The Environmental Water Needs of the Wimmera Terminal Lakes - Final Report

Wimmera Catchment Management Authority

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ECOLOGICAL ASSOCIATES REPORT BF001-A

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1.1 Introduction

Ecological Associates Pty Ltd was engaged by the Wimmera Catchment Management Authority (Wimmera CMA) to investigate the environmental water needs of the Wimmera terminal lakes.

Ecological Associates undertook this project in partnership with:

- Richard Clark, hydrologist;
- Lance Lloyd of Lloyd Environmental Pty Ltd, stream fauna ecologist and environmental flows specialist;
- Stuart Richardson of Resource and Environmental Management Pty Ltd, groundwater consultants; and
- Dr Mike Stewardson of The University of Melbourne, hydrologist and environmental flows specialist.

1.2 Scope of Work

The overall objective of this project was to determine the environmental water requirements of the terminal lakes of the Wimmera system, and to develop options to meet the environmental needs.

More specifically, this investigation was required to:

- determine the ecological values of the terminal lakes system;
- develop ecological objectives to achieve ecological health;
- determine environmental water requirements;
- develop options to optimally use water to address those requirements; and
- develop with the client and community a shared understanding of the long term future of the terminal lakes system.

1.3 Acknowledgements

This report was prepared with the assistance and advice of the project steering committee comprising:

- Rochelle Carter (Wimmera CMA);
- Paul Bennett (DSE);
- Peter Sandell (Parks Victoria);
- Kym Schramm (Parks Victoria);

- Elyse Riethmuller (Wimmera CMA);
- Clare Mason (Mallee CMA);
- Carol Paech (Friends of Lake Albacutya);
- Michael Gawith (Friends of Lake Hindmarsh); and
- Hugh Christie (Wimmera Mallee Water).

Walter Godoy of DSE also provided valuable advice over the course of the project.

2.1 Background

The Wimmera River

The Wimmera River is situated in north-west Victoria. With a catchment area of 23,500 km^2, it is Victoria's largest endoreic (internally draining) waterway. Several tributaries of the river rise in Mt Buangor State Park and the Pyrenees ranges and flow into the Wimmera upstream of Glenorchy. The river flows northwest to Horsham, and continues north through Dimboola and Jeparit. Downstream of Jeparit the Wimmera River reaches the terminal lakes, which are a series of large ephemeral lakes that extend north to the Wirrengren Plain in Wyperfeld National Park. There are two notable distributaries on the Wimmera River, the Yarriambiack and Dunmunkle Creeks. Annual rainfall in the catchment varies from up to 1,000 mm in the Grampians down to 300 mm in the northern plains.

The Terminal Lakes

The terminal lakes depend on the transmission of large, significant flows from the Grampian Ranges along the Wimmera River. Runoff in the relatively wet Grampians must pass through a dry catchment, with significant losses to evaporation and seepage. Modelling to date suggests that under natural conditions minor flow events failed to reach the lakes, so the lakes depended on large, intermittent flows. The lakes are therefore characterised by contrasting hydrological phases. When dry, the lakes assume many of the characteristics of terrestrial ecosystems, supporting grasslands and terrestrial vertebrate fauna. When flooded, the lakes and their connecting channels become major aquatic ecosystems, retaining water for several years and supporting significant breeding bird and fish populations with extensive aquatic plant communities.

The lakes have a high conservation significance. Lake Hindmarsh is a wetland of national significance. Lake Albacutya is recognised internationally under the Ramsar Convention and as such is a matter of national environmental significance under the Commonwealth Environment Protection and Biodiversity Conservation Act. Under the Ramsar Convention, Australia has an obligation to maintain the ecological character of Lake Albacutya at its time of listing. The Wimmera River between Polkemmet Bridge (upstream of Dimboola) and the Wirrengren Plain has been classified as a Heritage River.

Regulation of the Wimmera River

The Wimmera River is regulated by the Wimmera Mallee Domestic and Stock Supply system (WMDSS) which is operated by Grampians Wimmera Mallee Water (GWMW). The WMDSS captures, detains and distributes water in the Wimmera and Glenelg catchments primarily for use in domestic and stock supply. The GWMW storages have a total capacity of about 770,000 ML. Water is captured in winter and spring and released to consumers in summer and autumn.

Regulation has significantly reduced flooding of the terminal lakes. Prolonged periods of high rainfall, occurring over at least two years, are required to fill spare capacity in the system and efficiently transmit significant flows downstream of Lake Hindmarsh (Bren and Acenolaza 2000). Storages in the WMDSS have the capacity to capture a significant proportion of high flows over a long period, effectively reducing the frequency and magnitude of flow events reaching the terminal lakes.

The Northern Mallee Pipeline Project

The WMDSS comprises 18, 000 km of open, earthen channels and 12 storages. The system is highly inefficient and suffers distribution losses of 80-90% due to evaporation, distance and seepage.

In response to the poor distribution efficiency of the WMDSS, open channels in the Northern Mallee section of the system were recently replaced by pipework. Water savings generated by the Northern-Mallee Pipeline have provided an environmental allocation of 34, 690 ML to the Wimmera and Glenelg catchments. This allocation could assist in achieving environmental benefits in the terminal lakes.

The Wimmera-Mallee Pipeline Project

The Wimmera-Mallee Sustainable Water Management Strategy is an initiative aimed at replacing the remaining open channels with a new pipeline system throughout the region. This could generate water savings of 83 GL per year, which would be available for environmental flows. Together with the Northern Mallee Pipeline project, the total water savings available for the environment, will be nearly 120 GL annually. Some of this allocation could be used to provide for the water requirements of the terminal lakes.

Purpose of this Project

The purpose of this project was to assess the environmental water requirements terminal lakes and make recommendations for water provisions. Objectives for the ecological condition of the terminal lakes have been set and recommendations made for the water regime required to achieve them.

Strategic Basis for the Assessment and Provision of Environmental Water Requirements

The threat of reduced flooding to the conservation values of the terminal lakes has been recognised in the following strategies and management plans:

- Land Conservation Council Mallee Area Review – Final Recommendations 1989 (Recommendation O230, O231) (LCC 1989);
- Heritage Rivers and Natural Catchment Areas Draft Management Plans Volume 1 – Western Victoria (DNRE 1997a);

- Lake Albacutya Ramsar Site Strategic Management Plan (Management Objective 2) (DSE 2003);
- Mallee Parks Management Plan (DCNR 1996);
- Management of Victoria's Ramsar Wetlands – Strategic Directions Statement (Management Objective 2) (DNRE 2002a);
- Wimmera Regional Catchment Strategy (WRCLPB 1997); and
- Wimmera Regional Catchment Strategy (Resource Condition Target R4 – The provision of appropriate flow regimes to sustain waterway health in the streams and wetlands of the Wimmera River Basin by 2020) (Wimmera CMA 2003).

While these strategies refer to the need to maintain and enhance the ecological values of the terminal lakes through the provision of appropriate environmental flows, none specify the desirable ecological outcomes of water provision.

2.2 Adopted Approach for this Assessment

The methodology applied in this project broadly follows the FLOWS methodology to determine environmental water requirements in Victoria (DNRE 2002b).

Based on strategic water management and biodiversity conservation policies and documents, a vision for the ecological condition of the terminal lakes was proposed (Section 3).

The ecology of the system and its relationship to flow was described on the basis of existing ecological information and a site inspection (Section 4). The study area was classified into a series of reaches, based on common hydrological characteristics, such as channel morphology and hydrological behaviour, and common ecological relationships to flow.

In each reach, the relationship between flow and ecology was examined in detail using existing ecological data and hydrological modelling outputs generated by Wimmera REALM (see below). The difference in the duration and frequency of flooding between pre-regulation and current catchment management scenarios were assessed, and the implications for ecological values interpreted (Section 5).

The threats that hydrological change poses to ecological values were summarised (Section 6). Objectives were set for the desired ecological condition and for the hydrological regime to achieve them (Section 7).

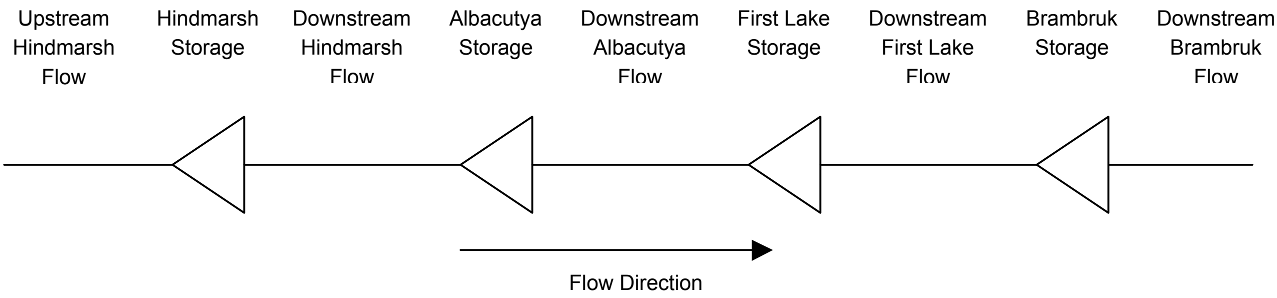
The capacity of water savings generated by the Northern-Mallee Pipeline to meet the hydrological objectives was assessed. The benefit of three scenarios was investigated; the allocation of an additional 60, 80 or 100 GL.

2.3 Wimmera REALM

Model Arrangement

REALM (Resource Allocation Model) is a water system simulation package developed by the Victorian Department of Sustainability and Environment. REALM is used to simulate the storage, flow, loss and distribution of water in water supply networks such as the WMDSS.

An existing model of the WMDSS was recently extended to include the terminal lakes as far as Lake Brambruk (DSE 2004). The revised model, Wimmera REALM, represents the terminal lakes as a series of storages and reaches which must fill before water spills downstream to the next reach, as presented below.



Wimmera REALM represents the following components of the terminal lakes:

- Upstream Hindmarsh Flow – Wimmera River from Horsham to Lake Hindmarsh;
- Hindmarsh Storage – Lake Hindmarsh;
- Downstream Hindmarsh Flow – Outlet Creek from Lake Hindmarsh to Lake Albacutya;
- Albacutya Storage – Lake Albacutya;
- Downstream Albacutya Flow – Outlet Creek and various wetlands between Lake Albacutya to First Lake;
- First Lake Storage – a nominal storage to represent the hydrology of various wetlands between Lake Albacutya and Lake Brambruk;
- Downstream First Lake Flow – Outlet Creek and various wetlands between the nominal First Lake storage and Lake Brambruk;
- Brambruk Storage – Lake Brambruk; and
- Downstream Brambruk Flow – Outlet Creek downstream of Lake Brambruk.

The system downstream of Lake Brambruk, including Lake Agnes and Wirrengren Plain, is not included in the model due to the unavailability of data for use in calibration. Lake Wirrengren has not flooded since 1874 and Lake Agnes has not been flooded since 1918 (Durham 2001).

The following runs were analysed:

- a natural run, to represent flows in the catchment in the absence of any storage or diversions;
- a current run, to represent current operating conditions for storage and diversion; and
- enhanced flow runs, to represent the effect of hypothetical releases of 60, 80 or 100 GL for environmental purposes.

The data consisted of monthly volumes and flows for each model element for a period of 97.5 years from January 1903 to June 2000. The period of simulation corresponds to the period for which rainfall and evaporation data are available as inputs to the model and flow data are available for calibrating the modelled flows at upstream locations. The current and enhanced runs incorporate the changes associated with the Northern-Mallee Pipeline.

In all runs it is assumed that the lake storages are empty and there is no flow in the reaches at the start of the simulation run.

Analysis of Output

Spell analyses were used to characterise the hydrology of the terminal lakes and to compare different model runs. For each reach, a series of storage levels or flow thresholds were identified that represented a significant change in ecological communities or geomorphology. The spell analyses reported the number of events where storage or flow levels exceeded these thresholds, the average duration of these events and the duration of the longest event. The spell analysis also reported these parameters for events below the thresholds.

Previous Assessments of the Hydrology of the Terminal Lakes

The estimates in this report of the frequency and duration of flooding in the terminal lakes vary from previous estimates.

Previous analyses of the hydrology of the lakes have been based on:

- a RORB model (Binnie and Partners 1991);
- a REALM model (Hydrotechnology 1993); and
- correlations between rainfall and historic flooding events (Bren and Acenolaza 2000).

All of these analyses have described the hydrology of the lakes differently. Estimates of the frequency of full events at Lake Albacutya (the point at which flow to the Wyperfeld National Park commences) from previous analyses and this report are presented in Table 1. Similar differences are reported in these sources for Lake Hindmarsh.

Table 1. Comparison of Estimates of Lake Albacutya Full Events

Author	Natural	Current
Binnie and Partners (1991)	1:17 years	1:23 years
Hydrotechnology (1993)	1:8 years	1:20 years
Bren and Acenolaza (2000)	1:20 years	1:100 years
DSE (2004)	1:4 years	1:49 years

These differences are due to assumptions made in the models and improvements incorporated into each successive model.

Wimmera REALM is considered the best available representation of the hydrology of the terminal lakes and is considered satisfactory for the purposes of this study. However, shortcomings remain in Wimmera REALM (as described below) and it is likely the estimates presented in this report will be again superseded by future, improved models. The limitations of Wimmera REALM are discussed in Appendix A.

Vision Statement

3.1 Vision

The vision for the terminal lakes is:

"The terminal lakes of the Wimmera River will respond to flooding by supporting wetland biodiversity values national and international significance and will provide valuable environments in their dry phases."

This statement:

- acknowledges that the wet and dry states of the system both have important ecological roles;
- recognises that when they are filled, the lakes have exceptional diversity and conservation value;
- recognises that the desired wetland environment depends on how the lakes respond to flooding; and
- requires that the lakes successfully transform into high value wetland environments when flooded.

4.1 Reaches of the Study Area

The study area comprises the Wimmera River from Lake Hindmarsh to the Wirrengren Plain (Figure 1). The study area has been divided into 5 reaches with distinct hydrological and ecological characteristics.

Lake Hindmarsh

Lake Hindmarsh is a large lake with a flat bed. The lake perimeter is narrow and relatively steep and supports woody vegetation (Plate 1). The lake bed is subject to saline groundwater discharge and features extensive areas with little or no vegetation when dry (Plate 2). The lake is the first to be filled, is filled more frequently and is filled for longer periods than reaches further downstream.

Outlet Creek from Lake Hindmarsh to Lake Albacutya

The term Outlet Creek is applied to the principal watercourse downstream of Lake Hindmarsh, and refers all creek sections between the downstream lakes.

The second reach of this study is the section of Outlet Creek between Lake Hindmarsh and Lake Albacutya (Plate 3). The creek has a well defined channel with a largely unobstructed bed approximately 20 m wide and largely continuous banks 2 to 3 m high. The creek has a narrow floodplain which includes billabongs and flood runners. This reach includes Ross Lakes (Figure 1), which is a substantial wetland area on the floodplain of Outlet Creek upstream of Lake Albacutya. Ross Lakes is flooded by overbank flows from Outlet Creek.

Lake Albacutya

Lake Albacutya is a large lake with a flat bed and narrow steep fringe. The lake is colonised by grasses and shrubs when dry and supports Red Gum and Black Box woodlands at the fringing flood level (Plate 4). The flood level is controlled by the sill at which water discharges to the next section of Outlet Creek downstream. The level of the sill above the lake bed is not described in the data reviewed in this project; a value of 5.2 m is used in Wimmera REALM.

Southern Wyperfeld

Downstream of Lake Albacutya, Outlet Creek enters the Wyperfeld National Park and passes through a mosaic of interconnected wetlands, some of which are located on the main stem of the creek and some at the end of branching channels. The Southern Wyperfeld reach comprises the creeks and wetlands flooded by Outlet Creek from Lake Albacutya to Lake Brambruk (Plate 5).

Northern Wyperfeld

Flow is mainly constrained within the Outlet Creek channel downstream of Lake Brambruk but does enter other wetland basins. This reach is characterised by two very large wetland basins, Lake Agnes (Plate 6) and the Wirrengren Plain (Plate 7), which represents the terminus of the system (Figure 1). The system downstream of Lake Brambruk is classified as Northern Wyperfeld.

4.2 Ecological Characterisation

All reaches of the system share similar ecological characteristics. The following section describes the general features of the terminal lakes from Lake Hindmarsh to the Wirrengren Plain, with the features of specific sites presented in Section 5. The lakes generally have a central lake bed which has a flat-lying surface and is the lowest point of the lake. The lake bed rises by approximately 1 m at the outer edge of the lake to form a distinct ecological zone with different habitat values. The lakes are fringed by Red Gum woodlands, which occur near the elevation at which water spills to lakes downstream. The upper limit of flooding is vegetated with Black Box woodlands, which are flooded when lakes are temporarily surcharged by high flows.

While the channel bed and fringing Red Gum and Black Box communities of Outlet Creek follow a narrow channel, they have comparable ecological characteristics to the communities of the lakes.

The various reaches of Outlet Creek feature a channel bed similar to the lake beds and fringing Red Gum and Black Box communities similar to the lake fringes.

The conservation importance of the lakes and connecting channels may be summarised by two key characteristics:

- the extensive size and overall preservation of the system, which supports very large populations of diverse wetland flora and fauna; and
- the ecological interactions between the wetland and surrounding Mallee environments, which provides a critical set of habitat components for many rare and threatened species.

All reaches spend extended periods dry, are infrequently flooded, and develop mature ecological communities in both states.

Central Lake Bed

When dry, the clay soils in the centre of all lakes are colonised by terrestrial grasses and herbs. Common native species include Wallaby Grass, Spear Grass and *Maireana* sp. The central lake bed is invaded by exotic plants in many areas, particularly by Paterson's Curse, Horehound and False Sow-thistle (Durham 2001). The bed of Lake Hindmarsh, which is more saline than the other lakes, has a lower density of vegetation.

The lake bed vegetation dies when the lakes flood, but provide important nutrients that support primary productivity in the flooded lakes and promote the abundance and diversity of the invertebrate fauna on which birds and fish depend. Flooded lake bed vegetation also provides important structural habitat for aquatic invertebrates and small fish. Lake water has been reported to be clear at Lake Albacutya (Carol Paech pers. comm. Friends of Lake Albacutya 12-7-04).

The lake beds are an important local source of aquatic invertebrates. Even in lakes that are rarely flooded, the endemic invertebrate communities that emerge from resting stages significantly influence the structure and diversity of aquatic invertebrate communities (Jenkins and Boulton 1998; Jenkins and Boulton 2003).

The centre of the flooded lakes provides deep, open water habitat and provides habitat for large fish including Murray Cod, Freshwater Catfish and Golden Perch (DNRE 2000). This area provides habitat for species such as Australian Pelican, Pied Cormorants and Black Swans (Parks Victoria 2001).

The shallow muddy environment created by rising and receding lake levels provides important habitat for wading birds such as spoonbills, terns, avocets, Masked Lapwing, Whiskered Tern and many migratory species (DSE 2003). Waterbird species will generally leave the system when the wetland dries and the majority of aquatic fauna, including fish, will be stranded and die.

The salinity of lake waters increases as wetlands dry out. Morton and Heislers' (1978) report salinities increasing from 1,000 to 2,000 mg/L over a five month period in 1977 as lakes dried out. Much higher salinities are reported for Lake Hindmarsh as it dries out (SKM 2003).

Outer Lake Bed

The shallower and sandier soils at the fringes of the lake are colonised by shrubs (e.g. Three-nerved Wattle and Stick Hop-bush), Lignum, chenopods (e.g. *Atriplex suberecta*), sedges (e.g. Knobby Club-rush), grasses (e.g. Wallaby Grass and Spear Grass). These plants also die when flooded, but again provide important temporary structural habitat for aquatic fauna and contribute to the nutrient status of the lake.

When flooded, the vegetation zone will eventually be succeeded by submerged and emergent aquatic vegetation (e.g. Eel Grass, Water-milfoil and Pondweed) which provide habitat for small fish such as Flathead Gudgeon and Australian Smelt and waterbirds such as Australian Shelduck, Darter, Coot, Crake and Pacific Black Duck. Following complete drying events, fish populations will be entirely re-established by migration or movement from upstream.

The eradication of terrestrial vegetation during flooding is important for the drying phase of the lakes. Flooding re-sets the ecological succession of plant communities on the lake bed and provides habitat for plants that recolonise the lake bed such as Australian Hollyhock, Native Orache and Three-nerved Wattle (Durham 2001).

Fringing Woodlands

The fringing Red Gum and Black Box woodlands provide important and complex habitats during the flooded and dry phases of the lake.

When dry, the understorey comprises terrestrial woodland species such as Sticky Hop-bush, Three-nerved Wattle, Ruby Saltbush, Berry Saltbush, Nodding Saltbush and Short-leaf Bluebush (Morton and Heislers 1978). The understorey accumulates woody debris from fallen branches and organic matter from leaves, bark and twigs.

The flooded understorey vegetation contributes nutrients and structural habitat to the lake ecosystems, which is important for invertebrate diversity and abundance, for small fish and for waterbirds.

The terrestrial Red Gum understorey species die during periodic high lake levels and are replaced by wetland species such as Red water-milfoil, Southern Liquorice, Common Reed and Australian Salt-grass (Morton and Heislers 1978).

Lignum persists in the understorey of Red Gum and Black Box during the flooded and dry phases of the lake. Lignum and other emergent shrubby species provide nesting sites for colonial nesting waterbirds such as Nankeen Night-heron, egret and ibis. Flooded Red Gum and Black Box is also important to the breeding of these species by providing roosting sites. Many other waterbirds depend on the hollows in fringing Red Gum to breed including Cormorants, Coot, Black Duck and Wood Duck.

Flooding is important to the survival and recruitment of Red Gum, Lignum and Black Box, but particularly Red Gum. Flood waters increase soil moisture and reduce salt concentrations in the root zone. Red Gum will grow more quickly while flooded and will be better able to tolerate subsequent dry periods. Red Gum and Black Box seedlings densely colonise the fringes of lakes as the water level recedes and are eventually recruited to the adult population to replace older, dying trees (Morton and Heislers 1978).

Linkages to the Mallee Landscape

The Red Gum fringing the lakes, provide important habitat for Mallee fauna that depend on tree hollows. A number of bird species feed in the Mallee and depend on Red Gum tree hollows to nest including Regent Parrot, Sulphur Crested Cockatoo, Mallee Ringneck and Major Mitchell's Cockatoo. Barking Owl requires large trees, hollows and small mammalian prey. Magpie-lark and White-winged Chough build mud nests in the hollows. Common Brushtail Possum and Chocolate Wattled Bat also benefit from Red Gum tree hollows (Allen 1995, Durham 2001).

River Red Gum trunks also provide habitat for Marbled Gecko and Carnaby's Skink (Allen 1995), which are species normally associated with Mallee habitats. Dead trees provide perching and nesting sites for raptors, such as the White-bellied Sea-eagle.

The dry lake beds are grazed by Western Grey Kangaroo and Emu and, occasionally in the Wyperfeld National Park, by Red Kangaroo. The combination of shrubby, grassy and woodland vegetation adjacent to large Mallee reserves supports Bustard, Gilbert's Whistler and Bush Thick-knee.

Morton and Heislers (1978) report that many land birds made use of flood waters in the Southern Wyperfeld Reach. Emus, cockatoos and parrots often drank at flooded lakes. Sacred Kingfishers and Swamp Harriers were occasionally observed. Increased insect life attracted insectivorous birds including Rainbow Bee-eater, Welcome Swallow, Australian Tree Martin and Willie Wagtail.

5.1 Lake Hindmarsh

Reach Description

Lake Hindmarsh is the first lake in the terminal lakes system. The lake is fed principally from the Wimmera River which enters at Jeparit (Figure 2), although the lake has a small local catchment and also collects rainfall. The lake bed is flat lying and covers an area of 13,500 ha. When full, the lake is fresh and reaches a depth of 3.4 m and stores 378 GL. Salinities are higher at lower lake levels due to the increased effects of evaporative concentration and groundwater inflow.

Inflowing water initially accumulates near the shore in the south-eastern part of the lake and gradually spreads across the remainder of the lake bed. Water flows out via Outlet Creek, an ephemeral channel located at the northern end of the lake. The lake has a relatively steep and narrow littoral zone and floodplain. The extent of the lake is limited by outcropping Parilla Sands to the west and a lunette system to the east.

The lake receives groundwater discharge from the Woorinen Formation water table aquifer. The water table lies within 2 m of the surface and has reported salinities of more than 40,000 EC to the east and south east of the lake (Lewis 1995, Appendix B). As the lake dries it becomes progressively more saline, with concentrations of up to 7,906 EC reported (SKM 2003). Soil samples collected in 2003 from Four Mile Beach (at the southern end of the lake) report very high salinities of up to 52,000 EC (EC 1:5) at the surface (pers. comm. Rochelle Carter, Wimmera CMA 2 June 2004). As a result of the high salinities, vegetation in the deepest parts of the lake bed in the south-eastern area is limited to very sparse halophytes, particularly *Halosarcia* sp.

The lake bed comprises a 6 m deep layer of Quaternary sands which are underlain by clay. The clay layer may play an important role in the formation of a fresh groundwater lens following flooding events (Appendix B). The water table aquifer appears to be recharged by flooding in the lake, such that wells which report salinities as high as 30,000 mg/L between floods reported salinities of 2,500 mg/L during flooding in 1992/1993 (Appendix B).

There is little data to describe lake surface water salinity. However, it can be expected invertebrate community composition will change in response to lake level and salinity.

Environmental Values and Assets

Lake Hindmarsh is the largest and most frequently flooded lake in the system. It is the largest freshwater lake in Victoria. It has a very high carrying capacity for waterbirds, many of which breed at the site. A number of native fish are reported from the lake, including Flat-headed Gudgeon, Golden Perch, Murray Cod and Freshwater Catfish (DNRE 2000). These last four species have been translocated or stocked into the Wimmera catchment, but have conservation significance at a Victorian or national level. With the exception of Freshwater Catfish, they are native to the catchment.

In addition to the wetland environment described above, Lake Hindmarsh supports Slender Cypress-pine woodland on the lunette on the eastern side. Lignum shrublands and Salt Paperbark shrublands occur in saline depressions behind the dunes and lunettes of the southern part of the lake.

Lake Hindmarsh is more saline than the other reaches. High salinities limit the extent and density of emergent reedy vegetation, and contribute to more extensive mudflat and open water habitat. The lake bed supports less vegetation than the other lakes when dry and will provide limited habitat for terrestrial fauna when dry.

The linkages to terrestrial habitat are relatively weak at Lake Hindmarsh, where most of the Mallee landscape surrounding the lake has been cleared. The Birdcage Flora and Fauna Reserve adjoins the lake to the north-east and shares plant and animal species with the lake.

These habitat components contribute to the following recognised environmental values at Lake Hindmarsh:

- it is part of the Wimmera Heritage River (DNRE 1997a);
- it is a Wetland of National Importance (Environment Australia 2001) and satisfies the following criteria
  - it is a good example of a wetland type occurring within a biogeographic region in Australia;
  - it is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex;
  - it is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail;
  - the wetland is of outstanding historical or cultural significance.
- it is the largest freshwater lake in Victoria;
- it contributes to the habitat corridor between Wyperfeld National Park and the Little Desert National Park to the south;
- bush birds of conservation significance including the Bush Thicknee, Mallee Ringneck, Bush Stone-curlew and Gilbert's whistler which use the northern end of the lake (DNRE 1997a);
- habitat for migratory waterbirds protected under JAMBA (Japan Australian Migratory Bird Agreement) and CAMBA (China Australia Migratory Bird Agreement) treaties;
- habitat for plants of conservation significance;
- a high waterbird diversity, with over 50 waterbirds reported (LCC 1989);
- a high carrying capacity for waterbirds, with seven waterbird species reported to visit in significant abundances;

- an important waterbird breeding site, with nine waterbird species reported to breed in significant numbers;
- one of the few breeding habitats in Victoria for the Australian Pelican and Pied Cormorant; and
- communities of Salt Paperbark which were recommended to be zoned for nature conservation by the LCC (1989).

Hydrology

A spell analysis is used to characterise differences between water regimes under the natural and current scenarios. The spell analysis reports on events where the water level is above or below a representative threshold. The analysis may be visualised on Figure 3 which shows thresholds and the natural and current scenario hydrographs for Lake Hindmarsh. The number of events, their average duration and the duration of the longest event above or below the thresholds are reported in Table 2.

Under the natural scenario, the lake always contained water, except for the first five months of the model run (see Appendix A for a discussion of starting conditions and assumptions in Wimmera REALM).

Table 2. Spell Analysis for Lake Hindmarsh. 'Empty' represents a nominal storage of 10 GL. 'Shallow' represents flooding to approximately 0.92 m depth (80 GL), 'Full' represents the point at which water spills to Outlet Creek (378 GL) and 'Full +2m' represents (630 GL), the level required to create a substantial flow in Outlet Creek of 57 GL/month.

Scenario	Threshold	Lake level below threshold			Lake level above threshold		
		No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)	No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)
Natural	Empty	(always above threshold)			(always above threshold)		
	Shallow						
	Full	36	9.2	55	35	24	92
	Full + 2m	26	42.4	226	25	2.7	6
Current	Empty	14	9	19	14	74.6	329
	Shallow	10	34.8	94	9	91.3	306
	Full	22	43.6	366	21	10	32
	Full + 2m	4	290.3	642	3	3	4

Under natural conditions, the lake level exceeded the Outlet Creek threshold 35 times over the modelled period with an average duration of each event of 24 months. Vegetation at the perimeter of the lake would be watered by lake levels fluctuating at this level. A very high outflow was achieved 25 times, with events lasting on average 2.7 months.

In contrast, under current conditions the lake exceeded the Outlet Creek threshold 21 times, with each event 10 months on average. Importantly, the very high flows required to deliver large quantities of water down the system occurred only 3 times (compared to 25 times), although the duration of these events was similar to pre-regulation conditions. The lake failed to reach the full level for 22 years following 1928. A decline in the health of the fringing Red Gum community would be expected over this period, although no relevant ecological records for this period have been reviewed.

In summary, under current conditions lake levels rarely reach the level required to deliver substantial flows down the system and the lake level is shallow for a much greater duration. Under natural conditions the lake level fluctuated at the Red Gum level more frequently than under current conditions.

While average spell durations are reported in Table 2, it is important to recognise that spells occur with a range of durations and with a range of frequencies, and that these different events achieve different ecological outcomes. Figure 4. shows the recurrence intervals of the duration of full lake events (378 GL) generated in the natural and current scenarios.

In the natural scenario, full lake events lasting 6 months occur approximately every 3 to 4 years, but occur every 9 years in the current scenario. Events lasting 2 years occur approximately every 7 years in the natural scenario, but in the current scenario the recurrence interval has increased to 30 years.

5.2 Outlet Creek from Lake Hindmarsh to Lake Albacutya

Reach Description

Water overflowing from Lake Hindmarsh flows north to Lake Albacutya via the first section of Outlet Creek (Figure 5). The shore of Lake Hindmarsh forms a significant sill approximately 2 m above the bed level of the creek. The sill appears to form as a result of natural sediment movement in the lake (M. Cooling personal observation). The sill was deliberately lowered in 1976 in order to lower the lake level and prevent flooding at Jeparit (Carol Paech pers. comm. Friends of Lake Albacutya 26-5-04).

Downstream of the sill, the creek has a well defined channel with fairly consistent dimensions of approximately 20 m wide and 2 to 3 m deep. Before reaching Lake Albacutya, channel depth and width increases to 5 m deep and 30 m wide.

Flows that exceed the capacity of the channel are conveyed by a floodplain which extends approximately 250 m either side of the channel. The floodplain features billabongs and meander cut-offs. The floodplain widens significantly to 1-2 km at Ross Lakes, which are two significant wetland basins located just upstream of Lake Albacutya.

Beyond the floodplain the landscape rises to the undulating sands of the surrounding Woorinen Plain.

Ross Lakes initially receive water via a narrow channel 1 m above the bed level of Outlet Creek. The lakes receive overbank flows at Outlet Creek levels above 2 m. The lakes capture and store water, acting as large billabongs.

Environmental Values and Assets

Outlet Creek shares many features in common with the lake environments, although the only substantial flooded area occurs in Ross Lakes. Wetland habitat along most of the reach is limited to the channel and billabongs and backwaters on the floodplain.

The creek corridor is vegetated principally by Black Box, although there is a significant Red Gum Woodland at Ross Lakes and Red Gum also lines the creek channel and some floodplain depressions. This reach is less likely to provide habitat for waterbirds that require open water (such as Australian Pelican), but may provide important habitat for colonial nesting birds and other species that require a close interaction between woodland and wetland environments.

The key environmental values and assets of this reach are:

- it is part of the Wimmera Heritage River (DNRE 1997a);
- Ross Lakes were considered of such ecological value that their inclusion in the Lake Albacutya Park was recommended by the LCC (1989);
- it provides a corridor of intact native vegetation for migration of aquatic and terrestrial fauna along the Wimmera River;
- it provides habitat for terrestrial fauna via Lake Hindmarsh and the Birdcage Flora and Fauna Reserve; and
- it provides extensive wetland and floodplain habitat.

Hydrology

The hydrographs for the natural and current scenarios in Outlet Creek are shown in Figure 6. Two flow thresholds are assessed using channel dimensions of 2 m wide by 3 m deep and a flow rate of 0.5 m/s. Ten GL/month corresponds to low flows in Outlet Creek that are likely to persist through to Lake Albacutya but will remain within the channel banks. The higher threshold of 57 GL/month represents flows at or near the bank-full level of the channel, above which the floodplain will be inundated.

It should be noted that the 'low flow' threshold in Outlet Creek does not correspond directly with the 'full' threshold in Lake Hindmarsh. It is slightly higher and is therefore achieved with different event frequencies and durations and a lower overall duration (frequency x duration).

Table 3 shows that under natural conditions Outlet Creek flowed on 33 occasions, with each event lasting 24.5 months on average. It was dry on 34 occasions, each lasting 10.7 months on average.

Under current conditions the creek flowed on 18 occasions, but each event lasted 10.4 months on average. It was dry on 19 occasions, each lasting 51.7 months.

The longest period of no flow increased from 56 months under natural conditions (4.6 years) to 368 months under current conditions (30.6 years).

Table 3. Spell Analysis for Outlet Creek from L. Hindmarsh to L. Albacutya. 'Low flow' represents 10 GL/month and 'High flow' represents 57 GL/month.

Scenario	Threshold	Creek level below threshold			Creek level above threshold		
		No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)	No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)
Natural	No flow	34	10.7	56	33	24.5	91
	Low flow	51	18.9	93	50	4.1	10
	High flow	24	46.5	226	23	2.4	5
Current	No flow	19	51.7	368	18	10.4	31
	Low flow	10	114.5	392	9	2.8	5
	High flow	4	290.3	643	3	3	4

Under natural conditions Outlet Creek conveyed water from Lake Hindmarsh to Lake Albacutya 50 times, with each event lasting 4.1 months on average. Very high flows, which would inundate the floodplain and fill Ross Lakes, occurred 23 times and lasted 2.4 months on average.

Under current conditions Outlet Creek conveyed water to Lake Albacutya only 9 times and in shorter events (only 2.8 months duration) than under natural conditions. High flows occurred only 3 times and lasted 3 months on average.

The recurrence intervals of low flow events in Outlet Creek are shown in Figure 7. In the natural scenario, flow events of 3 months occur approximately every 2 to 3 years, but in the current scenario the recurrence interval for these events is approximately 20 years.

Recurrence intervals for high flow events are shown in Figure 8. In the natural scenario, high flow events lasting 2 months occur approximately every 6 to 8 years, but this increases to a recurrence interval of approximately every 30 years in the current scenario.

5.3 Lake Albacutya

Reach Description

Lake Albacutya is a large ephemeral freshwater lake which, when full, covers an area of 5,500 ha (Bren and Acenolaza 2000), has a depth of 8 m (DSE 2003) and stores 230 GL (this is the threshold used in Wimmera REALM). The lake is illustrated in Figure 9. Water enters the lake at the southern end, at Albacutya township, initially filling the south-eastern section of the basin. As the lake fills, water spreads across the remainder of the lake bed. The normal full supply level of the lake is controlled by the sill level and capacity of the next section of Outlet Creek, into which water flows from the lake's northern end.

The bed of the lake is flat and comprises sediments of the Coonambidgal Formation. The banks of the lake rise at the perimeter. Within approximately 1 km of the lake perimeter, the lake bed rises by 1 to 2 m. This zone is colonised by shrublands during dry phases. The lake bed then rises by a further 2 m at the outer perimeter over a distance of approximately 250 m, where Red Gum and Black Box woodlands are located. This relatively steep zone merges with the deep sandy soils of the Lowan Sands to the west and the sandy clays of a lunette system to the east.

The lake is a groundwater recharge zone, with the potentiometric surface of the water table aquifer approximately 14.8 m below the surface (reported in 2002) with a salinity of 13,650 mg/L (reported in 2000; see Appendix B). The water table has fallen since 1996 due to low rainfall recharge.

Unlike Lake Hindmarsh, stratigraphic data describing the lake bed has not been reviewed. However, it is expected that Lake Albacutya would have a similar structure, with the potential for a perched aquifer to form in lake bed sediments as a result of recharge during flood events (Appendix B).

When the lake is full, groundwater wells in the Lowan Sands to the west of the lake are reported to rise (meeting with the Friends of Lake Albacutya pers. comm. 26-5-04). This process would be consistent with the formation of a local perched aquifer during floods.

Environmental Values and Assets

Lake Albacutya is less affected by salinity than Lake Hindmarsh and supports dryland vegetation throughout the lake bed during the dry phase. The fringing shrubland vegetation is dense and diverse and extends from the Red Gum fringe for a distance of approximately 500 m.

The lake has an intimate connection with the neighbouring Mallee vegetation of the Wyperfeld National Park which is continuous with the northern and western boundaries. Red Gums at the edge of the lake provide nesting habitat for species which feed in the Mallee including Regent Parrot, Major Mitchell's Cockatoo and Sulphur-crested Cockatoo. Other species dependent on the Mallee that occur at the lake include Western Grey Kangaroo, Emu, Common Dunnart, Tree Goanna, Mitchell's Hopping Mouse, Bush Stone-curlew and Australian Bustard.

The vegetation in and around the lake bed is largely intact. The vegetation and significant size of the wetland Lake Albacutya particularly important for waterbirds.

The important ecological values of Lake Albacutya include:

- it is a wetland of international significance under the Ramsar Convention (DSE 2003) and qualifies under the following criteria
    - Criterion 1 – it contains a rare, representative or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region;
    - Criterion 3 – it supports populations of plant and / or animal species important for maintaining the biological diversity of a particular biogeographic region;

  - Criterion 5 – it regularly supports 20,000 or more waterbirds;
  - Criterion 6 – it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
- it is part of the Wimmera Heritage River (DNRE 1997a);
- it is a Wetland of National Importance (Environment Australia 2001);
- it is listed on the Register of the National Estate;
- it is a 'high value wetland system' (DCNR 1993);
- it contributes to the habitat corridor between the Little Desert and Wyperfeld National Parks;
- it supports a high diversity of waterbirds, with over 42 species reported;
- it has a high carrying capacity for waterbirds with 10 species reported to visit in significant numbers, including up to 10% of the Victorian population of the rare Freckled Duck;
- it supports significant breeding by more than seven waterbird species;
- it supports migratory waterbirds;
- it supports threatened waterbird species;
- it supports other rare fauna including Regent Parrot, Common Dunnart, Tree Goanna, Freshwater Catfish and Mitchell's Hopping Mouse.

Dorrington Point at Lake Albacutya is the source of an important variety of Red Gum that has been cultivated for its salt tolerance, drought tolerance, straight trunk and rapid growth (Bren and Acenolaza 2000).

Hydrology

Lake storage levels under the current and natural scenarios are illustrated in Figure 10.

Table 4 shows that under natural conditions Lake Albacutya was dry on 6 occasions with each event lasting 16.2 months on average. The lake spent a much greater total duration (i.e. ‘frequency’ x ‘average duration”) at or below the 'shallow' threshold in the current scenario; low a total of 954 months currently compared with 224 months in the natural scenario.

Table 4. Spell Analysis for Lake Albacutya. 'Shallow' represents flooding to 1 m depth in the lake (25 GL or 0.75 m), 'Full' represents the point at which water spills to Outlet Creek downstream (230 GL) and 'Full +2m' represents the level required to create substantial flow in Outlet Creek (320 GL).

Scenario	Threshold	Lake level below threshold			Lake level above threshold		
		No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)	No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)
Natural	Empty	6	16.2	43	6	178.8	392
	Shallow	7	32.7	55	7	134.4	322
	Full	23	32.5	321	22	19.2	50
	Full + 2m	18	61.3	382	17	3.9	8
Current	Empty	7	122.9	368	6	51.7	112
	Shallow	6	159.7	387	5	42.4	98
	Full	3	382.7	647	2	11	21
	Full + 2m	2	583.5	875	1	3	3

Water flooded the perimeter vegetation and generated outflow on 22 occasions under the natural scenario, with each event lasting 19.2 months. This declined dramatically to only two occasions under the modelled current conditions, with the first occurring in 1956 and the second occurring in 1975.

A substantial outflow was only generated once under the current scenario and lasted only 3 months. Under natural conditions this event occurred 17 times and lasted 3.9 months on average. These large events would be required to flood fringing Black Box vegetation.

The recurrence intervals of full lake events are shown in Figure 11. Flooding events of 6 months occur approximately every 6 years in the natural scenario, but occur with an interval of approximately 60 years in the current scenario.

In the natural scenario, full lake events of two years duration occur approximately every 10 years. In the current scenario, the recurrence interval of these events is greater than 100 years.

5.4 Southern Wyperfeld

Reach Description

Water discharging from Lake Albacutya enters a complex of wetlands and channels in Wyperfeld National Park, which have been grouped into a single reach termed Southern Wyperfeld (Figure 12). The reach includes (in downstream order):

- Leg of Mutton Lake (in-stream);
- Lake Werrebean (terminal);

- The Kidneys (in-stream);
- House Lake (in-stream);
- Little Black Flat (in-stream);
- Black Flat (in-stream);
- Lake Brimin (terminal);
- Maiden Swamp (in-stream);
- Lake Brambruk (in-stream);
- Lake Jerriwirrup (in-stream); and
- Wonga Lake (terminal).

The reach includes several large wetlands, including Lake Brambruk (150 ha), Lake Brimin (96 ha) and Black Flat (52 ha) as well as smaller named and un-named wetlands.

The wetlands and channels are scattered within the Mallee landscape of the Lowan Sands. The wetlands generally feature a central flat area, a surrounding shelf rising approximately 1 m above the lake bed and a steeply rising perimeter which continues to the dunes of the surrounding Mallee. The lake bed comprises Coonambidgal Clay and the surrounding dunes comprise Lowan Sands.

The sands appear to shift over the clay surface over time. Several wetlands are isolated from the surface drainage network by dunes and dune vegetation. They retain wetland vegetation and may now be flooded by sub-surface seepage from nearby wetlands and by rain seepage from surrounding dunes.

Surface water is conveyed via channels of Outlet Creek and other channels. The channels are up to 20 m wide and 5 m deep. The clay bed of the channel is free of woody vegetation but the steep banks support dense Black Box woodland vegetation.

Environmental Values and Assets

The central bed of the Southern Wyperfeld wetlands supports a well developed terrestrial plant community of native and exotic grasses (e.g. Wallaby Grass, Spear Grass and Barley Grass.) and shrubs (eg. Short-leaf Bluebush). The lake beds are widely infested with weeds, particularly Capeweed, Horehound and Patterson's Curse. Capeweed is a favoured food of Stumpy-tailed Lizards (Durham 2001). The lake beds also provide grazing for Emus, Western Grey Kangaroos and, less commonly, Red Kangaroos (Durham 2001).

The shrub vegetation at the edge of the lake bed is less well developed and appears to have gradually declined in extent in the second half of the 20^{th} century (Morton and Heislers 1978). Common species include Three-nerved Wattle, Grey Mulga and Small Cooba. Shrubby vegetation had recently been burnt at the time of inspection (27-5-04) at Lake Brimin and Lake Brambruk.

The extent of Red Gum woodland varies according to the geomorphology of the wetlands with a relatively narrow zone approximately 50 m wide at Leg of Mutton Lake, but extensive woodlands at Lake Brambruk. Similarly, the extent of Black Box is relatively limited where the wetland bed rises steeply to the dunes, but extends over an extensive area between Leg of Mutton Lake and Lake Werrebean.

When last flooded in 1977, the lakes supported diverse and abundant waterbird and bush bird communities, many of which bred at the lake (Morton and Heislers 1978).

These conservation values are recognised in that the Southern Wyperfeld Reach:

- is part of the Wyperfeld National Park;
- is part of the Wimmera Heritage River;
- Lake Jerriwirrup is a Reference Area under the Reference Areas Act as a relatively undisturbed area (Heritage River Plan);
- it supports a wide variety of flood-dependent plants of conservation significance;
- it supports a high diversity of waterbirds when flooded;
- it supports breeding by waterbirds when flooded, including migratory species and other species of conservation significance; and
- it supports mesic fauna, which depend on both the Mallee and wetland environments, many of which have conservation significance (Allen 1995).

Hydrology

Water levels in Lake Brambruk under natural and current conditions are illustrated in Figure 13.

Table 5 shows that under the modelled natural scenario Lake Brambruk was empty on 3 occasions over the modelled period, each lasting 128.3 months on average. In the current scenario the lake had two prolonged dry spells with an average duration of 542.5 months. The total duration (i.e. 'frequency' x 'average duration') the lake spends dry therefore increased from 384.9 months under natural conditions to 1085 months under current conditions.

Under the modelled natural conditions, Lake Brambruk filled on 16 occasions, each lasting 22.6 months on average. Under current conditions this declined to a single, 20 month occasion over the modelled period. This event corresponds to the rainfall conditions in 1974/75, which did not in fact become deep enough to inundate the woodlands surrounding the lake (Bren and Acenolaza 2000).

Table 5. Spell Analysis for Lake Brambruk (Southern Wyperfeld). The Wimmera REALM assigns a maximum storage of 15 GL to the lake. Surcharge above this level is not modelled.

Scenario	Threshold	Lake level below threshold			Lake level above threshold		
		No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)	No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)
Natural	Empty	3	128.3	273	3	261.7	130
	Full	17	47.6	340	16	22.6	49
Current	Empty	2	542	875	1	86	86
	Full	2	575	878	1	20	20

Lake Brambruk filled on 16 occasions in the natural scenario, with each event lasting on average 22.6 months. These events would have inundated all the Red Gum woodland on the upper shelves of Lake Brambruk and would have inundated the surrounding Black Box fringe. Under current conditions this degree of flooding was achieved only once, in 1974/1975 and lasted 20 months.

Recurrence intervals for full lake events are shown in Figure 14. In the natural scenario, full lake events lasting 1 year occur approximately every 8 years. Full lake events did not occur with sufficient frequency in the current scenario to analyse trends.

5.5 Northern Wyperfeld

Reach Description

There are fewer wetlands along Outlet Creek downstream of Wonga Lake and the creek is constrained within a meandering channel for the next 10 km (Figure 15). Outlet Creek fills a final mosaic of wetlands at the terminus of the system, the most significant of which are Lake Agnes (375 ha) and the Wirrengren Plain (4,876 ha). Other large, un-named nearby lake beds are isolated by dunes but may be fed by groundwater seepage or minor channels.

Lake Agnes and the Wirrengren Plain share a similar geomorphology (M. Cooling personal observation 27-5-04). They have a central flat clay bed which makes up most of the lake area. A shelf 1 to 2 m above the lake bed occupies the perimeter of the lakes and is 0.5 to 1 km wide. The lake surface rises by a further 2 to 3 m at the outer perimeter over a zone approximately 0.5 km wide, after which it meets the abruptly rising dunes of the surrounding Lowan Mallee.

The section of Outlet Creek connecting Lake Agnes and the Wirrengren Plain meanders in a well defined trench approximately 3 m deep and 60 m wide. The creek has a clay bed and progressively more sandy soils on the bank which merge with the surrounding Mallee.

The Pine Plains property, which includes the Wirrengren Plain, was public land grazed under licence before being included in the Wyperfeld National Park in 1991 on the recommendation of the Land Conservation Council. The council recommended that stock grazing be phased out at Pine Plains by 1996.

Groundwater was reported 3 m below the surface at Lake Agnes in 2004. Salinities increased by approximately 40% in the monitored period between 1997 and 2001 reaching 27,560 mg/L. Groundwater conditions beneath the Wirrengren Plain are similar (Appendix B). However, current monitoring data is insufficient to fully characterise the groundwater conditions and trends in the Northern Wyperfeld reach.

Environmental Values and Assets

The beds of Lake Agnes and the Wirrengren Plain support low grassy vegetation with a high proportion of exotic species including False Sow-thistle, Capeweed and Horehound. Native species on the lake bed include Wallaby Grass and Bluebush.

The shallow shelf of the outer lake bed supports an open woodland of Red Gum which includes scattered Black Box. The understorey to the Red Gum is less disturbed than the lake bed and includes chenopod shrubs and grasses including Saltbush, Ruby Saltbush, Australian Salt-grass, New Holland Daisy, Spear Grass and Wallaby Grass.

The outer perimeter of the lake comprises an open Black Box woodland with a similar understorey. This community extends to the limits of the Mallee vegetation, which commences on the deep sands of the surrounding dunes.

Water has not reached Lake Agnes since 1918 and has not reached the Wirrengren Plain since 1874. No information has been found that describes the wetland environments that develop in the lakes during floods. It can be expected that the lakes would support a high diversity of wetland fauna and provide major breeding opportunities for visiting aquatic fauna, particularly waterbirds.

The recognised conservation values of the Northern Wyperfeld Reach are:

- its inclusion in the Wyperfeld National Park;
- its inclusion in the Wimmera Heritage River; and
- it provides tree hollows for a wide variety of fauna, including species of conservation significance.

Hydrology

Lake Brambruk outflows for the current and natural scenarios are presented in Figure 16.

Historical records show that the Wirrengren Plain was last flooded in 1874. It was flooded on 3 occasions in the 19th century, each lasting between 4 and 13 years (Sandell 1995). Wimmera REALM output shows that storage and diversions in the Wimmera catchment at the start of the 20th century had already reduced flows to the Northern Wyperfeld reach to the extent that flooding in 1910 and 1917 did not occur.

Table 6. Spell Analysis for Lake Brambruk outflows (Northern Wyperfeld). 'Low flow' represents 3 GL/month and 'High flow' represents 25 GL/month.

Scenario	Threshold	Creek level below threshold			Creek level above threshold		
		No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)	No. Events (in 97.5 yrs)	Average Spell Duration (months)	Maximum Spell Duration (months)
Natural	No flow	16	53.4	342	15	21.1	47
	Low flow	18	59	370	17	6.4	23
	High flow	15	76.8	383	14	1.3	3
Current	No flow	3	386	879	2	6	10
	Low flow	2	583	879	1	5	5
	High flow	Nil					

The summary of Wimmera REALM output in Table 6 shows that low flows were generated downstream of Lake Brambruk on 17 occasions under the natural scenario, with each event lasting on average 6.4 months. The longest event was 23 months. High flows were generated on 14 occasions, with the longest event lasting 3 months. The highest outflow events occurred in 1909, 1956 and 1975. Wimmera REALM does not model storages downstream of Lake Brambruk and it does not indicate whether these events would have been sufficient to inundate the Northern Wyperfeld Reach.

In the current scenario, a low flow was generated downstream of Lake Brambruk once and lasted 5 months.

The recurrence intervals of high outflow events (25 GL/month) are shown in Figure 17. High flow events lasting longer than 3 months occur every 50 years in the natural scenario, but never occurred in the current scenario.

6.1 Red Gum Health

Threat

Red Gum in the terminal lakes system are generally in poor health with a number of trees having diminished crown size and density and increased dead branches (Wouters 1993; The University of Ballarat 1998; Bren and Acenolaza 2000). Further deterioration in tree health will lead to local extinctions and patchiness in Red Gum extent.

Poor tree health at Lake Albacutya has been related to water stress (Marcar undated) and water stress also affects trees in other reaches. The condition of trees in areas that were inundated by floods in 1975 to 1977 is markedly better than unflooded sites (Bren and Acenolaza 2000) and this finding is supported by recent Red Gum health mapping (The University of Ballarat 2004).

Salinity presents an additional risk to the health of Red Gum at Lake Hindmarsh. The water table at Lake Hindmarsh is saline and shallow and is likely to be a significant cause of stress in trees (Wouters 1993). The presence of remnant halophytic plant communities near the lake, particularly Salt Paperbark, indicates that saline, shallow groundwater is a natural phenomenon.

Salinity also represents a risk to Red Gum in the Northern Wyperfeld reach, where the water table is shallow and salinities have increased significantly in recent years (Appendix B).

The salinity below intermittently flooded lakes can be mitigated by flooding and generating a temporary reservoir of low salinity groundwater. More frequent flooding at Lake Hindmarsh may provide less stressful conditions for Red Gum between flooding events.

Required Water Regime

The flooding regime to maintain Red Gum health depends on how long the benefits of flooding last between flood events. A review of Red Gum health (Bren and Acenolaza 2000) and mapping of tree health (The University of Ballarat 2004) indicate that trees in Wyperfeld National Park that were flooded in 1974-1975 are in better condition than trees in areas that were not flooded, even after more than 25 years. Red Gum trees have persisted for over 100 years without flooding in the Wirrengren Plain, although these trees are in poor health and lack the understorey plant species and habitat normally associated with this community.

Survival of Red Gum is determined by the availability of groundwater with a tolerable salinity (Roberts and Marston 2000). Floods replenish groundwater, reduce its salinity and provide a reservoir to support growth until the next flooding event. The degree to which water stress develops between floods will depend on local soil and groundwater characteristics and on climate.

Studies on Red Gum on the River Murray report that Red Gum growth is optimal with flooding 9 years in 10, with a minimum duration of 1 month and a preferred duration of 5 months (Dexter 1978). However, this flooding regime reflects the particular soil and groundwater characteristics of the Barmah-Millewa study site as much as the inherent requirements of Red Gum. For example, Red Gum have survived in the Wirrengren Plain and many other sites without flooding for more than 100 years, due to suitable soil water conditions.

An attempt to prescribe an optimal flooding frequency for Red Gum therefore has limited value, as there is insufficient data to describe the soil-water relations of this species in the terminal lakes system. It is known that Red Gum communities in the terminal lakes benefit from flooding which occurs with a recurrence interval of as much as 90 years in some areas and as little as 1 year in others. The most appropriate approach is to significantly increase the frequency of flooding from the current stressful conditions, closer to the natural conditions. It is also appropriate to consider the water requirements of other ecological objectives, which are likely to also benefit Red Gum health.

The flooding duration must be sufficient to replenish soil moisture and mitigate salinity, which may require a flood duration of between 1 and 5 months.

6.2 Red Gum Recruitment

Threat

There is little recruitment of Red Gum in any of the reaches (Wouters 1993, Bren and Acenolaza 2000, Durham 2001, Marcus Cooling personal observation 2004). Red Gum depends on flooding to promote the production of seed in mature trees and seed germination (Roberts and Marston 2000). The last significant recruitment events recorded in the Southern Wyperfeld reach occurred between 1975 and 1977 when floods of 12 to 23 months receded (Morton and Heislers 1978, Bren and Acenolaza 2000). The current population of Red Gum is ageing with few young trees to replace old, mature trees when they die. Mature Red Gum provide the majority of tree hollows for fauna and are important producers of the leaf litter and woody debris production on which aquatic fauna depend. Red Gum recruitment is likely to be reduced by infrequent flooding and reduced flooding duration. Immature trees are likely to be subject to drought and salinity stress between flood events and are less likely to survive.

Required Water Regime

The flooding regime to maintain Red Gum recruitment will depend on the required density and age structure of the Red Gum population. With sufficient soil moisture, trees will create a shrubby understorey within 2 years and will provide nesting and roosting habitat in 10 years. The creation of significant hollows may take more than 100 years. The declining population of mature trees in Northern Wyperfeld suggests that after 100 years the population will suffer significant depletion.

At Lake Hindmarsh and Lake Albacutya, the priorities will be to provide a dense community with diverse tree structures to support a wide range of aquatic and terrestrial birds and animals. This objective may best be achieved with a flooding frequency of between 5 and 10 years.

In Northern Wyperfeld, the priority will be to maintain a population of mature trees which provide nesting hollows and roosts. This objective may best be achieved with a flooding frequency of 50 years, which is approximately half the period at which the population is reported to become significantly depleted.

6.3 Viability of Dependent Fauna Populations

Threat

The decline in flooding frequency from natural to current conditions will have had significant, but unquantifiable, impacts on fauna dependent on the lake's wetland phase. Because the lakes are naturally flooded intermittently, aquatic fauna must use them intermittently. During dry phases, mobile fauna may migrate to aquatic habitats elsewhere and aestivating fauna may become dormant.

Waterbirds which breed in the terminal lakes also make use of other major wetland systems such as Lake Eyre, the Lower Lakes of the River Murray, Bool Lagoon and Hattah-Kulkyne. The availability of breeding habitat at these sites depends on climatic patterns and is stochastic. By making use of a range of sites, the likelihood that suitable conditions are available in any given year is increased. Similarly, a decline in flooding in any single component will reduce the overall availability of breeding habitat. While the terminal lakes make an important contribution to this mosaic of breeding habitats, it is not possible to quantify the frequency with which flooding must occur in the context of these other sites.

Differences in invertebrate communities in lakes with a range of prior dry periods has been demonstrated in fauna arising from resting stages at Chowilla on the River Murray (Boulton and Lloyd 1992). Resting stages may persist for many decades, but are likely to be significantly depleted after 100 years (Hairston et al. 1995).

The impact of less frequent flooding may be accommodated by aquatic fauna populations in the short term, but in the long term it will reduce the size of dependent populations and increase their vulnerability to drought and other disturbances. These impacts are of course exacerbated by the decline in wetland habitat elsewhere in Victoria and Australia (DNRE 1997b).

Required Water Regime

There is insufficient data to quantify the contribution of the terminal lakes to the viability of dependent populations, and therefore to recommend a flooding frequency. This issue may be best addressed by providing significant growth and breeding opportunities for fauna with a flooding frequency and duration similar to natural conditions.

6.4 Development of Wetland Characteristics

Threat

The reduction in the duration of 'full' lake events from natural to current conditions has significantly reduced the capacity of the lake to develop the characteristics of a mature, productive and diverse aquatic ecosystem when flooded. A mature ecosystem will be represented by the:

- death of terrestrial vegetation from the lake bed;
- development of extensive beds of aquatic vegetation;
- relief of drought and salinity stress in fringing woodland vegetation, with associated tree growth and seed production;
- colonisation, growth and reproduction of large fish including Macquarie Perch, Golden Perch, Catfish and Murray Cod;
- the development of communities of aquatic prey species (e.g. macro-invertebrates/zooplankton/small fish) for predatory fish and waterbirds, with associated piscivorous bird and fish guilds; and
- capacity for completed breeding cycles for waterbirds.

Lakes currently spend only brief periods at their full level and are more likely to flood partially. The current duration of flooding may provide temporary habitat for generalist fauna such as waterfowl, Australian Pelican and Ibis. However species and processes which depend on extensive aquatic vegetation and mature aquatic food webs, such as predatory fish and waterbirds, are more likely to require floods that last two years or more.

Required Water Regime

Floods of different durations will fulfil different ecological roles. It is recommended that floods of long and short durations are provided in the management of the lakes.

Short floods may last approximately 6 months and will provide habitat for opportunistic and generalist species such as waterfowl, Australian Pelican and Ibis and will support small native fish that make use of the habitat provided by flooded terrestrial vegetation on the lake bed. Under natural conditions, short floods were typical of the water regime of Lake Hindmarsh and Lake Albacutya and may be required at least once a decade.

Floods lasting two years or more represent opportunities for the lakes to develop their characteristic wetland values which includes complex and mature aquatic ecosystems. Long floods are naturally highly variable events. If local seed sources are retained in healthy fringing vegetation, it is likely that the wetlands will retain the potential to develop these characteristics even with a very rare flooding frequency because the wetlands depend to a high degree on imported flora and fauna propagules and resting stages and seeds in the wetland. A frequency of between 10 and 20 years is recommended to retain the ecological character of the lakes and to make a significant contribution to regional fauna populations.

7.1 Key Ecological Objectives

The key ecological values of the terminal lakes depend on:

- the relief of drought and salinity stress in fringing Red Gum;
- regular recruitment in fringing Red Gum to provide a diverse age structure in the tree population;
- sufficiently frequent flooding to contribute significantly to the viability of visiting aquatic fauna populations; and
- the complete transition of the lake from a terrestrial ecosystem to a mature and diverse aquatic ecosystem during flooding phases.

Table 7. Ecological Objectives and Proposed Indicators

Ecological Objectives	Indicators
Fringing Red Gum populations have a diverse age structure	- at least one successful recruitment event every ten years
Fringing Red Gum populations persist at the perimeter of the lakes	- salinity and drought stress in fringing Red Gum is completely relieved in 50% of occasions when lake is 'full'
The aquatic phase of the lakes contributes significantly to the viability of visiting fauna populations	- breeding success (recruitment) of visiting fauna (e.g. fish, waterbirds, White-bellied Sea Eagle)*
A mature and diverse aquatic ecosystem develops during 'full' lake events	- death of terrestrial vegetation from the lake bed - development of extensive communities of aquatic vegetation - colonisation, growth and reproduction by indicator predator guilds

*this is not a direct indicator of the viability of populations, but could be used to compare the contribution of the terminal lakes to fauna populations with other major breeding sites.

7.2 Lake Hindmarsh Flow Objectives

The capacity of the Lake Hindmarsh water regime to meet the ecological objectives can be interpreted from three flood event types (Table 8):

- 6 month lake-full events;
- 24 month lake-full events; and
- 36 month lake-full events.

Table 8 (and subsequent tables in Section 7) presents the relevance of these events to the ecological objectives. Events on which the objectives principally depend are indicated by three ticks (✓✓✓) and events which significantly contribute to the objectives are marked with two ticks (✓✓). Events which make a minor contribution to ecological objectives are indicated by one tick (✓). Events which are not relevant are not ticked.

Relatively frequent lake-full events of 6 months duration are important to promote the growth and health of Red Gum woodland communities at the lake fringe. Regular floods of this duration will promote the germination of new trees and will sustain their growth. Emergent macrophytes, will persist between floods or regenerate from dormant root-stock, and will form stands at the lake fringe. Many fauna dependent on flooding, such as fish, waterbirds and frogs, will complete one breeding cycle.

Two year lake-full events will eradicate terrestrial vegetation from the lake bed and provide time for aquatic vegetation to grow and spread from seeds, rhizomes and other propagules. Predatory aquatic fauna guilds will develop, supporting species higher in the food chain such as piscivorous fish and waterbirds, including the White-bellied Sea-eagle. Two years of flooding is likely to promote significant growth in fringing Red Gum. This flood duration will allow the completion of two complete breeding cycles and allow for fauna migration.

After three years of flooding, Lake Hindmarsh is expected to develop the characteristics of a permanent lake community. Areas of submerged aquatic plants are likely to be replaced by open water. Fringing emergent macrophyte communities will be dense and extensive. Fish and bird communities will reach a high reproductive capacity.

The current frequency of these events is considered insufficient to meet the ecological objectives. Six-month events currently occur only every 9 years, which allows for significant water stress to develop in fringing Red Gum communities. A recurrence interval of 5 years is recommended. A recurrence interval of 10 years is recommended for floods of 2 years duration to substantially replenish seed banks and to maintain Red Gum health and a diverse plant community in the fringing vegetation. Two and three year floods will support major breeding events that will make major contributions to regional waterbird and fish populations. A recurrence interval of 20 years is recommended.

Table 8. Hydrological objectives for lake-full events (storage volume of 378 GL) at which outflow commences) at Lake Hindmarsh, showing the relevance to the ecological objectives.

Event Duration	Recurrence Interval (years)			Ecological Objectives Addressed			
	Natural	Current	Recommended	Red Gum age structure	Red Gum persistence	Viability of visiting fauna population	Aquatic ecosystem maturity in full lake events
6 months	3-4	9	5	✓✓✓	✓✓✓	✓	✓
24 months	7	30	10	✓✓	✓✓	✓✓	✓✓
36 months	10	>100	20	✓	✓	✓✓	✓✓✓

In recognising that the lake ecosystem is adapted to intermittent dry periods, the reduction in flood frequency at Lake Hindmarsh is not considered a significant threat to the ecological objectives, as long as the flood duration is increased.

7.3 Outlet Creek from Lake Hindmarsh to Lake Albacutya Flow Objectives

The capacity of the flow regime of Outlet Creek to meet the ecological objectives is assessed in terms of:

- low flows (>10 GL/month) of 3 months duration; and
- high flows (>57 GL/month) of 2 months duration (Table 9).

Regular low flows support aquatic vegetation, invertebrate and frog communities in the channel, which quickly appear after rainfall or the commencement of flow. The current frequency of 3 month low-flow events (a recurrence interval of 20 years) is considered insufficient to maintain instream plant and animal populations and their habitat. It is expected that aquatic plant communities will be depleted between flow events by water stress and grazing, so that they would provide poor habitat for fauna when flow re-commences. It is also expected that the populations of aestivating aquatic invertebrates and frogs will be significantly depleted between flows. A recurrence interval of 5 years is recommended to provide regular breeding and recruitment opportunities to maintain riparian and instream vegetation such as Water Ribbons, sedges and rushes and fauna such as frogs and aquatic invertebrates in the intervening dry periods.

Table 9. Hydrological Objectives for Outlet Creek Downstream of Lake Hindmarsh, showing the relevance to the ecological objectives.

Flow	Event Duration	Recurrence Interval (years)			Ecological Objectives Addressed			
		Natural	Current	Recommended	Red Gum age structure	Red Gum persistence	Viability of visiting fauna population	Aquatic ecosystem maturity in full lake events
>10 GL/month	3 months	2-3	20	5	✓	✓		
>57 GL/month	2 months	6-8	30	15	✓✓✓	✓✓	✓	

Occasional high flows inundate the floodplain, sustaining the growth of Red Gum, Black Box, Lignum and other floodplain plants and supporting germination and recruitment. Inundation of the floodplain and Ross Lakes provides habitat and breeding opportunities for colonising fish and water birds. The current recurrence interval of 30 years provides rare recruitment events for floodplain vegetation and is considered insufficient to maintain the Red Gum woodland plant community set out in the ecological objectives. The quality of habitat for aquatic fauna during floods and between floods is compromised. The breeding by aquatic fauna associated with the low frequency of these events provides only a minor contribution to regional populations. A maximum interval of 15 years is recommended to inundate the floodplain and fill Ross Lakes. This flow regime is expected to maintain Red Gum health, promote Red Gum and Black Box recruitment, to preserve populations of other flood dependent flora such as Lignum and help maintain populations of aquatic fauna that depend on flooding to breed, such as waterbirds.

7.4 Lake Albacutya Flow Objectives

The capacity of the flow regime of Lake Albacutya to meet the ecological objectives is assessed in terms of:

- 6 month lake-full events; and
- 24 month lake-full events.

Lake full events of 6 months duration provide a significant temporary wetland habitat that supports breeding by aquatic fauna and, importantly, the growth and recruitment of the fringing Red Gum woodland community. A recurrence interval of 8 years is recommended to preserve the ecological character of the fringing plant communities and to provide a regular breeding habitat for aquatic fauna. Flooding of this frequency will support aquatic herbland communities on the lake bed and will provide a productive environment for terrestrial fauna between floods. This longer interval recognises the lower proportion of flood-dependent plants at the fringes of Lake Albacutya than Lake Hindmarsh and the naturally lower flooding frequency.

Lake full events of 2 years duration will provide major breeding events for waterbirds that will make a significant contribution to regional populations. A flooding interval of 20 years is recommended. These events will result in the death of terrestrial vegetation from the lake bed, the development of widespread aquatic plant communities, diverse aquatic fauna communities, including predatory guilds and large fauna populations. Intermittent flooding of fringing Black Box communities is likely while the lake level remains high. The processes supported by floods of this duration are an important aspect of the ecological character (in terms of the Ramsar convention) of the site.

Table 10. Hydrological objectives for lake full events (storage volume of 230 GL, at which outflow commences) in Lake Albacutya, showing relevance to the ecological objectives

Event Duration	Recurrence Interval (years)			Ecological Objectives Addressed			
	Natural	Current	Recommended	Red Gum age structure	Red Gum persistence	Viability of visiting fauna population	Aquatic ecosystem maturity in full lake events
6 months	6	60	8	✓✓✓	✓✓✓	✓	✓
24 months	10	>100	20	✓✓	✓✓	✓✓✓	✓✓✓

7.5 Southern Wyperfeld Flow Objectives

The capacity of the flow regime of Southern Wyperfeld to meet the ecological objectives is assessed in terms of:

- 6 month lake-full events; and
- 24 month lake-full events in Lake Brambruk.

Wimmera REALM reports that Lake Brambruk was only filled once over the modelled run, for a 20 month period (Figure 14). Therefore the recurrence interval for 6 and 24 month events can only be estimated as less than and greater than100 years, respectively (Table 11).

A recurrence interval of 10 years for floods of six months duration is recommended to sustain woodland communities. This is expected to result in regular Red Gum recruitment, sustained Red Gum health, high vegetation diversity through alternating plant succession in flooded and dry phases and a significant contribution to visiting fauna habitat requirements. The wetlands will have sufficient time between floods to reach a climax community as a terrestrial habitat.

Longer floods of 2 years duration will provide major breeding events for visiting fauna and will make a significant contribution to regional waterbird populations. A recurrence interval of 20 years is recommended to achieve this objective.

Table 11. Hydrological Objectives for lake-full events (storage volume of 15 GL) at Lake Brambruk, showing relevance to ecological objectives

Event Duration	Recurrence Interval (years)			Ecological Objectives Addressed			
	Natural	Current	Recommended	Red Gum age structure	Red Gum persistence	Viability of visiting fauna population	Aquatic ecosystem maturity in full lake events
6 months	7	<100	10	✓✓✓	✓✓✓	✓	✓
24 months	10	>100	20	✓✓	✓✓	✓✓✓	✓✓✓

7.6 Northern Wyperfeld Flow Objectives

Wimmera REALM provides little guidance on the natural flooding regime of the Northern Wyperfeld Reach, except that significant flows were generated 1 in 7 years and lasted, on average for 1.3 months.

The Northern Wyperfeld system is flooded very rarely and unpredictably, and it cannot be considered essential to the viability of any aquatic plant or animal populations, apart from local Red Gum and Black Box communities. Nevertheless, the provision of wetland habitat in the lakes is an important and desirable event. The environment is unique in Victoria and would support considerable populations of wetland biota including waterbirds, fish and plants.

The critical role of flooding is to maintain the population of Red Gum in order to provide habitat, including hollows, for Mallee fauna. Floods have reportedly provided the only recruitment events in the Northern Wyperfeld reach (Durham 2001), making the youngest trees at Lake Agnes 80 years old and the youngest trees at Wirrengren 130 years old. The trees do not apparently depend on flooding once they have established and, while they are not in optimal health, significant stands of Red Gum survive today. However, recent monitoring data suggests the lakes are subject to rising groundwater salinity (Appendix B) which may represent a significant threat to trees.

Flow should therefore be provided at intervals that maintain the age structure of the Red Gum population by providing recruitment events significantly more frequently than the life span of the trees, and that will reduce groundwater salinity.

A flooding interval of 50 years is proposed. These events must persist long enough for mature wetland communities to develop and significant groundwater recharge to take place. Given that the lake beds will provide very little allocthonous wetland biota, a long flood duration, of 3 years is proposed to ensure a fully mature aquatic ecosystem can become established. The relationship between Lake Brambruk outflows and flooding of the Northern Wyperfeld reach has not been investigated in this study.

It should be noted that the role of flooding in protecting vegetation from high groundwater salinity has been interpreted from very limited monitoring data. Additional data should be collected to further characterise groundwater processes in the area.

7.7 Priority of Environmental Water Requirements

In environmental water requirement investigations, priorities are often set according to the value and threat of ecosystem components. Priorities are helpful because investments can be made in proportion to environmental demand, and the highest priority water requirements can be addressed first.

The following basis prioritise water regimes is proposed.

- The first priority is to maintain the structural components of the ecosystem, particularly those which have a slow response to improved hydrological conditions. The involves maintaining the health and age structure of Red Gum and associated vegetation communities at the fringes of the lakes. These communities have suffered a gradual decline in health since the water regime was significantly affected in the early 20th century. These communities may take a similar time to recover, particularly with respect to the provision of mature trees and nesting hollows. This priority may be addressed by providing lake-full events of the prescribed frequencies for periods of more than 6 months and up to 2 years. By addressing this requirement first, the capacity of the system to meet the other ecological objectives will be maintained.

- The second priority is to support populations of visiting fauna that depend on the lakes. This is a high priority because of the role that the lakes play, in conjunction with other major breeding sites, in maintaining regional populations of waterbirds. It is emphasised by the Ramsar status of Lake Albacutya. This depends on lake-full events of the prescribed frequency of at least 6 months and preferably for more than 2 years.

- The third priority is to achieve the mature ecosystem condition that occurs after prolonged flooding. This objective requires floods at least two years, at the prescribed frequencies.

The following basis to prioritise the water requirements of reaches is proposed.

- Lake Albacutya is the highest priority reach. As a Ramsar site, it has the highest conservation significance and the most significant environmental obligations. Tree health in many areas is poor due to lack of flooding.
- Southern Wyperfeld is the second priority. The wetlands in this reach provide complex fauna habitats in the context of the mallee vegetation of Wyperfeld National Park. Tree health in this reach has suffered significantly from lack of flooding.
- The water requirements of the previous two reaches cannot be met without also providing water to Lake Hindmarsh. Even so, it is proposed as the third priority due to the relatively intact condition of fringing vegetation, and the significant degree of stress present in vegetation in several areas.
- Northern Wyperfeld is the fourth priority. This reach would provide long-term wetlands of major conservation significance in terms of the diversity and size of the fauna populations they would support. Red Gum vegetation in this reach is in very poor condition.
- Outlet Creek from Lake Hindmarsh to Lake Albacutya is the lowest priority, even though its water requirements would be addressed by providing water to the previous four reaches. While the structure and condition of habitats in this reach is similar to Lake Hindmarsh and Lake Albacutya, the extent of wetland habitat, and its potential to provide wetland habitat over prolonged periods is significantly less.

8.1 Introduction

An assessment was conducted of the effect of hypothetical environmental flow allocations on the hydrology and ecology of the terminal lakes. The scenarios were modelled using Wimmera REALM from data provided by the Department for Sustainability and Environment (DSE 2004). The assessment was intended to indicate the degree to which water savings projects such as the Wimmera-Mallee Pipeline might address environmental water requirements of the terminal lakes.

Three scenarios were assessed; the annual release of:

- 60 GL;
- 80 GL; and
- 100 GL.

The scenarios were modelled using the same post Northern-Mallee Pipeline configuration as the 'current' scenarios. The releases were made at an undefined location between the MacKenzie River – Wimmera River confluence and Lake Hindmarsh. The releases originate from the headworks either by regulated releases from storage or unregulated flows, or a combination of both (Walter Godoy pers. com. Department for Sustainability and Environment, 27-8-04).

Previous modelling by Hydrotechnology (1993) demonstrated that the effectiveness of releases for environmental benefit depends critically on storage levels in the terminal lakes at the time releases are made. If levels in Lakes Hindmarsh and Albacutya are low, even large releases are not transmitted downstream, but are absorbed by the capacity of these lakes with little effect on water regimes. However, if pre-existing levels in Lakes Hindmarsh and Albacutya are significant, releases are transmitted downstream and have a greater likelihood of affecting water regimes.

Therefore the scenarios modelled in this assessment were designed to occur when levels in the terminal lakes were favourable. Releases were made over a one month period per year when Lake Hindmarsh is spilling (i.e. storage exceeds 378 GL) and Lake Albacutya storage exceeds 60 GL.

The degree to which the flow scenarios meet the hydrological objectives is presented in Table 12. The table presents the recurrence intervals of the critical events. The statistics for the current scenario are provided for comparison. Scenarios where the recurrence interval exceeds (fails to meet) the objective are shown in white cells, and scenarios where the recurrence interval approximately meets the objective are shown in grey cells. Scenarios where the objective is met or exceeded are shown in black cells. Hydrographs illustrating the scenarios in comparison to the current conditions are provided in Figures 18 to 22. Plots of recurrence intervals and spell duration for the critical events are presented in Figures 23 to 27.

Wimmera REALM does not provide data to assess hydrological objectives in northern Wyperfeld, but Lake Brambruk outflows are presented in Figures 22 and 27 to indicate the effect of the scenarios on the system downstream.

Spell analysis tables for all scenarios are presented in Appendix C.

The seasonality of flows is not analysed because it is not significantly influenced by management. All of the hydrological targets for the system involve very large volumes or water that can only be generated by rare, prolonged, high-rainfall events. The seasonality is therefore controlled principally by climatic factors.

The volumes required are too great to be achieved by managed releases from storage (Hydrotechnology 1993). The role of management is to increase the transmission of flow in appropriate climatic events by priming Lake Hindmarsh and Lake Albacutya (DSE 2004) and increasing spill from storages in the catchment.

Table 12. Comparison of Current and Recommended Water Regimes with Enhanced Flow Scenarios

Reach	Event		Recurrence Interval (approx. years)				
	Level / Flow	Duration (months)	Current	Hydrological Objective	60 GL scenario	80 GL scenario	100 GL scenario
Lake Hindmarsh	Lake Full	6	9	5	7	6	6
	Lake Full	24	30	10	20-30	10	7
	Lake Full	36	>100	20	40	20-30	15
Outlet Creek	10 GL/m	3	20	5	10	6	4
	57 GL/m	2	30	15	30	20	15
Lake Albacutya	Lake Full	6	60	8	20-30	18	8
	Lake Full	24	100	20	60	20	10
Southern Wyperfeld	Lake Full	6	<100	10	20	20	10
	Lake Full	24	>100	20	100	30	20
Northern Wyperfeld	Lake Full	36	no data	50	no data	no data	no data

Key:

Meets or exceeds objective	(black)
Largely meets objective	(grey)
Fails to meet objective	(white)

8.2 Scenario 1 – 60 GL

The 60 GL scenario increases the frequency of the critical flow events but fails to meet the hydrological objectives.

The recurrence interval of lake-full events in Lake Hindmarsh is reduced, but fails to meet the target recurrence interval of 5 years. There is little change to 24 month recurrence interval and the 36 month lake-full event remains very infrequent.

The recurrence interval of 3 month low-flow events in Outlet Creek decreases in this scenario from 20 to 10 years but fails to meet the target of 5 years. The recurrence of high flow events is not affected in this scenario and remains at the current recurrence interval of 30 years.

The recurrence interval of 6 month long lake-full events at Lake Albacutya is 20-30 years and remains significantly longer than the recommendation of 10 years. This scenario has relatively little impact on the frequency of 24 month lake-full spells, which occur every 60 years compared to the target of 20.

The new, brief flooding events introduced in this scenario substantially increase the frequency of 6 month lake-full events in the Southern Wyperfeld from the current recurrence interval of more than 100 years to 20 years. However the 24 month lake-full events remain very rare at 100 years. Both events are less than the target.

Figure 22 shows that this scenario marginally increases the outflows from Lake Brambruk to Northern Wyperfeld.

In conclusion, the 60 GL scenario alters the current water regimes by introducing additional, brief flow peaks and marginally prolonging existing flow events. The scenario provides a benefit to Lake Hindmarsh and Outlet Creek, but a marginal benefit to Lake Albacutya and Southern Wyperfeld. The benefit to Northern Wyperfeld appears insignificant.

8.3 Scenario 2 – 80 GL

The hydrological targets for Lake Hindmarsh are largely met in the 80 GL scenario. The annual recurrence interval for 6 month, 24 month and 36 month floods are close to or match the target. While the target recurrence interval for low outflows to Outlet Creek is largely met, the recurrence interval of 20 years for high flows remains greater than the target of 15 years.

This scenario provides a significant benefit to Lake Albacutya, by significantly increasing the frequency of 6 month and 24 month lake-full events. The recurrence interval of the longer events meets the target, but the recurrence interval for 6 month events is 18 years and remains well above the target of 8 years.

The additional lake-full events introduced in Lake Brambruk (Southern Wyperfeld) in the 60 GL scenario are also introduced in the 80 GL scenario to provide a recurrence interval of 20 years for 6 month events and 30 years for 24 month events. These represent a significant change from current conditions but fail to meet the targets of 10 and 20 years, respectively.

The 80 GL scenario marginally increases outflows from Lake Brambruk to Northern Wyperfeld but is unlikely to significantly alter the water regime of Lake Agnes and the Wirrengren Plain.

8.4 Scenario 3 - 100 GL

The 100 GL scenario largely meets the hydrological objectives in all reaches. Therefore this scenario is expected to achieve the ecological objectives.

In some cases floods occur more frequently than the recommendation.

8.5 Other Benefits

It is important to examine the hydrographs when assessing the ecological effect of the scenarios. The hydrological targets for Lakes Hindmarsh, Albacutya and Brambruk were set with respect to the full lake level because of the importance of maintaining fringing woodland communities. While the 60 GL and 80 GL scenarios inadequately address the targets, they markedly change the water regime at lower lake levels. The hydrographs for Lakes Albacutya (Figure 20) and Brambruk (Figure 21) show a substantial increase in the duration of moderate lake levels in all scenarios, although this is not reflected by the frequency and duration of full lake events.

In this regard, even the 60 GL scenario would contribute significantly to the ecological objectives (see Section 7.1) of prolonging the aquatic phase of the lakes:

- "the aquatic phase of the lakes contributes significantly to the viability of visiting fauna populations"; and
- "a mature and diverse aquatic ecosystem develops during 'full' lake events".

The 60 and 80 GL scenarios would maintain important ecological characteristics of the lakes by providing floods of significant duration and frequency. However, because a smaller area of the lakes is filled, the size of the lakes would be smaller and may result in the migration of fringing woodland and shrubland communities down-slope to a new equilibrium. Of course, by failing to reach the ecological objectives the existing woodland communities would continue to decline. It should be noted that predictions of the benefits of water regimes that differ significantly from the requirements of the current ecosystem are highly speculative.

Despite their shortcomings, the benefits of the 60 and 80 GL scenarios should be compared with the current conditions, in which none of the ecological objectives are met.

8.6 Conclusions

Capacity to Achieve Objectives

The 60 GL scenario does not significantly address the hydrological targets and is expected to make a limited contribution to the ecological objectives. Because the scenario does not greatly increase the frequency of full lake events, Red Gum communities, and the fauna and other flora that depend on them, are likely to continue to decline. The 60 GL scenario does increase the frequency of flooding at lower lake levels however, and will increase the availability of aquatic habitat. It may provide minor ecological benefits that differ from the objectives identified in this report.

The 80 GL scenario significantly contributes to the hydrological targets, particularly by increasing the frequency of flooding in Lakes Hindmarsh, Albacutya and Brambruk. The frequency of flooding generally remains inadequate in most reaches, although the duration substantially achieves the hydrological target for 24 month floods at Lake Albacutya. This scenario substantially increases the frequency of flooding below the target 'lake full' levels. This scenario is expected to have significant ecological benefits to aquatic ecosystems in the lakes and provide improvements to fringing woodland communities. It is not expected to fully meet the ecological objectives.

The 100 GL substantially meets the hydrological objectives and is expected to achieve the ecological objectives.

Other Threats to Ecological Objectives

9.1 Overview

In addition to water regime, the ecological objectives are influenced by other threats. These threats introduce a risk that ecological objectives will not be achieved even if the required water regime is provided. This section identifies these threats and makes recommendations for their management.

9.2 Carp

European Carp (*Cyprinus carpio*) are present in the Wimmera River and will be introduced to the terminal lakes with any river flows. Carp potentially degrade habitat in the lakes by increasing water turbidity and uprooting aquatic vegetation. High densities of carp and falling lake levels also potentially generate anoxic conditions that are unsuitable for most aquatic fauna.

The management of carp is a state-wide and regional issue and beyond the scope of the management of the terminal lakes. The flows that fill the lakes are too great for any effective local measures to exclude carp, such as fish screens. Control measures are currently the subject of nationally and state-funded programs and may include biological control measures such as the introduction of the Daughterless Carp gene into populations.

9.3 Blockages to Flow in the Terminal Lakes

The period between flow events in the terminal lakes is significant, and there is potential for flow paths to become obstructed by sand drifts or vegetation. Inspection of the outlet of Lake Hindmarsh to Outlet Creek in this study suggested that a significant volume of sand had accumulated, significantly raising the sill level, and therefore the storage volume required in Lake Hindmarsh before flow to Outlet Creek and Lake Albacutya could begin. Similarly, inspection of Outlet Creek between Lake Agnes and the Wirrengren Plain suggested that the flow path may be completely blocked in places. Residents near Lake Hindmarsh report that in 1975 excavations were required at the outlet of Lake Hindmarsh to remove accumulated sand and vegetation to facilitate flow and reduce the risk of flooding at Jeparit.

There is no data to describe the integrity of the flow path through the terminal lakes. It is possible that significant blockages would prevent ecological objectives being achieved, even if required water regimes are delivered upstream.

This issue should be addressed locally.

A longitudinal physical survey of Outlet Creek is required, with occasional cross sections to better describe the capacity of the flow path and nature of any flow restrictions.

The risks of flow constrictions to the delivery of hydrological objectives should be assessed and a plan prepared to manage them.

9.4 Grazing

Intense grazing of lake beds during dry phases represents a significant threat to the diversity and extent of herbland communities. High grazing pressures are attributed to large populations of Western Grey Kangaroo and, historically, Rabbits (Durham 2001, DSE 2003). Grazing is believed to have promoted weed species such as Horehound, False Sow-thistle and Paterson's Curse while preventing the establishment of native herbland species.

High grazing pressures may impact on the ecological objectives by reducing density of native vegetation on the lake bed, which provides important habitat for invertebrates, fish and birds when lakes are flooded. Intensive grazing of drying lake beds may impact on aquatic plant communities and reduce their potential to recolonise the lake when next flooded.

High grazing pressures should be addressed locally.

Parks Victoria has instituted an integrated grazing management program which includes kangaroo and Rabbit management.

In recent years Rabbits have been successfully controlled by the ripping of warrens, burrow fumigation, shooting, 1080 poisoning programs and Rabbit calicivirus (Rabbit Haemorrhagic Disease) (Durham 2001).

9.5 Bees

European Honey Bees have historically been kept for honey production in the Wyperfeld National Park. Populations can reach very great sizes where they pose a risk to human safety and contaminate water supplies. Bees form hives in the hollows of mature Red Gum and Black Box, which are also used by many native fauna. Bee hives are reported to reduce the availability of hollows for breeding by the endangered Regent Parrot (Oldroyd et al. 1994). Bees in Wyperfeld National Park have been the subject of recent research by the Behaviour and Genetics of Social Insects Laboratory at the University of Sydney, where population dynamics were investigated (Oldroyd et al. 1997).

Bees potentially impact on the ecological objectives to promote woodland communities by reducing quality of woodland habitat for vertebrate fauna.

Bees affect natural ecosystems more widely than the terminal lakes and regional management strategies should be developed.

9.6 Fish Passage

The terminal lakes potentially provide important breeding sites and short-term refuges for native fish. The lakes potentially support large populations which would contribute to the size, stability and diversity of native fish populations in the Wimmera River. While the lakes are likely to be colonised by native fish during large flow events, the migration of fish upstream to the catchment will take place at lower flows.

Flow control structures on the Wimmera River have been identified as blockages to fish passage including Jeparit Weir, Antwerp Weir and Dimboola Weir (Wimmera CMA 2002). These structures undermine the potential contribution of the lakes to regional fish populations.

Fish passage is being addressed as a regional issue under the Wimmera Waterway Management Strategy and key structures have been identified for retrofitting, subject to further investigations (Wimmera CMA 2002).

10.1 Conclusions

The terminal lakes of the Wimmera River have high conservation significance. Lake Hindmarsh is a wetland of national significance and the importance of Lake Albacutya is recognised internationally under the Ramsar convention. The convention obliges Australia to continue to maintain and, if possible, improve the ecological character of Lake Albacutya as it was at the time of Ramsar listing, in accordance with Ramsar convention obligations. The Wimmera River between Polkemmet Bridge and the Wirrengren Plain has been classified as a Heritage River. These systems are unique and support a range of listed flora and fauna due to their well-preserved state, linkages to other important habitats, significant size and their alternating aquatic and terrestrial phases. This study was undertaken to identify the environmental water requirements of the lakes to support their environmental values.

The study has established this vision for the terminal lakes:

> "The terminal lakes of the Wimmera River will provide valuable environments in their dry phases and will respond to flooding by becoming wetlands of major national and international significance and diversity."

The vision recognises the important ecological roles of both wet and dry phases and the fact that the lakes have exceptional diversity and conservation value, in particular, when they are filled.

This study investigated the current and natural flow regimes within the terminal lakes using Wimmera REALM, a monthly time-step flow allocation model for the Wimmera River provided by the Department for Sustainability and Environment. The system was analysed in five reaches, each of which has a distinct hydrology and ecology:

- Lake Hindmarsh;
- Outlet Creek from Lake Hindmarsh to Lake Albacutya;
- Lake Albacutya;
- Southern Wyperfeld (which includes Leg of Mutton Lake, Black Flat and Lake Brambruk); and
- Northern Wyperfeld (which includes Lake Agnes and the Wirrengren Plain).

This investigation showed that under current catchment water management, the frequency and duration of flow to the terminal lakes has declined significantly compared with natural conditions.

Hydrological change threatens the ecological values of the lakes, particularly in terms of their capacity to maintain their unique ecological character, to support threatened species and to support large populations of dependent fauna. Four specific ecological objectives were identified to represent the range of ecological values that are threatened by water regime changes, and that must be achieved to realise the vision:

- the relief of drought and salinity stress in fringing Red Gum;

- regular recruitment in fringing Red Gum to provide a diverse age structure in the tree population;
- sufficiently frequent flooding to contribute significantly to the viability of visiting aquatic fauna populations; and
- the complete transition of the lake from a terrestrial ecosystem to a mature and diverse aquatic ecosystem during flooding phases.

Environmental flow targets were proposed to achieve the ecological objectives in each reach. The flow targets were compared with the current water regime and hypothetical water allocations of 60, 80 and 100 GL per year, released as a single pulse per year and when the lakes where sufficiently primed. The modelling results suggest that only the 100 GL allocation meets the majority of the flow requirements of the system. However, it may be possible to increase the effectiveness of the 80 GL allocation by amending the rules under which the water is released. This is a subject for future investigations.

The benefits of meeting these objectives would be to ensure the Wimmera terminal lakes System:

- Continues to be listed as an internationally recognised wetland and regarded as a site of high conservation significance;
- Has fringing Red Gum populations that are healthy with a diverse age structure and persist at the perimeter of the lakes over time;
- Has a mature and diverse aquatic ecosystem that develops during 'full' lake events and contributes significantly to the viability of visiting fauna populations;
- Has a diverse range of wetland habitats which provide habitat for a diverse flora and fauna (including many listed species in Victoria);
- Can support the colonisation, growth and reproduction of several fish species including Golden Perch, Catfish and Murray Cod;
- Provide for the development of communities of aquatic prey species for predatory fish and waterbirds, with associated piscivorous bird and fish guilds;
- Supports significant breeding or habitat for local and migratory waterbird species;
- Supports significant fringing woodlands;
- Provides relief of drought and salinity stress in fringing woodland vegetation, with associated tree growth and seed production; and
- Contributes to the habitat corridor between the Little Desert and Wyperfeld National Parks;

10.2 Recommendations

A number of actions or investigations are required to take the conclusions of this study into implementation. These are:

1. Secure the allocation of environmental water required to support the ecological objectives identified in this report.

2. Develop a monitoring program that can be implemented during flood events to describe and test the hydrological and ecological responses of the system anticipated by this report.

3. Investigate the potential for a more detailed and complex hydrological model with a daily time-step that can accommodate simple backwater situations to enable various options to be assessed for their effectiveness in meeting the ecological and flow objectives. The sensitivity of the model to the storage volumes at the start of runs should be evaluated.

4. Continue the Parks Victoria instituted integrated grazing management program for kangaroo and Rabbit management.

5. Conduct a longitudinal physical survey of Outlet Creek, with occasional cross sections to better describe the capacity of the flow path and nature of any flow restrictions.

6. Investigate the stability of spill levels and the relationship between depth, volume and outflow rates using both hydraulic and geomorphological disciplines.

7. The risks of flow constrictions to the delivery of hydrological objectives should be assessed and a plan prepared to manage them.

8. Investigate the barriers to fish passage within the Wimmera River and terminal lakes and any structures identified as barriers should be further investigated for retrofitting to provide passage past them.

9. Support state-wide and national initiatives for the management of carp.

10. Institute a more formal and representative groundwater monitoring program to address the specific questions of:

- how does the water table respond to flooding and drying
- how does discharge from the water table contribute to the hydrology of the lakes
- to what extent does the water table contribute to the water requirements of fringing woodland vegetation
- how are regional trends in water table elevation and salinity expressed at the lakes.

11. Conduct a study into the most efficient and effective means of transferring water from the WMDSS headworks through the terminal lakes System while maximising the environmental benefits.

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