-establishment is influenced by dry phase and particular water regime on re-flooding. The seedbanks of floodplain grasslands dominated by *Pseudoraphis spinescens* are fairly rich, with 11,000 seeds m^{-2} as detained by the emergence technique, of which 55% is *P. spinescens* (Finlayson *et al.,* 1990), and can be dispersed downstream. On re-flooding, germination is substantially reduced under water (only about 10% of the numbers on moist soil) and can be prolonged, lasting up to 40 weeks (Finlayson *et al.,* 1990, p. 172).

Recommendation

Studies of Spiny Mud Grass / Moira Grass should be initiated to cover the following themes:

- *Regeneration strategies, whether from vegetative perennating parts or seedbanks, and whether and how this changes according to disturbance.*
- *Status of seedbank and/or propagules under different water regimes and under different grazing pressures, throughout Barmah Forest.*
- *Factors determining productivity and habitat value of stoloniferous floating aquatic grasslands in Barmah Forest.*
- *Comparative ecology of stoloniferous aquatic grasses occurring in Barmah Forest, eg Pseudoraphis spinescens, Amphibromus fluitans, Paspalum distichum.*
- *Responses to grazing (defoliation, mechanical damage) on biomass, reproductive output and perennating organs.*

Regeneration and persistence of Giant Rush *Juncus ingens:* Giant Rush *Juncus ingens* has a rather special place in Barmah Forest. First, unlike other dominant plant species, it has a restricted distribution, occurring mainly in the River Murray valley; there is therefore little likelihood of studies being done elsewhere that would be relevant to Barmah Forest. Second, it is dioecious, with separate male and female plants (rare amongst *Juncus* species) hence its reproductive ecology is potentially interesting. Third, it has two personalities in Barmah Forest: one is as a native but invasive emergent macrophyte, expanding under current management to the detriment of the iconic species *Pseudoraphis spinescens;* the other is as a favoured nesting habitat for colonial water birds. The future management of Barmah Forest requires knowledge about both these personalities.

Observations suggest Giant Rush has great capacity to set seed and establish under favourable conditions, almost as an episodic recruitment strategy; but that once established, the species is conservative, with little turnover. Altered water regime is clearly implicated in its persistence, and the most likely components are; depth (shallow), duration (long) and timing (summer). Water-logged conditions are known to favour the persistence of juncus seeds (eg Holzel and Otte 2001) raising the possibility that this is true also for *Juncus ingens.* All these are plausible ideas that need confirming or refining, and then being turned into useful management advice.

Recommendation

Despite its importance within Barmah Forest, there have been no ecological studies of Giant Rush. Questions that are critically important that need to be investigated and incorporated into forest and flow management are:

- *Gemination ecology and seedling establishment; the role of temperature, season, flow regime, and heat / desiccation stress in the germination and establishment of seedlings.*
- *Tolerance, growth response, and mortality of seedlings to fixed and variable water depths.*
- *Persistence and growth ecology of established plants, and factors that build or deplete carbohydrate reserves.*
- *Ecological values or otherwise of Giant Rush, habitat value, structural characteristics and the potential for encouraging flexibility in use by water birds.*
- *Historical perspective of Giant Rush stands; documentation and probable reasons for recent expansions in Barmah Forest and also billabongs along the River Murray between Hume and Barmah Forest; what communities have been displaced; an assessment of the potential for rehabilitation.*

Rare and Threatened Species: Currently there is very little firm knowledge of how flow regime might be impacting on the abundance and successful completion of life-cycle for rare and threatened species listed in Appendix 3 of the Ramsar plan (DSE 2003). The first step in improving this is to find the species in the field, and build up a knowledge of their ecology and flow requirements from repeated visits, systematic observations and accurate locations, such that could be subsequently included in a floodplain inundation model.

Recommendation

Conduct intermittent and opportunistic searches for rare and threatened species; as best possible, searches should cover a range of seasons, conditions, and flood phases from rising to recession to post-recession. Compiling a reasonable set of observations will take time and may be difficult to resource separately from other activities, so alternatives should be explored. One possibility is to develop a protocol for recording observations, collecting specimens, and a field sheet for routine use while staff are involved in other projects.

6.7.6 Grazing

Given the debate about the presence of cattle in the Forest, in a Ramsar site and in land of interest to the Yorta Yorta people (Orthia 2002), it is imperative to address the concerns of the public, the stakeholders and the resource managers by initiating some targeted research, and, if necessary, preparing for a relatively long investigation. Isolating appropriate questions for investigation is a challenge, and one worth investing some time and expertise (eg from temperate grassy woodlands) to set up. Instances where the role of cattle or grazing need to be clarified are numerous and include:

- Whether or not species composition of the Forest understorey shows trends or patterns consistent with composition (based on functional attributes) of heavily grazed grassy woodlands elsewhere in temperate Australia.
- Whether or not cattle suppress fuel and if so to what an extent and where, and how this relates to actual fire risk areas.

- Whether or not cattle have or have had a role facilitating either the establishment and/or the persistence of Giant Rush *Juncus ingens*, an unpalatable species, through removal of competition.
- Whether or not there are areas within the Forest that are preferentially sought out and used by free-ranging cattle; and conversely, areas that are relatively free from grazing.
- Whether or not cattle trampling on soft soils is having an effect on soil structure and organic matter distribution, and on persistence of seedbanks and propagules, particularly in association with Moira Grass Plains.

Recommendation

Scope the content and direction of a long-term grazing-investigation program through a technical scientific workshop. Preparatory and briefing material could include field inspections, likely grazing-related questions and management concerns, vegetation descriptions and maps, and re-interpretation of understorey communities in functional groups following ideas of McIntyre et al. (1995) and McIntyre and Lavorel (2001). The workshop should also scope risks and establish a protocol for identifying sensitive and high risk areas, relative to management objectives.

7. Waterbirds and Water Regimes

Julian Reid

7.1 Background

This chapter focuses on aspects of Task 2 of the Terms of Reference. First the ecological objectives relating to waterbirds in the Asset Environmental Water Plan (DSE AND GBCMA 2005) are listed and their adequacy is assessed from three perspectives, unambiguous clarity in their expression, amenability to compliance monitoring (can the success of environmental management be evaluated with respect to stated objectives?), and desirability from a waterbird conservation viewpoint (whether at the international, national, Victorian or local Asset scale). Specifically it is considered whether the wording or intention of the Ecological Objectives can be improved. Additionally, the ease (costs, practicality) with which environmental monitoring can be implemented has to be considered here, as there is little point in setting objectives which cannot be evaluated with any rigour. Then the Water Regime Requirements advanced by DSE and GBCMA (2005) to meet these Ecological Objectives are evaluated in relation to the available scientific evidence. Also, waterbird objectives cannot be considered in isolation from other stated or desirable objectives for the use of environmental water allocations (EWAs), and so some consideration is paid to where there may be conflicts between objectives (trade-offs).

The waterbird and other relevant ecological literature upon which DSE and GBCMA (2005) based the development of Water Regime Requirements are assessed, and any gaps indicated. There is a tension between the great body of general theory developed and knowledge gained from the study of waterbird species and wetlands elsewhere (whether internationally, Australia, other parts of the Murray-Darling Basin) and the particular environmental circumstances peculiar to the Barmah wetlands and to which local waterbird individuals and populations respond. In particular, the nesting requirements of waterbirds at Barmah in terms of habitat structure and water regimes (e.g. spatial and temporal extents of inundation around nesting sites) may not be the same as in other parts of Australia. Knowledge gaps pertinent to the local environment in the Barmah wetlands can always be identified, and so only the gaps believed to be critical and warranting future research as a priority are addressed here. Some outstanding issues are identified, such as managing for rare and threatened waterbirds. Barmah Millewa Forest refers to the Barmah-Millewa Forest.

7.2 Waterbird Ecological Objectives for EWA in Barmah Forests

Adapted from DSE and GBCMA (2005):
<u>General Ecological Objectives</u>

- Enhance breeding and recruitment of waterbirds
- Provide suitable habitat for waterbirds
- Ensure breeding success of colonial waterbirds

<u>Overriding Ecological Objective</u>

- Provide successful recruitment of large colonies of colonial waterbirds

7.2.1 Evaluating waterbird management objectives

While the wording of objectives needs to be sufficiently precise to allow an explicit assessment of management success, there is a risk of making objectives overly prescriptive and which could hamper wetland managers making informed, context-specific, tactical decisions as conditions dictate at the time such as during a flood event and EWA. Managers of large complex ecosystems need room to move (the 'learning by doing' principle of adaptive management). Essentially, the current general pitch of the waterbirds objectives is appropriate.

A balance has been struck between all waterbirds and a focus on the iconic colonially nesting waterbirds in favour of the latter. It is generally agreed (e.g. Kingsford 2000, 2004; Kingsford & Norman 2002) that among Australian waterbirds it is the colonial waterbirds as a group (egrets, some herons, Royal Spoonbill *Platalea regia* and ibis species) which has been hardest hit by river regulation and water abstraction/use in the MDB. Therefore, the emphasis on colonial waterbirds and their breeding effort is appropriate.

Notwithstanding the desirability of focusing on the reproductive success of colonial waterbirds, it is important that the feeding and nesting requirements of other functional groups of waterbirds be met, and prescribed as a measurable objective if possible. Waterbird monitoring programs, if feasible, should **not** neglect these other functional groups.

It may be convenient to refer to non-breeding habitat for waterbirds as maintenance habitat, and so the second General Ecological Objective should be reworded:

- **"Provide breeding and maintenance habitat for waterbirds"**.

Maintenance of body condition in the non-breeding periods, which may extend for several years in extended dry phases, is critical to the survival of waterbirds, and probably influences breeding initiation and success (at least in some waterbird species: Briggs 1990; Scott 1997). Therefore, the provision of *maintenance habitat* should not be neglected.

A second revision is required to ensure that a **wide diversity** of waterbirds' feeding and nesting habitats are managed for. In particular, it seems possible that large colonial breeding events of just one or mainly one among a few species might occur (as happens in the Chowilla wetlands with the Australian White Ibis *Threskiornis molucca*, SA, M. Harper *personal communication*) and this may be a far from satisfactory outcome of an EWA (see Section 7.6.). Accordingly, all the objectives should be modified to add "**a wide range of**" before the words 'waterbirds' or 'colonial waterbirds' in the four objectives relating to waterbirds.

The recommended new waterbird Objectives become:
<u>General Ecological Objectives</u>

- Enhance breeding and recruitment of a wide range of waterbirds
- Provide breeding and maintenance habitat for a wide range of waterbirds
- Ensure breeding success of a wide range of colonial waterbirds

<u>Overriding Ecological Objective</u>

- Ensure successful recruitment at large colonies of a wide range of colonial waterbirds

7.3 Water Regime Requirements to meet Ecological Objectives

The water regime requirements to meet ecological objectives for waterbird management are (summarised from Table 2 of DSE and GBCMA (2005:19):

- Annual summer-autumn drying phase (most years).

- Small floods maintained for four months in spring in 50% of years, and the return time between such events not to exceed five years.
- Small-medium floods, delivered as at least one month of large flow with flooding maintained for four months, in 40% of years.
- Medium-large floods, delivered as at least one month of very large flow (but with no requirement for flooding to be maintained for four months), in 30% of years.

7.3.1 Evaluation of Water Regime Requirements

The last two requirements are aimed more at the maintenance of River Red Gum communities than at waterbirds per se, but there will be flow-on benefits for all birds occupying red gum forest and woodland including waterbirds to a degree (Briggs & Thornton 1999). To what extent waterbirds would benefit from the last requirement depends on the length of inundation of the red gum communities. A range of foraging (and perching) options will be provided immediately, but successful reproduction by tree-nesting (non-colonial species) such as some herons and ducks would be limited if drying occurs too rapidly.

The first requirement – to aim for annual draw-down of currently permanently inundated floodplain wetlands – is laudable, there being direct benefits for breeding waterfowl as backed by scientific evidence (e.g. in Australia: Maher & Carpenter 1984; Crome 1986, 1988; Crome & Carpenter 1988), and many anecdotal or reported observations (e.g. Briggs 1981; Briggs & Maher 1985). The intermittent drying of wetlands allows a greater burst of productivity on subsequent re-filling, and this gives ducks and other waterbirds a greater chance of successful reproduction than on permanently inundated wetlands (Crome 1986, 1988; Briggs *et al.,* 1997).

In terms of the second requirement, DSE and GBCMA (2005) cite REG C (2003) as the authority for the "**4-month medium floods**" requirement to allow "successful recruitment of large colonies of colonial waterbirds", and this time period (four months), in part at least, appears to be founded on the observations of successful breeding by 15 000 pairs during the 2000 environmental water allocation of 341 Ml over a four-month period to the Barmah-Millewa forests (Leslie & Ward 2002). Briggs & Thornton (1999) suggested that five months was the minimum period required for the altricial colonial waterbirds to settle, pair up, and fledge young successfully. Scott (1997) suggested 10 months might be required for all species to complete a large breeding event successfully, and Briggs & Thornton's (1999) results also suggest that 6-10 months is an optimal period for large-scale breeding. Therefore, while we have the direct evidence of positive results at Barmah in 2000-01, uncertainty remains over the **minimum period of flooding required by colonial waterbirds to breed successfully**. In any event and as undertaken at Barmah-Millewa in the summer of 2000-01 (Leslie & Ward 2002), operational adjustments can be made (i.e. release more water) **if there is sufficiently close monitoring of breeding progress during each EWA event**, and O'Connor & Ward (2003) recommended frequent monitoring of this kind. Time of year is likely to be one determinant of the length of time required to complete a large successful colonial breeding event, the period likely being longer in cooler months, i.e. after autumn flooding (Briggs & Thornton 1999), but further investigation is again required (e.g. Maher 1993).

A spatially explicit context is missing from the water regime requirements in DSE and GBCMA (2005). Apart from the permanently inundated main stem and major channels, it is necessary to know how many wetlands (and what proportion of total wetland area) in the Barmah region are in an unnatural, permanently flooded state, as it may be prudent to investigate the installation of more level-control structures to restore a more natural flooding/drying regime to some wetlands/wetland areas in this category, in order to restore some lost wetland function to these sites and increase (peak) wetland productivity generally.

By deploying such structures – perhaps at considerable investment cost initially – it may be able to improve the provisioning of better quality maintenance and breeding habitat in the long term, and so achieve higher rates of breeding success (fledged young) for a given volume of EWA. Of course, any such interventions should be treated as an experiment (some replication, some controls) and closely monitored (AEM).

7.4 Conclusions with respect to Objectives and Water Regimes for Waterbirds

Currently small parts of the floodplain are regularly flooded in December to April far more frequently than historically (DSE and GBCMA 2005), and strategies to reduce the adverse effects of this regime need to be reinforced. An investigation is needed of the feasibility and desirability of returning artificially permanently inundated wetlands to a more natural water regime, and the options of targeting other small basins for seasonal filling and drying, to increase both the 'high-productivity phase' of these wetlands (upon refilling) and their 'high-food availability phase' during the draw-down phase. Briggs & Thornton (1999) advise that some permanent maintenance and drought-refuge wetland habitat ought to be provided given the huge level of water diversions from rivers in the MDB. A balance may need to be struck, therefore, between the recommended action and the retention of permanent wetlands, but given the current constraints of irrigation needs it seems unlikely that the balance could tilt too far towards non-permanence.

Apart from its direct effects on waterbirds, changes to the distribution, areal extent and structure of vegetation communities may also have adverse impacts on waterbirds. A primary example is the loss of Moira Grass, floating and non-emergent plant communities and the concomitant increase in dense beds of emergent reeds, grasses, rushes and sedges. Also the conversion of much of the River Red Gum forest to dense stands of saplings and loss of areas of open water amidst the forest have probably been equally detrimental. These propositions can be tested with a carefully designed observational study incorporating some habitat manipulation.

More flow regulatory structures (to enable precise and intensive flow management within the Forest) may be required to reverse undesirable vegetation changes and to restore productivity and health to parts of the floodplain. See Chapter 8 (Section 8.3) for a discussion of the potential ecological costs of pursuing an engineering-only solution.

An examination of duration and season of flooding during previous colonial breeding events in the Barmah Millewa Forest is required. The temporal and spatial extents of flooding both around the actual colony sites and amongst the surrounding (Barmah Millewa Forest-wide) wetlands need to be specified. Size of breeding event (number of pairs of each species nesting) is also required so that the relationship between duration/size of flooding and nesting effort can be examined. The documentation necessary to explore these relationships in sufficient detail may be lacking, and if so future events require better documentation.

The basis for the four-month flood period minimum to complete a 'large' successful colonial waterbird breeding event requires further investigation, as figures of 5-10 months have been suggested in the literature (Briggs & Thornton 1995, 1999; Scott 1997). Inevitably it seems that the conflict revolves around the definition of 'large', as a longer duration flood of the same height should enable a more extended breeding season, and therefore, 'larger' event. The trade-offs (and practicalities) between extending a flood event compared with boosting the flood height, for a given total EWA, need to be modelled and then investigated in the field with actual water releases. It is anticipated that greater flood height will inundate a greater portion of the floodplain with benefits for a greater proportion of the ecosystem (noting the potential risk for some wetland management units to be flooded for too short a duration – research required). Time of year may also vary the length of time it takes for breeding to commence, while smaller species have a faster breeding cycle than larger species, and so these aspects will need to be considered in the investigation.

Where an EWA specifically targets a breeding event by colonial waterbirds, breeding progress should be closely monitored to allow for water allocation adjustments. This admirable practice seems to be in place already (O'Connor & Ward 2003).

GIS mapping of regularly used colony sites, their aquatic and vegetated communities, and detailed knowledge of the water regime (current and natural) at these sites are required. [Note – these maps and tools may exist already, but it is not apparent from reading DSE and GBCMA (2005) – in Section 5.1 (p. 23), "Delivering Water to the Asset", a sound series of steps required to achieve this objective is outlined, but its progress is not described.] Similarly GIS mapping and modelling of all wetlands within the Barmah Millewa Forest needs to be improved, if the trade-offs are to be investigated. It is likely that colonial nesters range as far as 20 km from the nest site to feed (Custer & Galli 2002; Richardson & Taylor 2003; J. Reid *personal observations*), and it is likely that a range of wetlands in different states of vegetation and phases of filling/drawing down need to be available throughout the Asset for a large successful breeding event. With sufficient structures in place and if the wetland models are sufficiently sophisticated, spatio-temporal variability across wetland units could then be optimised for colonial waterbirds.

Closer research and monitoring attention than that implied in DSE and GBCMA (2005) needs to be paid to the other non-colonial waterbirds of the Barmah Forest wetlands, to ensure that appropriate abundances of the full range of species are maintained and that successful breeding occurs periodically. Ideally, appropriate objectives would be set for these other species. Rare and Threatened species (e.g. Australasian Bittern *Botaurus poiciloptilus*) and breeding by the non-colonial waterbirds are obvious candidates, but careful selection of species and groups is needed to enure feasibility.

7.5 Scientific Justification for Waterbird Objectives and Water Regime Requirements

Scant literature was cited in the waterbird material within DSE and GBCMA (2005), with Leslie & Ward (2002) being the primary source for sections addressed above. In Section 11 (pp. 37-39), three other primary sources of information are cited, namely **MFAT** (the Murray Flow Assessment Tool; see below), Blanch (1999), and O'Connor & Ward (2003).

The study of O'Connor & Ward (2003), although not in the formal literature (Agency report, Web published), is an apposite example of sound management-oriented research (monitoring), where the researchers/managers used appropriate survey techniques (aerial survey followed by focussed ground surveys), and used the results of their observations to guide subsequent management intervention, successfully by their own accounts. As with the interventions described by Leslie & Ward (2002), these cases are considered praiseworthy Australian examples of 'Adaptive Environmental Management' in action.

7.5.1 Literature not Cited

There was **only one primary, peer-reviewed, journal paper** found in a literature search on the response of waterbirds to flooding in the Barmah Forest (Leslie 2001). Conveniently, Leslie (2001) reviewed all the historical (1900-1978) Australian (regional) ornithological literature relating to breeding by colonial waterbirds in the Barmah region, and compiled a 17-year contemporary data set (1979-1997) of the same responses. Leslie (2001) used the contemporary data set to derive waterbird breeding response models to three hydrological predictors, and then tested the validity of his model with the earlier observations, and he obtained a reasonable degree of fit. It is surprising Leslie (2001) has not been referred to by DSE and GBCMA (2005).

There are many peer-reviewed papers in the primary journal literature attributable to R.T Kingsford and colleagues, based on waterbird observations in the Murray-Darling Basin **but not** pertaining specifically to the Barmah wetlands region – only a few are cited here: Kingsford (2000); Kingsford & Johnson (1998); Kingsford & Thomas (2004); Kingsford & Auld (2005). The second and fourth relate to the Macquarie Marshes wetland region (NSW), the third to the lower Murrumbidgee (Bidgee) wetlands (NSW).

R.T. Kingsford (School of Biological, Earth and Environmental Sciences, University of New South Wales) has generalised his experience and understanding of waterbirds' ecological requirements in the waterbird breeding and habitat modules of the MFAT model (for Living Murray initiative, LM). As far as I am aware, this work has not been published in a peer-reviewed journal, but it has been documented in Young *et al.,* (2003). These models of waterbird breeding and maintenance habitat requirements with respect to a few general hydrological measures can be regarded as hypotheses, which can be explicitly tested with independent data; the models can be accordingly refined and improved as required. There were selected wetland sites used for the MFAT modelling within the Barmah wetlands (REG-C). If feasible these sites ought to be used for subsequent monitoring of waterbird use, so that the models and model assumptions can be tested and refined (as necessary). In my opinion the models contained in MFAT are generally sound **from a strategic perspective**, but no doubt could be improved with future targeted testing, and probably tailored (fine-tuned) to particular regions/reaches of the Murray (see, for instance, waterbird comments in Roberts *et al.,* 2003). In particular, the issue of minimum duration of flooding (4 months in MFAT for colonial waterbirds to breed successfully) requires further study. Also, from an **operational (management) viewpoint** these models need to be developed further, to be made **spatially explicit**.

The research by Dr S.V. Briggs and her colleagues (Briggs 1988, 1990; Briggs & Maher 1985; Briggs & Thornton 1995, 1999; Briggs *et al.,* 1997) has been overlooked, both in the AEMP of DSE and GBCMA (2005) and in the GBCMA's "database of literature" provided to the client. This is a major oversight. The research presented in these and other (mostly peer-reviewed) papers, although not conducted along the Murray River, is pitched directly at asset-scale (i.e. wetland) management and, in most cases, focuses on waterbird breeding requirements in River Red Gum dominated wetland environments.

A recent study of waterbird habitat use and reproduction at six wetlands each in the NSW and Victorian portions of the Barmah-Millewa region was conducted by Webster (2004a) over the period 1999-2003. While this is an unpublished report (and presumably not peer-reviewed), it contains a valuable body of systematic observations over a four-year period. As the author acknowledges in the report, some of the important colonial waterbird sites were not surveyed. Flood years resulted in a greater abundance of diversity of waterbirds, and in breeding response than did non-flood years (two years in each category), confirming the customary expectation that size of flood regulates waterbird abundance and activity. The design is simple with low replication, and is an observational study (rather than a 'manipulated treatments with controls' experiment). The data cannot be analysed rigorously, because the effect of flood vs non-flood 'treatment' is confounded with 'year' (as in the typical repeated-measures design), and so the brief statistical analyses reported here are appropriate, noting that the interpretation of results should be treated cautiously because the degrees of freedom used in the analysis are inflated above the real power of the design.

Table 7.1. provides a critique of the literature. Only new literature of direct relevance to wetlands management in the Barmah Forest is reviewed here.

Table 7.1a. State of knowledge: References cited in AEMP to support waterbird ecological objectives and required hydrological conditions

Publication	Source (peer review)	Study Area	Type of Evidence	Value to Managers
Leslie & Ward (2002)	Journal article **(but difficult to be sure that peer review is required)**	Barmah-Millewa Forest	*Scientific Commentary*: partly based on Leslie (2001) which was a Scientific Investigation of hydrology waterbird breeding relationships. Sound modelling, with calibration used.	*High Value*: adaptive management in action
MFAT (2003)	Agency report	Murray River generally	*Conceptual Models*. Distillation of authoritative ecological understanding of waterbird maintenance and breeding habitat requirements into simple, effective hydrological-waterbird response models.	*Moderate Value*: needs to be developed and made spatially explicit at the asset scale
Blanch (1999)	Conference presentation published on an NGO website	Murray-Darling Basin	*Scientific Commentary*	*Limited Value*
O'Connor & Ward (2003)	Agency report	Barmah Forest	*Observations*. Waterbird breeding response to EWA, with adaptive management to ensure greater breeding success. Sound.	*High Value*: adaptive management in action

Table 7.1b. State of knowledge: References not cited in AEMP that could be used to support waterbird ecological objectives and required hydrological conditions

Publication	Source (peer review)	Study Area	Type of Evidence	Value to Managers
Leslie (2001)	Journal article	Barmah-Millewa Forest	*Scientific Investigation* of hydrology waterbird breeding relationships. Sound modelling, with calibration used.	*High Value*
Kingsford & Johnson (1998); Kingsford & Thomas (2004); Kingsford & Auld (2005)	Journal articles	Murray Darling Basin rivers generally	*Scientific Investigation* of hydrology waterbird breeding relationships. Sound modelling, with some calibration.	*Limited Value*: not relevant to asset-scale management
Briggs (1988)*; Briggs & Maher (1985); Briggs & Thornton (1995, 1999); Briggs *et al.*, (1997)	Journal articles peer reviewed (*except unsure about peer review of status of this one)	Murray-Darling Basin, particularly middle Murrumbidgee	*Observations*. Careful observational design with measurement of environmental variables (water level, period and extent of inundation) allows for strong conclusions.	*High Value*: targets wetland managers directly
Crome (1986).	Journal article	Murray-Darling Basin	*Observations*. Careful observational design with measurement of environmental variables (duck food) allows for strong conclusions.	*Moderate Value*: emphasises need to dry out wetlands
Webster (2004a)	Agency report	Barmah	*Observations*. Waterbird breeding response to annual variations in flow magnitude.	*Moderate Value*

7.5.2 Literature not Sourced

Two reports by D. Leslie (1988, 1998) 'cited' in DSE (2003: *Barmah Forest Ramsar Site: Strategic Management Plan*, the SMP) and containing interesting waterbird observations and opinions could not be traced, nor therefore evaluated. Although referred to in the SMP, they were not listed in the References section. Nor are there publications attributed to Leslie for these years in the GBCMA literature database.

7.6 Other Issues

7.6.1 Waterbirds v Other Biota, Barmah v Other Icons of the Murray

With current levels of water extraction from the Murray River, it seems unrealistic that pre-1750 levels of waterbird breeding and abundance could be restored to the Barmah wetlands. Given this assumption, it seems that appropriate use of structures and channel will be required to optimise the delivery of packets of river flow to particular locations for particular periods of time in order to meet stated ecological objectives, whether waterbirds or other biota/ecological functions. That is, there will need to be trade-offs, spatially and temporally, as to which parts of the Barmah Forest (and which ecological functions) are targeted. These trade-offs need to be explicitly stated, discussed by the wider community and agreed on. Targeted monitoring of the affected areas and functions, i.e. those aspects predicted to benefit and those predicted to be adversely affected, then needs to be designed and implemented, to provide feedback and allow fine-tuning of the management prescriptions. It is noted that current management of rain-rejection events follows this rationale (K. Ward, *personal communication*; Chapter 8), with flows directed in alternate years to the NSW and Victorian portions of the Barmah Millewa Forest, but this management action is not directed at waterbird breeding; ideally, the predicted productivity and nutrient-cycling benefits of this strategy should be investigated. Anticipated trade-offs between waterbirds and other biota/ecological functions, and between waterbird species, require further investigation, the formulation of conceptual models (with predictions), and testing. In the same light, trade-offs between delivering additional water to the Barmah Millewa Forest vs other significant assets downstream need to continually revisited as more information accumulates (see Section 7.7.).

7.6.2 Waterbird Functional Group Classification – a Useful Approach?

Leslie (2001) classified the colonial waterbirds of the Barmah-Millewa wetlands into four functional groups, based on nest location and habitat. Other authors (Kingsford 1991; Roshier *et al.,* 2002) have used different arrangements, recognising six or seven groups (among **all** waterbirds) based largely on their feeding habits and habitats, with the classification of Roshier *et al.* derived from that of Kingsford; there is a strong influence of taxonomy in their classifications, since there is a great correspondence between taxonomy and form/function. Leslie's inclusion of a wide range of waterbirds (e.g. grebes, Black Swan *Cygnus atratus*, Black-winged Stilt *Himantopus himantopus*, Brolga *Grus rubicunda*) within colonial waterbirds is unusual. Most authors restrict colonial waterbirds to two Orders of waterbird, the Pelecaniformes (pelicans, storks, cormorants and allies) and Ciconiiformes (egrets, herons, spoonbills, ibis and allies), with or without terns and gulls.

Leslie's arrangement of colonial waterbirds into four main groups, and with the ground/open water nesters subdivided into three more classes, is useful to managers, because it indicates a wide range of structural habitats needs to be maintained throughout the wetlands, and identifies particular types of nesting habitat used by each group of species. Unfortunately, the distinctions are blurred between colonial and solitary nesters, as some colonial species (e.g. White-necked Heron *Ardea pacifica*, Darter *Anhinga melanogaster*) will nest as single pairs in some situations, while some solitary species (e.g. Yellow-billed Spoonbill *Platalea flavipes*) will nest in a semi-colonial manner or nest among other species in a large mixed-species colony.

Ultimately, there is no single correct functional group arrangement, as each species has its own particular idiosyncratic habitat requirements. A further complication is that species may respond to the distribution of aquatic resources at different spatial scales, from the local to continental in scope (Roshier *et al.,* 2001). Consequently, while several species may respond similarly to local wetland conditions at one time, their abundance, behaviour and habitat use patterns may be different on other occasions due to changing external conditions. Functional groupings are most useful for general reporting purposes, modelling (Leslie 2001), or in situations where identification to species is problematic, as with aerial surveys (Roshier *et al.,* 2002) or rapid estimation of size of distant flocks of birds in ground surveys. While the functional group approach facilitates understanding and allows managers to group waterbird species with similar requirements, its indiscriminate use as an ecological indicator or for reporting purposes is unhelpful, and in a closely monitored, iconic site like the Barmah-Millewa wetlands, the most appropriate focus for monitoring is at the species level (e.g. Webster 2004a,b). An illustration is given below using Australian White Ibis.

It is recommended that the occurrence, distribution, abundance and breeding behaviour be recorded for all waterbird species and that monitoring and annual reports detail these results for each species. When the 1998 and 2000 EWAs were reviewed (see Chapter 9), it proved impossible to ascertain from the ‘Second Use’ EWA report (Maunsell McIntyre 2001) how many waterbird species were detected breeding during the 2000-01 flood event.

7.6.3 A Problem with the Functional Group Approach

Although the following assertion requires further consideration and evaluation by a broader audience and may be simplistic, it reflects the author’s opinion and can be generalised to a broader NRM debate, that of invasive, pest or ‘increaser’ *native species*. Most species of Australian waterbirds seem to have been adversely impacted by land use changes, water abstraction and river regulation in south-eastern Australia including the MDB (e.g. Kingsford 1999, 2000, 2004). However, a few species seem to have benefited from these changes, and the Australian White Ibis *Threskiornis molucca* is one. Accordingly, given the current *Ecological Objective* of “Ensure breeding success of colonial waterbirds” (DSE and GBCMA 2005), a large successful breeding event by Australian White Ibis alone would satisfy this objective. Yet if the above assertion is correct, successful breeding by only this species is probably not a desired outcome of an EWA. Great Egret *Ardea alba*, Intermediate Egret *A. intermedia* and Royal Spoonbill *Platalea regia*, in particular, should be the species that managers want to see breeding successfully, while success can also be measured by the diversity of colonial nesters that breed successfully, and the more species nesting the better.

Caveats to the above assertion regarding Australian White Ibis as a potentially ‘undesirable’ species include:

- the size of the species’ breeding population appears to have declined historically (Chesterfield *et al.,* 1984);
- the species may play an important ecological function in the BM wetlands (alternatively, it cannot be ruled out that they could have undesirable trophic effects on some aquatic biota);

- the species' success relative to other colonial species may be a consequence of changes within the Barmah Millewa Forest environment, and land-use changes across the broader region (its relative success could be seen as a symptom); and
- it is not suggested that the species is having a negative effect on other waterbirds (but nor can this be ruled out either).

In the same light, increases in breeding populations of Nankeen Night-Heron *Nycticorax caledonicus* and the self-introduced Cattle Egret *Bubulcus ibis* may not be desirable, because of their possible depredatory behaviour at other species' nests (e.g. Todd 1996). Of course it may be difficult to impossible to manage water within the Barmah Millewa Forest such that these species are discouraged from breeding. However, consideration needs to be given to (relative) increases in native waterbird species and their potential negative impacts and use as indicators.

7.6.3 Other Trade-offs, a Strategic, Flexible and Longer-Term View

Some of the Operating Rules for when to initiate/trigger an EWA, to which parts of the floodplain to deliver/deny flows, and how much(?) are quite sophisticated conditional, branching (if … then … else if etc) decision-making rules. A similar degree of sophistication should be aimed for (eventually) with respect to Ecological Objectives, although this aim is not yet achievable because ecosystem and ecological knowledge lags behind that of hydrology and water engineering. However, there are likely to be many trade-offs – spatial, temporal, biotic/trophic and functional (processes) – in a large complex wetland environment with insufficient water (Barmah Millewa Forest!), and so not all ecological targets can be met with any one EWA.

A framework is required that accepts not all Ecological Objectives can be met or met equally with each EAW and flood, and that antecedent conditions – examples include season of natural flood that triggers an EWA release, or time since a defined event (e.g. successful Bluenose Cod *Maccullochella macquariensis* recruitment) last occurred – may dictate what the priorities for a particular event should be. It may take many years and several EWAs to satisfactorily meet most/all Objectives. The framework needs to be flexible so that priorities can be altered as current/antecedent conditions dictate and accepts that priorities will be reviewed and altered if necessary after each significant flow event. Such a sophisticated prioritisation framework can only be successful if a comprehensive and effective ecological monitoring program is in place; comprehensive means the study of a wide range taxa/processes at many locations within the wetlands.

7.7 Research Gaps and Future Directions

7.7.1 Explore Trade-offs and Quantify Where Possible

Currently ca 70% of River Murray water is extracted for consumptive human uses. Icon sites such as Barmah Forest have been targeted for EW allocations. It seems obvious, therefore, that there are trade-offs involved. The other wetlands along the river have already been 'traded-off' to an extent. There is still the risk that insufficient volumes of water will be delivered to meet specified targets (Blanch 1999). Therefore, it might be prudent to run scenarios to allow a risk analysis of the trade-offs involved in the various options, which include:

- do nothing (i.e. pre-2000, say);
- provide more water to (some) icon sites, at the expense of other icon sites or other reaches of the river generally ("bigger bang for buck" principle);

- robbing non-consumptive water from other parts of the river to boost EWAs; and
- smearing EW allocations broadly along the system.

The danger in providing an insufficient volume of water to fulfil an ecological objective is that a substantial environmental allocation of water could be seen as 'wasted'. Note however, that the EWA delivered to Barmah Forest in 2000/01 described by Leslie & Ward (2002) is a good example of rapid response by management to increase the allocation so that the specific objective (successful recruitment of colonial waterbirds) was fulfilled.

Obviously, considerable deliberation went into the decision to prioritise EWAs to particular icon sites along the length of the Murray. There is no point in revisiting previous decision-making processes. However, it is vital that allocations of water to particular parts of the river be based on sound analysis and judgement (including scientific), preferably through a transparent process, and that these decisions are frequently revisited.

Any trade-offs between extending flooding through EW allocations to promote greater waterbird breeding success and enhancing other environmental assets need to be explicitly examined and modelled (and put out to the community for discussion and feedback). There are two main sorts of potential trade-offs here, namely those due to:

1. direct interactions, particularly predation, between waterbirds and other organisms – the abundance of favoured prey organisms (e.g. frogs, fish, large crustaceans) may decrease substantially (indirect effects via trophic cascades are also a possibility but less likely); and
2. spatially targeted delivery of water to breeding sites at the expense of other parts of the Barmah wetlands.

Research is required to demonstrate that these suggested trade-offs are real and quantify them. See Section 7.6.1 and Issues 5 & 6.

7.7.2 Focus on Rare, Threatened and Declining Waterbird Species

As well as the colonial waterbird breeders, attention should be paid to those non-colonial species that are listed as 'Threatened' under national and state legislation/schedules and which occur in the Murray Basin. Further research is required to assess the validity of current listings – there are probably other species declining which warrant 'threatened species' status. Then autecological studies of these species' maintenance and breeding habitat requirements should proceed, focussing on the role of hydrology and water regimes (from an EWA perspective), but with due consideration of potential threatening processes and other limiting environmental constraints on the species.

The priorities for waterbird flow objectives should be reviewed after such a study. The following list of 18 species of waterbird and other water-dependent birds, listed below, are classified as near-Threatened (LR), Vulnerable (Vul) or Endangered (End, CEn) under Victoria's *Flora and Fauna Guarantee Act, 1988,* and are known to occur in the Barmah wetlands (after DSE 2003):

- Australasian Bittern *Botaurus poiciloptilus* (End);
- Australasian Shoveler *Anas rhynchotis* (Vul);
- Azure Kingfisher *Alcedo azurea* (LR);
- Blue-billed Duck *Oxyura australis* (End);
- Brolga *Grus rubicunda* (Vul);
- Glossy Ibis *Plegadis falcinellus* (LR);

- Great Egret *Ardea alba* (Vul);
- Hardhead *Aythya australis* (Vul);
- Intermediate Egret *Ardea intermedia* (CEn);
- Latham's Snipe *Gallinago hardwickii* (LR);
- Little Bittern *Ixobrychus minutus* (End);
- Little Egret *Egretta garzetta* (End);
- Musk Duck *Biziura lobata* (Vul);
- Nankeen Night Heron *Nycticorax caledonicus* (LR)*;
- Pied Cormorant *Phalacrocorax varius* (LR);
- Royal Spoonbill *Platalea regia* (Vul);
- Whiskered Tern *Chlidonias hybridus* (LR); and
- White-bellied Sea-Eagle *Haliaeetus leucogaster* (Vul).

[* notwithstanding this species' listing in Victoria as near-Threatened, an increase in the breeding population in the Barmah Millewa Forest may not be desirable.]

One species in particular, the Australasian Bittern, requires immediate survey effort and targeted management. It is a cryptic species and Keith Ward (*personal communication*) suggests that the rush and reed beds of Barmah Forest might be a stronghold of this endangered species. It is the author's opinion and that of his colleague, R.P. Jaensch, Wetlands International, an Australian authority on inland waterbirds and their conservation status (*personal communication*), that the Australasian Bittern is critically endangered nationally. Determining its current population status in the Barmah Forest is a high priority. The endangered Little Bittern *Ixobrychus minutes* should be surveyed concomitantly, and so the survey should be undertaken in the spring-summer breeding season of both species.

The feasibility of monitoring selected species, focusing on predicted benefits from EWAs, also needs exploring.

7.7.3 Study of Colonial Waterbirds' Lifetime Mobility and Nest-Site Fidelity

How far do birds that breed at Barmah roam between nesting events? Do these individuals only attempt to breed at Barmah? If they breed elsewhere, over what spatial extent – is it local (e.g. Murray-Murrumbidgee catchments), regional (Murray-Darling Basin), or continental in scope? What degree of site fidelity do adults that have bred previously at Barmah display compared with birds that have been bred at Barmah? If these questions could be answered through capture and marking studies or with satellite telemetry, and for a range of colonially nesting species, then Barmah wetland managers would be in a better position to prioritise the use of EWA for waterbird breeding events. If it were demonstrated that individual colonial waterbirds have the capacity to breed in locations as well as Barmah-Millewa, then it might be sensible to reassess the priority currently given to this group.

A pilot satellite telemetry study on the Australian White Ibis is recommended first, to determine proof of concept, before extending the study to a broader range of species.

7.7.4 Study of Colonial Waterbirds' Foraging Distances and Feeding Habitats During Breeding Events

How far do birds forage from the colony? Do the species vary in the distances travelled and locations/habitats visited? Do individuals shift in the locations used for foraging through a breeding event? These questions could be answered through capture and telemetry (with satellite and/or conventional methods). The data and results could be used to test the following hypotheses that:

- availability of a wide range of wetland types in asynchronous stages of filling and drying promote larger colonial waterbird recruitment events; and
- preferred foraging habitats for some species are limiting.

Ideally this research would be integrated with the following (7.7.5.). See Issue 4.

7.7.5 Waterbird Community's Habitat Preferences

Ideally suited to an integrated portfolio of Honours, Masters and PhD studies (three years minimum), current maps of vegetation distribution and 'water management units' within the Barmah wetlands can be the stratification basis for a well-designed observational study of waterbird abundance, distribution and feeding preferences. The waterbird study needs to be tied to food availability measurements within the distinct habitats, while a manipulative component to the studies is essential (examining the effects of: different drying/wetting regimes; directing an EWA to some wetlands and not others of the same hydrological and vegetation defined habitat). Objectives of such a study would include but not be limited to:

- ascertaining the habitat and apparent food preferences of all frequently occurring species of waterbirds in the Barmah region;
- evaluating, from waterbirds' perspective, the relative richness and productivity of the various major vegetation communities under a small range of water regimes; and
- independently measuring wetland productivity and biomass of instream biota.

This research should be integrated with the breeding colony's foraging distance study (7.7.4).

8. Evaluation of the 1998 and 2000 Environmental Water Allocations : Servicing the Floodplain Ecology of Barmah Forest

Julian Reid and Jane Roberts

8.1 The Environmental Water Allocation: a Hydrological Perspective

This chapter provides an evaluation of the results of the Barmah wetland environmental water allocation (EWA) releases in 1998 and 2000 satisfying Task 4 of the Issues and Options brief, which specifies:

- flow and/or water regimes required to sustain the floodplain vegetation communities supported by the Barmah wetlands, and their ecological, social, cultural and economic functions; and
- the efficacy of different water delivery options considered in Task 3 (Chapter 8, Phase II report).

Included are recommendations for use and planning of future EWAs, highlighting the need for a scientific approach to the delivery of EWAs and ecological monitoring of their effects on the wetland's biota.

This evaluation concerns vegetation and waterbird values mainly, consistent with the expertise of the contributing authors, with an emphasis on underlying hydrological processes given hydrology's key role in the system as the most important ecological driver ('*maestro'*: Walker *et al*., 1995). It does not consider other managed floods, such as the sustained flooding during 2002 resulting from passing water through the Forest as a controlled spill to meet demands downriver.

The major objectives considered in this evaluation are (from Table 4.1, Chapter 4 in this report):

- Restore and maintain a mosaic of vegetation communities representing the relative areas and attributes of pre-regulation communities in Barmah Forest.
- Maintain or enhance important functional groups of fauna [waterbirds in this context].
- Maintain or enhance specified vegetation communities within each WMU, in terms of composition, diversity, structure and area.
- Maintain or enhance populations of selected rare or endangered species of flora and fauna.

Note that the environmental water requirements of rare and endangered plant species were considered earlier (Chapter 6.3.5 Issues for rare and threatened species), so the fourth objective has already been partly evaluated.

The evaluation was undertaken using the information contained in two reports about the 1998 and 2000 EWAs (Maunsell McIntyre, 1999, 2001) with additional information provided by Keith Ward in *personal communications*.

The evaluation of vegetation refers specifically to Barmah, whilst the evaluation of waterbirds considers the ecological entity, which is the floodplain system known as the Barmah-Millewa Forest. This is awkward and regrettable, but is a reflection of the state of knowledge and availability of information, and the brief. Notwithstanding these points, it is both short-sighted and counterproductive to envisage the management of the Barmah Forest in isolation from the River Murray and distinct from the Millewa Forests (see Recommendations in 8.4.1).

8.1.1 Hydrological change and the need for an EWA

No part of Barmah Forest receives the same inundation regime under Current Conditions as it did under Natural Conditions, other than areas generally accepted as being above the reach of floods such as sandhills. The combination of different effects of river regulation and its localised effects (Chapter 6.2) means that, in simple terms, some parts of Barmah Forest are now ‘wetter’ and some are now ‘drier’, with the point of transition from wetter to drier being somewhere around 15,000 ML day on the Tocumwal gauge. This flow threshold of 15,000 ML day translates roughly into about 22% of Barmah Forest being ‘wetter’ and the remainder being ‘drier’. A guide to the plant communities within each of these broad categories is given below (Table 8.1).

Table 8.1 Altered condition of Barmah Forest:

Wetter and drier conditions in Barmah Forest were identified by spells analyses of flow thresholds for Current v Natural simulated daily time series at Tocumwal, as well as a consideration of high in-channel flows and rain rejections (Chapter 6.2). These can be re-expressed as area or percentage of Barmah Forest using published relationships: “Bren and Chesterfield” refers to flow-inundation area relationship of Bren *et al.* (1988) using peak flows at Tocumwal and the vegetation mapping and communities described by Chesterfield (1986).

	“Bren and Chesterfield” Barmah Forest	
	Flow level	Area
Wetter	Up to around 15,000 ML day	22% of Barmah Forest, which is roughly equivalent to: - Giant Rush beds - Moira grass plains - Red Gum with Moira grass understorey - River Red Gum regeneration on plains
Drier	Greater than 15,000 ML day.	78% of Barmah Forest, which is roughly equivalent to: - Red Gum with combinations of Terete Culm Sedge, Common Spike Rush, Warrego Summer Grass and wallaby grasses - Box communities

The purpose of the EWA is to redress the effects of river regulation (Chapter 6.2). For areas that are ‘drier’ or affected by flows of 15,000 ML day and greater (subject to a confirmatory analysis), this means that the EWA can be used to target:

- Reduced frequency of flooding
- Shorter floods
- Loss of autumn-winter floods

It is more difficult to see how the EWA can be used for areas that are ‘drier’ without supporting a potentially risky flow regime, and hence aggravating an ecological condition.

8.1.2 Environmental Water Allocation (EWA) for Barmah Forest

The Environmental Water Allocation (EWA) is for the Barmah-Millewa Forests, not just for the Barmah Forest, but here it is considered specifically in relation to Barmah Forest.

The EWA is a parcel of water specifically to be used for environmental benefit of Barmah-Millewa Forests. The quantity is variable, ranging from 0 to 700 GL, and can accumulate through time, if not used, up to a maximum of 700 GL. The EWA is added to, on an annual basis, with an input of 50 GL by each of the two adjoining states, New South Wales and Victoria, i.e. totalling 100 GL per annum. There is potential for additional inputs of 25 GL per state based on Victoria meeting a sales target with this and this then being matched by New South Wales: but although 25 GL has been added occasionally this has never been carried over (Maunsell McIntyre, 2001). Additional inputs have come from the NSW environmental allocation and from the Victorian wetland allocation. Rules for managing the EWA are summarised in Maunsell McIntyre (p.33, 2001)

To expedite and shorten what could otherwise be lengthy negotiations and time-absorbing decisions as to when and how to use the EWA, a comprehensive process has been set up and is described in the report, *Barmah-Millewa Forest Significant Ecological Asset: Management Plan for 2005-2006* (MDBC, 2005). It comprises a set of operating rules and triggers, a decision tree, and a way to determine priority areas for receiving the EWA (Appendices C, D and H in MDBC, 2005). Rules have been evolving through time; the current rules, adopted in March 2001, are 'interim' and are in place until June 2006; the method for prioritising areas for receiving environmental water is also temporary, as it is likely to be revised under The Living Murray process (p. 77 in MDBC, 2005).

Limitations of the EWA: In practical terms, the EWA is constrained in what it can achieve because:

- **Volume available** is only a small amount relative to volumes travelling down the River Murray, even under non-flood conditions, and particularly during floods. The annual addition of 100 GL is equivalent to 10 days within-channel flow through Barmah Choke; the maximum of 700 GL is equivalent to 35 days flow at 20,000 ML day at Tocumwal.
- **Frequency** of supplying the maximum EWA is, theoretically, about once every 7 years, if not used in-between, based on annual inputs from each of the neighbouring states of 50 GL; this return time can be shortened slightly through additional inputs. In practice, however, the frequency is likely to be much less and the event size much less than maximum. This is because the EWA is likely to be used I between and so not accumulate the full amount, and also there is the general objective for the EWAs of "in 5th year, release all accumulated entitlement and manage as well as possible on the floodplain to reach ecological benefits" (DSE & GBCMA, 2005, Section 4.2).
- **Maximising effectiveness** means the EWA is most efficiently used when the channel is already full, which is during the irrigation season or when flows are being transferred downstream or during a natural flood. Therefore, the EWA will often be seasonally constrained.
- **Maximum flows** refers to the channel capacity between Hume and Yarrawonga which is the volume that can be delivered downstream without incurring compensation costs for overbank flooding. This is in the order of 25,000 ML day.

Volume can be used to target flood magnitude or flood duration, but delivery constraints mean that flows only up to about 20-25,000 ML day can be used, either for magnitude or for flood duration. Thus, flood magnitudes that can be achieved by relying solely on the EWA are relatively minor. For example, the maximum volume of 700 GL could mean a flow of 25-30,000 ML day at Tocumwal for 23-28 days (assuming no in-transit losses) which, based on Bren's flow-area relationship, is equivalent to being able to guarantee a flood over 50-55% of Barmah Forest, once every 7 years for 20-25 days in spring-summer. Compared with natural conditions for this flow threshold, the EWA guarantee is shorter than average duration and later than typical (Figures 6.1 and 6.2). For volumes less than 700 GL, such as 550 GL and retention up to 5 years, this is equivalent to a flow of 25-30,000 ML at Tocumwal for only 18-22 days, every 5th year, equivalent to 2/3 duration of natural average.

Flood durations can be increased, as has been done with the EWA (see below), by extending the receding limb of the hydrograph, or by "connecting" two flood peaks i.e. preventing water levels falling back to within-channel levels. The drive to maintain water levels is driven by a specific ecological imperative, namely the breeding success of colonial water birds. Currently, floods up to about the 30,000 ML day threshold are, on average, shorter than natural, making them candidates for extending their durations (Figure 6.1).

Maximising effectiveness is the concern to flood as much of the floodplain as possible for a given volume of EWA used. This forces the EWA to be delivered at times when the river channel is already full, or close to full, and makes it possible to deliver a minor flood at virtually any time within a nine-month period of the year, except for the seasons most severely affected, i.e. autumn-winter. This seasonal bias is a consequence of the relatively small volume of EWA available, compared to an actual flood.

In summary, the EWA as currently comprised and delivered cannot easily address the effects of regulation, notably:

- Increase the flooding frequency for plant communities on the floodplain lying higher than areas reached by 25,000 ML day at Tocumwal
- Trigger or set in train life-cycles, growth phases, ecosystem processes that are contingent on autumn-early winter floods

Release of the EWA: The interim rules (Appendix C, MDBC 2005), governing the release of the EWA, currently recognise four sets of conditions (Table 8.2) when a release would be worthwhile. These can be varied and refined by agreement.

Table 8.2. Agreed conditions for release of EWA:

Antecedent flow conditions to be satisfied before EWA can be released (Rule 8 in Appendix C, in MDBC 2005). Note that a volume of 660 GL month is equivalent to a sustained flow of 22,000 ML day for a month; 500 GL per month is equivalent to maintaining a flow of about 17,000 ML per day for 30 or 31 days; 400 GL month is equivalent to about 13,000 ML day for 30 to 31 days.

Number	Antecedent flow conditions determining the release of the EWA Forest Allocation
1	**IF** there is a flood >= 500 GL per month from September through to November, **THEN** maintain flows at 400 GL month in December.
2	**IF** there is a flood >= 500 GL per month in September or October **AND** kitty is >=400 GL (including overdraw), **THEN** keep flows at 500 GL per month till November and 400 GL month in December.
3	**IF** 4 years pass with no release and no flood of >= 500 GL in September to November and 400 GL in December, **TRY FOR** 500 GL per month in October & November and 400 GL in December.
4	**IF** 3 years pass with no month from August to November with >= 660 GL, **THEN** **IF** a release starts in October or November, the target flow increases to 660 GL at Yarrawonga.

Rules 1 and 2 target duration, and Rules 3 and 4 target frequency or, more correctly, a long spell with no flooding; Rules 1 and 2 and 3 affect the 'wetter' parts of the Forest, and Rule 4 affects low-lying parts of the 'drier' Forest. In all rules, the EWA is to be delivered in spring or summer, i.e. extending the flood into summer. In all rules, flood size is given as GL per month so is not a perfect guide to peak within a month (the basis for flow-inundation relationships). However, based on mean daily flows, all flood events are relatively minor (see caption to Table 8.2).

Summary: The EWA rules as described above mean that the EWA can only address two of the three consequences of river regulation, and only for parts of the Forest: duration and frequency (in drought or dry phases); they do not address timing.

The emphasis on duration and in particular on guaranteeing a summer flood appears to be a decision, taken in the past. A press release included in Appendix B1 (Maunsell McIntyre, 2001) refers to: "*Research and river modelling indicates that the best use of the EWA involves extending the duration of natural (sic) flooding, rather than creating large floods of short duration*" and later "*the Forest needs a guaranteed supply of water between September and January to enable floodplain plant and animals to reproduce successfully*." Neither the outcomes of this modelling nor the criteria used to evaluate it were available.

8.2 History of using EWA

The EWA Forest Allocation has now been used three times; in October 1998; in October and again in December-January 2000-2001; in 2005. The first and second uses of EWA have been well-documented (Maunsell McIntyre, 1999, 2001), hence there is no need to repeat the documentations here, except in summary form for ease of reference.

The purpose of this section is to summarise salient points about the two uses of the EWA. Issues arising are considered below.

8.2.1 Characteristics of EWA events

The characteristics of the two EWA events, as documented by Maunsell McIntyre (1999, 2001) are:

First EWA in October 1998:

The characteristics of the flood on the first occasion of using the EWA are as follows:

- **Duration** was increased by releasing the EWA to the receding limb of a low-volume flood.
- **River flood** came from the Ovens River, had peaked at 70,000 ML day at Tocumwal: this was a rapid-rise and rapid-fall peak of low volume. A peak of this size is exceeded on average 4 years in 10 (Maunsell McIntyre, 1999, p11).
- **EWA** was released in a single event, over an 18-day period, from 14-31 October 1998; flows were to be sustained at around 16,000 ML day until the EWA reserve was depleted (p14 Maunsell McIntyre 1999). The amount released was approximately 100 GL.
- **Purpose of EWA** release was largely as a trial and as a learning exercise (Maunsell McIntyre, 1999, p8).
- **Flooded area** in Barmah Forest was 14,107 ha or 47% of the forest for the Ovens flood, and 7691 ha or 25% for the EWA. Areas and extent of flooding were determined from on-ground inspections, and entered into a GIS.
- **Ecological objectives of EWA release** were to observe the effects on forest and ecology, particularly in terms of vegetation, forest health, flowering stage of aquatic plants and waterbird breeding.

- **Main conclusions** were that an ecological baseline was required to determine the effects of the EWA and that much more water was required (at least 400 GL) to achieve a substantial benefit, particularly to extend the receding limb of the flood to increase the duration of floodplain ponding.

The nature of this trial, as inferred from the documentation, was principally an investigation of floodplain hydrology, specifically the extent of flooding and role of regulators. In terms of assessing ecological benefits, there was no design, and no 'before' or benchmark data against which comparisons were made. Ecological benefits were documented based on field observations of persons familiar with the forest.

Second EWA in October 2000 & November-January 2001:

The characteristics of the flood on the second occasion of using the EWA are as follows:

- **Duration** was increased [1] by using the EWA to keep flows high enough to maintain floods running through the forest until a second flood event began (i.e. to connect two flood events) and [2] by releasing the EWA to the receding limb of the second flood peak.
- **River flood** actually had multiple peaks, the third being the largest: the first was flow from the Ovens River following pre-releases from Hume and peaked at Tocumwal in mid-September at 68,100 ML day; a minor peak in late September was followed by the largest which peaked at 92,200 ML day at Tocumwal in early November; and the fourth peaked at 40,700 ML day at Tocumwal. The largest peak was equivalent to a 1:5 (or 20% exceedance) event. The whole flood comprised 4425 GL between September and January 2001.
- **EWA** was released as three separate releases, for a total of 67 days: 9 days in October, briefly early in November and then more than 51 days continuously from November to January 2001. The amount released was 341 GL in total which was 8% of the total flood volume downstream of Yarrawonga between September and January (p. 33 and p. 91, Maunsell McIntyre, 2001).
- **Purpose of EWA release** was primarily to enhance bird breeding by controlling the rate of recession and by providing backflows into Moira Lake (NSW) via Gulpa Creek (p.94 Maunsell McIntyre, 2001).
- **Flooded area:** Flooded area due to the river flood of mid-November was 25,610 ha or 85% of Barmah Forest; and in January 2001, due to the EWA was 1872 ha or 6% of Forest. Flooded area was determined by on-ground inspections in late November, and infra-red aerial photography, flown 6 December 2000.
- **Main conclusions** were 1) the EWA was highly successful in allowing a major waterbird breeding event, and that its strategic use – to slow the flood recession – was critical to this success; and 2) that previous drought and drying of the wetland in combination with the large natural flood event (flooding > 85% of the floodplain) had primed the system for a big ecological response.

8.2.2 Ecological Effects of Flooding and EWA

Assessments of the ecological benefits of EWA appear to have been based on incidental observations in the case of vegetation during both EWA events, and birds in 1998; but used more systematic and planned observations of breeding at mixed species waterbird colonies in the 2000/01 EWA. Generally, the lack of a formal sampling strategy means that it has not been possible to make the formal comparisons necessary to determine the effects of flooding on wetland values. What is reported here is a summary of that reported by Maunsell

McIntyre after the first and second EWA releases (1999, 2001), with some comments placing the report in perspective.

First EWA in October 1998

This flood event resulted in two distinct inundation patterns: a brief spring flood (late September) refers to the areas affected by the Ovens flood; and a longer and lower spring flood (October) which refers to the areas affected by both the Ovens flood and the EWA. These two patterns are distributed across the major plant communities rather unevenly, as set out below (Table 8.3).

Inundation of Wetland and Floodplain Vegetation

The plant communities experiencing a longer spring flood, i.e. that were covered by the Ovens peak and by the EWA, included nearly all of the Rushlands and Open Plain both of which were nearly completely flooded by the EWA (all except <0.5 and 1.9% respectively: Table 8.3), as well as the majority of Red Gum regenerating on Plain and Site Quality I (all except 14.0 and 13.5% respectively). Plant communities experiencing only a very short spring flood (i.e. only flooded by the Ovens River flood) were most of SQ II and SQ III.

Table 8.3. Inundation extent of selected plant communities in the 1998 EWA:

Plant communities are based on those described by Chesterfield (1986) combined with the forestry classification based on timber quality. Flooded area per plant community given in hectares; in brackets is the area flooded by higher flood but not the lower flood, also given as a percentage of flooded area. Adapted from Table 5.6.4 in Maunsell McIntyre (1999). Areas of 'Open Water' and 'Unclassified' (after Maunsell McIntyre 1999) not shown.

Plant Community	Area (ha) experiencing a brief spring flood (Ovens flood only)	Area (ha) experiencing a longer spring flood (Ovens flood + EWA)
Rushlands (A)	381 ha (2 ha or <0.5% of all)	382 ha
Open Plain	1020 ha (19 ha or 1.9% of all)	1001 ha
Red Gum regeneration on Plain	896 ha (125 ha or 14.0% of all)	770 ha
Site Quality I (SQ I)	2817 ha (380 ha or 13.5% of all)	2436 ha
Site Quality II (SQ II)	7867 ha (5286 ha or 67.2% of all)	2581 ha
Site Quality III (SQ III)	521 ha (386 ha or 74% of all)	135 ha
Box	174 ha (156 ha or 90% of all)	18 ha

(A): The two values for Rushlands are as reported in Maunsell McIntyre (1999). Given the methods used in compiling actual area flooded, these two values are considered to be equal, and with the 2 ha difference being equivalent to negligible. Rounding errors probably apply to all reported areas.

Response of Vegetation to Inundation

In terms of the vegetation, there were three points of interest:

- the condition of the forest and its understorey;
- the reproductive status of Moira Grass (subject of a Recommendation in Chapter 6); and
- whether flooding had drowned seedling River Red Gums.

- **Forest and Understorey:** Observers in the field in October 1998 noted positive signs such as a very healthy forest and a lush growth of spring grass but were unable to attribute this to the recent flooding due to the lack of comparable 'before' data and to confounding effects such as recent rainstorms, and reduction in grazing pressure.

The healthy forest occurred in flooded and unflooded areas. ‘Forest’ could refer to any or all of SQ I to SQ III. A positive response to flooding would be likely only in areas exposed to a longer spring flood, i.e. the majority of SQ I and parts of SQ II and SQ III (Table 8.3).

- **Reproductive Status of Moira Grass:** Moira Grass flowered after flood recession, in November-January, but did not achieve maximum rates of flowering. The EWA was clearly important and effective in extending flood duration for Moira Grass (Table 8.3), as only a negligible area (1.9%) of Open Plain was not affected by the EWA. However flood durations were not enough to achieve full flowering and a further 2 months was considered necessary.
- **Mortality of River Red Gum Seedlings:** Submergence for 6 weeks resulted in extensive seedling mortality at Hut Lake (an area probably exposed to the longer flood) but not a complete kill. The EWA affected most (i.e. 86%) of the area accepted as Open Plains suffering from River Red Gum regeneration. The wisdom of having mortality of River Red Gum seedlings as an objective for EWA was challenged (p. 100-101, Maunsell McIntyre, 1999).

In summary, for a number of reasons, it was not possible to state unconditionally that the EWA, as applied in October 1998, had resulted in a positive effect on floodplain or wetland vegetation; and, considering that much of the area affected falls into the ‘wetter’ category, may even have compounded an existing problem.

As regards mortality of River Red Gum seedlings, there was a potential opportunity with this event to assess a competing hypothesis by inspecting areas exposed only to the shorter Ovens flood, the counter hypothesis being that seedlings would die or lose vigour due to heat stress and/or desiccation in the absence of extended flooding. This hypothesis was apparently not considered, but could be incorporated into future EWA monitoring.

Response of Waterbirds to First EWA

In terms of the waterbirds, there appeared to be three main points of interest that can be gleaned from the Maunsell McIntyre (1999) report:

- the general abundance and diversity of waterbirds during the flood;
- the reproductive status of ducks; and
- whether flooding would be sufficiently large and long to stimulate colonial waterbirds to breed.
- However, as with vegetation, there were not specific Objectives or targets set in relation to anticipated (hoped for) outcomes. The Forest managers realised after the 1998 EWA that flooding was insufficient to promote colonial waterbirds to have a successful breeding event based on the following prescription (Maunsell McIntyre, 1999: Section 6.2, Table 6.2.1):

“Bird Floods” Monthly minimum flow required (GL)

Month	Prescription	1998/99
August	>240	242
September	>550	568
October	>550	478
November	>480	332
December	>480	302
January	>230	314

- **Waterbird Observations by Forest Managers**: The report noted that surprisingly few waterbirds were observed during inspections by vehicle and air in October and November 1998 (p. 41, pp. 79-84, Maunsell McIntyre, 1999), about 20 species in all. The only breeding specifically noted was that by Black Swan ('*Black Swan Cygne*t' observations in October 1998: Figure 8.1.1, Maunsell McIntyre, 1999). According to popular local theory, many waterbirds might have left the Barmah region for floodwaters further north.
- **Regional Waterbird Observations in Spring Summer 1998/99**: In Section 8.1.2.6 of Maunsell McIntyre (1999: p. 96), it is reported that "*the only breeding response was from Australian White Ibis and Royal Spoonbills and this was probably a result of the continued environmental flows down the Gulpa Creek following the completion of the environmental response.*" These breeding observations were apparently made by members of the Southern Riverina Field Naturalists Club, presumably after Forest management staff had completed their field inspections.

In summary then, it seems that the EWA, as applied in October 1998, had few positive effects on waterbirds in terms of diversity, abundance or breeding. It would be foolhardy to suggest that no ducks bred in the spring of 1998, as it cannot be ascertained from the report how thorough waterbird surveys were during general field inspections. Also, no unequivocal conclusions can be drawn about the small response by waterbirds, as there is no way to evaluate rigorously, and in retrospect, the effects of the EWA on waterbird abundance and diversity, and what the result may have been without the EWA. However, it is fairly safe to conclude that the 1998 Ovens flood and small EWA were, in combination, too small to initiate a pronounced breeding response. There is anecdotal evidence that the EWA **may have** allowed small numbers of ibis and spoonbills to breed. In terms of the conclusion that the combined Ovens and EWA flood was too small to promote much waterbird breeding, this observation lends further weight to the monthly flow thresholds prescription presented above.

Several other interesting observations about waterbirds are made by Maunsell McIntyre (1999), based largely on the then unpublished research and analyses of D. Leslie (later formally published in 2001):

- **Historical Waterbird Observations and Comparisons**: In Section 8.1.2.2 of Maunsell McIntyre (1999: p. 93), it is concluded from David Leslie's analyses that the breeding population of Royal Spoonbill may have increased in recent historical times. D. Leslie had grouped 24 species of communally nesting waterbirds into five functional groups, of which Groups 1 & 2 do not breed regularly in the Barmah-Millewa Forest, and only Group 5 species (Royal Spoonbill, Australian White Ibis, Straw-necked Ibis) appeared to be maintaining reasonable breeding populations through the 1980s and 1990s, probably due to an increase in their favoured nesting habitat of rushes and reeds, "*at the expense of areas previously vegetated by floating and attached aquatic species*" (emphasis added). Of most concern was the decline in Groups 3 & 4 species: Group 3 species build their nests with/on submerged/floating aquatic plants in shallow water, with some feeding on these aquatic and amphibious plants, and in particular, the declines in breeding numbers of Whiskered Tern, Black Swan and Eurasian Coots have been most pronounced. The "demise" of Group 4 species (tree nesters, e.g. egrets, herons, cormorants) "*is likely to be most closely associated with reduced nest security and food availability …*".

These observations and the similar peer-reviewed conclusions made subsequently by Leslie (2001) give two very strong pointers for future targeting of EWAs and general management of the Barmah wetland, namely:

- Increase the extent of areas of open water with submerged and floating aquatic and amphibious vegetation (e.g. Moira Grass, Wavy Marshwort) at the same time as reversing the encroachment of reed beds and rushes; and
- Increase the security, i.e. minimise disturbance and human visitation/recreation, of known nesting sites used historically by tree-nesting colonial waterbirds.

Increasing the relative proportion of wetland and total area dominated by amphibious plants such as Moira Grass and submerged/floating vegetation would have the dual benefit of providing additional preferred nesting and feeding sites for Leslie's Group 3 waterbirds and favoured feeding habitat for many Group 4 waterbird species. A disbenefit arising from reducing the area of rush and reed bed **may** be a decrease in available habitat for the Endangered Australasian Bittern (see Chapter 7). It is unlikely that the potential for ibis and spoonbill breeding would be adversely affected, and their main breeding sites should be managed for persistence of the current vegetation state.

Finally, a possible trade-off between waterbirds and another important wetland biotic element (frogs) was noted in the Maunsell McIntyre (1999), attributable to the observations of K. Ward and D. Leslie:

- Potential Trade-Offs between Waterbirds and Other Wetland Biota: In Section 8. 2 of Maunsell McIntyre (1999: p. 99), it is speculated that the "general lack of large numbers of predatory birds (eg, Egrets) this year may also assist in improving survival rates [of frogs]".

This observation and similar views expressed subsequently by K. Ward (*personal communications* 2005) are right on the mark! Waterbirds are the top predators in the Barmah wetlands, and it would be surprising if there were not some trophic cascade effects resulting from major variations in the abundance of waterbirds. This topic is returned to below in Section 8.3.1.

8.2.3 Second EWA in October, November and November-January 2000-2001:

The largest peak in late October-early November and the recession of December-January had different recession patterns. As with the first EWA, two patterns are distributed unevenly across the major plant communities, as set out below (Table 8.4). The major flood of early November 2000 inundated extensive areas of SQ I, SQ II and SQ III, considerably more than in October 1998 (Table 8.3), but similar areas of Rushland and Red Gum regeneration on Plain.

Wetland and Floodplain Vegetation: In terms of vegetation, again there were no specific ecological objectives. Pending the establishment of a forest monitoring study using permanent transects, only a few notes were made, on the forest itself: trees changed from being visibly stressed to being healthy with "*crowns full of fresh growth and green leaves*" (p120, Maunsell McIntyre, 2001). There were no comments on the understorey or on Moira Grass in the Barmah Forest, unless the comment on p. 121 – that there was an abundance of Moira Grass throughout low-lying areas of the forest and wetland – relates generally to the Barmah-Millewa Forest.

For both EWAs, but in particular for the EWA of 2000-2001, it is regrettable that no incidental or systematic observations were made elating to plant ecology of major wetland species, of species phenology, or regeneration events; that no opportunity has been taken to compare events, for example using even the most basic of techniques, such as photo-points; and that no collecting has been done, looking for and documenting the locations of any rare and unusual species.

Table 8.4. Inundation extent of selected plant communities in the 2000 EWA:

Plant communities are based on those described by Chesterfield (1986) combined with the forestry classification based on timber quality. Areas and percentages are for Barmah Forest. Re-worked from data in Tables 4.8.2 and 4.8.3 in Maunsell McIntyre (2001): areas of Open Water and Unclassified not shown.

Plant Community	Area (ha) under a major flood (late October-early Nov)	Area (ha) inundated during late recession (December – January)
Rushlands	400	320
Open Plain	3556	1426
Red Gum regeneration on Plain	1067	121
Site Quality I (SQ I)	10843	1422
Site Quality II (SQ II)	27154	661
Site Quality III (SQ III)	5126	32
Box	1624	2

Response of Waterbirds to Second EWA

A major waterbird ("*most exceptional*": p. 110, Maunsell McIntyre 2001) breeding event was recorded in spring summer 2000/01 across the entire Barmah-Millewa Forest in response to the one-in-five year flood augmented with the EWA. Twenty-six species were detected (or strongly suspected to be) breeding, and '*many thousands'* of colonial waterbirds (dominated apparently by Australian White Ibis, Straw-necked Ibis and Nankeen Night-Heron) bred. In summary and across Barmah-Millewa Forest, "*at least 15,000 pairs of 20 or more species*" bred during the 2000/01 flood (p. 111, Maunsell McIntyre, 2001). At least 9000 waterbirds were present in the Barmah Forest in December 2000, and eight species of colonial waterbirds, totalling 3780 nests (dominated by Australian White Ibis and Straw-necked Ibis) bred.

Critique of Documentation of Waterbird Counts and Monitoring, Second EWA

The emphasis given to waterbird ecological objectives and outcomes in the Maunsell McIntyre (2001) report results in 12 pages in the body of the report, and 14 pages in six appendices, but is nonetheless difficult to review the material. The difficulty with interpretation largely stems from there being separate agencies and consultants or NGOs involved with waterbird monitoring, such that four separate methodologies were used through the 2000-01 flood. Inevitably this has led to inconsistent approaches in the presentation of the results of waterbird counts and monitoring. Instances include but are not restricted to:

- **Summary Maps of Colonial Waterbird Breeding Sites**: Figure 6.1.1 of Maunsell McIntyre (2001: p. 104) provides a highly informative mapped summary of 10 breeding colonies with estimates of the number of nests of each species at each colony in the Millewa Forests (NSW) – it is excellent. A similar map and summary for Barmah Forest should have been presented. In the text (p. 106, Maunsell McIntyre, 2001) observations of colonial species breeding at four sites in Victoria are presented but estimates of number of nests are not given and, further, one 'new' site, "Green Deadwoods" is described yet this locality is not specified or mapped.
- **Comparison of Colonial Waterbird Species Numbers with Other Years**: Section 6.1.9 and Table 6.1.6 of Maunsell McIntyre (2001: pp. 109-110) provides this comparison in the broadest terms only. The information states that during the 2000 breeding event there were 10 species with more than 10 nests and five additional

colonial species with less than 10 nests recorded throughout the Barmah-Millewa Forest, and that this ranks the 2000 season as equal fifth in the past 100 years in terms of number of species with at least 10 pairs nesting; it ranks equal first (tied with 1939) in terms of 15 colonial species nesting. There are two problems with this section: first, the nesting effort for all 15 species in 2000, combined across the Barmah-Millewa Forest, should have been presented; second, the reader is reliant on a reference to a secondary source of information (Leslie 1998) for the summaries of breeding effort in other years, for the above rankings to be deduced. [This report, Leslie (1998), is included in the References (taken from Maunsell McIntyre, 2001), but has not been sourced by the consultant – see Chapter 7, Section 7.5: "Literature not Sourced".] While it is fortunate that David Leslie's excellent research was subsequently formally published (Leslie, 2001), the quantitative comparisons between the 2000 breeding event and the historical record over the past 100 years are considered highly questionable. Having examined two of the early historical records (Mattingley, 1907, 1908; Ross 1906, 1933), it is obvious that a rigorous comparison affording unbiased ranking between years is impossible – the naturalists involved neither systematically surveyed the entire Barmah-Millewa Forest wetlands nor presented total counts of the nests and species they observed (Webster 2004); what can be gleaned from their observations must surely be an undercount of both species nesting and numbers of pairs involved. Very few years, if any, are likely to have had as much bird survey effort as occurred in 2000.

- The absence of an annotated list of all waterbird species observed and total breeding effort across the Barmah-Millewa Forest is an oversight and critical deficiency. This deficiency can probably still be and ought to be rectified, and it is noted that the documentation of subsequent waterbird monitoring efforts in relation to a 2002 'EWA' (O'Connor & Ward, 2003) is likewise deficient in this respect.

8.2.4 Conclusions about the Effectiveness of the 1998 & 2000 EWAs

In one sense, the history of the 1998 and 2000 EWAs and the lessons learnt from them, as becomes apparent in the refinement of Ecological Objectives and Water Delivery Options presented in the Barmah Forest AEMP (DSE and GBCMA, 2005), are a cogent example of 'learning by doing', a tenet of successful Adaptive Environmental Management. Steadily and surely, the hydrological management of the Barmah-Millewa Forest is becoming more refined and strategic as the knowledge base improves. On the other hand, and as required by the brief, a review of the two EWAs and the documented ecological responses (Maunsell McIntyre, 1999, 2001) leads to the following conclusions with respect to EWA benefits provided to wetland-dependent vegetation and waterbirds:

1. Clear ecological objectives were not unambiguously specified in 1998 or 2000 prior to the EWAs occurring; therefore, the success of the EWAs in terms of goal achievement could not be evaluated.
2. Clearly, the volume released in the 1998 EWA (100 GL) was insufficient, as acknowledged by the forest managers.
3. Coherent, structured and systematic methodologies for monitoring the responses of vegetation and waterbirds to the EWAs were not adopted.
4. Anecdotal observations of ecological responses to flooding were not compiled and documented in a comprehensive or coherent manner; this criticism particularly applies to waterbirds and vegetation monitoring in the 2000 EWA.
5. At the asset scale, the potential and likely existence of trade-offs was not explicitly recognised – a single quota of an EWA cannot optimally service all parts of the river and floodplain (**spatial**), across all required seasons (**temporal/seasonal**), all biotic groups equally (**biotic/trophic**), or all important ecological processes equally (**functional**).

These four sets of trade-offs require further consideration and, if possible, in the future, measurement and verification/refutation, so that appropriate priorities can be set.

6. Similarly, the numerous other barriers and constraints to the optimal delivery of EWAs for specified ecological outcomes were not examined and weighed sufficiently. As well as the obvious deficiencies in environmental funding and the total volume of EWAs available to the Barmah-Millewa Forest managers, mandated multiple land uses are undertaken in the Barmah-Millewa Forest, most important of which are water transfers for **irrigation** downstream, stock **grazing**, **forestry**, **recreation**, and nature conservation. The first four of these resource and land uses and various historical legacies (e.g. introduction of pest plant and animals, flow regulatory structures) constrain the potential benefits of EWAs to river and floodplain health, function and specific biodiversity outcomes. The most important of these barriers and constraints need to be identified and evaluated, and it then needs to be ascertained whether alternative and affordable management options and solutions exist. In like vein, there may be disturbance and population control processes (natural and artificial) which, if instituted prior to, during or after an EWA, could enhance attainment of ecological objectives.
7. The impacts of the EWAs on Rare and Threatened plants and animals, specifically those that are dependent on flows, were not paid particular attention.
8. The impacts of the EWAs on nuisance and pest species of plants and animals, especially those that are dependent on flow regime, were also not paid particular attention.

Many of these shortcomings have since been addressed (DSE AND GBCMA, 2005), or are being addressed (as through this consultancy and parallel processes), and it is acknowledged that continual refinement of Objectives, Water Delivery Triggers and Prescriptions, and procedures for ecological monitoring will continue to be refined through future iterations and EWAs (and as they should under adaptive environmental management frameworks). The current strategy to manage rain-rejection events by passing the overbank flows to alternate sides of the river annually is an excellent example of improved water management; and one that if monitored, could return information useful for wetland rehabilitation.

8.3 The EWA: an Ecological Perspective

Intelligent calls on the natural flow paradigm (see Chapter 6: Section 6.3.2.) should govern the use of EWAs, in terms of setting Ecological Objectives generally and targeting specific objectives in an individual EWA event. With a few exceptions, hydrological variability across several time scales has been reduced under Current Conditions. At the scale of months, river regulation acts to reduce the number of peaks within a flood/flow event and dampen down these peaks, while some seasonal and inter-annual variability has been lost with the reduction in both winter-spring floods and medium sized floods generally. Up to 10% of the Barmah-Millewa Forest floodplain is now permanently inundated due to higher than natural summer flows, while the overall reduction in annual river flows means that large parts of the floodplain are inundated less frequently than occurred historically.

In general, EWAs should be used to restore some of this lost variability, while accepting the limitation of reduced water overall. The use of further engineering works should be investigated to facilitate a return to greater variability in flow regime and flooding patterns, but the use of such structures needs to be sensitive to the aims of enhancing lateral connections between the river, main distributary channels and the floodplain (Bunn & Arthrington, 2002).

There was insufficient time to treat the following topics in detail.

8.3.1 Trade-offs

Although it is convenient to classify trade-offs into the four types recognised here, most flow delivery decisions involve trade-offs that embrace two or more categories. The most obvious dilemma in using an EWA is whether to deliver a 'larger' flood of limited duration that inundates a greater proportion of the floodplain or to extend the duration of the receding limb of a natural flood as has been practised to date. There are trade-offs in all four categories (spatial, trophic, biotic, functional) and, as warned in Chapter 8, an ill-judged choice in favour of the former option may actually be counterproductive (blackwater events, water losses, floodplain inundation for insufficient duration to reap ecological benefits). The ecological consequences of duration v peak discharge require careful consideration.

With the proposed Ecological Objectives in the AEMP (Table 2 in DSE & GBCMA, 2005), there is a heavy emphasis on using EWAs for red gum management, while past and current use of EWAs has focused on promoting/extending colonial waterbird breeding events. It is important that other species and trophic groups become the primary targets in **some** future EWAs. Not all ecological benefits can be realised within each flood event, and so it will be necessary to vary goals through time and successive EWAs. Waterbirds **will** gather in the Barmah wetlands if there is a high density of food resources and provided conditions are not substantially better elsewhere across south-eastern Australia and in the Channel Country. However, even if the colonial waterbirds settle to breed during a flood event, forest managers can still set alternative ecological targets, such as native fish and frog recruitment, and deliver an EWA appropriately. There is a potential trade-off between a successful, drawn-out colonial waterbird breeding event and high levels of frog and fish recruitment, but this is only speculative and requires empirical support. In the absence of a large breeding event it is quite possible that large numbers of frog and fish-eating waterbirds will gather and concentrate in the wetlands during a flood that achieves a high level of frog and fish recruitment (it would be unlikely for waterbirds **not** to behave in this manner!). This topic requires intensive research as there are many untested assumptions (that waterbirds exert **any** population regulatory pressure on their prey) and unanswered questions. For now, it is recommended that the forest managers prioritise other animal/trophic groups for ecological benefits in **some** EWAs, and that in these events water should not be used to extend waterbird breeding if higher-discharge releases of limited duration are required to meet these non-waterbird targets.

A high-risk trade-off would be to attempt to create a winter flood as opposed to backing up a 'natural' flood in spring using an EWA to create a longer recession in summer as is practised currently. An EWA could be used to generate a winter-spring flood as 1) floods in this season, once prominent, have become scarce (natural paradigm), 2) it may well have unexpected benefits for some frog and native fish species, and 3) it is unlikely to result in a large colonial waterbird breeding event.

8.3.2 Constraints and Barriers

There are several unresolved issues which impinge on best-practice with regards to water management in the Barmah Forest, in addition to the major constraint of providing summer flows to irrigators downstream:

Unseasonal and permanent flooding caused by the current management of rain-rejection events and passage of downstream irrigators' water through summer. Any affordable means by which some currently permanently flooded areas can be allowed to draw down – even if on a biennial basis – should be further explored.

Flow regulatory structures – too many or not enough? There is an unresolved or unexpressed philosophical debate about 'naturalness' vs engineering solutions, with perhaps some blurring of the boundaries between naturalness and the aim of achieving **natural flows**. If affordable engineering solutions maximise the return towards more natural flow regimes, then they should be pursued, within the adaptive management framework (monitoring) to ensure that new problems are not being created.

8.3.3 Non-target Effects of EWA

Non-target effects of applying an EWA refers to potentially negative effects that ideally should be incorporated into management decisions. They are:

- Low-lying creeks and wetlands that used to have a seasonal flow and water regime are now near permanent, because the drawdown time is too short to allow complete drying. The consequences of this include that the soil is not developing the deep cracks characteristic of its gilgai nature. Use of EWA only re-enforces this; in effect an EWA is actually a risk to floodplain ecology.

8.3.4 Monitoring: more than one focus

Monitoring associated with implementing the first and second EWA are, at heart, verificationist, i.e. are predicated on need to measure or 'demonstrate ' ecological benefits. This raises questions about the philosophy underpinning a monitoring program. Is it to be accountable ? Is it to inform management ? Is it to be an early warning?

As outlined above (non-target effects of EWA), the size of the EWA and constraints on its delivery mean that realistically it can only target certain parts of the Barmah Forest and that, coincidentally, much of these parts already fall into the category of being 'wetter' (Chapter 6.2); in short, the EWA also carries certain risks.

8.3.5. Future Research

Assuming that a flow regime is actually an integrated package of flows that set up conditions, and 'pull' triggers' and have a sequence that floodplain ecology is naturally responsive to (following the natural paradigm) then the challenge is to determine from an ecological question:

- whether it is better to 'drop' (i.e. shed) a particular component of the flow regime ? (such as winter floods, duration of high flows)
- and if so, then which one(s) ?
- or whether it is better to retain the overall characteristics of the flow regime but just crank it down by a couple of flow-bands and so sacrifice the highest areas ?
- and would that make any sense anyway, in terms of geomorphology (assuming the flow regime and geomorphological template are related and that ecology is the response to these).

8.4 Recommendations and Knowledge Gaps

8.4.1 Recommendations

Priority Recommendation

Knowledge about an early flood is essential. Under current management these floods are less and less frequent with poorly known and largely ignored consequences for the ecology of the Forest. As pointed out earlier (Chapter 6.7 Flow-Ecology Relationships), investigations into the role of seasonality have worked within a sub-set and have failed to address the question of the ecological significance – if any – of an early flood. Without this knowledge it will never be certain what the implied trade-offs are from using an EWA to extend a flood into summer. Questions such as 'what is the ecological significance of an early flood compared with a later flood' or 'are later floods ecologically equivalent to an early flood' are simple to state but will require careful planning to answer, both logistically and scientifically. Such a flood may well have unexpected benefits for some frog and native fish species, and is unlikely to result in a large colonial waterbird breeding event.

- An EWA, if necessary also combined with pre-releases from Hume Dam, should be used to generate a winter-spring flood, i.e. one starting early.
- This flood should be considered as an experiment, and as such the scientific questions and monitoring and analyses will need to be planned as rigorously as possible.
- Preparation should include some roundtable discussions to formulate the most useful hypotheses, considering not just the importance of icon species but the sustainability of the forest.
- In reality, predictions about the likely ecological effects of a winter-spring flood can only be qualitative (e.g. 'a particular species of native fish will not breed', 'only species of southern frog will breed', 'there will be particular suites of zooplankton and macro-invertebrates that boom'), and so a monitoring program should be devised around at least one winter spring and one spring-summer EWA-enhanced flood (ideally more), to allow quantitative comparisons.

Other Recommendations

The remaining recommendations are not prioritised but organised by themes.

<u>Overall Approach and Planning</u>

- The legacy of property, politics and bureaucracy is that the Barmah-Millewa Forests are perceived as at least two systems, the Barmah and the Millewa, and sometimes more than two such as Barmah-Millewa-Gulpa Forests and WMAs), systems. Inherent in this mental attitudes is the risk of managing a wonderful system into fragments. There is an urgent need to think of, plan, and manage this as a single floodplain.
- Ensure there is the necessary correspondence between specific Ecological Objectives, ecological monitoring methods, and evaluation procedures.

<u>Environmental Water Allocation</u>

- Ensure there is sufficient flexibility maintained in the tactical delivery of EWAs for forest managers to be able to refine Ecological Objectives/targets as conditions indicate, and so ensure the speedy encapsulation and communication of the results of ecological monitoring during an EWA. It is acknowledged that there is a tension between setting in advance 'fixed' objectives, implementing a specific water delivery regime and undertaking systematic ecological monitoring on the one hand, and retaining management flexibility during an EWA event on the other!
- Explore the many potential **spatial**, **temporal/seasonal**, **biotic/trophic** and **functional** trade-offs of various EWA options, and commence a long-term program of research and measurement to investigate the validity and strength of these trade-offs, in the search for 'optimal' strategies.
- Continually revisit the constraints and barriers that other land uses and historical legacies present to achieving optimal EWA ecological outcomes, and investigate the means to reduce the severity of the most damaging of them.

- Prioritise other animal/trophic groups for ecological benefits in **some** EWAs, and that in these events water should not be used to extend waterbird breeding if higher-discharge releases of limited duration are required to meet these non-waterbird targets. There needs to a longer-term view taken of ecological objectives so that a **series** of EWAs is planned to deliver a fuller range of benefits/measurable targets; sufficient flexibility needs to be retained so that priorities can be re-orderd during single EWAs and within a series of them.
- Review the environmental cost(s) and biases implied in using EWA to target duration.

Monitoring the EWA

Comments on the monitoring that was implemented in relation to the EWA of 1998 and the EWA of 2000-2001 were included above throughout Section 8.2.2., Ecological Effects of Flooding and EWA. The comments highlight a range of issues, principally missed opportunities, inconsistent methods, incomplete records, lack of clear objectives, and they are mostly repeated in Section 8.2.3., Conclusions about the effectiveness of the 1998 & 2000 EWAs. The obvious recommendations arising from these are:

- Develop a flexible, easy to implement approach to monitoring, possibly drawing on volunteer skills, and including capacity to record information other than the standard icons of colonial water birds and Moira grass program; monitoring should not target simply one phase of the flood but attempt to respond to different phases, from rising, peak, falling and post-recession.
- The process initiated with Maunsell McIntyre (1999, 2001) of compiling and documenting has been very useful in an adaptive management sense, and should be continued, aiming for a publicly accessible document. The reporting needs to be made more rigorous.
- Compliance monitoring, which here means all aspects of hydrology and flood extent, may need to develop a standard format and be done rigorously.

Monitoring water management actions

The time-sharing of 'unseasonal flows' between the states is an important move in possibly reducing environmental degradation, or at least preventing its further spread.

- Track the condition, vigour and growth of species formerly benefiting from unseasonal flows namely Giant Rush *Juncus ingens* and the species it is believed to have replaced Moira Grass *Pseudoraphis spinescens,* down flow paths, comparing unchanged, recently changed and unaffected sites.

Species of significance

- Compile a comprehensive list of Rare and Threatened plants, animals and ecological communities within the Barmah-Millewa Forest, review their historical and current status (and trends), and consider whether EWAs (in isolation of or in conjunction with other land management practices) can/should be used to maintain or improve their stocks.

Waterbirds

- Review the state of knowledge of all species of waterbird recorded in the Barmah-Millewa Forest, focussing on 1) five facets, namely abundance (including historical and other variations), foraging habitat preferences, breeding information (locations, effort, historical changes, habitat requirements), seasonal status and conservation status, and 2) how hydrological management (including EWAs) and other forms of management may influence these facets. Australian waterbird ecology has advanced considerably in the 22 years since R. Loyn (in Chesterfield *et al.,* 1984) undertook the last comprehensive review.

- Ensure future waterbird monitoring documentation includes an annotated list of all waterbird species detailing distribution and abundance, habitat preferences, and nesting attempts/results/habitat. Retrospectively, compile this information for the 2000 EWA.

8.4.2 Knowledge Gaps and Future Research Directions

- Do waterbirds regulate frog and fish populations? Are there significant trade-offs between the colonial waterbirds and frog and native fish populations?
- Moira Grass establishment and recruitment, and impacts of grazing on its ecology.
- Can winter or autumn floods be used to enhance recruitment of certain frogs and native fish species?
- Study of the Australasian Bittern in Barmah-Millewa Forest (breeding and foraging habitat needs, population size) and assessment of impacts of reed bed reduction on its status.

9. Water Management Options

Ian Overton

9.1 Purpose and content of this chapter

Figure 1.1 shows the hierarchical relationship between the vision and values of Barmah Forest, (Chapter 3), value delivery and system maintenance objectives (Chapter 4), water requirements and other factors affecting the biota (Chapters 6, 7 and 8) and water inputs. This chapter focuses on the last of these - the actual and potential water delivery options to achieve the objectives discussed in Chapter 4, by meeting the plant and waterbird water regime requirements discussed on Chapters 6 - 8.

Chapter 6 has described and analysed the major changes in the hydrology of Barmah Forest resulting from river regulation and off takes for irrigation. Understanding those changes is a prerequisite for understanding the options for water management discussed in this chapter, but that material is not repeated here. The state of knowledge of the water requirements of plants and waterbirds of Barmah Forest (Chapters 6-8) is the other foundation for this Chapter, but current lack of knowledge makes it unwise to specify in this chapter the water regimes that would satisfy those water requirements. Rather this chapter identifies and evaluates the range of options available for getting water to the Barmah Forest and using it effectively there. Assembling those options into strategies is the task of the managers, but we do discuss some of the issues around the construction of strategies.

This chapter deals first with managing water within Barmah Forest, including the need for better modelling and mapping of flow-inundation relationships, the need for better-defined water management units (WMUs), the potential for improving control structures, and options and strategies for managing water within Barmah Forest. We then broaden the scale of analysis and discuss the delivery of water to Barmah-Millewa Forest, covering the policy background, potential improvements in water delivery from changing rules and triggers, and options for getting water to Barmah-Millewa Forest in the amounts and at the times it is needed. This is followed by a discussion of research needs, and the chapter ends with a summary.

9.2 Water management within Barmah Forest

The changes in surface hydrology are discussed in Chapter 6, and consequent changes in flow regimes for plants and waterbirds are covered in Chapters 6 and 7. Understanding changes in surface hydrology and their consequences for biota is a prerequisite for this chapter, but they are discussed in Chapters 6 and 7 and are not repeated here. Those Chapters identified weaknesses in past work, and the need for better modelling and mapping of the relationship between river flow and floodplain inundation. Improving the accuracy of estimates of these relationships is critically important for the definition of water management units, and we turn to it next. After that we discuss the potential for improving management within Barmah Forest by changing control structures, and water management options and strategies within Barmah Forest. Internal water management options and strategies cover trade-offs, the need for groundwater management, getting water to areas of higher elevation in the floodplain, and managing water quality and erosion.

9.2.1 Improved modelling and mapping of flow-inundation relationships

Correlations between floodplain vegetation patterns and flood regimes has been used to infer water requirements of plants on the floodplain. Chapter 6 pointed out the major limitations of this approach, but noted that in the absence of experimental data it remains a major method for inferring plant water requirements, which can provide a means of defining water management units (discussed below), hence the need to improve estimates of flow-inundation relationships. Table 9.1 lists the main literature on flow-inundation relationships through to the present, but the later works have not yet had a strong influence on management plans.

Chapter 6 reviewed the modelling of flow-inundation relationships by Bren, (1988b), Bren *et al.* [, O'Neill and Gibbs,] (1987) and Leitch (1989). Current management of water is based largely on those works, though it is 15 or more years old and did not use the advanced GISs, digital elevation models, remote sensing and simulations that are now available. REG C (2003), for example, developed a flow and inundation relationship based on Bren and others (1987, 1988b) (Figure 9.1). They identified the flow levels at which each major vegetation type begins to flood (commence-to-flow thresholds). Chapter 6, noted the assumptions and limitations underlying this work, and section 6.5.1 commented on the disagreement between the commence-to-flow thresholds and the % areas of the vegetation tupes in Bren *et al.* (1988), and the flow threshold estimates in Figure 4 of DSE and GBCMA (2005).

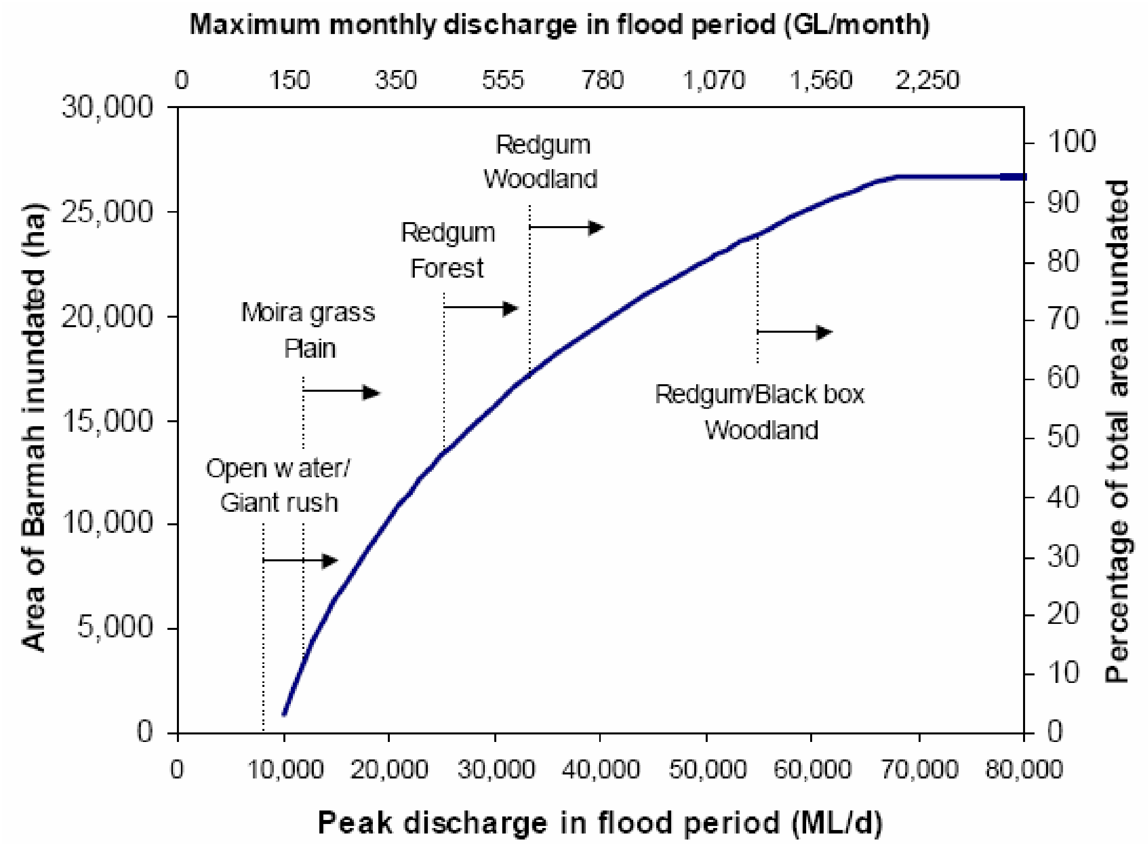


Figure 9.1: Relationship between peak discharge, area inundated, and flooding thresholds for vegetation types.
Source Reg C (2003). The diagram shows the commence-to-flood for areas of the floodplain of increasing elevation. The line indicates the area inundated and the percentage of the floodplain as a relationship with the maximum monthly and peak flow. For example Red Gum forest requires a maximum of approximately 400 GL/month up to approximately 560 before the Red Gum becomes woodland and covers an area from 14,000 to 17,000 (ha).

Table 9.1: Major literature on the mapping and modelling of flood extent in the Barmah-Millewa Forest

Publication	Source (peer review)	Title	Type of Evidence
Bren (1988b)	Journal paper	Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia.	Grid-based analysis of flood maps Not calibrated
Bren, O'Neill and Gibbs (1987; 1988)	Journal paper	Flooding of the Barmah Forest and its relation to flow in the Murray-Edward River system.; Use of map analysis to elucidate flooding in an Australian riparian river red gum forest.	Map analysis of flood extent Not calibrate
Abuzar and Ward (2003)	Agency report	Flood and vegetation mapping in the Barmah-Millewa Forests during October-December 2002 using remote sensing technology.	Satellite image extent of known flood events Calibrated but not validated
Overton (2005) Overton *et al* . (2006)	Journal paper and technical report	Modelling Floodplain Inundation on a Regulated River: Integrating GIS, Remote Sensing and Hydrological Models; The River Murray Flood Inundation Model – RiM-FIM. CSIRO Technical Report.	Satellite image model of one-dimensional flood prediction Calibrated but not validated
Water Technology (2005)	Technical report	Barmah-Millewa Forest Hydrodynamic Model	MIKE FLOOD model of two-dimensional flood prediction Calibrated but not validated

Subsequently Abuzar and Ward (2003) used satellite imagery to map the inundation extent from the October-December 2002 flood period. They mapped vegetation growth using a Normalised Difference Vegetation Index (NDVI). The distribution of surface flooding and fresh vegetation growth was mapped for three periods between October and December 2002. The area of most actively growing vegetation corresponded well with areas that had been flooded.

Overton *et al.* (2006) have also used satellite imagery to build up a flood history for the Barmah-Millewa Forest. Satellite image analysis of flood events from Hume Dam to the Lower Lakes have been used to build a River Murray Flood Inundation Model (RiM-FIM) as part of the CSIRO Water for a Healthy Country project (Overton, 2005; Overton *et al.*, 2006). Using mathematical image interpolation they have created the flood extent from every 1,000 ML/day flow at Tocumwal. Table 9.2 and Figure 9.2 show the area of inundation of the Barmah-Millewa Forest under increasing River Murray flows when a flow of that size first enters the region as gauged at Tocumwal (Overton *et al.*, 2006). Figure 9.1 is for the Barmah Forest only, whereas Figure 9.2 includes the Millewa Forest. As the areas are not the same you would not expect the results of flow to be the same but the percentages should be similar as the Millewa is in the same reach of the River.

Table 9.2: Barmah-Millewa Forest flood inundation under increasing River Murray flows (initial extent on rising flow). Source: Overton *et al.*, 2006.

Flow (ML/day)	Hectares	Percentage of Barmah Forest Floodplain
5,000	960	1%
5,000 – 20,000	4,435	6%
20,000 – 30,000	6,182	8%
30,000 – 40,000	19,252	25%
40,000 – 50,000	31,780	40%
50,000 – 60,000	32,917	42%
60,000 – 70,000	48,337	62%
70,000 – 80,000	48,447	62%
80,000 – 90,000	49,044	62%
90,000 – 100,000	49,138	62%
100,000 – 110,000	51,676	66%
> 110,000	78,522	100%

The relationship of 'percentage inundation' to 'peak flow at Tocumwal' derived by Bren (1988a) for the Barmah Forest (Figure 9.1.) is much lower than that estimated by Overton for the Barmah and Millewa Forests. There are expected differences because of the differences in areas, however, similarities could be drawn. The difference could be attributed to changes in the extent of flooding from control structures and barriers developed since 1988. Also, Bren *et al.* noted that "*In all floods considered, the regulators were substantially open*." (p.136, Bren *et al.* 1987). Further, Bren's relationship is derived from the maximum extent of inundation following a natural flood event, whereas Overton *et al.*'s is the initial flood extent from the peak flow. These two relationships could therefore be taken as the 'commence to inundate' extent and the 'maximum' extent following several months of flooding, with the qualification that control structures may have been configured differently.

Water Technology (2005) used the newly available LiDAR high resolution Digital Elevation Model to build a hydrodynamic model of the Barmah-Millewa Forest using MIKE FLOOD software. The MIKE FLOOD model combines the one dimensional MIKE 11 river channel modelling with MIKE 21 two-dimensional floodplain flood modelling. The model is capable of predicting flood extent from a range of river flows, under various configurations of the regulatory structures, or when new ones are added or existing ones removed. It can model the effects of levee or dam failures, and model channels that are smaller than the grid-cell width of the RiM-FIM, making these channels invisible to the RiM-FIM. Water Technology (2005) used flood maps developed by Abuzar and Ward to calibrate the hydrodynamic model. These were considered by the authors more than adequate for the purpose of the model at the time. Higher resolution FIM may be needed for applications requiring very high precision, such as the analysis of the effects of existing or potential new regulatory structures.

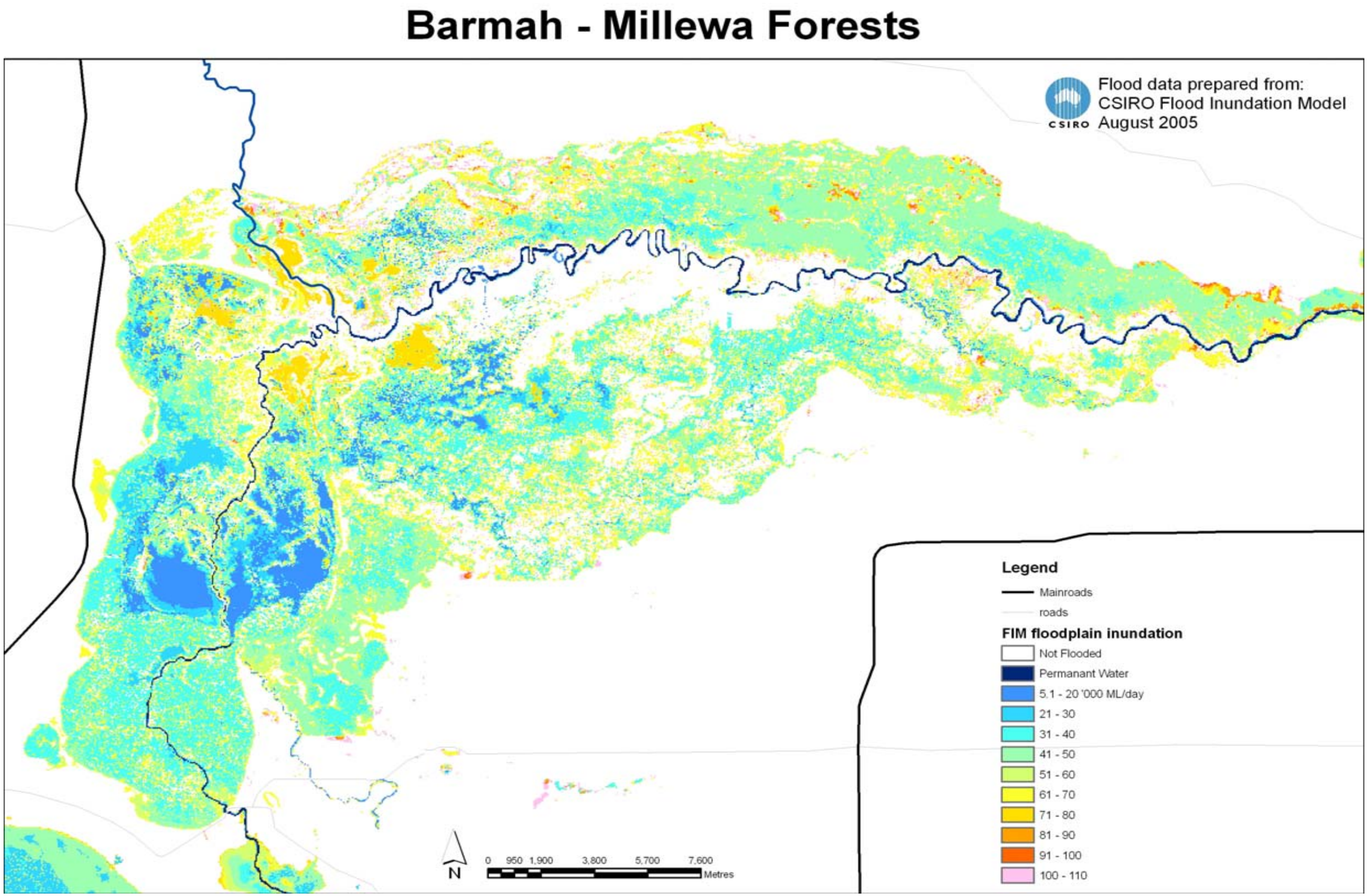


Figure 9.2: Flood inundation in the Barmah-Millewa SEA under increasing River Murray flows. Source: Overton *et al*. (2006).

The FIM and/or the hydrodynamic model have the potential to identify water management units (WMUs) that would enable water to be distributed where, when and in the right amounts to meet plant water requirements. We discuss WMUs next.

9.2.2 The need for better Water Management Units

The insufficiency of water in winter and spring and excess in summer and autumn mean that means that water allocations will at times have to be prioritised to particular vegetation types, and that some parts of Barmah Forest may have to be sacrificed at times by receiving too little or too much water. While Barmah-Millewa Forest must be managed as a whole system as far as possible, the need to make trade-offs within Barmah Forest, together with the need to allocate scarce water as effectively as possible, requires that the area is divided into units that can be managed autonomously to some extent. Maunsell (1992) developed 11 water management areas for this purpose. Ward *et al.*, 1994 modified these and identified specific management goals for each (Figure 9.3.).

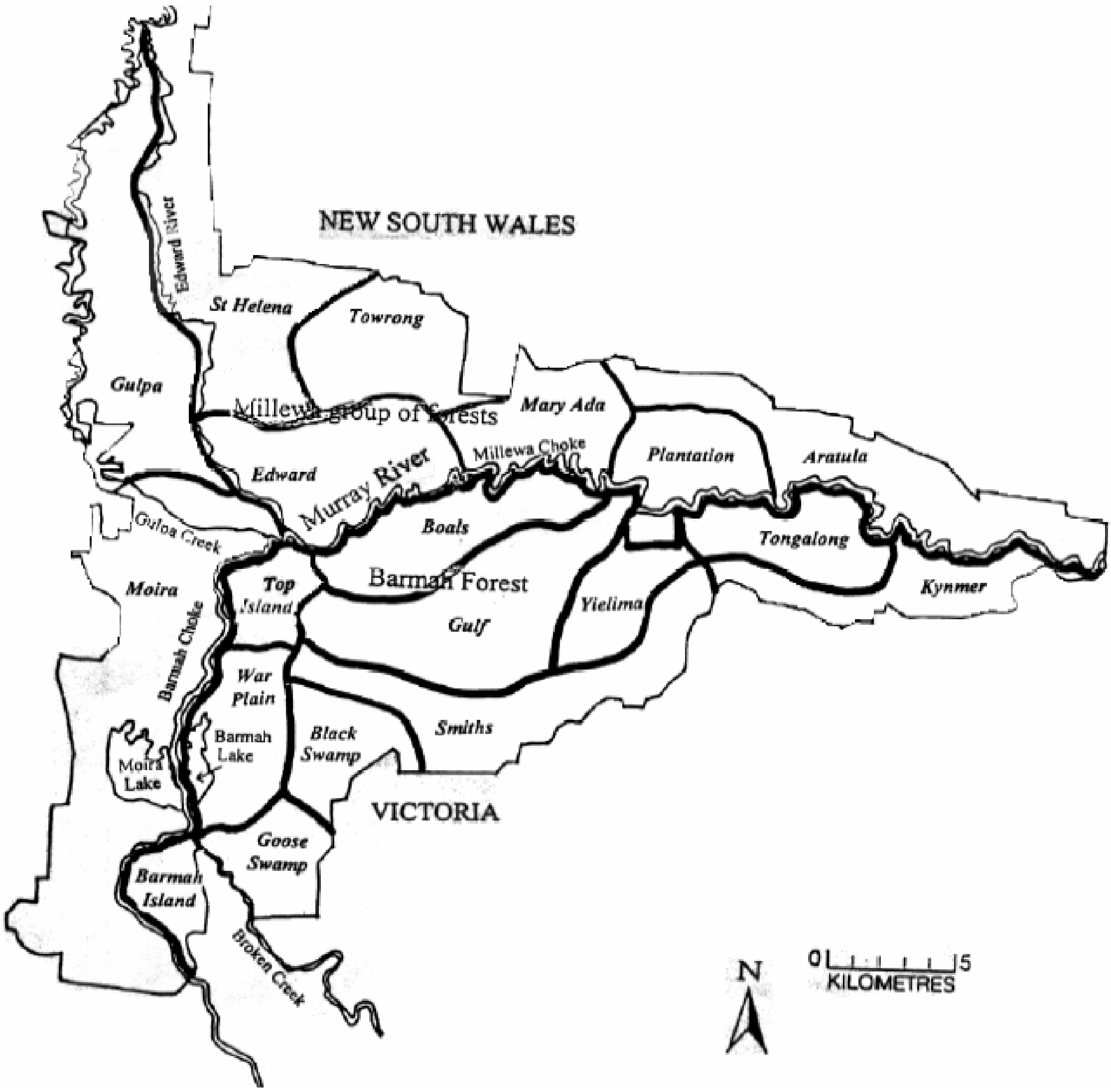


Figure 9.3: Water Management Areas defined by Ward *et al* . 1994 (modified from Maunsell 1992)

In Chapters 3 and 4 we wrote of the need to specify and align value delivery objectives with the values they support, and to specify system maintenance objectives so that values are delivered sustainably. We also discussed the potential and actual conflicts among objectives and values. Achievement of objectives and management of conflicts among them requires a better alignment between vegetation communities and water management areas than is now possible, and more precise allocation of water to vegetation communities in time and space. We therefore recommend redefinition of the Water Management Areas, and distinguishing them by renaming them Water Management Units (WMU). This is justified on the basis on ability to address specific ecological requirements within specific WMUs rather than complex mosaics of objectives in the original Water Management Areas. We propose the following process for identifying WMUs:

1. identify places on the floodplain where particular value delivery and system maintenance objectives should be met (Chapter 4);
2. over-lay vegetation communities on maps of flood extent relative to river flow generated by RiM-FIM or Water Technology's (2005) hydrodynamic model of the Barmah-Millewa Forest;
3. delineate WMUs, based on the overlays from 2 above, seeking greater homogeneity of vegetation within than between WMUs, and taking into account the current or potential capacity to manage the WMU as a hydrological unit through regulators, local topography or timing. The hydrodynamic model will be needed to do this well;
4. for each WMU, define the flow regime that would meet the water requirements of its plants, in terms of temporal pattern and sequences of timing, depth, duration, frequency, rate of change and time between flows. There is a lack of knowledge about plant water requirements (Chapter 6), so regimes would in most cases be hypotheses about 'Thresholds of Potential Concern' (Chapter 4), to be tested and modified through adaptive management;
5. taking into account existing and potential new regulatory structures, define the river flow characteristics necessary to provide the flow regimes for these WMUs. There are likely to be threshold flows necessary to supply some WMUs. The hydro-dynamic model or RiM-FIM would provide information on river height or discharge associated with the inundation of particular WMUs;
6. the hydrodynamic model could provide a basis for estimating wetting up, evaporation and other losses, and for estimating how much water would be retained on the floodplain and what proportion returned to the river and at what point. The timing of returns could also be described;
7. use MDBC's MSM-Bigmod and/or Victoria's REALM model to estimate the river flow regime that meets the water requirements of the vegetation in the WMUs.

In practice this will be an iterative procedure. It is based initially only on the water requirements for vegetation, ignoring the requirements of water birds and other biota. We propose this because of the central role of vegetation in maintaining system function. We envisage that the needs of water birds and other biota should be taken into account through the adjustment of a WMU classification based first on vegetation.

Before the WMUs can be delineated, vegetation communities must be mapped at a suitable resolution using appropriate categories (Chapter 5). We explore briefly three ways of doing this. They are expanded in the Appendix to this chapter. The first is a functional response classification of vegetation in which plants are grouped according to the similarity of their water requirements. We used Frood's and Ward's (2000) high resolution classification of Barmah Forest to identify the spatial occurrences of species. We then placed these species into Casanova's and Brock's (2000) functional response categories, and subjectively assigned Frood's and Ward's mapping units into a functional response category that summarised the responses of the species within the mapping unit. Indicator species were also identified to link this method with the second, species-based approach. The resulting functional community map, (Appendix Figure 1) is too complex to use in the definition of

WMUs. This functional community map layer was not intersected with the RiM- FIM for three reasons: the complexity of the mapping units; the need to further develop the functional classification; and the stepped nature of the RiM-FIM outputs. If these problems are addressed successfully this may become a useful approach as it would be applicable to other wetlands.

The second approach used for mapping the vegetation as a basis for delineating WMUs used two species - *Pseudoraphis spinescens* (Moira Grass), and *Eucalyptus camaldulensis* (Red Gum) as examples of how a species-based classification might be carried out. Details on how this was done are in the Appendix. The mapping units in Figure 9.4. were intersected with RiM-FIM output grouped into 10,000 ML/d classes. The distribution of Red Gum versus flow in Figure 9.5 shows the wide distribution of this type relative to flow regimes. Red Gum can tolerate large amounts of flooding, as well as exist in higher parts of the floodplain where alternate water sources exist. In areas alongside creeks and wetlands, Red Gum can utilise the available water. In other areas of the floodplain, Red Gum do use groundwater (Bacon *et al.* 1993). The distribution of Moira Grass versus flow shown in Figure 9.6 identifies its strong correlation with frequent flooding in the 10,000 ML/d and 20,000 ML/d flow ranges.

The next step should be to seek correlations between less coarsely–classified flow regimes and the extent of other indicative species. The usefulness of this approach would be judged on the result.

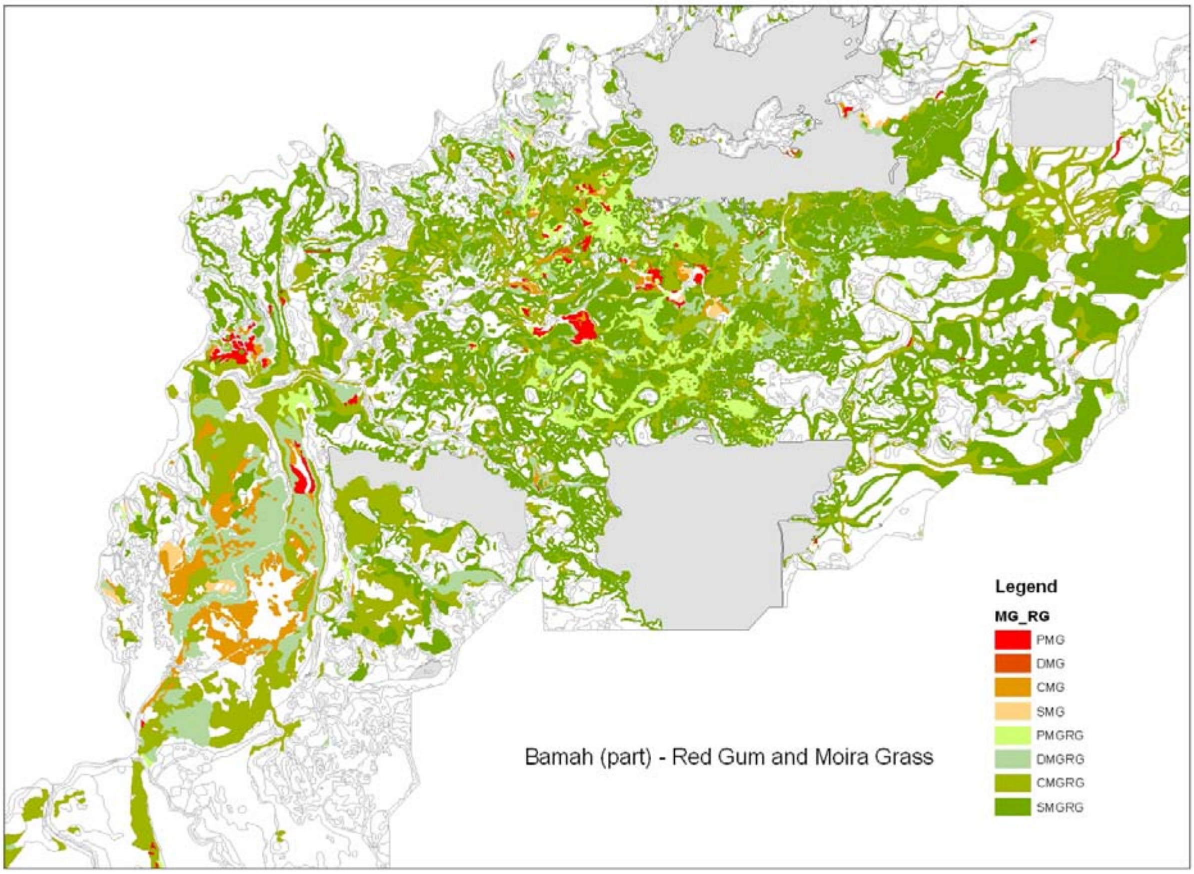


Figure 9.4: Moira Grass and Red Gum distribution over part of Barmah Forest.
Pure Moira grass (PMG), dominant (DMG), codominant (CMG) or subdominant (SMG). Red Gum (RG)

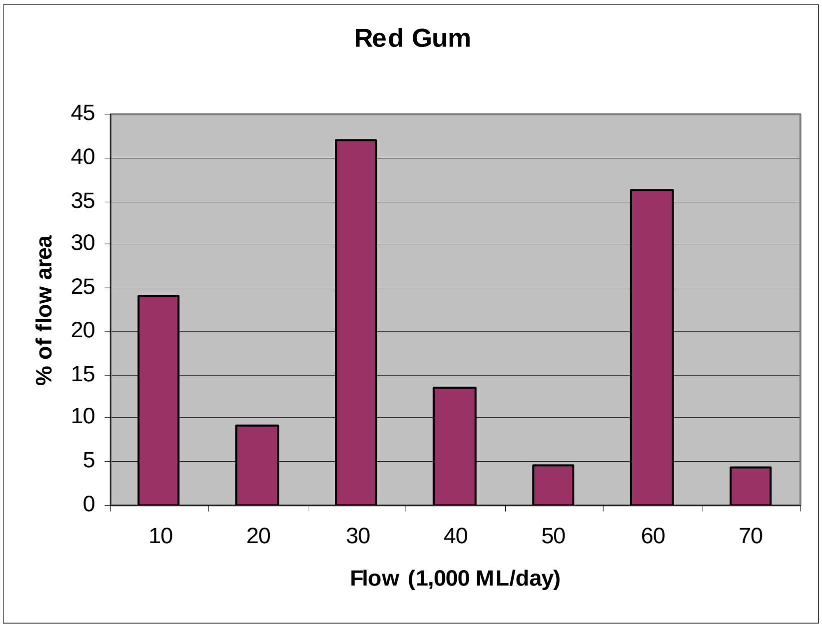


Figure 9.5: Distribution of all categories of Red Gum in relation to Flow (,000ML at Tocumwal).
To smooth the graphs the areas are presented as % of the areas of Barmah inundated at each flow class. For example a flow of between 30 and 40KML/day at Tocumwal greatly increases the area of Red Gum flooded. (These are preliminary results as the vegetation map is not complete and the FIM has marked steps in its interpolation.

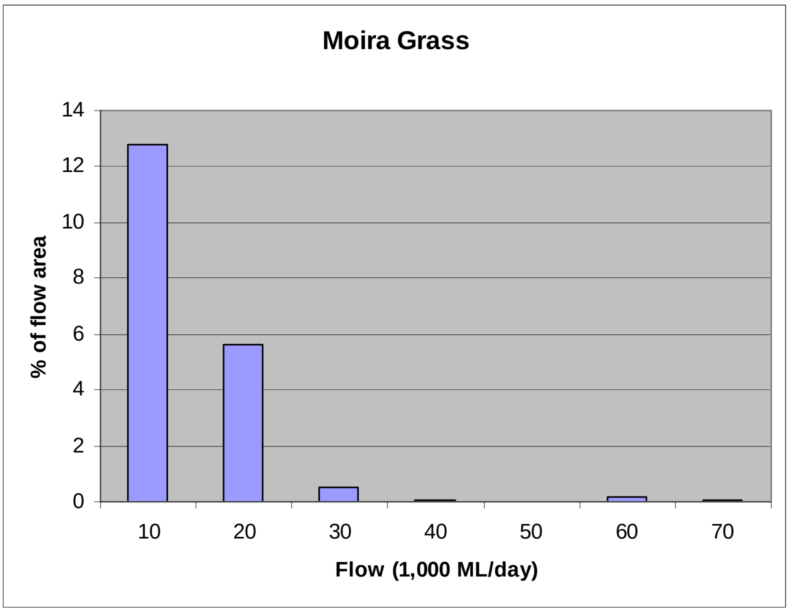


Figure 9.6: Moira Grass distribution in relation to Flow at Tocumwal).
To smooth out the graphs the areas are presented as % of the areas inundated at each flow group level. At 10 KML/day 13 % of the Moira grass is inundated, a further 5.5 % is inundated with flows up to 20KML/day. This approximately totals the 20% area inundated in Fig 9.1.

A third way of simplifying Frood's and Ward's mapping is to match it to the Ecological Vegetation Classes being developed for Victoria. These reflect environmental attributes such as soil, elevation, hydrological condition and recruitment triggers. Revision of the wetland EVCs has been undertaken by Frood (DSE, 2005) and a revised EVC map of Barmah is proposed to be done by March 2006 (Chapter 5). This will enable Barmah vegetation to be viewed in a regional context. Therefore it is recommended that the potential for defining WMUs through the intersection of the new EVCs with the RiM-FIM is explored when the EVC map becomes available.

9.2.3 The potential for improving water management through changes to control structures

Within the Barmah-Millewa floodplain the flow waters spread out across the floodplain through a number of creeks. Because the Barmah Choke constrains flow in the main channel, a large proportion of the River Murray flow leaves the river to travel through the Edward-Wakool system when flow in the main channel is high. Figure 9.7 shows the creek network in the Barmah Forest. Water management structures in the Barmah wetland system consist of regulators across flow routes into the wetland system. Most of the large structures were originally built in the late 1930s following regulation of the River Murray and subsequent summer wetland flooding that this caused. Within the last decade, many smaller structures have been constructed to permit flow into previously blocked flow paths or in areas where more precise control of water was needed for ecological purposes.

These regulating structures can be designated as Primary, Secondary and Tertiary according to their relative size and flow management capabilities (Table 9.3). In all, eight primary structures, two secondary structures and at least 27 sites containing miscellaneous small regulating structures (pipes, headwall, culverts, etc) are managed in the wetland system. Various other structures are planned or are being further investigated.

Table 9.3: Current Internal Control Structures

Primary	Secondary	Tertiary
• Sandspit Ck	Stewarts Kitchen	20 distributed pipe culverts (on minor flow depressions radiating into the wetland system at high river levels)
• Gulf Ck (x2)	Bull Paddock	7 wetland box culvert sites (Tongalong Ck and Goose Swamp)
• Punt Paddock Ck		
• Big Woodcutter Ck		
• Boals Ck		
• Sapling Ck		
• Island Ck		

The water management structures are operated by the Department of Sustainability and Environment with funding assistance from River Murray Water. Their operation is guided by the Annual Operating Plans prepared by the Barmah-Millewa Forum, and by consultation with River Murray Water (RMW), State Forests of NSW and Parks Victoria. Consultation occurs before each major allocation decision. Goulburn-Murray Water (G-MW) maintains the Victorian water regulating structures on behalf of RMW. An asset register that details background information on all of these structures is currently being prepared (Ward, *in prep*).

The flow triggers for operating the control structures in the Barmah Forest In 2005 are summarised in Tables 9.7 and 9.8. Table 9.9 shows the regulators that would have been opened in Millewa Forest to accept unseasonal flows in 2005. That year was the turn of New South Wales to accept rain rejection flows.

Until recently the control structures were not rated, so the influence of each structure on the area of inundation and the opportunities and limitations of using each structure under different flow regime conditions has not been explored. However, the construction of new regulating structures on some currently unregulated flow paths into the wetland could potentially assist in reaching objectives through either:

- preventing unseasonal water from entering areas which do not require it; or
- preventing en-route loss of Environmental Water Release destined for another location.

Water Technology's (2005) hydrodynamic model would assist greatly in evaluating the current system of control structures and appraising additions and removals.

Many current regulating structures do not have fishways, and native fish are being trapped in plunge pools behind some regulators (Ward pers. com., 2005). There is a need to fit fishways to some regulators (e.g. Gulf Regulators).

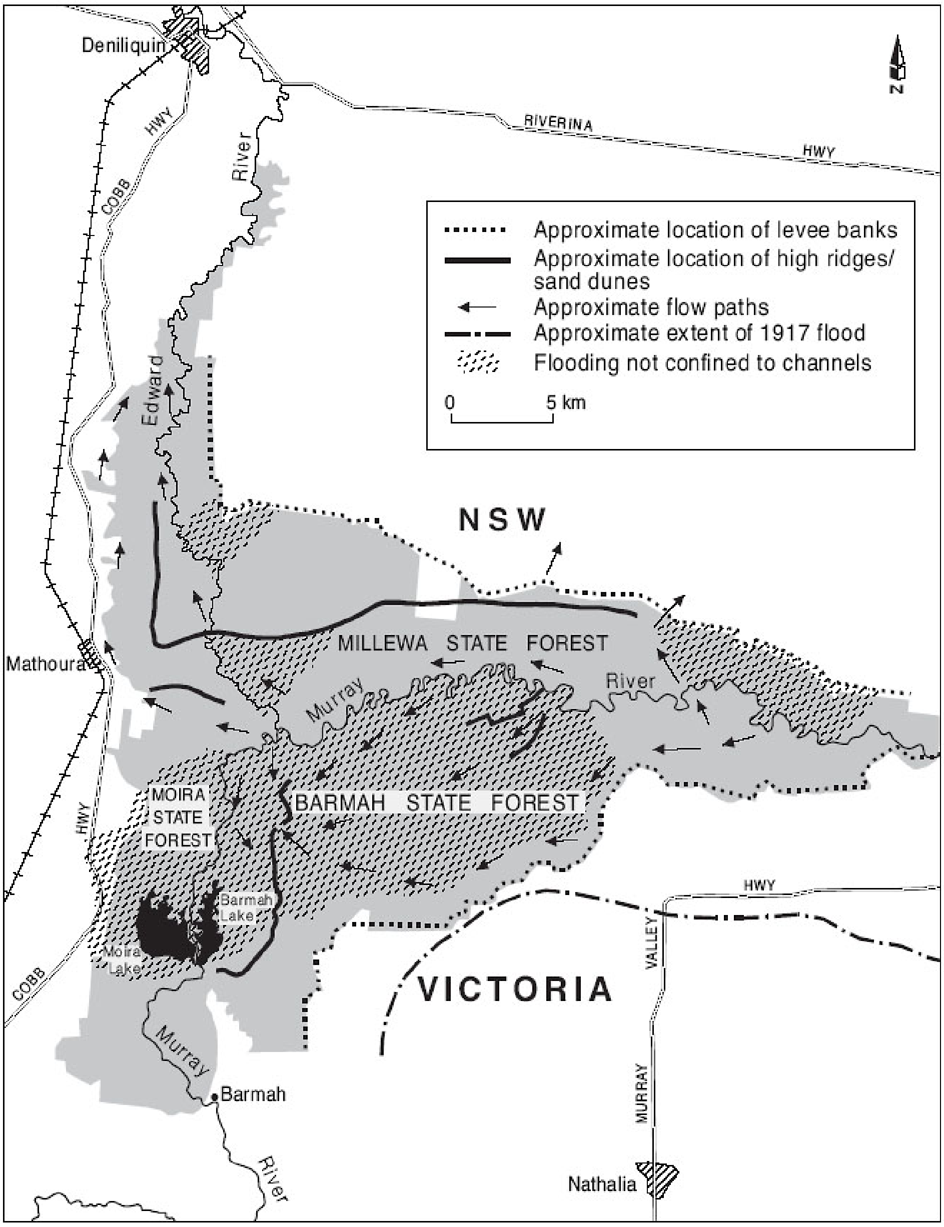


Figure 9.7: Location map of Barmah Millewa Forest showing flow paths and blockages (Chong, 2003 after Maunsell, 1992).

There is currently a debate over the relative merits and impacts of attempting to maintain or enhance the wetland system through either:

- releasing large volumes of water to inundate Barmah Forest; or
- using control structures to divert, spread and pond water selectively within the Forest.

Ponding water carries a cost by preventing fish movement, potentially creating deleterious blackwater events, and potentially decreasing the volume of water that returns to the river system. Instead, it may therefore be likely that a combination of the two strategies be required where the current volumes of water that can be managed through the wetland system for environmental purposes are insufficient to achieve all of the stated aims of wetland system and wetland management.

Table 9.4: Barmah Forest: regulator operation for seasonal flows – June to December 2005 (MDBC 2005). (Water Management Areas refer to Figure 9.3)

River Murray Flow at Yarrawonga (ML/d)	Regulators to be opened	WMA's Affected
<12,000	Tertiary Regulators plus partial Boals	Predominantly high ground in WMA F (Boals)
12,000	Boals, Bull Paddock, Stewarts Kitchen, 25% Gulf	WMA Smiths Creek and Boals Deadwood
13,000	Boals, Sandspit, Bull Paddock, Stewarts Kitchen, 50% Gulf	WMA Smiths Creek, Boals Deadwood and Gulf Creek
14,000	All 100% except for 75% Gulf	All WMAs except parts of WMA Boals Deadwood
15,000 and greater	All	All

Table 9.5: Millewa Forest: regulator operation for seasonal flows – June to December 2005 (MDBC 2005). (Water Management Areas refer to Figure 9.3)

River Murray Flow (ML/d) with duration of greater than 7 days	Forest Regulators to be opened	WMA's affected
11,000-12,000	Small freshes during the core flooding period can be used to assist refilling of dry wetlands.	Moira WMA
12,000 – 15,000	All River Murray regulators except Mary Ada (depending on duration)	All WMAs except Aratula, Plantation and Towrong.
15,000 and greater	All regulators open	Potentially all WMAs

Table 9.6: Millewa Forest: priority forest regulators for acceptance of unseasonal flows in 2005 (MDBC 2005). (Water Management Areas refer to Figure 9.3)

River Murray Flow at Yarrawonga (ML/d)	Regulators to be opened	WMA Affected
12,000	House Creek	Mary Ada
13,000	House Creek, Pinchgut	Mary Ada
14,000	House Creek, Pinchgut, Nestrons, Nine Panel, Walthours	Mary Ada, Edward, St Helena
15,000	All	All

9.2.4. Water management options and strategies within Barmah Forest

Background to water management strategy

Table 9.7 shows the major literature on water management strategies in the Barmah-Millewa Forest. The most significant shift in management principles has been the move away from the idea of using rain rejection flows to water the forest (Maunsell 1992a, 1992b). Current emphases are on the use of Environmental Water Allocations (EWAs) to achieve ecological objectives, and the need for (unnatural) summer and autumn flows to be managed to minimise their adverse impacts (Chapters 6, 7 and 8).

The flow objectives to meet the ecological objectives for Barmah Forest for the current Environmental Water Allocation are (DSE and GBCMA, May 2005):

- flood between August and December, extending to January only if needed to complete a bird breeding event;
- magnitude of 15,000 -18,000 ML/day measured at Yarrawonga (i.e., a medium level flood);
- three floods every 10 years;
- minimum 4 months duration, up to 5 months if required; and
- no more than 5 years between 4-month floods – in 5th year release all accumulated entitlement and manage as well as possible on the floodplain to reach ecological objectives.

These objectives are aimed at restoring some of the lost attributes of the pre-regulation flow regime (Chapter 6). In the absence of experimental data (Chapters 6 and 7) they are derived pragmatically from correlations, expert knowledge and observations. They serve as hypotheses being tested through adaptive management.

The Barmah-Millewa Forum Water Management Strategy (2000), and the forthcoming Water Management Plan for Barmah Forest are intended to be the main means of implementing the Asset Environmental Management Plan for Barmah Forest (DSE and GBCMA, May 2005), and achieving the vision for Barmah Forest and its value delivery and system maintenance objectives (Chapters 3 and 4). More specific flow objectives, determined annually, are detailed in Annual Operating Plans prepared by the Barmah-Millewa Forum in conjunction with wetland system agencies and MDBC prior to the start of each flood season (e.g. BMF 2004). These plans include an outlook of flows at Yarrawonga based on the probability of receiving a given flow in each calendar month, estimated using the MDBC Monthly Simulation Model (MSM).

Table 9.7: Major literature on the water management strategies of Barmah

Publication	Source (peer review)	Title
Bren, O'Neill, and Gibbs (1987)	Journal paper	Flooding of the Barmah Forest and its relation to flow in the Murray-Edward River system
DCFL (1989) [Leitch]	Agency report	Towards a Strategy for Managing the Flooding of Barmah Forest
DNRE (1992)	Agency report	Barmah State Park and Barmah State Forest Management Plan
DNRE (1992)	Agency report	Watering the Barmah-Millewa Red Gum Forest
Maunsell P/L (1992)	Agency report	Barmah-Millewa Forests Water Management Plan
DNRE (1993)	Agency report	Water Management Options for the mid-Murray Wetlands
DNRE (1993)	Agency report	The Integrated Watering Strategy (IWS) for mid-Murray Wetrlands
Barmah-Millewa Community Reference Group (1994)	Agency report	Final Report on the Barmah-Millewa Forest Water Management Plan
DNRE and MDBNRM (1994) [Ward, Leitch, Lloyd and Atkins]	Agency report	Interim Water Management Strategy for Barmah Forest – Integrated Watering Strategy Report
DNRE (1994)	Agency report	An Environmental Bulk Water Entitlement for the River Murray
State Forests NSW and NSW DLWC (1996) [Leslie and Harris]	Agency report	Water Management Plan for the Millewa Forests
DLWC (1996)	Agency report	Unseasonal Surplus Flow Management - Barmah-Millewa Forest
DNRE (1997)	Agency report	Barmah-Millewa Forest Water Management Strategy
GBCMA Land Protection Board (1997)	Agency report	Goulburn Broken Regional Catchment Strategy
DNRE (1997)	Agency report	Water Management Activities Adjacent to the Edward River and Associated Anabranches
Maunsell P/L (1998)	Agency report	Barmah-Millewa Forest Water Management Plan Part 1
Barmah-Millewa Forum and MDBC (2000)	Agency report	The Barmah-Millewa Forest Water Management Strategy
Thoms *et al* . (200)	Agency Report	Report of the River Murray Scientific Panel on Environmental Flows.
Barmah-Millewa Forum (2004)	Agency report	Annual Operating Plan 2004-2005
Chong (2003)	University technical report	Analysis and Management of Unseasonal Surplus Flows in the Barmah-Millewa Forest
DSE and GBCMA (2005)	Agency report	Asset Environmental Management Plan: Barmah Significant Ecological Asset
MDBC (2005)	Agency report	The Barmah-Millewa Forest Significant Ecological Asset – Asset Environmental Management Plan for 2005/2006

The volume of flow received and the ability to manipulate flows within the floodplain, are currently considered by DSE and GBCMA (May 2005) to be insufficient to meet ecological objectives. This is supported by the analyses in Chapter 8. With an increased EWA, the establishement of flood easements, plus potential for various on-ground works and shared water management activities (e.g. transfer of water destined for downstream consumption to be passed through the wetland system when desirable), ecological objectives could be better met (DSE and GBCMA, May 2005).

The current strategy is to create desired flood events through releasing water reserves, such as the EWA, to maintain higher river levels following natural flood peaks, thus enhancing floodplain-riverine connectivity and the ecological benefits that this brings. These benefits include steady carbon cycling flow into the river, unrestricted fish movement and spawning opportunities, gradual flushing of accumulated leaf material to avoid ‘blackwater’ events. In section 9.2.3 we noted the debate over whether to use large environmental flows to supplement natural floods and thus inundate the floodplain, or whether to use a smaller volume of water in a more targeted way by using control structures. The second option saves water but at the cost of connectivity. Water Technology’s hydrodynamic model or RiM-FIM would be useful for evaluating these options. .

Given the current and expected future scarcity of water, and the impacts of current flow regimes, we discuss in the rest of this section the need to make trade-offs, the need for groundwater management, getting water to areas of higher elevation in the floodplain, and managing water quality and erosion.

Making trade-offs

Chapter 8 identifies four kinds of trade-off: spatial, trophic, biotic and functional. Temporal trade-offs can be made within each of these categories. We have already commented on the scarcity of water in winter-spring, and the excesses of it in summer-autumn. Clearly not all system maintenance and value delivery objectives can be met with every flood, and at times it may be necessary to sacrifice some areas by inundating them in summer in order to conserve other areas. DSE and GBCMA (May 2005) state that near annual flooding of Moira Grass plains of > 0.5m depth and 3-6 months duration remain one of the highest priorities. This requires preferentially diverting all seasonal inflows into wetland locations containing Moira Grass plains, and avoidance of flooding such wetlands from unseasonal flooding (such as arises from rain-rejection events occurring during summer) (DSE and GBCMA, May 2005). Some summer flooding is unavoidable. Thoms *et al.* (2000) recommended a study to determine the comparative ecological values of the wetlands, anabranches (including the Edward River) and creeks and to identify areas of high conservation value (Chapters 3 and 4), and areas that might be used as zones of sacrifice. We propose the units of spatial trade-off within Barmah Forest will be the proposed Water Management Units (Section 9.2.2.).

MDBC (2005) describes a process for making spatio-temporal trade-offs among water management areas in the Barmah-Millewa Forum’s Annual Operating Plans. A “numeric scoring method” proposed by Bren has been used to determine priority WMAs (Figure 9.3.) for 2005-2006. Each WMA is assigned an “annual flood score” based upon flood rankings from 0 for “no flooding at all” to 3 for “completely flooded”. Given that Bren’s ideal flooding score is based on the ideal long term flooding frequency, a seven-year period has been used to analyse the present flooding history. Adopting a seven-year weighted score and an arbitrary cut off at –3.4, the analysis, not surprisingly given the number of recent dry years in the record, shows 13 of the 21 WMA’s as priority watering areas for 2005-2006 (Table 9.8.).

This approach has limited benefit for assessing management options where outcomes are not dependant on the same flooding thresholds. A preferred approach would be to determine an annual flood score on each objective that relates to each Water Management

Unit and then rank the operating regime on the basis of achieving high scores all objectives in a particular WMU.

In Chapter 4 we discuss conflicts and trade-offs among objectives, consequently among value delivery and system maintenance objectives. Chapter 8, discusses trade-offs between allocating water for Red Gum management and for the breeding of waterbirds, and between waterbird breeding and the abundance of fish and frogs. In that chapter we recommend that watering or flood-avoidance priorities should shift over time. Our assumption is that although water and places to receive excess water are both scarce at particular seasons, if allocation priorities are rotated rather than fixed a higher proportion of system maintenance and value delivery objectives can be met.

Getting water to higher elevations in the floodplain

DSE and GBCMA (2005) report that drought stressed Red Gum which occupies most of the higher elevations can usually only be watered from large natural flood events, which have become rarer. Management of rain-rejection events depends upon their volume and timing, but it tends to be prioritised towards higher drought-stressed Red Gum areas away from wetland basins. These high areas need to be focused on to achieve the threshold flow durations needed to sustain the Red Gum communities or they will become sacrificial areas.

Groundwater management

Little is known about the interaction of groundwater and vegetation in Barmah Forest. Red Gum and Black Box woodland communities do utilise groundwater aquifers (Bacon *et al.* 1993; Roberts, 2001). However, monitoring of groundwater shows that levels are rising and there is a risk of salinisation. Black Box tolerates salt (Roberts 2001), but many other species do not. It may be necessary to lower the water table in some higher value conservation areas where the species at risk from salt and high water table are considered more valuable than those dependent on access to the water table. Pumping is one option, subject to costs and access to disposal sites.

Water Quality

Decreased velocity can lead to blackwater events, when standing water is high in carbon, causing rapid de-oxygenation and consequent death of fish and other biota. There is also a risk of anabaena (cyanobacteria “blue-green algae”) blooms when standing water is left for 3 months or more. The period between wetland flooding events has increased compared with pre-regulation conditions. Flooding flushes accumulated debris (particularly Eucalypt leaves and twigs that contain high levels of polyphenolic compounds that can be harmful to aquatic life) from the wetland floor, so the potential for deleterious ‘blackwater’ events has increased. This has been exacerbated by the increase in Eucalypt density believed to be due to both altered flood regimes and silvicultural measures (DSE and GBCMA, May 2005).

A model of blackwater events has been applied to the Barmah-Millewa and others wetlands downstream (Ward pers.com., 2005). Warm months with large leaf litter and low flows are triggered as risk and can signal the need for increased volumes of water with flushing flows.

Erosion rate

Riverbank slumping and increases in flow path erosion result from increased duration of summer flows. Wash from boats, burrowing activities of carp and unrestricted stock access also contribute (DSE and GBCMA, May 2005). The increased sediment load reduces water quality and modifies microtopography. The factors affecting erosion can in some circumstances be reduced by modifying flows.

Table 9.8: Water Management Areas and the priority given to watering.

Water Management Area	Observed flooding score							Ideal average annual flood score#	Accumulated score, Winter 1998-2005	Ideal score, Winter 1998-2005	Surplus Deficiency, Winter 1998-2005	Watering analysis 2005-2006^
	1998	1999	2000	2001	2002	2003	2004					
Kynmer Creek (A)	1	1	2	0	1	0	0	1.3	5	9.1	-4.1	Priority
Tongalong Creek (B)	1	1	3	0	1	1	1	1.5	8	10.5	-2.5	
Smiths Creek (C)*	3	1	3	0	1	0	0	1.5	8	10.5	-2.5	
Yielima (D)	2	1	3	0	0	0	0	1.5	6	10.5	-4.5	Priority
Black Swamp (E)*	2	1	3	0	0	0	0	1.6	6	11.2	-5.2	Priority
Gulf Creek (F)	2	1	3	0	2	1	1	1.9	10	13.3	-3.3	
Boals Deadwood (G)	2	1	2	0	1	1	1	1.9	8	13.3	-5.3	Priority
Top Island (H1)	2	1	3	0	1	1	1	1.9	9	13.3	-4.3	Priority
Steamer/War Plain (H2)	2	1	3	0	2	2	2	2	12	14	-2	
Goose Swamp (H3)	1	1	3	0	1	1	0	1.55	8	10.85	-2.85	
Barmah Island (H4)	2	1	3	0	2	2	2	2	12	14	-2	
Aratula Creek (J)	3	0	3	0	0	0	0	1.5	6	10.5	-4.5	Priority
Plantation (L)	2	0	3	0	0	1	0	2	6	14	-8	Priority
Mary Ada (M)	3	0	3	0	0	1	1	1.9	8	13.3	-5.3	Priority
Edward River (N)	3	1	3	0	0	1	1	2.3	9	16.1	-7.1	Priority
Towrong Creek (P)	3	0	3	0	0	0	1	1.4	7	9.8	-2.8	
St Helena Swamp (Q)	2	1	3	0	0	1	1	2.2	8	15.4	-7.4	Priority
Gulpa Creek (R)	2	1	3	0	0	1	2	2.2	9	15.4	-6.4	Priority
Moira Lake (S)	2	1	3	0	2	1	2	2	11	14	-3	

Dr Leon Bren's scoring basis
0 = "no flooding the WMA"
1 = "some flooding the WMA"
2 = "lot of flooding"
3 = "completely flooded"

Based on the proportion of wetlands, SQI, SQII, SQIII in each WMA and desirable flooding frequencies of 10 years out of 10 for wetlands, 8 years, 5 years and 3 years out of 10 for SQI, SQII and SQIII.

^ Priorities are determined using arbitrary cut-off of -3.4

* Water management of Black Swamp WMA (E) is hydraulically linked to Smiths WMA (C).

H2-H4 Scoring for these WMAs was previously presented as part of H1 scores.

9.3 Delivering water to Barmah Forest and managing and adapting to river flows

In section 9.2 we discussed the management of water within Barmah Forest. In this section we discuss issues and options affecting the delivery of water to Barmah Forest and the management of and adaptation to river flow regimes. We deal first with the availability of water and threats to supply, then discuss options for getting water to Barmah Forest and adapting to adverse river flows. Those options address the problems of unseasonal summer-autumn flooding, insufficient winter-spring flooding, and the lack of variability of flows. Table 9.9 shows the major literature on the Environmental Water Allocation for Barmah-Millewa Forest.

Table 9.9: Major literature on the environmental water allocation in Barmah

Publication	Source (peer review)	Title	Type of Evidence
Barmah-Millewa Forum (1999)	Agency report	Report on Barmah Millewa Flood of October 1998 and the First Use of Barmah-Millewa Forest Allocation	Field assessment
Barmah-Millewa Forum (2001)	Agency report	Report on Barmah-Millewa Forest Flood of Spring 2000 and the Second Use of the Barmah-Millewa Forest Environmental Water Allocation	Field assessment
Barmah-Millewa Forum and DPI (2003) [Abuzar and Ward]	Agency report	Flood and Vegetation Mapping in the Barmah-Millewa Forests during October-December 2002 using Remote Sensing Technology	Satellite imagery of flood extent

9.3.1 Availability of water and threats to supply

The volumes and timing of water received by the Barmah-Millewa Significant Ecological Asset are strongly dependent on releases from Lake Hume, Lake Mulwalla and the inflow from the Ovens River. As a result of the Living Murray Initiative First Step Decision to release an Environmental Water Allocation (EWA) for all SEAs, the managers of the Barmah-Millewa SEA are able to increase the frequency and extend the duration of flooding, and address the loss of autumn-winter floods. Chapter 8 describes the sources and volumes of the EWA, and outlines the operating rules. Reiterating the former, the available quantity of EWA for Barmah-Millewa Forest ranges from zero to 700GL, and it can accumulate over time, if not used, up to a maximum of 700 GL. New South Wales and Victoria add 50 GL every year additional to the 700 GL. A further 25 GL from each state can in theory be added depending on water sales. Additional inputs can be made from the NSW environmental allocation, and the Victorian Wetlands allocation. There is access to 25,000 of the 27,600 ML Flora and Fauna Bulk Entitlement of high security water to enhance the flora and fauna in Northern Victoria. Part of this entitlement was used to augment flood events and other environmental releases into Barmah Forest in 2000 and 2001 (DSE, 2003).

The annual NSW contribution is only made available after general security allocations in NSW have reached 30% of their target. The EWA is not always available to be used. In conditions where rainfall is dry to average and inflows are low to medium, both States are likely to seek to re-borrow the EWA for domestic water supply and irrigation, including borrowing of their respective annual 50 GL contribution. This would eliminate the availability of the EWA for use in the Forest. If very wet conditions and high inflows do occur, then it is likely that any water borrowed by the States would be paid back into the EWA account (MDBC, 2005).

Chapter 8 also analyses the limitations of the EWA: the small volume compared with the river flows, the infrequency with which it can be applied, and seasonal and channel capacity constraints on its use. In 2005-2006, the Barmah-Millewa Forest EWA will continue to be managed according to its interim operating rules and triggers, but current levels of water supply will not necessarily remain unchanged. The low flooding conditions in the period 1995 to 2005 resulted from river regulation and drought, which increases demand and decreases supply, so a sequence of wetter years would favour an increased allocation. On the other hand, changes to the Ovens River are a major potential threat. It is largely unregulated, a rarity for a relatively large lowland river system in this region. The river is extremely important in providing seasonal flows to the Barmah wetlands, as its outfall into the River Murray is downstream of any large reservoir. The negative impact of a reservoir within its catchment would exceed the positive contribution of The Living Murray Initiative (DSE and GBCMA, May 2005). However, the current EWA may be in reality a first step towards higher allocations in the future. Whether the availability of water for Barmah-Millewa Forest increases, decreases, remains at the current low level or changes in seasonality will depend upon the political pressures on governments from the various interest groups, as well as climatic change. Effective use of the current allocation, realisation of beneficial ecological responses from the SEAs, and increased benefits from tourism and recreation would strengthen the case for larger EWAs and allocations from other sources.

9.3.2 Options for getting water to Barmah Forest and managing and adapting to adverse river flows

Unseasonal Summer-Autumn Flooding

Flooding in late summer and early autumn has increased substantially because of the regulation of the River Murray (Chapter 6). Unseasonal flooding is primarily caused by rain rejection events in the latter half of the irrigation season or by high flows from flashy summer storms. The Barmah-Millewa section of the river is run at full channel capacity during this period when downstream demand for water is high and the additional volume from a rain rejection event can easily result in unseasonal flooding. Thoms *et al.* (2000) recommended that during the period, December to end of the irrigation season, Barmah Choke should be run below channel capacity (i.e. < 10,600 ML/day at Tocumwal) in order to prevent summer flooding.

The high summer flows that keep this section of the River at channel capacity have in the past had an adverse effect on parts of the forest, irrespective of rain rejection events (Chapter 6). High river flows can still enter the forest through unregulated low points and effluents on the river, which caused the near-permanent inundation of wetlands and lower parts of the floodplain. Installation of regulators on these points, originally utilitarian to prevent water ‘losses’ into the forest, are now a useful management tool to allow wetland areas to undergo a drying phase.

When the river is kept full, regulators alone cannot prevent flooding from rain rejection events. Victoria and New South Wales have agreed that they will take turns in accepting rain rejection flooding every other year, using the intricate system of forest creeks (Figure 9 shows the larger ones) to carry the water out of the forest. This currently allows each State’s wetland areas to undergo a drying phase roughly every two years – a major improvement. However, there are still unregulated low points where water enters both sides of the forest, and there is also a limit to the amount of rain rejection water each state can cope with before widespread flooding occurs. Therefore on occasions some water will also have to be sent through the Forest that should be undergoing its drying phase, affecting vegetation, and reducing access for recreation and other users.

Chong (2003) found that there would have been significantly less frequent unseasonal flooding of the Barmah-Millewa Forest if the system had been managed differently. If 1980 - 2000 is assumed to represent current water demand conditions, then unseasonal flooding frequency could be reduced from 38.3% to 15.5% by:

- increasing Yarrawonga Weir by 9100 ML (maintaining height at 124.9m, 0.195m below the maximum); or
- limiting the maximum flow at Tocumwal to 9600 ML/day.

Smaller increases in system flexibility can have a significant impact on reducing flooding frequency, e.g. a frequency of 20% will be achieved by increasing airspace by just 5000 ML or limiting the maximum flow at Tocumwal to 9900 ML/day (Chong, 2003).

There has been an investigation of options for reduction of rain rejections by DIPNR Deniliquin (Ward pers. com., 2005) to mitigate the rain rejection flows that currently pass through Lake Mulwala. This will help prevent unseasonal flooding of the Barmah–Millewa floodplain. Lake Mulwala rain rejection management has been identified for funding under the EWMP.

Chong (2003) has modelled potential management options for reducing unseasonal flooding in the Forest. She also undertook an economic analysis on the costs associated with the options.

Insufficient Winter-Spring Flooding

Since regulation of the Murray River, the frequency and magnitude of floods during Winter and Spring has decreased because rainfall in the upper catchments is caught in storage. The forest flooding that occurs during June to December is usually the result of rainfall in the Ovens and Kiewa catchments (Figure 2.1). These enter the Murray below Hume Dam, so their high flows cannot be stored. Lake Mulwala, located upstream of the forest, is unable to store these flows as it is kept close to capacity to provide sufficient head to operate the major irrigation supply channels. This results in high flows entering Barmah Forest through low points and effluents and by spilling over the banks through sections of the forest known as ‘chokes’ due to their small channel capacity. In these circumstances regulators on the main river channel are opened to allow water to enter the forests in as natural a progression as possible via the natural low points and effluents on which the regulators are located. The size of the river flow plays a role in determining which combinations of regulators are opened. It also determines if the Environmental Water Allocation (EWA) is triggered for release, depending on the timing and duration (Barmah-Millewa Forum Website, 2005).

The Barmah-Millewa wetland system currently has an EWA of 100 GL high security and 50 GL low security water. This water is accrued in storage and released to extend the duration of long, medium-sized floods. The water allocation has been used twice in the past in 1998 and 2000 (Barmah Millewa Forum, 1999; Barmah Millewa Forum, 2001).

The current lack of suitable easements in the Hume to Yarrawonga reach reduces the ability to deliver environmental water allocations to the Barmah-Millewa wetlands when required in the volumes desired. Current moves by River Murray Water to achieve suitable easements will mitigate this impact, though timelines and ability to gain desired higher-level easements remain a limitation for unrestricted EWA delivery (DSE and GBCMA, May 2005).

A recent study is looking at the feasibility of Hume-Yarrawonga Easement acquisition (River Murray Water (Ward pers. com., 2005). This project is investigating options to improve flooding regimes throughout the River Murray System downstream of Hume Dam. It will also consider acquisition of flow rights to temporarily pass regulated flows at rates up to 45,000 ML/d, to provide increased operational flexibility for control of flooding of the Barmah–Millewa floodplain. The acquisition of easements (Hume to Yarrawonga) is one of six projects currently identified for funding under the EWMP to facilitate watering and help achieve the ecological objectives of Barmah-Millewa Forest.

A number of works have been planned and undertaken in the Yarrawonga to Tocumwal reach. Between 2001 and 2004, a range of works has been completed to manage environmental water at twelve priority wetland sites. The works allow increased flood frequencies into the wetland in spring, as under natural conditions, whilst maintaining the natural dry regime over the summer and autumn months.

Various other options have been explored to improve the management of flow to the Barmah-Millewa floodplain. These include improved flooding of the lower Goulburn with the buyback of land and the decommissioning of Lake Mokoan. These plans will improve flows in the lower Goulburn which will influence River Murray flows back to the Barmah lakes region. Thoms *et al.* (2000) recommended a review should be undertaken of the River Murray in this river zone (Zone 3 – Tocumwal to Torrumbarry Weir) to identify opportunities to increase the watering of targeted wetlands and the reaches that would most benefit from this.

The lack of variability of flows in relation to bank erosion and in-stream habitats

Because the river in this reach is highly regulated Barmah Forest would benefit from the introduction of some variability in flow levels to reduce bank erosion and to introduce some wetting and drying of in-stream habitats (Thoms *et al.* 2000). There would be trade-offs which may be unacceptable, such as the risk of summer flooding of wetlands. To achieve increased variability would require fluctuating the flows through Tocumwal and regulating the control structures in Barmah at low flows to create gradual rises and falls in the river and creeks.

9.4 Recommendations

We propose the recommendations below; 1-11 are about managing water within Barmah Forest, and 12-15 focus on getting water to Barmah Forest.

1. Water management should be set within the hierarchical framework used in this report, described in Chapter 1, and summarised in figure 1.1.
2. Water management will necessarily be based in the short term upon the ‘natural paradigm’ and on the analysis of correlations between patterns of inundation and the distribution and observed responses of species and ecological communities. However, the limitations of these approaches should be acknowledged in management recommendations, investments made in experimental manipulations supported by modelling, and a strong adaptive management program pursued.
3. Chapters 6-8 have stressed the lack of formal scientific information on the responses of biota to water regimes, and Barmah and Millewa Forests are currently being managed using expert local knowledge and adaptive management. Water management objectives are therefore aimed at supporting a set of pragmatic ecological objectives. This report advocates in Chapters 4, 6, 7 and 8 a rethinking of those ecological objectives, and flags the research needed to develop them. Options for delivering water to and managing it within Barmah Forest will need to be developed to support those new ecological objectives. Meanwhile, however, research

should proceed meanwhile on known problems of getting water to and distributing it within Barmah Forest. These include the needs for better modelling and mapping of river flow and floodplain inundation, improved definition of water management units, the potential for changing control structures, trade-offs, among water management units, the need for groundwater management, getting water to areas of higher elevation in the floodplain, and managing water quality and erosion.

4. *Better modelling and mapping of river flow and floodplain inundation* (section 9.2.1.) - we noted the limitations of using correlations between flow regimes and plant distribution in 2. above, but there is still much to be learned through this approach. Chapter 6 argued that to relate flow regime to plant water requirements, information is needed at a resolution suitable for management within Barmah Forest on temporal pattern and specific sequences of timing, depth, duration of inundation, frequency of flooding, rate of change, and duration of dry phase. Rim-FIM and Water Technology's MIKE FLOOD hydrodynamic are both available for Barmah Forest. Problems with delineating channels are affecting the accuracy of both methods. Current research by CSIRO's Ecological Outcomes project is addressing it.

5. *Improved definition of water management units* (section 9.2.2.) – better spatio-temporal modelling of flow-inundation relationships will provide the basis for redefining water management units. The dynamic nature of MIKE FLOOD suits it to this task, and Water Technologies are already contracted to provide runs to GBCMA. The task is to i). choose a vegetation classification (section 9.2.2.) that relates water requirements to vegetation types, ii). identify places on the floodplain where particular value delivery and system maintenance objectives should be met (Chapter 4), iii). over-lay vegetation communities on output from MIKE FLOOD, iv) delineate WMUs, taking into account the current or potential capacity to manage the WMU as a hydrological unit through regulators, local topography or timing; v). for each WMU, define the flow regime that would meet the water requirements of its plants. This should be an iterative process, including iteration with the examination of control structures (6 below).

6. *The potential for improving management through changes to control structures* (section 9.2.4.) – the control structures are already included in MIKE FLOOD. We recommend the effectiveness of the structures, and the potential for removing or adding structures be evaluated using this model. There should be iteration between the evaluation of control structures and the delineation of WMUs. There is a need to put fish passages into some existing structures, and a process for prioritising this is needed.

7. *Trade-offs* - we also propose that MIKE FLOOD should also be used to explore trade-offs in time and space among the WMUs. There is a need to identify sacrificial areas of relatively low conservation value to accept summer floods, and high priority conservation areas to which scarce winter-spring floodwaters should be targeted. There is also scope for rotating these priorities among the WMUs so that the adverse impacts of unseasonal flooding or drying are spread among the WMUs. A new approach has been suggested to determine an annual flood score on each objective that relates to each Water Management Unit and then rank the operating regime on the basis of achieving high scores all objectives in a particular WMU.

8. *The need for groundwater management* (section 9.2.4.) – Pumping may be necessary to lower the water table in some higher value conservation areas where the species at risk from salt and high water table are considered more valuable than those dependent on access to the water table. The recommendation is to monitor groundwater levels across the floodplain with the focus on areas where groundwater is approaching 3 metres below the surface. If groundwater is within three metres it is likely that soil salinisation will become a serious issue.

9. *Getting water to areas of higher elevation in the floodplain* (section 9.2.4.) - Identifying the Red Gum communities that are under stress due to lack of water availability from their high elevation will define one of the water management units. This WMU can then be targeted to achieve flow thresholds required by the Red Gums in this area.

10. *Managing water quality* (section 9.2.4.) - Decreases in channel velocity and the increase in detritus have increased the chances of blackwater events. It is recommended to use the developed blackwater risk model to assess the risk in the Barmah-Millewa forest and ensure that flushing flows occur to remove detritus and reduce stagnant water occurrences.

11. *Managing erosion* (section 9.2.4.) – subject to the negative consequences for other objectives, increase variability of low flows to reduce the risk of erosion and introduce some wetting and drying of instream habitats. To achieve this would require fluctuating the flows through Tocumwal and regulating the control structures in Barmah at low flows to create gradual rises and falls in the river and creeks.

12. *Unseasonal Summer-Autumn Flooding* (section 9.3.2.) - options include increasing the pool level at Yarrawonga Weir, and maintaining the flow through Barmah Choke through the irrigation season. Using the control structures in the summer-autumn could reduce unseasonal flooding. Other options include building a bypass channel to transport the irrigation water or on-route storages. Thoms *et al.* (2000) also suggest a general improvement in on-farm efficiencies to reduce the demand and charging irrigators for water ordered even if not used could reduce the volume of water needed to be moved through the forest at this time of year.

13. *Insufficient Winter-Spring Flooding* (section 9.3.2.) - establish easements between Hume Dam and Yarrawonga, use MIKE FLOOD to explore the usefulness of engineering works in the Yarrawonga to Tocumwal reach, and use backflows from the Goulburn River to flood Barmah-Millewa Forest. The EWA could be used to transfer water to Lake Victoria at rates above channel capacity.

14. *Lack of variability of flows* (section 9.3.2.) - Look at the changes that could be made on a regular basis to fluctuate the water levels of low flows. This could include manipulating the weir height at Tocumwal or manipulation of the control structures in Barmah and Millewa forests.

15. *Impact of damming the Ovens River on reduced flows* – estimate the impact on river flow at Tocumwal and the use MIKE FLOOD or RiM-FIM to model the consequences for inundation of Barmah Forest.

Chapter 9 APPENDIX: Exploring alternative ways of classifying and mapping vegetation in Barmah Forest to enable the delineation of Water Management Units.

Judith Harvey

In this appendix we explore three ways of classifying vegetation to enable the delineation of Water Management Units: functional response, species distribution and Ecological Vegetation Class.

Exploring a functional response classification

A functional response classification is one that groups plants according to the similarity of their water requirements. None yet exists for Barmah Forest, but its vegetation has been mapped in great detail by Frood (Frood and Ward, 2000). Sixty six categories are mapped as pure and as mosaic units, totaling 556 combinations. We disaggregated these so that a functional response classification could be applied and the individual species extracted and mapped.

The forty eight species listed in the description field of Frood's map units were assigned to a functional category according to a classification developed by Casanova and Brock's (2000) (Appendix 9 Table 1.). Thirteen of the Barmah species were included in their experiments with a further six similar species from matching genera. All species were entered into the National Herbarium database which, if the information was available, classified the species as an Inundation plant (requires periodic inundation), Riparian, Helophyte (swamp plant), Halophyte (salt tolerant plant), or Hydrophyte (aquatic, rooted or floating). The Flora of New South Wales and Flora of Victoria also provided information on water requirements. Further information was obtained from Roberts and Marston (2000). Additional suggestions and corrections were made by Roberts (pers. com). The resulting classification of Barmah species according to Casanova and Brock's (2000) is presented in (Appendix 9 Table 2). Then a subjective summary was compiled for groups of species making up each of Froods 66 units. This resulted in 27 functional categories and combinations (two or three functional categories). These are shown in Appendix 9 Figure 1 Some of these only cover small areas and could be combined with other categories. Indicative species for each functional type were selected for Barmah based on their common occurrence and characteristic association with each functional category. Further knowledge of the water requirements of these species may change this classification which may inturn be refined into more categories applicable to the Murray Riverine Plan (Casanova and Brocks classification was derived from tank based experiments.

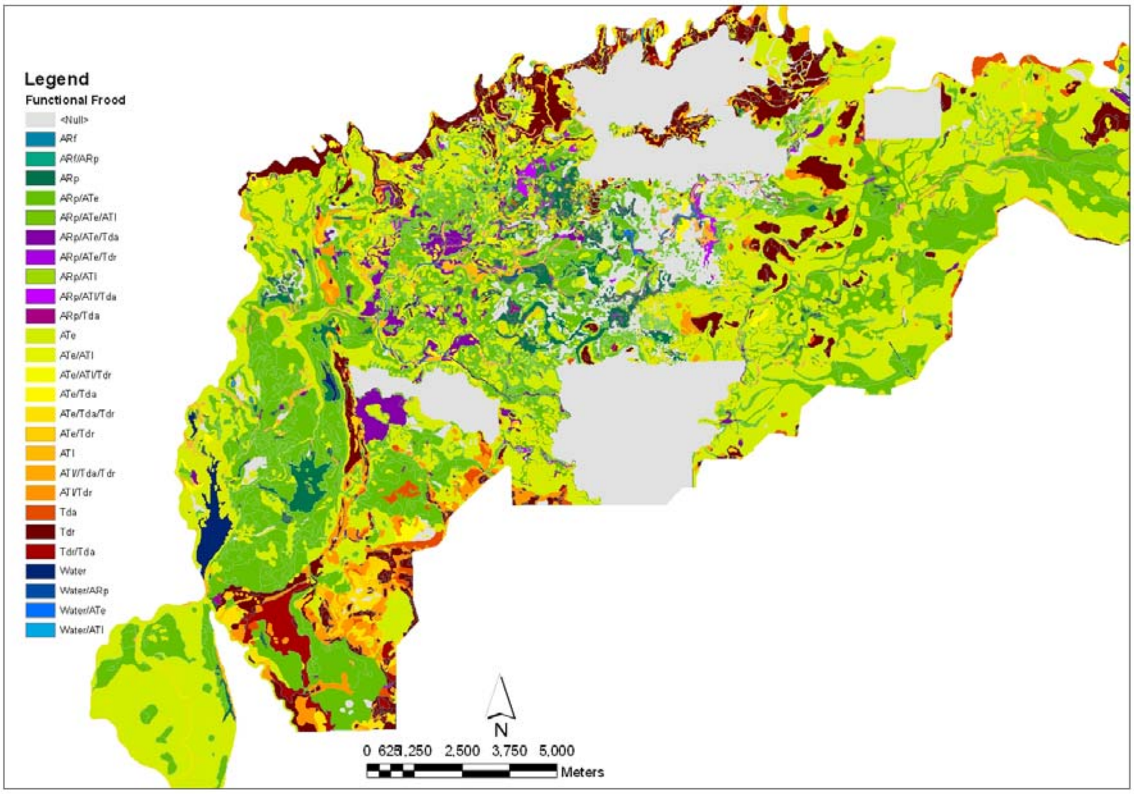
Appendix 9 Table 1: Categories developed by Casanova and Brock (2000) from field surveys and experiments, and examples of species from Barmah assigned to those categories

Primary category	Secondary category	Description	Indicative species for Barmah
Terrestrial	Dry species: Tdr	Species which germinate, grow and reproduce where there is no surface water and the water table is below the soil surface	Austrodanthonia spp.
Terrestria	l Damp species: Tda	Species which germinate, grow and reproduce on saturated soil	Austrodanthonia duttoniana Poa labillardierei Miclolaena stipoides
Amphibious Fluctuation-tolerators	Emergent species: ATe	Species which germinate in damp or flooded conditions, which tolerate variation in water-level, and which grow with their basal portions under water and reproduce out of the water	Setaria jubiflorum Eleocharis acuta Carex tenuicaulis Juncus ingens
Amphibious Fluctuation-tolerators –	Low-growing species: ATl	Species which germinate in damp or flooded conditions, which tolerate variation in water-level, which are low-growing and tolerate complete submersion when water-levels rise.	Centrpedia cunnighamii Persicaria spp
Amphibious Fluctuation-responders	Morphologically plastic species: ARp	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and which have morphological plasticity (e.g. heterophylly) in response to water-level variation.	Myriophyllum spp ?Pseudoraphis spinescens
Amphibious Fluctuation-responders	Species with floating leaves: ARf	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and which have floating leaves when inundated.	?Pseudoraphis spinescens Ludwgia peploides Triglochin procerum Nymphoides crenata
Submerged: S		Species which germinate, grow and reproduce underwater	

Appendix 9 Table 2: Functional classification of Barmah Forest species mentioned in vegetation mapping by Frood and Ward (2000).

Species listed alphabetically	Functional group	Species grouped functionally	Functional group
Acacia acinacea	Tdr	Isolepis fluitans	ARf
Acacia dealbata	Tdr	Ludwigia peploides	ARf
Agrostis avenacea	ATe	Nymphoides crenata	ARf
Amphibromus fluitans	ARp	Amphibromus fluitans	ARp
Amphibromus nervosus	ATe	Myriophyllum crispatum	ARp
Austrodanthonia duttoniana	Tda	Myriophyllum spp.	ARp
Austrodanthonia spp.	Tdr	Pseudoraphis spinescens	ARp
Austrostipa scabra	Tdr	Triglochin procerum	ARp
Bolboschoenus medianus	ATe	Agrostis avenacea	ATe
Callitriche sp	ATl	Amphibromus nervosus	ATe
Carex gaudichaudiana	ATe	Bolboschoenus medianus	ATe
Carex tereticaulis	ATe	Carex gaudichaudiana	ATe
Centipeda cunninghamii	ATl	Carex tereticaulis	ATe
Cynodon dactylon	Tdr	Cyperus exaltatus	ATe
Cynodon var pulchellus	Tdr	Cyperus gymnocaulos	ATe
Cyperus exaltatus	ATe	Eleocharis acuta	ATe
Cyperus gymnocaulos	ATe	Juncus ingens	ATe
Digitaria ammophila	Tdr	Muehlenbeckia florulenta	ATe
Einadia nutans	Tdr	Persicaria spp.	ATe
Eleocharis acuta	ATe	Phragmites australis	ATe
Eleocharis pusilla	ATl	Schoenoplectus validus	ATe
Eragrostis spp.	Tdr	Setaria jubiflorum	ATe
Isolepis fluitans	ARf	Typha domingensis	ATe
Juncus amabilis	Tda	Typha oreintalis	ATe
Juncus holoschoenus	Tda	Callitriche sp	ATl
Juncus ingens	ATe	Centipeda cunninghamii	ATl
Juncus subsecundus	Tdr	Eleocharis pusilla	ATl
Ludwigia peploides	ARf	Austrodanthonia duttoniana	Tda
Microlaena stipoides	Tda	Juncus amabilis	Tda
Muehlenbeckia florulenta	ATe	Juncus holoschoenus	Tda
Myriophyllum crispatum	ARp	Microlaena stipoides	Tda
Myriophyllum spp.	ARp	Poa labillardierei	Tda
Nymphoides crenata	ARf	Rumex tenax	Tda
Paspalum dilatatum	Tdr	Stellaria caespitosa	Tda
Paspalum distichum	Tdr	Acacia acinacea	Tdr
Paspalum vaginatum	Tdr	Acacia dealbata	Tdr
Persicaria spp.	ATe	Austrodanthonia spp.	Tdr
Phalaris aquatica	Tdr	Austrostipa scabra	Tdr
Phalaris aquatica	Tdr	Cynodon dactylon	Tdr
Phragmites australis	ATe	Cynodon var pulchellus	Tdr

Species listed alphabetically	Functional group	Species grouped functionally	Functional group
Poa labillardierei	Tda	Digitaria ammophila	Tdr
Pseudoraphis spinescens	ARp	Einadia nutans	Tdr
Rumex tenax	Tda	Eragrostis spp.	Tdr
Schoenoplectus validus	ATe	Juncus subsecundus	Tdr
Sclerolaena muricata	Tdr	Paspalum dilatatum	Tdr
Setaria jubiflorum	ATe	Paspalum distichum	Tdr
Stellaria caespitosa	Tda	Paspalum vaginatum	Tdr
Triglochin procerum	ARp	Phalaris aquatica	Tdr
Typha domingensis	ATe	Phalaris aquatica	Tdr
Typha oreintalis	ATe	Sclerolaena muricata	Tdr



Appendix Figure 1: Functional classification of Frood's mapping based on a summary of the functional classification of the common species in each unit.

Because of the complexity of this map, the need to further develop the functional classification and the stepped nature of the River Murray Flood Inundation Model (RiM-FIM) this functional community map layer was not intersected with the RiM- FIM. When this is possible it may refine the distribution of functional units based on flooding inundation. This would be a useful approach as it would be applicable to other areas where a difference suite of species could produce a comparable functional classification

Species Distribution

The distribution of Moira Grass and Red Gum provide a simpler spatial pattern than the functional classes to intersect with the RiM-FIM (Figures 9.4-9.6). All records of *Pseudoraphis spinescens* (Moira Grass) were extracted from the description of each mapping unit, and placed in four classes: Pure Moira grass (PMG), dominant (DMG), codominant (CMG) or subdominant (unit dominated by another species) (SMG). Further information on dominance was obtained from Frood and Ward (2000). This classification was then applied to each of the mapping unit and subjectively summarised back into the 4 categories and plotted on a map of Frood's vegetation boundaries. This was then intersected with the Red Gum layer to give the 4 categories of Moira Grass with and without Red Gum. (Figure 9.6).

Chapter 6 commented on the limitations of the modelling that generated Figure 9.2. With these comments in mind, the RiM-FIM (Overton *et al.*, 2006) for Barmah-Millewa was intersected with the Moira Grass and Red Gum extents for Barmah. –It does not solve the fundamental limitations of inferring water requirements from flood extent. It is useful for looking at small scale changes in inundation across the floodplain but is unable to identify large scale changes from the manipulation of the flow control structures (regulators into the Forest were "substantially open" in the Bren *et al.* (1987, p 136) modelling on which the REG C work was based).

The Rim-FIM output was grouped into 10,000 ML/day classes and intersected with the Moira Grass and Red Gum layers from the Frood mapping (Frood and Ward, 2000) to obtain areas of each vegetation type covered by the range of floods levels presented in the RiM-FIM (see Figures 9.4-9.6).

The distribution of Red Gum versus flow in Figure 9.4 shows the wide distribution of Red Gum relative to flow regimes. Red Gum can tolerate large amounts of flooding, as well as exist in higher parts of the floodplain where alternate water sources exist. In areas alongside creeks and wetlands, Red Gum can utilise the creek water. In other areas of the floodplain, Red Gums can use groundwater (Bacon *et al.* 1993). The distribution of Moira Grass versus flow shown in Figure 9.5 identifies its strong correlation with frequent flooding in the 10,000 ML/day and 20,000 ML/day flow ranges.

The next step should be to seek more refined correlations between flow regimes and the extent of other indicative species to enable the definition of WMUs. Limitations would include the gaps where chosen indicator did not occur or where only uncommon species occurred. The transferability would only be possible where the same species occurred.

Ecological Vegetation Classes

A third way of simplifying Frood's mapping was to try and match it to the Ecological Vegetation Classes being developed for Victoria. These reflect environmental attribute such as soil, elevation, hydrological condition and recruitment triggers. Revision of the wetland EVCs has been undertaken by Frood (DSE, 2005) and a revised EVC map of Barmah is proposed to be done by March 2006 (see chapter 5). This will enable Barmah vegetation to be viewed in a regional context. This presumably would result in a resolution more suitable for the definition of WMUs. Therefore it is recommended that the potential for defining WMUs through the intersection of the new EVCs with the RiM-FIM is explored when the EVC map becomes available? This method would be transferable all along the Victorian side of the Murray River

10. Conclusions and Recommendations

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10.1 Values

We advocate the framework in Figure 3.1. to classify values as it is useful for categorising the values of Barmah Forest in a way which can be directly linked to the objectives for management. It is also useful when choosing between alternative management strategies, as the options can be compared in terms of the net changes in values. Such comparisons require the systematic identification of the particular values affected, and an explicit means to guard against double-counting or omission of significant values which this framework offers.

Key issues relating to the values of Barmah Forest include:

1. Barmah Forest generates multiple values at several scales. We propose that a social process be used to rank the values and reduce the conflicts between them. Management measures for addressing conflicts among objectives are discussed below.
2. There is a pressing need for research on the use and non-use values which are not reflected in the market, about which we have little understanding or information. These include Indigenous cultural values, biodiversity conservation values and tourism and recreation (which do have some flow-on market values to the local region). The CSIRO Flagship Water for a Healthy Country project 'Water Benefits in the River Murray Region' is estimating some of these values in Barmah Forest and the Coorong.

10.2 Objectives for Environmental Water Use

The current set of ecological objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005) confuse means and ends, and focus on particular vegetation communities or faunal groups to the neglect of others. Some contain mixed purposes in the one objective, and some are subsumed within other objectives in the set. We propose the development of new objectives following the framework in Figure 1, and applying these principles:

- a clear chain of reason linking realisation of vision and values to inputs of water
- Distinction of System Maintenance Objectives (SMOs) and Value Delivery Objectives (VDOs). Each objective should address a single, well defined purpose.
- The relative importance of values which the system should deliver needs to be made explicit. A social process is needed for this
- SMOs are based on the concept of maintaining structure, function and composition of geomorphic, flora and fauna elements within specified limits based on 'Thresholds of Potential Concern'
- Water and other management strategies are specified for each objective in terms of Thresholds of Potential Concern;
- Particular objectives would be applied either at the whole system (Barmah Forest) scale, or the Water Management Unit (WMU) scale, or the same objective may be applied to a sub-set of WMUs.

10.3 Classification of floodplain vegetation communities

In their present form, none of the classifications are appropriate bases for the proposed new Water Management Units. A classification that groups plant species in terms of their water requirements is advocated.

10.4 Floodplain Vegetation Responses to Water Regime, Grazing and Fire

10.4.1 Objectives for Vegetation Management

In considering the vegetation management objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005), we propose that future management plans need to:

- address the importance of spatial heterogeneity in ecological processes within Barmah Forest and the need to maintain it;
- take account of the roles of other factors such as grazing and fire in determining species composition and dominance;
- shift the focus away from a few species and towards the maintenance of ecological communities.

10.4.2 Improving the Vegetation Management and Hydrological Knowledge Base

The Asset Environmental Management Plan authors (DSE and GBCMA 2005) have made very effective use of available information, including expert knowledge. However the knowledge base for managing Barmah Forest is small for such an important asset, out of date, and its accuracy uncertain. Research needs include:

- a detailed hydrological analysis to characterise, natural, historical, current and future flow regimes in the River Murray as it affects inundation of the Barmah floodplain
- linking the above to a new high precision flow-inundation model to then identify areas of change, and the extent of change;
- a set of studies to understand what, if any, is the difference in the effects on ecosystem processes between cooler season and warmer season floods, and whether there are ecological changes resulting or if a suite of species disadvantaged if cooler season floods occur only very infrequently;
- an understanding of the past and current roles of effluent creeks within the Barmah floodplain in maintaining floodplain functions;
- an ecological history of Barmah Forest to help understanding of the causes of vegetation changes, and to assist in site selection for monitoring or research;
- revisitation of the Red Gum encroachment analysis. It used a 15-year time step, finishing in 1985. Now is the time to test the trends predicted by the model 1985-2000;
- analysis of existing descriptions of understorey vegetation (Frood unpublished, MPPL 1990) to describe spatial patterns and identify functional groups (currently being undertaken by CSIRO's Ecological Outcomes project);
- ecological studies of Moira Grass (*Pseudoraphis spinescens*) and Giant Rush (*Juncus ingens*) should be initiated;
- conduct searches for rare and threatened species as opportunity presents to cover specific seasons, conditions, and wet-dry inundation phases;

- conduct research on the spatial and temporal impact of cattle grazing in Barmah Forest, and how this interacts with effects of river regulation in influencing the forest-woodland understorey and in the spread of Giant Rush (*Juncus ingens*);

10.5 Waterbird Responses to Water Regimes

10.5.1 Objectives and Water Regimes

The waterbird management objectives in the Asset Environmental Management Plan (DSE and GBCMA 2005) need modification to emphasise a wider range of species and the provision of maintenance habitat outside the breeding season.

The water regimes specified for birds do not give guidance on where the water should be applied, so it is difficult to assess the need for changes in the control structures, and to relate waterbird management to the proposed new Water Management Units.

The adaptive management approach taken to waterbird management is endorsed by us, but there is a need to conduct it within a better-defined framework that enables priorities to be redetermined as circumstances change, and to change the focus of particular watering events without losing sight of longer term goals.

10.5.2 Improving The Waterbird Management Knowledge Base

Research priorities are to:

- explore trade-offs, at the scale of Barmah Forest and Barmah-Millewa Forest, among species, functional groups, and vegetation communities, between the maintenance of ecological processes and the maintenance of species, and between immediate and longer term objectives;
- evaluate trade-offs between the various Assets of the Murray River;
- review the status and trends of all waterbird species both within the Barmah Millewa Forest and in the Murray basin
- conduct research on non-colonial species listed as 'Threatened' – the Australasian Bittern (*Botaurus poiciloptilus*) is a high priority;
- understand the relative importance to colonially nesting waterbirds of Barmah Forest at local, regional, and broader scales to enable better prioritisation of EWAs;
- study the effects on waterbirds of long-duration and unseasonal flooding on lower-lying areas of Barmah Forest with a view to returning some to a pre-regulation flow regime
- explore the need and potential for providing permanent maintenance and drought refuge habitat for waterbirds within Barmah Forest;
- examine the duration, extent and season of flooding during previous colonial breeding events in Barmah Millewa Forest and relate these to what is known of the breeding event;
- understand the duration of flooding needed for colonial waterbirds to complete their breeding.

10.6 Evaluation of the 1998 and 2000 Environmental Water Allocations

EWAs are best seen as a series of events that in total drive Barmah Forest towards the long-term goals. Each on its own may produce no more than a modest gain towards specific value delivery or system maintenance objectives.

Objectives for the EWA need to be set beforehand, once the timing and volume of the event can be estimated. Objectives should vary between years according to the attributes of the flood, and because it will be necessary to 'rotate' priorities among the competing value delivery and system maintenance objectives. Objectives for the EWA may change during the event too if conditions alter, but throughout this adaptive process it is important the long term goals are not lost.

A more systematic and flexible monitoring system is needed, possibly drawing on volunteer skills, and including capacity to record information other than the standard icons of colonial water birds and Moira grass program. The compiling and documenting of anecdotal information needs to be made more thorough, and the reporting reflect the more systematic monitoring system we advocate. Future waterbird monitoring documentation should include an annotated list of all waterbird species detailing distribution and abundance, habitat preferences, and nesting attempts/results/habitat. This information should be compiled retrospectively for the 2000 EWA.

The potential and actual contribution to the status and trends of rare and endangered biota needs to be evaluated.

10.7 Water management options

10.7.1 Allocating Water Within Barmah Forest

1. Water management should be set within the framework used in this report, described in section 1.
2. In the short term water management will necessarily be based upon the 'natural paradigm' and on correlations between patterns of inundation and the distribution and observed responses of species and ecological communities. However, the limitations of these approaches should be acknowledged, and investments made in experimental manipulations supported by modelling. Meanwhile a better-designed adaptive management program should be pursued.
3. This report advocates a rethinking of ecological objectives. Options for delivering water to and managing it within Barmah Forest will need to be developed to support those new ecological objectives. Meanwhile research should proceed on known problems of getting water to and distributing it within Barmah Forest (4-15 below).
4. *Better modelling and mapping of river flow and floodplain inundation* - despite the limitations of using correlations between flow regimes and plant distribution, there is still much to be learned through this approach if information is collected at high resolution on temporal pattern and specific sequences of timing, depth, duration of inundation, frequency of flooding, rate of change, and duration of dry phase. MIKE FLOOD and RIM-FIM are now available for this.
5. *Improved definition of water management units* – better spatio-temporal modelling of flow-inundation relationships will provide the basis for redefining water management units using MIKE FLOOD and RIM-FIM.

6. *The potential for improving management through changes to control structures* - the effectiveness of the structures, and the potential for removing or adding structures should be evaluated using MIKE FLOOD
7. *Trade-offs* - we also propose that MIKE FLOOD should also be used to explore trade-offs in time and space among the WMUs. We suggested a new approach for evaluating these trade-offs.
8. *The need for groundwater management* – pumping may be necessary to lower the water table in some higher value conservation areas where the species at risk from salt and high water table are considered more valuable than those dependent on access to the water table.
9. *Getting water to areas of higher elevation in the floodplain* - identifying the Red Gum communities that are under stress due to lack of water availability from their high elevation will define one of the water management units. This WMU can then be targeted to achieve flow thresholds required by the Red Gums in this area.
10. *Managing water quality* - it is recommended that the blackwater risk model is used to assess the risk in the Barmah-Millewa forest and ensure that flushing flows occur to remove detritus and stagnant water.
11. *Managing erosion* – it is desirable to increase the variability of low flows in the flow pattern to reduce the risk of erosion and introduce some wetting and drying of in-stream habitats.

10.7.2 Getting water to Barmah-Millewa Forest and Managing Unseasonal Flows

1. *Unseasonal Summer-Autumn Flooding* – new options to remedy this include: lowering the water level at Yarrawonga; increasing the weir level at Yarrawonga but not raising the water level; reducing the flow through Barmah Choke through the irrigation season; sending water to sacrificial areas; building a bypass channel; en-route storages.
2. *Insufficient Winter-Spring Flooding* - the easements needed between Hume Dam and Yarrawonga are already being planned. MIKE FLOOD can be used to explore the usefulness of engineering works in the Yarrawonga to Tocumwal reach, and of using backflows from the Goulburn River to flood Barmah-Millewa Forest.
3. *Managing bank erosion and in-stream habitat by increasing the variability of low flows* - options could include manipulating the weir height at Tocumwal or manipulation of the control structures in Barmah and Millewa forests.
4. *Impact of damming the Ovens River on reduced flows* – the impact on river flow at Tocumwal can be estimated, then MIKE FLOOD or RiM-FIM can model the consequences for inundation of Barmah Forest.

10.8 Water and the Future of Barmah Forest

Current levels of water supply are unlikely to remain unchanged. Regulation of the Ovens River is major potential threat. The negative impact of a reservoir within its catchment would exceed the positive contribution of The Living Murray Initiative. On the other hand, the current EWA may be just a first step towards higher allocations. Whether the availability of water for Barmah-Millewa Forest increases, decreases, remains at the current low level or changes in seasonality will depend upon the political pressures on governments, as well as climatic change. Realisation of beneficial ecological responses, and increased benefits from tourism and recreation would strengthen the case for larger EWAs

References

Abuzar, M. & Ward, K.A. (2003) Flood and vegetation mapping in the Barmah-Millewa Forests during October-December 2002 using remote sensing technology. Report prepared for the Barmah-Millewa Forum. Department of Primary Industries, Tatura.

Ahern, L, Macfarlane S., Boyle C., Lowe K., Handley K., Howe M. & Robinson D (2003) Biodiversity Action Planning Landscape Plans for the Goulburn Broken CMA, Shepparton Irrigation Region - North Zones Department of Sustainability and Environment, Victoria Goulburn Broken Catchment Management Authority.

Anon, 2003. Indigenous Response to the Living Murray Initiative. Report to the Murray Darling Basin Commission. (http://thelivingmurray.mdbc.gov.au/reports).

ARIER (2003) The Vegetation of North-West Victoria. A report to the Wimmera, North Central and Mallee Catchment Management Authorities. Arthur Rylah Institute for Environmental Research, July 2003.

Asaeda, T. and Karunaratne, S. (2000). Dynamic modelling of the growth of *Phragmites australis*: model description. *Aquatic Botany,* **67:** 301-318.

Asaeda, T., Trung, V.K. and Manatunge, J. (2000). Modelling the effects of microphyte growth and decomposition on the nutrient budget in Shallow Lakes. *Aquatic Botany,* **68:** 217-237.

Bacon P.E., Stone, C., Binns, D.L., Leslie D.J., and Edwards, D.W., 1993. Relationships between water availability and *Eucalyptus camaldulensis* growth in a riparian forest. *Journal of Hydrology,* **150:** 541-561.

Barmah-Millewa Forum (1999) Report on Barmah Millewa Flood of October 1998 and The First Use of Barmah-Millewa Forest Allocation.

Barmah-Millewa Forum (2000) The Barmah-Millewa Forest Water Management Strategy. Murray-Darling Basin Commission, Canberra.

Barmah-Millewa Forum (2001) Report on Barmah-Millewa Forest Flood of Spring 2000 and The Second Use of Barmah-Millewa Forest Environmental Water Allocation, Spring/Summer 2000/2001.

Barmah-Millewa Forum (2005) Website accessed December 2005 http://www.mdbc.gov.au/naturalresources/barmah_millewa/

Benson, J.S. (in review a) Classification and assessment of the native vegetation of New South Wales, Australia: Part 1. Introduction, methods, the NSWVCA database, threat categories and threat criteria. Submitted to *Cunninghamia*.

Benson, J.S. (in review b) Classification and assessment of the native vegetation of New South Wales, Australia: Part 2. The plant communities of the NSW Western Plains. Submitted to *Cunninghamia*:

Best, E.P.H., Buzzelli, C.P., Bartell, S. M., Wetzel, R. L., Boyd, W.A., Doyle, R.D. and Campbell, K.R. (2001). Modelling submersed macrophyte growth in relation to underwater light climate: modelling approaches and application potential. *Hydrobiologia,* **444:** 53-70.

Biggs, H.C., and Rogers, K.H., 2003. An Adaptive System to Link Science, Monitoring , and Management in Practice, pages 59-80 in du Toit, J.H., Rogers, K.H., and Biggs, H.C. *The Kruger Experience: Ecology and Management of Savanna Heterogeneity*. Island Press, Washington.

Blanch, S. (1999) Environmental flows: present and future. Presented at the Australian National Committee on Large Dams 1999 Conference on 15-16 November, Jindabyne, NSW.

Blanch, S. J. and Brock, M.A. (1994). Effects of grazing and depth on two wetland plant species. *Australian Journal of Marine & Freshwater Research,* **45:** 1387-94.

BMF (2000) Barmah–Millewa Forest Water Management Strategy. Barmah-Millewa Forum for Murray-Darling Basin Commission, Canberra.

Boulton, A. and Brock, M. (1999). *Australian Freshwater Ecology: processes and management*. Gleneagles Publishing, Glen Osmond, South Australia.

Bren, L. (1988a) Flooding characteristics of a riparian red gum forest. *Australian Forestry*, **51:** 57-62.

Bren, L. (1988b) Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia. *Regulated Rivers Research and Management*, **2:** 65-77.

Bren, L. (1992) Tree invasion of an intermittent wetland in relation to changes in the Flooding Frequency of the River Murray, Australia. *Australian Journal of Ecology*, **17:** 395-408.

Bren, L.J. and Acenolaza, (2002). *Impact of burning on Red Gum regeneration on Moira Grass plains in Barmah Forest*. Draft final Report. January 2001.

Bren, L. and Gibbs, N. (1986) Relationships between flood frequency, vegetation and topography in a river red gum forest. *Australian Forest Research*, **16:** 357-370.

Bren, L. J., O'Neill, I.C. & Gibbs, N.L. (1987) Flooding in the Barmah forest and its relation to flow in the Murray-Edward river system. *Aust. For. Res.,* **17**, 127-144.

Bren, L. J., O'Neill, I.C. & Gibbs, N.L. (1988) Use of map analysis to elucidate flooding in an Australian riparian River Red Gum forest. *Water Resources Research,* **24**(7): 1152-1162.

Briggs, S.V. (1990) Waterbirds. In: N. Mackay & D. Eastburn (eds) *The Murray*, pp. 337-44. Murray-Darling Basin Commission, Canberra.

Bunn, S.E. and Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes and aquatic biodiversity. *Environmental Management,* **30**(4): 492-507.

Casanova M, T. and Brock, M. A. (2000) How do depth, duration and frequency of flooding influence the establishment of wetland communities *Plant Ecology,* **147:** 237–250.

Chesterfield, E.A. (1986) Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Australian Forestry,* **49** (1): 4-15.

Chesterfield, E.A., Loyn, R.H. and MacFarlane, M.A. (1984) Flora and Fauna of Barmah State Forest and their Management. Melbourne Forests Commission of Victoria 1-115.

Chong, J. (2003). Analysis and Management of Unseasonal Surplus Flows in the Barmah-Millewa Forest. Cooperative Research Centre for Catchment Hydrology. Technical Report 03/2.

Chong, J. and Larsdon, A.R. (2003) Analysis and Management of Unseasonal Flooding in the Barmah-Millewa Forest, Australia. *River Research and Applications,* **19:** 161-180.

Clary, W.P. (1995). Vegetation and soil responses to grazing simulation on riparian meadows. *J. Range Management,* **48:** 18-25.

Commonwealth Government of Australia 1997. Wetlands Policy of the Commonwealth Government of Australia. Environment Australia, Canberra. (http://www.deh.gov.au/water/wetlands/publications/pubs/policy.pdf)

Commonwealth of Australia and Natural Resources and Environment (1996) East Gippsland Regional Comprehensive Assessment: National Estate Report' Commonwealth of Australia.

Corbett , L., Hertog, A.L. and Muller, W.J. (1996). An experimental study of the impact of feral swamp buffalo Bubalus bubalis on the breeding habitat and nesting success of Magpie Geese *Anseranus semipalmata* in Kakadu National Park. *Biological Conservation,* **76:** 277-287.

Crome, F.H.J. & Carpenter, S.M. (1988) Plankton community cycling and recovery after drought – dynamics in a basin on a floodplain. *Hydrobiologia,* **164**:193–211.

Crome, F.H.J. (1986) Australian waterfowl do not necessarily breed on a rising water level. *Australian Wildlife Research,* **13**:461-480.

Crome, F.H.J. (1988) To drain or not to drain? – Intermittent swamp drainage and waterbird breeding. *Emu,* **88**:243-248.

Crossle, K. and Brock, M.A. (2002). How do water regime and clipping influence plant establishment from seed banks and subsequent reproduction ? *Aquatic Botany* **74:** 43-56.

Curr, E. M. (2001). *Recollections of squatting in Victoria*. Second edition, facsimile edition. Rich River Printers, Echuca.

DCE (1992) Barmah Management Plan - Barmah State Park & Barmah State Forest. Department of Conservation and Environment, Victoria.

Dexter, B.D. (1970) Regeneration of River Red Gum, *Eucalyptus camaldulensis*, Dehn. School of Forestry, University of Melbourne. 231pp.

Dexter, B.D. (1978) Silviculture of the river red gum forests of the central Murray floodplain. *Proceedings of the Royal Society of Victoria,* **90**: 175-194.

Dexter, B.D. (1979). To flood or not to flood: that is the red gum question. *Forest and Timber,* **15:** 5-8.

Dexter, B.D., Rose, H. and Davies, N. (1986) River Regulation and Associated Forest Management Problems in the River Murray Red Gum Forests. *Australian Forestry Research,* **49**(1):16-27.

DNRE (2001) Our Forests Our Future- Timber Pricing Review. Discussion paper. Department of Natural Resources and Environment, Melbourne. http://www.dse.vic.gov.au/dse/nrenfor.nsf/646e9b4bba1afb2bca256c420053b5ce/f3e8f765206b2009ca256e6c007f9d3c/$FILE/DiscussionPaper.pdf

DNRE (2002). Forest Management Plan for the Mid-Murray Forest Management Area. Department of Natural Resources and Environment, Melbourne. http://www.dse.vic.gov.au/dse/nrenfor.nsf/LinkView/FAF90F17A028EC11CA256BB900177F1AD360ED010525D0564A256DEA00155A28

DNRE Annual Report 200/01 www.dpi.vic.gov.au

Donovan, P. (1997). *A history of the Millewa Group of River Red Gum Forests*. Prepared for State Forests of New South Wales. Donovan & Associates, Blackwood, SA 5051. April 1997.

DSE (2003) Barmah Forest Ramsar Site: Strategic Management Plan. Department of Sustainability and Environment, Melbourne

DSE (2005) Index of wetland Condition; Assessment of wetland vegetation, Department of Sustainability and Environment Victoria.

DSE (2005). Framework for describing the ecological character of Ramsar wetlands: including a description of the ecological character of Barmah Forest Ramsar Site. Department of Sustainability and Environment, Victoria.

DSE & GBCMA (2005) Asset Environmental Management Plan: Barmah Significant Environmental Asset. Department of Sustainability & Environment, Benalla, and Goulburn Broken Catchment Management Authority, Shepparton, 11 May 2005.

Dyer, F. and Roberts, J. (2006). *Monitoring vegetation response to environmental flows in the Wimmera: a strategic approach*. A report to the Wimmera Catchment Management Authority, Horsham. In2fluve, O'Connor, Canberra. January 2006 (submitted).

Environment Australia (2001). Directory of Important Wetlands in Australia. Third Edition. Environment Australia, Canberra. (http://www.deh.gov.au/water/wetlands/database/directory/pubs/directory.pdf).

Executive Steering Committee for Australian Vegetation Information (ESCAVI) (2003) Australian Vegetation Attribute Manual: National Vegetation Information System, Version 6.0. Department of the Environment and Heritage, Canberra.

Eyles, D. (2004). Understanding fire effects in river red gum forest. Unpublished document, provided by GBCMA.

Fahey, C., (1986). Barmah Forest – a History. Department of Conservation, Forests and Lands, Victoria. (http://www.boardofstudies.nsw.edu.au/multimedia/waterlines/LIBRARY/BARMAH.PDF)

Finlayson, C.M., Cowie, I,D. and Bailey, B.J. (1990). Sediment seedbanks in grassland on the Magela Creek floodplain, northern Australia. *Aquatic Botany* **38:** 163-176.

Finlayson, C.M. (1991). Production and major nutrient composition of three grass species on the Magela floodplain, Northern Territory, Australia. *Aquatic Botany* **41:** 263-280.

Finlayson, C.M., Bailey, B.J., Freeland, W.J. and Fleming, M.R. (1988). Wetlands of the Northern Territory. In: A,J.McComb and P.S. Lake (eds.) :"*The conservation of Australian wetlands*". Surrey Beatty & Sons Pty Ltd., Chipping Norton, NSW 2170.

Forests Commission Victoria (1962). Barmah State Forest 1960-61. Assessment Report, 10pp. (Unpublished).

Forests Commission Victoria (1983). Proposed Strategic Plan for the Management of Barmah Forest District.

Frood, D.& Ward, K. (2001) Mapping of the understorey vegetation in Barmah Forest, Victoria. Department of Natural Resources and Environment Tatura 102pp

GBCMA (2003) Goulburn Broken Regional Catchment Strategy. Goulburn Broken Catchment Management Authority, Shepparton, Victoria.

George, A. K. (2004). Eucalypt regeneration on the Lower Murray floodplain, South Australia. Unpub Ph.D. School of Earth and Environmental Sciences, University of Adelaide. September 2004.

Gippel, C.J. and Lucas, R. (2002). *Review of fluvial geomorphology and recent environmental changes*. Specialist Review Attachments. River Murray Action Plan. Yarrawonga to Echuca. Report by Earth Tech Engineering Pty Ltd to Goulburn-Broken Catchment Management Authority, Department of Land and Water Conservation, and Murray-Darling Basin Commission. April 2002.

Goodison, P. (1992). Murray River landscape and recreation study, Echuca Moama Study Area. Department of Conservation and Environment.

Goulburn Broken Catchment Management Authority (2003). *Regional Catchment Strategy*. Goulburn Broken CMA, November 2003.

Grace, J.B. and Wetzel, R.G. (1981) Habitat partitioning and competitive displacement in cattails (*Typha*): experimental field studies. *American Midland Naturalist* **118**(4): 463-474.

Hein, L., van Koppen, K., de Groot, R.S., and van Ierland, E.C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* **57:**209-228.

Heimlich, R.E., Wiebe, K.D., Claasen, R., Gadsby, D., and House, R.M. (1998). *Wetlands and agriculture: private interests and public benefits*. Resource Economics Division, Economic Research Service, US Department of Agriculture, Washington.

Hibbins, G. M. (1991). *Barmah Chronicles*. Lyndoch Publications.

Holzel, N. and Otte, A. (2001). The impact of flooding regime on the soil seed bank of flood-meadows. *Journal of Vegetation Science* **12:** 209-218.

Ife, D. (1998) The Hydrogeology of the Barmah Forest. Investigations Report No. 1988/32, Rural Water Commission of Victoria.

James, C.D., Landsberg, J. and Morton, S.R. (1999). Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environments* **41:** 87-121.

Jansen, A. and Healey, M. (2003). Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. *Biological Conservation* **109:** 207-219.

Jansen, A. and Robertson, A. I. (2005). Grazing ecological condition and biodiversity in riparian river red gum forests in south-eastern Australia. *Proceedings Royal Society Victoria*.

Jansen, A. and Robertson, A. I. (2001). Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* **38:** 63-75.

Jansen, A., Robertson, A., Thompson, L. and Wilson, A. (2005). *Rapid appraisal of riparian condition*. Version 2. River Management Technical Guideline No 4A. Land and Water Australia, Canberra.

Jolly, I.D. (1996) The effects of river management on the hydrology and hydroecology of arid and semi-arid floodplains. In: M.G. Anderson, P.G. Walling and P.D. Bates (eds) “Floodplain processes”. John Wiley and Sons Ltd.

Kenyon, C. and Rutherfurd, I.D. (1999). Preliminary evidence for pollen as an indicator of recent floodplain accumulation rates and vegetation changes; the Barmah-Millewa Forest, SE Australia. *Environmental Management,* **24:** 359-367.

Kingsford, R.T. & Auld, K.M. (2005) Waterbird breeding and environmental flow management in the Macquarie Marshes, arid Australia. *River Res. Appl.,* **21**:187-200.

Kingsford, R.T. & Johnson, W. (1998) Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. *Colonial Waterbirds,* **21**:159-170.

Kingsford, R.T. & Thomas, R.F. (2004) Destruction of wetlands and waterbird populations by dams and irrigation on the Murrumbidgee River in arid Australia. *Environmental Management,* **34**: 383-396.

Kingsford, R.T. (1991) *Australian waterbirds: a field guide*. Kangaroo Press, Kenthurst, New South Wales.

Kingsford, R.T. (1999) Aerial surveys as a measure of river and landscape and floodplain health. *Freshwater Biology,* **41**:425-438.

Kingsford, R.T. (2004) Regional reports. South-eastern Australia. [In: The State of Australia’s Birds 2004: Water, Wetlands and Birds.] *Wingspan,* **14** (4), Supplement: 14.

Kirkpatrick, J. (1994). *A continent transformed: Human impact on the natural vegetation of Australia*. Oxford University Press, Australia.

Law, B., and Anderson, J., 1999. A survey of the southern myotis *Myotis macropus* (*vespertilionidae*) and other bat species in river red gum *Eucalyptus camaldulensis* forests of the Murray River, New South Wales. *Australian Zoologist,* **31:** 166-174.

LCC (1985) Final recommendations for the Murray Valley area. Land Conservation Council, Melbourne.

Leitch, C. (1989) Towards a strategy for managing the flooding of Barmah Forest. Seminar on Barmah Forest organised by the State Working Group on River Murray Wetland and Forest Management, Department of Conservation Forests and Lands, Benalla Region, Victoria.

Lenssen, J., Menting, F. van der Puten, W. and Blom, K. (1999). Control of plant species richness and zonation of functional groups along a freshwater flooding gradient. *Oikos,* **86:** 523-534.

Leslie, D.J. (2001) Effect of river management on colonially-nesting waterbirds in the Barmah-Millewa forest, south-eastern Australia. *Regulated Rivers Research and Management*, **17:** 21-36.

Leslie D.& Harris K (1996) Water Management Plan for the Millewa Forests. State Forests of NSW and Dept of Land and Water Conservation, NSW.

Leslie, L. (1995). *Moira Lake – a case study of the deterioration of a River Murray natural resource.* Unpublished MSc, University of Melbourne.

Loyn, R.H., Lumsden, L.F. & Ward, K.A. (2002) Vertebrate fauna of Barmah Forest, a large forest of River Red Gum *Eucalyptus camaldulensis* on the floodplain of the Murray River. *Victorian Naturalist,* **119**:114-132.

Maher, M. & Carpenter, S.M. (1984) Benthic studies of waterfowl breeding habitat in south-western New South Wales. II. Chironomid populations. *Aust. J. Mar. Freshw. Res.,* **35**: 97-110.

Maher, P. (1993) Breeding success of colonial waterbirds in Moira Lake and Gulpa Creek wetlands. *Proc. South Riverina Field Naturalists Club* **1**:47-57.

Maheswari, B.L., Walker, K.F. and McMahon, T.A. (1995). Effects of river regulation on the flow regime of the River Murray, Australia. *Regulated Rivers: Research and Management,* **10:** 15-38.

Maunsell McIntyre (1999). *Report on Barmah-Millewa Flood of October 1998, and the First Use of Barmah-Millewa Forest Allocation*. August 1999.

Maunsell McIntyre (2001) *Report on Barmah-Millewa Forest Flood of Spring 2000 and the Second Use of Barmah-Millewa Forest Environmental Water Allocation, Spring Summer 2000/2001.* Maunsell McIntyre. July 2001, Sydney.

Maunsell Pty Ltd (1992) Barmah-Millewa Forests Water Management Plan: Final Report. Murray-Darling Basin Commission, Canberra.

McCarthy, B., Nielsen, D., Baldwin, B., Meredith, S., Roberts, J., King, A. and Reid, J. (2006). *Barmah Wetland System Environmental Monitoring Program. Part B: Monitoring program*. Report to the Goulburn-Broken Catchment Management Authority. Murray-Darling Freshwater Research Centre.

McIntyre, S., and Lavorel, S. (2001). Livestock grazing in subtropical pastures: steps in the analysis of attribute response and plant functional types. *Journal of Ecology,* **89:** 209-226.

McIntyre, S., Lavorel, S and Tremont, R.M. (1995). Plant life-history attributes; their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology* **83:** 31-44.

McKinnon, L.J., (1993). A significant record of the endangered trout cod, *Maccullochella macquariensis (Pisces: percichthyidae)* made during fish surveys of the Barmah Forsest, Victoria. *Victorian naturalist,* **110:** 186-190.

MDBC (2005) Living Murray Environmental Watering Plan 2004-2005 Interim Arrangements MDBC Publication No. 08/05 Murray-Darling Basin Commission, Canberra.

MDBC (2005) The Barmah-Millewa Forest Asset Environmental Management Plan 2005/2006. Murray Darling Basin Commission, Canberra.

MDBC (1998). Floodplain Wetlands Management Strategy for the Murray-Darling Basin. Murray Darling Ministerial Council, Canberra.

Middleton, B. (1999). Succession and herbivory in monsoonal wetlands. *Wetlands Ecology and Management,* **6:** 189-202.

Miller, C. and Wells, A. (2003). Cattle grazing and the regeneration of totara (Podocarpus totara var. waihoensis) on river terraces, south Westland, New Zealand. *New Zealand Journal of Ecology,* **27:** 37-44.

MPPL (1990). *Riparian Vegetation of the River Murray*. Prepared for MDBC by Margules and Partners Pty Ltd, P and J Smith, and Department of Conservation Forests and Lands. MDBC Canberra.

MPPL (1999) *Draft Report on Barmah-Millewa Flood of October 1998 and the First Use of Barmah-Millewa Allocation.* Maunsell McIntyre Pty Ltd for Murray-Darling Basin Commission, Canberra.

Nielsen, D.L.& Chick, A.J. (1997) Flood mediated changes in aquatic macrophyte community structure. *Marine and Freshwater Research,* **48:**153-157.

NRE (2002) Forest Management Pan for the Mid-Murray Forest Management Area. Department of Natural Resources and Environment, Victoria.

NRE (2002) Management of Victoria's Ramsar Wetlands Strategic Directions Statement. Department of Natural Resources and Environment, Victoria. www.nre.vic.gov.au

O'Connor, P.G. & Ward, K.A. (2003) Waterbird monitoring in Barmah Forest, 2002-2003. Department of Sustainability & Environment, Tatura, Victoria.

Orthia, L. (2002). Evidence from the scientific literature supporting the environmental component of the Yorta Yorta Management plan for the Barmah-Millewa forest ecosystem. Friends of the Earth, Melbourne, and Barmah-Millewa Collective.

Overton, I.C. (2005) Modelling Floodplain Inundation on a Regulated River: Integrating GIS, Remote Sensing and Hydrological Models. *River Research and Applications*, **21:** 991-1001.

Overton, I.C., McEwan, K., Gabrovsek, C. and Sherrah, J. (2006) The River Murray Flood Inundation Model – RiM-FIM. CSIRO Technical Report. (in preparation).

Parkinson, A. and Mac Nally, R. (2000). *An analysis of historical information on coarse woody debris loads on southern Murray-Darling Basin Floodplains*. Report Number R7007.1, riverine program, NRMS, Murray-Darling Basin Commission. Monash university, Victoria 3800. May 2000.

Ramsar Convention. The Ramsar Strategic Plan 2003 – 2008. . http://www.ramsar.org/key_strat_plan_2003_e.htm

REG C (2003) Regional Evaluation Reference Group assessment of reference point flow scenarios for Zone C of the River Murray System (Yarrawonga Weir to the Wakool junction). Regional Evaluation Group C report as part of the Scientific Reference Panel to the Living Murray Initiative, Murray Darling Basin Commission, Canberra.

Reid, M. A. and Quinn, G. P. (2004). Hydrologic regime and macrophyte assemblages in temporary floodplain wetlands: implications for detecting responses to environmental water allocations. *Wetlands,* **24:** 586-599.

Richardson, A.J & Taylor, I.R. (2003) Are rice fields in southeastern Australia an adequate substitute for natural wetlands as foraging areas for egrets? *Waterbirds,* **26**:353-363.

Roberts J., (2004). Floodplain Forests and Woodlands in the southern Murray-Darling Basin. Prepared for the Australian conservation Foundation. Report JR 03/2004, Canberra ACT.

Roberts, J. & Marston, F. (2000) Water regime of wetland and floodplain plants in the Murray- Darling Basin. A sourcebook of ecological knowledge. *Technical Report 30-00*, CSIRO Land and Water, Canberra.

Roberts, J. (2003) Vegetation and water regime at Purda Billabong. Canberra, ACT 2602.

Roberts, J., Campbell, B., Erdmann, B., Harper, M., Herbert, T., Jolly, I., Meredith, S., Scholz, O., Reid, J. and Jenkins, K. (2003) Ecological habitat condition assessment for Zone E downstream of Lock 11 to upstream side of Lock 3. Unpublished report prepared as part of the Living Murray MFAT project, Murray-Darling Basin Commission, Canberra.

Robertson, A.I., Bacon,P. & Heagney,G. (2001) The responses of floodplain primary production to flood frequency and timing. *Journal of Applied Ecology,* **38:** 126-136.

Roshier, D.A, Robertson, A.I, Kingsford, R.T. & Green, D.G. (2001) Continental-scale interactions with temporary resources may explain the paradox of large populations of desert waterbirds in Australia. *Landscape Ecology,* **16:** 547-556.

Roshier, D.A., Robertson, A.I., Kingsford, R.T. (2002) Responses of waterbirds to flooding in an arid region of Australia and implications for conservation. *Biological Conservation,* **106**: 399-411.

Sappidean, B., 1992. Valuing the recreation benefits of Sale Wetlands using contingent valuation. In M.Lockwood and T.De Lacey. Valuing Natural Areas: Applications and Problems of the Contingent Valuation method. Charles Sturt University, Johnstone Centre of Parks, Recreation and Heritage, Albury.

Scarlett, N.H. and Parsons, R.F. (1993). Rare or threatened plants in Victoria. In: D.B. Foreman and N.G. Walsh (eds) "*Flora of Victoria Volume 1. Introduction*". Inkata Press, Melbourne.

Scott, A. (1997) Relationships between waterbird ecology and river flows in the Murray Darling Basin. CSIRO Land and Water, Tech. Rep. 5/97, Canberra.

Sharley, T. and Huggan, C. (eds). *Chowilla Resource Management Plan.* Final Report. Prepared for the Murray-Darling Basin Commission. March 1995.

Siebentritt, M.A., Ganf, G.G. and Walker, K.F. (2004). Effects of an enhanced flood on riparian plants of the River Murray, South Australia. *River Research and Applications,* **20:** 765-774.

Slavich, P.G., Walker, G.R. & Jolly, I.D. (1999) A flood history weighted index of average root-zone salinity for assessing flood impacts on health of vegetation on a saline floodplain. *Agricultural Water Management,* **39:** 135-151.

Slavich, P.G., Walker, G.R., Jolly, I.D., Hatton, T.J. and Dawes, W.R. (1999). Dynamics of Eucalyptus largiflorens growth and water use in response to modified watertable ad flooding regimes on a saline floodplain. *Agricultural Water Management,* **39:** 245-64.

Silvers, L. (1993). T*he effects of grazing on fuel loads and vegetation in the Barmah Forest, Victoria.* Unpub. Hons, Faculty of Science and Agriculture, Charles Sturt University.

SKM and Roberts (2003). *Assessment of water management options for Lindsay and Walpolla islands*. Sinclair Knight Merz, Armadale, VIC 3143. May 2003.

Smith R.B. (1983) Analysis of growth in red gum forest – Barmah 1983., Barmah Forest Inventory Report No. 46 Forests Commission Victoria, Melbourne.

Smith, R.G.B. & Brock, M.A. (1996) Coexistence of *Juncus articulatus* L. and *Glyceria australis* C.E.Hubb. in a temporary shallow wetland in Australia. *Hydrobiologia,* **340:**147-151.

Stone, A., 1992. Contingent valuation of the Barmah Wetlands, Victoria. Pp 47-70 in Lockwood, M., and de Lacy, T. 1992. *Valuing natural areas: applications and problems of the contingent valuation method*. Proceedings and related papers from a workshop held 20 and 30th June 1992. The Johnstone Centre of Parks and Heritage, Charles Sturt University, Albury.

Thoms, M., Suter, P., Roberts, J., Koehn, J., Jones, G., Hillman, T. and Close, A. (2000) *Report of the River Murray Scientific Panel on Environmental Flows*. Murray Darling Basin Commission, Canberra.

Todd, F.S. (1996) *Natural history of the waterfowl.* Ibis Publishing, Vista, California.

Van Coller, A. L., Rogers, K.H. and Heritage, G. L. (2000). Riparian vegetation-environment relationships: complementarity of gradients versus patch hierarchy approaches. *Journal of Vegetation Science,* **11:** 337-350.

Wahren, C-H., Williams, R.J. and Papst, W.A. (1999). Alpine and subalpine wetland vegetation on the Bogong High Plains, south-eastern Australia. *Australian Journal of Botany,* **47:** 165-188.

Walsh, N.G. and Entwistle, T. J. (eds.) (1994). *Flora of Victoria. Volume 2. Ferns and Allied Plants, Conifers and Monocotyledons*. Inkata Press, Melbourne.

Watson, D. (1992). *Grazing behaviour patterns of cattle*. La Trobe University, Bundoora.

Wilson, A.D. (1990). The effect of grazing on Australian ecosystems. In: D.A. Saunders, A.J.M. Hopkins & R.A.How (eds) "*Australian Ecosystems: 200 years of utilisation, degradation and reconstruction*" Surrey Beatty & Sons, Pty Ltd, Chipping Norton NSW 2170.

Ward, K. (1994) *Flood requirements of the wetland flora in Barmah Forest, Victoria*. Unpublished report Department of Conservation and Environment, Victoria.

Ward K.A. (1991) *Investigation of the flood requirements of the Moira Grass plains in Barmah Forest, Victoria*. Unpublished report Department of Conservation and Environment, Victoria.

Ward, K. A. (1991) *Barmah-Millewa Forests trial watering -Investigation of the Moira Grass plains in Barmah Forest, Victoria*. Report prepared for the Murray-Darling Basin Commission.

Ward, K.A., Leitch, C., Lloyd, L.N., & Atkins, B.A. (1994) Interim water management strategy for Barmah forest, Victoria Integrated Watering Strategy Report No. 12. Floodplain Ecology Group, Department of Conservation & Natural Resources, Shepparton.

Ward, K.A., Leitch, C., Lloyd, L.N., & Atkins, B.A. (1994) Interim water management strategy for Barmah Forest, Victoria. Integrated Watering Strategy Report No. 12. Floodplain Ecology Group, Department of Conservation & Natural Resources, Shepparton.

Ward, J.V., Tockner, K. and Schiemer, F. (1999) Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated rivers: research and management*, **15:** 125-139.

Water Technology (2005). *Barmah-Millewa Forest Hydrodynamic Model*. Report prepared for the Goulburn Broken Catchment Management Authority. Report NoJ129/R01.

Whitten, S.M., and Bennett, J. (2005). *The Private and Social Values of Wetlands*. Edward Elgar, Cheltenham.

Yorta Yorta Clans Group Inc. 2001. Management Plan for Yorta Yorta Cultural Environmetnal Heritage Project – Final Report.