Feasibility Investigation of Options for the Hattah Lakes

Final Report

Mallee Catchment Management Authority

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1.1 Introduction

Ecological Associates Pty Ltd was engaged by the Mallee Catchment Management Authority to investigate the feasibility of options for the Hattah Lakes. Ecological Associates undertook this project in partnership with:

- Lloyd Environmental Pty Ltd;
- URS Australia Pty Ltd; and
- Water Technology Pty Ltd.

1.2 Scope of Work

The overall objective of this project was to develop options to manage water for environmental purposes in Hattah Lakes and to assess their feasibility in terms of cost, risk and benefits.

The specific objectives were to:

- set objectives for the ecological condition of the system;
- describe the water regime required to achieve these ecological objectives;
- develop management options to provide the required water regime;
- with the assistance of the hydraulic model developed for the site, evaluate the effectiveness of the water management options in providing the required water regimes;
- assess the costs and risks associated with the water management options; and
- recommend how water management should be monitored.

1.3 The Study Area

The study comprises the floodplain associated with Hattah Lakes and comprises the area within the 1956 flood boundary between Chalka Creek East Arm and Chalka Creek North Arm.

The Hattah-Kulkyne Lakes are a component of the River Murray floodplain in north-western Victoria near the township of Hattah. The system is a complex of lakes, anabranches, termporary swamps and floodplain.

2.1 Background

The Hattah Lakes is a complex of small (<10 ha) to medium (up to 195 ha) sized lakes adjacent to the River Murray between Robinvale and Mildura. The lakes are connected to the River Murray via Chalka Creek during medium sized floods and freshes, but overbank flow is a significant source of water entering the lakes when infrequent large floods occur in the River Murray.

The River Murray is a key driver of the hydrology of the lakes. Changes in river regulation directly affect the timing, duration and frequency of inundation in the lakes system (Figure 1).

Consistent with previous studies (SKM 2004 and SKM, 2005) we analysed the behaviour of the lakes under 'natural conditions' and 'current conditions'. Natural conditions are defined as the flow regime in the River Murray prior to any regulation but with the current floodplain morphology and operating rules. Current conditions represent the River Murray flow regime under all known system modifications to date including existing operating rules. In each case the hydraulic model includes current floodplain and channel morphology within the Hattah Lakes system. While the 'natural conditions' do not entirely represent pre-settlement conditions, they provide a basis for comparison with current conditions. The differences in the scenarios are overwhelmingly due to changes in river hydrology – the effect of the current operating rule to close Messengers Regulator on the flood recession is expected to have relatively little impact on floodplain hydrology under pre-regulation flows.

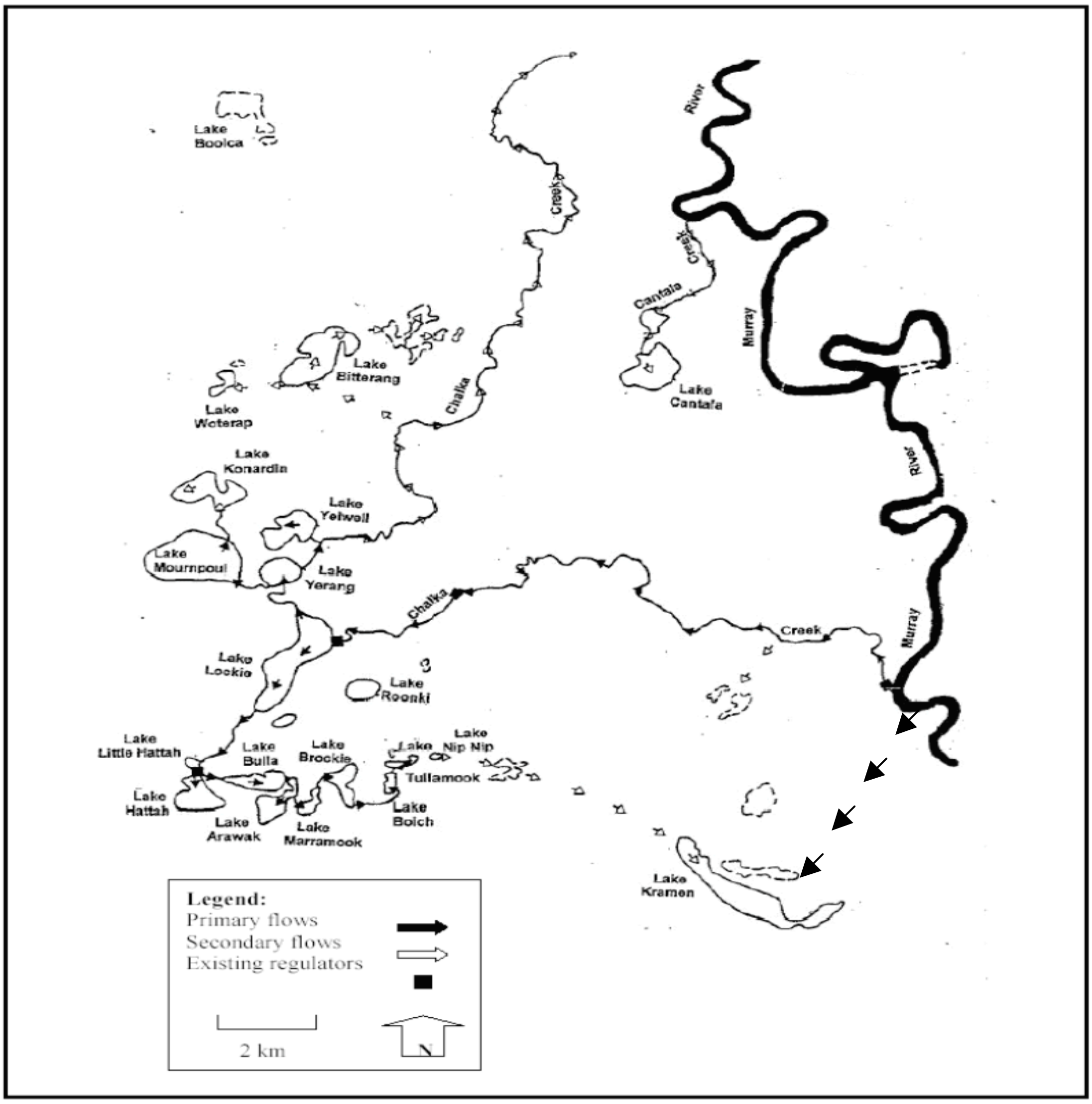
River Murray flow data for natural and current conditions was sourced from the Murray Darling Basin Commission. The flows are modelled daily time series extracted from the main system model MSM BIGMOD and represent a 92 year period (1908 – 1999 inclusive).

Time series of water level behaviour in the Hattah Lakes were generated by Sinclair Knight Merz (SKM) in January 2006 by running natural and current River Murray flows through a two dimensional hydraulic model of the system (D. Enever, *Pers. Comm.)*. The time series provided are average weekly (7 day) lake levels for each of a number of wetlands within the Hattah Lakes system. Average weekly data was considered by SKM (*ibid*.) to be the most accurate short timestep data able to be extracted from the hydraulic model. Review of recorded hydrographs at Lake Hattah suggests that there is a long recession period following inundation so that there should be little error in estimation of inundation frequencies using weekly data compared with shorter periods (eg a daily).

The hydrology of the Hattah Lakes system has been investigated on a number of occasions (see for example Puckridge et al (1997), Cumming and Lloyd (1991), SKM (2004) and SKM, 2005). SKM (2004) provide a compendium of previous studies and much of the following is based upon a review of their work including updates based upon GIS and hydrological analysis prepared by URS.

Figure 1 The Hattah Lakes and flow paths

(sources: SKM, 2004 after Cumming & Lloyd, 1991)



2.2 Inflows, thresholds and flow paths

In this section we investigate the linkages between River Murray flows and inflows to the Hattah Lakes, the thresholds and constraints on inflows, changes in flows between natural and current condition, and flow paths within the lake system.

Thresholds and Critical Flows

SKM (2004) linked the flooding of individual lakes within the Hattah Lakes system to critical flows in the River Murray at Euston based upon earlier work by Puckridge et al (1997) together with further analysis of gauged flows at Euston, aerial photography and reports of historic flood events. Critical flows at Euston were determined for eighteen lakes based upon natural and current conditions in the River Murray and the changes to structures and channels in the Hattah Lakes themselves.

Table 1 Critical flows in the River Murray at Euston

(source: SKM, 2004)

Lake	Critical Flows in the River Murray @ Euston for lake to fill (ML/D)	
	Natural Conditions	Current Conditions
Lockie	48 900	36 700
Little Hattah	48 900	36 700
Hattah	48 900	36 700
Bulla	48 900	45 000
Arawak	50 500	50 500
Marramook	52 000	52 000
Brockie	53 000	53 000
Boich	54 000	54 000
Tullamook	55 000	55 000
Nip Nip	65 000	65 000
Kramen	152 000	152 000
Yerang	48 900	40 000
Mournpall	48 900	40 000
Yelwell	55 000	55 000
Konardin	60 000	60 000
Bitterang	70 000	70 000
Cantala	45 000	45 000

Modifications to the Hattah Lakes system

The Hattah Lakes system has been modified since the early 1900s when a channel was cut between Lake Lockie and Lake Hattah to improve the reliability of water supply for Victorian Railways. A list of known modifications is presented below.

Table 2 Known modifications to the Hattah Lakes System

(source: SKM, 2004)

Year	Effect on flows within Hattah Lakes system.
1908	Channel cut between Lake Lockie and Lake Hattah. Retention level of channel between Lake Lockie and Lake Hattah reduced by 0.69 m from 42.80 mAHD to 42.11 mAHD.
1964	Earth bank constructed between Lake Hattah and Lake Little Hattah. Retention level between Lake Hattah and Lake Little Hattah increased from below 42.11 mAHD to 43.58 mAHD.
1966	Regulator constructed between Lake Hattah and Lake Little Hattah. Invert of regulator set at 41.70 mAHD allows Hattah to almost drain completely. Maximum retention level between Lake Hattah and Lake Little Hattah increased by 0.01 m to 43.59 mAHD.
1972/73	Natural bar removed at Messengers Crossing and remodelling of Chalka Creek to approximately 1 km upstream of Lake Lockie. Channel constructed between Lake Lockie and Lake Hattah. Bars constructed on northern and southern arms of Chalka Creek, however southern arm later removed. Regulators constructed along Chalka Creek at Messengers Crossing, near Lake Roonki, and at the inlet to Lake Lockie. Second two regulators along Chalka Creek scoured out after installation and rendered ineffective. Critical River Murray flow for inflow to Chalka Creek reduced from 39,100 ML/day down to 36,700 ML/day. Retention level along Chalka Creek reduced from 42.58 mAHD to 41.64 mAHD. Critical River Murray flow for inflow to Lake Lockie and subsequent lakes reduced from 48,900 ML/day down to 36,700 ML/day. Retention level of channel between Lake Lockie and Lake Hattah unknown. Retention level of north arm of Chalka Creek estimated to be approximately 42.67 mAHD. Regulator at Messengers constructed to have a maximum retention level of 43.40 mAHD.
1986/97	Soil removed in two high spots along channel between Lake Lockie and Lake Hattah. Retention level of channel between Lake Lockie and Lake Hattah reduced by 0.3 m. Current Messengers crossing reconfigured to allow greater inflows. Current practice is to close Messengers regulator once flows out north arm of Chalka Creek cease. Gates between Lake Hattah and Lake Little Hattah removed. Messengers regulator invert reduced by 0.2 m, however no evidence to suggest the critical River Murray flow for inflow to Lake Lockie has reduced. Maximum retention level of Messengers regulator not changed. Retention level between Lake Hattah and Lake Little Hattah reduced to 41.70 mAHD. Invert of regulator allows Hattah to almost drain completely.

According to SKM (2004) the net effect of these modifications is as follows:

- A decrease in the flow in the River Murray at Euston needed to initiate inflow to Lake Lockie (ie a reduction in the critical flow from 48,900 ML/day to 36,700 ML/day).
- A subsequent reduction in critical flows for other lakes in the system.
- A decrease in the retention level of Lake Hattah.

Table 1 contains a listing of natural and current critical flows at Euston required to initiate filling of each lake. ‘Current’ critical flows account for all historic changes to the Hattah Lakes system.

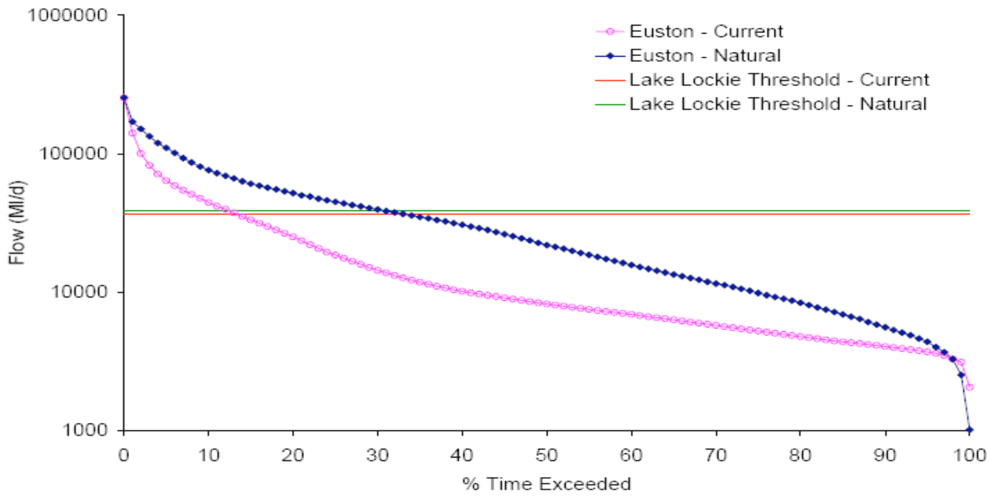
Changes in River Murray flow regime

Since 1936 a succession of dams, weirs and locks has been built along the River Murray to ensure reliable supply of water for irrigation and urban use. The general impact has been to reduce peak flows, change the seasonality of flows and increase minimum flows.

SKM (2005) analysed changes in River Murray flows at Euston Weir by comparing annual flow duration curves referenced to the critical flows required to commence filling of Lake Lockie.

Figure 2 Annual flow duration curve for River Murray at Euston

(source SKM, 2005)

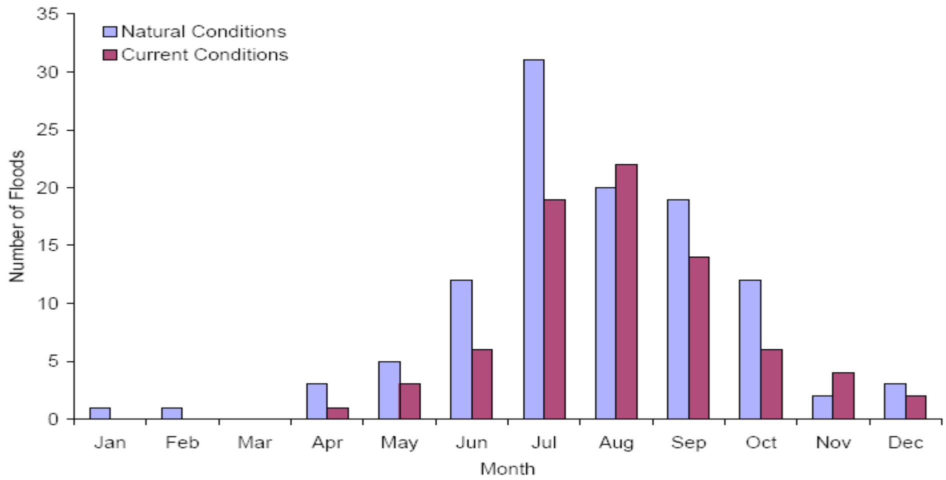


There is a significant shift across the range of observed flows in the River Murray between natural and current conditions. At the threshold level for inflows to Lake Lockie there has been a shift in frequency of inflows from around 30% to 12% of the time. With the reduction in Lake Lockie threshold arising from the installation of Messengers Regulator few additional inflows can be expected.

SKM (2005) suggest that it is physically impossible to restore a natural flooding regime to the lakes under the current Murray River flow regime without using mechanical means to deliver the water.

SKM (2005) also analysed the commencement month of floods in the River Murray under natural and current conditions. The analysis (Figure 3) indicates that there has been a significant modification of flooding in the River Murray with a shift in the mode of the frequency distribution of flooding from August to July, significant reductions in flood frequency for most of months, and much smoother distribution of floods throughout the year.

Figure 3 Commencement month for floods in the River Murray at Euston



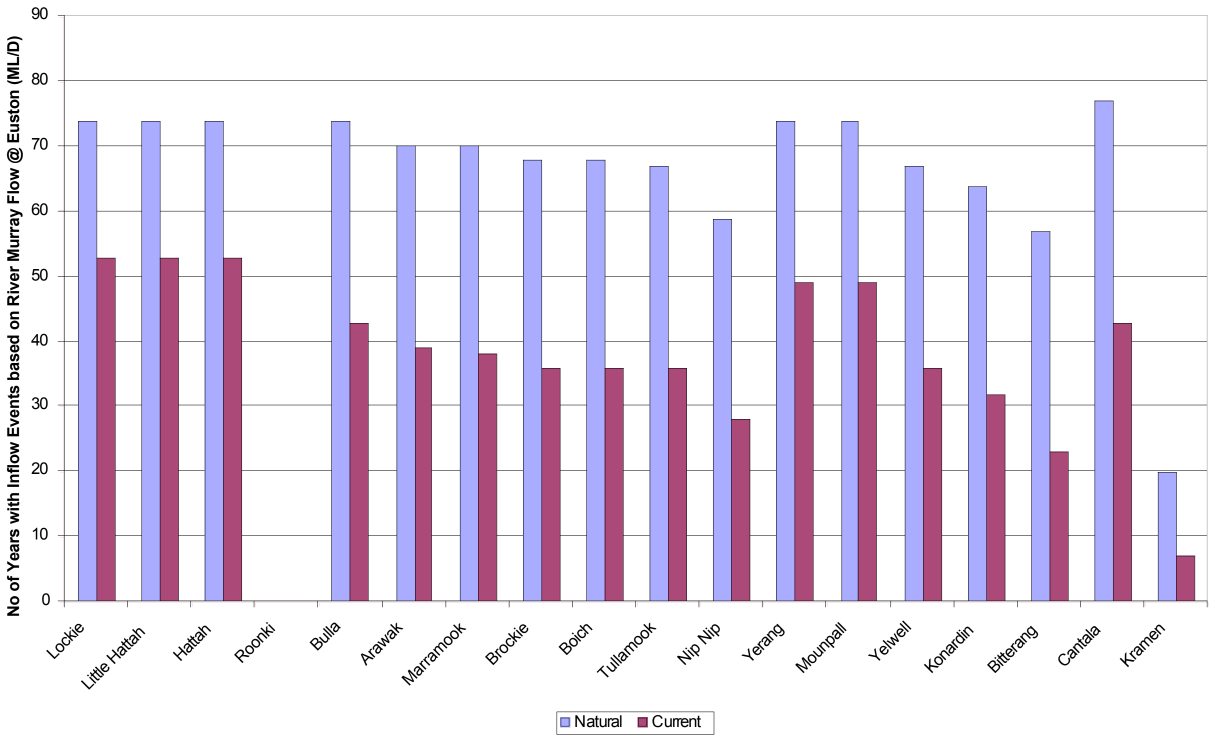
Years with inflows

The number of years with inflows to each lake significantly decreased under current conditions compared to natural conditions (Figure 4 and Appendix A).

Under natural conditions, Lake Cantala has the most number of years with inflow events (77) due to its low critical flow required in the River Murray at Euston. Lakes Lockie, Hattah, Little Hattah, Bulla, Yerang and Mournpall have the next highest number of years of inflows. Kramen, as expected, has the lowest number of years with inflow events due to high critical flows required before it can be filled up.

Lakes Nip Nip, Konardin, Bitterang and Kramen have incurred a reduction of more than 50% in years of inflow compared to natural conditions.

Figure 4 Number of years with inflows to the Hattah Lakes (1908 – 1999)



Monthly inflows

Plots of monthly inflows into the Hattah Lakes are provided for groups of lakes with similar critical flows in the River Murray at Euston.

Figure 5 shows that the majority of monthly inflows to lakes Lockie, Little Hattah and Hattah occur between July to September with majority of inflows in August under natural and current conditions.

A similar monthly inflow pattern is evident for lakes Yerang and Mournpall (Figure 7) with most inflows occurring between July to September and the highest number of inflows in August under both natural and current conditions.

For lakes Tullamook and Yelwell (Figure 6) monthly inflows occur between July to September with most inflows in August under natural conditions. Under current conditions the majority of inflows have shifted to August to October peaking in September.

Under natural conditions, inflow events occur mostly between July to September in most of the lakes except Nip Nip and Kramen with majority of the events happening in August (Appendix B). Under current conditions majority of inflow events occurred between August and October in lakes Arawak, Marramook, Brockie, Boich, Tullamook, Nip Nip, Yelwell, Konardin, Bitterang and Kramen with most of the inflows occurring in September.

Figure 5 Monthly inflows for Lockie, Little Hattah and Hattah (1908 – 1999)

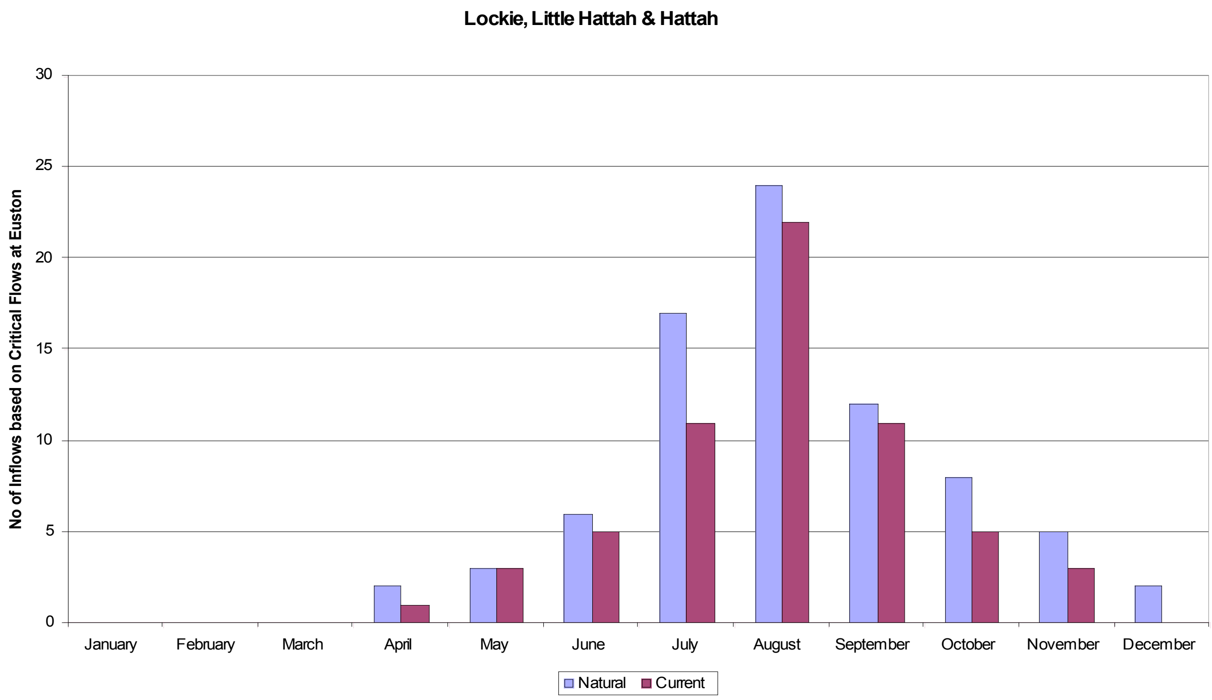


Figure 6. Monthly inflows for Tullamook and Yelwell (1908-1999)

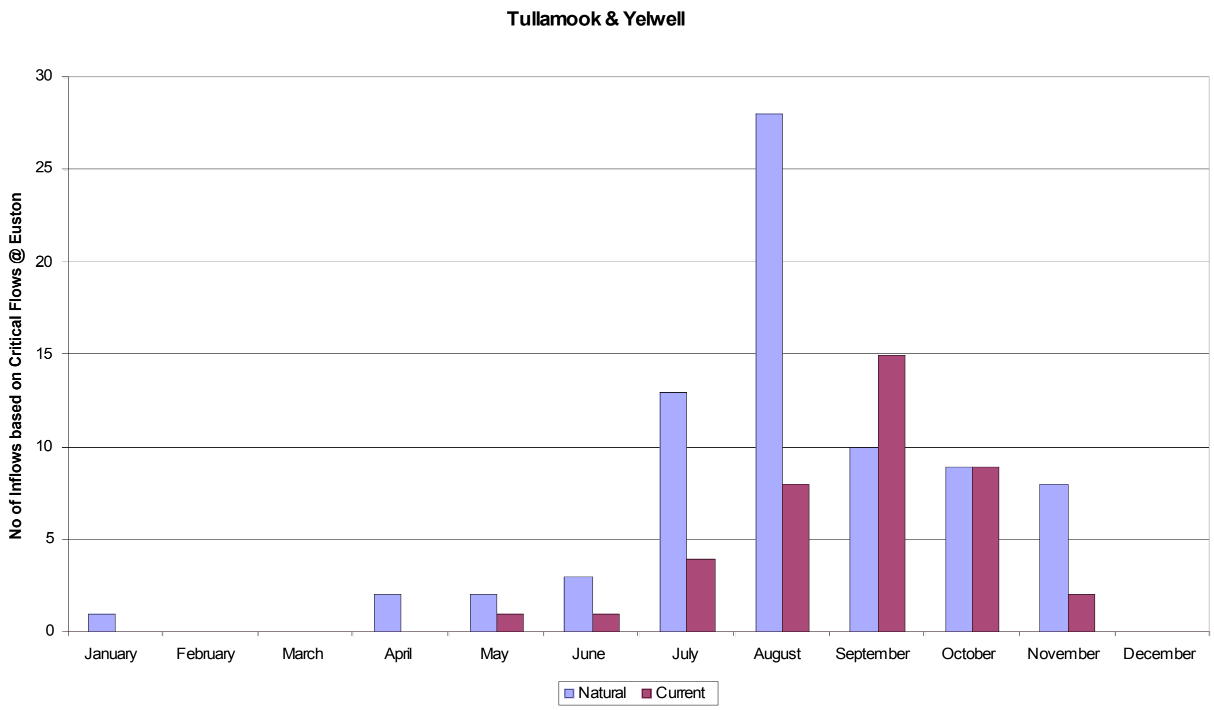
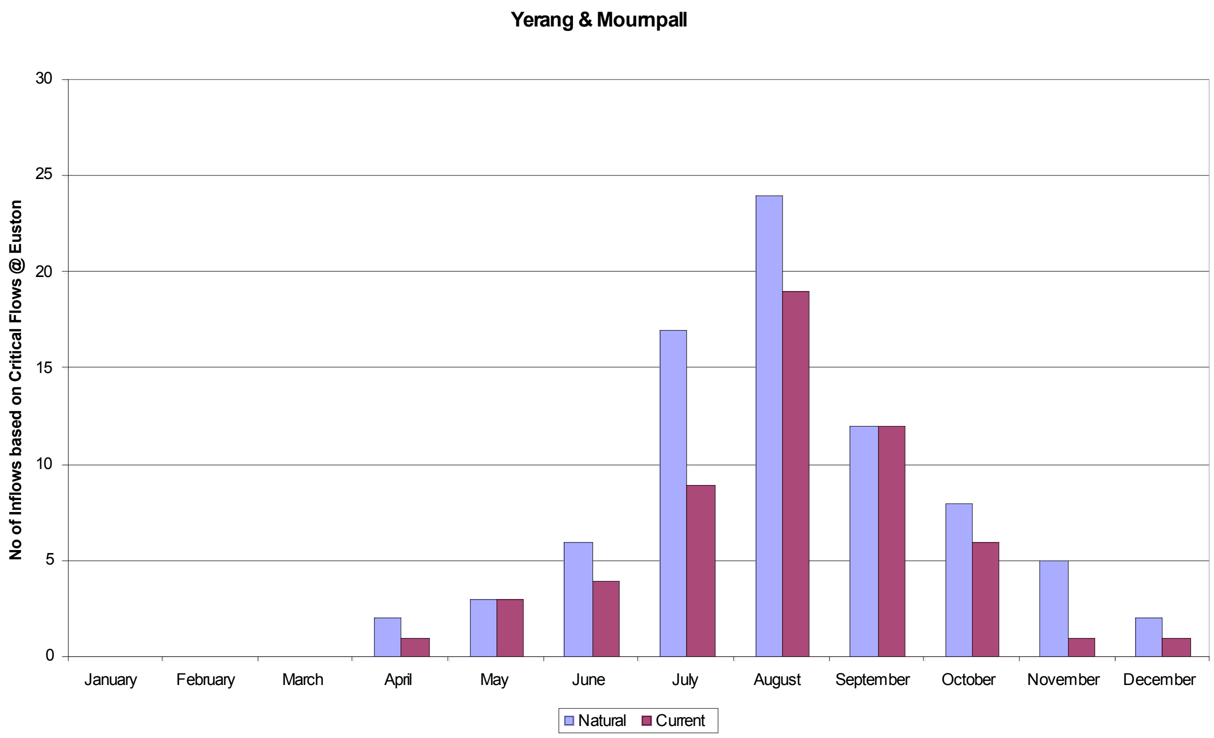


Figure 7. Monthly inflows for Yerang and Mournpall (1908-1999)



Flow Paths and Travel Times

Figure 1 provides an overview of the flow paths within the Hattah Lakes system based upon the SKM (2004) modification of the original analysis by Cumming and Lloyd (1992).

Water enters the system via Chalka Creek. Chalka Creek can act as a small backwater if inflows are insufficient, but once a threshold is reached water then moves into Lake Lockie and from there southwards to Lake Hattah and Lake Little Hattah. Once another threshold is reached, water will flow north into Lake Yerang and Lake Mournpall. Beyond this point water flows either further south through Lake Bulla, Lake Arawak, Lake Marramook, Lake Brockie, Lake Boich, Lake Tullamook and Lake Nip Nip; or north to Lake Konardin, Lake Yelwell, Lake Bitterang and Lake Woterap.

The DEM suggests that Lake Roonki initially receives water via small channels and wetlands to the south-east of Lake Lockie.

Lake Kramen appears to fill mainly from a flow path running south from Chalka Creek near the River Murray. There has been some suggestion that flows running south through the series of lakes to Lake Nip Nip may eventually reach Lake Kramen but this is thought to occur very rarely.

Water drains from the lake system via both the southern and northern arms of Chalka Creek. In smaller floods, provided Messenger's Regulator is open all water drains via the southern arm of Chalka Creek. For floods in excess of a threshold which corresponds to a River Murray peak flow of somewhere between 50,000 and 80,000 ML/day, water also drains via the northern arm of Chalka Creek.

Lake Cantala receives water from the River Murray via Cantala Creek.

SKM (2004) and Puckridge et al (1997) estimated flood flow travel times from Euston into the Hattah Lakes as shown below.

Table 3 Approximate travel times from Euston

Location	Travel time (days)	Source
Chalka Creek	2	Puckridge et al (1997)
Lake Lockie	6	Puckridge et al (1997)
Lake Little Hattah	11	Puckridge et al (1997)
Lake Hattah	11	Puckridge et al (1997)
Lake Bulla	14?	SKM (2004)
Lake Arawak	16	Puckridge et al (1997)
Lake Marramook	18	Puckridge et al (1997)
Lake Brockie	21	SKM (2004)
Lake Boich	23	SKM (2003)
Lake Tullumook	26	Puckridge et al (1997)
Lake Nip Nip	28	Puckridge et al (1997)
Lake Kramen	>32?	SKM (2004)
Lake Yerang	7	SKM (2004)
Lake Mournpall	9	Puckridge et al (1997)
Lake Yelwell	9	SKM (2004)
Lake Konardin	11	SKM (2004)
Lake Bitterang	32	Puckridge et al (1997)
Lake Cantala	4	SKM (2004)

NOTE ? speculative estimates (SKM, 2005)

2.3 Lake level behaviour

The following section provides an overview of lake level behaviour in the Hattah Lakes. Sections include a discussion of 'typical' lake levels represented by averages and medians, proportions of time the lakes are wet or dry, a review of wetting and drying behaviour, and a spells analysis for specified lake level ranges.

Average and median water levels

The average and median water levels of all the lakes are lower under current conditions than under natural conditions (Figure 8 and Figure 9). Water levels statistics for each lake are tabulated in Appendix C.

Figure 8 Average lake levels under natural and current conditions

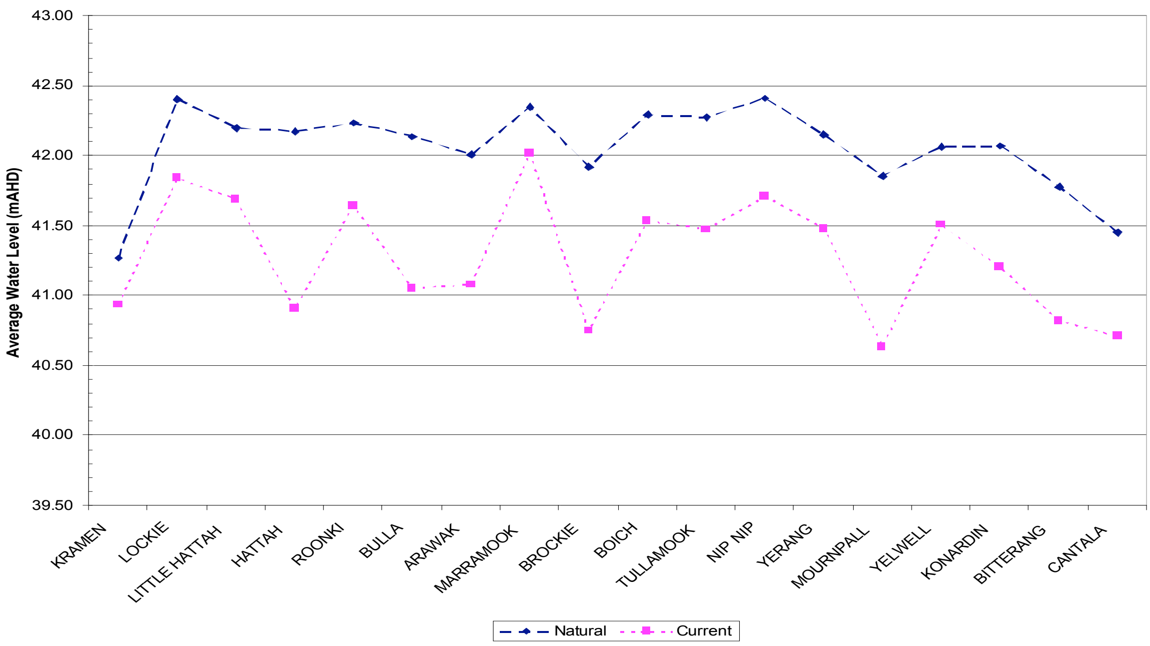


Figure 9 Median lake levels under natural and current conditions

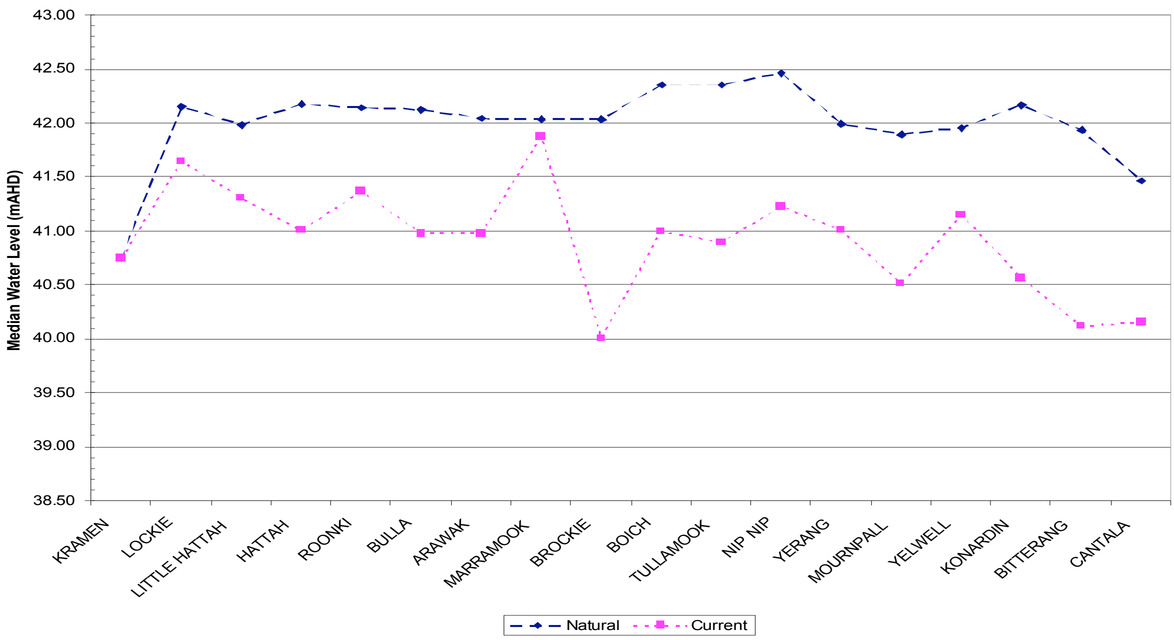
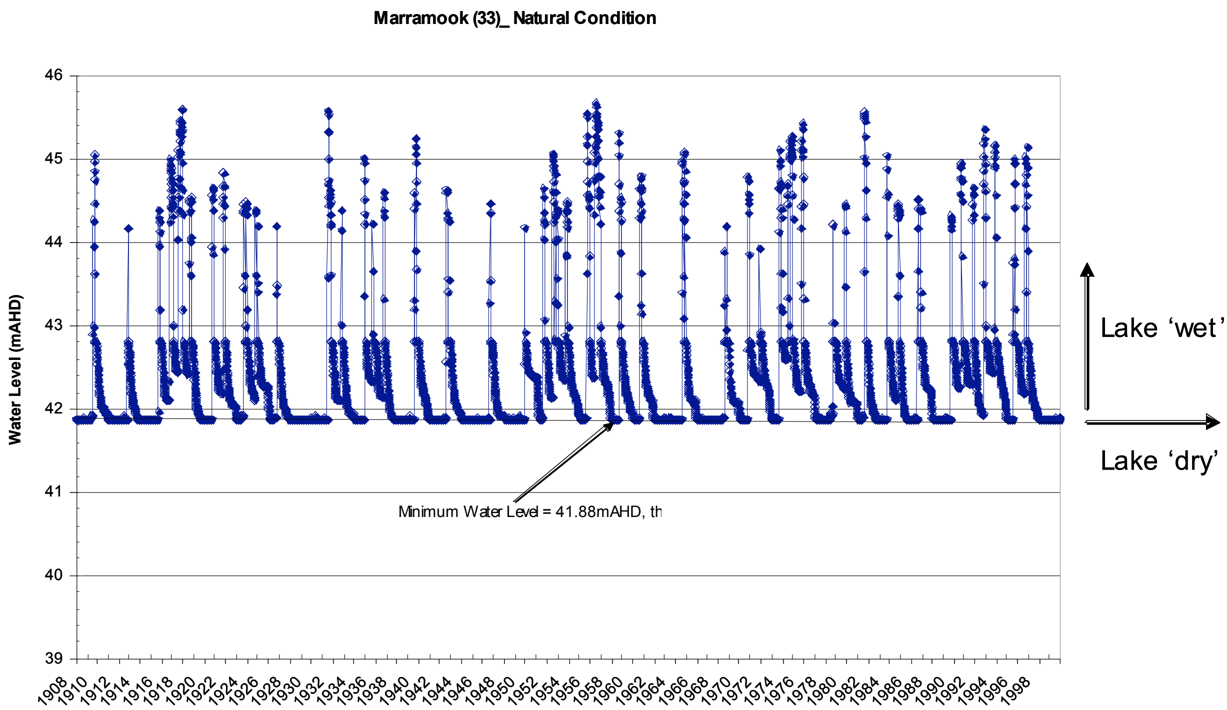


Figure 10 provides an example of the definition of wet and dry lake levels for Lake Marramook.

Figure 10 Definition of 'wet' and 'dry' lake levels

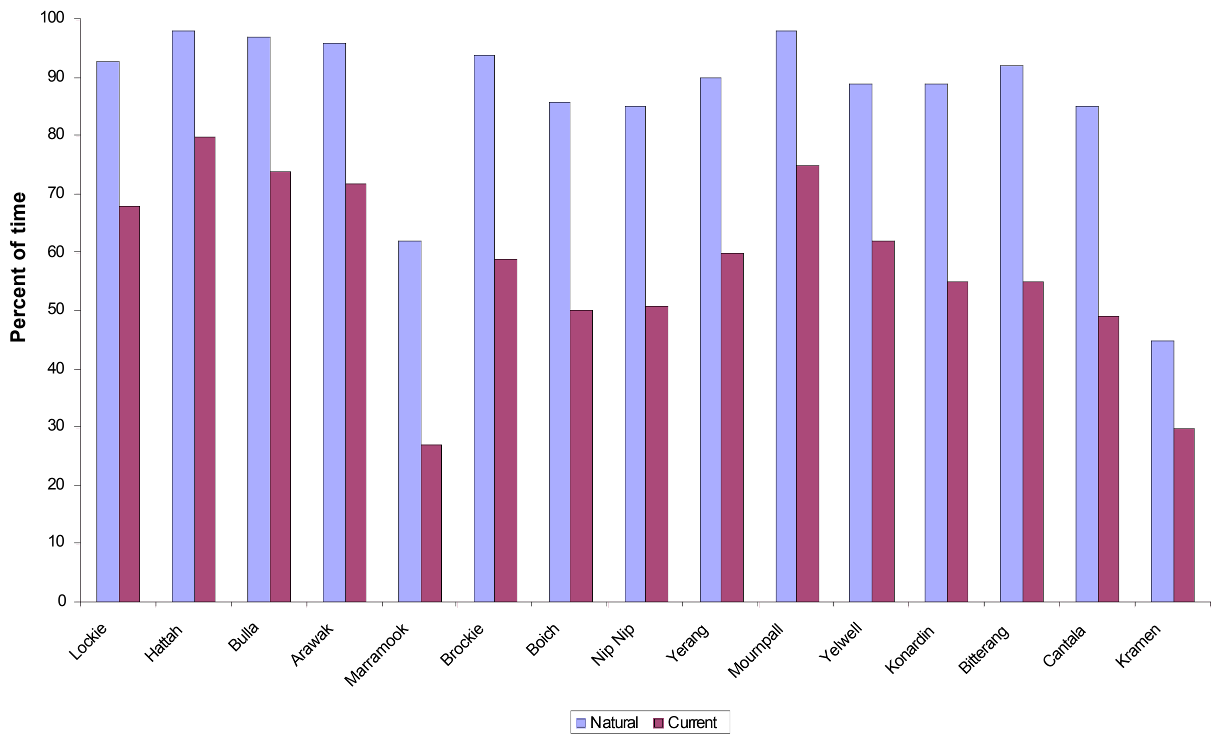


Proportion of time that lakes are 'wet'

For the purposes of this analysis, a lake was considered 'wet' when the observed average weekly water level was higher than the minimum modelled water level across the entire period 1908 – 1999 inclusive. A lake was considered 'dry' only when the modelled water level was equal to the minimum modelled lake water level (see for example Figure 10). For some purposes this may overestimate the duration of wet events because the there is an exponential decay in water levels as wetlands dry out. The model predicts a long 'tail' to these drying events, whereas the wetlands actually dry out faster than this. The 25% full threshold used in the spell analysis (below) provides an alternative estimate of dry events.

An analysis of the 92-year weekly lake level data shows that all the lakes are now drier than under natural conditions (Figure 11).

Figure 11 Percentage of time Hattah Lakes are wet (1908-1999)



Wetting and Drying

The wetting and drying behaviour of the lakes was examined by counting the number of years that lakes are wet/dry for at least 1 week or for at least 4 weeks. All results are expressed as a percentage of modelled lake level years (Table 4).

Table 4. Percent of years lakes are wet/dry for at least one week (1908 – 1999)

Lake	Wet		Dry	
	Natural	Current	Natural	Current
Lockie	100	100	19	59
Hattah	100	100	3	30
Little Hattah	100	99	37	72
Bulla	100	99	6	36
Arawak	100	98	9	38
Roonki	100	100	18	53
Marramook	93	91	65	86
Brockie	100	99	13	56
Boich	100	95	25	65
Tullamook	100	91	25	70
Nip Nip	100	98	29	73
Yerang	100	99	20	66
Mournpall	100	99	4	40
Yelwell	100	98	23	61
Konardin	100	92	23	68
Bitterang	100	97	17	62
Cantala	100	92	28	71
Kramen	99	99	78	93

Table 5. Years lakes are wet/dry for at least four weeks (1908 – 1999)

Lake	Wet		Dry	
	Natural	Current	Natural	Current
Lockie	100	87	17	55
Hattah	99	91	3	30
Little Hattah	96	79	39	74
Bulla	99	91	7	37
Arawak	99	90	9	40
Roonki	99	88	18	55
Marramook	83	61	61	93
Brockie	99	83	12	59
Boich	97	77	26	70
Tullamook	98	74	23	70
Nip Nip	96	87	27	71
Yerang	98	84	18	63
Mournpall	99	89	4	36
Yelwell	98	85	20	58
Konardin	99	75	23	65
Bitterang	99	78	15	60
Cantala	97	75	26	70
Kramen	71	61	76	92

Spells Analysis

A spells analysis was undertaken for the following lake levels under natural and current conditions:

zero% (minimum water level, the lake is considered dry)

<25% of retention level

>25% of retention level

>50% of retention level

>75% of retention level

>100% (higher than the retention level)

42.5m to 45.5 at an interval of 0.5m

The retention level of each lake was identified by GIS analysis of the LIDAR data. The retention levels from SKM (2004) were not used since they were based on sketchy and anecdotal information prior to the availability of LIDAR.

For this analysis a spell was considered to occur when lake levels are above or below the nominated threshold value, as appropriate. The spell duration is the number of weeks when the storage level is continuously above or below a given threshold.

Table 6 shows the following under the natural and current conditions:

- the percentage of time that the threshold capacities were exceeded = number of weeks above the threshold divided by the total number of weeks;
- the percentage of years with events = number of years at threshold divided by the number of years; and
- the result of the spell analysis such as the number of events, the average and median durations of each event in weeks.

The number of dry spells within the 92-year data set and the average duration of each spell in weeks increased under the current condition than under the natural condition in majority of the lakes with the exception of Marramook, Yelwell, and Kramen where the average duration of each spell decreased under the current condition. The number of wet spells (>25% lakes' capacity) decreased and the average duration of each spell is shorter under the current condition in most of the lakes except Lockie, Little Hattah, Bulla, Arawak, Yerang and Mournpall where the number of wet spells increased (Table 6).

The average duration of a spell is significantly longer than the median duration showing the high degree of skew in the distribution of spell durations and is assumed to reflect the influence of a small number of significant flood sequences that lead to long spell durations. Changes in the median inundation durations are shown graphically in Figure 12 to Figure 29. The inundation duration curves often show two clear steps in median duration of inundation.

On the flood recession, flood water is able to discharge relatively freely from the floodplain to the river while the water level is greater than 43 or 43.5 m AHD. Accordingly, the depth of inundation on the floodplain falls relatively quickly until this point, and the rate is expected to correspond closely to the falling limb of the river hydrograph. Recorded lake level hydrographs in the system together with mapping of the 1956 event (RWC and WRC, 1986) supports this behaviour.

At 43 or 43.5m AHD the median duration of inundation is significantly higher. This is interpreted to be due to the local topography around various lakes with constrictions slowing the return of flood water to the River Murray. The constrictions appear to retain water on the floodplain around groups of lakes in approximately five discernable regions:

- Mournpall, Yelwell and Yerang;
- Bitterang and Konardin;
- Nip Nip, Tullamook and Boich;
- Brockie, Bulla, Roonki, Arawak and Marramook; and
- Hattah, Little Hattah and Lockie.

Once the retention levels of the lakes are reached (typically around 42.3 m AHD) the median event duration increases very significantly since the loss of water is governed by the net effect of evaporation from and rainfall onto the lake surface.

Lakes Kramen and Cantala do not fit this pattern. At these sites, flood water appears to recede freely until the retention level of the lake is reached.

Table 6. Spells analysis of Hattah Lakes water levels

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Lockie	**41.24m (0%)**	**93.0**	**16.3**	**38.0**	**8.8**	**6.0**	**68.3**	**55.4**	**161.0**	**9.4**	**5.0**
	41.48m (<25%)	**88.8**	**17.4**	**16.0**	**33.4**	**28.0**	**56.0**	**32.2**	**30.0**	**70.2**	**35.5**
	41.48m (>25%)	**88.7**	**18.5**	**17.0**	**249.7**	**22.5**	**55.6**	**30.4**	**30.0**	**88.7**	**69.5**
	41.72m (>50%)	**82.6**	**34.8**	**34.0**	**116.3**	**81.0**	**46.0**	**38.0**	**38.0**	**57.9**	**43.0**
	41.96m (>75%)	**65.8**	**58.7**	**60.0**	**52.5**	**38.5**	**32.9**	**46.7**	**47.0**	**33.5**	**29.0**
	42.20m (>100%)	**46.9**	**75.0**	**77.0**	**29.2**	**28.0**	**22.8**	**46.7**	**46.0**	**23.7**	**23.0**
	>42.50m	**30.5**	**63.0**	**78.0**	**18.7**	**20.5**	**13.8**	**42.4**	**44.0**	**15.0**	**14.5**
	>43.00m	**19.7**	**68.5**	**82.0**	**11.5**	**9.5**	**8.0**	**38.0**	**46.0**	**8.4**	**6.0**
	>43.50m	**13.5**	**59.8**	**78.0**	**8.3**	**6.0**	**4.8**	**28.3**	**33.0**	**6.9**	**4.0**
	>44.00m	**9.2**	**50.0**	**67.0**	**6.6**	**5.0**	**3.2**	**21.7**	**24.0**	**6.4**	**3.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.9**	**12.0**	**12.0**	**7.4**	**5.0**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.4**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Little Hattah	41.30m (0%)	82.8	37.0	69.0	12.0	8.0	52.0	69.6	176.0	13.1	7.5
	41.55m (<25%)	73.7	32.6	31.0	40.6	31.0	35.5	33.7	31.0	99.6	77.0
	41.55m (>25%)	73.5	30.4	28.0	125.5	118.5	35.2	31.5	29.0	58.0	56.0
	41.80m (>50%)	63.1	41.3	39.0	77.4	71.0	27.6	31.5	31.0	42.6	27.0
	42.05m (>75%)	46.0	54.4	58.0	38.0	31.0	18.6	37.0	39.0	22.8	20.0
	42.30m (>100%)	30.7	63.0	74.0	19.9	22.0	12.4	38.0	43.0	13.7	14.0
	>42.50m	22.3	57.6	74.0	14.4	15.0	8.9	34.8	38.0	11.2	9.5
	>43.00m	13.9	59.8	77.0	8.6	7.0	5.2	29.4	33.0	7.6	5.0
	>43.50m	10.6	53.3	72.0	7.1	5.0	4.0	25.0	29.0	6.6	4.0
	>44.00m	8.9	48.9	66.0	6.5	5.0	3.1	21.7	24.0	6.3	3.0
	>44.50m	4.9	33.7	41.0	5.7	4.0	1.8	12.0	12.0	7.3	4.5
	>45.00m	2.0	19.6	21.0	4.5	3.0	0.8	6.5	10.0	3.7	2.5
	>45.50m	0.3	5.4	5.0	2.8	2.0	0.1	1.1	1.0	3.0	3.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Hattah	39.20m (0%)	98.2	3.3	8.0	10.8	8.5	80.5	28.3	64.0	14.6	9.5
	39.98m (<25%)	96.1	5.4	5.0	37.0	23.0	68.2	15.2	14.0	108.8	65.0
	39.98m (>25%)	96.1	5.4	5.0	919.8	291.0	68.2	14.1	13.0	250.9	172.0
	40.75m >50%)	91.4	10.9	10.0	437.0	337.0	55.5	20.7	21.0	126.5	112.0
	41.52m (>75%)	77.0	28.3	26.0	141.7	131.5	35.8	31.5	30.0	57.1	50.0
	42.30m (>100%)	40.9	56.5	65.0	30.1	28.0	12.3	38.0	43.0	13.7	14.0
	>42.50m	28.9	58.7	68.0	20.3	23.5	8.9	34.8	38.0	11.2	9.5
	>43.00m	13.9	60.9	77.0	8.7	7.0	5.2	29.4	33.0	7.6	5.0
	>43.50m	10.6	53.3	72.0	7.1	5.0	4.0	25.0	29.0	6.6	4.0
	>44.00m	8.9	48.9	66.0	6.5	5.0	3.1	21.7	24.0	6.3	3.0
	>44.50m	4.9	33.7	41.0	5.7	4.0	1.8	12.0	12.0	7.3	4.5
	>45.00m	2.0	19.6	21.0	4.5	3.0	0.8	6.5	10.0	3.7	2.5
	>45.50m	0.3	5.4	5.0	2.8	2.0	0.1	1.1	1.0	3.0	3.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Roonki	**40.98m (0%)**	**91.0**	**17.4**	**43.0**	**10.0**	**7.0**	**65.0**	**56.5**	**164.0**	**10.2**	**6.0**
	41.31m (<25%)	**80.8**	**25.0**	**24.0**	**38.3**	**23.0**	**50.7**	**23.9**	**22.0**	**107.1**	**79.0**
	41.31m (>25%)	**80.6**	**26.1**	**25.0**	**154.2**	**136.0**	**50.6**	**22.8**	**21.0**	**115.2**	**113.0**
	41.64m (>50%)	**73.5**	**30.4**	**29.0**	**121.2**	**110.0**	**43.6**	**27.2**	**26.0**	**80.2**	**61.0**
	41.97m (>75%)	**61.5**	**41.3**	**42.0**	**70.0**	**57.5**	**27.8**	**37.0**	**34.0**	**39.1**	**28.5**
	42.30m (>100%)	**39.1**	**53.3**	**59.0**	**31.7**	**29.0**	**17.1**	**40.2**	**40.0**	**20.5**	**20.0**
	>42.50m	**27.4**	**56.5**	**64.0**	**20.5**	**22.5**	**12.5**	**40.2**	**40.0**	**15.0**	**14.5**
	>43.00m	**12.9**	**58.7**	**78.0**	**7.9**	**6.0**	**6.5**	**37.0**	**39.0**	**8.0**	**6.0**
	>43.50m	**10.4**	**54.4**	**71.0**	**7.0**	**5.0**	**4.4**	**25.0**	**30.0**	**7.0**	**4.0**
	>44.00m	**8.7**	**48.9**	**67.0**	**6.2**	**5.0**	**3.2**	**21.7**	**24.0**	**6.3**	**3.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.9**	**12.0**	**12.0**	**7.4**	**5.0**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.4**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Bulla	**39.85m (0%)**	**97.1**	**5.4**	**9.0**	**15.7**	**10.0**	**73.9**	**31.5**	**67.0**	**18.7**	**11.0**
	40.46m (<25%)	**93.5**	**8.7**	**8.0**	**38.8**	**30.5**	**60.1**	**19.6**	**18.0**	**106.1**	**70.5**
	40.46m (>25%)	**93.5**	**8.7**	**8.0**	**559.3**	**348.5**	**60.1**	**18.5**	**17.0**	**169.1**	**120.0**
	41.08m (>50%)	**86.6**	**16.3**	**15.0**	**276.3**	**191.0**	**47.8**	**25.0**	**23.0**	**99.4**	**77.0**
	41.69m (>75%)	**71.4**	**31.5**	**31.0**	**110.1**	**98.0**	**31.2**	**31.5**	**30.0**	**49.8**	**35.0**
	42.30m (>100%)	**38.3**	**52.2**	**56.0**	**32.7**	**29.0**	**11.2**	**33.7**	**36.0**	**14.9**	**15.0**
	>42.50m	**26.8**	**57.6**	**64.0**	**20.1**	**22.5**	**8.0**	**30.4**	**33.0**	**11.6**	**12.0**
	>43.00m	**12.5**	**59.8**	**80.0**	**7.5**	**5.0**	**4.6**	**27.2**	**31.0**	**7.1**	**4.0**
	>43.50m	**10.2**	**52.2**	**69.0**	**7.1**	**5.0**	**3.8**	**23.9**	**28.0**	**6.5**	**4.0**
	>44.00m	**8.7**	**48.9**	**66.0**	**6.3**	**5.0**	**3.1**	**21.7**	**24.0**	**6.2**	**3.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.8**	**12.0**	**12.0**	**7.3**	**4.5**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.8**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Arawak	39.94m (0%)	95.6	9.8	14.0	15.2	10.0	72.1	33.7	58.0	23.0	16.5
	40.53m (<25%)	89.7	13.0	12.0	41.0	30.5	59.4	19.6	18.0	107.9	73.0
	40.53m >25%)	89.5	13.0	13.0	329.5	141.0	59.2	18.5	17.0	166.7	119.0
	41.12m (>50%)	80.9	17.4	18.0	214.9	178.0	46.2	26.1	24.0	92.1	75.5
	41.71m (>75%)	63.6	34.8	33.0	92.2	75.0	30.3	30.4	30.0	48.3	33.0
	42.30m (>100%)	33.2	50.0	55.0	28.9	27.0	11.2	33.7	36.0	14.9	15.0
	>42.50m	24.3	56.5	61.0	19.0	22.0	8.0	30.4	33.0	11.6	12.0
	>43.00m	10.9	53.3	72.0	7.2	5.5	4.6	27.2	31.0	7.1	4.0
	>43.50m	9.7	51.1	67.0	6.9	5.0	3.8	23.9	28.0	6.5	4.0
	>44.00m	8.4	48.9	66.0	6.1	5.0	3.1	21.7	24.0	6.2	3.0
	>44.50m	4.9	33.7	41.0	5.7	4.0	1.8	12.0	12.0	7.3	4.5
	>45.00m	2.0	19.6	21.0	4.5	3.0	0.8	6.5	10.0	3.7	2.5
	>45.50m	0.3	5.4	5.0	2.8	2.0	0.1	1.1	1.0	3.0	3.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Marramook	**41.88m (0%)**	**61.7**	**44.6**	**71.0**	**25.8**	**16.0**	**27.3**	**77.2**	**141.0**	**24.7**	**17.0**
	41.98m (<25%)	**52.4**	**30.4**	**28.0**	**81.4**	**75.0**	**15.0**	**19.6**	**18.0**	**225.9**	**144.0**
	41.98m (>25%)	**52.4**	**29.4**	**27.0**	**92.8**	**81.0**	**15.0**	**17.4**	**17.0**	**42.2**	**29.0**
	42.09m (>50%)	**47.1**	**29.4**	**34.0**	**66.2**	**58.0**	**12.5**	**18.5**	**17.0**	**35.2**	**24.0**
	42.20m (>75%)	**40.3**	**38.0**	**36.0**	**53.6**	**37.0**	**10.7**	**20.7**	**19.0**	**26.8**	**21.0**
	42.30m (>100%)	**33.7**	**42.4**	**41.0**	**39.3**	**31.0**	**8.7**	**20.7**	**20.0**	**20.9**	**19.5**
	>42.50m	**23.6**	**47.8**	**46.0**	**24.5**	**23.0**	**6.4**	**20.7**	**20.0**	**15.4**	**14.0**
	>43.00m	**9.2**	**48.9**	**65.0**	**6.8**	**5.0**	**3.3**	**20.7**	**23.0**	**6.9**	**4.0**
	>43.50m	**8.5**	**48.9**	**66.0**	**6.1**	**5.0**	**2.9**	**19.6**	**22.0**	**6.3**	**3.5**
	>44.00m	**7.7**	**47.8**	**63.0**	**5.8**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.8**	**12.0**	**12.0**	**7.3**	**4.5**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.4**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Brockie	**39.99m (0%)**	**94.1**	**14.1**	**36.0**	**7.9**	**4.0**	**58.6**	**59.8**	**179.0**	**11.1**	**6.0**
	40.57m (<25%)	**85.7**	**14.1**	**13.0**	**52.7**	**40.0**	**38.8**	**14.1**	**13.0**	**225.2**	**139.0**
	40.57m (>25%)	**85.7**	**13.0**	**12.0**	**341.6**	**202.5**	**38.8**	**13.0**	**12.0**	**154.8**	**115.0**
	41.14m (>50%)	**75.9**	**19.6**	**18.0**	**201.7**	**144.0**	**29.1**	**16.3**	**15.0**	**92.9**	**77.0**
	41.72m (>75%)	**61.0**	**27.2**	**26.0**	**112.3**	**97.0**	**22.1**	**16.3**	**15.0**	**70.3**	**55.0**
	42.30m (>100%)	**33.6**	**42.4**	**41.0**	**39.2**	**30.0**	**8.6**	**20.7**	**20.0**	**20.7**	**19.0**
	>42.50m	**23.5**	**47.8**	**46.0**	**24.4**	**23.0**	**6.4**	**20.7**	**20.0**	**15.2**	**14.0**
	>43.00m	**9.2**	**48.9**	**65.0**	**6.8**	**5.0**	**3.2**	**20.7**	**23.0**	**6.7**	**4.0**
	>43.50m	**8.4**	**48.9**	**66.0**	**6.1**	**5.0**	**2.8**	**19.6**	**22.0**	**6.2**	**3.5**
	>44.00m	**7.7**	**47.8**	**63.0**	**5.8**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.8**	**12.0**	**12.0**	**7.3**	**4.5**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.4**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Boich	41.00m (0%)	86.1	21.7	40.0	16.7	12.0	49.7	60.9	131.0	18.4	11.0
	41.40m (<25%)	77.4	18.5	17.0	63.6	58.0	33.8	17.4	16.0	198.1	115.5
	41.40m (>25%)	77.2	17.4	16.0	230.9	144.0	33.6	16.3	15.0	107.2	98.0
	41.80m (>50%)	65.3	26.1	24.0	130.3	103.5	27.6	16.3	16.0	82.4	71.0
	42.20 (>75%)	57.6	28.3	26.0	105.9	84.5	22.8	16.3	15.0	72.7	57.0
	42.60m (>100%)	34.7	41.3	39.0	42.6	32.0	12.6	18.5	17.0	35.4	24.0
	>43.00m	18.5	44.6	48.0	18.5	18.0	6.6	20.7	20.0	15.7	14.5
	>43.50m	8.7	48.9	66.0	6.3	5.0	3.0	20.7	23.0	6.2	3.0
	>44.00m	7.7	47.8	63.0	5.9	4.0	2.7	18.5	21.0	6.1	4.0
	>44.50m	4.9	33.7	41.0	5.7	4.0	1.8	12.0	12.0	7.3	4.5
	>45.00m	2.0	19.6	21.0	4.5	3.0	0.8	6.5	10.0	3.7	2.5
	>45.50m	0.3	5.4	5.0	2.8	2.0	0.1	1.1	1.0	3.0	3.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Tullamook	**40.90m (0%)**	**87.2**	**19.6**	**27.0**	**22.7**	**18.0**	**48.1**	**56.5**	**103.0**	**24.1**	**17.0**
	41.32m (<25%)	**79.0**	**17.4**	**16.0**	**62.8**	**59.0**	**35.0**	**15.2**	**14.0**	**222.3**	**139.5**
	41.32m (>25%)	**79.0**	**16.3**	**15.0**	**251.9**	**132.0**	**35.0**	**14.1**	**13.0**	**128.6**	**106.0**
	41.75m (>50%)	**66.5**	**25.0**	**24.0**	**132.5**	**105.5**	**28.1**	**16.3**	**15.0**	**89.7**	**75.0**
	42.18m (>75%)	**58.3**	**28.3**	**26.0**	**107.4**	**86.5**	**23.3**	**16.3**	**15.0**	**74.4**	**60.0**
	42.60m (>100%)	**34.7**	**41.3**	**39.0**	**42.5**	**32.0**	**12.6**	**18.5**	**17.0**	**35.4**	**24.0**
	>43.00m	**18.4**	**44.6**	**49.0**	**18.0**	**18.0**	**6.6**	**20.7**	**20.0**	**15.7**	**14.5**
	>43.50m	**8.7**	**48.9**	**66.0**	**6.3**	**5.0**	**3.0**	**20.7**	**23.0**	**6.2**	**3.0**
	>44.00m	**7.7**	**47.8**	**63.0**	**5.9**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.8**	**12.0**	**12.0**	**7.3**	**4.5**
	>45.00m	**1.9**	**18.5**	**21.0**	**4.4**	**3.0**	**0.8**	**6.5**	**9.0**	**4.0**	**3.0**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.8**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Nip Nip	**41.22m (0%)**	**85.2**	**23.9**	**56.0**	**12.7**	**9.0**	**50.6**	**64.1**	**161.0**	**14.7**	**10.0**
	41.56m (<25%)	**76.1**	**18.5**	**17.0**	**67.2**	**65.0**	**32.7**	**17.4**	**16.0**	**201.2**	**117.0**
	41.56m (>25%)	**76.1**	**17.4**	**16.0**	**227.6**	**139.0**	**32.7**	**16.3**	**15.0**	**104.3**	**93.0**
	41.91m (>50%)	**65.3**	**26.1**	**24.0**	**130.3**	**103.5**	**27.6**	**16.3**	**16.0**	**82.4**	**71.0**
	42.26m (>75%)	**58.9**	**28.3**	**26.0**	**108.4**	**89.0**	**24.0**	**17.4**	**16.0**	**71.6**	**60.5**
	42.60m (>100%)	**41.5**	**35.9**	**34.0**	**58.3**	**41.0**	**15.5**	**17.4**	**16.0**	**46.4**	**30.5**
	>43.00m	**21.6**	**46.7**	**46.0**	**22.5**	**21.0**	**7.8**	**20.7**	**21.0**	**17.7**	**17.0**
	>43.50m	**8.8**	**48.9**	**66.0**	**6.4**	**5.0**	**3.1**	**20.7**	**23.0**	**6.4**	**4.0**
	>44.00m	**7.8**	**47.8**	**63.0**	**5.9**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.50m	**4.9**	**33.7**	**41.0**	**5.7**	**4.0**	**1.8**	**12.0**	**12.0**	**7.3**	**4.5**
	>45.00m	**2.0**	**19.6**	**21.0**	**4.5**	**3.0**	**0.8**	**6.5**	**10.0**	**3.7**	**2.5**
	>45.50m	**0.3**	**5.4**	**5.0**	**2.8**	**2.0**	**0.1**	**1.1**	**1.0**	**3.0**	**3.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Yerang	40.89m (0%)	89.7	18.5	34.0	14.4	9.0	60.1	55.4	122.0	15.7	10.0
	41.27m (<25%)	79.6	27.2	25.0	39.0	25.0	42.6	30.4	28.0	98.1	70.5
	41.27m (>25%)	79.6	27.2	25.0	152.4	132.0	42.6	27.2	27.0	75.4	71.0
	(41.64m (>50%)	70.9	32.6	30.0	113.1	91.5	32.8	31.5	30.0	52.2	38.5
	42.02m (>75%)	48.0	54.4	61.0	37.7	31.0	19.8	34.8	37.0	25.6	16.0
	42.40m (>100%)	28.5	63.0	76.0	18.0	20.0	11.3	40.2	43.0	12.6	11.0
	>42.50m	25.1	62.0	77.0	15.6	18.0	10.0	39.1	43.0	11.1	9.0
	>43.00m	15.9	64.1	76.0	10.0	8.0	6.2	34.8	37.0	8.0	5.0
	>43.50m	11.8	58.7	78.0	7.2	5.0	4.2	25.0	29.0	6.9	4.0
	>44.00m	8.7	48.9	66.0	6.3	5.0	3.1	21.7	24.0	6.2	3.0
	>44.50m	4.1	30.4	36.0	5.4	3.5	1.6	10.9	10.0	7.8	5.0
	>45.00m	1.3	13.0	16.0	3.9	3.0	0.5	4.4	5.0	5.0	3.0
	>45.50m	0.1	2.2	2.0	2.0	2.0	0.0	1.1	1.0	2.0	2.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Mournpall	39.22m (0%)	97.8	4.4	10.0	10.6	10.0	75.1	34.8	77.0	15.5	10.0
	40.02m (<25%)	93.9	7.6	7.0	41.4	29.0	59.0	20.7	19.0	103.4	52.0
	40.02m (>25%)	93.9	7.6	7.0	642.0	424.0	59.0	17.4	18.0	156.7	128.5
	40.81m (>50%)	84.3	16.3	17.0	237.2	132.0	42.1	20.7	20.0	100.8	85.0
	41.60m (>75%)	64.3	33.7	32.0	96.2	75.5	26.5	23.9	22.0	57.6	57.0
	42.40m (>100%)	22.5	57.6	62.0	17.3	20.0	8.3	25.0	27.0	14.7	15.0
	>42.50m	19.3	54.4	62.0	14.9	16.5	7.1	22.8	25.0	13.6	14.0
	>43.00m	10.6	53.3	71.0	7.1	5.0	4.0	25.0	30.0	6.4	4.0
	>43.50m	9.5	50.0	67.0	6.8	5.0	3.4	22.8	26.0	6.3	3.5
	>44.00m	8.2	48.9	66.0	5.9	4.5	2.8	19.6	22.0	6.1	3.0
	>44.50m	4.0	30.4	36.0	5.4	3.5	1.6	10.9	10.0	7.8	5.0
	>45.00m	1.3	13.0	16.0	3.9	3.0	0.5	4.4	5.0	5.0	3.0
	>45.50m	0.1	2.2	2.0	2.0	2.0	0.0	1.1	1.0	2.0	2.0

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural % of Time Exceeded	Natural % of Years with Spells	Natural No. of Spells	Natural Duration (weeks/event) Average	Natural Duration (weeks/event) Median	Current % of Time Exceeded	Current % of Years with Spells	Current No. of Spells	Current Duration (weeks/event) Average	Current Duration (weeks/event) Median
Yelwell	40.89m (0%)	89.2	19.6	30.0	17.3	11.5	61.8	52.2	111.0	16.5	10.0
	41.22m (<25%)	78.9	26.1	25.0	40.5	28.0	48.8	25.0	23.0	106.6	84.0
	41.22m (>25%)	78.9	26.1	25.0	150.9	133.0	48.8	23.9	22.0	106.0	84.5
	41.54m (>50%)	71.9	31.5	29.0	118.6	106.0	38.8	30.4	29.0	63.9	57.0
	41.87m (>75%)	56.5	43.5	44.0	61.4	47.0	27.5	33.7	32.0	41.0	27.5
	42.20m (>100%)	33.3	57.6	61.0	26.2	27.0	16.1	35.9	36.0	21.4	21.0
	>42.50m	20.8	56.5	66.0	15.0	17.0	8.7	33.7	37.0	11.2	10.0
	>43.00m	12.1	58.7	79.0	7.4	5.0	4.8	28.3	33.0	7.0	5.0
	>43.50m	10.0	51.1	68.0	7.0	5.0	3.7	23.9	28.0	6.4	4.0
	>44.00m	8.1	48.9	66.0	5.9	5.0	2.9	19.6	22.0	6.3	3.5
	>44.50m	4.0	30.4	36.0	5.3	3.5	1.6	10.9	10.0	7.6	5.0
	>45.00m	1.3	13.0	16.0	3.9	3.0	0.5	4.4	5.0	5.0	3.0
	>45.50m	0.1	2.2	2.0	2.0	2.0	0.0	1.1	1.0	2.0	2.0

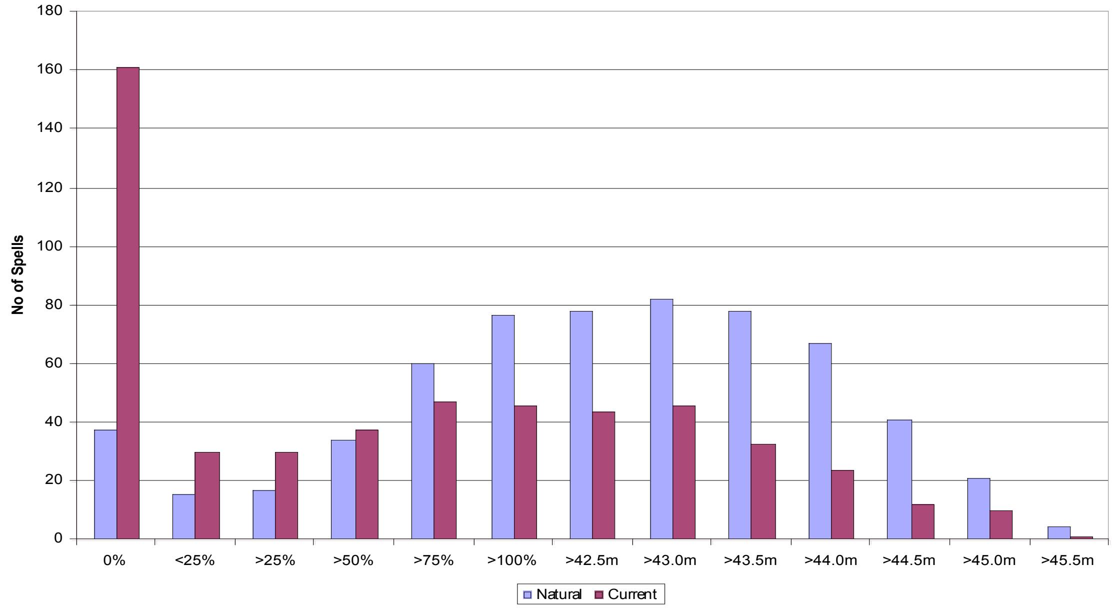
Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Konardin	**40.57m (0%)**	**89.0**	**18.5**	**27.0**	**19.5**	**18.0**	**49.8**	**56.5**	**103.0**	**23.3**	**16.0**
	41.00m (<25%)	**81.1**	**17.4**	**16.0**	**56.5**	**52.0**	**37.3**	**14.1**	**13.0**	**230.9**	**14.3**
	41.00m (>25%)	**81.1**	**15.2**	**15.0**	**258.7**	**231.0**	**37.3**	**13.0**	**12.0**	**148.6**	**110.0**
	41.44m (>50%)	**69.4**	**22.8**	**21.0**	**158.1**	**132.0**	**.29.49**	**16.3**	**16.0**	**88.2**	**77.5**
	41.87m (>75%)	**60.8**	**27.2**	**25.0**	**116.3**	**111.0**	**24.9**	**16.3**	**15.0**	**79.5**	**67.0**
	42.30m (>100%)	**41.2**	**35.9**	**35.0**	**56.3**	**39.0**	**15.1**	**17.4**	**16.0**	**45.0**	**30.5**
	>42.50m	**29.5**	**45.7**	**42.0**	**33.6**	**27.0**	**10.7**	**19.6**	**18.0**	**28.5**	**21.0**
	>43.00m	**9.4**	**48.9**	**65.0**	**6.9**	**5.0**	**3.4**	**21.7**	**24.0**	**6.7**	**4.0**
	>43.50m	**8.4**	**48.9**	**66.0**	**6.1**	**5.0**	**2.9**	**19.6**	**22.0**	**6.3**	**3.5**
	>44.00m	**7.6**	**47.8**	**63.0**	**5.8**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.50m	**4.0**	**30.4**	**36.0**	**5.4**	**3.5**	**1.6**	**10.9**	**10.0**	**7.8**	**5.0**
	>45.00m	**1.3**	**13.0**	**16.0**	**3.9**	**3.0**	**0.5**	**4.4**	**5.0**	**5.0**	**3.0**
	>45.50m	**0.1**	**2.2**	**2.0**	**2.0**	**2.0**	**0.0**	**1.1**	**1.0**	**2.0**	**2.0**

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Bitterang	**40.11m (0%)**	**91.6**	**15.2**	**31.0**	**13.0**	**9.0**	**54.7**	**57.6**	**129.0**	**16.8**	**10.0**
	40.71m (<25%)	**82.1**	**16.3**	**15.0**	**57.0**	**51.0**	**37.8**	**14.1**	**13.0**	**229.0**	**143.0**
	40.71m (>25%)	**82.1**	**15.2**	**14.0**	**280.6**	**236.0**	**37.8**	**13.0**	**12.0**	**150.6**	**114.5**
	41.30m (>50%)	**66.9**	**25.0**	**23.0**	**139.1**	**120.0**	**28.1**	**16.3**	**15.0**	**89.7**	**76.0**
	41.90m (>75%)	**51.0**	**29.4**	**27.0**	**90.4**	**80.0**	**19.2**	**16.3**	**16.0**	**57.5**	**46.5**
	42.50m (>100%)	**20.7**	**45.7**	**47.0**	**21.1**	**21.0**	**7.2**	**20.7**	**20.0**	**17.3**	**17.5**
	>43.00m	**7.4**	**42.4**	**56.0**	**6.3**	**5.0**	**2.5**	**17.4**	**19.0**	**6.3**	**4.0**
	>43.50m	**6.0**	**41.3**	**53.0**	**5.5**	**4.0**	**2.1**	**14.1**	**15.0**	**6.7**	**5.0**
	>44.00m	**3.5**	**26.1**	**30.0**	**5.6**	**4.0**	**1.4**	**9.8**	**9.0**	**7.6**	**5.0**
	>44.50m	**1.3**	**14.1**	**17.0**	**3.8**	**3.0**	**0.5**	**4.4**	**5.0**	**5.2**	**3.0**
	>45.00m	**0.1**	**2.2**	**2.0**	**2.0**	**2.0**	**0.0**	**1.1**	**1.0**	**2.0**	**2.0**
	>45.50m										

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Cantala	**40.16m (0%)**	**85.3**	**21.7**	**37.0**	**19.0**	**18.0**	**49.2**	**58.7**	**122.0**	**19.9**	**12.0**
	40.72m (<25%)	**70.9**	**26.1**	**24.0**	**58.1**	**47.0**	**31.3**	**17.4**	**16.0**	**205.4**	**119.5**
	40.72m (>25%)	**70.4**	**23.9**	**22.0**	**153.0**	**128.5**	**31.2**	**16.3**	**15.0**	**99.5**	**85.0**
	41.28m (>50%)	**57.1**	**28.3**	**26.0**	**105.1**	**90.0**	**24.4**	**16.3**	**15.0**	**77.7**	**64.0**
	41.84m (>75%)	**29.2**	**42.4**	**41.0**	**34.1**	**27.0**	**11.2**	**19.6**	**19.0**	**28.3**	**22.0**
	42.40m (>100%)	**9.3**	**48.9**	**65.0**	**6.9**	**5.0**	**3.3**	**21.7**	**24.0**	**6.6**	**4.0**
	>42.50m	**9.1**	**48.9**	**65.0**	**6.7**	**5.0**	**3.3**	**21.7**	**24.0**	**6.5**	**3.5**
	>43.00m	**8.3**	**48.9**	**66.0**	**6.0**	**5.0**	**2.9**	**19.6**	**22.0**	**6.2**	**3.5**
	>43.50m	**7.6**	**47.8**	**63.0**	**5.8**	**4.0**	**2.7**	**18.5**	**21.0**	**6.1**	**4.0**
	>44.00m	**5.3**	**38.0**	**46.0**	**5.5**	**4.0**	**1.9**	**12.0**	**12.0**	**7.5**	**5.0**
	>44.50m	**2.5**	**22.8**	**25.0**	**4.7**	**2.0**	**1.0**	**7.6**	**8.0**	**6.3**	**5.0**
	>45.00m	**0.2**	**4.4**	**4.0**	**1.8**	**1.5**	**0.0**	**1.1**	**1.0**	**2.0**	**2.0**
	>45.50m										

Lake	Water Level (m AHD) (% of Retention Levels of Lake)	Natural					Current				
		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)		% of Time Exceeded	% of Years with Spells	No. of Spells	Duration (weeks/event)	
					Average	Median				Average	Median
Kramen	**40.75m (0%)**	**45.4**	**76.1**	**191.0**	**13.7**	**8.0**	**29.9**	**91.3**	**271.0**	**12.4**	**8.0**
	41.46m (<25%)	**21.3**	**6.5**	**6.0**	**627.5**	**625.0**	**7.2**	**3.3**	**3.0**	**1479.7**	**1898.0**
	41.46m (>25%)	**21.3**	**5.4**	**5.0**	**203.8**	**236.0**	**7.2**	**2.2**	**2.0**	**172.5**	**172.5**
	42.18m (>50%)	**15.7**	**5.4**	**5.0**	**149.8**	**153.0**	**5.6**	**2.2**	**2.0**	**135.0**	**135.0**
	42.89m (>75%)	**11.3**	**5.4**	**5.0**	**107.6**	**125.0**	**4.2**	**2.2**	**2.0**	**100.5**	**100.5**
	43.60m (>100%)	**8.0**	**4.4**	**4.0**	**95.5**	**92.0**	**2.2**	**2.2**	**2.0**	**51.5**	**51.5**
	>44.00m	**5.1**	**5.4**	**5.0**	**48.6**	**34.0**	**1.6**	**1.1**	**1.0**	**77.0**	**77.0**
	>44.50m	**3.2**	**4.4**	**4.0**	**37.8**	**41.5**	**1.3**	**1.1**	**1.0**	**63.0**	**63.0**
	>45.00m	**1.1**	**2.2**	**2.0**	**26.0**	**26.0**	**0.6**	**1.1**	**1.0**	**29.0**	**29.0**
	>45.50m	**0.1**	**2.2**	**2.0**	**1.5**	**1.5**	**0.0**	**1.1**	**1.0**	**1.0**	**1.0**

Figure 12. Lockie spells analysis and inundation duration curve



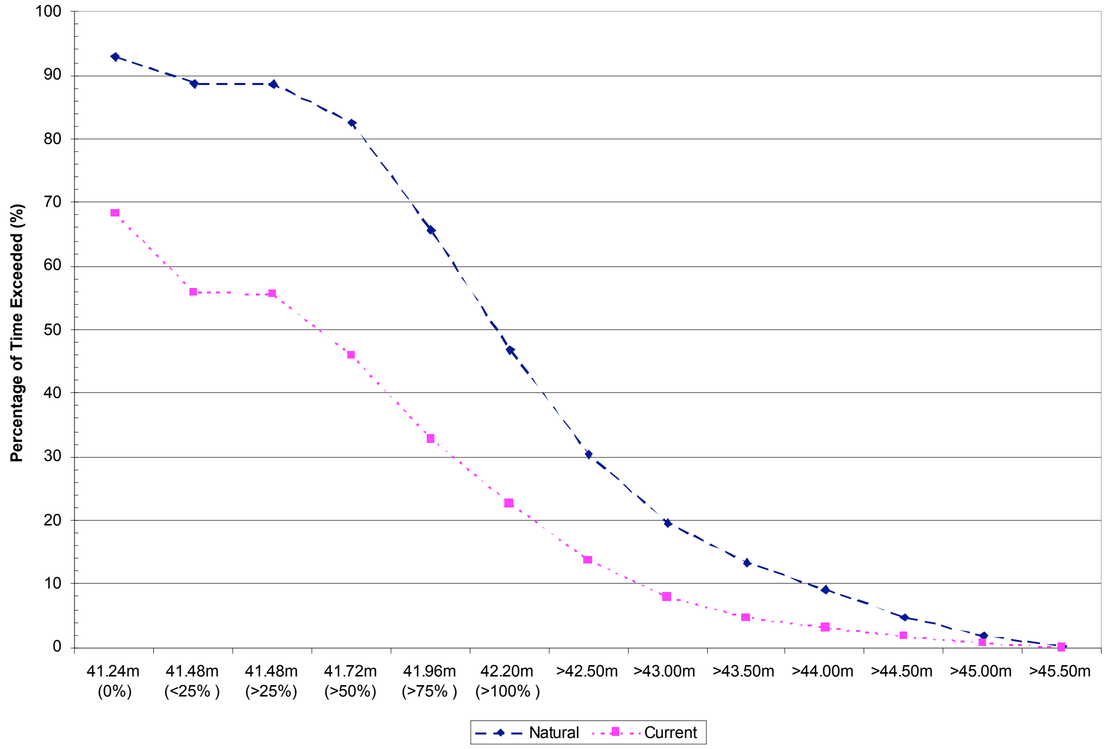
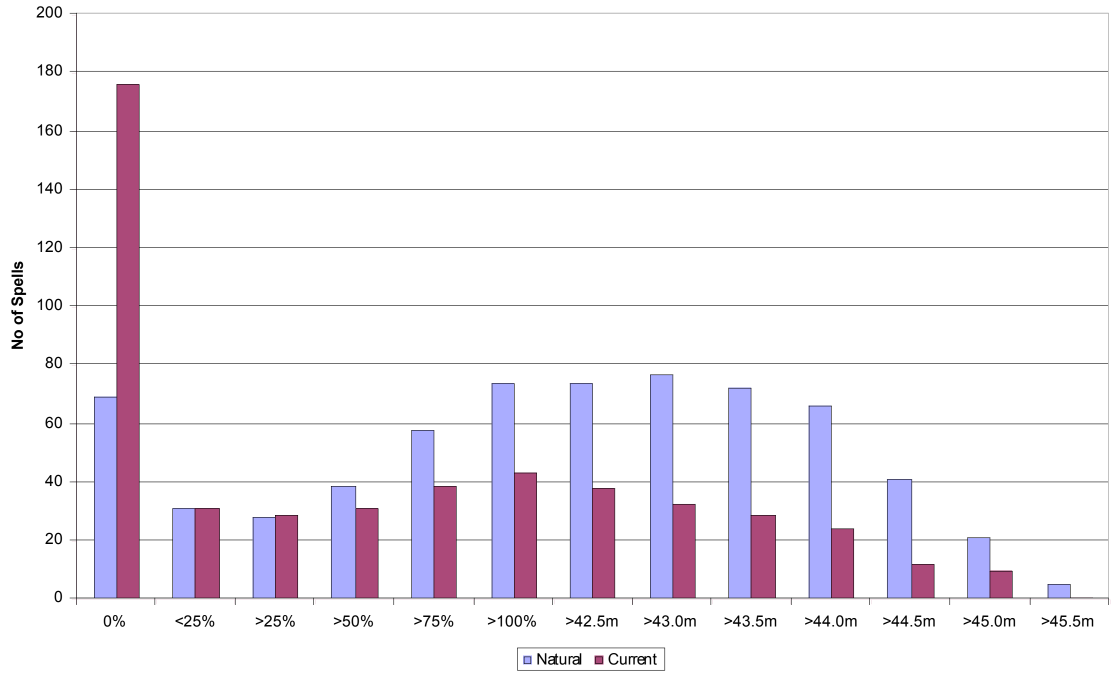


Figure 13. Little Hattah spells analysis and inundation duration curve



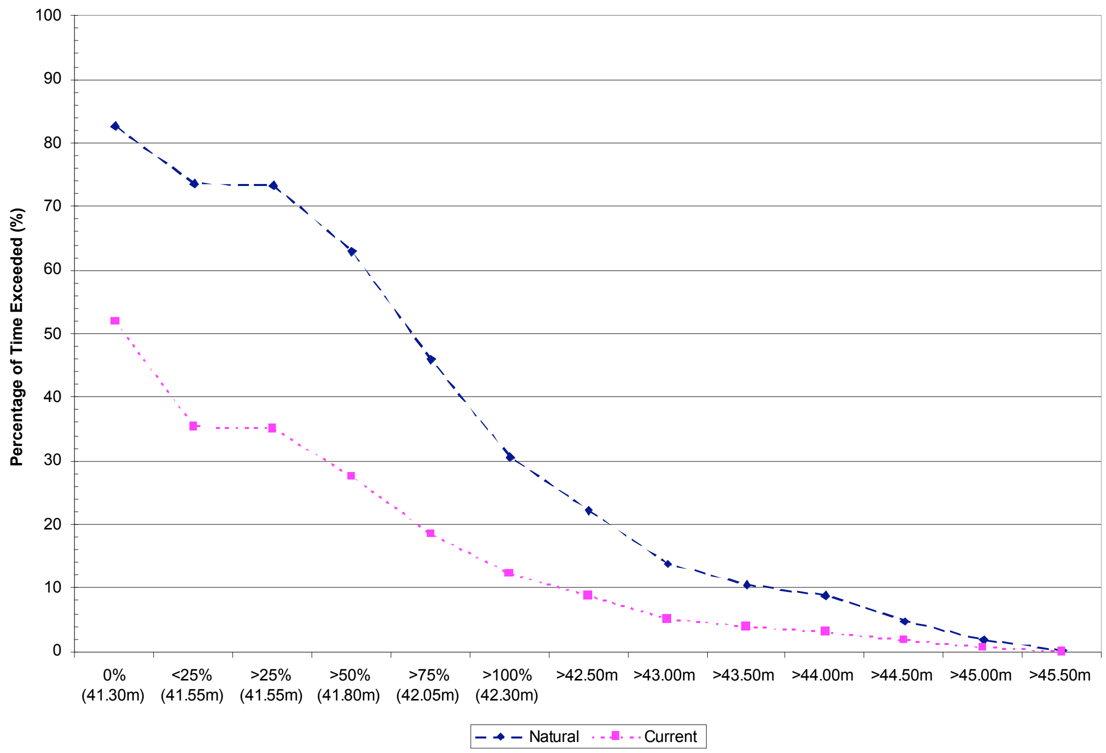
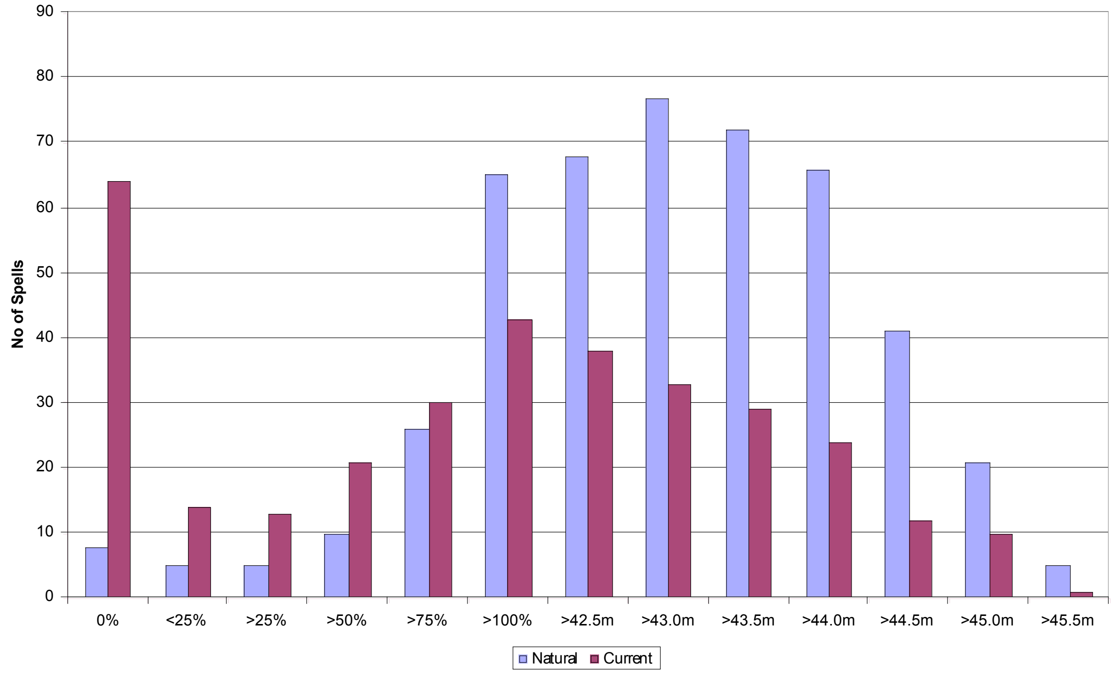


Figure 14. Hattah spells analysis and inundation duration curve



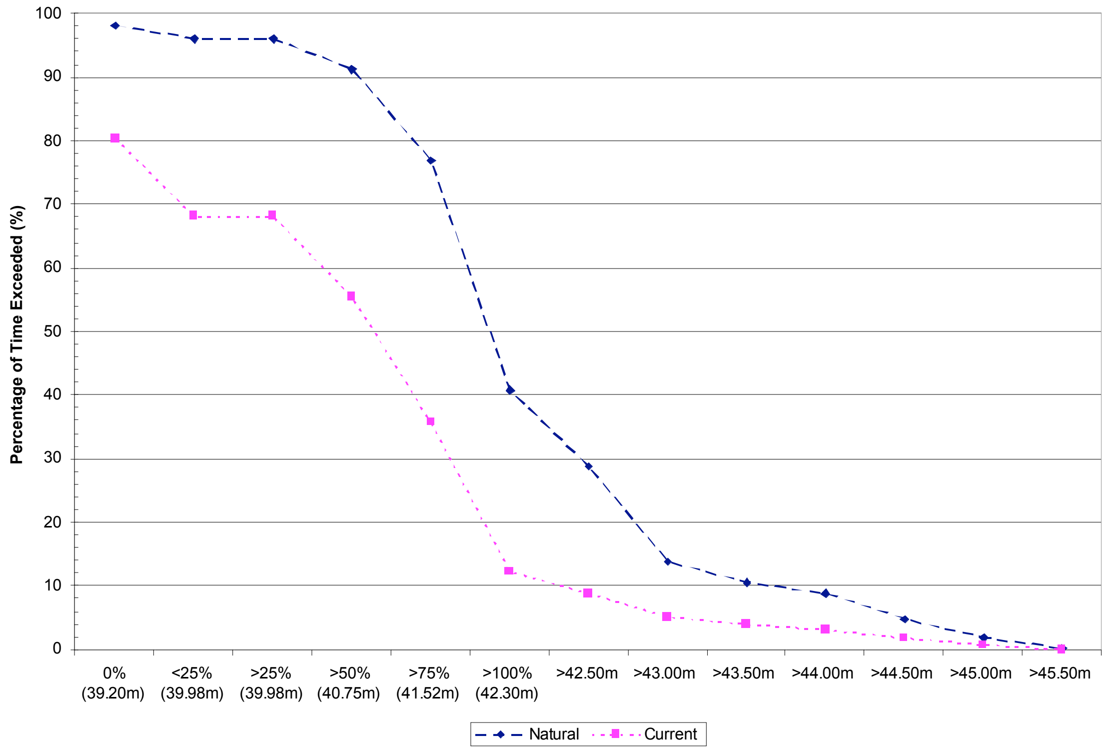
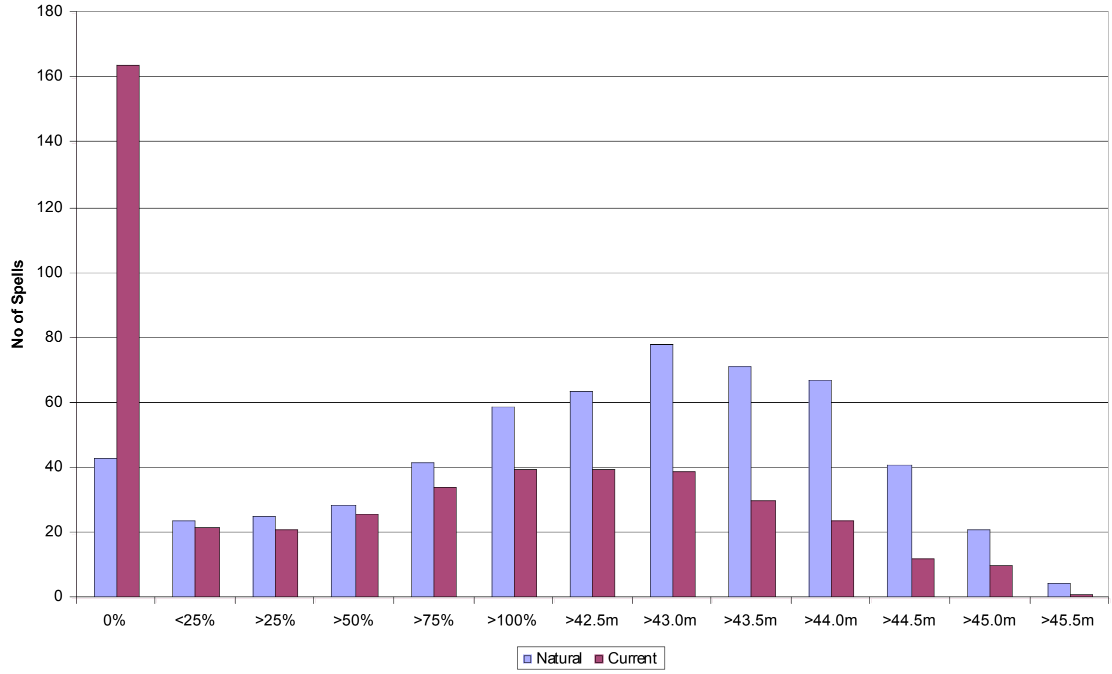


Figure 15. Roonki spells analysis and inundation duration curve



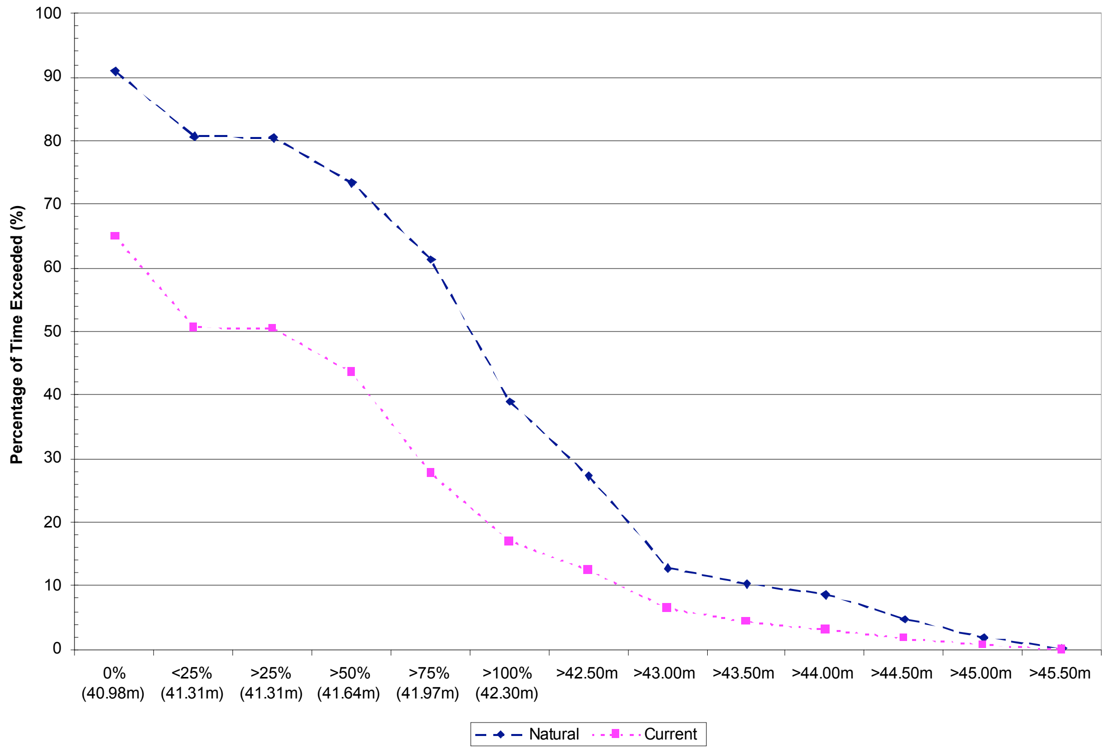
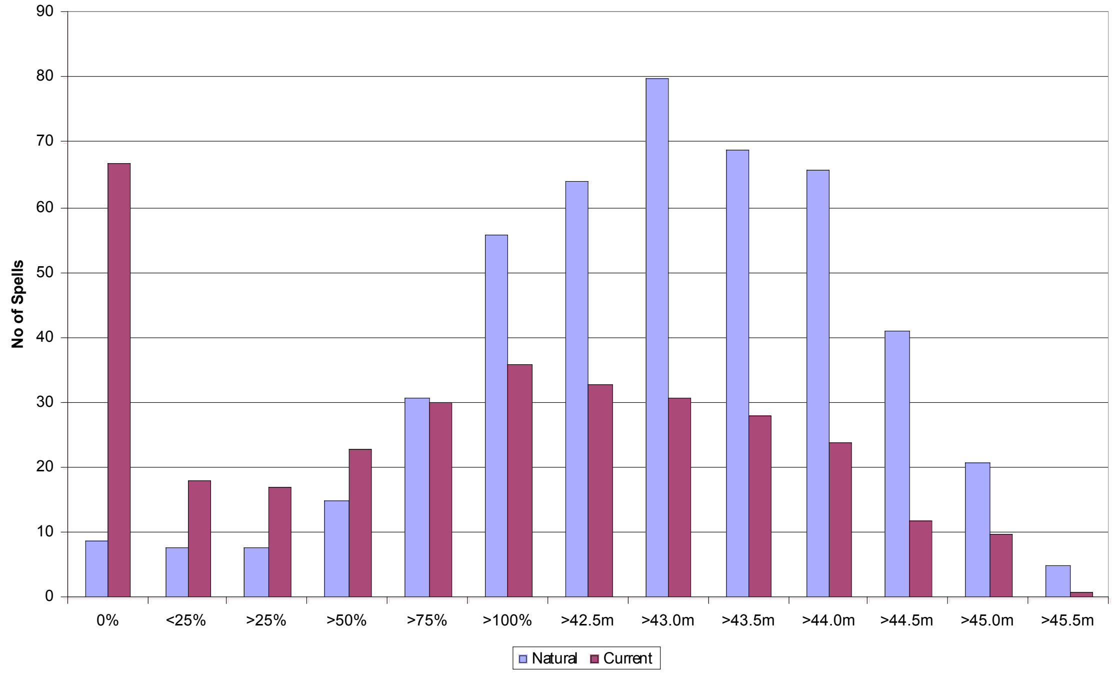


Figure 16. Bulla spells analysis and inundation duration curve



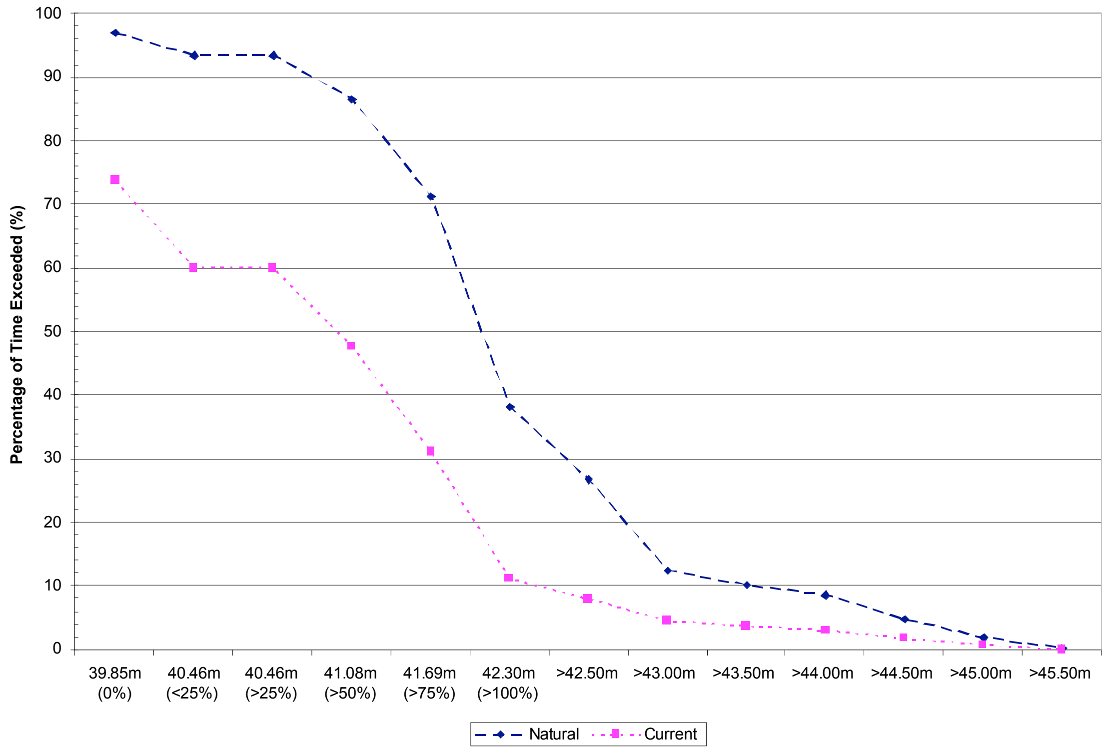
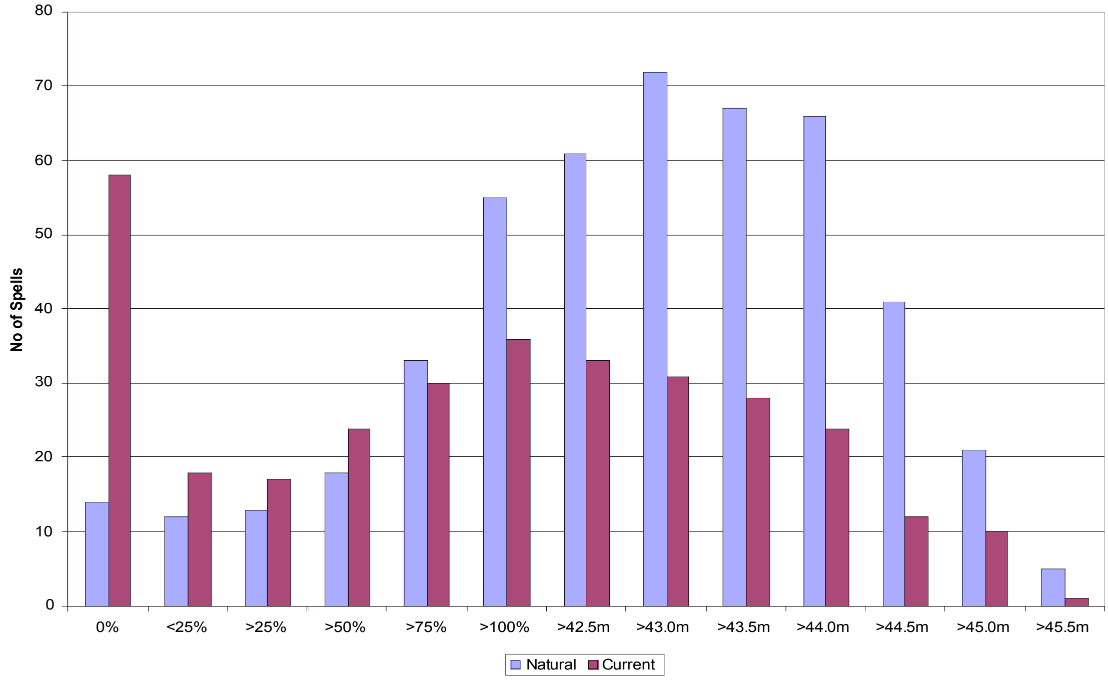


Figure 17. Arawak spells analysis and inundation duration curve



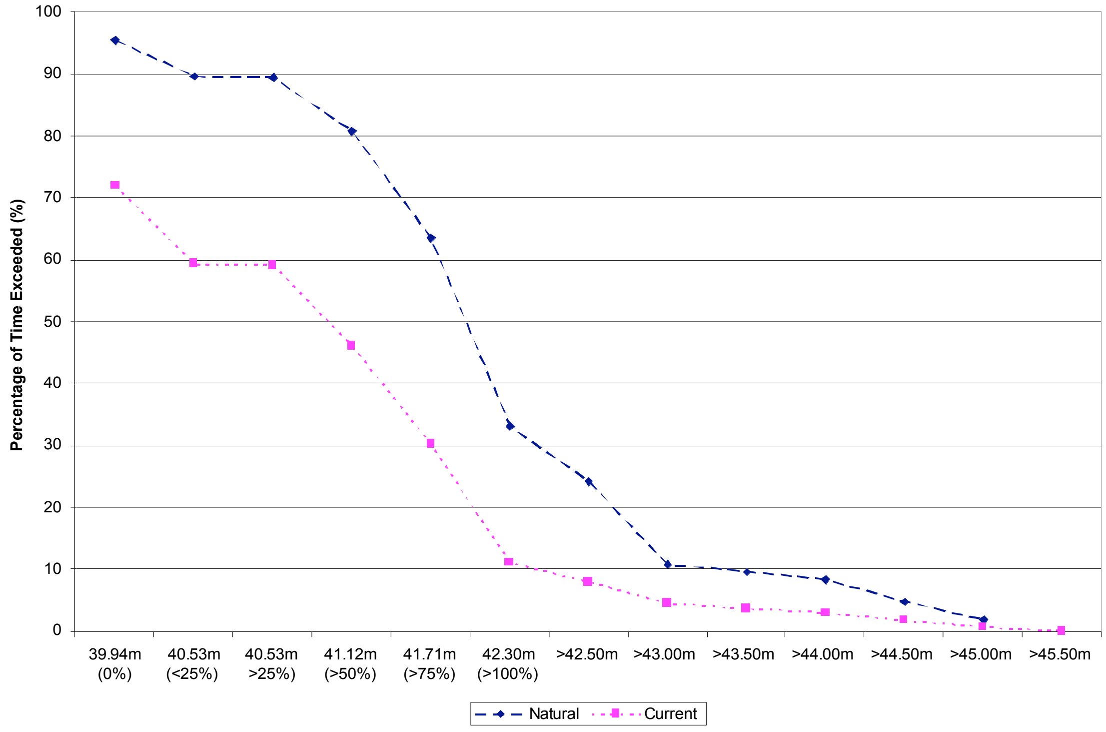
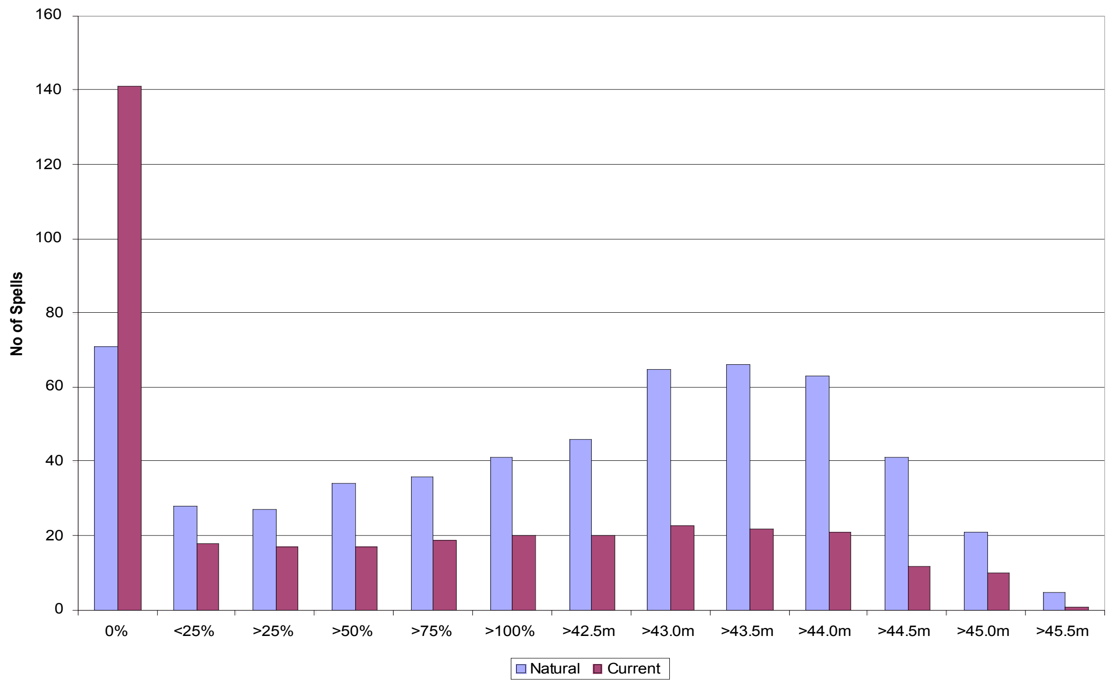


Figure 18. Marramook spells analysis and inundation duration curve



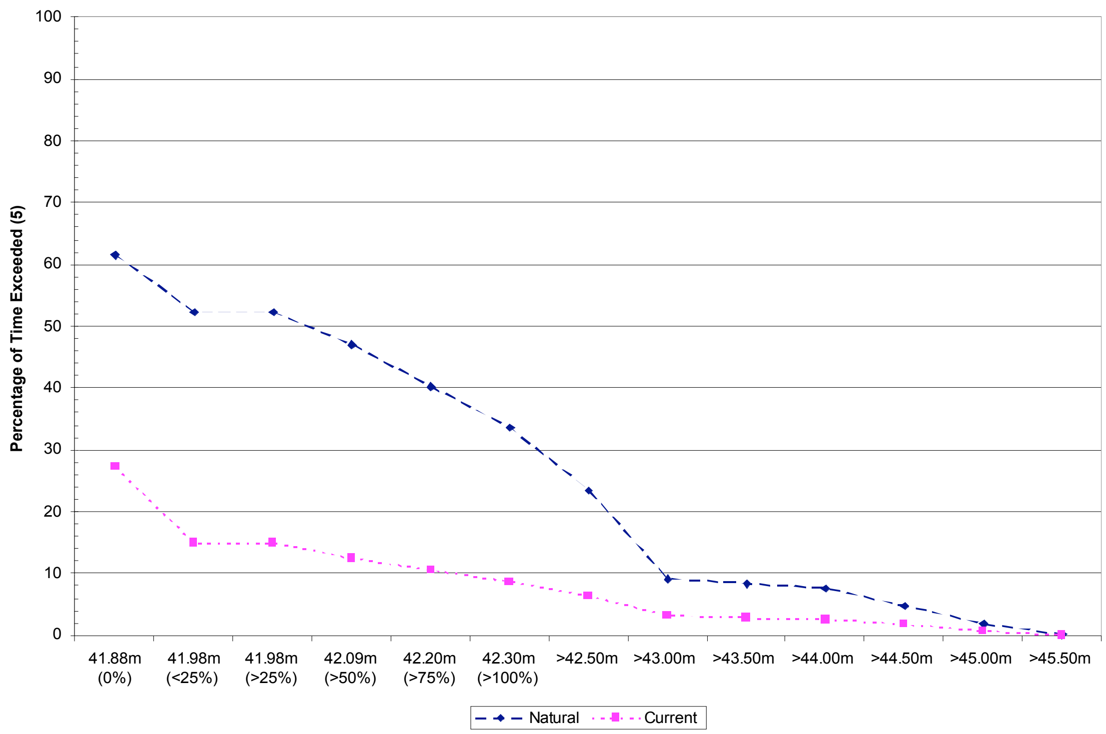
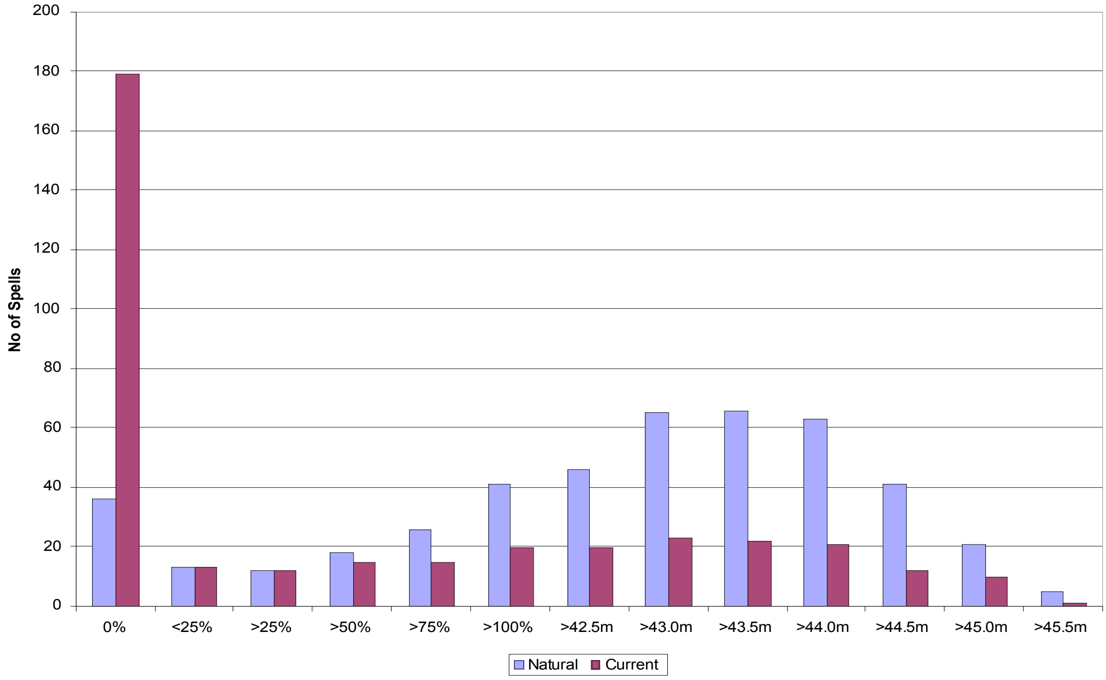


Figure 19. Brockie spells analysis and inundation duration curve



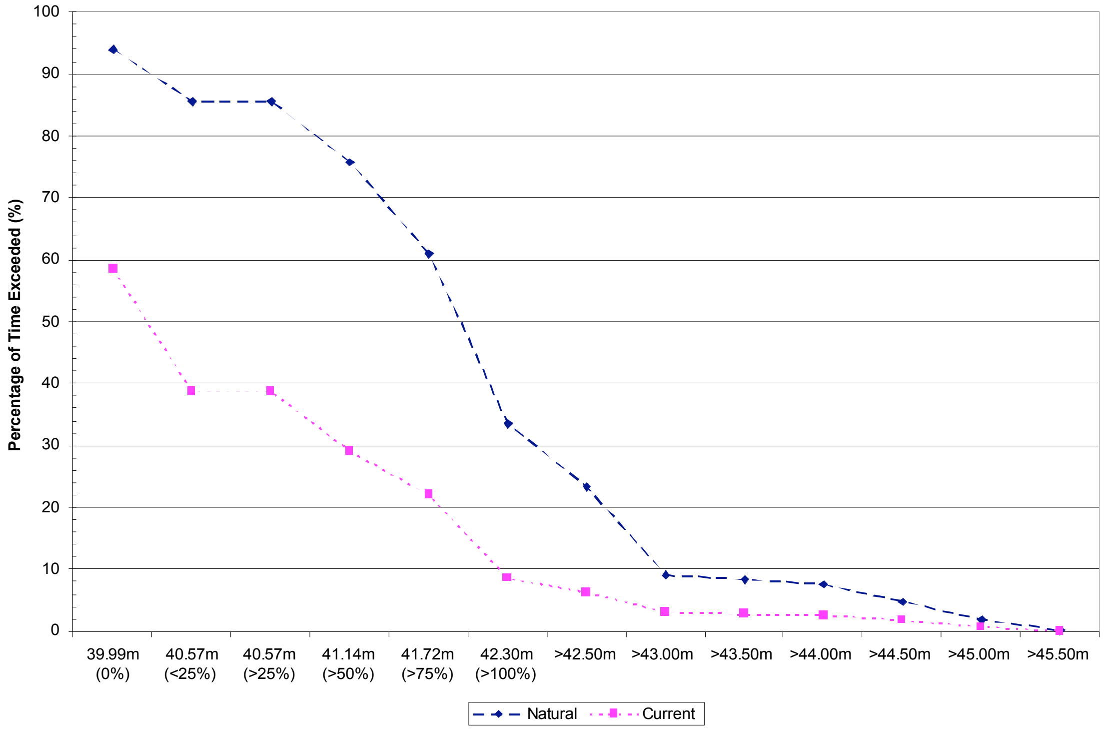
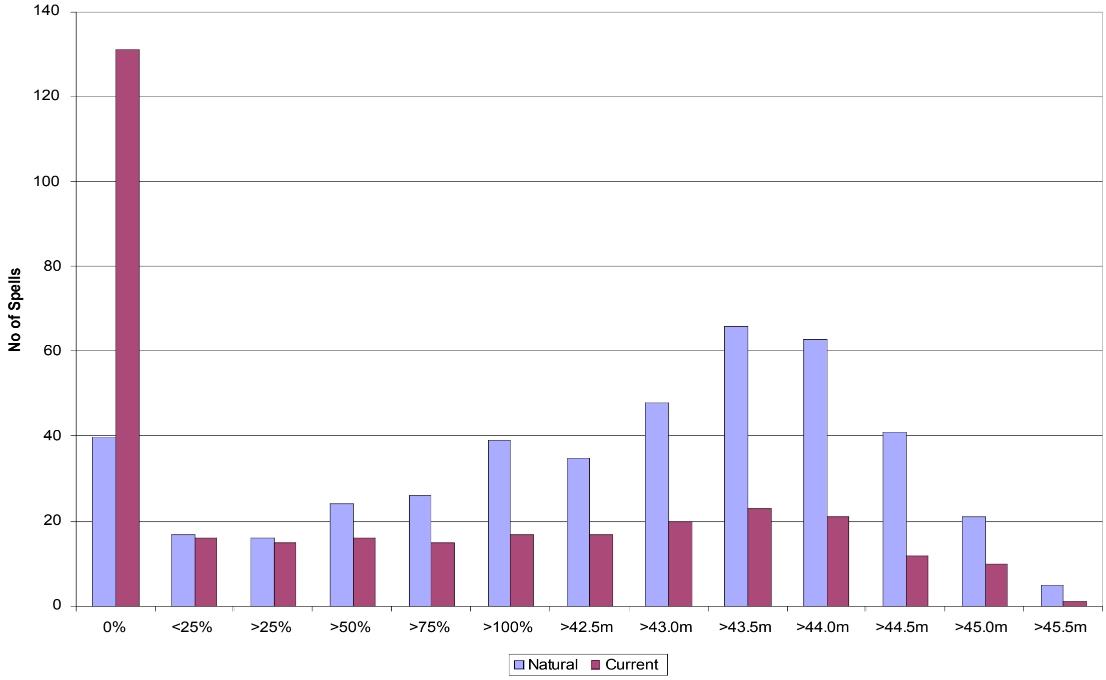


Figure 20. Boich spells analysis and inundation duration curve



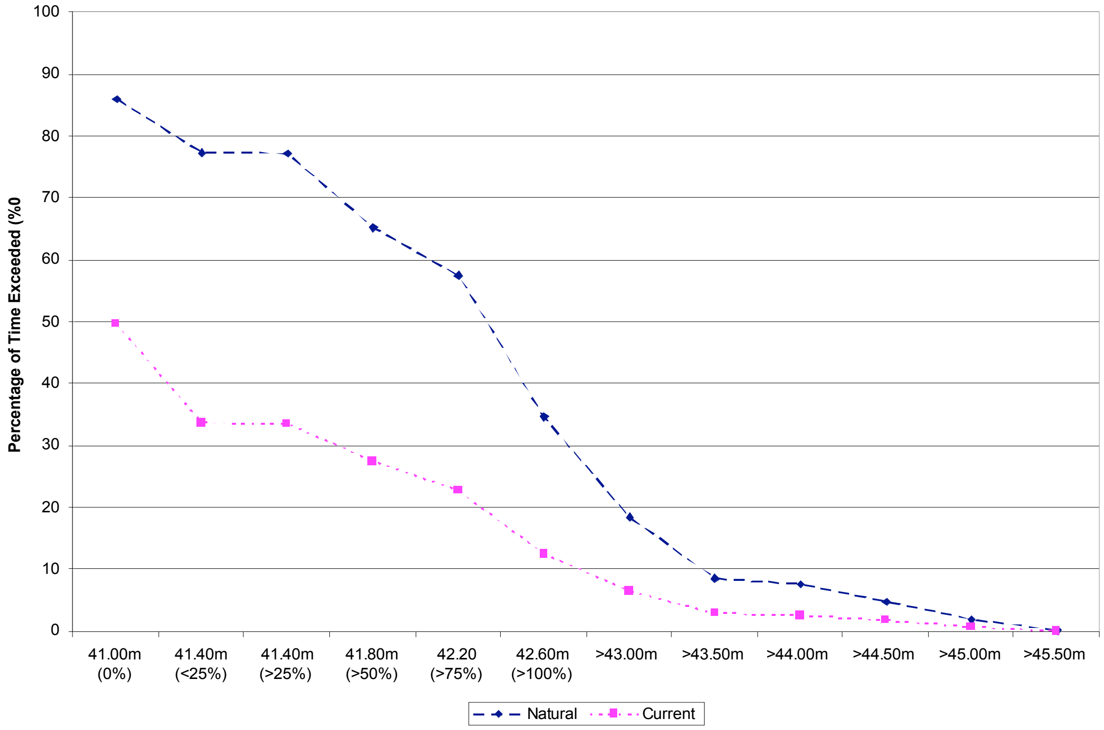
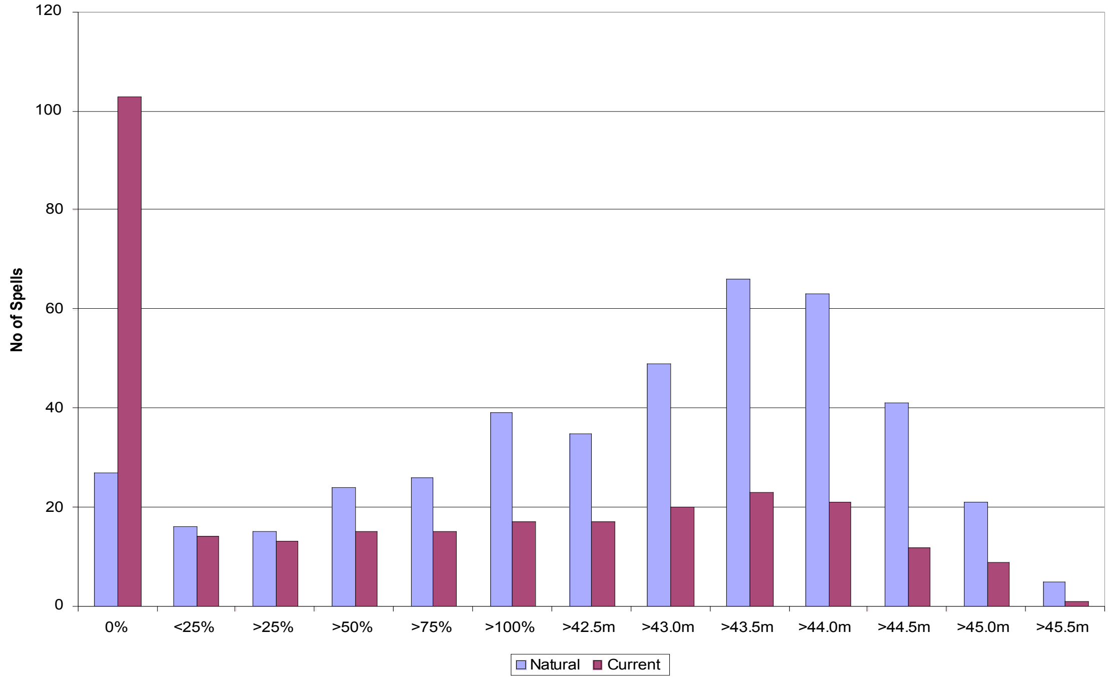


Figure 21. Tullamook spells analysis and inundation duration curve



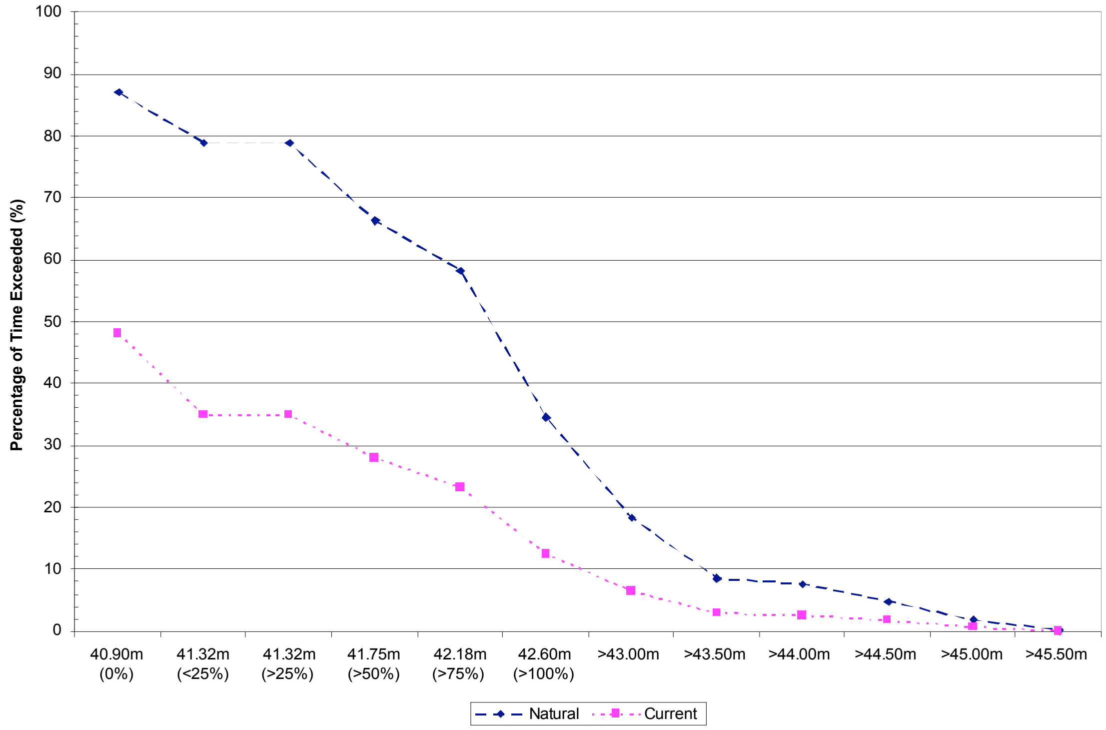
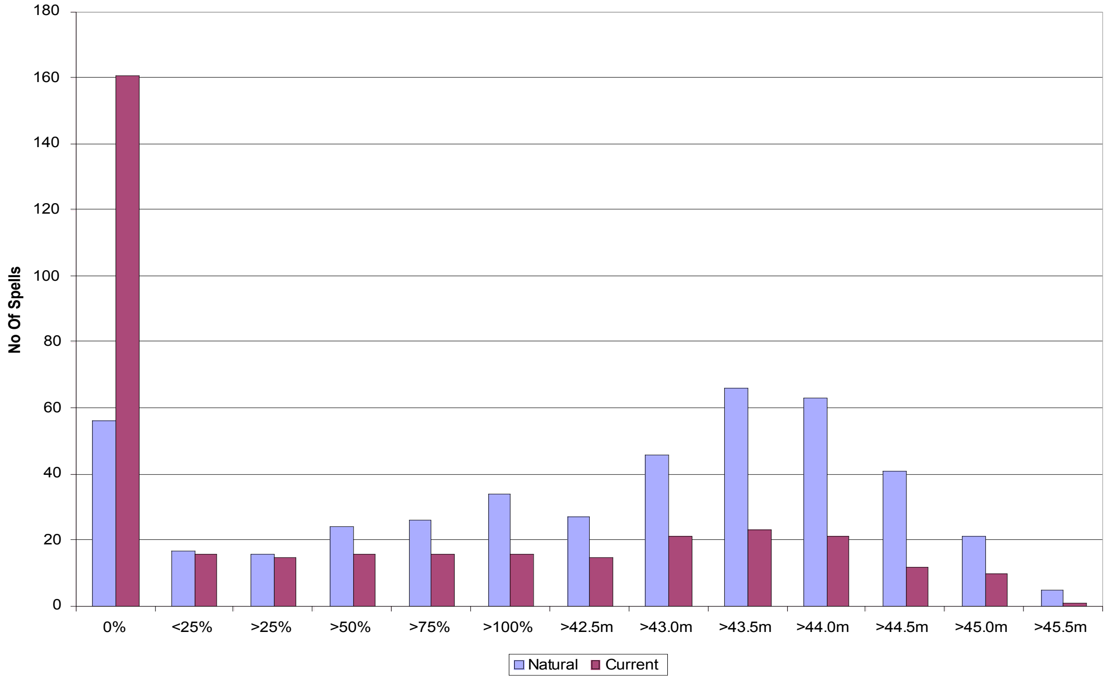


Figure 22. Nip Nip spells analysis and inundation duration curve



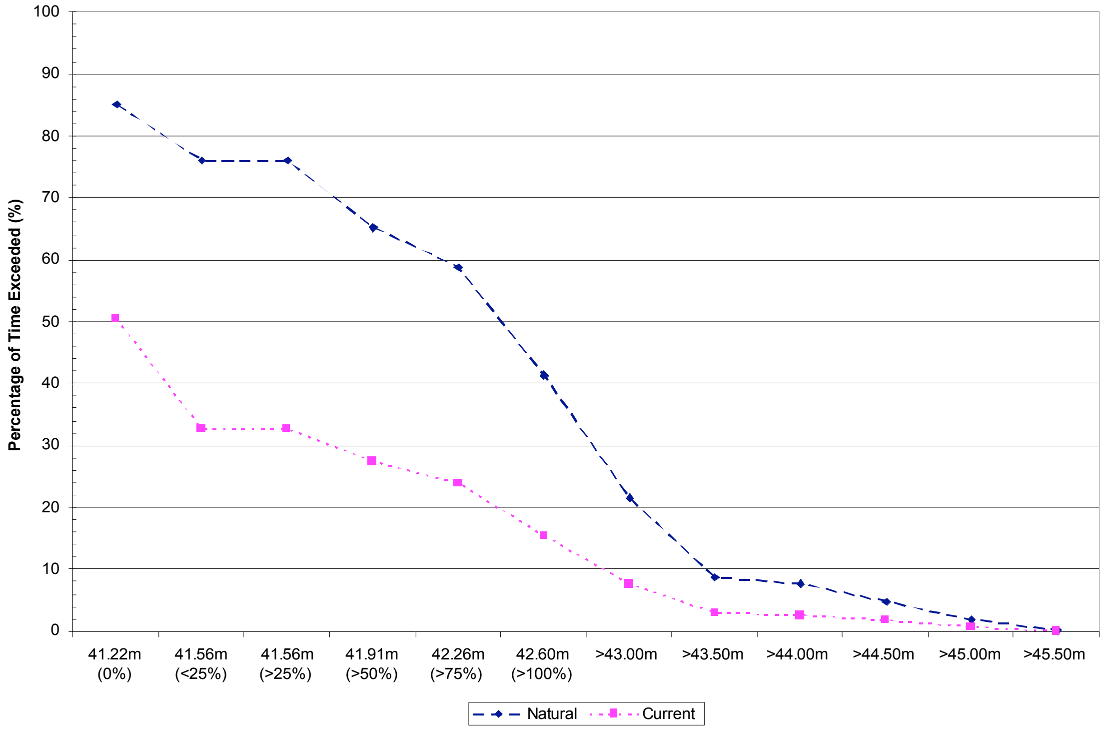
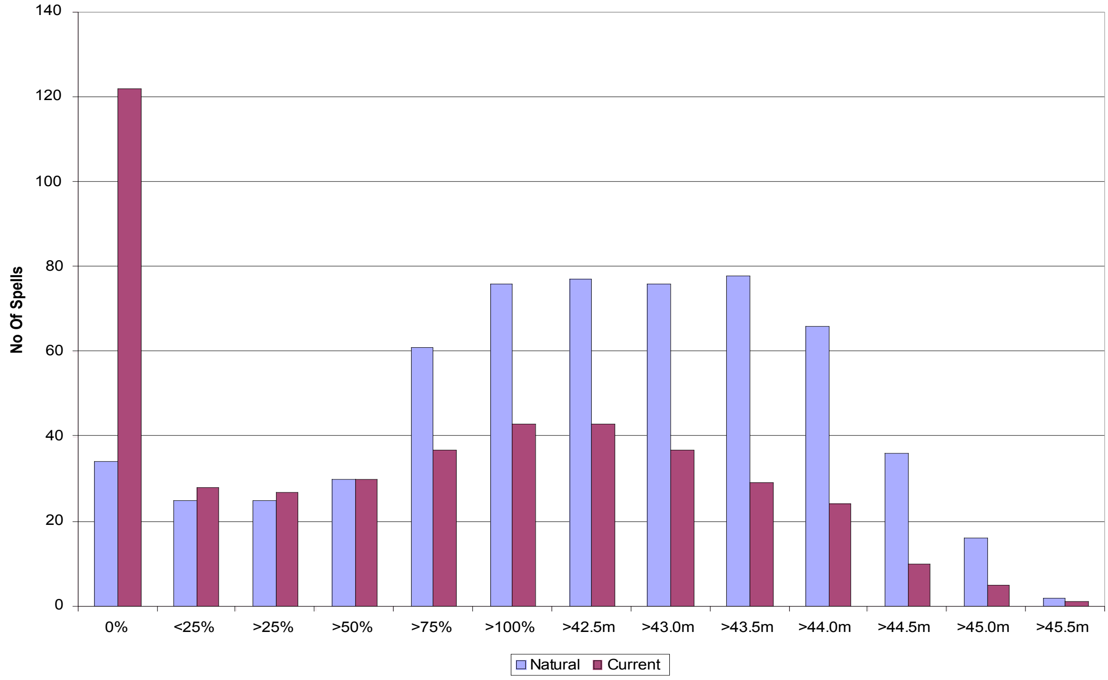


Figure 23. Yerang spells analysis and inundation duration curve



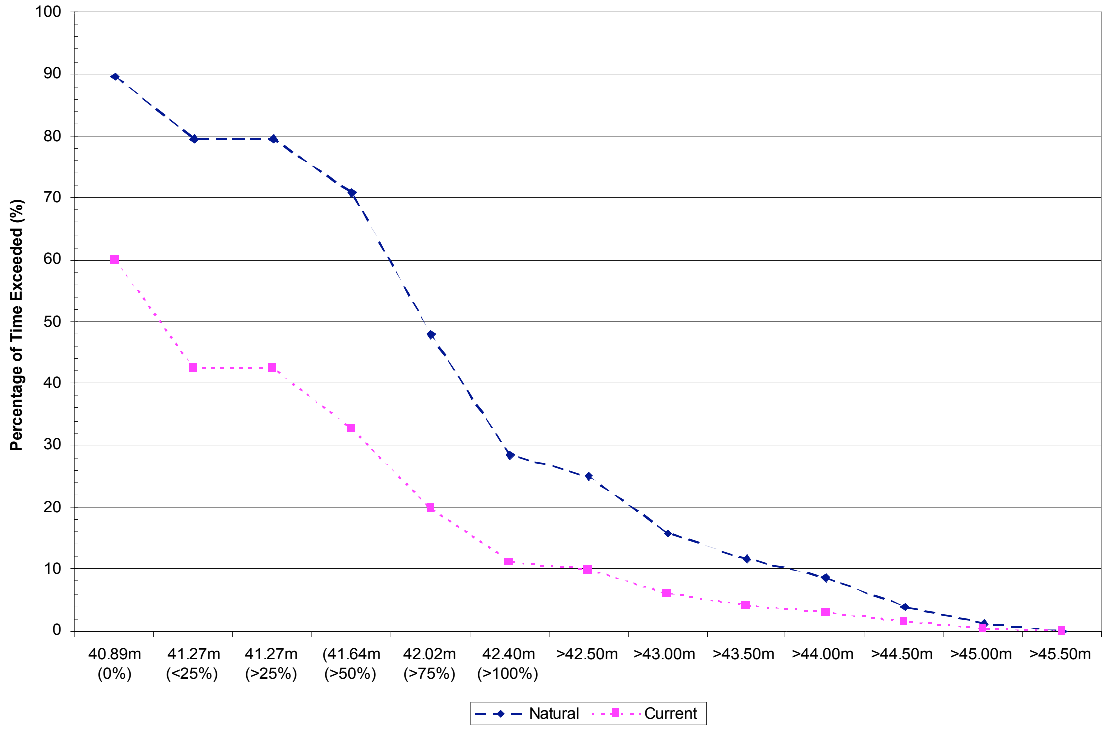
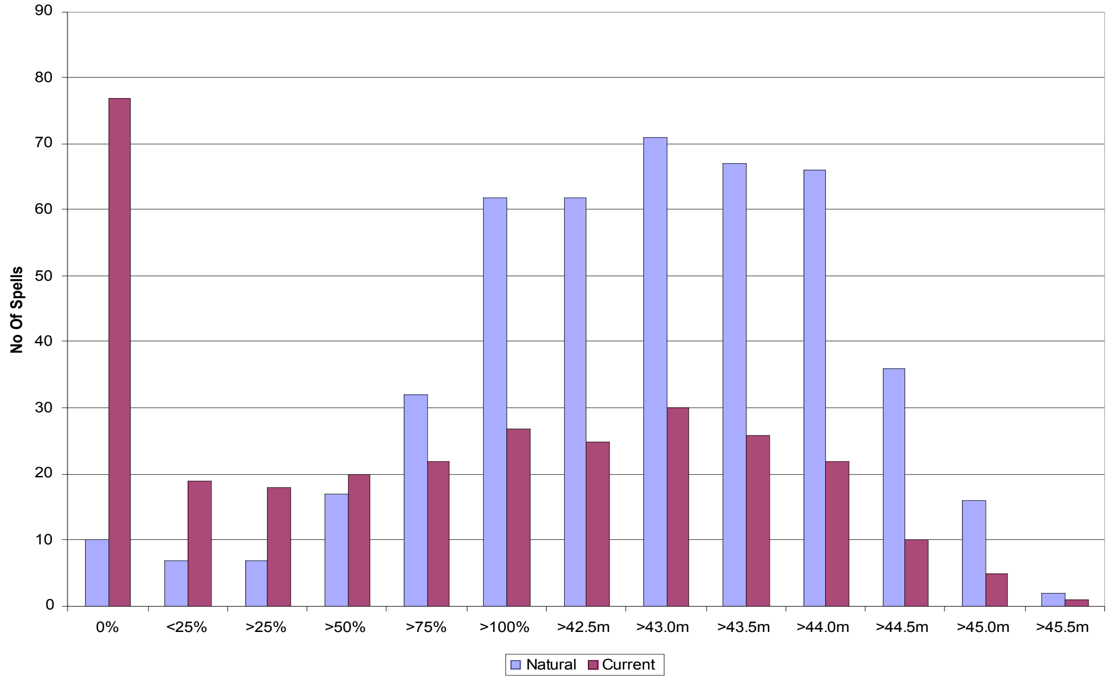


Figure 24. Mournpall spells analysis and inundation duration curve



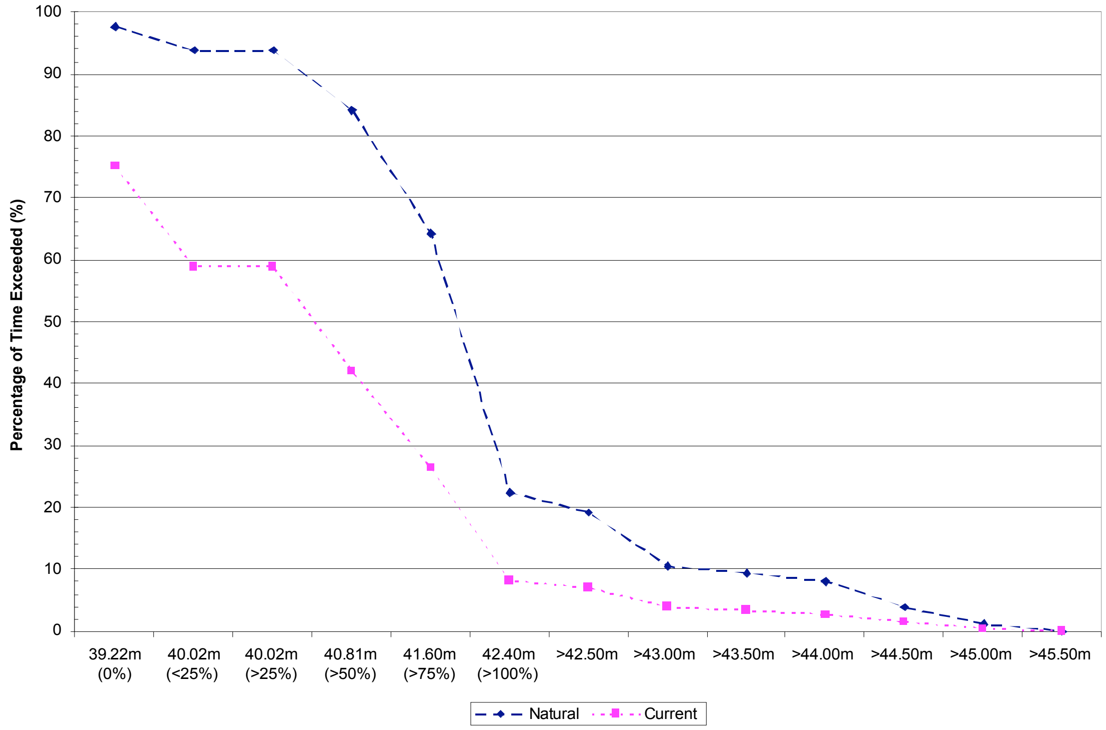
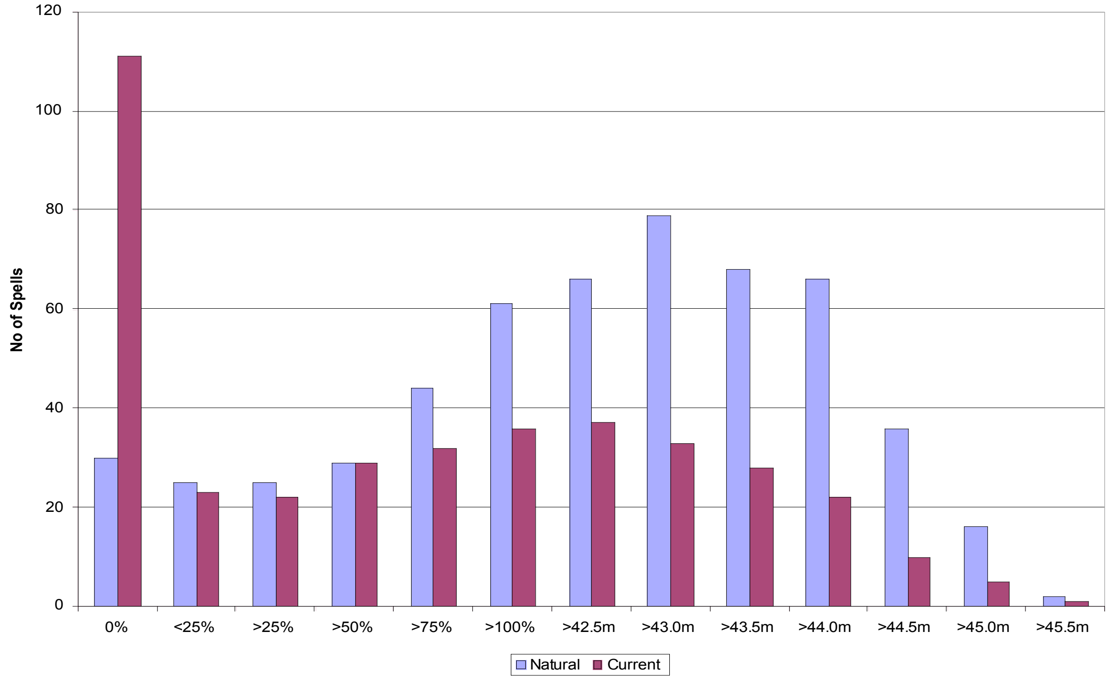


Figure 25. Yelwell spells analysis and inundation duration curve



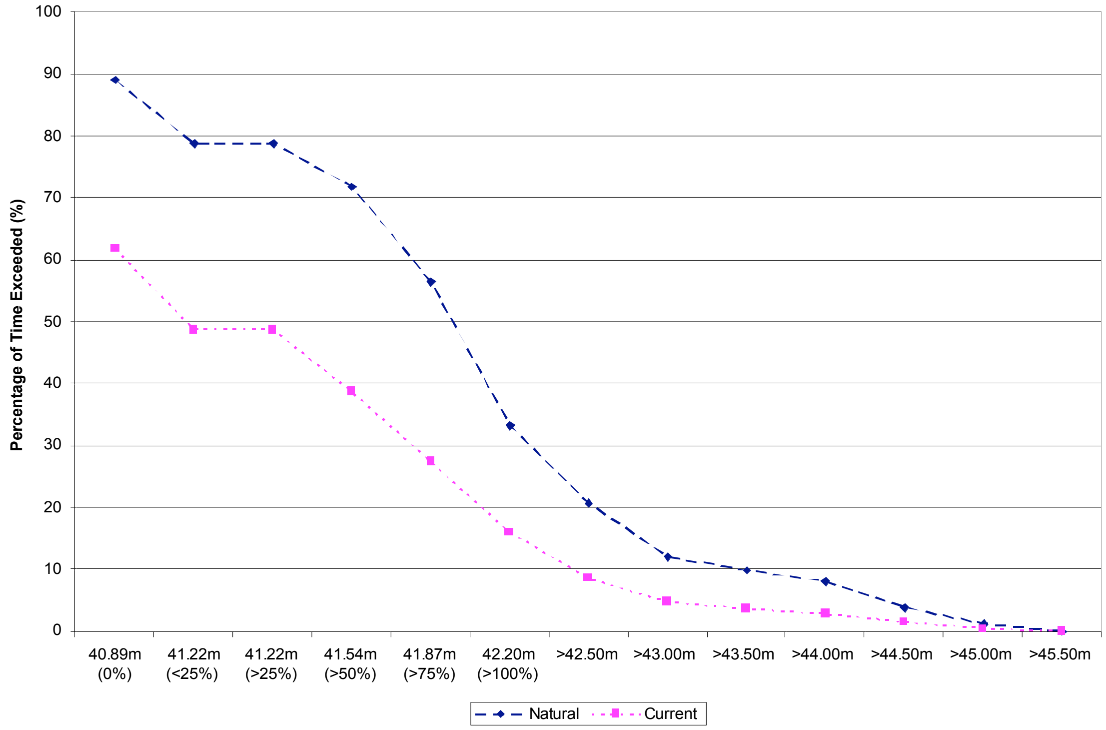
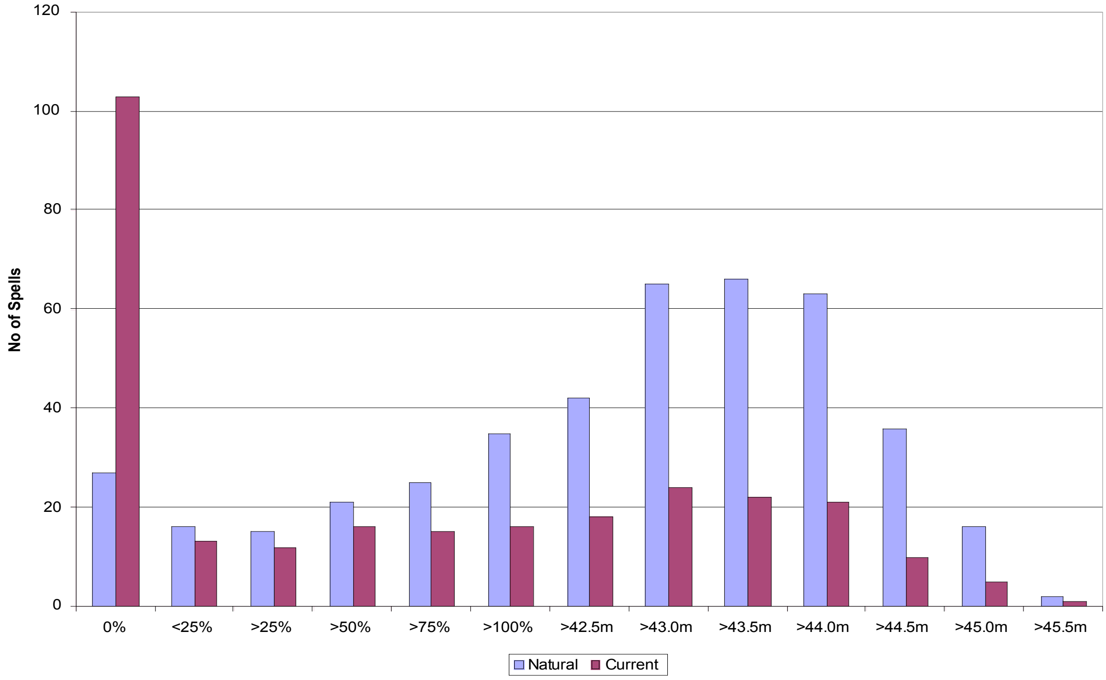


Figure 26. Konardin spells analysis and inundation duration curve



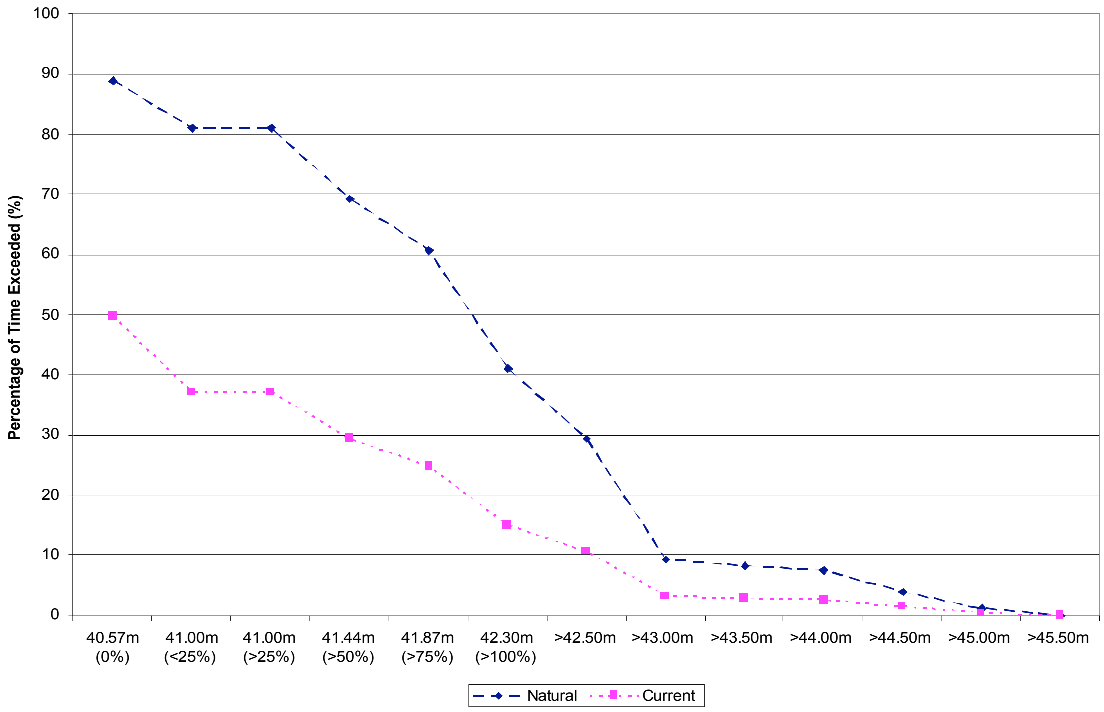
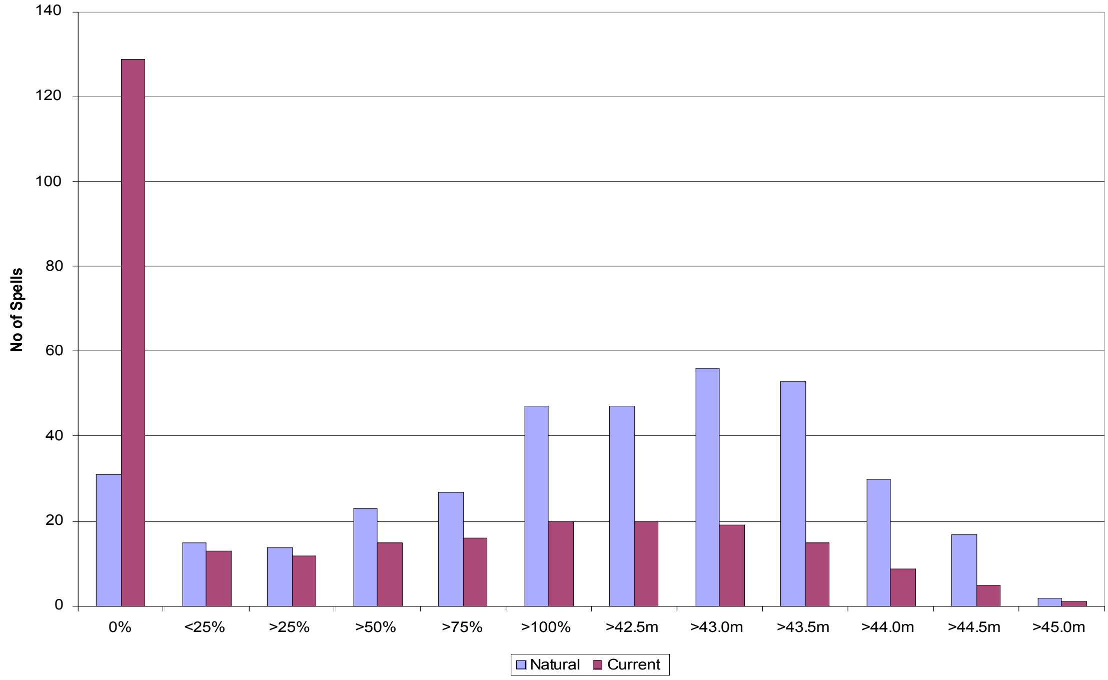


Figure 27. Bitterang spells analysis and inundation duration curve



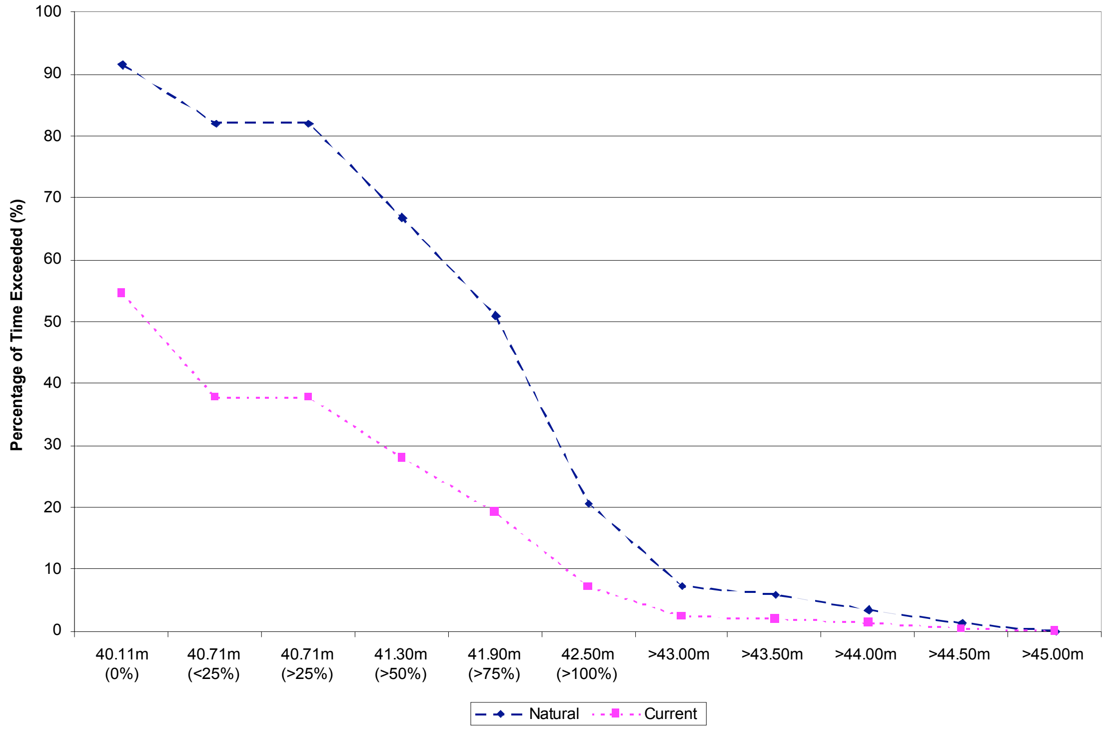
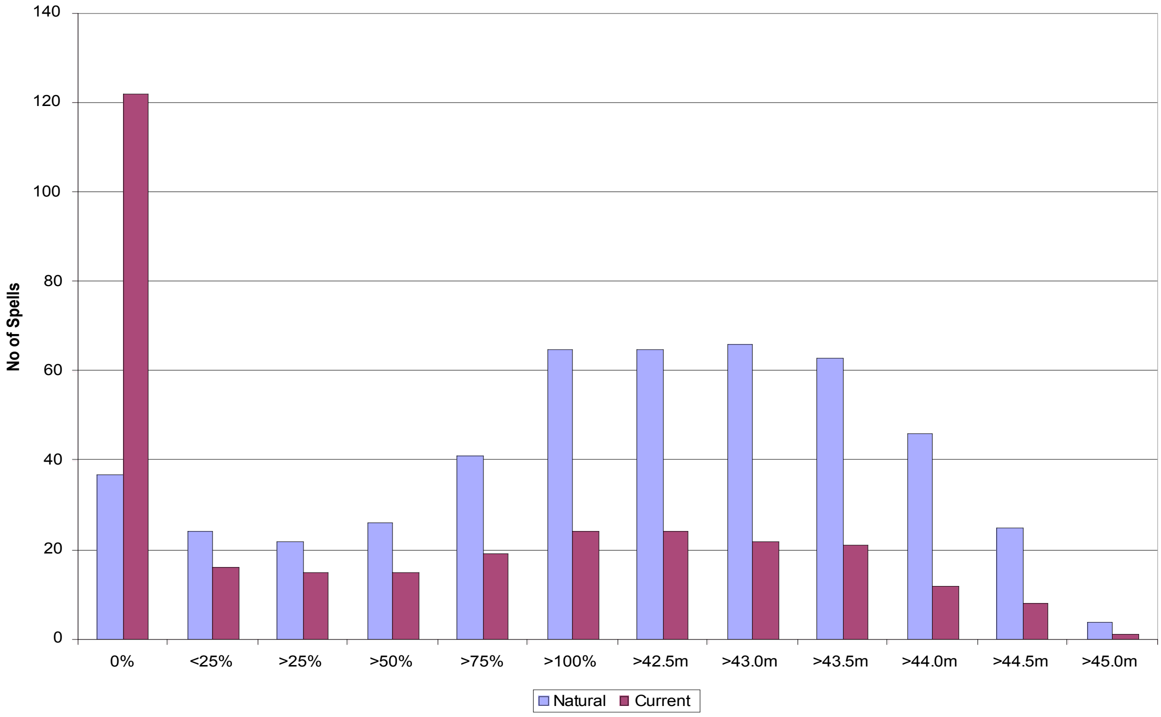


Figure 28. Cantala spells analysis and inundation duration curve



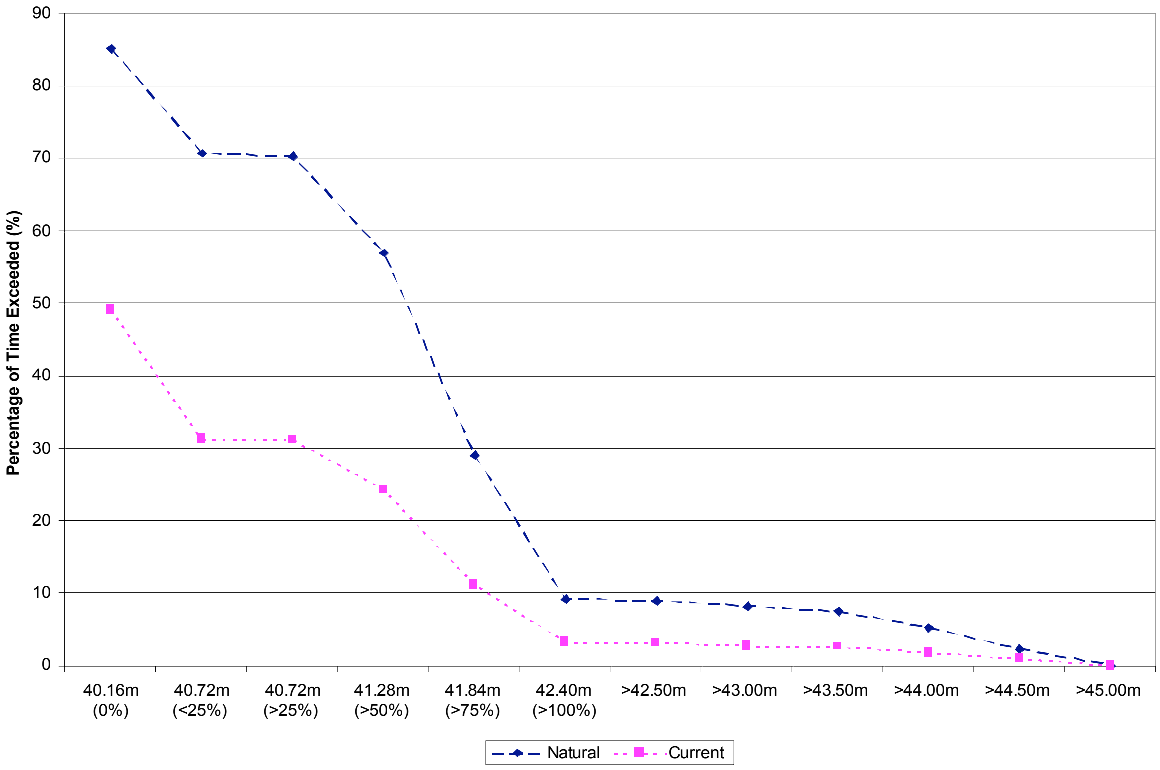
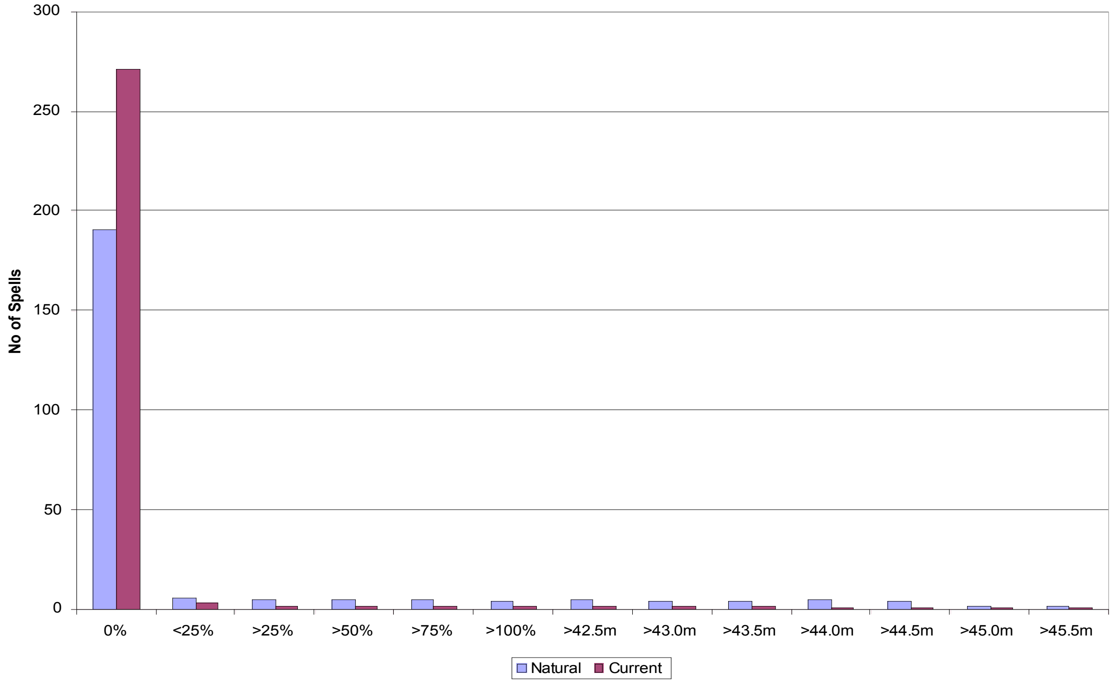
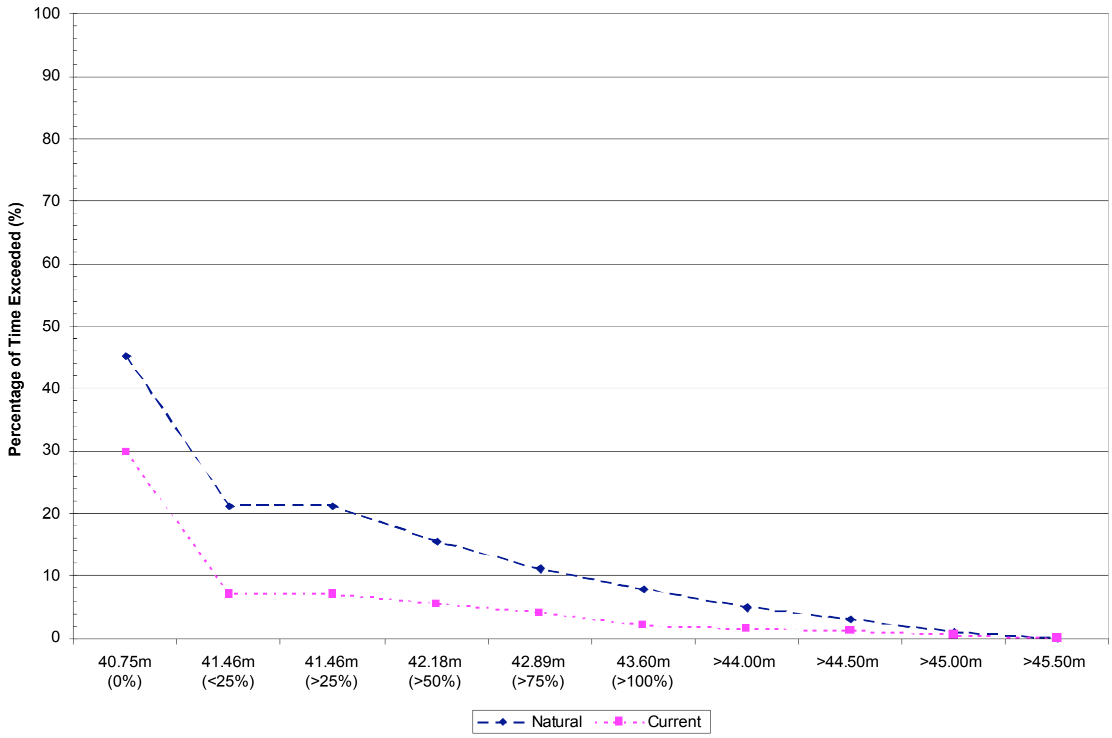


Figure 29. Kramen spells analysis and inundation duration curve





2.4 Analysis of Ecological Vegetation Classes

Digital Elevation Model (DEM)

A DEM was constructed using extensive LIDAR Survey data sourced from the Mallee Catchment Management Authority (CMA). This required thinning of data in order to reduce survey to a manageable amount able to be handled by 12D (terrain analysis software). 12D was used to produce a triangulated surface required for use in:

- assigning elevation to ecological vegetation class (EVC) boundaries by draping them onto the newly created surface;
- determination of lake retention levels;
- determination of creek invert levels;
- initial investigation of elevation range of individual EVC over the entire floodplain which suggested the requirement of a regional approach to understanding how EVC relate to elevation; and
- determination of suitable locations for possible engineering works to alter the hydraulics of the lakes capable of provide maximum ecological benefit.

EVC boundaries were identified by Ecological Associates and supplied to URS for GIS analysis.

GIS EVC Floodplain Analysis

In order to best understand pre-regulation watering of each EVC within regions of the entire floodplain a relationship was developed between inundation levels and EVC areas. Essentially, this was achieved by:

- segregating wetlands and floodplains into 8 contiguous regions within similar hydrological characteristics (Figure 30)
- constructing multiple inundation level (m) grid layers (eg. 40, 40.5 – 46m)
- extracting EVC area information from each inundation level for all 8 regions

From this analysis a set of EVC depth-area relationships have been developed for each region. The EVC within the Hattah Lakes system comprised of:

- Fringing Red Gum Woodland (FRGW)
- Black Box Woodland (BBW)
- Red Gum Woodland with Flood Tolerant Understorey (RGW-FTU)
- Red Gum Forest (RGF)
- Lignum Shrubland (LS)
- Wetland

Figure 30 Hydrologically similar regions used for EVC analysis

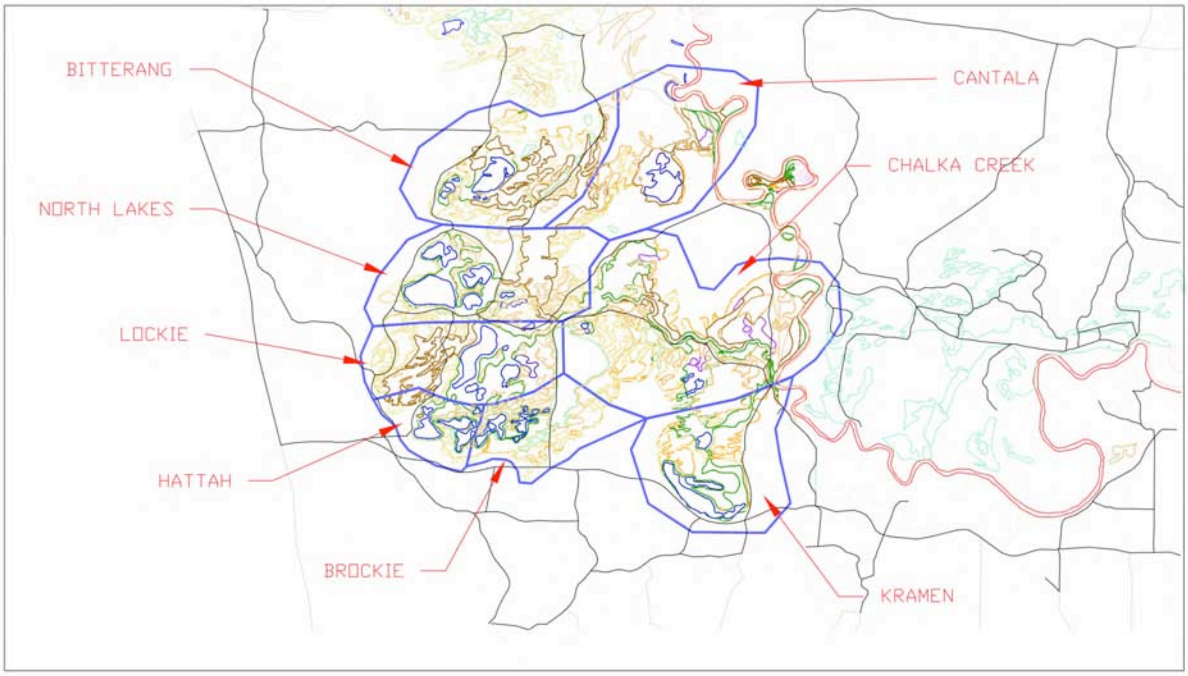


Figure 31 to Figure 38 show the depth – area relationship for each of the eight regions. The bar chart represents the area (ha) inundated for each ecological vegetation class within the region while the line chart represents the percentage of area inundated to the total area within the region. The data are presented in tabular form in Appendix D. The results in spells analysis could be used to determine the frequency of wetting and drying of each region.

Figure 31. Lockie region depth-area relationship

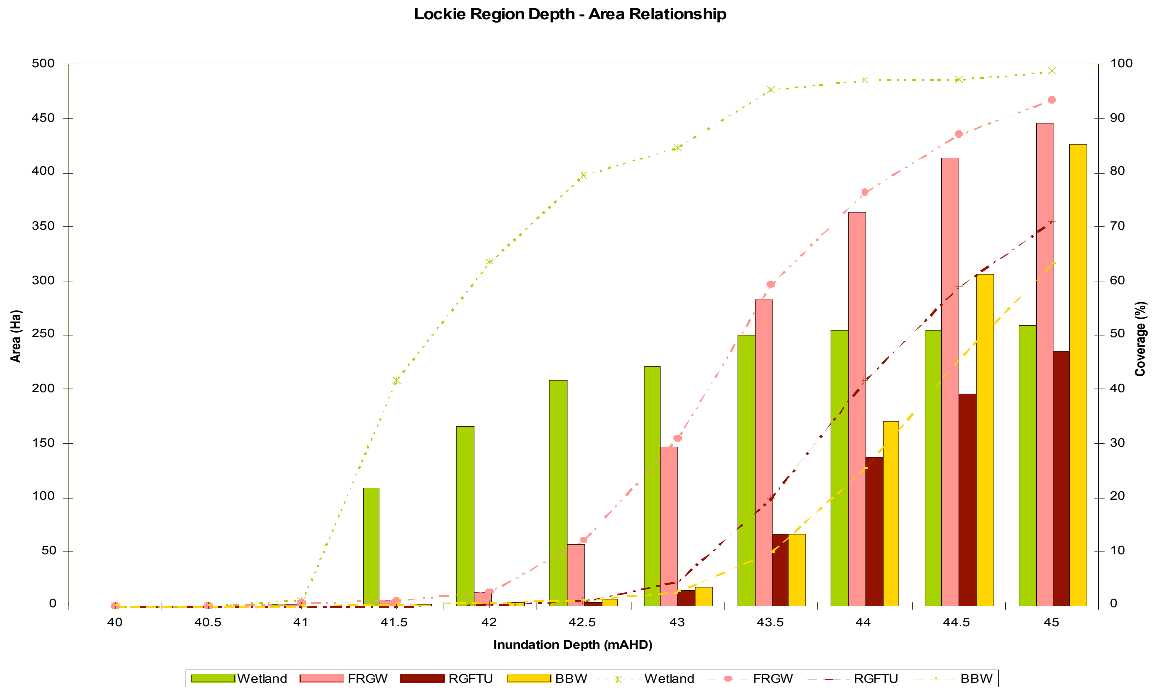


Figure 32. Bitterang region depth-area relationship

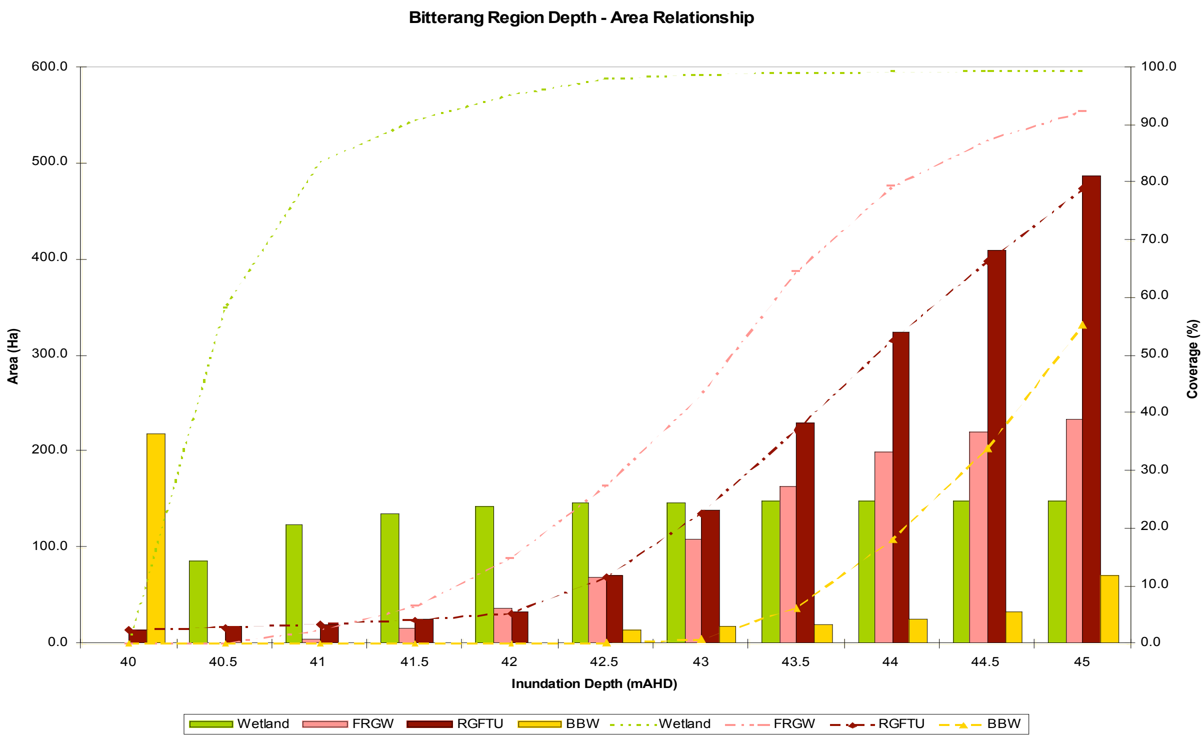


Figure 33. Brockie region depth-area relationship

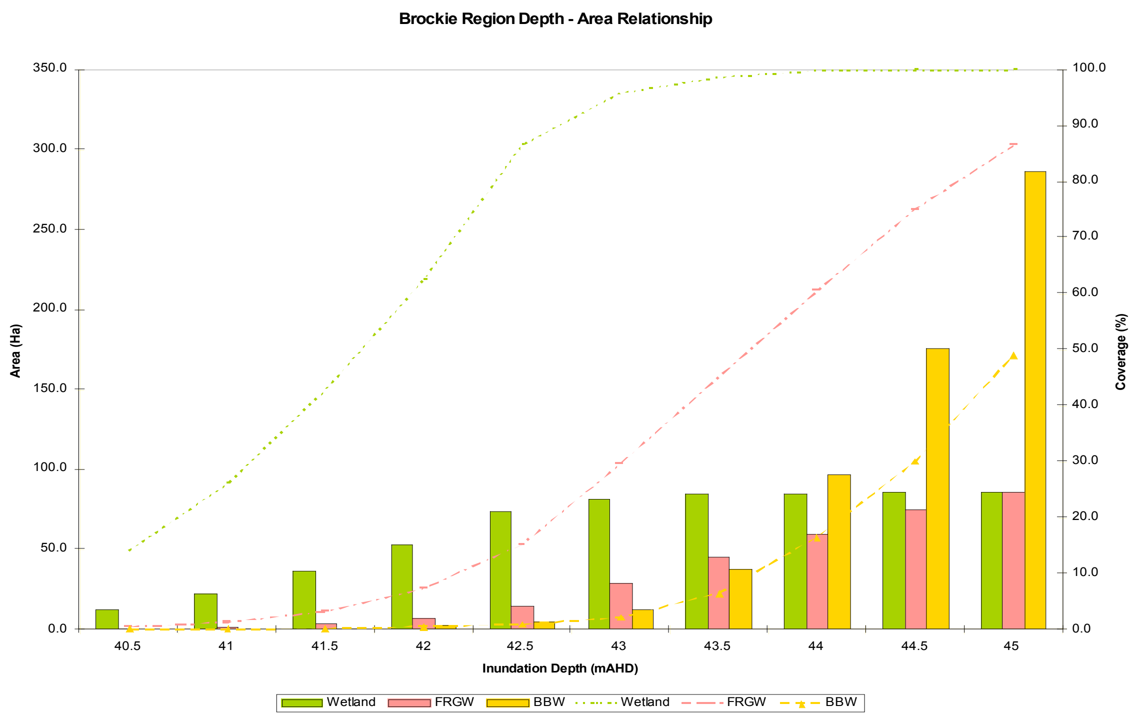


Figure 34. Cantala region depth-area relationship

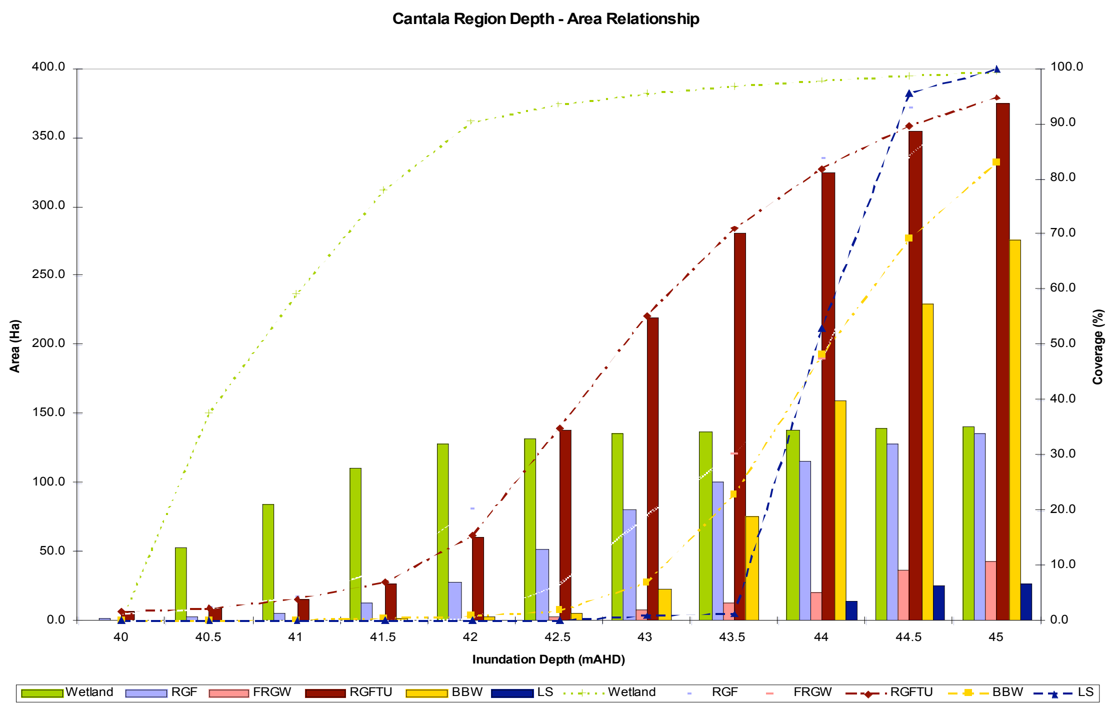


Figure 35. Chalka region depth-area relationship

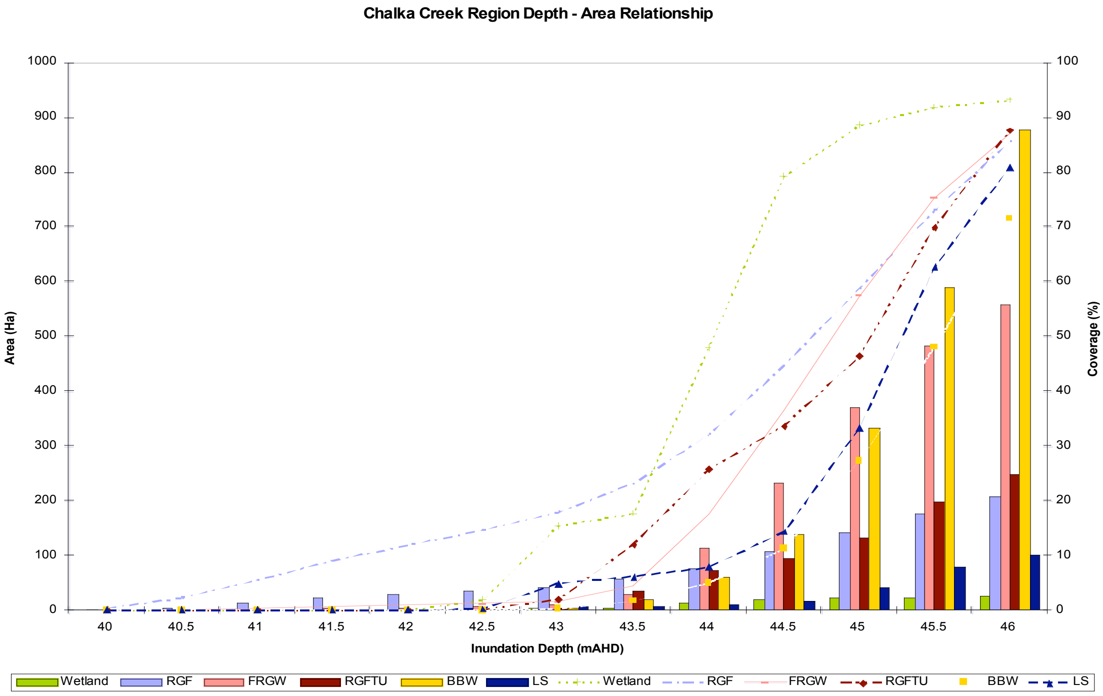


Figure 36. Hattah region depth-area relationship

Figure 37. Kramen region depth-area relationship

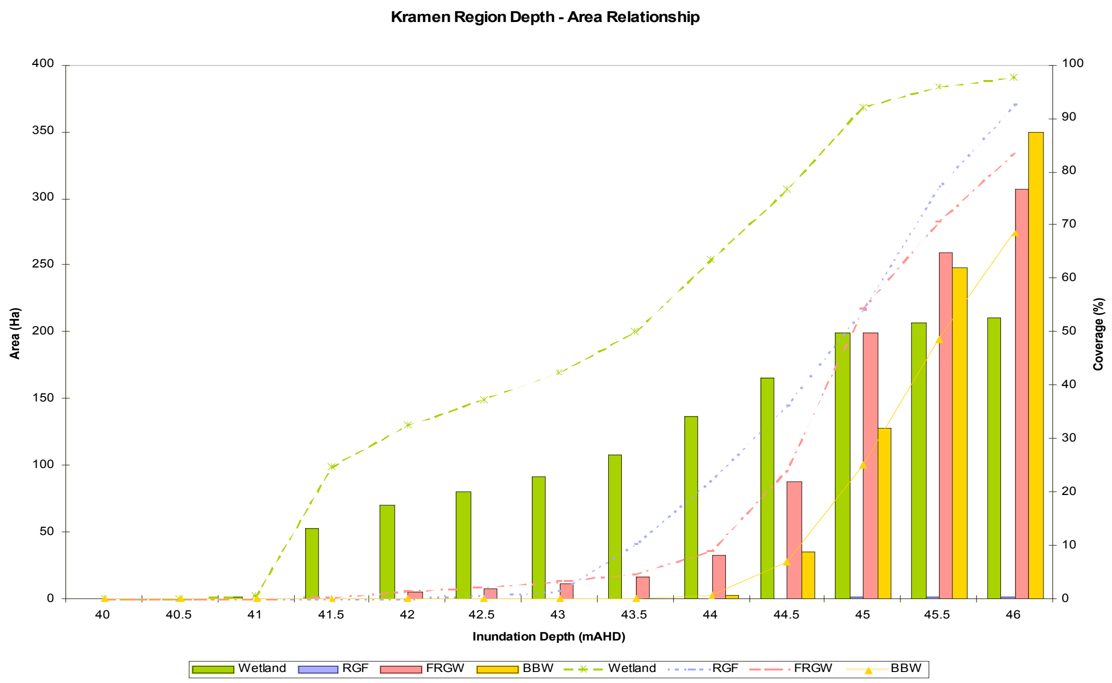
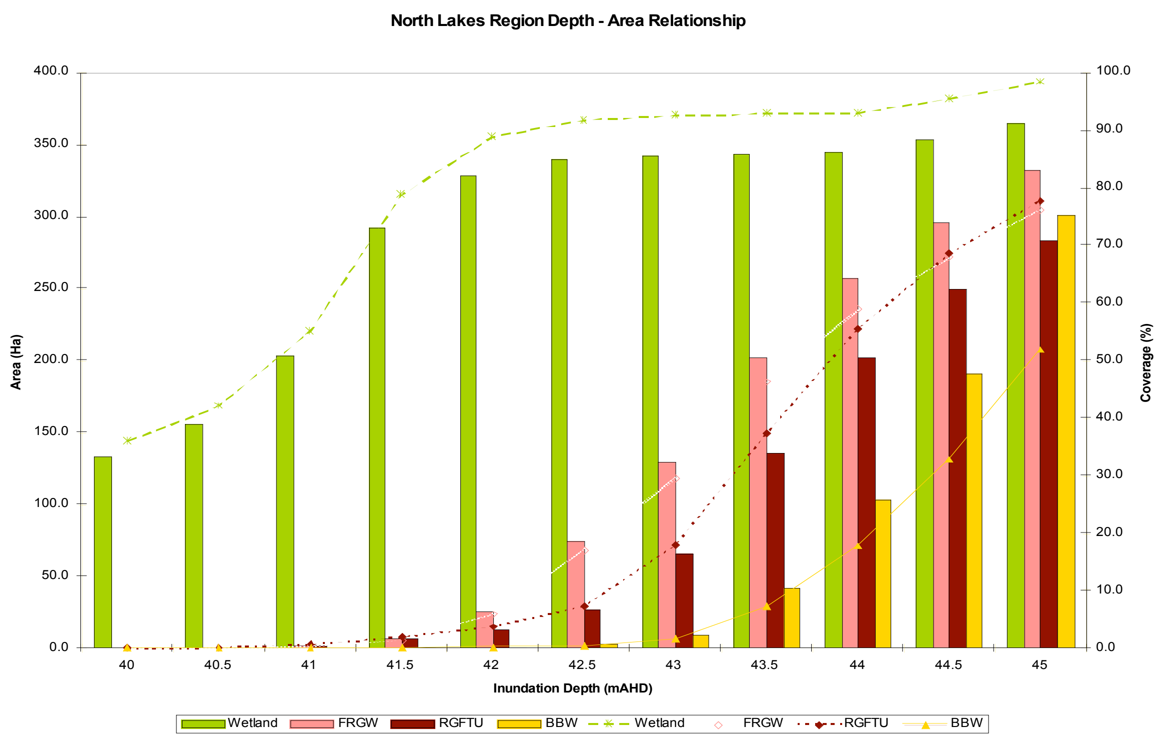


Figure 38. North lakes region depth-area relationship



2.5 Summary

The spell analysis has been interpreted to classify the wetlands in four groups. Statistics from the Natural scenario that best distinguish between the classes are presented in Table 7. The percent time when wetlands are more than 50% full is used to indicate the persistence of water in the wetlands. The events when the wetlands are less than 25% full is used to describe likelihood and duration of dry conditions. Events when the wetlands are more than 100% full are used to describe events when the wetlands are overtopped.

Table 7. Hydrology of Wetland Classes under Natural Conditions

Wetland	Depth	% time > 50% full	Events < 25% full (dry events)		Events > 100% full (full events)	
			% years with events	Median event duration	% years with events	Median event duration
Semi-permanent Wetlands						
Hattah	3.1	91	5	23	55	28
Bulla	2.5	87	9	31	51	29
Arawak	2.4	81	13	31	50	27
Mournpall	3.2	84	8	29	58	20
Brockie	2.3	76	13	40	42	30
Persistent Temporary Wetlands						
Little Hattah	1.0	63	32	31	62	22
Cantala	2.2	57	25	47	49	5
Bitterang	2.4	67	15	51	46	21
Tullamook	1.7	66	16	59	41	32
Boich	1.6	65	17	58	41	32
Nip Nip	1.4	65	17	65	36	41
Lockie	1.0	82	17	28	74	28
Konardin	1.7	69	16	52	36	39
Roonki	1.3	73	25	23	52	29
Yelwell	1.3	72	26	28	57	27
Yerang	1.5	71	27	25	63	20
Temporary Wetlands						
Marramook	0.4	47	29	75	42	31
Episodic Wetlands						
Kramen	2.9	16	7	625	4	92

Semi-permanent Wetlands are relatively deep. Water is very persistent and the wetlands remain more than 50% full between 76 and 91% of the time. Dry events are rare, occuring in less than 13% of years, and last less than one year. The full level of the wetlands is reached in approximately 50% of years and is generally exceeded for 30 weeks.

Persistent Temporary Wetlands are shallower. Water is persistent and the wetlands are more than 50% full approximatley 60% of the time. The wetlands dry out approximately 1 year in 4 and dry events have a median duration of approximately 6 to 12 months. The frequency of full events varies widely. The low-lying wetland Lockie (sill level 42.2 m AHD) is overtopped in 74% of years whereas Nip Nip with a relatively high sill of 42.6 is only overtopped in 36% of years.

Marramook is distinctive in that it is shallow with a water level that frequently ranges between full (events occur in 42% of years) and dry (events in 29% of years).

Kramen has a relatively high sill (42.6 m AHD) and receives inflow only rarely. The median duration of dry periods is long (625 days). However the duration of events which overtop the wetland are also long (92 days) although they occur rarely.

Water Regime Classes

The data describe a general trend where Red Gum Forest is flooded first, then Fringing Red Gum then Red Gum FTU and finally Black Box Woodland. This describes a general relationship between vegetation and water regime, as expressed on the elevation gradient. However, there is significant overlap in the distribution of water regime classes; lower classes need not be entirely inundated before flooding of higher classes commences. The overlap indicates a degree of error in the relationship which may be explained by the following:

- There may be factors other than water regime that affect the distribution of vegetation, such as soil type and soil salinity.
- There may be errors in the EVC mapping on which the analysis was based.
- There may be errors in the hydraulic model.
- The relationship between elevation and hydrology may not be completely consistent within the analysed floodplain regions due to local depressions, drainage features and constrictions on the spread of water.

Nevertheless, characteristic elevations can be assigned to the water regime classes to distinguish their hydrology and distribution (Table 8). This has been done for water regime classes that represent a significant proportion of the floodplain zones. Classes that represent a minor proportion of the area have not been presented as they are likely to have a higher degree of error. The exceedence / elevation data (Figure 31 to Figure 38) was used to identify the elevation at which approximately 60% of the water regime classes was inundated in each hydrological region. The spells analysis was then used to characterise the hydrology of those elevations.

Table 8. Hydrology of Water Regime Classes at an Elevation Corresponding to Approximately 60% of the Area of the Water Regime Class

Region	Water Regime Class	Threshold for Significant Inundation (area in region: % (ha))	Elevation (m AHD)	Natural		Current	
				Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Lockie	Fringing Red Gum	59 (283)	43.5	6	60	4	28
	Red Gum FTU	59 (196)	44.5	4	34	5	12
	Black Box	63 (427)	45.0	3	20	3	7
Hattah	Fringing Red Gum	61 (75)	43.5	5	53	4	25
	Black Box	63 (87)	44.5	4	34	5	12
	Red Gum FTU	68 (45)	45.0	3	20	3	7
Brockie	Fringing Red Gum	60 (60)	44.0	4	48	4	18
	Black Box	49 (287)	45.0	5	20	3	6.5
North Lakes	Fringing Red Gum	59 (257)	44.0	6	48	3	20
(Mournpall)	Red Gum FTU	69 (301)	44.5	5	30	5	11
	Black Box	52 (250)	45.0	4	13	3	4
Bitterang	Fringing Red Gum	65 (163)	43.5	5	41	5	14
	Red Gum FTU	66 (409)	44.5	3	14	3	4
	Black Box	55 (218)	45.0	2	2	2	1
Cantala	Red Gum Forest	58 (80)	43.0	6	49	4	20
	Red Gum FTU	71 (282)	43.5	4	48	4	18
	Fringing Red Gum	84 (37)	44.5	2	23	5	8
	Lignum Shrubland	96 (26)	44.5	2	23	5	8
	Black Box	69 (230)	44.5	2	23	5	8
Kramen	Fringing Red Gum	71 (260)	45.5	1.5	2	1	1
	Black Box	69 (350)	46.0				

The Lockie, Hattah, Brockie and Mournpall regions are relatively closely linked hydrologically and water regime classes tend to occur at similar elevations. Greater variation in the other regions reflects their different hydrologies. Approximately 60% of the Fringing Red Gum is consistently inundated at an elevation of 43.5 or 44 m AHD. Under natural conditions Fringing Red Gum is generally inundated for 4 to 6 weeks in 50 to 60% of years.

A similar proportion of Red Gum FTU is generally inundated at an elevation of 44.5 m AHD. Under natural conditions this water regime class was generally inundated for 3 to 4 weeks in 20 to 30% of years.

At an elevation of approximately 45 m AHD 60% of Black Box woodland is generally inundated. Under natural conditions this water regime class was inundated for 2 to 4 weeks in 20% of years.

Red Gum Forest only occurs near the river bank and is a component of the Cantala region. It is inundated at the lowest elevation (60% inundated at 43 m AHD) and under natural conditions where it was generally inundated in 50% of years for 6 weeks.

Flood Recession

The data suggests that there are geomorphological controls on the recession of flood water from the system. In most regions, areas above 43.5 or 43 m AHD are flooded for significantly longer than higher elevations. This suggests that flood water drains back to the river relatively freely, perhaps via broad, overbank flow, until this elevation is reached. Below this level, flow may be limited to well-defined creeks and channels and may occur relatively slowly. Structures that address drainage through well-defined flow paths would be an effective way to prolong flooding.

3.1 Framework to Set Ecological Objectives

This report identifies priorities for water management based on conservation importance and hydrological threat. To do this, a framework has been developed to identify conservation values that depend on water. The framework is based on a **broad ecological objective** that describes the intended condition and conservation status of the system.

A detailed description of the dependence of the ecosystem on flooding is used to identify the species, communities and ecological processes within the ecosystem that must be preserved for the broad ecological objective to be achieved. These are the **specific ecological objectives** and are used to locate and assess local or regional environmental threats to the ecosystem. The specific ecological objectives are measurable, and can be used to set management targets. Listed alongside the specific ecological objectives are the ecosystem components on which they depend. Ecosystem components include hydrological environments, physical habitat and food sources. The detailed descriptions (or conceptual models) are presented for each water regime class in this section of the report.

Due to the complexity of the system and the large number of important conservation values present, a large number of specific ecological objectives are identified. While it is important to identify all of the specific objectives, the number of objectives is too cumbersome to assess threats to the ecosystem and to evaluate the effectiveness of management options.

Therefore a subset of **representative ecological objectives** was selected. These objectives were chosen to share all of the habitat requirements of the specific objectives, so that by achieving the representative objectives, the habitat requirements of all objectives can be provided. A checklist was used to compare all the habitat components required by the specific objectives against the habitat requirements of the representative objectives to ensure that all were represented.

3.2 Broad Ecological Objective

The overall objective of water management at Hattah-Kulkyne Lakes is:

"to achieve the original species diversity, structure and function of the ecosystem by providing the hydrological environments required by indigenous plant and animal species and communities".

The *species diversity* of the ecosystem represents the current species composition of the system, including resident and visiting species, in relation to the interpreted original species composition. This component of the overall objective requires that emphasis is given to species with a recognised conservation status at a regional, state or national level. Also relevant are species that are locally extinct or threatened but which may not have a formal conservation significance.

The *structure* of the ecosystem represents the hydrological environments and plant communities that exist and that contribute to the habitat requirements of indigenous flora and fauna. In this study ecosystem structure has been defined by water regime classes. These provide a classification of broad plant communities and hydrological environments according to their flooding history, flow relationships and geomorphology. This component of the overall objective requires that all water regime classes are represented.

The *function* of the ecosystem refers to the habitat linkages and hydrological processes that must exist for the system to effectively provide habitat for floodplain flora and fauna. Ecosystem function refers to the passage of fauna between habitat components, such as between the mallee and the floodplain or between the floodplain and the river. It refers to the appropriate provision of habitat components in space, so that the proximity of feeding, sheltering and breeding habitat support target species.

3.3 Approach

Water regime classes are a spatial classification of the floodplain into areas with common water regimes and ecological characteristics. Water regime classes provide the basis to establish objectives for the location, extent and condition of components of the floodplain ecosystem, and therefore to set hydrological objectives. Water regime classes were defined using existing information that describes the vegetation and aquatic habitat values of the floodplain and lakes. Water regime classes were defined at a scale that reflects the broad range of flood-dependent habitats and the scope of water management to address them individually.

The structure of floodplain plant communities strongly reflects long term flooding histories. The duration, depth, frequency and timing of flooding influences plant species present, their relative abundances and their growth habit. Plant community classifications are therefore a useful way to directly relate water regime to plant habitat and indirectly to fauna habitat.

The plant communities present on the floodplain at Hattah have been mapped in detail and described by White et al. (2001) as Ecological Vegetation Classes (EVCs). Possible relationships between EVCs and water regime were assessed. Using topographic data and information on the known spread of water on a rising hydrograph, EVCs were arranged in the order in which they are likely to be flooded and likely frequency and relative durations of flooding. This environmental gradient was refined by reviewing the EVC descriptions, which set out the species present during flooded and dry phases, their relative abundances and their habit. Species with known relationships to flooding could be used to rank the EVCs from most-likely to least-likely to be flooded.

EVCs were amalgamated into five floodplain water regime classes (Table 9). EVCs were amalgamated where there was no strong hydrological basis to treat the botanical differences reported in the EVC descriptions separately. The distribution of water regime classes is presented in Figure 39.

Table 9. Floodplain Water Regime Classes.

Water Regime Class	Component EVCs
Red Gum Forest	106 Riverine Grassy Forest
	811 Grassy Riverine Forest
Fringing Red Gum Woodland	813 Intermittent Swampy Woodland
	818 Shrubby Riverine Woodland
Red Gum with Flood Tolerant Understorey	295 Riverine Grassy Woodland
Black Box Woodland	823 Lignum Swampy Woodland
	103 Riverine Chenopod Woodland
Lignum Shrublands	808 Lignum Shrubland
	104 Lignum Wetland

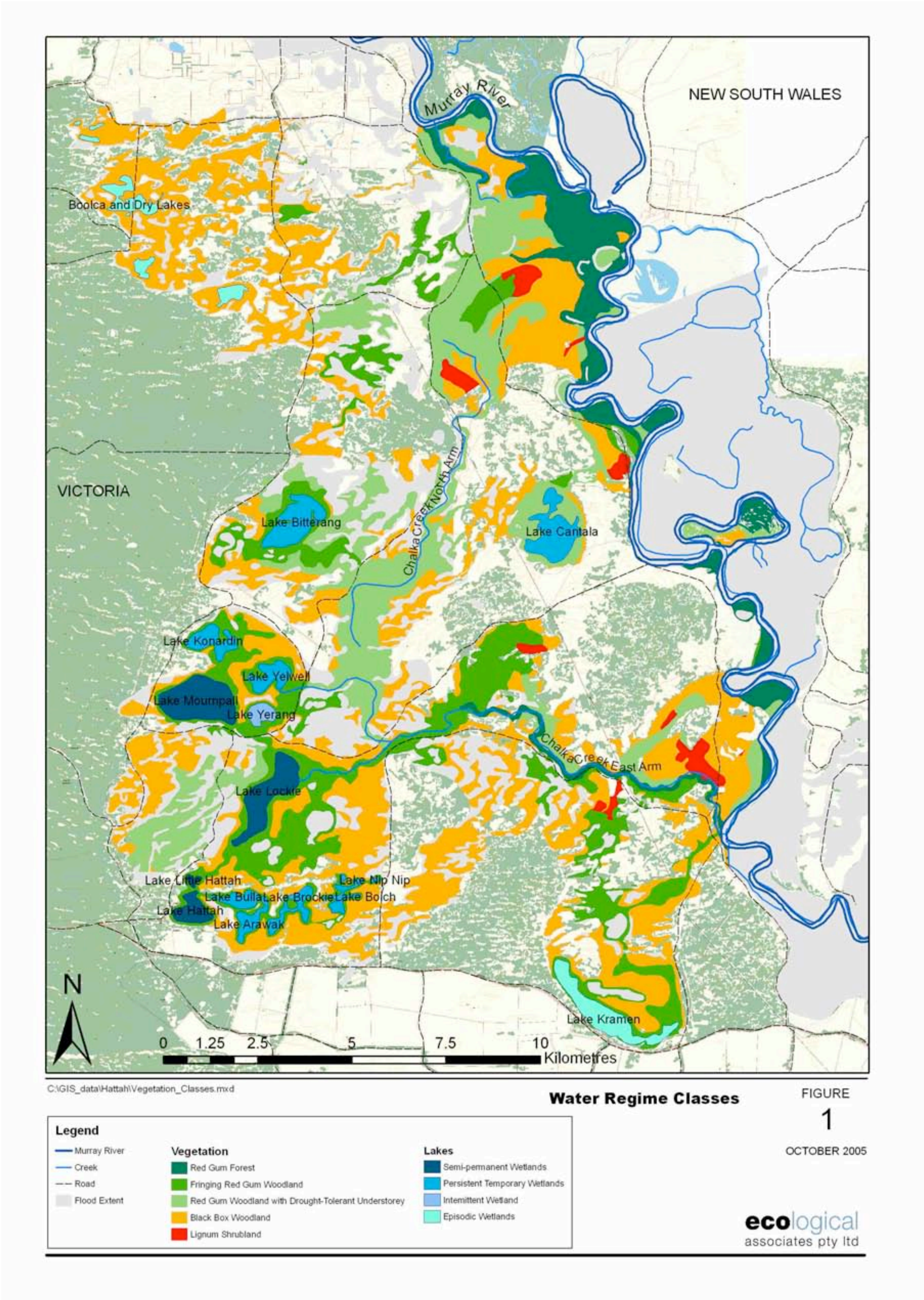


Figure 39. Water Regime Classes at Hattah Lakes

All the major lakes at Hattah are classified as EVC 107 Lake Bed Herbland, which does not reflect the important differences in habitat associated with the water regimes of the lakes. Therefore the hydrological analysis was used to classify the lakes into four water regime classes (Table 10).

An objective of the SEA Plan (Mallee CMA in prep.) is to restore examples of original wetland and floodplain communities. Therefore the natural depth and natural drying time was used to classify the lakes, even though these values have been altered through structural works in the system and changes to the river flow regime. The water regime classes are also described in terms of their likely pre-regulation condition and extent, rather than their current condition.

Table 10. Wetland Water Regime Classes

Water Regime Class	Lake
Semi-permanent Wetlands	Hattah
Semi-permanent Wetlands	Bulla
Semi-permanent Wetlands	Arawak
Semi-permanent Wetlands	Mournpall
Semi-permanent Wetlands	Brockie
Persistent Temporary Wetlands	Little Hattah
Persistent Temporary Wetlands	Brockie
Persistent Temporary Wetlands	Cantala
Persistent Temporary Wetlands	Bitterang
Persistent Temporary Wetlands	Tullamook
Persistent Temporary Wetlands	Boich
Persistent Temporary Wetlands	Nip Nip
Persistent Temporary Wetlands	Lockie
Persistent Temporary Wetlands	Konardin
Persistent Temporary Wetlands	Roonki
Persistent Temporary Wetlands	Yelwell
Persistent Temporary Wetlands	Yerang
Temporary Wetlands	Marramook
Episodic Wetlands	Kramen
Episodic Wetlands	Boolca and Dry Lakes

In addition, the flowing environment of Chalka Creek was defined as a separate water regime class.

The composition, distribution, extent and hydrology of the water regime classes is described in the subsections below.

The following conceptual models represent a network of hypotheses of how the lakes respond to flooding. The models are based on evidence from the known habitat requirements of plant and animals, records of the presence and behaviour of flora and fauna at the lakes, the site inspection and discussion with people with local knowledge.

A major assumption in these models is that the system is capable of supporting an extensive and complex vegetation in the woodland understorey and lake beds. Many of the interpreted fauna processes depend on this assumption. It is understood that the lakes currently have little emergent or submerged vegetation and these models may contradict local knowledge. Three factors may help explain the difference between the vegetation that the models predict and the vegetation that is actually present:

- vegetation has been suppressed by a long history of high grazing pressure;
- the growth of submerged vegetation is suppressed when lakes are flooded, possibly due to carp; and
- prolonged drought has reduced aquatic plant growth.

The conceptual models refer to fauna in terms of guilds, which are groups of species that share similar habitat requirements. The members of each guild and the Water Regime Classes on which they principally rely are presented in Table 11.

Table 11. The water regime classes used by fauna guilds.

Water regime classes are abbreviated as SPW Semi-permanent Wetland, PTW Persistent Temporary Wetland, TW Temporary Wetland, EW Episodic Wetland, LS Lignum Shrubland, RGF Red Gum Forest, FRG Fringing Red Gum Woodland, RGFTU Red Gum with Flood Tolerant Understorey, BBX Black Box Woodland, CK Chalka Creek.

Fauna Group	Guild	Number of Species and Species of Conservation Significance	Primary Water Regime Classes	Supplementary Water Regime Classes	Rarely Used Water Regime Classes
Waterbirds	Dabbling Ducks	7 spp. 2 sig.	PTW, TW	SPW, FRG	EW, RGFTU
	Deep Water Divers	3 spp. 3 sig.	SPW	PTW	EW
	Grazing Water Fowl	4 sp. 0 sig.	PTW, TW	SPW	FRG
	Large Waders	5 spp. 2 sig.	PTW, TW	SPW	FRG, RGFTU
	Small Waders	13 sp. 7 sig.	PTW, TW		
	Shoreline Foragers	6 sp. 0 sig.	PTW, TW	SPW	
	Piscivores	21 spp. 10 Sig.	SPW	RGF, PTW, TW	
Birds of Prey	Large Carnivores	2 spp. 1 Sig.	SPW	CK, RGF, PTW, TW, EW	
	Small Carnivores	16 spp. 2 Sig.	FRG, RGFTU, BBX		
Bushbirds	Insectivores	84 spp. 9 Sig.	FRG, RGFTU, BBX		
	Arboreal Granivores	17 spp. 3 Sig.	FRG, RGFTU, BBX		
	Ground Granivores	4 Spp. 0. Sig.	FRG, RGFTU, BBX		
	Nectivores/Omnivores	20 Sp. 3 Sig.	FRG, RGFTU, BBX		
	Frugivores	4 Spp. 0. Sig.	FRG, RGFTU, BBX		
Frogs	Terrestrial Frogs	5 Spp. 1 Sig.	PTW, TW, CK	SPW, FRG	RGFTU, EW
	Burrowing Frogs	3 Spp. 0 Sig.	FRG	RGFTU	
Mammals	Aquatic Mammals	1 Spp. 0. Sig	SPW	PTW, TW	EW, LS
	Arboreal Herbivores	1 Spp. 0. Sig	FRG	RGFTU	
	Ground Insectivores	1 Spp. 0. Sig	FRG, RGFTU, BBX		
	Ground Granivores	1 Spp. 1. Sig	FRG, RGFTU, BBX		
	Aerial Insectivores	10 Sp. 1 Sig.	FRG, RGFTU, BBX	SPW	
	Piscivores	1 Sp. 0 Sig.	SPW	PTW	
	Large Grazers	3 Spp. 1 Sig.	FRG, RGFTU, BBX		
Reptiles	Aquatic Reptiles	3 Spp. 0 Sig.	SPW	PTW, TW	EW, LS
	Large Carnivores	6 Sp. 2 Sig.	FRG, RGFTU	BBX	
	Small Carnivores	11 Sp. 0 Sig	FRG, RGFTU, BBX		
Fish	Large Fish	3 Spp. 2 Sig.	SPW, CK	PTW, TW, FRG	RGFTU, BBX, LS
	Small Fish	1 Sp. 0 Sig.	PTW, TW, CK	SPW, FRG	RGF, RGFTU, BBX, LS
	Vegetation Dependent	4 Spp. 3 Sig.	PTW, TW	CK, SPW, EW, FRG	BBX, LS
	Floodplain	0 Sp.	FRG, RGF	RG FTU	BBX, LS
Aquatic Invertebrates	Scraper	1 Sp. 1 Sig.	CK		

Waterbirds generally have specific requirements for breeding that involve vegetation types and aquatic environments. The relationship between these requirements and water regime classes is presented in Table 12.

Table 12. Use of Water Regime Classes by breeding waterbirds

Water regime classes are abbreviated as SPW Semi-permanent Wetland, PTW Persistent Temporary Wetland, TW Temporary Wetland, EW Episodic Wetland, LS Lignum Shrubland, RGF Red Gum Forest, FRG Fringing Red Gum Woodland, RGFTU Red Gum with Flood Tolerant Understorey, BBX Black Box Woodland, CK Chalka Creek.

Common Name	Breeding Stimulus	Nest Type	Principal Breeding Water Regime Classes	Supple-mentary Breeding Water Regime Classes	Rarely Used Water Regime Classes
Red-necked Avocet	Flooding, Seasonal	Ground scrape in flooded reeds	PTW, TW	SPW	EW, LS
Black-fronted Dotterel	Flooding	Ground scrape in flooded reeds	PTW, TW	SPW	EW, LS
Masked Lapwing	Flooding	Ground scrape in flooded reeds	PTW, TW	SPW	EW, LS
Red-capped Plover	Flooding	Ground scrape in flooded reeds	PTW, TW	SPW	EW, LS
Black-winged Stilt	Flooding	Ground scrape in flooded reeds	PTW, TW	SPW	EW, LS
Freckled Duck	Flooding, Seasonal	Platform in reeds or shrubs 1 m above water	PTW, TW	SPW	EW, LS
Black Swan	Flooding	Mattress of vegetation near reeds	PTW, TW	SPW	EW, LS
Musk Duck	Seasonal	Mattress of vegetation near reeds	PTW, TW	SPW	EW, LS
Australasian Grebe	Flooding	Raft of reedy vegetation over deep water	PTW, TW	SPW	EW, LS
Great Crested Grebe	Flooding	Raft of reedy vegetation over deep water	PTW, TW	SPW	EW, LS
Dusky Moorhen	Flooding	Platform in or on flooded reeds	PTW, TW	SPW	EW, LS
Purple Swamphen	Flooding	Platform in or flooded reeds	PTW, TW	SPW	EW, LS
Darter	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Little Egret	Flooding, Seasonal	Stick nest in flooded trees	FRG	RGFTU	BBX
While-necked Heron	Flooding, Seasonal	Stick nest in flooded trees	FRG	RGFTU	BBX
White-faced Heron	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Great Cormorant	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Little Black Cormorant	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Pied Cormorant	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Little Pied Cormorant	Flooding	Stick nest in flooded trees	FRG	RGFTU	BBX
Yellow-billed Spoonbill	Flooding, Seasonal	Stick nest in flooded trees	FRG	RGFTU	BBX

Common Name	Breeding Stimulus	Nest Type	Principal Breeding Water Regime Classes	Supple-mentary Breeding Water Regime Classes	Rarely Used Water Regime Classes
Australian Wood Duck	Flooding	Tree hollows near water	FRG	RGFTU	BBX
Pink-eared Duck	Flooding	Tree hollows or reedy platform	FRG	RGFTU	BBX
Blue-billed Duck	Flooding	Tree hollow or reedy platform	FRG, PTW, TW	SPW	EW, LS
Chestnut Teal	Flooding	Tree hollow or reedy platform	FRG, PTW, TW	SPW	EW, LS
Grey Teal	Flooding	Tree hollow or reedy platform	FRG, PTW, TW	SPW	EW, LS
Australian Shelduck	Flooding, Seasonal	Tree hollow or reedy platform	FRG, PTW, TW	SPW	EW, LS
Pacific Black Duck	Flooding	Tree hollow or reedy platform	FRG, PTW, TW	SPW	EW, LS

3.4 Semi-permanent Wetlands

Ecology

This water regime class represents the conditions expected in lakes Hattah, Bulla, Arawak and Mournpall prior to regulation. These wetlands were almost permanently flooded due to either frequent inflows (associated with a low flow threshold) and / or the capacity to retain water for prolonged periods. Hattah and Mournpall retain water to more than 3 m depth after flooding, while Bulla and Arawak have retention depths of approximately 2.4 m. The water level exceeded 50% of the wetland depth more than 80% of the time. The retention level of the wetlands was exceeded in 50% of years, generally for 6 months at a time.

This water regime class rarely dries and the normal state of the wetlands is to be full, or nearly full. The lake water level usually falls in summer and autumn, partially exposing the macrophytes fringing the lake bed and providing an opportunity for macrophytes to recover from inundation and spread down the wetland bank to some extent. The lakes are filled in winter by freshes in the River Murray. Early and persistent inundation of the wetland edge excludes emergent macrophytes from most of the wetland bed. However the freshes overtop the lake level and extend to the understorey of the Fringing Red Gum Woodland, providing suitable conditions for emergent species such as *Carex tereticaulis, Juncus* spp., and *Phragmites australis* to grow as an understorey in this adjacent water regime class.

Persistent, deep flooding excludes semi-emergent macrophytes the central part of the lake; they occur principally as a component of the fringing emergent macrophyte community.

There is a marked boundary between the water regime of the lakes and the surrounding floodplain. The water level on the floodplain falls rapidly as river levels decline, creating an intermittent water regime suitable for Red Gum woodland. In contrast, the water level in the lake declines very slowly after the flood level falls below the lake threshold, creating a stable, persistent water regime. This contrast delineates the wetland habitat from the woodland, creating a narrow zone for emergent macrophytes at the edge of the lakes and the absence of trees from the lake bed.

The lake level gradually falls between flood events. During major droughts the lakes can dry altogether. The lake bed will be colonised by opportunistic wetland and terrestrial plants such as *Centipeda cunninghamii, Agrostis avenacea* and *Eucalyptus camaldulensis.* However, perennial plants will be drowned and die when the lake is re-flooded.

The normal state of these lakes is a mature, lake habitat. The lakes support a relatively species poor climax community of aquatic invertebrates comprising large zooplankton (particularly Cladocera), Shrimp (*Parataya* sp. and *Macrobrachium* sp.) and large insect larvae such as mayfly and dragonfly. Together with small fish living in the fringing macrophytes, these provide prey for large pelagic fish which live in the deep open water in the central parts of the lakes, particularly Silver Perch, Golden Perch and Bony Bream. Large fish will also visit the fringing vegetation and snags which provide benthic invertebrate prey and shelter from piscivorous fish. Deep, persistent flooding would also support resident populations of Tortoise. The lakes represent an alternative habitat to the River Murray for these large aquatic species, which move between the floodplain and the river during peaks in river flow.

Between peaks in river flow, the bird fauna is dominated by fish-eating species such as Little Egret and Pelican. The lakes also provide a semi-permanent habitat for a wide range of waterbirds, which would become more abundant and diverse during drought periods.

Table 13. Specific Ecological Objectives for Semi-permanent Wetlands

Specific Objectives	Contribution of Water Regime Class
Feeding and breeding by resident populations of aquatic reptiles and amphibians	Deep water, aquatic habitat, aquatic macroinvertebrates, submerged aquatic vegetation
Feeding by dabbling ducks	Submerged aquatic vegetation, aquatic macroinvertebrates
Feeding by diving waterbirds	Deep water, aquatic macroinvertebrates, submerged aquatic vegetation
Submerged aquatic vegetation	Deep water, aquatic habitat
Feeding and breeding by resident populations of large fish	Small fish and aquatic invertebrate prey, shelter from predators in emergent aquatic vegetation and snags
Piscivorous waterbird predation	Small fish, large fish
Drought refuge for waterbirds	Semi-permanent water

Water Requirements

In order to maintain resident populations of aquatic fauna and to provide a drought refuge, Semi-permanent Wetlands may only dry out on very rare occasions. The wetlands should be dry for a maximum of 5% of the time and the level should exceed 50% of the wetland depth 80% of the time.

Ideally water should reach the wetland retention level in 50% of years for a minimum duration of 4 weeks and an ideal duration of 12 weeks to maintain the growth of fringing emergent macrophytes.

To provide regular breeding events and significant production in frogs, fish and waterbirds, events of 12 weeks should be provided in 50% of years. A lower frequency of 30% of years is likely to be sufficient to support these ecological objectives to a lesser degree. These events will also support the seasonal growth of emergent aquatic macrophytes at the wetland fringe.

Fringing Red Gum, which surrounds these wetlands, has water requirements for longer events which will interact with the management of Semi-permanent wetlands, as described below.

The peak water level should occur in August to match the natural seasonality of inflows. This will provide initial winter flooding and a gradually receding water level over spring.

3.5 Persistent Temporary Wetlands

Ecology

This water regime would be expected prior to regulation in lakes Little Hattah, Brockie, Konardin, Bitterang, Cantala, Marramook, Boich, Nip Nip and Lockie. Water is normally present in these lakes, but they are subject to greater water level fluctuations than Semi-permanent Wetlands and areas of the lake bed are more likely to dry out.

Water levels rise in response to River Murray freshes in winter and spring, inundating the lake fringes and possibly the surrounding floodplain. The lake bed is gradually exposed as levels decline over summer and autumn. Water levels will continue to decline if freshes do not occur in the following year.

Emergent macrophytes will occupy a broader zone around these lakes due to the more regular inundation and exposure of the lake shore. *Muehlenbeckia florulenta* is a component of the fringing vegetation, which includes *Phragmites australis* and *Juncus* spp. The deeper water towards the centre of the lake will support soft-leaved, semi-emergent macrophytes, such as *Myriophyllum* spp. and *Potamogeton* spp. The deepest parts of the lakes are only rarely exposed. They will tend to provide clear, open water when flooded and when dry will be either bare or provide habitat for lake bed herbs including *Alternanthera denticulata, Agrostis avenacea, Eleocharis acuta* and *Centipeda cunninghamii.*

Regular drying and re-flooding of part or all of the lake bed is important to the productivity of these wetlands. Flooding of the dry lake bed mineralises organic matter, promoting microbial, algal and macro-invertebrate production. Re-flooded lakes will be colonised by the larvae of flying insects such as notonectids and corixids and by crustaceans released from resting stages on the lake bed. These invertebrates, together with algae and biofilms will provide food other lake fauna. The first few years after re-flooding will provide habitat for dabbling ducks such as Freckled Duck, Australian Shoveller and Pink-eared Duck, which feed on semi-emergent plants and aquatic macro-invertebrates. These lakes will provide reliable breeding habitat for these species which will build nests using reeds on scrapes in and around the fringing vegetation, and require water to be present for at least three months in winter and spring. Reeds will provide terrestrial frogs with abundant aquatic invertebrates and flying insects, a substrate for eggs and shelter from predators.

Open water in the central part of the lakes supports Smelt, Bony Bream and Hardhead. Reed beds and semi-emergent vegetation will provide habitat for small vegetation-dependent fish such as Big-headed Gudgeon and Western Carp Gudgeon. Historically, Spotted Gudgeon and Pygmy Perch also occurred, but these are now locally extinct. These species feed on macro-invertebrates and algal biofilms and use the reeds and snags as shelter from predators.

Grazing waterfowl will also be favoured by semi-emergent vegetation in these lakes and will regularly breed. These are generally common species and include Black Swan, Australian Shelduck and Wood Duck. Fringing macrophytes will provide habitat for shoreline foraging waterbirds such as Rails, Moorhen and Swamphen and will provide nesting materials for Grebes and Terns.

The lake biota will change during prolonged flooding events. The area of semi-emergent plants will gradually decline and the area of open water will increase. The macro-invertebrate fauna will gradually become more dominated by large insect larvae such as mayfly and dragonfly. Large fish may become more abundant and fish eating water birds, such as Pelican and Cormorant, will also become more common. The lakes will begin to develop the characteristics of the Semi-permanent Wetlands.

Seasonal exposure of the lake shore promotes a dense and broad zone of riparian reeds. In sustained dry periods the lake levels will fall below the reed zone to expose a muddy herbland on the lake bed. Small wading birds such as Ruddy Turnstones and Red-necked Stint will feed on macro-invertebrates in shallow water and mud. Fish eating birds and carrion feeders, including White-bellied Sea-eagle, Wedge-tailed Eagle and Brush-tailed Possum, will feed on stranded fish.

Table 14. Specific Ecological Objectives for Persistent Temporary Wetlands

Specific Objectives	Contribution of Water Regime Class
Breeding by reed-dependent waterbirds	Emergent aquatic vegetation
Emergent aquatic macrophyte beds	Seasonal inundation of wetland perimeter
Submerged aquatic vegetation	Deep water, aquatic habitat
Feeding by large wading birds	Shallow water
Feeding by dabbling ducks	Aquatic macroinvertebrates, submerged aquatic vegetation
Feeding and breeding by aquatic reptiles and amphibians	Aquatic macroinvertebrates, flying insects, emergent aquatic vegetation
Aquatic macroinvertebrate production	Submerged aquatic vegetation
Small fish breeding and feeding	Submerged aquatic vegetation, emergent vegetation
Large fish breeding and feeding	Small fish and aquatic invertebrate prey, shelter from predators in emergent aquatic vegetation and snags
Piscivorous waterbird predation	Small fish, large fish
Feeding by small wading birds	Shallow water, mud flats

Water Requirements

To achieve the ecological objectives, the perimeter of the wetland should be regularly inundated and exposed on a seasonal cycle. This water regime will promote a broad zone of emergent macrophyte growth and, through nutrient mineralisation, will provide a highly productive environment for macroinvertebrates.

A seasonal fluctuation should occur in 50% of years where the water level reaches an annual minimum of half the wetland depth in May or June. The minimum level should be greater than this in 25% of years and less than this in 25% of years.

The wetland water level should reach the retention level in September or October in 50% of years. The duration of these events should be 12 weeks in 25% of all years and 24 weeks in 25% of all years. The shorter events will provide breeding and feeding opportunities for resident species with relatively short seasonal flooding requirements such as small fish and reed-dependent waterbirds. The longer events will provide significant breeding events for resident fauna and will support foraging by visiting fauna such as large fish and large wading birds.

3.6 Temporary Wetlands

Ecology

Lake Marramook has an exceptional water regime where there is a relatively low commence to flow (52,000 ML/d), but the lake retains water to only 0.4 m. It therefore fills frequently, but does not retain water for long periods. The lake receives inflows in most years, which persist for approximately six months before drying.

This water regime is expected to support the growth of perennial emergent macrophytes throughout the lake bed including *Schoenoplectus validus, Juncus ingens, Typha* sp. and *Phragmites australis*. Semi-emergent species likely to be present during flooding include *Myriophyllum papilosum, Pseudoraphis spinescens* and *Triglochin procerum*.

Seasonal flooding is likely to support high levels of production in algae and biofilms. The lake will support an abundant community of small macro-invertebrates, particularly micro-crustaceans that appear from resting stages on the lake bed and the larvae of flying insects such as notonectids and corixids. Small vegetation-dependent fish such as Western Carp Gudgeon and Big-headed Gudgeon will use these food sources and shelter in the reeds and fringing snags. The principal bird species will be large waders and dabbling ducks which are favoured by the sheltered habitat of the reeds and the availability of soft-leaved plants and macro-invertebrates.

Table 15. Specific Ecological Objectives for Temporary Wetlands

Specific Objectives	Contribution of Water Regime Class
Emergent aquatic macrophyte beds	Seasonal inundation
Breeding by reed-dependent waterbirds	Emergent aquatic macrophyte beds
Small fish breeding and feeding	Seasonal inundation of emergent aquatic macrophytes
Aquatic macroinvertebrate production	Seasonal inundation of emergent aquatic macrophytes
Feeding by large wading birds	Seasonal inundation of emergent aquatic macrophytes
Feeding and breeding by aquatic reptiles and amphibians	Seasonal inundation of emergent aquatic macrophytes

Water Requirements

The water level should reach the retention level (equivalent to a wetland depth of 0.4 m) in 40% of years with a median event duration of 6 months. Flooding should commence between July and September.

The water level should fall after this period so that after 75% of flood events the wetland is dry for a median duration of 4 months. The dry period should be timed approximately between February and June. This will promote the growth of emergent macrophytes that depend on seasonal flooding (e.g. *Schoenoplectus* spp.) and will limit the growth of emergent macrophytes dependent on constant, shallow summer flooding.

3.7 Episodic Wetlands

Ecology

Lake Kramen, Lake Boolca and the dry lakes to the north of the study area have very high flow thresholds and receive water only rarely.

The lakes have periods of many years when they remain dry between flooding events. The lakes therefore develop a mature terrestrial vegetation on the lake between inundation events comprising chenopods such as *Maireana* spp., *Atriplex* spp. and *Enchylaena tomentosa* and terrestrial grasses. The lakes are subject to seasonal waterlogging following winter rainfall, which provides suitable conditions for *Eragrostis australasica* and *Muehlenbeckia florulenta*. When dry the lakes will be grazed by large herbivores such as Western Grey Kangaroo and Red Kangaroo.

The lakes will become highly productive when flooded. Decaying plants and other organic matter will support microbial, algal and invertebrate production in the lakes, which will provide food for a variety of water birds, fish, frogs and aquatic reptiles. Flooded lake bed plants will provide a substrate for algal and microbial growth on which frog larvae, fish and macro-invertebrates will graze and will provide shelter for small fish.

Due to the infrequency of flooding, emergent macrophytes are absent from these lakes. Instead the vegetation is dominated by semi-emergent plants such as *Triglochin procerum* and *Myriophyllum papillosum*. These plants colonise the lakes by seeds and propagules brought in with flood water and form dense, extensive beds. The crustaceans that emerge from resting stages in these lakes are of particular note. Large taxa, such as Conconstrata, are likely to occur and provide a source of large prey for large fish soon after flooding. The lakes will be invaded by fish of this guild, as well as small fish and vegetation-dependent fish. While some of these may retreat to the River Murray, a large proportion will breed and die in the lakes. Similarly the lakes represent a temporary extension of habitat for waterbirds, particularly dabbling ducks, fish eating birds and large waders.

Table 16. Specific Ecological Objectives for Episodic Wetlands

Specific Objectives	Contribution of Water Regime Class
Submerged aquatic macrophyte growth	Intermittent prolonged inundation
Feeding by piscivorous waterbirds	Small fish, large fish
Feeding by dabbling ducks	Submerged aquatic macrophytes, macroinvertebrates
Feeding and breeding by aquatic reptiles and amphibians	Aquatic macroinvertebrates, flying insects, emergent aquatic vegetation
Aquatic macroinvertebrate production	Submerged aquatic vegetation
Feeding and breeding by small fish	Submerged aquatic vegetation
Feeding by large fish	Small fish and aquatic invertebrate prey, shelter from predators in snags
Breeding by flood-dependent waterbirds	Intermittently flooded Lignum and Canegrass
Grazing by large herbivores	Chenopod and grassland vegetation

Water Requirements

The ecological objectives require the lakes are filled in a minimum of 5% and a maximum of 10% of years. During these events water should reach the retention for a period 2 months. After this peak the depth should exceed 2 m for a period of 1.5 to 2.5 years after which the wetland should dry.

At other times the wetland should remain dry for a median period exceeding 5 years to allow a terrestrial vegetation community to develop.

3.8 Fringing Red Gum Woodland

Ecology

Fringing Red Gum Woodland occurs mainly in the floodplain area immediately surrounding the lakes. It represents the area where water first spills after the lakes fill. It also occurs to the north of the Chalka Creek East Arm where high creek levels break out on to the floodplain. This water regime has a limited extent around Lake Kramen and is absent from the fringes of Lake Cantala.

Fringing Red Gum is an important water regime class in Hattah Lakes in that it is critical to the growth and reproduction of many lake fauna. Fringing Red Gum Woodland is inundated by peaks in river flow, which occur in winter and spring in most years. The beds of emergent macrophytes present at the edge of the lakes continue to some extent in the understorey of the woodland, and includes perennial species such as *Phragmites australis, Juncus* sp. And *Carex tereticaulis.*

Flooding supports growth by perennial plant species including *Eucalyptus camaldulensis* and *Acacia stenophylla* with understorey wetland plants such as *Crassula* spp., *Setaria jubiflora, Sporobolus mitchellii* and *Cyperus gymnocaulos.* The damp understorey condition that follow floods in spring and summer promote the growth of a variety of understorey grasses and herbs including *Alternanthera denticulata, Agrostis avenacea* and *Wahlenbergia fluminensis.*

The Fringing Red Gum is flooded by the gradual spread of water from the lakes on to the floodplain as river levels rise. This increases the habitat available for lake fauna, particularly vegetation-dependent fish such as Western Carp Gudgeon and Big-headed Gudgeon and River Murray Catfish. The flooded grassy understorey of the fringing woodland particularly favours the small floodplain fish such as Rainbow Fish and Jollytail.

The habitat for terrestrial frogs, which is normally limited to the reeds fringing the lakes, will expand into the Fringing Red Gum Woodland when flooded. In addition, burrowing frogs which aestivate in the floodplain soil will become active. Other lake species which will extend into the flooded woodland will include Yabby, Tortoise and Swamp Rat.

The flooding events are too brief and intermittent to sustain the large populations of small floodplain fauna they generate. However, they represent a pulse in prey species that are important to the long term productivity of the lakes and the viability of fauna with longer life cycles.

The additional food will support significant waterbird breeding events while the fringing Red Gum is flooded. The trees will support a range of water birds that only breed over water such as Little Egret, White-necked Heron, White-faced Heron, Great Cormorant and Little Black Cormorant. It should be noted that successful breeding in these species depends critically on the duration of flooding. A range of other waterbird guilds are also likely to breed, including waterfowl, large waders and small waders.

The flood recession will bring much of the small floodplain aquatic fauna and other organic matter to the lakes where it represents an influx of food. In the large, deep, semi-permanent wetlands, which have relatively low productivity, this will sustain a predator-dominated fauna that includes large fish, large predatory macro-invertebrates and fish eating waterbirds. The food provided by the flood recession is also important to the Persistent Temporary Lakes and the River Murray, where the prey is likely to support breeding events in large aquatic fauna with long life cycles, such as Murray Cod.

The fringing Red Gum have an important role in providing structural habitat for lake and floodplain fauna, particularly snags which are used for grazing and shelter by fish such as Silver Perch, and in providing tree hollows for nesting Wood Duck, Carpet Python, bats, Brush-tailed Possum and a wide range of other animals. Fringing Red Gum also provide perches for nesting waterbirds and raptors such as White-bellied Sea-eagle. The tree growth triggered by flooding will provide much of the leafy and woody material on which the floodplain ecosystem depends and will also increase flowering which supports nectar-eating insects and birds and insectivorous birds.

3.9 Red Gum Forest

Ecology

Red Gum Forest represents a small component of the floodplain and is found only in areas subject to the most frequent flooding regimes. This water regime class occurs in the section of Chalka Creek leading from the River Murray to Lake Lockie and on the banks of the River Murray, particularly between Cantala Creek and the north arm of Chalka Creek.

Red Gum Forest has a closed canopy of tall *Eucalyptus camaldulensis*. The understorey comprises flood-dependent grasses, shrubs and aquatic macrophytes. This water regime class is subject to inundation in nearly all years, of sufficient duration to allow the growth of aquatic and regeneration of aquatic macrophytes such as *Triglochin procerum* and *Ranunculus inundatus*. These plants die back to rootstock or become dormant after flooding. Winter floods maintain the density, size and health of *Eucalyptus camaldulensis* and exclude other floodplain trees, such as *Acacia stenophylla*. The flood recession promotes the growth of other understorey herbs and shrubs including *Cynodon dactylon* var. *pulchellis, Centipeda cunninghamii, Alternanthera denticulata, Whalenbergia fluminensis, Senecio quadridentatus* and *Setaria jubiflora*.

Red Gum Forest provides similar habitat components to Fringing Red Gum Woodland, except it mainly occurs near the river and is not so closely linked to the ecological process of the lakes. Red Gum Forest has taller, larger trees and provides valuable habitat for arboreal species, particularly White-bellied Sea-eagle which select the tallest available trees for nesting.

Table 17. Specific Ecological Objectives for Red Gum Forest and Fringing Red Gum

Specific Objectives	Contribution of Water Regime Class
Flood-dependent waterbird breeding	Nesting habitat, foraging habitat
Small fish breeding and feeding	Seasonally flooded Red Gum
Feeding and breeding by aquatic reptiles and amphibians	Seasonally inundated floodplain, floodplain understorey vegetation
Breeding by hollow-dependent birds, mammals and reptiles	Seasonally inundated floodplain
Aquatic macroinvertebrate production	Inundated floodplain vegetation
Feeding by seed, plant, insect and nectar-dependent reptiles, mammals and birds	Understorey vegetation production, canopy vegetation production
Feeding by raptors, owls, omnivores and predatory reptiles	Small herbivorous and insectivorous prey / carrion
Red Gum woodland and forest	Seasonal flooding
Grazing by large herbivores	Seasonal periods without inundation

Water Requirements

The growth and recruitment of Red Gum is an essential outcome in these water regime classes. At Hattah-Kulkyne Lakes, this outcome is affected by flood inundation.

In the study area, rainfall is generally insufficient to trigger significant Red Gum germination or to maintain recruitment. Significant recruitment events are only expected as a result of floodplain inundation. Seedling germination is greatest in floods that recede in spring and early summer when abundant light and soil moisture promote plant growth (Dexter 1978). Seedlings may die if they are subsequently exposed to prolonged inundation (Marcar 1993) and may also die if soil moisture is not replenished by flooding while trees remain juvenile.

Tree growth is promoted by regular inundation. The minimum requirement for inundation of Stand Quality II Red Gum at Barmah-Millewa is for inundation of 4 weeks in 50% of years (Dexter 1978). This is a similar event frequency and duration to the natural water regime reported for the majority of Fringing

Red Gum at Hattah Lakes. The 'majority' of water regime class was defined as the lowest elevation at which more than 60% of the water regime class was inundated (Table 18). Areas at elevations of 43.5 to 44 m AHD (at which approximately 60% of the area supporting Fringing Red Gum is inundated) were naturally inundated in 41 to 60% of years with a median duration of 2 to 6 weeks.

Table 18. Hydrology of Fringing Red Gum at an Elevation Corresponding to Approximately 60% of the Area of the Water Regime Class

Region	Inundation Area % (ha))	Elevation (m AHD)	Natural		Current	
			Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Lockie	59 (283)	43.5	6	60	4	28
Hattah	61 (75)	43.5	5	53	4	25
Brockie	60 (60)	44.0	4	48	4	18
North Lakes (Mournpall)	59 (257)	44.0	6	48	3	20
Bitterang	65 (163)	43.5	5	41	5	14
Cantala	84 (37)	44.5	2	23	5	8

The hydrological analysis indicates that there is a narrow zone at the perimeter of wetlands where the floodplain can be inundated for significant longer periods of time. The retention level of most lakes lies at 42.2 or 42.3 m AHD. The median duration of events where the water level exceeds the wetland retention level is approximately 20 to 30 weeks under natural conditions (Table 6). A similarly long event duration is experienced above the retention level of the wetlands at an elevation of 42.5 m AHD (Table 19). At this elevation a significant area of Fringing Red Gum is inundated with an approximate median event duration of 18 to 23 weeks under natural conditions . Events of this duration would support significant waterbird breeding events and other ecological processes dependent on flooded Red Gum. In contrast, the duration of events exceeding 43.0 m AHD is relatively low. This water regime is consistent with the requirements for Red Gum SQI reported by Dexter (1978) and suggests that the lakes were originally surrounded by Red Gum Forest rather than Fringing Red Gum Woodland.

Table 19. Fringing Red Gum Hydrology at the Perimeter of Lakes Representative of Floodplain Regions

Region and Lake for which Hydrology Statistics are Presented	Elevation (m AHD)	Fringing Red Gum Inundated		Natural		Current	
		Area (ha)	Coverage (% of FRG in Region)	Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Lockie (Lockie)	42.5	58	12	21	63	15	43
	43.0	147	31	10	68	6	38
Hattah (Hattah)	42.5	38	31	24	59	10	35
	43.0	55	45	7	61	5	29
Brockie (Brockie)	42.5	15	15	24	48	14	21
	43.0	29	30	5	49	4	21
North Lakes (Mournpall)	42.5	75	17	16	54	14	23
	43.0	130	30	5	53	4	25
Bitterang (Bitterang)	42.5	69	27	21	46	17	21
	43.0	109	43	5	42	4	17

The hydrological analysis indicates that Red Gum Forest is flooded less frequently than the perimeter of the lakes. Most Red Gum Forest occurs on low-lying floodplain areas near the River Murray where access to fresh groundwater may promote dense tree growth. In other respects the water regime appears similar to that of Fringing Red Gum lying at elevations above 43.0 m AHD (Table 20). The water requirements of Red Gum forest are therefore not distinguished from Fringing Red Gum.

Table 20. Hydrology of Red Gum Forest at an Elevation Corresponding to 58% of the Area of the Water Regime Class

Region	Threshold for Significant Inundation (area in region: % (ha))	Elevation (m AHD)	Natural		Current	
			Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Cantala	58 (80)	43.0	6	49	4	20

Fringing Red Gum and Red Gum Forest provide important waterbird breeding habitat. Flood-dependent waterbirds are particularly sensitive to flood duration. They only breed successfully when their nests are surrounded by water. If water levels drop before the young birds fledge, adult birds often abandon their nests. Species such as darters, cormorants, herons, egrets, ibis and spoonbills take around 3-4 months to build their nests, lay, incubate their eggs and fledge their young. This means that for successful breeding these waterbirds require inundation for 5-7 months following spring floods and 6-10 months for autumn-winter floods (Briggs and Thornton, 1999). The hydrological analysis indicates that these conditions were provided from time to time at the fringes of the lakes.

The composition of the understorey is influenced by flooding frequency and duration. Spiny Mudgrass would be expected in the understorey of Red Gum Forest and requires floods of two to three months (Ward 1991). *Carex tereticaulis*, which is an indicative understorey species of less-frequently inundated areas has an optimal inundation duration of two months and tolerates floods of up to 4 months duration (Roberts and Marston 2000).

The ecological objectives relating to waterbird breeding and other fauna requirements will be achieved by inundating Red Gum Forest and the Fringing Red Gum (at the perimeter of wetlands to an elevation of less than 43.0 m AHD). Birds and other fauna with adapted to relatively brief floods will require inundation events of 12 weeks. Events of 24 weeks are a natural feature of the Hattah floodplain and will provide breeding habitat for birds with longer flood requirements. To achieve the objective of providing a reliable breeding habitat for flood-dependent waterbirds, it is recommended that events of 12 weeks are provided in 40% of years and that events of 24 weeks are provided in 20% of years.

The flood requirements of Red Gum Forest and Fringing Red Gum at elevations above 43.0 m AHD is indicated by the understorey vegetation. To maintain a community of perennial flood-dependent plants such as Warrego Summer Grass it is recommended that by inundation events with a median duration of 5 to 10 weeks are provided in 33 to 50% of years. This will also maintain Red Gum tree growth, productivity and recruitment in this zone.

To support vegetation growth and fauna breeding requirements, flooding should be initiated in August in most years.

3.10 Red Gum with Flood Tolerant Understorey

Ecology

This water regime class represents the driest habitat for Red Gum at Hattah. Significant areas occur to the west of Lake Lockie, in the floodplain adjacent to the north arm of Chalka Creek and at the fringes of Lake Cantala.

The water regime class has a woodland overstorey of *Eucalyptus camaldulensis* in which *E. largiflorens* may be present. The understorey includes predominantly terrestrial species that are likely to suffer during floods, but which are favoured by the longer and more usual dry phase of the water regime class. Understorey species include low shrubs chenopod shrubs such as *Einadia nutans, Atriplex semibaccata, Atriplex eardleyae, Sclerolaena muricate* var. *villosa, Chenopodium curvispicatum* and *Salsola kali.*

When dry, this water regime class supports a range of terrestrial fauna. The grassy understorey provides seeds and forage for granivores such as finches, cockatoos, Galah, Lorikeet and Budgerigar, the frugivorous Emu and large herbivores including Western Grey Kangaroo, Black Wallaby and Red Kangaroo. The trees directly support nectivorous and omnivorous birds such as honeyeaters and wattlebird. Both overstorey and understorey support insect production on which a wide range of insectivorous birds depend.

Floods in this water regime class are intermittent and brief. Flooding promotes the growth and recruitment of Red Gum which maintains a diverse age structure in the woodland and allows for the replacement of older trees. Terrestrial plants growing in the understorey will either tolerate floods or die, but will recolonise the woodland on the flood recession.

Floods do not usually have sufficient duration for an aquatic plant community to develop. Aquatic macrophytes that are present during flooding are likely to be limited to species that grow readily from fragments washed in with flood water such as *Myriophyllum* spp., *Pseudoraphis spinescens* and *Potamogeton* spp. The flood recession will promote a wide range of floodplain herbs and grasses including *Eleocharis acuta, Xerochrysum bracteatum, Wahlenbergia fluminalis* and *Amphibromus nervosus.* Floods will temporarily extend the habitat of fish, particularly floodplain fish (e.g. Rainbow Fish, Jollytail) and other aquatic fauna.

High levels of productivity will follow floods as elevated soil moisture promotes the growth and flowing of understorey grasses, shrubs and trees. The abundant food, including forage, insects, nectar and seeds, will provide major breeding opportunities for many floodplain fauna and visiting mallee fauna. These intermittent events may be important in sustaining the maintaining the population structure of species with life-spans that extend over the dry period between floods. Flooding also maintains the propagule banks of flood-dependent plants, such as *Eleocharis acuta,* which grows from drought-tolerant rhizomes when flooded and *Marselia drummondii* which grows from drought-tolerant spores. These propagule banks will gradually become depleted between flood events.

Table 21. Specific Ecological Objectives for Red Gum with Flood Tolerant Understorey

Specific Objectives	Contribution of Water Regime Class
Breeding by hollow-dependent birds, mammals and reptiles	Tree hollows
Feeding by seed, forage, insect and nectar-dependent reptiles, mammals and birds	Understorey vegetation production, canopy vegetation production
Feeding by raptors, owls, omnivores and predatory reptiles	Small herbivorous and insectivorous prey / carrion
Flood-tolerant understorey vegetation	Infrequently flooded woodland
Red Gum woodland	Intermittent inundation

Water Requirements

The understorey of Red Gum FTU includes aquatic species which respond opportunistically to flooding and terrestrial species which tolerate flooding. These plants therefore provide little guidance in terms of specific water requirements. The water requirements of this zone are therefore indicated by objectives dependent on tree health and productivity. Prolonged periods without flooding lead to tree death, as has been observed in 2005 in Red Gum trees at Hattah that were last inundated in 1996, a period of 10 years

(M. Cooling, Ecological Associates, personal observation September 2005). Dexter (1978) recommended a minimum water requirement of 2 weeks in 30% of years for Stand Quality III Red Gum, which is equivalent to Red Gum FTU. The hydrological analysis of Hattah-Kulkyne Lakes indicates that under natural conditions the area occupied by Red Gum FTU was inundated for approximately 4 weeks in 30% of years (Table 22). The current frequency of inundation has declined to 10 to 20% of years, but the duration remains similar.

Table 22. Hydrology of Red Gum with Flood Tolerant Understorey at an Elevation Corresponding to Approximately 60% of the Area of the Water Regime Class

Region	Threshold for Significant Inundation (area in region: % (ha))	Elevation (m AHD)	Natural		Current	
			Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Lockie	59 (196)	44.5	4	34	5	12
Hattah	68 (45)	45.0	3	20	3	7
North Lakes (Mournpall)	69 (301)	44.5	5	30	5	11
Bitterang	66 (409)	44.5	3	14	3	4
Cantala	71 (282)	43.5	4	48	4	18

It is recommended that to maintain tree health and recruitment, and to maintain vegetation productivity for fauna Red Gum FTU is inundated in 20 to 40% of years for a median duration of 4 weeks.

3.11 Black Box Woodland

Ecology

Black Box Woodland occurs in the least frequently inundated areas of the floodplain. It occurs at the outer limit of the floodplain, at the foot of the dunes of Lowan Sand and Woorinen Sand. Significant areas are located near the wetland complex near Lake Lockie, near Lake Kramen, in the dry lakes to the north of the site and near the bank of the River Murray north of Lake Cantala.

This water regime class is dominated by *Eucalyptus largiflorens* which occurs over a diverse shrubby understorey including *Muehlenbeckia florulenta, Acacia stenophylla,* grasses and a variety of chenopods. Other understorey species include *Eragrostis infecunda, Lepidium pseudohyssopifolium*. When flooded, aquatic species are present including *Marselia drummondii, Asperula gemella, Eleocharis acuta* and *Sporobolus mitchellii*.

The flooding response of Black Box woodland is similar to Red Gum with Flood-tolerant Understorey. The woodland develops a mature terrestrial flora and between flood events and briefly changes to an aquatic habitat during floods. Tree recruitment and the productivity trees is strongly linked to flooding, and regular floods are required to maintain a diverse age structure in the tree population. Trees grow very slowly in not inundated. Floods also support breeding in many floodplain biota, and is likely to be important to maintaining populations of long-lived species that depend on intermittent flooding events.

Black Box Woodland also has strong habitat linkages to the surrounding mallee landscape. The diversity of birds is particularly high as it contributes to the habitat requirements of both riverine and mallee species. In particular, Black Box Woodland supports a high proportion of ground foragers and hollow-nesting species, which is notable because large hollows do not form in mallee tree species.

An important contrast with the adjacent Red Gum Woodland is the importance of Black Box for canopy feeders. The avifauna includes species that found along the river that are typical of high-rainfall areas such as Superb Fairy-wren, Little Friarbird and Blue-faced Honeyeater. Black Box woodland also supports seasonal migrants normally associated with higher rainfall areas such as Grey Faintail and White-bellied Cuckoo-shrike.

Table 23. Specific Ecological Objectives for Black Box Woodland

Specific Objectives	Contribution of Water Regime Class
Breeding by hollow-dependent birds, mammals and reptiles	Tree hollows
Feeding by seed, forage, insect and nectar-dependent reptiles, mammals and birds	Understorey vegetation production, canopy vegetation production
Feeding by raptors, owls, omnivores and predatory reptiles	Small herbivorous and insectivorous prey / carrion, drying lake bed
Flood-tolerant understorey vegetation	Infrequently flooded woodland
Black Box woodland	Intermittent inundation

Water Requirements

Flooding promotes the growth of Black Box trees, promotes tree recruitment and increases the productivity of the woodland for dependent fauna. If the duration of events between floods is too long Black Box trees will suffer poor health and trees will die. Black Box that germinated following flooding in 1974 and have not been flooded since were on the verge of death when observed in 2005 (M. Cooling, Ecological Associates, personal observation 2005). At Barmah Forest, Black Box grows in areas flooded in 10% of years for 4 weeks. A similar flooding frequency is reported from the hydrological analysis of Hattah Lakes where areas occupied by Black Box were inundated in approximately 20% of years for 2 to 5 weeks under natural conditions (Table 24). Inundation events currently have a similar duration but occur in 1 to 12% of years.

Table 24. Flooding Frequency and Duration for Black Box under Natural and Current Conditions at Lakes Representative of Floodplain Regions

Region	Threshold for Significant Inundation (area in region: % (ha))	Elevation (m AHD)	Natural		Current	
			Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
Lockie	63 (427)	45.0	3	20	3	7
Hattah	63 (87)	44.5	4	34	5	12
Brockie	49 (287)	45.0	5	20	3	6.5
Kramen	69 (350)	46.0				
North Lakes (Mournpall)	52 (250)	45.0	4	13	3	4
Bitterang	55 (218)	45.0	2	2	2	1
Cantala	69 (230)	44.5	2	23	5	8

It is recommended that Black Box woodland is inundated for a median duration of 4 weeks in 10 to 20% of years.

3.12 Lignum Shrublands

Ecology

Lignum Shrublands occur on high floodplain terraces at similar positions to Black Box Woodland. Significant areas occur to the north of the east arm of Chalka Creek (near the River Murray), near the flow path from the River Murray to Lake Cantala and near the north arm of Chalka Creek.

The vegetation of this water regime class is dominated by *Muehlenbeckia florulenta* and can include *Eragrostis australasica.* It tends to occur in floodplain depressions away from watercourses which are only flooded during widespread inundation events. They may also be seasonally waterlogged by local rainfall, which will maintain the waterlogging-dependent species present between floods. In the absence of flooding this water regime class will gradually deteriorate. The health and density of *Muehlenbeckia florulenta* will decline and more terrestrial species, particularly *Atriplex lindleyi* and *Chenopodium nitrariacum* become more common. When flooded this area supports aquatic species such as *Marselia drummondii* and *Eleocharis acuta*.

Inundation of Lignum Shrubland represents an extension of the habitat for aquatic floodplain fauna such as fish, reptiles and macro-invertebrates. The dense vegetation may favour vegetation-dependent fish. Waterbird species that breed over water, such as Ibis and Spoonbill, are likely to nest in Lignum Shrublands when flooded.

Table 25. Specific Ecological Objectives for Lignum Shrublands

Specific Objectives	Contribution of Water Regime Class
Breeding by reed-dependent waterbirds	Flooded Lignum
Lignum shrubland	Seasonally waterlogged and periodically flooded clays
Breeding by flood-dependent waterbirds	Flooded Lignum
Feeding by raptors, owls, omnivores and predatory reptiles	Small herbivorous and insectivorous prey / carrion, drying lake bed

Water Requirements

Lignum tolerates a wide range of flooding frequencies and durations. A minimum flood requirement to maintain shrub growth and recruitment has been reported as 1 month in 40% of years (Roberts and Marston 2000). However Lignum is also an important waterbird breeding habitat. To meet the ecological objectives, events of 3 to 6 months are also required.

Most Lignum at Hattah-Kulkyne Lakes occurs near Lake Cantala. The hydrological analysis in this study reports that 96% of the Lignum in this region is inundated when water levels exceed 44.5 m AHD (Table 26). This threshold was exceeded in 23% of years under natural conditions for a median duration of 2 weeks. Under current conditions the threshold is exceeded in only 8% of years. The median duration is longer under current conditions (5 weeks), but this is more likely to reflect the unreliability of using a small number of events to predict typical event durations than a change in river hydrology. These statistics do not indicate the capacity of Lignum shrublands to retain water on the flood recession. The actual duration of flooding is likely to be greater than the duration of peaks that initiate flooding. Furthermore, flood duration is more likely to be promoted by short intervals between flood peaks than the duration of the peaks themselves.

Table 26. Flooding frequency and duration for Lignum Shrubland under Natural and Current Conditions in the Cantala Floodplain Region

Elevation (m AHD)	Area Inundated %, (ha)	Natural		Current	
		Median Duration of Inundation Events (weeks)	Years with Events (%)	Median Duration of Inundation Events (weeks)	Years with Events (%)
44.0	53 (14)	4	38	5	12
44.5	96 (26)	2	23	5	8

It is recommended that Lignum shrublands are inundated in 20% of years. To provide significant waterbird breeding opportunities and to maintain Lignum growth and recruitment, inundation should exceed a depth of 0.25 m for a median duration of 12 weeks.

3.13 Chalka Creek

Ecology

Prior to regulation, Chalka Creek was regularly inundated or flowing due to frequent freshes and floods in the River Murray. The turbulence created by flow maintained the channel form including deep holes and steep, well defined banks. Emergent vegetation would have been largely absent or limited to backwaters and the fringes of the watercourse. Flow-tolerant aquatic plants would grow in the channel, particularly *Triglochin procerum* but also *Myriophyllum* sp. and *Potamogeton* sp. *Eucalyptus camaldulensis* lining the creek would be supported by frequent flow. They would shade the channel, reducing water temperatures, and contribute snags and organic matter that provide habitat components for aquatic fauna.

While also an aquatic environment, the creek provides a different environment to the wetlands because it flows. Flowing water is an essential habitat requirement to a number of aquatic animals which depend on the cooler, more oxyenated and turbulent conditions created by flow. The creek would provide habitat for the locally extinct River Murray Crayfish (*Euastacus armatus*) which grazes epiphytes and other organic debris and preys on aquatic invertebrates. Other species which are favoured by flowing water include the River Snail (*Notopala hanlyie*), the Shrimp (*Macrobrachium australiense*) and River Mussel (*Alathyria jacksoni*).

The creek provides passage between the lakes and the river for migrating aquatic fauna including Golden Perch and Murray Cod. The flow of water in the creek may provide an important cue for the migration of these species in response to river peaks.

It is not clear whether the creek would have supported a resident or opportunistic community of flow-dependent fauna. Only one flow-dependent species, River Snail, has been reported from the site (Appendix E). Prior to regulation Chalka Creek flowed at a level sufficient to initiate flow to Lake Lockie (42.2 m AHD) in 74% of years and exceeded this level 50% of the time. Chalka Creek actually commences to flow below this level and these statistics underestimate flow frequency and persistence. The creek flowed in most years and provided semi-permanent pools in which aquatic fauna, and possibly flow-dependent species, resided between flow events. Assuming that flow-dependent fauna tolerate seasonal lapses in flow, it seems reasonable to set an objective for a resident population of flow-dependent aquatic macroinvertebrates (Table 27).

Table 27. Specific Ecological Objectives for Chalka Creek

Specific Objectives	Contribution of Water Regime Class
Resident population of flow-dependent macro-invertebrates	Flowing water, large woody debris, fringing Red Gum
Passage of large fish between floodplain and river	Fish passage, deep water, fringing Red Gum

Water Requirements

Murray Crayfish and River Mussel have been found to have similar oxygen requirements (Walker 1990). The LD_{50} (the oxygen concentration at which 50% of the test individuals die) is 2.2 mg $O_2.L^{-1}$. When juvenile crayfish were exposed to 2.75 $O_2.L^{-1}$ over a period of 3 days they showed 63% mortality (Geddes 1991, Geddes et al. 1993). This suggests that oxygen levels greater 3 $O_2.L^{-1}$ should be maintained for the survival of this species and its co-inhabitants (River Mussels and River Snails). This could be ensured through the provision of flowing, turbulent water and low water temperatures in which high oxygen concentrations can be achieved (McCarthy 2005).

Flowing water provides increased oxygen levels (through turbulence) and decreased temperatures (through deeper, flowing water), both of which will be beneficial to Murray Crayfish, River Mussel and River Snail. McCarthy (2004; 2005) showed that crayfish in the Mallee tract of the Murray River were only caught in flow velocities of between 0.25 $m.s^{-1}$ and 0.49 $m.s^{-1}$, indicating the critical nature of flow velocity for the survival of this species. It is recommended that flows should always be above 0.25 $m.s^{-1}$ in the deep permanent anabranches.

Water temperature is a limiting factor for the suite of flow dependent species. Murray Crayfish have a temperature LD_{50} of 30°C and a long term exposure LD_{50} of 27.7 °C (Geddes 1991). McCarthy (2005) reported that no Murray Crayfish were captured in temperatures over 21.8 °C and that crayfish are more active in the cooler months. It is known that crayfish activity decreases with increasing temperature, probably due to the increased metabolic cost of the activity under higher temperature conditions. While median temperatures have not increased in that tract of the Murray, vegetation clearance and the shallowing of channel beds (through sedimentation and low flows) can increase temperatures in watercourses. Water temperature is influenced by the shade provided by riparian vegetation and by the residence time of water in shallow reaches exposed to the sun. It is recommended that creek temperatures are maintained below 22°C.

To achieve a resident population of flow-dependent fauna, it is recommended that these conditions are provided in Chalka Creek for of 4 months per year in 75% of years.

3.14 Summary

Specific Ecological Objectives

The preceding descriptions of the ecology and water dependence of each water regime class have been used to identify specific ecological objectives that address the broad ecological objective. The specific objectives are summarised in Table 28. Species of conservation significance (Appendices E and F) that relate directly to the objectives have been identified. The specific objectives address the habitat requirements of all significant flora and all but one significant fauna species reported from the area. The habitat requirements of one species, the River Snail, are not included as this species depends on flowing water, which is not a normal feature of Hattah Kulkyne Lakes.

Table 28. Specific Ecological Objectives

Specific Objectives	Significant Species
Feeding and breeding by aquatic reptiles and amphibians	Barking Marsh Frog, Broad-shelled Tortoise
Feeding by dabbling ducks	Freckled Duck, Australasian Shoveler
Feeding by diving waterbirds	Hardhead, Musk Duck, Blue-billed Duck
Piscivorous waterbird predation	White-bellied Sea-eagle, Intermediate Egret, Little Egret, Nankeen Night Heron, Pied Cormorant, Great Egret, Whiskered Tern, Australasian Bittern, Gull-billed Tern, Little Bittern
Drought refuge for waterbirds	All waterbirds
Breeding by reed-dependent waterbirds	Freckled Duck, Australasian Shoveler, Blue-billed Duck, Hardhead, Musk Duck
Feeding by large wading birds	Royal Spoonbill, Glossy Ibis
Feeding by small wading birds	Sharp-tailed Sandpiper, Marsh Sandpiper, Ruddy Turnstone, Red-necked Stint, Common Greenshank, Common Sandpiper, Painted Snipe
Aquatic macroinvertebrate production	None
Resident population of flow-dependent macro-invertebrates	Murray Crayfish, River Snail, River Mussel, *Macrobrachium australiense*
Feeding and breeding by large fish	Silver Perch, Golden Perch, Freshwater Catfish
Small fish breeding and feeding	Crimson-spotted Rainbowfish, Western Carp Gudgeon, Big-headed Gudgeon
Passage of large fish between floodplain and river	Murray Cod, Golden Perch, Silver Perch, Freshwater Catfish
Breeding by flood-dependent waterbirds	Little Egret, Pied Cormorant, Royal Spoonbill
Grazing by large herbivores	Red Kangaroo
Breeding by hollow-dependent birds, mammals and reptiles	Brush-tailed Possum, Australasian Shoveler, Regent Parrot, Major Mitchell's Cockatoo, Elegant Parrot, Hooded Robin, Crested Bellbird, Carpet Python, Tree Goanna, Freckled Duck, Brown Tree-creeper, Red-backed Kingfisher (Gibbons and Lindenmayer 2000)
Feeding by seed, plant, insect and nectar-dependent reptiles, mammals and birds	Grey-fronted Honeyeater, Painted Honeyeater, Purple-gaped Honeyeater, Regent Parrot, Major Mitchell's Cockatoo, Elegant Parrot, Plains-wanderer, Brown Treecreeper, Ground Cuckoo-shrike, Brown Quail, Mallee Emu-wren, Fork-tailed Swift, Bush Stone-curlew, Hooded Robin, Crested Bellbird, Apostlebird, Red-backed Kingfisher, Brush-tailed Possum, Greater Long-eared Bat, Mitchell's Hopping Mouse
Feeding by raptors, owls, omnivores and predatory reptiles	Black-shouldered Kite, Black Falcon, White-bellied Sea-eagle, Tree Goanna, Carpet Python
Red Gum woodland and forest	Red Gum
Submerged aquatic vegetation	None
Emergent aquatic macrophyte beds	Lax Flat-sedge, Annual Flat-sedge, Dwarf Flat-sedge, Curly Flat-sedge, Slender Club-sedge, Button Rush
Flood-tolerant understorey vegetation	Jerry Jerry, Tall Kerosene Grass, Pop Saltbush, Spiny-fruit Saltbush, Silky Glycine, Desert Jasmine, Spiked Daisy-bush, Upright Adder's Tongue, Australian Broomrape, Skeleton Fan-flower, Spear-fruit Copperburr, Sand Sida, Pin Sida, Twiggy Sida, Trident Spyridium, Dwarf Swainson-pea, Silky Swainson-pea, Rabbit-ears Twin-leaf
Flood-dependent understorey vegetation	Dwarf Flat-sedge, Dwarf amanranth, Bergia trimera Riverine Flax-lily, Silky Umbrella-grass, Flycatcher, Purple Love-grass, Bristly Love-grass,

Specific Objectives	Significant Species
Lake bed vegetation	Small Water-fire, Spiny-fruit Saltbush, Hoary Scurf-pea, Cyperus pygmaeus, Purple Love-grass, Bristly Love-grass, Winged Peppercress, Lagoon Spurge, Bergia trimera
Lignum shrubland	Lignum
Black Box woodland	Black Box

Hydrological Objectives

The water regimes required to achieve the ecological objectives are summarised in Table 29. Hydrological objectives are presented for each water regime class and are related to particular ecological processes which depend on them.

Table 29. Hydrological Objectives

Water Regime Class	Recommended Water Regime	Basis for Recommendation
Semi-permanent Wetlands	Water level exceeds 50% retention level 80% of the time	Resident populations of large fish, small fish
	Wetland dry less than 5% of the time	Drought refuge
	Water level reaches the retention level in 30 to 50% of years for 12 weeks	Frog, fish and waterbird breeding Emergent macrophyte recruitment
	Peak seasonal water level in August	Emergent macrophyte recruitment Frog, fish and waterbird breeding
Persistent Temporary Wetlands	Water level falls to 50% of wetland depth in May or June in 50% of years	Support a broad zone of emergent macrophytes at the fringe of the wetland Mineralisation of organic matter Limit growth of Typha and Phragmites
	Water level reaches the retention level in September or October in 50% of years	Emergent macrophyte growth and recruitment Frog, fish and waterbird breeding
	Retention level should be exceeded for 12 weeks in 25% of years	Breeding and feeding by small fish, frogs and reed-dependent waterbirds
	Retention level should be exceeded for 24 weeks in 25% of years	Major breeding events by flood-dependent fauna
Temporary Wetlands	Water reaches retention level in 40% of years for a median duration of 24 weeks	Waterbird breeding Emergent macrophyte growth
	Full events generally commence between July and September	Emergent macrophyte growth Frog, fish and waterbird breeding
	Wetland is dry for 4 months after 75% of filling events (i.e. 37.5% of years)	Emergent macrophyte growth on the bed of the wetland Mineralisation of organic matter
	Dry events generally occur between February and June	Limit growth opportunities for Typha and Phragmites Support emergent macrophytes dependent on seasonal inundation
Episodic Wetlands	Lakes reach retention level in 5 to 10% years for 2 months	Initiate growth of emergent macrophytes at lake fringe
	Water depth exceeds 2 m for 1.5 to 2.5 years following full events	Waterbird, fish and frog breeding Submerged aquatic plant growth
	Wetland remains dry for a median duration exceeding 5 years between full events	Terrestrial plant community Mineralisation of organic matter Death of perennial aquatic plants
Fringing Red Gum at Lake Perimeter	Inundate for 12 weeks in 40% of years	Flood-dependent understorey growth Waterbird, fish and frog breeding Red Gum growth, productivity and recruitment
	Inundate for 24 weeks in 20% of years	Flood-dependent understorey growth Major breeding events for waterbirds, fish and frogs

Water Regime Class	Recommended Water Regime	Basis for Recommendation
	Flooding initiated in August in most years	Flood-dependent vegetation growth Fauna breeding
Red Gum Forest, Fringing Red Gum Woodland above 43.0 m AHD	Inundate for median duration of 5 to 10 weeks in 33 to 50% of years	Red Gum growth, productivity and recruitment Flood-dependent understorey growth
	Flooding initiated in August in most years	Flood-dependent vegetation growth
Red Gum with Flood Tolerant Understorey	Inundate for median duration of 4 weeks in 20 to 40% of years	Red Gum growth, productivity and recruitment
Black Box Woodland	Inundate for median duration of 4 weeks in 10 to 20% of years	Black Box growth, productivity and recruitment
Lignum Shrubland	Inundate to 0.5 m for a median duration of 12 weeks in 20% of years	Lignum growth and recruitment Flood-dependent waterbird breeding
Chalka Creek	Creek temperatures are less than 22°C when creek is flowing	Flow-dependent macro-invertebrate growth feeding
	Creek velocity exceeds 0.25 $m.s^{-1}$ for 4 months per year in 75% of years	Flow-dependent macro-invertebrate growth feeding Passage for fish between river and floodplain

Representative Objectives

The ecological objectives will be used to identify water regime classes with the highest priority for water management. They will also be used to evaluate the effectiveness of water management options. To simplify this process, a subset of the nineteen specific objectives was selected.

These ecological objectives represent effective provision of all the habitat components and flow events on which the specific ecological objectives depend. Table 30 presents the representative objectives and the habitat components on which they depend. This table demonstrates that together the representative objectives encompass all the habitat components of the specific objectives set out above.

Table 30. Representative Ecological Objectives

Representative Objectives	Habitat Components														
	Aquatic Macro-invertebrates	Submerged Aquatic Vegetation	Emergent Aquatic Vegetation	Deep Water	Shallow Water / Mud Flats	Large fish	Small fish	Small herbivorous and insectivorous prey	Dry Wetland Bed	Red Gum and Black Box Production	Understorey Vegetation Production	Seasonally Flooded Red Gum	Habitat Links to Mallee	Wetland / Woodland Mosaic	Flowing Water
Foraging and Breeding by White-bellied Sea-eagle				✓	✓	✓		✓	✓					✓	
Resident Populations of Small Fish	✓	✓	✓	✓								✓			
Breeding and Foraging by Flood-dependent Waterbirds	✓		✓		✓	✓	✓		✓			✓		✓	
Breeding by Regent Parrot											✓		✓	✓	
Resident Populations of Silver Perch and Golden Perch	✓			✓			✓								
Resident Populations of Carpet Python								✓		✓	✓				
Resident Population of Brushtail Possum					✓					✓	✓				
Resident Population of River Mussel														✓	✓

4.1 Adopted Prioritisation Approach

The prioritisation considers the importance of meeting the representative objectives and the importance of meeting objectives in different areas of the system.

Priority of Water Regime Classes

The priority of water regime classes is based on an assessment of the contributions they make to the representative objectives.

The priority of water demands is based on two factors:

- the importance of the water regime classes to the ecological objectives; and
- the significance of deficits in water requirements in each water regime class.

The relevance of each water regime class to the objectives is described (see Section 4.2 below). A score of 3, 2, 1 or 0 is applied according to the importance of each water regime class (Table 31). A high importance is assigned to a water regime class on which a function predominantly depends. A low score is assigned to a water regime class if the function occurs there only infrequently, opportunistically or to a small extent.

Degree of Threat to Water Regime Classes

The degree to which the water regime classes are threatened by changes in water management or groundwater is presented (Table 31). The significance of the threat is scored on the following basis:

3 – the representative objective can be met only rarely, intermittently or to a small extent

2 – the representative objective can be met only to a significantly reduced extent

1 – the representative objective can occur reliably, but below the optimum that would occur in the absence of water-related threats

0 – the contribution of the water regime class to the objectives is not impaired..

Overall Priority

Overall priority scores were determined by multiplying the scores for water regime classes with the scores for degree of threat (Table 31).

4.2 Contribution of Water Regime Classes to the Representative Ecological Objectives

Foraging and Breeding by White-bellied Sea-eagle

Mature White-bellied Sea-eagle have a diverse carnivorous diet which includes fish, mammals, birds and carrion. Nest trees, once established, are re-used each year and are usually located near major waterbodies such as the River Murray or permanent anabranches. Nests are constructed in the upper branches of tall living or dead Red Gum. The breeding season commences in May and continues until October.

The total Victorian population is believed to be very low, possibly fewer than 100 pairs.

White-bellied Sea-eagle depend on a reliable source of prey including arboreal vertebrates in forest areas (such as possums and snakes) and in waterbodies (such as fish). They depend on the availability of tall Red Gum for nesting, which occur near watercourses and wetlands.

Decline in the health of Fringing Red Gum and Red Gum Forest will have reduced the availability of nesting sites. Aquatic prey will have been reduced in wetlands through the reduced flooding of Semi-permanent Wetlands and Persistent Temporary Wetlands. Reduced flooding in Red Gum Forest, Fringing Red Gum and Black Box will have resulted in lower overall productivity and food availability.

Resident Populations of Small Fish

Floodplain wetlands provide ideal habitat for small fish and may be used as nursery habitat by many small native fish species. Dense aquatic vegetation provides habitat for Big-headed Gudgeon, Western Carp Gudgeon and Southern Rainbowfish. Ripe females may migrate to the floodplain as it becomes inundated, initially using it as a spawning area and later as a nursery area for hatched larvae. Eggs or larvae from the main channel may also be transported by flood waters on to the floodplain. Dense vegetation on the floodplain provides protection from predatory fish and birds and provides a food source in the form of epiphytes and macroinvertebrates. Fish larvae and juveniles may return to the river on the flood recession.

Breeding opportunities for small fish depends on the availability of submerged aquatic or terrestrial vegetation. Vegetation must be inundated for at least two to three months to allow juveniles to be recruited. This habitat is provided most reliably in the Persistent Temporary Wetlands and Red Gum Forest and Fringing Red Gum. It is provided to a lesser extent in reedbeds at the fringes of Semi-permanent Wetlands. Inundation of Black Box Woodland and Lignum Shrublands will provide habitat on infrequent occasions.

Semi-Permanent Wetlands will maintain a local population of small fish during prolonged periods of low flow. Under the current hydrological regime this no longer occurs.

The quality of floodplain habitat is also important to small fish breeding and feeding. Regular flooding of the Fringing Red Gum and Red Gum Forest maintains flood-dependent understorey vegetation which contributes to small fish habitat.

Due to the decline in flooding, aquatic habitat is available less frequently. When it is available, the limited development of perennial aquatic macrophytes provides relatively poor habitat quality.

Breeding and Foraging by Flood-dependent Waterbirds

Hattah-Kulkyne Lakes provides important habitat for waterbirds that nest in flooded vegetation. These species build nests in flooded Red Gum and other vegetation nest to lakes or wetlands. Species known to breed at the site include Darter, Little Egret, Little Pied Cormorant, Little Black Cormorant and Pied Cormorant (Atlas of Victorian Wildlife 2005). One of these species, Little Egret, nests in colonies. The provision of breeding habitat is important to the maintenance of regional populations.

Flood-dependent waterbirds rely on productive flooded Red Gum woodlands and shallow wetlands to forage during breeding, where they prey on invertebrates, frogs and fish. The availability of food in wetlands and Red Gum woodlands depends on regular flooding events, which promotes aquatic and grassy woodland vegetation, woody debris, submerged aquatic vegetation and other prey habitats..

The potential for Hattah-Kulkyne Lakes to support flood-dependent waterbird breeding has decreased due to declining flood frequencies and durations. The forest does not provide reliable breeding opportunities due to the infrequency of wetland and Red Gum woodland flooding. The loss of wetland habitat has reduced the extent of breeding habitat and the frequency of breeding opportunities. Declining flood frequencies in Red Gum and reduced the health of nesting trees and reduce recruitment.

Breeding by Regent Parrot

Regent Parrot depend on River Red Gum and Black Box communities for nesting and large diverse blocks of mallee woodland in which to feed. Regent Parrot species only occurs in areas where mallee lies adjacent to riverine woodlands. Nest trees are typically mature, senescent or dead with a height of 30 m. Hollows used for nesting average 21 m above the ground. All nesting sites are located near water and within 20 km of mallee foraging habitat (NSW Parks and Wildlife Service 1999). Regent Parrot are reported to breed in the study area (Atlas of Victorian Wildlife 2005).

Other parrot species also feed in the mallee but depend on tree hollows provided on the floodplain, including Major Mitchell Cockatoo, Scarlet-chested Parrot and Elegant Parrot. The tree hollows on which Regent Parrot depend are also required by a large number of other mammal, bird and reptile species (see Table 28).

The most important water regime class for Regent Parrot is Red Gum Forest and Fringing Red Gum Woodland. Black Box Woodland is also important in linking floodplain habitat with nearby mallee.

Resident Populations of Large Fish

The Semi-permanent Wetlands, particularly Lakes Hattah and Mournpall potentially provide habitat Silver Perch, Golden Perch and Freshwater Catfish. These species benefit from the habitat complexity provided by snags, deep water and emergent vegetation, which provide resting locations, feeding habitat and protection from predators. Habitat complexity is provided by variations in bed depth in wetlands and by Fringing Red Gum which contribute large woody debris. Passage to the river is also important to allow large fish to disperse. The prey and organic matter produced during floods maintain the productivity of permanent aquatic habitats and support populations of large fish.

Resident Populations of Carpet Python

Carpet Python prey on small mammals, birds and reptiles. Hatchlings will often prey on lizards. Carpet Python find much of they prey in tree hollows where they also shelter from predators. They also prey in dense shrub or ground debris.

Carpet Python are an indirect indicator of floodplain production and tree health. Many of their prey species depend on food generated by a productive Red Gum and Black Box woodlands, such as forage, nectar, insects and seeds. The abundance of prey will therefore be closely linked to the appropriateness of flooding frequency and duration.

Shelter for Carpet Python will be available mainly in the large tree hollows present in Red Gum Forest and Fringing Red Gum. Prey will be available throughout the forest, including in smaller tree hollows in Black Box Woodland and in woody debris throughout the forest.

Fewer prey are expected to be available to Carpet Python as a result of reduced flooding and the corresponding decline in floodplain productivity. Poor tree recruitment will also affect Carpet Python in the long term as fewer hollow-bearing trees are avaible.

Resident Population of Brushtail Possum

Brushtail Possum are omnivorous arboreal mammals. They feed on flowers, leaves and insects and, when available, carrion. The Red Gum Forest and Fringing Red Gum are the principal sources of food, where regular flooding promotes seed production and flowering in trees and understorey shrubs. Black Box Woodland also provides these food sources. The large tree hollows available in Red Gum woodlands provide sheltering sites. Brushtail Possum will feed on stranded fish or abandoned fledglings when wetland water levels fall.

Reduced flooding affects the quality of habitat for Brushtail Possum by reducing the productivity of flower and forage-producing vegetation and prey. In the long term, poor tree recruitment will result in fewer hollow-bearing trees being available.

Resident Population of River Mussel

River Mussel occurs in flowing habitats of the Murray-Darling Basin (Sheldon and Walker 1989). River Mussel appears to be intolerant of low levels of disolved oxygen and is found predominantly in flowing, well-oxygenated habitats. It is a filter feeder, living in muddy substrates. It tolerates intermittent exposure but relies principally on an aquatic environment. Chalka Creek potentially provides habitat for River Mussel if a reliable flowing habitat is restored. This species is indicative of other important ecological functions in the creek, particularly habitat for other flow-dependent macroinvertebrates, the passage of fish between the floodplain and the river and the maintenance of the creek channel form through turbulence and scour.

River Mussell has not been reported from from Hattah Lakes but it is considered reasonable to assume that under natural conditions Chalka Creek provided suitable habitat.. The provision of habitat for this species depends on the provision of regular flowing habitat in Chalka Creek, the health of riparian Fringing Red Gum which provide woody debris and contribute to turbulence and the productivity of seasonally inundated wetlands which contribute food.

4.3 Degree of Threat to Water Regime Classes

Scores for the degree of threat to water regime classes are presented in (Table 31).

The water regime of Semi-permanent Wetlands does not meet the recommendation. The water level in Lakes Hattah and Mournpall exceed 50% of the wetland depth only 56 and 42% of the time, respectively whereas compared with the recommendation of 80%. It was recommended that the water level reaches the retention level in 50% of years for a median duration of 12 weeks whereas this currently occurs in 38% of years at Lake Hattah and 25% of years at Mournpall. The duration of full events is similar to the recommendation of 12 weeks, being 15 and 12 weeks at Lakes Hattah and Mournpall, respectively. Under the current water regime these wetlands do not provide reliable habitat for resident populations of large fish and do not provide a drought refuge for aquatic fauna.

The water regime for Persistent Temporary Wetlands fails to meet the recommendation to various degrees. In general wetlands are as dry or drier than the recommendation for wetlands to be 50% full in 50% of years. The recommendation for 'full' events to occur in 50% of years is not met in most cases and generally occurs in 20 to 30% of years. The median duration of full events is similar to the recommendation. These wetlands are not currently flooded sufficiently to maintain perennial emergent macrophyte beds and do not provide reliable aquatic habitat for waterbirds, fish or frogs.

The Temporary Wetland water regime class was based on the natural water regime of Lake Marramook. The lake is currently full in 21% of years for a median duration of 20 weeks whereas full events were recommended in 40% of years for a duration of 24 weeks. It is recommended that the wetland dries for 4 months in 75% of years. This requirement is exceeded excessively where the wetland is currently dry for 85% of the time. The current water regime is insufficient to support emergent macrophyte vegetation or to provide breeding habitat for fish or waterbirds dependent on reeds when flooded.

The current duration of full events in Episodic Wetlands is 52 weeks and is similar to the recommendation of 1.5 to 2.5 years. However events only occur in 2% of years compared with the recommendation of 5 to 10% of years. This deficit will result in fewer breeding opportunities for aquatic fauna, particularly waterbirds, when the wetlands are flooded. However the deficit is minor relative to the other water regime classes.

There is a deficit between the recommended and current water regime of Fringing Red Gum growing at the perimeter of the lakes. Inundation events currently occur in 21 to 43% of years whereas a frequency of 60% of years is recommended. The duration of events is currently similar to the recommendation (Table 29). The current water regime is insufficient to sustain perennial flood-dependent understorey plants and provides limited breeding opportunities for fish, frogs, tortoise, birds and other flood-dependent fauna.

The growth of Red Gum trees will also be retarded and the duration of dry periods between floods may be too great for saplings to survive.

Red Gum FTU currently experiences flood events of 3 to 5 weeks, which is similar to the recommendation of 4 weeks. However, events only occur in 4 to 18% of years whereas a frequency of 20 to 40% of years is recommended. This flood frequency will result in low productivity in fauna dependent on tree and understorey production, in poor tree health and poor tree recruitment.

Black Box Woodland is currently inundated by events of 2 to 5 weeks, which is similar to the recommendation of 4 weeks. The frequency of events is similar to, but generally lower than the recommendation of 10 to 20% of years. The current water regime represents a relatively minor threat to Black Box tree health and woodland productivity.

The frequency of inflows to Lignum Shrublands is less than the recommendation. Events currently occur in 8% of years compared with the recommendation of 20%. Data on the duration of inundation within the shrublands has not been analysed, but is expected to be controlled by evaporation and seepage. The duration of events expected to be similar under natural and current conditions and is expected to meet the recommendation of 12 weeks. Lignum are expected to suffer significant stress from the reduction in inundation event frequency. The reduction in inundation events also reduces breeding opportunities for flood-dependent fauna.

The flow objectives in Chalka Creek mainly relate to habitat for flow-dependent fauna. The level in Chalka Creek currently exceeds 42.2 m AHD in 47% of years for an average duration of 23 weeks. This exceeds the flow objective of providing flow for 4 months per year, but fails to meet the objective to provide events in 75% of years. It may be possible for flow-dependent fauna to occasionally tolerate the absence of flow, but the current flow regime is likely to exclude flow-dependent species.

4.4 Water Regime Class Priority

The contribution of the water regime classes to the representative ecological objectives is presented in Table 31.

Table 31. Contribution of Water Regime Classes to Representative Ecological Objectives

Water Regime Classes are abbreviated as follows: SPW Semi-permanent Wetlands, PTW Persistent Temporary Wetlands, TW Temporary Wetlands, EW Episodic Wetlands, RGF / FRG Red Gum Forest / Fringing Red Gum, RGFTU Red Gum with Flood Tolerant Understorey, BBX Black Box, LS Lignum Shrubland, CK Chalka Creek.

Element	Representative Ecological Objective	Water Regime Class								
		SPW	PTW	TW	EW	RGF / FRG	RG FTU	BBX	LS	CK
A	Foraging and Breeding by White-bellied Sea-eagle	3	2		1	3	1	1	1	1
	Resident Populations of Small Fish	3	3	2	1	1			1	
	Breeding and Foraging by Flood-dependent Waterbirds	3	2	1	1	3			1	
	Breeding by Regent Parrot					3	2			1
	Resident Populations of Large Fish	3	2			1				1
	Resident Populations of Carpet Python	1	1			3	2	2	2	1
	Resident Population of Brushtail Possum		1	1		3	2	2		1
	Resident Population of River Mussel	2	2	1		2				3
ΣA	Importance	15	13	5	3	19	7	5	5	8
B	Degree to which Water Regime is Threatened	3	3	2	1	2	2	1	2	2
B x ΣA	**Priority Score**	**45**	**39**	**10**	**3**	**38**	**14**	**5**	**10**	**16**

The greatest priority for water management is the Semi-permanent Wetlands which makes a key contribution to a large number of objectives and is significantly threatened by deficiencies in flooding. Persistent Temporary Wetlands are the next highest priority due to the diversity of habitats they provide and degree of threat to their water requirements. Fringing Red Gum Woodland and Red Gum Forest are the next highest priority. These classes are critical to several representative objectives and have a high overall importance, but are not as threatened as the two wetter wetland classes.

Chalka Creek contributes to the requirements of a range of objectives, but particularly to the habitat requriements of River Mussel. While the water regime is significantly threatened with regard to this species, it is only moderately threatened with regard to the other objectives. Red Gum FTU and Lignum Shrublands make relatively small contributions to the ecological objectives and have a lower priority for management. The lowest priorities for management are Lignum Shrublands, Black Box Woodland and Episodic Wetlands. These make relatively smaller contributions to the ecological objectives and their water requirements are not as threatened as the other classes.

4.5 Priority of Water Regime Classes

The analysis of the system's water requirements has classified the floodplain into a number of water regime classes to which hydrological and ecological features may be attributed. The classes have been prioritised according to their conservation significance and the degree to which their water requirements are threatened.

The priority of water requirements from highest to lowest is:

- Semi-permanent Wetlands;
- Persistent Temporary Wetlands;
- Fringing Red Gum and Red Gum Forest;
- Red Gum Flood Tolerant Understorey; followed by
- Lignum Shrublands, Temporary Wetlands, Black Box Woodlands and Episodic Wetlands.

The benefits of flooding lakes and their surrounding floodplain are linked and it is desirable to apply options that inundate woodlands surrounding the wetlands.

Approach to Developing Water Management Options

5.1 Overview

The following options were identified to address the water requirements of the Hattah Lakes system:

- lower Chalka Creek;
- retain floodwater in central Lakes Region;
- confine flooding north of Lake Hattah;
- confine flooding south of Lake Yerang;
- confine flooding in Lakes Lockie and Little Hattah;
- lower and regulate Cantala Creek;
- new regulator to the east of Lake Bitterang;
- raise rock bar in the River Murray at Chalka Creek East; and
- pump water to fill the lakes.

This section presents the approach used to evaluate the options. The options are described in detail and evaluated in Section 6. Their cost-effectiveness is reported in Section 8.

5.2 Deficits in Water Requirements

Water management options are evaluated by how well they provide the required water regimes of wetlands and floodplain areas. This requires a comparison of water regimes before and after options are implemented and a comparison of the relative effectiveness of alternative options.

This simple objective is made difficult by the number and diversity of variables used to describe water regime in Section 3. Table 1 summarises the water requirements of each water regime class and illustrates the complexity of the hydrological factors considered important to the ecological outcomes. These include timing of events, depth, duration, frequency and contingent factors where if one event occurs another specified event must follow. A very complex analysis would be required to compare the degree to which these targets are achieved in each option and in reach region and to compare their achievement between options and regions.

The main purpose of this project was to identify water management options worthy of further development and detailed design. Therefore a smaller set of representative thresholds was used in the analysis in Section 6 to evaluate the options. This focussed on the persistence of water in the lakes (the frequency and duration of events when the lakes were more than half full) and the frequency and duration of floodplain inundation.

Table 1. Comparison of Current and Required Water Regime

Water Regime Class	Recommended Water Regime	Current Water Regime
Semi-permanent Wetlands	Water level exceeds 50% retention level 80% of the time Wetland dry in less than 5% of years Water reaches the retention level in 30 to 50% of years for 12 weeks Peak seasonal water level in August	Water level exceeds 50% retention level approximately 45% of the time Wetland dry in approximately 15% of years Water reaches wetland retention level in approximately 30% of years for approximately 15 weeks Peak seasonal water level in August
Persistent Temporary Wetlands	Water level falls to 50% of wetland depth in May or June in 50% of years, i.e. wetland level exceeds 50% of wetland depth 92% of the time Water level reaches the retention level in September or October in 50% of years Retention level should be exceeded for 12 weeks in 50% of years Retention level should be exceeded for 24 weeks in 25% of years	Water level falls to 50% of wetland depth in approximately 30% of years. Seasonality of lowest water level not analysed but likely to be May or June. Water level reaches the retention level in approximately 30% of years. Seasonality of highest water level not analysed but likely to be September or October. Retention level exceeded for approximately 20 weeks in approximately 30% of years
Temporary Wetlands	Water reaches retention level in 40% of years for a median duration of 24 weeks Full events generally commence between July and September Wetland is dry for 16 weeks after 75% of filling events (i.e. 37.5% of years) Dry events generally occur between February and June	Water reaches retention level in 21% of years for a median duration of 20 weeks Seasonality of water level not analysed but likely to be between July and September Wetland is dry in 18% of years with a median duration of 144 weeks. Seasonality of dry events not analysed but likely to be between February and June
Episodic Wetlands	Lakes reach retention level in 5 to 10% of years for 8 weeks Water depth exceeds 2 m for 1.5 to 2.5 years following full events Wetland remains dry for a median duration exceeding 5 years between full events	Retention level exceeded in 2% of years with median duration of 52 weeks Average duration of events with a depth of more than 2 m is 1.94 years Average duration of dry events is 31 years
Fringing Red Gum at Lake Perimeter (approximate elevation 42.5 m AHD)	Inundate for 12 weeks in 40% of years Inundate for 24 weeks in 20% of years Flooding initiated in August in most years	Events occur in approximately 30% of years with a median duration of approximately 13 weeks Events of lower frequency not analysed Flooding initiated most frequently in August or September.
Red Gum Forest, Fringing Red Gum Woodland above 43.0 m AHD	Inundate for median duration of 5 to 10 weeks in 33 to 50% of years Flooding initiated in August in most years	60% of area is inundated in approximately 20% of years for 4 weeks Flooding initiated most frequently in August or September.

Water Regime Class	Recommended Water Regime	Current Water Regime
Red Gum with Flood Tolerant Understorey	Inundate for median duration of 4 weeks in 20 to 40% of years	Approximately 60% of area is inundated in 4 to 18% of years for a median duration of approximately 4 weeks
Black Box Woodland	Inundate for median duration of 4 weeks in 10 to 20% of years	Approximately 60% of area is inundated for a median duration of 4 weeks in 10% of years
Lignum Shrubland	Inundate to 0.5 m for a median duration of 12 weeks in 20% of years	Inundation threshold for approximately 50% of area is exceeded for a median duration of 5 weeks in 12% of years

5.3 Hydraulic Modelling

The hydraulic model developed by SKM was used to predict the effects of proposed water management options on wetland and floodplain hydrology (SKM 2006b). Four scenarios were modelled.

- Scenario A – lower Chalka Creek and lower Cantala Creek
- Scenario B – Scenario A plus the operation of new regulators on Mournpall Island and on Lake Cantala
- Scenario C – Scenario A, Scenario B plus the operation of new regulators to confine flooding to lakes to the north of Lake Lockie
- Scenario D – Scenario A, Scenario B plus the operation of regulators to confine flooding in lakes to the south of Lake Lockie

A hydrodynamic model was used to simulate in detail the movement of water in the study area during discrete flood events. A simplified 'water balance model' was used to estimate the water level at key points of the study area over a 92 year time sequence. The water balance model infers water levels from the Murray River flow passing Euston Weir, rainfall data and evaporation data.

The hydraulic model reported levels at 39 locations on a weekly basis over the modelled period. To analyse the overall effect of the modelled options, a spells analysis was conducted at 10 locations that include lakes likely to be affected by the options. The locations were selected from a range of hydrological zones that would demonstrate the effects of manipulating water in different areas. These locations were:

- Bitterang (Bitterang Zone);
- Cantala1 (Cantala Zone);
- Lockie1 (Central Zone);
- Little Hattah (Central Zone);
- Mournpall (Northern Lakes);

- Yelwell (Northern Lakes);
- Hattah (Southern Lakes);
- Arawak (Southern Lakes); and
- Brockie (Southern Lakes).

The full spells analysis of the modelled data is presented in Appendix G. Interpretation of the hydraulic model centres on the persistence of water in the lakes and the inundation of the surrounding floodplain. Persistence is reported in terms of the time lake levels exceed 50% full and the number of years in which lake levels exceed 50% full. Inundation of the floodplain is reported in terms of the number of events and median duration of events when water spills from the lakes to the surrounding floodplain. In general, significant spill commences at 43.0 m AHD with water spreading further at 43.5 m AHD (Table 2).

Table 2. Water regime classes inundated at 43.0 and 43.5 m AHD

Zone	Elevation (m AHD)	Water Regime Class							
		Area Inundated (ha)				Area Inundated (% of area in zone)			
		RGF	FRG	RG FTU	Black Box	RGF	FRG	RG FTU	Black Box
Chalka Creek	43.0	43	9	6	4	18	1	2	0
	43.5	56	28	34	20	23	4	12	2
Lockie	43.0	np	147	15	17	np	31	4	3
	43.5	np	283	66	67	np	59	20	10
Hattah	43.0	np	55	3	7	np	45	4	5
	43.5	np	75	10	38	np	61	16	28
Brockie	43.0	np	29	np	13	np	30	np	2
	43.5	np	45	np	38	np	45	np	6
Bitterang	43.0	np	109	140	3	np	43	23	1
	43.5	np	163	229	25	np	65	37	6
Cantala	43.0	80	8	219	23	58	19	55	7
	43.5	101	13	282	76	73	30	71	23
North Lakes	43.0	np	129	65	10	np	30	18	2
	43.5	np	202	136	42	np	46	37	7

(abbreviations: np not present in this zone, RGF Red Gum Forest, FRG Fringing Red Gum, RG FTU Red Gum with Flood Tolerant Understorey, Black Box Black Box Woodland)

Relevant results from the spells analysis in Appendix G are presented in tables in the body of this report to assist in interpretation.

For the purposes of modelling, a retention level of 43.4 m AHD was used for Messengers Regulator and proposed new regulators. This is marginally lower than the surveyed retention level of 43.45 m AHD for Messengers Regulator (SKM 2006b).

5.4 Cost Estimates

Approximate cost estimates are provided for the works to be considered in the water management options.

Cost estimates for structures are based upon recent cost estimates for similar structures generated for water management options in Gunbower Forest, Victoria and using recent cost estimates developed for similar water management options between Nyah and Robinvale, and within Lindsay, Mulcra and Wallpolla Islands within Victoria.

The cost of regulators was derived for both a typical fully automated and manually operated structure. Unless indicated otherwise cost estimates were derived assuming gated structures with typical 2.0 m x 1.5 m openings and includes the cost of associated earthworks at each site. The cost of these structures is generally reflective of the number of openings and structural works and less of the amount of earthworks required. As a minimum it is recommended that a two gated structure is adopted to safeguard against malfunction. However, in some cases a one gated structure is considered sufficient to meet ecological objectives given existing channel constraints.

In addition it is also recommended that a fully automated (i.e. includes actuators) structure is adopted as opposed to a structure requiring manual operation. Reasons include:

- access during flooding may be restricted;
- lack of resources required to operate the structures (two people per structure); and
- OH&S considerations.

It was decided that coffer dams would not be required during construction for options where the presence of water was unlikely. This would be the case for options where construction locations are not within the influence of a weir pool, lagoon and/or creek. Unless indicated otherwise the installation and removal of coffer dams during construction were not included.

Any earthworks required as a component of works for any given option has been costed assuming works will be carried out at the same time as the major works for each option (i.e. avoiding significant variation in mobilisation and de-mobilisation costs).

Allowances for tree removal have been made when costing lowering of sills/bed levels, given the likelihood of trees within creeks.

It should be noted that the direct cost of mobilisation/site establishment and demobilisation was $10,000 and $5,000 respectively. However, these are estimates only and should be used as a guide only. To better cost both mobilisation and demobilisation a better understanding is required of the characteristics and circumstances related to each site. This should be considered at a later stage. At this stage the above estimates were considered sufficient.

Unless indicated otherwise, cost estimates are for total costs associated with each option component. Total cost estimates include allowance for mobilisation/site establishment, construction of access tracks, survey, design and construction, project management and contingencies related to works for each option. In particular 10% of the total option component cost is allowed for Survey and Design, 10% for Project Management and a further 40% for contingencies.

It should be noted that all cost estimates are very preliminary and are indicative only. The actual cost of these structures could vary from these estimates. The estimates are based on the LIDAR survey and general rates for this type of work. No investigation of soil conditions, or access arrangements have been made and no design work has been undertaken at this stage. The estimates are provided to give an approximate indication of cost for option comparison and early budget consideration only.

6.1 Option 1 - Lower Chalka Creek

Objective

The objective of this option is to increase the frequency, duration and rate of inflows to the system by lowering the bed level of Chalka Creek.

The intended benefits are:

- prolong flooded and flowing conditions in Chalka Creek; and
- increase flood frequency and duration in Semi-permanent, Persistent Temporary and Temporary Wetlands and in Fringing Red Gum.

Design

A review of the DEM showed that the bed of Chalka Creek is higher than the invert of Messengers Regulator (41.7 m AHD) at several locations. If lowered, the creek would divert water from peaks in River Murray flow more frequently and for longer periods.

This option proposes to lower Chalka Creek and to use Messengers Regulator with current invert level and retention level to manage/retain flows within the lake regions. The invert of the creek would be lowered for approximately 1700 m commencing at the River Murray from the current level of up to 43 m AHD to that of Messenger's Regulator of 41.7 m.

This option is expected to lower the threshold flow at Euston in the Murray from 36,700 ML/d to approximately 20,000 ML/d before flow enters Chalka Creek. This is based on the previously developed (SKM 2006a) relationship between flow at Euston and water level at Messenger's Regulator.

The approximate location of required works are provided in Figure 40.

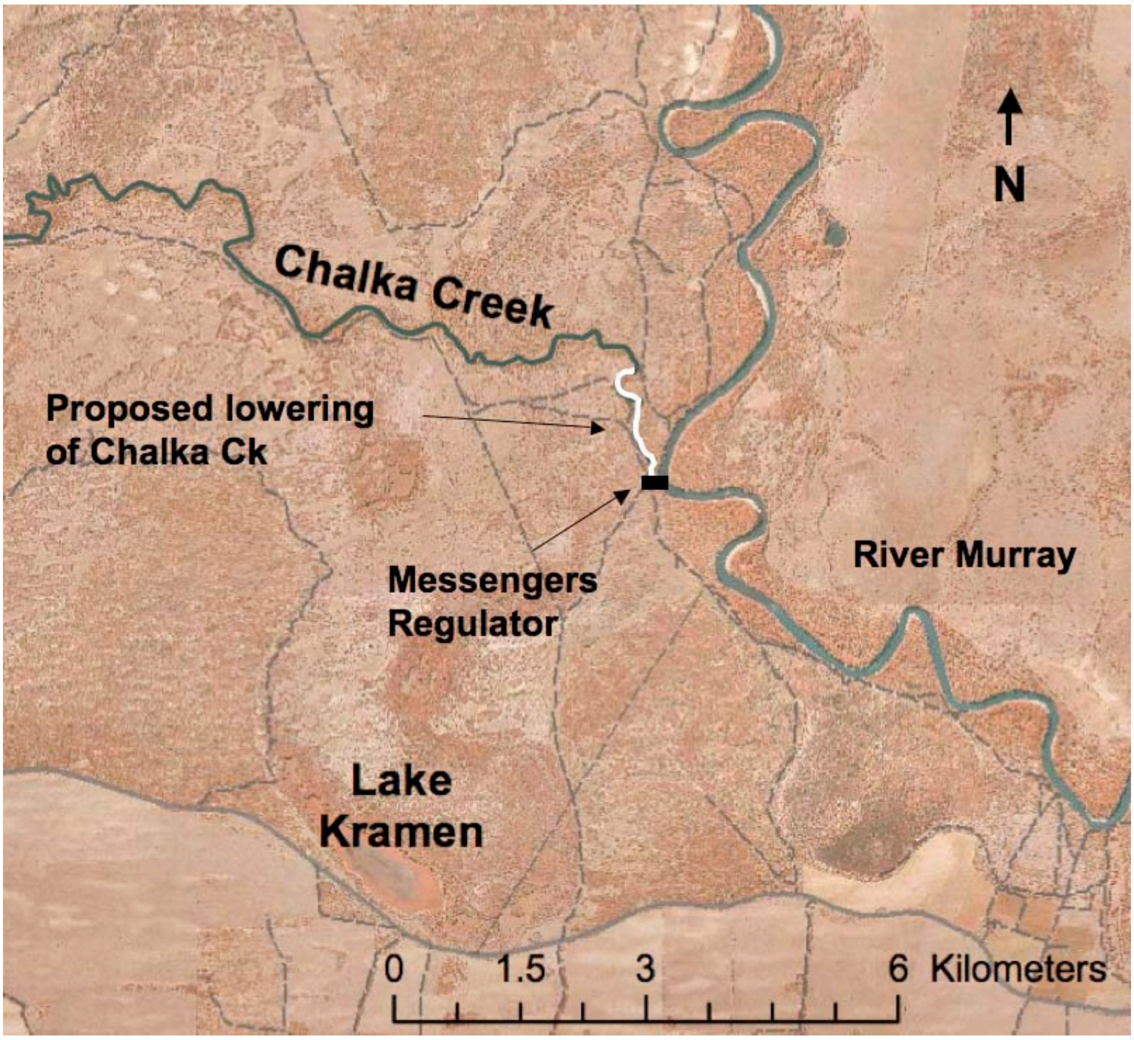


Figure 40. Approximate location of works to lower Chalka Creek (Option 1)

Cost

The estimated cost of these works is $220,000 based on a rate of $130/m for work on the channel over 1,700 m. A further assessment of the costs and risks should be undertaken at a later stage and must take into account issues related to the working conditions and environmental constraints at Chalka Creek.

Ongoing monitoring and reporting of Chalka Creek conditions should be included in this option to regularly check the creek invert for blockage by snags and build up of sediment. This could be done by a combination of visual inspection and checking of creek levels using GPS and could cost approximately $10,000 per report. This monitoring may identify the need for periodic clean out and/or repositioning of snags, the cost of which has not been estimated.

Effectiveness

The hydraulic model was run to evaluate the effects of this option on the water regime of the lakes over a 92 year period. The model was run with Chalka Creek lowered to 41.7m AHD, as described above. Messengers Regulator was operated to allow all inflows and to prevent outflow below the retention level of the structure (Scenario A, SKM 2006b).

The effects of the option can be illustrated by the maximum inundation extent and depth for the 2000 flooding event (SKM 2006b; Figure 41). For this event, lowering Chalka Creek resulted in water spreading further:

- beyond Lake Hattah, to Lake Marramook and Lake Brockie;
- at the perimeter of Lake Yelwell; and
- to the floodplain adjacent to Lake Roonki.

A greater depth was also achieved, particularly in Lakes Mournpall, Roonki, Bulla and Arawak.

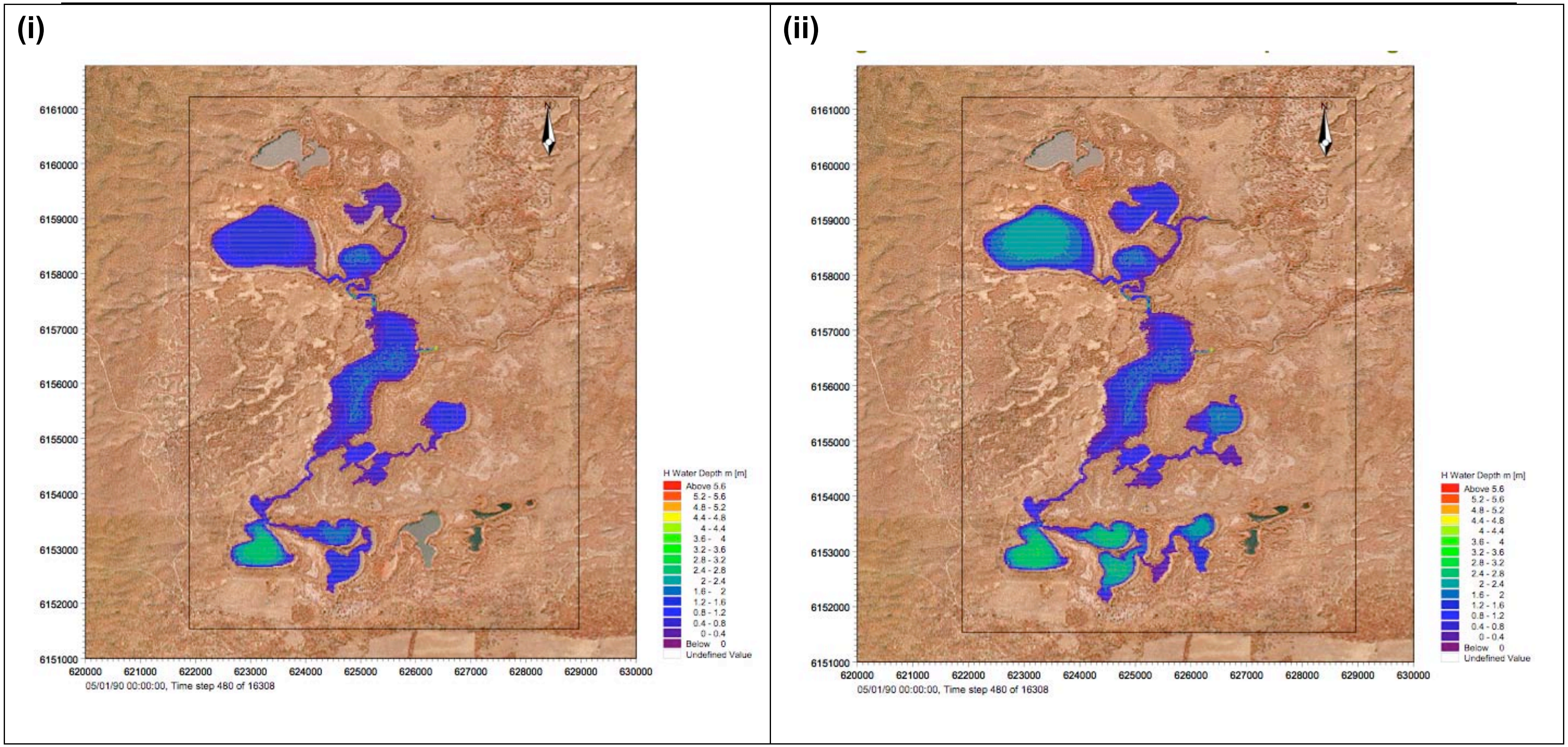


Figure 41. Maximum extent of inundation in 2000 flood event under current conditions (i) and under Option 1 (ii). Data from SKM (2006b)

Lowering Chalka Creek increased the permanence of the wetlands (Table 3). By introducing water to the system more frequently, the wetlands are regularly topped up and are less likely to dry out. The works generally increase the likelihood of a lake exceeding 50% full in any year by approximately 10 to 15 percentage points. The time that the water level exceeds 50% also increases; the greatest change is in Lake Hattah where the lake is more than 50% full 70% of the time compared with 56% of the time currently. Lake Brockie is also significantly affected, possibly because it lies towards the end of a long flow path and new flood peaks enter the system before this area entirely drains.

There is a minor improvement in Lake Bitterang even though this lake is quite distant from the works on Chalka Creek.

Table 3. Effects of Lowering Chalka Creek on Persistence in Lakes

Lake	Threshold	Current (years when threshold exceeded, % time exceeded)	Lower Chalka Creek (years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	76, 46	84, 57
Little Hattah	>50% full	60, 28	74, 39
Northern Lakes			
Mournpall	>50% full	64, 42	76, 56
Yelwell	>50% full	67, 39	67, 47
Southern Lakes			
Hattah	>50% full	75, 56	85, 70
Arawak	>50% full	72, 47	76, 53
Brockie	>50% full	49, 29	76, 53
Chalka Ck North			
Bitterang	>50% full	47, 28	49, 30

This option does not significantly affect the behaviour of water at or above the lake edge. The frequency and duration of events above the full level of most lakes (around 42.3 m AHD) is similar to current conditions (Table 4). This option does not significantly contribute to one of the key targets to promote flooding of the Red Gum woodland fringing the wetlands (but does not significantly detract from it either).

A notable exception is Lake Brockie where inundation of the adjacent floodplain increases. This is likely to be because the lower sill in Chalka Creek allows water to re-enter the outer southern lakes before they have fully drained.

Table 4. Effects of Lowering Chalka Creek on Floodplain Inundation

Lake	Level Above Lake at 43 m AHD	Current (median duration, no. events in 92 years)	Lower Chalka Creek (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	6.5 weeks, 44 times	7 weeks, 45 times
Little Hattah	full + 0.7 m	5.5 weeks, 32 times	4 weeks, 35 times
Northern Lakes			
Mournpall	full + 0.6 m	4 weeks, 28 times	4 weeks, 29 times
Yelwell	full + 0.7 m	5 weeks, 33 times	4 weeks, 35 times
Southern Lakes			
Hattah	full + 0.7 m	5.5 weeks, 32 times	4 weeks, 35 times
Arawak	full + 0.7 m	4 weeks, 31 times	4 weeks, 35 times
Brockie	full + 0.7 m	3.5 weeks, 24 times	5.5 weeks, 32 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

This option has no benefit to the floodplain adjacent to Lake Bitterang.

Risks

A risk associated with channel works on the floodplain is bank instability and erosion in Chalka Creek during a flood. If the works are designed to prevent erosion, the risk is considered to be very low.

Another risk is that the lakes will not benefit from the works if the river level does not exceed the lowered threshold any more frequently than the current threshold. Historic flood records indicate the lower threshold will be reached significantly more frequently. Therefore this risk is not significant.

Excavations of this scale present a significant risk of disturbance to features of Aboriginal cultural significance. This may include disturbance to significant trees, disturbance to artefacts and changes to the character of Chalka Creek. It would be necessary to identify matters of cultural significance in advance, to arrange works to minimise impacts and to monitor impacts during site works.

Flooding promoted by the works may reduce vehicle access to some parts of the system. This may present a minor social risk.

Implementation and Operation

As in the current circumstances, this option requires that Messengers Regulator is closed when the level in Chalka Creek is below the retention threshold and falling, and that the regulator is re-opened when river levels exceed the level in Chalka Creek.

This option will involve significant disruption to a small section of Chalka Creek. The creek level will be lowered by up to 1.3 m over a distance of 1700 m and excavated to a width equivalent to the capacity of the creek elsewhere. This will require the removal of large Red Gum trees with significant habitat value, the removal of small Red Gum, Eumong, Lignum and other shrub and understorey vegetation, the loss of in-stream habitat features such as large woody debris, overhanging banks and vegetation and deep pools. However, the affected area is only a small proportion of the total length of Chalka Creek and elsewhere these features will remain. It may be possible to design the works to re-incorporate some of these features (e.g. large woody debris and snags) in the modified channel. It may also be possible to align the excavations to minimise impacts on trees or features of high cultural or conservation significance.

In bringing to the site machinery required for excavation and tree removal, it may be necessary to remove limbs from trees on access tracks.

The impact of the works on flora and fauna must be assessed. Under Victorian legislation, the impacts on native vegetation and fauna habitat are assessed under Victoria's native vegetation management framework (DNRE 2002). As a Ramsar site, the work affects a matter of national environmental significance and must be referred to the Commonwealth Minister for the Environment for approval under the Environment Protection and Biodiversity Conservation Act 1999. The work also affects, or potentially affects, flora and fauna species of national environmental significance (e.g. tree hollows for Regent Parrot) and these matters must also be identified and referred under the EPBC Act.

Both of the native vegetation management framework and EPBC Act consider how these impacts are offset by environmental benefits elsewhere. In the case of Chalka Creek benefits will include:

- improved health of riparian vegetation in the modified reach and elsewhere in Chalka Creek due to more frequent inflow;
- the more frequent provision of aquatic habitat in the modified reach, elsewhere in Chalka Creek and in the lakes due to more frequent inflow;
- improved health of Red Gum woodland vegetation surrounding the lakes.

It is expected that these benefits will justify the impacts associated with this option.

Matters of cultural significance affected by vehicle access, tree and vegetation removal, excavation and spoil disposal must be assessed.

The creek will be subject to silt and debris accumulation. It will be necessary to monitor the capacity of the creek annually and to arrange debris and silt removal as required. It is expected that maintenance work will be required very infrequently.

Detailed design of this option will involve:

- a physical survey of the length of the creek in question;
- a desktop and field assessment of matters of cultural significance;
- a flora and fauna survey to report species matters of state and national conservation significance affected;
- an assessment of the degree to which the proposal will improve habitat elsewhere;

- a site inspection and detailed design to quantify the excavations and finalise the route with regard to maximising inflow and minimising impacts on habitat and matters of cultural significance;
- a vegetation impact report under Victoria's native vegetation management framework (DNRE 2002); and
- a referral to the Commonwealth Minister for the Environment under the EPBC Act 1999.

6.2 Option 2 – Retain Floodwater in Central Lakes Region

Objective

The objective is to raise the level to which water can be retained on the floodplain to 43.4 m AHD.

The intended benefit is to:

- prolong flooding in the North Lakes, Lockie, Hattah, Brockie and Chalka Creek regions.

Design

Messengers Regulator is constructed to retain water up to an elevation of 43.45 m AHD (SKM 2006b). However the structure is not effective to this elevation because water drains from the system via Chalka Creek North at an elevation of approximately 42.5 m AHD. At this elevation, water is not effectively retained in Fringing Red Gum Areas but is merely contained within wetlands and channels.

It is proposed to regulate Chalka Creek North at two locations to retain flood water in the system. The preferred location for the first regulator (NL1) is between 500 and 3000 m downstream of Lake Yelwell near Rim Crossing (to the north of Mournpall Island), where the channel is relatively narrow and well defined (approximately 626441, 6159017 GDA 1994 MGA Zone 54). . The invert level of the regulator would be 40.6 m AHD. At this location the channel is approximately 50 m wide with a bed level of approximately 40.6 m AHD.

A second regulator (NL2) is required on the watercourse to the east of Mournpall Island (approximately 628114, 6157551 GDA 1994 MGA Zone 54). The sill level of the watercourse at Chalka Creek is 42.7 m AHD. A structure on this channel would prevent water from escaping via this watercourse to Chalka Creek North beyond the Rim Crossing regulator. The invert level of the regulator would be 41.3m AHD. The channel at this location is approximately 27 m wide with a bed level of approximately 41.3 m AHD.

At both locations a one gated structure is proposed.

Both structures would have a retention level of 43.4 m AHD. This elevation was chosen for the purposes of modelling and is approximately equivalent to the current level of Messengers Regulator. At this elevation a significant proportion of the Fringing Red Gum would be inundated and water would be retained in all the Semi-permanent, Persistent Temporary and Temporary Wetlands in the North Lakes (Mournpall, Konardin, Yelwell, Yerang,) Lockie (Lockie, Roonki), Hattah (Little Hattah, Hattah, Bulla, Arawak) and Brockie (Marramook, Brockie, Boich, Tullamook, Nip Nip) regions. These regions together with the approximate locations of all regulators and the 43.4 m AHD contour (derived from LIDAR survey) are shown in Figure 42 below.

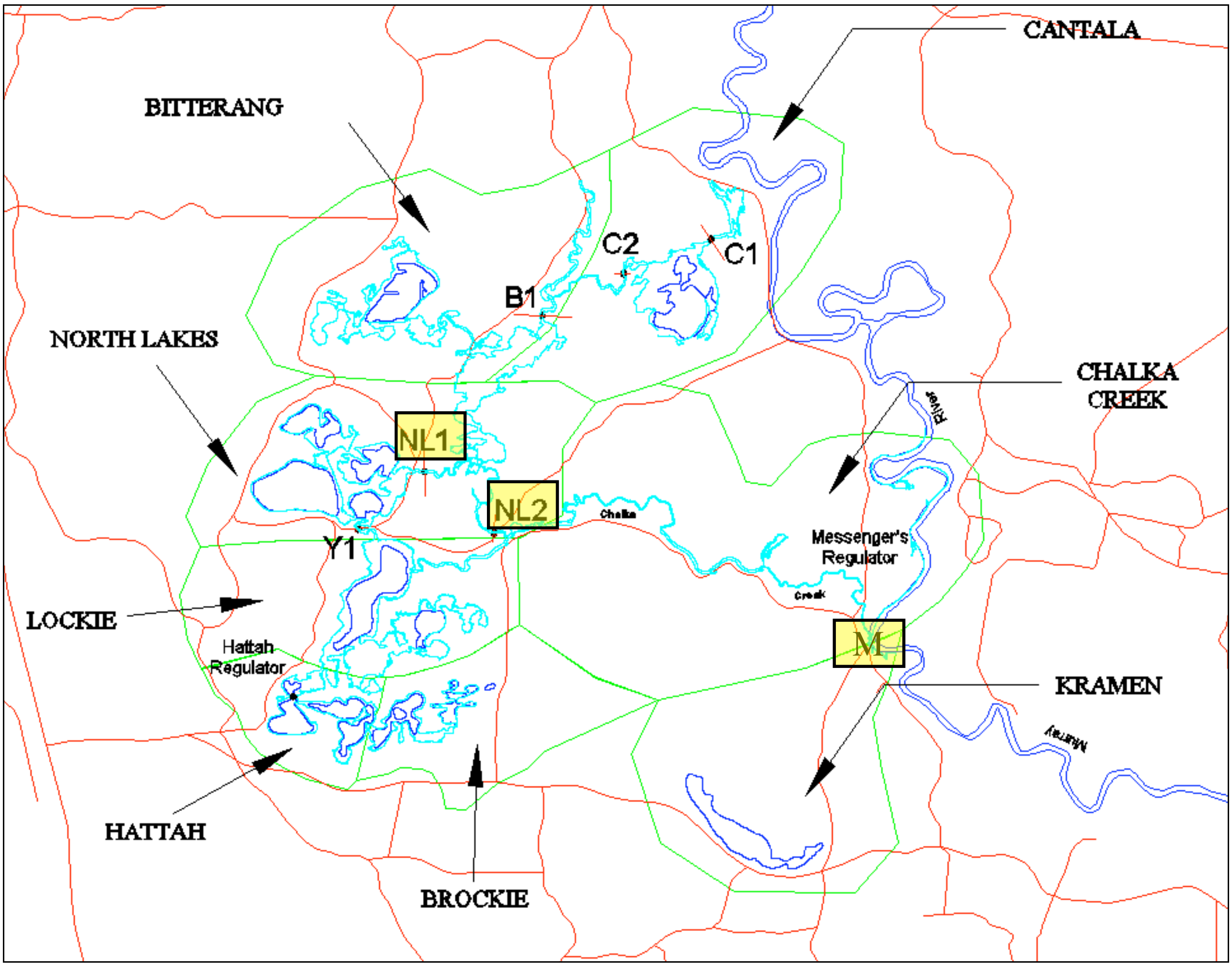


Figure 42. Approximate Location of Regulators within Wetland Regions. Option 2 regulators highlighted in yellow

The regulators would be operated to allow maximum inflow, either from Chalka Creek East or Chalka Creek North and would be closed to retain water to the maximum level possible.

At this stage it is not recommended that the level of Messengers Regulator is raised any further. The area inundated at 43.4 m AHD remains very large. Changes to the retention level might be considered in the light of the hydraulic modelling results.

This option would increase the benefits of the proposal to lower Chalka Creek, but would have little effect if Chalka Creek were not lowered. It is therefore recommended that this option would only be implemented in conjunction with lowering Chalka Creek.

Cost

The cost of the Regulators NL1 and NL2 is estimated to be $150,000 each for automated structures and $120,000 each for manually operated structures.

Additionally, this option requires the lowering of Chalka Creek which is costed at $220,000.

Effectiveness

The hydraulic model was run to evaluate the effects of this option. The model was run with Chalka Creek lowered, as described in Option 1. Regulators equivalent to NL1, NL2 and Messengers Regulator were operated to allow all inflow but to prevent outflow below the retention level (Scenario B SKM 2006b).

In comparison to Option 1, this option does not increase the maximum extent of inundation under normal circumstances (Figure 41). Option 2 controls the recession of water, but does not improve inflow any further. Therefore the spatial effects of this option were not illustrated by SKM (2006b).

Closing the proposed regulators on Mournpall Island marginally increases the persistence of flooding compared with the option of lowering Chalka Creek alone (Table 5). This option does not affect the number of inflow events, so the number of years when the lakes are more than half full is similar to Option 1. However the regulators detain water at greater depths by preventing outflows to Chalka Creek North. Therefore water persists in the area for longer and the lakes are more than half full for longer periods. All lakes in the Central, Northern and Southern areas are more than half full for more than 50% of the time with persistence exceeding 75% of the time in Lake Hattah.

Table 5. Effect of Lowering Chalka Creek and Operating New Mournpall Island Regulators on Persistence in Lakes

Lake	Threshold	Lower Chalka Creek (Scenario A) (% years when threshold exceeded, % time exceeded)	Mournpall Island Regulators (Scenario B) (% years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	84, 57	87, 67
Little Hattah	>50% full	74, 39	79, 52
Northern Lakes			
Mournpall	>50% full	76, 56	80, 64
Yelwell	>50% full	67, 47	75, 57
Southern Lakes			
Hattah	>50% full	85, 70	88, 76
Arawak	>50% full	76, 53	78, 63
Brockie	>50% full	76, 53	77, 63
Chalka Ck North			
Bitterang	>50% full	49, 30	49, 30

The regulators at Mournpall Island significantly increase floodplain inundation compared with current conditions. Floodplain inundation is reported for the 43 m AHD threshold at which there is significant spread of water from the lakes to the surrounding woodland vegetation (Table 6). This elevation is below the retention level of the regulators, but is indicative of the water regime on the floodplain immediately surrounding the wetlands. Under current conditions the median event duration is between 3 and 6.5 weeks in the central, northern and southern lakes, with events generally occurring in 30% of years. Closing the proposed regulators at Mournpall Island increases the duration of these events to approximately 20 weeks. Flooding of this duration and frequency is likely to achieve ecological objectives in Fringing Red Gum relating to tree health and recruitment, understorey vegetation composition, aquatic fauna and waterbird breeding and feeding and floodplain productivity. The frequency of events does not change.

This option has no effect on Lake Bitterang; closing the regulators does not reduce flooding in this area.

Table 6. Effects of Operation of Proposed Mournpall Island Regulators on Low Floodplain Inundation

Lake	Level Above Lake at 43 m AHD	Current (median duration, no. events in 92 years)	Mournpall Island Regulators (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	6.5 weeks, 44 times	17 weeks, 41 times
Little Hattah	full + 0.7 m	5.5 weeks, 32 times	20 weeks, 31 times
Northern Lakes			
Mournpall	full + 0.6 m	4 weeks, 28 times	22 weeks, 22 times
Yelwell	full + 0.7 m	5 weeks, 33 times	20.5 weeks, 30 times
Southern Lakes			
Hattah	full + 0.7 m	5.5 weeks, 32 times	20 weeks, 31 times
Arawak	full + 0.7 m	4 weeks, 31 times	20 weeks, 31 times
Brockie	full + 0.7 m	3.5 weeks, 24 times	21 weeks, 27 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

This option does not benefit the floodplain above the retention level of the regulator, as illustrated by the 43.5 m AHD threshold in the spells analysis results presented in Table 7. There is no significant increase in flood duration or frequency at this elevation (Table 7). These elevations are predominantly occupied by Red Gum with Flood Dependent Understorey and Black Box Woodland and do not benefit from the works.

Table 7. Effects of Operation of Proposed Mournpall Island Regulators on High Floodplain Inundation

Lake	Level Above Lake at 43.5 m AHD	Current (median duration, no. events in 92 years)	Scenario B (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 1.3 m	4 weeks, 33 times	5 weeks, 33 times
Little Hattah	full + 1.2 m	4 weeks, 28 times	4 weeks, 28 times
Northern Lakes			
Mournpall	full + 1.1 m	3.5 weeks, 26 times	4 weeks, 25 times
Yelwell	full + 1.2 m	4.5 weeks, 26 times	4 weeks, 28 times
Southern Lakes			
Hattah	full + 1.2 m	4 weeks, 28 times	4 weeks, 28 times
Arawak	full + 1.2 m	4.5 weeks, 26 times	4 weeks, 28 times
Brockie	full + 1.2 m	3.5 weeks, 22 times	4 weeks, 28 times
Chalka Ck North			
Bitterang	full + 1.0 m	5 weeks, 15 times	5 weeks, 15 times

The abruptness with which the effect of this option changes between 43.0 m AHD and 43.5 m AHD reflects the modelled retention level of the structures at 43.4 m AHD. The benefit could therefore be increased using structures with a higher retention level. This could be explored in a new run of the hydraulic model using structures with a retention level of 44.0 m AHD.

Risks

There is a risk that regulating structures will be damaged or destabilised during flood events. The structures should be designed to accommodate possible erosion risks during the design phase. The structures will be subject to significant stress if they are overtopped when closed. This risk will be reduced by appropriate operating rules and will be further reduced by armouring surfaces near the regulators. The regulators must also be designed to withstand pressures and impacts from large woody debris. A contingency should be included in the design to allow the regulator to be opened even if it is overtopped to some degree.

There is a risk that it would not be possible to access regulator NL2 during high water levels. This can be accommodated by designing NL1 to provide vehicle access to Mournpall Island and NL2.

The works present a significant risk of disturbance to features of Aboriginal cultural significance. This may include disturbance to significant trees and disturbance to artefacts. It would be necessary to identify matters of cultural significance in advance, to arrange works to minimise impacts and to monitor impacts during site works.

The works will marginally reduce the duration of flooding and flow in Chalka Creek North. This represents a minor ecological risk to the condition of the creek. However this impact is expected to be more than compensated by benefits to the floodplain elsewhere.

Flooding promoted by the works may reduce vehicle access to some parts of the system. This may present a minor social risk.

Implementation and Operation

This option requires that Messengers Regulator is closed as the level in Chalka Creek is below the retention level and falling, and that the regulator is re-opened when river levels exceed the level in Chalka Creek.

Additionally, it is necessary to close regulators NL1 and NL2 when the level in the area enclosed by the regulator is below the retention level and falling, and that the regulator is re-opened whenever levels in Chalka Creek north exceed the level in the enclosed area.

This option will involve significant disruption to Chalka Creek as described for Option 1.

In addition the construction of the regulators will involve excavation in the creek bed, the disposal of excavated material and the storage of equipment and materials on site. It may be necessary to remove native vegetation on the site and along tracks that provide access to the site.

It is expected that these benefits will justify the impacts associated with this option.

Matters of cultural significance affected by vehicle access, tree and vegetation removal, excavation and spoil disposal must be assessed.

Detailed design of this option will involve the tasks outlined for Option 1 plus investigations at the site of the regulators including:

- a desktop and field assessment of matters of cultural significance;
- a flora and fauna survey to report species matters of state and national conservation significance affected;
- an assessment of the degree to which the proposal will improve habitat elsewhere;
- a site inspection and detailed design to finalise the site of the works with regard to maximising hydraulic benefits and minimising impacts on habitat and matters of cultural significance;
- a vegetation impact report under Victoria's native vegetation management framework (DNRE 2002);
- a report to the Commonwealth Minister for the Environment under the EPBC Act.

6.3 Option 3 – Confine Flooding North of Lake Hattah

Objective

The objective of this option is to increase the depth of inundation that can be achieved in small floods or by emergency pumping by reducing/confining the spread of water to:

- Lakes Lockie;
- Little Hattah;
- Mournpall;
- Yelwell;
- Yerang;
- Konardin; and
- floodplain adjacent to Chalka Creek.

By confining water into a smaller area it would be possible to achieve a greater flood depth for a given event than under Option 2. Water would fill the smaller available area and spill more readily from the lakes to the surrounding floodplain. However, water would be excluded from Lake Hattah and lakes downstream unless the water level exceeded the retention level of the Little Hattah regulator.

The intended benefit is to increase the depth of flooding in these lakes and to increase the frequency and duration of flooding in the surrounding woodland areas.

Design

The decommissioned regulator situated between Lake Little Hattah and Lake Hattah would be refurbished to retain water up to 43.4 m AHD. Refurbishment of the existing Hattah regulator requires removal of the existing walkway above the structure and installation of three undershot gates capable of holding water on both sides of the structure.

Regulators at Messengers, NL1, NL2 and Little Hattah would be operated to maximise the depth of flooding achieved up to a level of 43.4 m AHD. The option would be effective for small and moderate floods. It would increase the duration of flooding in the enclosed area and would increase the frequency and duration of flooding in surrounding floodplain areas. This option would not apply if levels were expected to exceed, or actually exceeded, 43.4 m AHD. To prevent the regulators from being overtopped, the Little Hattah regulator would first be opened to flood lakes to the south, and then NL1 and NL2 regulators would be opened to release water to Chalka Creek north. Nor would the option apply if small floods of long duration were anticipated, if they were likely to distribute water as widely as short, high floods.

The regulators would be operated to achieve flooding of up to 3 months in floodplain areas. After that time, water from shedding floodplain would be released to the river and only water within lake basins would be retained. This would provide ecological benefit to the River Murray by contributing woody debris and other organic matter and invertebrates and small fish, some of which would contribute to regional populations and some of which would become prey for larger fauna.

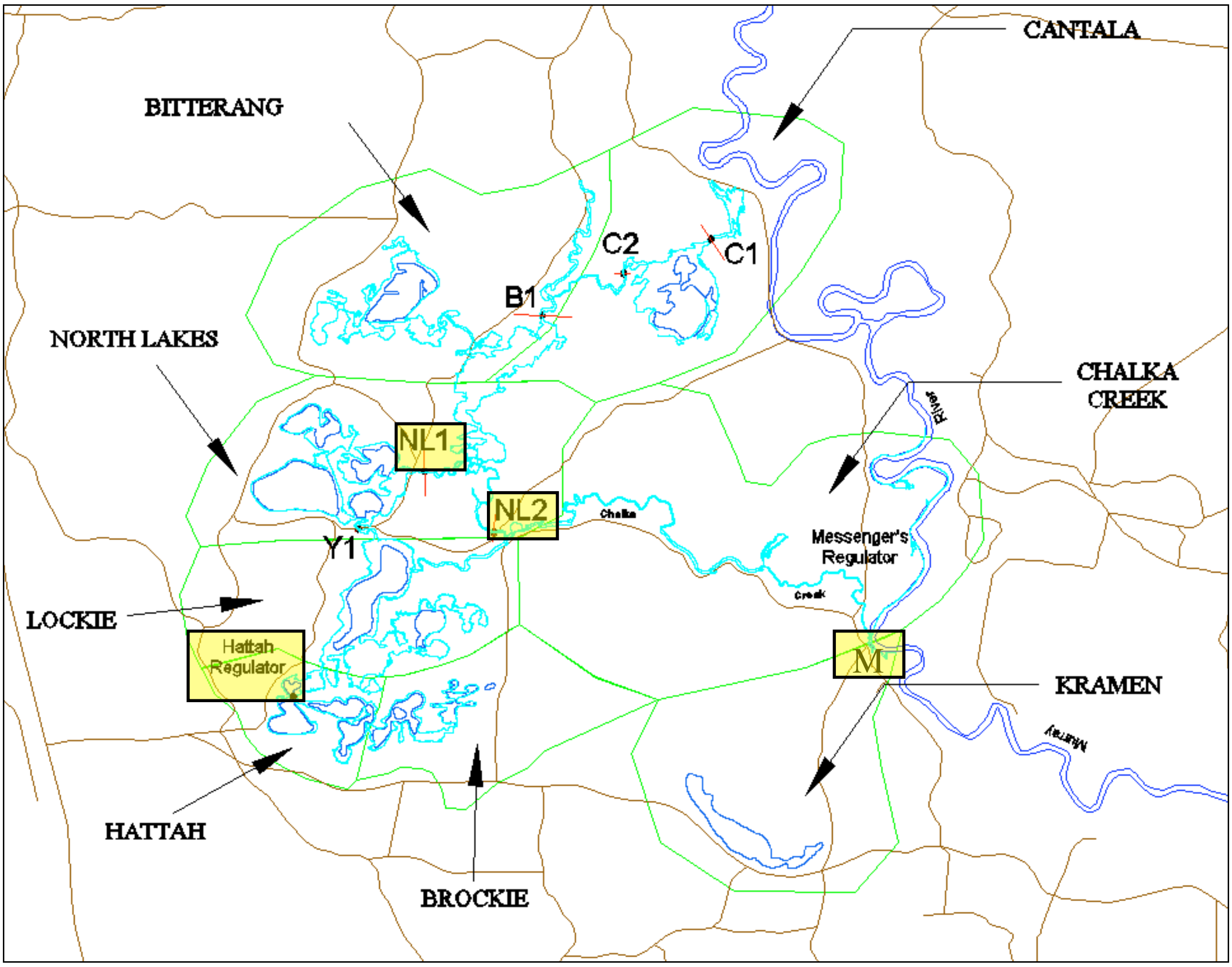


Figure 43. Approximate Location of Regulators within Wetland Regions. Option 3 regulators highlighted in yellow

Cost

The cost of refurbishment of the Little Hattah Regulator is estimated to be $85,000 however a cost of $150,000 would apply if an automated structure were installed.

In addition, this option involves the lowering of Chalka Creek ($220,000) and the construction of regulators NL1 and NL2, which are costed at $150,000 each for automated structures and $120,000 each for manually operated structures.

Lowering Chalka Creek increased the permanence of the wetlands (Table 3). By introducing water to the system more frequently, the wetlands are regularly topped up and are less likely to dry out. The works generally increase the likelihood of a lake exceeding 50% full in any year by approximately 10 to 15 percentage points. The time that the water level exceeds 50% also increases; the greatest change is in Lake Hattah where the lake is more than 50% full 70% of the time compared with 56% of the time currently. Lake Brockie is also significantly affected, possibly because it lies towards the end of a long flow path and new flood peaks enter the system before this area entirely drains.

There is a minor improvement in Lake Bitterang even though this lake is quite distant from the works on Chalka Creek.

Table 3. Effects of Lowering Chalka Creek on Persistence in Lakes

Lake	Threshold	Current (years when threshold exceeded, % time exceeded)	Lower Chalka Creek (years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	76, 46	84, 57
Little Hattah	>50% full	60, 28	74, 39
Northern Lakes			
Mournpall	>50% full	64, 42	76, 56
Yelwell	>50% full	67, 39	67, 47
Southern Lakes			
Hattah	>50% full	75, 56	85, 70
Arawak	>50% full	72, 47	76, 53
Brockie	>50% full	49, 29	76, 53
Chalka Ck North			
Bitterang	>50% full	47, 28	49, 30

This option does not significantly affect the behaviour of water at or above the lake edge. The frequency and duration of events above the full level of most lakes (around 42.3 m AHD) is similar to current conditions (Table 4). This option does not significantly contribute to one of the key targets to promote flooding of the Red Gum woodland fringing the wetlands (but does not significantly detract from it either).

A notable exception is Lake Brockie where inundation of the adjacent floodplain increases. This is likely to be because the lower sill in Chalka Creek allows water to re-enter the outer southern lakes before they have fully drained.

Table 4. Effects of Lowering Chalka Creek on Floodplain Inundation

Lake	Level Above Lake at 43 m AHD	Current (median duration, no. events in 92 years)	Lower Chalka Creek (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	6.5 weeks, 44 times	7 weeks, 45 times
Little Hattah	full + 0.7 m	5.5 weeks, 32 times	4 weeks, 35 times
Northern Lakes			
Mournpall	full + 0.6 m	4 weeks, 28 times	4 weeks, 29 times
Yelwell	full + 0.7 m	5 weeks, 33 times	4 weeks, 35 times
Southern Lakes			
Hattah	full + 0.7 m	5.5 weeks, 32 times	4 weeks, 35 times
Arawak	full + 0.7 m	4 weeks, 31 times	4 weeks, 35 times
Brockie	full + 0.7 m	3.5 weeks, 24 times	5.5 weeks, 32 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

This option has no benefit to the floodplain adjacent to Lake Bitterang.

Risks

A risk associated with channel works on the floodplain is bank instability and erosion in Chalka Creek during a flood. If the works are designed to prevent erosion, the risk is considered to be very low.

Another risk is that the lakes will not benefit from the works if the river level does not exceed the lowered threshold any more frequently than the current threshold. Historic flood records indicate the lower threshold will be reached significantly more frequently. Therefore this risk is not significant.

Excavations of this scale present a significant risk of disturbance to features of Aboriginal cultural significance. This may include disturbance to significant trees, disturbance to artefacts and changes to the character of Chalka Creek. It would be necessary to identify matters of cultural significance in advance, to arrange works to minimise impacts and to monitor impacts during site works.

Flooding promoted by the works may reduce vehicle access to some parts of the system. This may present a minor social risk.

Implementation and Operation

As in the current circumstances, this option requires that Messengers Regulator is closed when the level in Chalka Creek is below the retention threshold and falling, and that the regulator is re-opened when river levels exceed the level in Chalka Creek.

This option will involve significant disruption to a small section of Chalka Creek. The creek level will be lowered by up to 1.3 m over a distance of 1700 m and excavated to a width equivalent to the capacity of the creek elsewhere. This will require the removal of large Red Gum trees with significant habitat value, the removal of small Red Gum, Eumong, Lignum and other shrub and understorey vegetation, the loss of in-stream habitat features such as large woody debris, overhanging banks and vegetation and deep pools. However, the affected area is only a small proportion of the total length of Chalka Creek and elsewhere these features will remain. It may be possible to design the works to re-incorporate some of these features (e.g. large woody debris and snags) in the modified channel. It may also be possible to align the excavations to minimise impacts on trees or features of high cultural or conservation significance.

In bringing to the site machinery required for excavation and tree removal, it may be necessary to remove limbs from trees on access tracks.

The impact of the works on flora and fauna must be assessed. Under Victorian legislation, the impacts on native vegetation and fauna habitat are assessed under Victoria's native vegetation management framework (DNRE 2002). As a Ramsar site, the work affects a matter of national environmental significance and must be referred to the Commonwealth Minister for the Environment for approval under the Environment Protection and Biodiversity Conservation Act 1999. The work also affects, or potentially affects, flora and fauna species of national environmental significance (e.g. tree hollows for Regent Parrot) and these matters must also be identified and referred under the EPBC Act.

Both of the native vegetation management framework and EPBC Act consider how these impacts are offset by environmental benefits elsewhere. In the case of Chalka Creek benefits will include:

- improved health of riparian vegetation in the modified reach and elsewhere in Chalka Creek due to more frequent inflow;
- the more frequent provision of aquatic habitat in the modified reach, elsewhere in Chalka Creek and in the lakes due to more frequent inflow;
- improved health of Red Gum woodland vegetation surrounding the lakes.

It is expected that these benefits will justify the impacts associated with this option.

Matters of cultural significance affected by vehicle access, tree and vegetation removal, excavation and spoil disposal must be assessed.

The creek will be subject to silt and debris accumulation. It will be necessary to monitor the capacity of the creek annually and to arrange debris and silt removal as required. It is expected that maintenance work will be required very infrequently.

Detailed design of this option will involve:

- a physical survey of the length of the creek in question;
- a desktop and field assessment of matters of cultural significance;
- a flora and fauna survey to report species matters of state and national conservation significance affected;
- an assessment of the degree to which the proposal will improve habitat elsewhere;

- a site inspection and detailed design to quantify the excavations and finalise the route with regard to maximising inflow and minimising impacts on habitat and matters of cultural significance;
- a vegetation impact report under Victoria's native vegetation management framework (DNRE 2002); and
- a referral to the Commonwealth Minister for the Environment under the EPBC Act 1999.

6.2 Option 2 – Retain Floodwater in Central Lakes Region

Objective

The objective is to raise the level to which water can be retained on the floodplain to 43.4 m AHD.

The intended benefit is to:

- prolong flooding in the North Lakes, Lockie, Hattah, Brockie and Chalka Creek regions.

Design

Messengers Regulator is constructed to retain water up to an elevation of 43.45 m AHD (SKM 2006b). However the structure is not effective to this elevation because water drains from the system via Chalka Creek North at an elevation of approximately 42.5 m AHD. At this elevation, water is not effectively retained in Fringing Red Gum Areas but is merely contained within wetlands and channels.

It is proposed to regulate Chalka Creek North at two locations to retain flood water in the system. The preferred location for the first regulator (NL1) is between 500 and 3000 m downstream of Lake Yelwell near Rim Crossing (to the north of Mournpall Island), where the channel is relatively narrow and well defined (approximately 626441, 6159017 GDA 1994 MGA Zone 54). . The invert level of the regulator would be 40.6 m AHD. At this location the channel is approximately 50 m wide with a bed level of approximately 40.6 m AHD.

A second regulator (NL2) is required on the watercourse to the east of Mournpall Island (approximately 628114, 6157551 GDA 1994 MGA Zone 54). The sill level of the watercourse at Chalka Creek is 42.7 m AHD. A structure on this channel would prevent water from escaping via this watercourse to Chalka Creek North beyond the Rim Crossing regulator. The invert level of the regulator would be 41.3m AHD. The channel at this location is approximately 27 m wide with a bed level of approximately 41.3 m AHD.

At both locations a one gated structure is proposed.

Both structures would have a retention level of 43.4 m AHD. This elevation was chosen for the purposes of modelling and is approximately equivalent to the current level of Messengers Regulator. At this elevation a significant proportion of the Fringing Red Gum would be inundated and water would be retained in all the Semi-permanent, Persistent Temporary and Temporary Wetlands in the North Lakes (Mournpall, Konardin, Yelwell, Yerang,) Lockie (Lockie, Roonki), Hattah (Little Hattah, Hattah, Bulla, Arawak) and Brockie (Marramook, Brockie, Boich, Tullamook, Nip Nip) regions. These regions together with the approximate locations of all regulators and the 43.4 m AHD contour (derived from LIDAR survey) are shown in Figure 42 below.

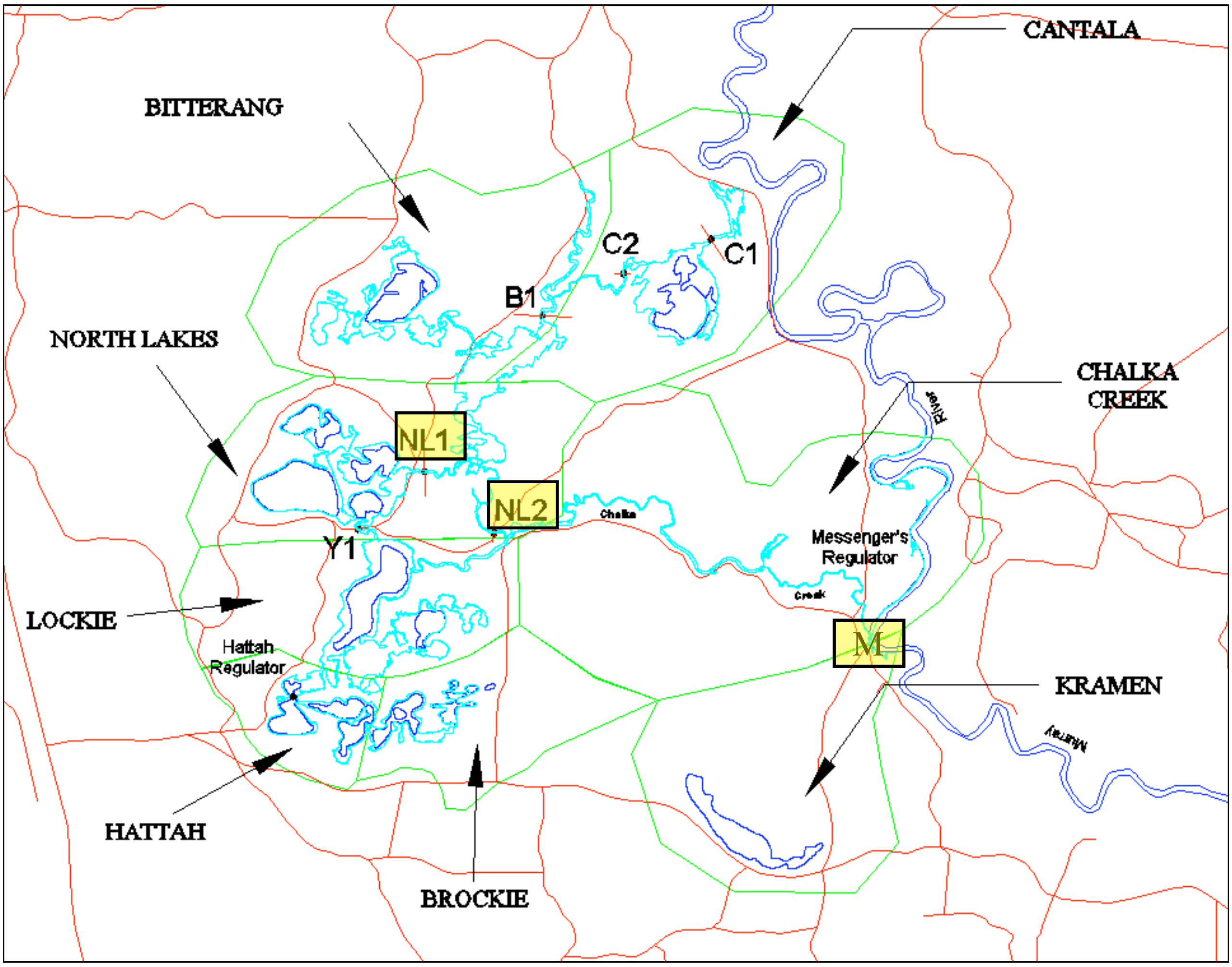


Figure 42. Approximate Location of Regulators within Wetland Regions. Option 2 regulators highlighted in yellow

The regulators would be operated to allow maximum inflow, either from Chalka Creek East or Chalka Creek North and would be closed to retain water to the maximum level possible.

At this stage it is not recommended that the level of Messengers Regulator is raised any further. The area inundated at 43.4 m AHD remains very large. Changes to the retention level might be considered in the light of the hydraulic modelling results.

This option would increase the benefits of the proposal to lower Chalka Creek, but would have little effect if Chalka Creek were not lowered. It is therefore recommended that this option would only be implemented in conjunction with lowering Chalka Creek.

Cost

The cost of the Regulators NL1 and NL2 is estimated to be $150,000 each for automated structures and $120,000 each for manually operated structures.

Additionally, this option requires the lowering of Chalka Creek which is costed at $220,000.

Effectiveness

The hydraulic model was run to evaluate the effects of this option. The model was run with Chalka Creek lowered, as described in Option 1. Regulators equivalent to NL1, NL2 and Messengers Regulator were operated to allow all inflow but to prevent outflow below the retention level (Scenario B SKM 2006b).

In comparison to Option 1, this option does not increase the maximum extent of inundation under normal circumstances (Figure 41). Option 2 controls the recession of water, but does not improve inflow any further. Therefore the spatial effects of this option were not illustrated by SKM (2006b).

Closing the proposed regulators on Mournpall Island marginally increases the persistence of flooding compared with the option of lowering Chalka Creek alone (Table 5). This option does not affect the number of inflow events, so the number of years when the lakes are more than half full is similar to Option 1. However the regulators detain water at greater depths by preventing outflows to Chalka Creek North. Therefore water persists in the area for longer and the lakes are more than half full for longer periods. All lakes in the Central, Northern and Southern areas are more than half full for more than 50% of the time with persistence exceeding 75% of the time in Lake Hattah.

Table 5. Effect of Lowering Chalka Creek and Operating New Mournpall Island Regulators on Persistence in Lakes

Lake	Threshold	Lower Chalka Creek (Scenario A) (% years when threshold exceeded, % time exceeded)	Mournpall Island Regulators (Scenario B) (% years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	84, 57	87, 67
Little Hattah	>50% full	74, 39	79, 52
Northern Lakes			
Mournpall	>50% full	76, 56	80, 64
Yelwell	>50% full	67, 47	75, 57
Southern Lakes			
Hattah	>50% full	85, 70	88, 76
Arawak	>50% full	76, 53	78, 63
Brockie	>50% full	76, 53	77, 63
Chalka Ck North			
Bitterang	>50% full	49, 30	49, 30

The regulators at Mournpall Island significantly increase floodplain inundation compared with current conditions. Floodplain inundation is reported for the 43 m AHD threshold at which there is significant spread of water from the lakes to the surrounding woodland vegetation (Table 6). This elevation is below the retention level of the regulators, but is indicative of the water regime on the floodplain immediately surrounding the wetlands. Under current conditions the median event duration is between 3 and 6.5 weeks in the central, northern and southern lakes, with events generally occurring in 30% of years. Closing the proposed regulators at Mournpall Island increases the duration of these events to approximately 20 weeks. Flooding of this duration and frequency is likely to achieve ecological objectives in Fringing Red Gum relating to tree health and recruitment, understorey vegetation composition, aquatic fauna and waterbird breeding and feeding and floodplain productivity. The frequency of events does not change.

This option has no effect on Lake Bitterang; closing the regulators does not reduce flooding in this area.

Table 6. Effects of Operation of Proposed Mournpall Island Regulators on Low Floodplain Inundation

Lake	Level Above Lake at 43 m AHD	Current (median duration, no. events in 92 years)	Mournpall Island Regulators (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	6.5 weeks, 44 times	17 weeks, 41 times
Little Hattah	full + 0.7 m	5.5 weeks, 32 times	20 weeks, 31 times
Northern Lakes			
Mournpall	full + 0.6 m	4 weeks, 28 times	22 weeks, 22 times
Yelwell	full + 0.7 m	5 weeks, 33 times	20.5 weeks, 30 times
Southern Lakes			
Hattah	full + 0.7 m	5.5 weeks, 32 times	20 weeks, 31 times
Arawak	full + 0.7 m	4 weeks, 31 times	20 weeks, 31 times
Brockie	full + 0.7 m	3.5 weeks, 24 times	21 weeks, 27 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

This option does not benefit the floodplain above the retention level of the regulator, as illustrated by the 43.5 m AHD threshold in the spells analysis results presented in Table 7. There is no significant increase in flood duration or frequency at this elevation (Table 7). These elevations are predominantly occupied by Red Gum with Flood Dependent Understorey and Black Box Woodland and do not benefit from the works.

Table 7. Effects of Operation of Proposed Mournpall Island Regulators on High Floodplain Inundation

Lake	Level Above Lake at 43.5 m AHD	Current (median duration, no. events in 92 years)	Scenario B (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 1.3 m	4 weeks, 33 times	5 weeks, 33 times
Little Hattah	full + 1.2 m	4 weeks, 28 times	4 weeks, 28 times
Northern Lakes			
Mournpall	full + 1.1 m	3.5 weeks, 26 times	4 weeks, 25 times
Yelwell	full + 1.2 m	4.5 weeks, 26 times	4 weeks, 28 times
Southern Lakes			
Hattah	full + 1.2 m	4 weeks, 28 times	4 weeks, 28 times
Arawak	full + 1.2 m	4.5 weeks, 26 times	4 weeks, 28 times
Brockie	full + 1.2 m	3.5 weeks, 22 times	4 weeks, 28 times
Chalka Ck North			
Bitterang	full + 1.0 m	5 weeks, 15 times	5 weeks, 15 times

The abruptness with which the effect of this option changes between 43.0 m AHD and 43.5 m AHD reflects the modelled retention level of the structures at 43.4 m AHD. The benefit could therefore be increased using structures with a higher retention level. This could be explored in a new run of the hydraulic model using structures with a retention level of 44.0 m AHD.

Risks

There is a risk that regulating structures will be damaged or destabilised during flood events. The structures should be designed to accommodate possible erosion risks during the design phase. The structures will be subject to significant stress if they are overtopped when closed. This risk will be reduced by appropriate operating rules and will be further reduced by armouring surfaces near the regulators. The regulators must also be designed to withstand pressures and impacts from large woody debris. A contingency should be included in the design to allow the regulator to be opened even if it is overtopped to some degree.

There is a risk that it would not be possible to access regulator NL2 during high water levels. This can be accommodated by designing NL1 to provide vehicle access to Mournpall Island and NL2.

The works present a significant risk of disturbance to features of Aboriginal cultural significance. This may include disturbance to significant trees and disturbance to artefacts. It would be necessary to identify matters of cultural significance in advance, to arrange works to minimise impacts and to monitor impacts during site works.

The works will marginally reduce the duration of flooding and flow in Chalka Creek North. This represents a minor ecological risk to the condition of the creek. However this impact is expected to be more than compensated by benefits to the floodplain elsewhere.

Flooding promoted by the works may reduce vehicle access to some parts of the system. This may present a minor social risk.

Implementation and Operation

This option requires that Messengers Regulator is closed as the level in Chalka Creek is below the retention level and falling, and that the regulator is re-opened when river levels exceed the level in Chalka Creek.

Additionally, it is necessary to close regulators NL1 and NL2 when the level in the area enclosed by the regulator is below the retention level and falling, and that the regulator is re-opened whenever levels in Chalka Creek north exceed the level in the enclosed area.

This option will involve significant disruption to Chalka Creek as described for Option 1.

In addition the construction of the regulators will involve excavation in the creek bed, the disposal of excavated material and the storage of equipment and materials on site. It may be necessary to remove native vegetation on the site and along tracks that provide access to the site.

It is expected that these benefits will justify the impacts associated with this option.

Matters of cultural significance affected by vehicle access, tree and vegetation removal, excavation and spoil disposal must be assessed.

Detailed design of this option will involve the tasks outlined for Option 1 plus investigations at the site of the regulators including:

- a desktop and field assessment of matters of cultural significance;
- a flora and fauna survey to report species matters of state and national conservation significance affected;
- an assessment of the degree to which the proposal will improve habitat elsewhere;
- a site inspection and detailed design to finalise the site of the works with regard to maximising hydraulic benefits and minimising impacts on habitat and matters of cultural significance;
- a vegetation impact report under Victoria's native vegetation management framework (DNRE 2002);
- a report to the Commonwealth Minister for the Environment under the EPBC Act.

6.3 Option 3 – Confine Flooding North of Lake Hattah

Objective

The objective of this option is to increase the depth of inundation that can be achieved in small floods or by emergency pumping by reducing/confining the spread of water to:

- Lakes Lockie;
- Little Hattah;
- Mournpall;
- Yelwell;
- Yerang;
- Konardin; and
- floodplain adjacent to Chalka Creek.

By confining water into a smaller area it would be possible to achieve a greater flood depth for a given event than under Option 2. Water would fill the smaller available area and spill more readily from the lakes to the surrounding floodplain. However, water would be excluded from Lake Hattah and lakes downstream unless the water level exceeded the retention level of the Little Hattah regulator.

The intended benefit is to increase the depth of flooding in these lakes and to increase the frequency and duration of flooding in the surrounding woodland areas.

Design

The decommissioned regulator situated between Lake Little Hattah and Lake Hattah would be refurbished to retain water up to 43.4 m AHD. Refurbishment of the existing Hattah regulator requires removal of the existing walkway above the structure and installation of three undershot gates capable of holding water on both sides of the structure.

Regulators at Messengers, NL1, NL2 and Little Hattah would be operated to maximise the depth of flooding achieved up to a level of 43.4 m AHD. The option would be effective for small and moderate floods. It would increase the duration of flooding in the enclosed area and would increase the frequency and duration of flooding in surrounding floodplain areas. This option would not apply if levels were expected to exceed, or actually exceeded, 43.4 m AHD. To prevent the regulators from being overtopped, the Little Hattah regulator would first be opened to flood lakes to the south, and then NL1 and NL2 regulators would be opened to release water to Chalka Creek north. Nor would the option apply if small floods of long duration were anticipated, if they were likely to distribute water as widely as short, high floods.

The regulators would be operated to achieve flooding of up to 3 months in floodplain areas. After that time, water from shedding floodplain would be released to the river and only water within lake basins would be retained. This would provide ecological benefit to the River Murray by contributing woody debris and other organic matter and invertebrates and small fish, some of which would contribute to regional populations and some of which would become prey for larger fauna.

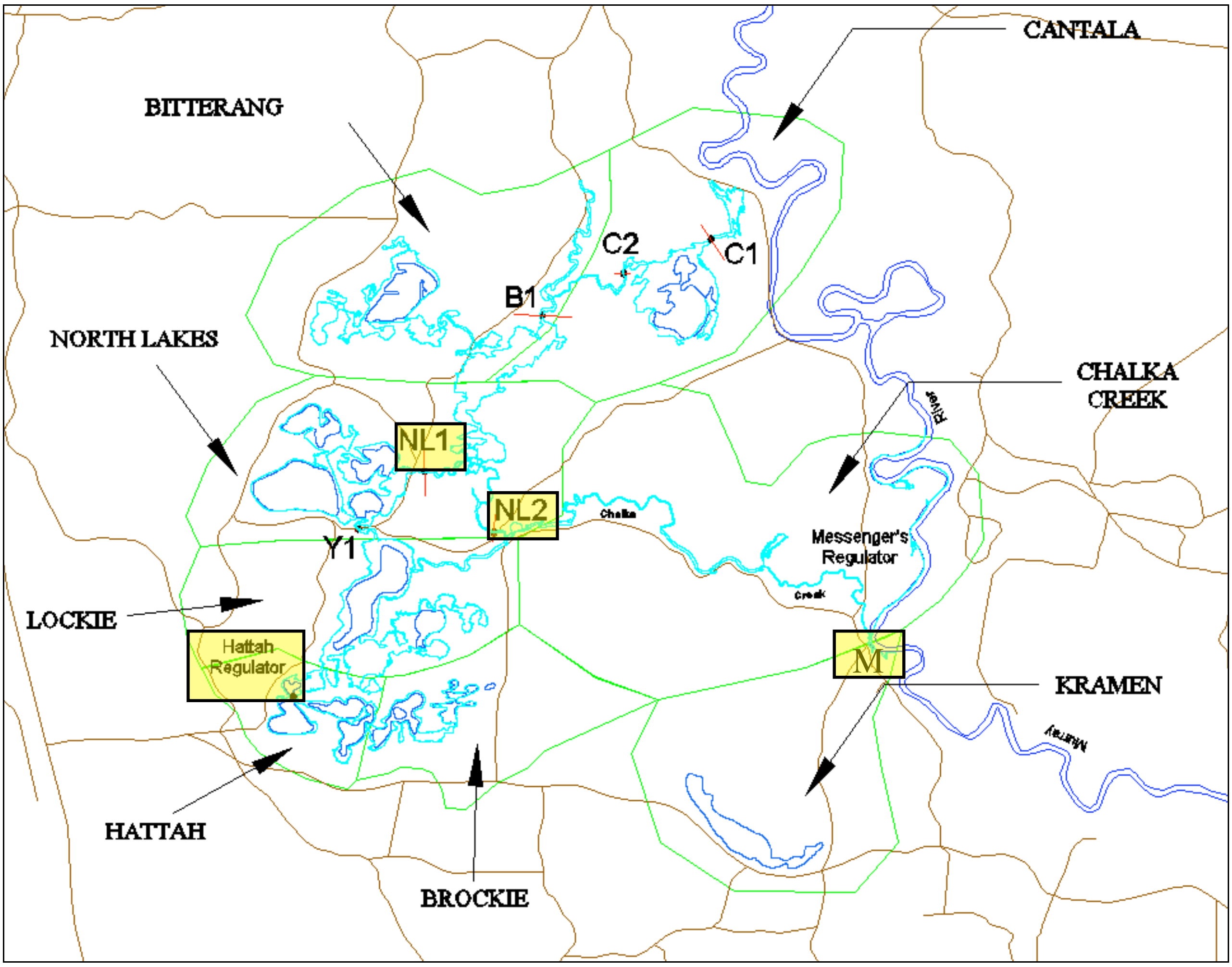


Figure 43. Approximate Location of Regulators within Wetland Regions. Option 3 regulators highlighted in yellow

Cost

The cost of refurbishment of the Little Hattah Regulator is estimated to be $85,000 however a cost of $150,000 would apply if an automated structure were installed.

In addition, this option involves the lowering of Chalka Creek ($220,000) and the construction of regulators NL1 and NL2, which are costed at $150,000 each for automated structures and $120,000 each for manually operated structures.

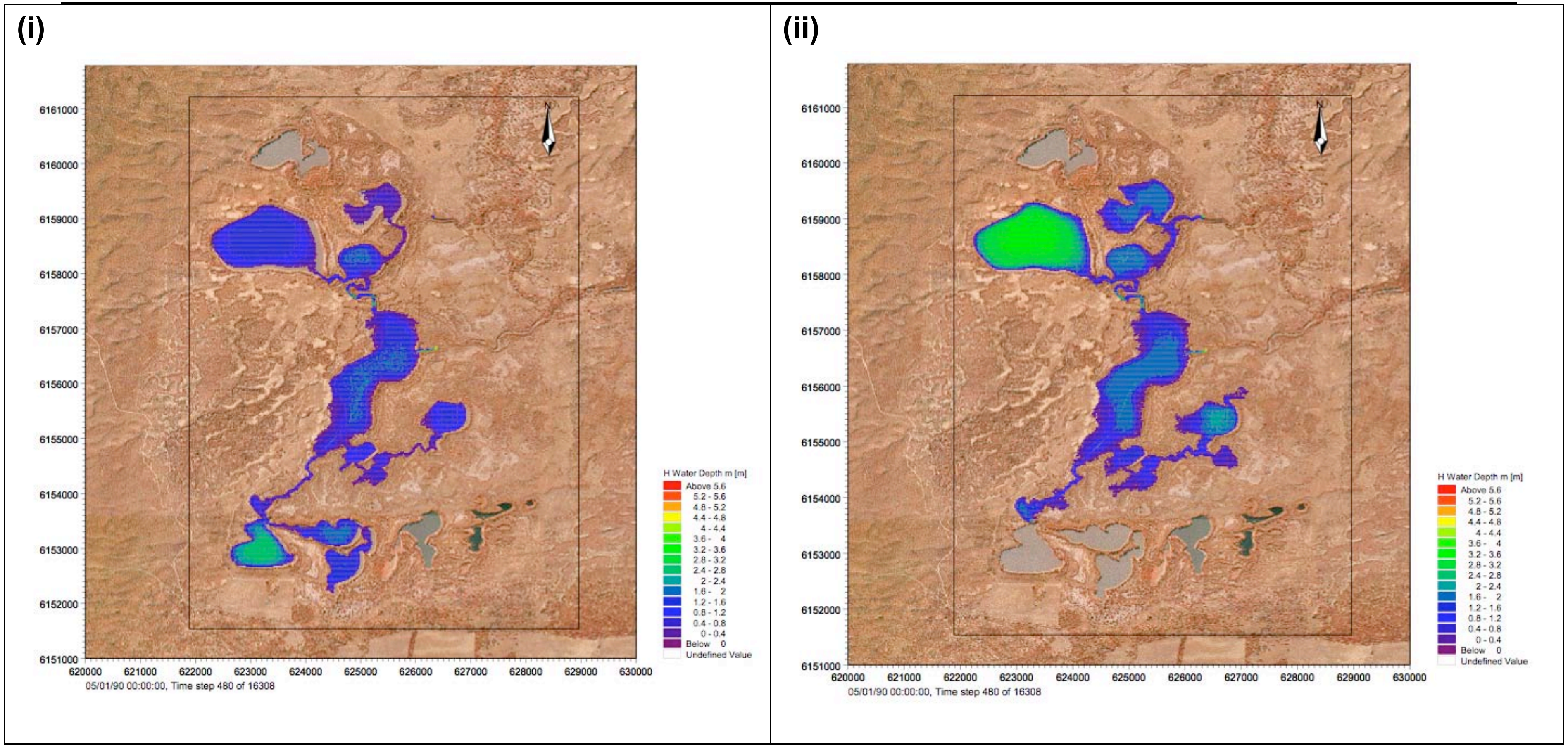


Figure 44. Maximum extent of inundation in 2000 flood event under current conditions (i) and under Option 3 (ii). Data from SKM (2006b)

Effectiveness

The hydraulic model was used to evaluate the effectiveness of this option. Due to the constraints of the model, the run did not completely replicate the required conditions. Instead, the Little Hattah regulator was permanently closed and allowed to overtop when levels exceeded 43.4 m AHD. Regulators NL1 and NL2 were operated as described for Option 2. The scenario was run with the Chalka Creek modifications as described in Option 1 (Scenario C SKM 2006b).

The effects of this option on the spread of water are illustrated by the maximum flood extent achieved in the 2000 event (Figure 44). This option increased the depth achieved in all lakes enclosed by the regulators, but particularly Lake Mournpall. Water also spilled more widely around Lake Roonki and Lake Yelwell. In this event, the regulators prevented the spread of water to Lakes Hattah, Bulla and Arawak.

This option is slightly more effective in promoting persistence in the central and northern lakes than Option 2 alone (Mournpall Island Regulators). Persistence is increased in Lake Mournpall but there is little change in the behaviour of the other lakes (Table 8).

This option reduces the persistence of flooding in the southern lakes: Hattah, Arawak and Brockie (Table 8). The time the lakes spend more than half full decreases from more than 60% in Scenario B to less than 50% in Scenario C with the most dramatic reduction in Lake Hattah. The number of years in which the lakes are more than half full is also reduced from more than 75% of years in Scenario B to less than 60% of years in Scenario C.

Table 8. Effect of Containing Water in Central and Northern Lakes on Persistence

Lake	Threshold	Mournpall Island Regulators (Scenario B) (% years when threshold exceeded, % time exceeded)	Confine Flooding North of Hattah (Scenario C) (% years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	87, 67	87, 67
Little Hattah	>50% full	79, 52	83, 62
Northern Lakes			
Mournpall	>50% full	80, 64	86, 73
Yelwell	>50% full	75, 57	75, 58
Southern Lakes			
Hattah	>50% full	88, 76	59, 48
Arawak	>50% full	78, 63	55, 44
Brockie	>50% full	77, 63	54, 43
Chalka Ck North			
Bitterang	>50% full	49, 30	49, 30

This option is more effective in promoting floodplain inundation around the central and northern lakes than the operation of the Mournpall Island regulators alone (Table 9). The duration of events is maintained but the frequency of events increases significantly to occur on more than 40 occasions, with the exception of Lake Mournpall where events occur on 30 occasions.

Closing the Little Hattah Regulator reduces the number of flooding events to the floodplain surrounding the southern lakes. Under Option 2 the lakes are significantly overtopped in approximately 33% of years. When the Little Hattah Regulator is closed this falls to less than 20% of years. The duration of events is not changed.

Table 9. Effects of Containing Water in the Central and Northern Lakes on Floodplain Inundation at 43 m AHD

Lake	Level Above Lake at 43 m AHD	Mournpall Island Regulators (median duration, no. events in 92 years)	Confine Flooding North of Hattah (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	17 weeks, 41 times	10 weeks, 45 times
Little Hattah	full + 0.7 m	20 weeks, 31 times	10 weeks, 45 times
Northern Lakes			
Mournpall	full + 0.6 m	22 weeks, 22 times	21 weeks, 31 times
Yelwell	full + 0.7 m	20.5 weeks, 30 times	17 weeks, 41 times
Southern Lakes			
Hattah	full + 0.7 m	20 weeks, 31 times	23 weeks, 18 times
Arawak	full + 0.7 m	20 weeks, 31 times	23 weeks, 18 times
Brockie	full + 0.7 m	21 weeks, 27 times	23 weeks, 18 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

An assessment of the effectiveness of this option must balance the advantages to the central and northern lakes with the disadvantages to the southern lakes. The main advantage is that the frequency of floodplain inundation increases to occur almost 50 times per 100 years in Scenario C compared with approximately 33 times per 100 years in Scenario B. The persistence of water in the lakes does not change dramatically (Table 8). The main disadvantage is that the frequency of floodplain inundation decreases in the southern lakes to much less than frequency under current conditions (Table 6) although the duration of events is longer.

When modelled, a strict rule was applied where flow was excluded by the regulator until it was overtopped. In reality, the regulator may be opened more frequently and the impact on lakes downstream of Hattah may be less than the model describes.

Risks

The risks associated with the Options 1 and 2 apply.

This option assumes that the benefit achieved by meeting ecological objectives in a small area of the system exceeds either:

- the impact of reducing flooding in lakes downstream of Lake Hattah; or
- the water regime achieved by Option 2 alone.

This risk would be assessed in the approval process under state and federal legislation as set out below.

It is possible that the exclusion of water from wetlands could be criticised by members of the public. This social risk could be managed by informing the public of the objectives of the strategy.

Implementation and Operation

This option requires the regulators at Messengers, NL1 and NL2 to be operated as described in Option 2.

It is necessary to refurbish the Little Hattah regulator to detain water up to 43.4 m AHD. This would not require significant additional disruption to the floodplain.

It is necessary to assess the magnitude and duration of anticipated flood peaks and to operate the Little Hattah regulator accordingly. The regulator would be closed for small or brief peaks but would be opened if flood peaks were larger than anticipated or if levels in the confined area exceed the Little Hattah regulator retention level. Operational guidelines could be developed for a range of floods, based on the 92 year model results for Scenario C.

This option significantly reduces the duration of flooding in wetlands downstream of Lake Hattah and it therefore affects ecological character of the Hattah Lakes Ramsar Site (Ecological Associates 2005). It potentially affects other matters of national environmental significance under the national Environment Protection and Biodiversity Conservation Act. A referral to the Commonwealth Minister for the Environment would be required comparing the impact to the anticipated benefit of enhanced flooding elsewhere.

By degrading the habitat for flood-dependent vegetation and fauna, the impact of this option must also be assessed under Victoria's Native Vegetation Framework (DNRE 2002). The nature of the impact and the extent of the impacted area must be assessed in comparison to the anticipated benefit elsewhere.

Detailed design of this option would include the tasks set out in Options 1 and 2.

6.4 Option 4 – Confine Flooding South of Lake Yerang

Objective

The objective of this option is to increase the depth of inundation that can be achieved in small floods or by emergency pumping by confining the spread of water to:

- Lakes Lockie;
- Little Hattah;
- Hattah;
- Bulla;
- Arawak;
- Maramook
- Brockie;
- Boich;
- Tullamook;
- Nip Nip; and
- floodplain adjacent to Chalka Creek.

By confining water into a smaller area it would be possible to achieve a greater flood depth for a given event and to force water to spill to the surrounding floodplain. However, water would be excluded from Lakes Yerang, Mournpall and Yelwell unless the water level exceeded the retention level of the new Lake Yerang regulator or very prolonged floods were anticipated.

Lake Konardin is downstream of the Yelwell Regulator, but is only filled by large flows which are beyond the scope of this option.

The intended benefit is to increase the depth of flooding in these lakes and to increase the frequency and duration of flooding in the surrounding woodland areas.

Design

A new regulator would be required between Lake Yerang and Lake Lockie with a retention level of 43.4 m AHD at location Y1 (Figure 45).

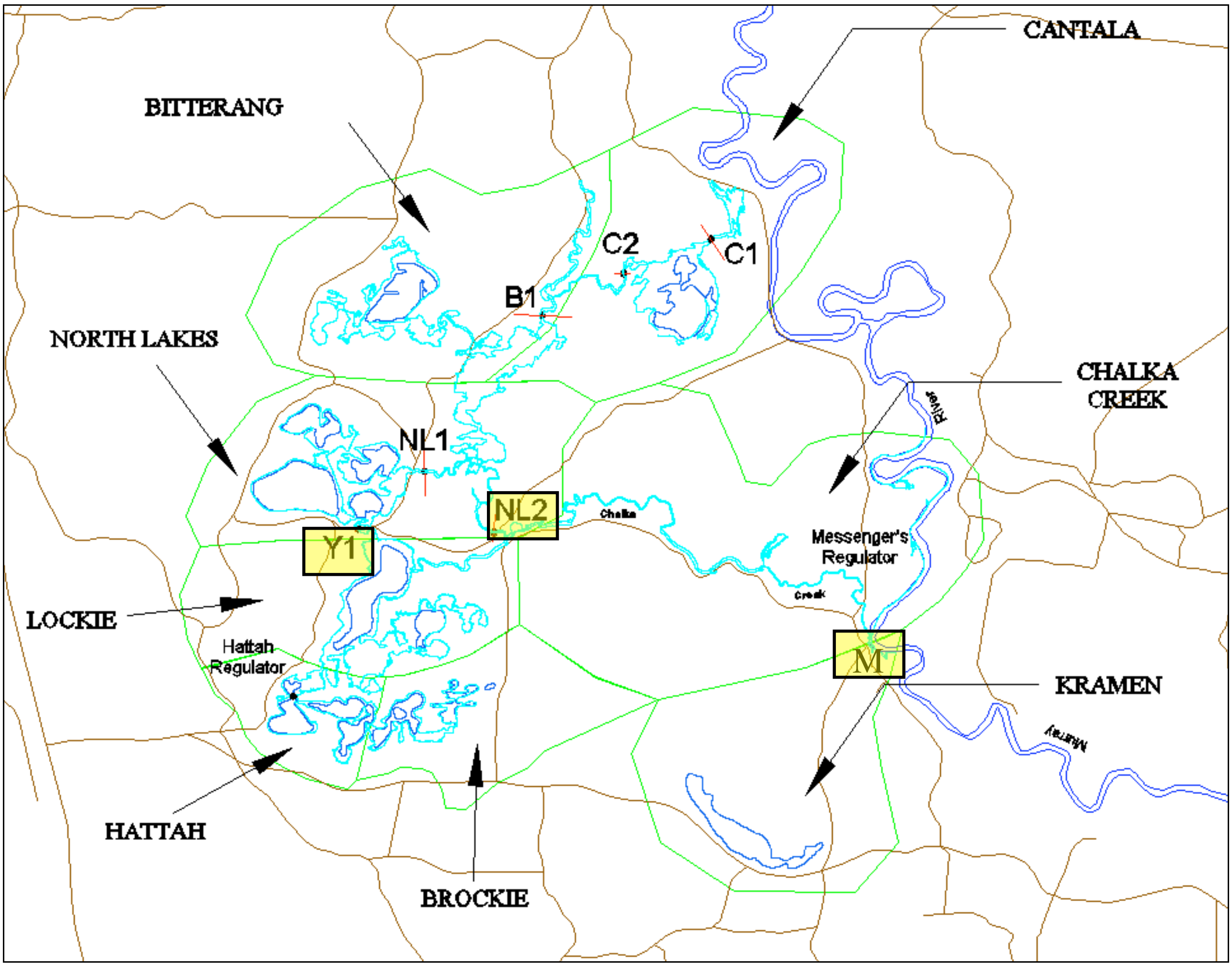


Figure 45. Approximate Location of Regulators within Wetland Regions. Option 3 regulators highlighted in yellow

Regulators at Y1, NL2 and Messengers would be operated to maximise the depth of flooding achieved up to a level of 43.4 m AHD. The option would be effective for small and moderate floods. It would increase the duration of flooding in the enclosed area and would increase the frequency and duration of flooding in surrounding floodplain areas. This option would not apply if levels were expected to exceed, or actually exceeded, 43.4 m AHD. To prevent the regulators from being overtopped, the Yerang regulator would first be opened to flood lakes to the north, and then NL2 regulator would be opened to release water to Chalka Creek north. Nor would the option apply if small floods of long duration were anticipated, if they were likely to distribute water as widely as short, high floods.

The regulators would be operated to achieve flooding of up to 3 months in floodplain areas. After that time, water from shedding floodplain would be released to the river and only water within lake basins would be retained.

Works necessary to raise the level to which water can be retained on the floodplain to 43.4 m AHD include construction of Regulator Y1 and NL2 on Chalka Creek North.

Regulator Y1 would be constructed between Lake Lockie and Lake Yelwell. At this location (see Figure 42) the channel is approximately 35 m wide with a bed level of approximately 40.8 m AHD. Regulator NL2 would be constructed as described above for Option 2. A one gated structure is considered sufficient to match the capacity of the channel.

Costs

The cost of the new regulator Y1 is estimated to be $150,000 for an automated structure and $120,000 for a manually operated structure. The regulator would be located at 624823, 6159629 (GDA 1994 MGA Zone 54) where the channel is narrow and an effective structure can be built economically.

In addition, this option involves the lowering of Chalka Creek ($220,000) and the construction of Regulator NL2 which is costed at $150,000 for an automated structure and $120,000 for a manually operated structure.

Effectiveness

The hydraulic model was used to evaluate the effectiveness of this option. Due to the constraints of the model, the run did not completely replicate the required conditions. Instead, the Yerang regulator was permanently closed and allowed to overtop when levels exceeded 43.4 m AHD. Regulator NL2 was operated as described for Option 2. The scenario was run with the Chalka Creek modifications as described in Option 1 (SKM 2006b).

Effectiveness

The hydraulic model was used to evaluate the effectiveness of this option. Due to the constraints of the model, the run did not completely replicate the required conditions. Instead, the Little Hattah regulator was permanently closed and allowed to overtop when levels exceeded 43.4 m AHD. Regulators NL1 and NL2 were operated as described for Option 2. The scenario was run with the Chalka Creek modifications as described in Option 1 (Scenario C SKM 2006b).

The effects of this option on the spread of water are illustrated by the maximum flood extent achieved in the 2000 event (Figure 44). This option increased the depth achieved in all lakes enclosed by the regulators, but particularly Lake Mournpall. Water also spilled more widely around Lake Roonki and Lake Yelwell. In this event, the regulators prevented the spread of water to Lakes Hattah, Bulla and Arawak.

This option is slightly more effective in promoting persistence in the central and northern lakes than Option 2 alone (Mournpall Island Regulators). Persistence is increased in Lake Mournpall but there is little change in the behaviour of the other lakes (Table 8).

This option reduces the persistence of flooding in the southern lakes: Hattah, Arawak and Brockie (Table 8). The time the lakes spend more than half full decreases from more than 60% in Scenario B to less than 50% in Scenario C with the most dramatic reduction in Lake Hattah. The number of years in which the lakes are more than half full is also reduced from more than 75% of years in Scenario B to less than 60% of years in Scenario C.

Table 8. Effect of Containing Water in Central and Northern Lakes on Persistence

Lake	Threshold	Mournpall Island Regulators (Scenario B) (% years when threshold exceeded, % time exceeded)	Confine Flooding North of Hattah (Scenario C) (% years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	87, 67	87, 67
Little Hattah	>50% full	79, 52	83, 62
Northern Lakes			
Mournpall	>50% full	80, 64	86, 73
Yelwell	>50% full	75, 57	75, 58
Southern Lakes			
Hattah	>50% full	88, 76	59, 48
Arawak	>50% full	78, 63	55, 44
Brockie	>50% full	77, 63	54, 43
Chalka Ck North			
Bitterang	>50% full	49, 30	49, 30

This option is more effective in promoting floodplain inundation around the central and northern lakes than the operation of the Mournpall Island regulators alone (Table 9). The duration of events is maintained but the frequency of events increases significantly to occur on more than 40 occasions, with the exception of Lake Mournpall where events occur on 30 occasions.

Closing the Little Hattah Regulator reduces the number of flooding events to the floodplain surrounding the southern lakes. Under Option 2 the lakes are significantly overtopped in approximately 33% of years. When the Little Hattah Regulator is closed this falls to less than 20% of years. The duration of events is not changed.

Table 9. Effects of Containing Water in the Central and Northern Lakes on Floodplain Inundation at 43 m AHD

Lake	Level Above Lake at 43 m AHD	Mournpall Island Regulators (median duration, no. events in 92 years)	Confine Flooding North of Hattah (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	17 weeks, 41 times	10 weeks, 45 times
Little Hattah	full + 0.7 m	20 weeks, 31 times	10 weeks, 45 times
Northern Lakes			
Mournpall	full + 0.6 m	22 weeks, 22 times	21 weeks, 31 times
Yelwell	full + 0.7 m	20.5 weeks, 30 times	17 weeks, 41 times
Southern Lakes			
Hattah	full + 0.7 m	20 weeks, 31 times	23 weeks, 18 times
Arawak	full + 0.7 m	20 weeks, 31 times	23 weeks, 18 times
Brockie	full + 0.7 m	21 weeks, 27 times	23 weeks, 18 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

An assessment of the effectiveness of this option must balance the advantages to the central and northern lakes with the disadvantages to the southern lakes. The main advantage is that the frequency of floodplain inundation increases to occur almost 50 times per 100 years in Scenario C compared with approximately 33 times per 100 years in Scenario B. The persistence of water in the lakes does not change dramatically (Table 8). The main disadvantage is that the frequency of floodplain inundation decreases in the southern lakes to much less than frequency under current conditions (Table 6) although the duration of events is longer.

When modelled, a strict rule was applied where flow was excluded by the regulator until it was overtopped. In reality, the regulator may be opened more frequently and the impact on lakes downstream of Hattah may be less than the model describes.

Risks

The risks associated with the Options 1 and 2 apply.

This option assumes that the benefit achieved by meeting ecological objectives in a small area of the system exceeds either:

- the impact of reducing flooding in lakes downstream of Lake Hattah; or
- the water regime achieved by Option 2 alone.

This risk would be assessed in the approval process under state and federal legislation as set out below.

It is possible that the exclusion of water from wetlands could be criticised by members of the public. This social risk could be managed by informing the public of the objectives of the strategy.

Implementation and Operation

This option requires the regulators at Messengers, NL1 and NL2 to be operated as described in Option 2.

It is necessary to refurbish the Little Hattah regulator to detain water up to 43.4 m AHD. This would not require significant additional disruption to the floodplain.

It is necessary to assess the magnitude and duration of anticipated flood peaks and to operate the Little Hattah regulator accordingly. The regulator would be closed for small or brief peaks but would be opened if flood peaks were larger than anticipated or if levels in the confined area exceed the Little Hattah regulator retention level. Operational guidelines could be developed for a range of floods, based on the 92 year model results for Scenario C.

This option significantly reduces the duration of flooding in wetlands downstream of Lake Hattah and it therefore affects ecological character of the Hattah Lakes Ramsar Site (Ecological Associates 2005). It potentially affects other matters of national environmental significance under the national Environment Protection and Biodiversity Conservation Act. A referral to the Commonwealth Minister for the Environment would be required comparing the impact to the anticipated benefit of enhanced flooding elsewhere.

By degrading the habitat for flood-dependent vegetation and fauna, the impact of this option must also be assessed under Victoria's Native Vegetation Framework (DNRE 2002). The nature of the impact and the extent of the impacted area must be assessed in comparison to the anticipated benefit elsewhere.

Detailed design of this option would include the tasks set out in Options 1 and 2.

6.4 Option 4 – Confine Flooding South of Lake Yerang

Objective

The objective of this option is to increase the depth of inundation that can be achieved in small floods or by emergency pumping by confining the spread of water to:

- Lakes Lockie;
- Little Hattah;
- Hattah;
- Bulla;
- Arawak;
- Maramook
- Brockie;
- Boich;
- Tullamook;
- Nip Nip; and
- floodplain adjacent to Chalka Creek.

By confining water into a smaller area it would be possible to achieve a greater flood depth for a given event and to force water to spill to the surrounding floodplain. However, water would be excluded from Lakes Yerang, Mournpall and Yelwell unless the water level exceeded the retention level of the new Lake Yerang regulator or very prolonged floods were anticipated.

Lake Konardin is downstream of the Yelwell Regulator, but is only filled by large flows which are beyond the scope of this option.

The intended benefit is to increase the depth of flooding in these lakes and to increase the frequency and duration of flooding in the surrounding woodland areas.

Design

A new regulator would be required between Lake Yerang and Lake Lockie with a retention level of 43.4 m AHD at location Y1 (Figure 45).

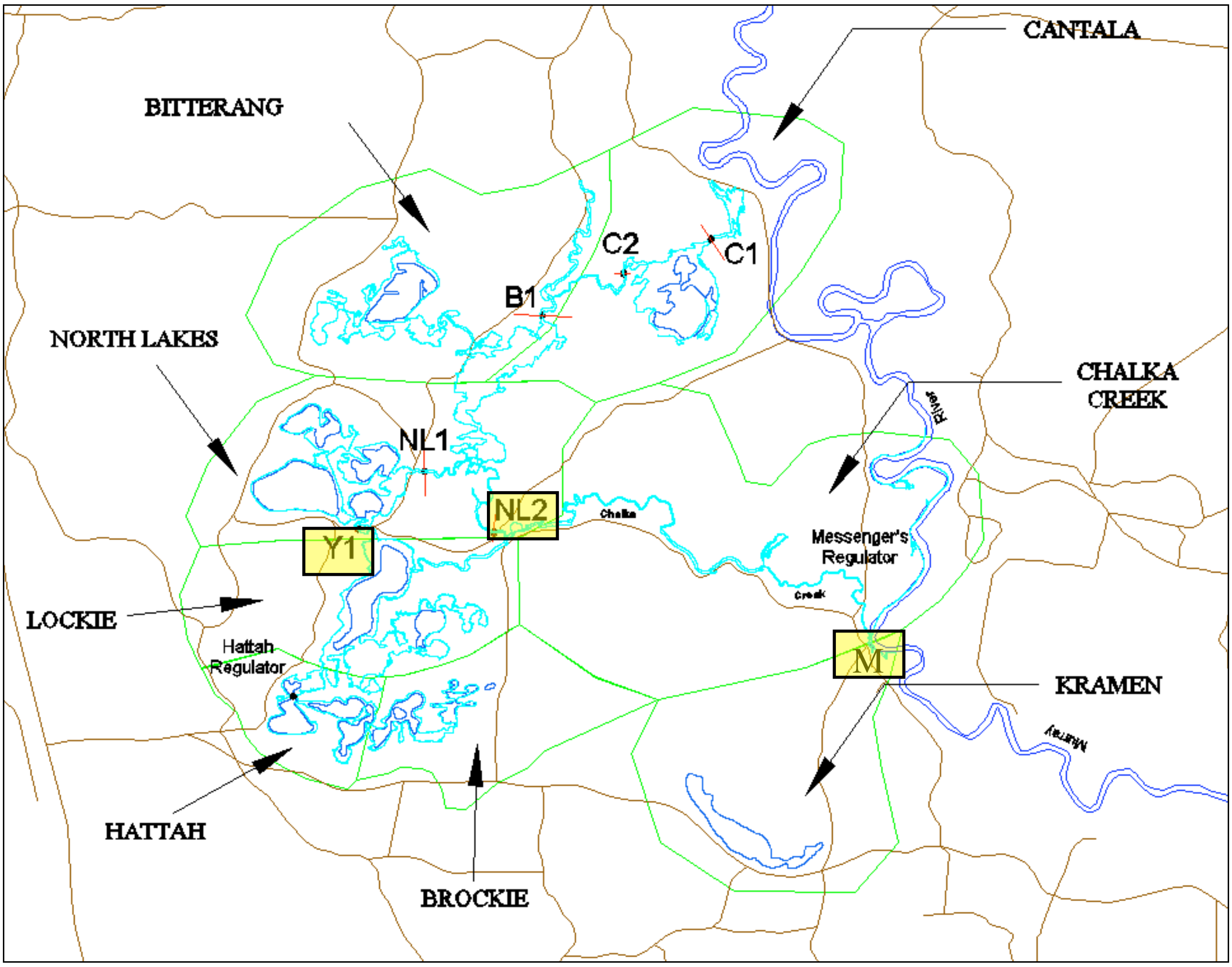


Figure 45. Approximate Location of Regulators within Wetland Regions. Option 3 regulators highlighted in yellow

Regulators at Y1, NL2 and Messengers would be operated to maximise the depth of flooding achieved up to a level of 43.4 m AHD. The option would be effective for small and moderate floods. It would increase the duration of flooding in the enclosed area and would increase the frequency and duration of flooding in surrounding floodplain areas. This option would not apply if levels were expected to exceed, or actually exceeded, 43.4 m AHD. To prevent the regulators from being overtopped, the Yerang regulator would first be opened to flood lakes to the north, and then NL2 regulator would be opened to release water to Chalka Creek north. Nor would the option apply if small floods of long duration were anticipated, if they were likely to distribute water as widely as short, high floods.

The regulators would be operated to achieve flooding of up to 3 months in floodplain areas. After that time, water from shedding floodplain would be released to the river and only water within lake basins would be retained.

Works necessary to raise the level to which water can be retained on the floodplain to 43.4 m AHD include construction of Regulator Y1 and NL2 on Chalka Creek North.

Regulator Y1 would be constructed between Lake Lockie and Lake Yelwell. At this location (see Figure 42) the channel is approximately 35 m wide with a bed level of approximately 40.8 m AHD. Regulator NL2 would be constructed as described above for Option 2. A one gated structure is considered sufficient to match the capacity of the channel.

Costs

The cost of the new regulator Y1 is estimated to be $150,000 for an automated structure and $120,000 for a manually operated structure. The regulator would be located at 624823, 6159629 (GDA 1994 MGA Zone 54) where the channel is narrow and an effective structure can be built economically.

In addition, this option involves the lowering of Chalka Creek ($220,000) and the construction of Regulator NL2 which is costed at $150,000 for an automated structure and $120,000 for a manually operated structure.

Effectiveness

The hydraulic model was used to evaluate the effectiveness of this option. Due to the constraints of the model, the run did not completely replicate the required conditions. Instead, the Yerang regulator was permanently closed and allowed to overtop when levels exceeded 43.4 m AHD. Regulator NL2 was operated as described for Option 2. The scenario was run with the Chalka Creek modifications as described in Option 1 (SKM 2006b).

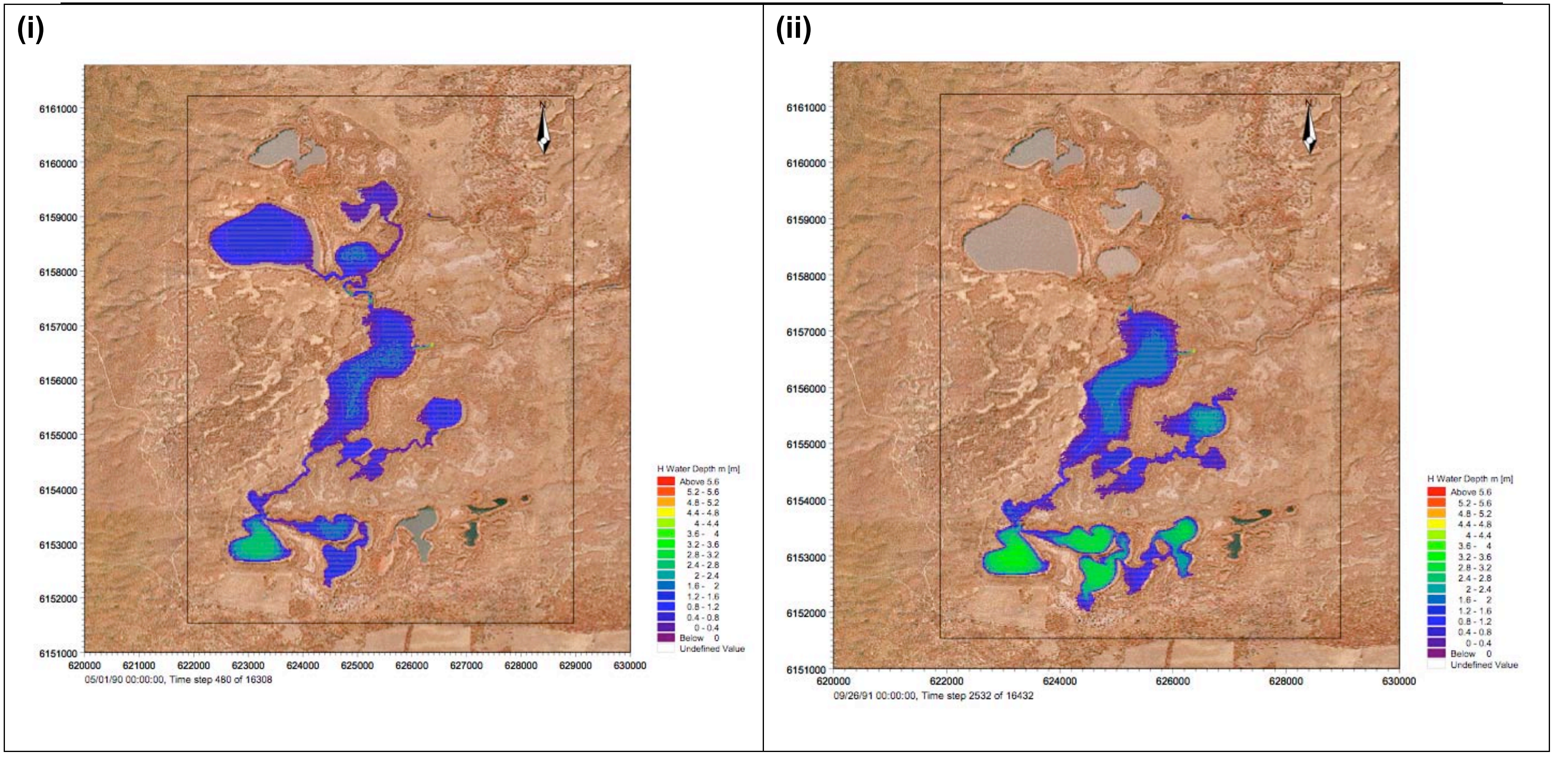


Figure 46. Maximum extent of inundation in 2000 flood event under current conditions (i) and under Option 4 (ii). Data from SKM (2006b)

Effectiveness

The effect of this option on the spread of water is illustrated by the model output presented for the maximum spread of water in the 2000 event (Figure 46). In this event, water was excluded from Lakes Mournpall, Yerang and Yelwell. Water spread further in the south to Lakes Marramook and Brockie and more widely around Lake Roonki. A greater depth was achieved in all lakes, but particularly in Lakes Hattah, Bulla and Arawak.

Excluding water from the northern lakes marginally increases the persistence of flooding in the central and southern lakes (Table 10). There is a minor increase in the time the water levels exceed 50% full. The number of years when the lakes exceed this level also increases to a small degree. There is a significant reduction in the persistence of flooding in Lakes Mournpall and Yelwell, where water is excluded.

Table 10. Effect of Containing Water in Central and Southern Lakes on Persistence

Lake	Threshold	Mournpall Island Regulators (% years when threshold exceeded, % time exceeded)	Confine Flooding South of Yerang (% years when threshold exceeded, % time exceeded)
Central Lakes			
Lockie	>50% full	87, 67	88, 69
Little Hattah	>50% full	79, 52	82, 61
Northern Lakes			
Mournpall	>50% full	80, 64	59, 47
Yelwell	>50% full	75, 57	52, 38
Southern Lakes			
Hattah	>50% full	88, 76	89, 80
Arawak	>50% full	78, 63	82, 68
Brockie	>50% full	77, 63	80, 68
Chalka Ck North			
Bitterang	>50% full	49, 30	49, 30

Excluding water from the northern lakes promotes inundation of the floodplain around the central and southern lakes (Table 11). The number of events that exceed 43 m AHD around Lakes Hattah, Arawak and Brockie increases from approximately 30 to 38 over the modelled period. The median duration of events also increases slightly. There is a similar change around the central lakes.

The frequency and duration of inundation around the northern lakes is less than under Option 2. There is a minor change around Lake Mournpall but a more dramatic reduction near Lake Yelwell where the number of events decreases from 30 in Option 2 (Mournpall Island Regulators) to 18. However the frequency and duration of inundation in the northern lakes still exceeds current conditions.

This option has no effect on Lake Bitterang.

Table 11. Effects of Containing Water in the Central and Southern Lakes on Floodplain Inundation at 43 m AHD

Lake	Level Above Lake at 43 m AHD	Mournpall Island Regulators (median duration, no. events in 92 years)	Confine Flooding South of Yerang (median duration, no. events in 92 years)
Central Lakes			
Lockie	full + 0.8 m	17 weeks, 41 times	21 weeks, 45 times
Little Hattah	full + 0.7 m	20 weeks, 31 times	21.5 weeks, 38 times
Northern Lakes			
Mournpall	full + 0.6 m	22 weeks, 22 times	23 weeks, 18 times
Yelwell	full + 0.7 m	20.5 weeks, 30 times	23 weeks, 18 times
Southern Lakes			
Hattah	full + 0.7 m	20 weeks, 31 times	21.5 weeks, 38 times
Arawak	full + 0.7 m	20 weeks, 31 times	21.5 weeks, 38 times
Brockie	full + 0.7 m	21 weeks, 27 times	21.5 weeks, 38 times
Chalka Ck North			
Bitterang	full + 0.5 m	4 weeks, 19 times	4 weeks, 19 times

An assessment of the effectiveness of this option must balance the advantages to the central and southern lakes with the disadvantages to the northern lakes. The main advantage is that the frequency of floodplain inundation around the central and southern lakes increases to occur more than 40 times per 100 years in Scenario D compared with approximately 33 times per 100 years in Scenario B. The water regime within the lakes does not change dramatically. The main disadvantage is that the frequency of floodplain inundation decreases in the southern lakes to much less than under current conditions (Table 6) although the duration of events is significantly longer than under current conditions.

The model was configured to prohibit flow past the regulator until it was overtopped. In reality, a regulator might be operated to allow flows at other times, so that water would not be excluded as frequently as the model reports.

Risks

The risks associated with Options 1 and 2 apply.

This option assumes that the benefit achieved by meeting ecological objectives in a small area of the system exceeds either:

- the impact of reducing flooding in Lakes Yerang, Mournpall and Yelwell; or
- the water regime achieved by Option 2 alone.

This risk would be assessed in the approval process under state and federal legislation.

It is possible that the exclusion of water from wetlands could be criticised by members of the public. This social risk could be managed by informing the public of the objectives of the strategy.

Implementation and Operation

This option requires that regulators at Messengers NL2 are operated as described in Option 2.

It is necessary to assess the magnitude and duration of anticipated flood peaks and to operate the Y1 regulator accordingly. The regulator would be closed for small or brief peaks but would be opened if flood peaks were larger than anticipated or if levels in the confined area exceed the Y1 regulator retention level. Operational guidelines could be developed for a range of floods, based on the 92 year model results for Scenario C.

Additionally, it is necessary to close regulator Y1 when the level in the area influenced by the regulator is below the retention level and falling, and that the regulator is re-opened whenever levels in Chalka Creek North exceed the level in the enclosed area.

Detailed design of this option would include the tasks set out in Options 1 and 2 plus an environmental and cultural assessment of works at Site Y1.

6.5 Option 5 – Confine Flooding in Lakes Lockie and Little Hattah

Objective

The objective is to increase the depth of inundation that can be achieved in small floods or by emergency pumping by confining the spread of water to Lakes Lockie, Roonki and Little Hattah.

Design

This option would require the construction of the previously described regulators Y1 and NL2, the refurbishment of the Little Hattah regulator and lowering of Chalka Creek. The structures would be operated to allow all inflow and to prevent outflows below 43.4 m AHD.

The option would be effective for small and moderate floods. It would increase the duration of flooding in the enclosed area and would increase the frequency and duration of flooding in surrounding floodplain areas. This option would not apply if levels were expected to exceed, or actually exceeded, 43.4 m AHD. To prevent the regulators from being overtopped they would be opened to release water to other lakes. Nor would the option apply if small floods of long duration were anticipated, if they were likely to distribute water as widely as short, high floods.

The regulators would be operated to achieve flooding of up to 3 months in floodplain areas. After that time, water from shedding floodplain would be released to the river and only water within lake basins would be retained.

Cost

The cost of this option would include refurbishment of the Little Hattah Regulator which is costed at $85,000, however a cost of $150,000 would apply if an automated structure were installed. The cost of the new regulator Y1 is estimated to be $150,000 for an automated structure and $120,000 for a manually operated structure.

In addition, this option involves the lowering of Chalka Creek ($220,000) and the construction of the NL2 regulator, which is costed at $150,000 for an automated structure and $120,000 for a manually operated structure.

Effectiveness

This option was not modelled.

The modelling for Options 3 and 4 provide an indication of the likely effect of this option on flooding persistence. This is not likely to increase the persistence of flooding in Lakes Little Hattah, Lockie and Roonki but is likely to increase the frequency and duration of inundation in the surrounding floodplain.

The additional inundation of the floodplain under Options 2 and under Options 3 and 4 indicate the likely additional effects of this option. Option 2 significantly increases the frequency and duration of floodplain inundation. The additional effect of Options 3 and 4 is to increase duration but not frequency because frequency becomes limited by the number of large inflow events from the River Murray. Further confining water in the cental lakes area in this Option 5 is therefore likely to marginally increase event duration but is unlikely to affect event frequency.

This option is most likely to have more severe impacts than Option 3 or 4 by excluding flooding from a larger area and less benefits by promoting flooding in a smaller area. It is not considered further.

6.6 Option 6 - Lower and Regulate Cantala Creek

Objective

The objective is to increase the frequency, duration and rate of inflows to the system by lowering the bed level of Cantala Creek and to retain flood water in the lake with a regulator.

The intended benefits are:

- prolong flooded and flowing conditions in Cantala Creek; and
- increase flood frequency and duration in Lake Cantala and the surrounding floodplain.

Design

Lake Cantala receives inflow from the River Murray via Cantala Creek. A review of the LIDAR has shown that the bed level of Lower Cantala Creek is generally uniform, with an invert level of approximately 42 m whereas the bed of the wetland lies at 40.16 m AHD. Inflow to the lake could be achieved at lower River Murray flows and therefore more frequently and for longer periods by lowering the bed of the creek closer to the bed of the wetland. It is proposed to lower Cantala Creek from 42 m to 41 m. These works would require excavating in excess of 2 km of creek bed. Snags and other habitat features could be restored to some extent in the lowered creek bed.

Water could be retained in Lake Cantala by regulating Cantala Creek and the channel between the lake and Chalka Creek North. Sites C1 and C2 have been identified as suitable sites where retention levels up to 43.4 m AHD can be achieved. At this level all of Lake Cantala is inundated, as is a significant area of the surrounding floodplain.

Further inspection of channel dimensions and bed level at C2 may reveal that a regulating structure may not be necessary. The Lidar indicates that the current bed level at this location is approximately 43.1 m, only 300 mm less than the desired 43.4 m retention level. If the Lidar is accurate, only one regulator (C1) would be required to retain water to 43.1m.

The regulators (C1 and C2) would be opened on a rising water level. They would be closed when water levels are below the obvert of the regulator and falling.

The approximate location of the works are provided in Figure 47.

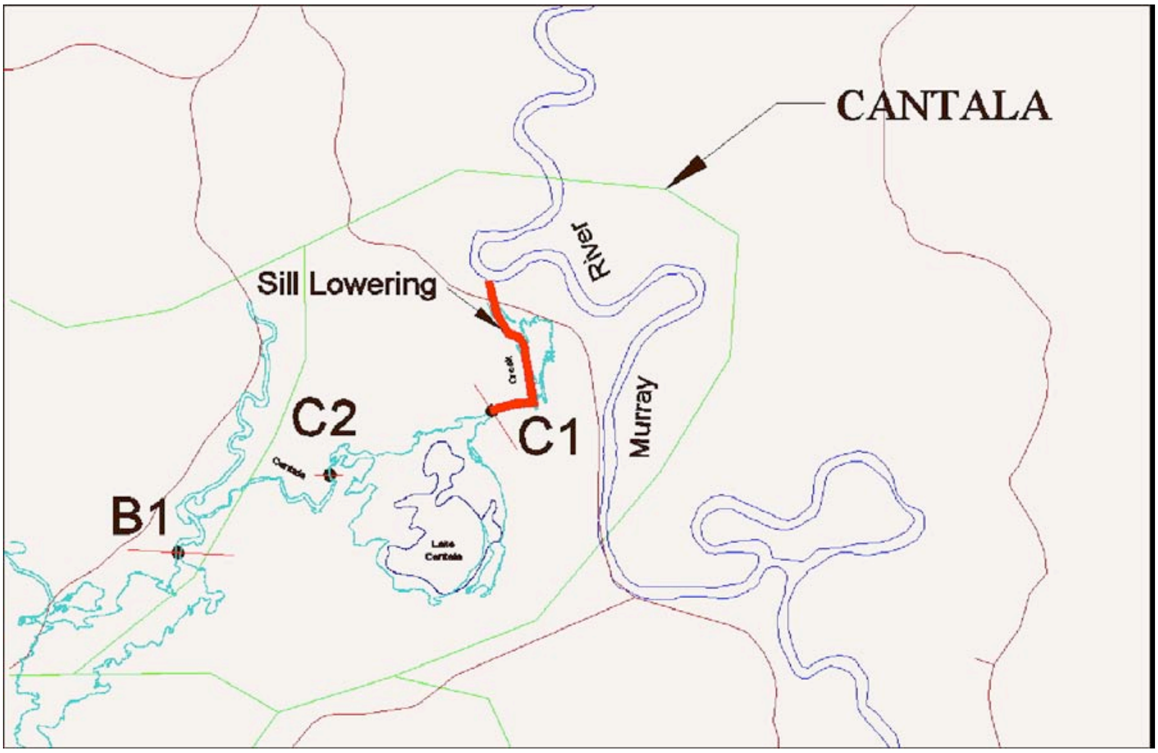


Figure 47. Approximate location of proposed works on Cantala Creek

Costs

The estimated cost to lower Cantala Creek is $310,000 based on a rate of $130/m over 2350 m. A further assessment of the costs and risks should be undertaken at a later stage and must take into account issues related to the working conditions and environmental constraints at Cantala Creek.

Ongoing monitoring and reporting of Cantala Creek conditions should be included in this option to regularly check the creek invert for blockage by snags and build up of sediment. This could be done by a combination of visual inspection and checking of creek levels using GPS and could cost approximately $10,000 per report. This monitoring may identify the need for periodic clean out, the cost of which has not been estimated.

Regulator C1 would be constructed on Cantala Creek north-east of Lake Cantala. At this location (Figure 47) the channel is approximately 70 m wide with a bed level of approximately 40.3 m AHD. A structure with two gates is proposed and is estimated to cost $150,000. The coordinates of the location are 633384, 6164645 (GDA 1994 MGA Zone 54).

Effectiveness

The hydraulic model was run to evaluate the effectiveness of this option. The model was run with Cantala Creek lowered (Scenario A SKM 2006) and again with regulators in place to prevent outflows below the retention level of 43.4 m AHD (Scenario B SKM 2006b).

Lowering Cantala Creek introduces water to the lake more frequently and increases the persistence of flooding. The lake is more than 50% full 29% of the time under current conditions but more than 36% of the time if the creek is lowered (Table 12). The number of years in which the lake exceeds this threshold also increases.

Lowering Cantala Creek does not affect floodplain inundation (Table 13).

The proposed regulator further increases the persistence of water in the lake above lowering the creek alone. The lake exceeds 50% full for 56% of the time and in 78% of years (Table 12). However the greatest effect of the regulator is to significantly promote floodplain inundation (Table 13). The median duration of events increases by 5 times to 22 weeks, with events occurring 21 times in the modelled run.

Table 12. Effects of Lake Cantala Options on Persistence of Flooding

Lake	Threshold	Current (% years when threshold exceeded, % time exceeded)	Lower Cantala Creek (% years when threshold exceeded, % time exceeded)	Lake Cantala Regulators (% years when threshold exceeded, % time exceeded)
Cantala	>50% full	53, 29	71, 36	78, 56

Table 13. Effects of Lake Cantala Options on Floodplain Inundation

Lake	Level Above Lake at 43 m AHD	Current (median duration, no. events in 92 years)	Lower Cantala Creek (median duration, no. events in 92 years)	Lake Cantala Regulators (median duration, no. events in 92 years)
Cantala	full + 0.6 m	4 weeks, 26 times	3.5 weeks, 28 times	22 weeks, 21 times

Risks

The risks identified in Option 1 apply here.

Implementation and Operation

This option will involve significant disruption to Cantala Creek. The creek level will be lowered by up to 1 m over a distance of over 2000 m and excavated to a width equivalent to the capacity of the creek elsewhere. This will require the removal of large Red Gum trees with significant habitat value, the removal of small Red Gum, Eumong, Lignum and other shrub and understorey vegetation, the loss of in-stream habitat features such as large woody debris, overhanging banks and vegetation and deep pools. It may be possible to design the works to re-incorporate some of these features (e.g. large woody debris and snags) in the modified channel. It may also be possible to align the excavations to minimise impacts on trees or features of high conservation significance.

The construction of the regulators would require temporary set-down areas, excavation of the creek bed, possible removal of vegetation and the construction of the regulator. Retention banks may also be required but LiDAR data is not reliable confirm this.

In bringing to the site machinery required for excavation, construction and tree removal, it may be necessary to remove limbs from trees on access tracks.

The impact of the works on flora and fauna and matters of cultural significance must be assessed as described in Option 1.

The creek will be subject to silt and debris accumulation. It will be necessary to monitor the capacity of the creek annually and to arrange debris and silt removal as required. It is expected that maintenance work will be required very infrequently.

Detailed design of this option will involve:

- a physical survey of the creek;
- a desktop and field assessment of matters of cultural significance;
- a flora and fauna survey to report matters of state and national conservation significance affected;
- an assessment of the degree to which the proposal will improve habitat elsewhere;

- a site inspection and detailed design to quantify the excavations, to finalise the route with regard to maximising inflow and minimising impacts on habitat and matters of cultural significance and to re-create habitat in and adjacent to the modified creek;
- a vegetation impact report under Victoria's native vegetation management framework (DNRE 2002); and
- a report to the Commonwealth Minister for the Environment under the EPBC Act.

6.7 Option 7 - New Regulator to East of Lake Bitterang

Objective

The objective is to raise the level to which water can be retained on the floodplain to 43.4 m AHD.

The intended benefit is to:

- prolong flooding in the North Lakes, Lockie, Hattah, Brockie and Chalka Creek regions; and
- additionally prolong flooding in the Bitterang region.

As an alternative to the preceding proposal, a single regulator (B1) as shown in Figure 42 could be constructed on Chalka Creek North, just south of the junction of the watercourse that links Chalka Creek to Lake Cantala. At this location, the contours indicate that a less cost-effective structure could be built to retain water to at least 43.4 m AHD. If no modification were made to Messenger's Regulator, as recommended, the retention level would be 43.4 m AHD.

Design and Costs

This option was identified late in the project as a refinement to the modelled option and has not been costed.

Effectiveness

This option has not been modelled.

The water regime of Lake Bitterang is similar to Lake Cantala, suggesting that a similar improvement to the water regime could be achieved with the proposed structure. The structure would detain water in a significant area of Red Gum woodland around the lake and adjacent to Chalka Creek North, in addition to the area enclosed by Messengers Regulator and the proposed Mournpall Island regulators.

It is likely that the spread of water to this additional area would reduce the effectiveness of floodplain inundation in the wetlands to the south. The modelling results for Options 2, 3 and 4 demonstrate that the smaller the area in which flooding is confined the more effectively the floodplain can be inundated. It therefore follows that the operation of B1 instead of NL1 and NL2 would result in shorter and less frequent floodplain inundation events. There is no data to assess whether this effect would significantly compromise the ecological objectives.

This option could be considered in addition to NL1 and NL2. It would be possible to close B1 only after very large or sustained flood events; otherwise NL1 and NL2 would detain flood water.

This option should be given further consideration, possibly through an additional run in the hydraulic model.

Risks

The risks described in Option 2 apply here.

Implementation and Operation

The implementation and operation issues described in Optioin 2 apply here.

6.8 Option 8 - Raise Rock Bar in the River Murray at Chalka Creek East

Objective

The objective is to increase the frequency, duration and rate of inflows by raising the existing rock bar downstream of the location where Chalka Creek East leaves the River Murray.

The intended benefit is to:

- increase the frequency and duration of inundation in wetlands and low-lying floodplain areas.

Design

A natural rock bar extends across the river just downstream of the junction of Chalka Creek East and the river. The rock bar extends from the left (east or Victorian) bank almost across the river to the NSW side. The level of the bar is 1 to 2 m above the level of the river when flowing at 5,000 ML/d.

The rock bar acts as a natural weir, raising the river level upstream until it is completely drowned out. The rock bar promotes inflow to Chalka Creek by raising the river level to the threshold of the creek at lower flows than would otherwise occur.

Previous modifications to the rock bar have made it less effective with regard to Chalka Creek inflows. The bar has been breached near the right bank to allow river boats to pass and now holds water at lower levels at any given flow.

It would be possible to increase its effectiveness by raising the level of the rock bar artificially.

Effectiveness

An analysis of this option was undertaken. The analysis explored the effect of the rock bar raising on the stage-discharge relationship previously developed for flow at Euston (ML/d) and water level at Messenger's regulator (m AHD).

The analysis included determination of the river geometry at and immediately upstream of the rock bar. This was achieved using available LIDAR survey data. However, this data could not be used to determine the river bed level. A river bed level of 38 m AHD was assumed for the analysis, which implies a water depth of approximately 1.5 m near the left bank of the river (at the rock bar location) at the time the survey was undertaken. At this location the river is approximately 165 m wide (including the rock bar).

It is proposed that the rock bar is raised by 1-2 metres to constrict flow in the river, with the intention of increasing backwater to increase the frequency of water entering Chalka Creek. Investigation of LIDAR data suggests that the rock bar extends approximately 70 m across the river, commencing from the left bank near the entrance to Chalka Creek. In addition, the rock bar could only practically be constructed to a maximum level of 42 m AHD. It was for this water level that the effectiveness of extending/raising the rock bar was analysed.

The analysis was carried out using an hydraulics of bridge waterways approach (Bradley, 1978). This approach includes the computation of backwater due to the constriction of flow. In this instance raising the rock bar to a level of 42 m AHD for 70 metres across the river would reduce the flow area by approximately 484 m^2 (1896 m^2 to 1412 m^2). Using the stage-discharge relationship developed for flow at Euston and water level at Messenger's regulator, a flow of 23,000 ML/d would be required to produce a water level of 42 m AHD at Messenger's regulator. This flow was used to compute the backwater effect due to the constriction in flow as a result of raising the rock bar as this would give the maximum reduction in river cross section and the maximum impact on water levels in the River Murray. In this instance the backwater effect was found to be negligible (0.001 to 0.002 metres). This being the case a cost estimate for this option was not developed as raising the rock bar alone was not considered a viable option. Therefore, this proposal was dismissed and was not considered further.

However, it should be noted that this option only considers raising the existing rock bar to a most practical level and does not consider greater constriction of flow achievable with larger channel modifications and/or structures at this location.

Costs

This option was not considered to be effective and costs were not assessed.

Risks

There are significant risks associated with this option including:

- destabilisation of the river banks at low flows and elevated flows:
- disruption to navigation;
- disruption to pump operation upstream; and
- unintended diversion of water to other low effluents and wetlands upstream at low flows and elevated flows.

Implementation and Operation

This option was not considered to be effective and its implementation was not considered further.

6.9 Option 9 – Pump Water to Fill Lakes

Objective

Pumping from the River Murray into the Hattah Lakes system is an option to augment wetting of some of the Hattah Lakes area during extended periods of low flow in the River Murray. Recent pumping in 2005 and 2006 has provided water for Chalka Creek and Lakes Lockie, Little Hattah, Hattah, Yerang, Mournpall, Bulla, Arawak, Marramook and Brockie. This was achieved with 13.5 GL pumped between Autumn 2005 and December 2006.

The aim of the pumping would be to increase the wetting of these areas to achieve the recommended watering regime as per Table 1 of this report.

Effectiveness

This assessment could be superimposed on the results of the hydraulic modelling for a range of modelling scenarios. For example at Lake Lockie some of the following scenarios have already been modelled and the results are provided in Table 14.

Table 14. Lake Lockie – Pumping Requirements

Scenario	Natural conditions percentage of time wet (at least 50% retention)	Recommended percentage of time wet (at least 50% retention)	Number of times pumping is required in 100 year period
Natural Conditions	Approximately 91 %	80 %	zero
Existing Conditions	59 to 69 %	80 %	To be determined
Future Conditions, with lowering of Chalka Creek	To be determined by hydraulic model (between 59 and 91%)	80 %	To be determined

The amount of times that pumping is required in the 100 years of the hydraulic model (water balance model) could be determined from inspection of the long term duration water level plots for Lake Lockie for each modelling scenario. The volume of water to be pumped each time would be the amount of water required to fill Chalka Creek, Lake Lockie and Lake Little Hattah to the required retention level.

Costs for pumping for each scenario could then be estimated.

This proposed approach would give approximate estimates of

- the number of times per 100 years that pumping would be likely to be required for each scenario to achieve the recommended watering regime for Lakes Lockie and Little Hattah;
- the volume of water to be pumped each time; and
- the approximate cost of pumping over a 100 year period.

This would be a simpler method than adding the pumping options to each scenario in the water balance model as it would limit the number of model runs and the amount of iterations and rules required in the modelling runs. Alternatively by adding the pumping option to the modelling runs would give a better result in terms of the distribution of pumping water along Chalka Creek and into the Lakes in terms of wetting times and water levels.

Implementation and Operation

Pumping is proposed to supplement the additional inflows achieved by other water management options. Depending on the frequency with which pumping is required, either a temporary facility (using diesel pumps) or a permanent facility (using electric pumps and a power line to the site) may be appropriate. The most appropriate approach will become evident as other options are further refined and the remaining deficit in water requirements can be evaluated.

7.1 Potential for Salinity Impacts from Living Murray Actions

The key Living Murray action for Hattah Lakes is to inundate areas of the floodplain with a greater frequency than under current conditions, to achieve ecological objectives set for the lakes.

In a Basin-wide review of Living Murray actions, Richardson et al. (2005) identified flow modification to off-stream areas as ”potentially causing the greatest impact (salinity debit) because it could affect the largest area of the floodplain resulting in the flushing of salts that have accumulated within the surface soils and potentially cause additional recharge to the underlying near surface aquifers resulting in increased discharge of groundwater, with higher salinities, to the main river channel”.

The potential for this action to mobilise salt beyond current levels is dependent on initiation of site specific groundwater processes.

For Hattah Lakes there is unlikely to be additional salt wash off since water will be ponded using regulators. Infiltration and groundwater recharge issues require an assessment of the local hydrogeology.

7.2 The local hydrogeology

An extensive drilling program by Thorne et al. (1990) allowed the hydrogeology of the Hattah Lakes and surrounding regions to be described. The major regional geological units consist of the Woorinen Formation, Blanchetown Clay, the Parilla Sands Aquifer, and the deeper Renmark Group. Within the river channel, the Coonambidgal sand aquifer is semi-confined by the Coonambidgal Formation.

Within the Hattah Lakes area, groundwater flow in the Parilla Sand aquifer is in a north-westerly direction. Interaction between the Channel Sands aquifer and the river is complex. Regions of groundwater discharge, recharge or partial flow through occur along the river under low flow conditions. At high river levels the general condition becomes one of aquifer recharge by the river (Thorne et al., 1990).

The Coonambidgal Sands form a thin continuous shallow aquifer within the trench, hydraulically separated from the Parilla Sands aquifer by the Blanchetown Clay. The depth of separation north of Hattah Lakes is approximately 20 metres which gradually decreases to less than 5 metres upstream of Hattah Lakes.

Transmissivity of the Parilla Sand aquifer was calculated as 218 m^2/d giving a hydraulic conductivity of 4.0 m/d. A storage coefficient of 3.37×10^{-4} was determined. Vertical hydraulic conductivity of the Blanchetown Clay was calculated as 3.48×10^{-9} m/s. A pump test conducted in the channel sands aquifer within the study area indicated a transmissivity of 90 m^2/d and a storage coefficient of 1 to 7×10^{-4}.

More recent tests completed by URS (2005) found the transmissivity of the Parilla Sands to be between 150 - 300 m^2/d with a storage coefficient of 4.5×10^{-4}. For the Blanchetown Clay hydraulic conductivity was measured between 3×10^{-9} and 1×10^{-7} m/s.

Groundwater salinity in the Parilla Sand aquifer ranges between 40 000 to 60 000 EC whilst groundwater salinity in the channel sands aquifer is highly variable ranging from 1000 EC near the banks of the river increasing to 40 000 EC with distance from the river.

A summary of long term regional watertable trends in the Parilla Sands was conducted by SKM (2003). Key outcomes of this study include (1) water table levels are generally static to the north and south east of the national park, where irrigation activity is occurring, (2) there has been a long term decline in groundwater levels in the low-lying areas and lakes, to the west of the national park, and (3) since 1993 to 1994, there has been a general decline in water level in the regional Parilla Sand aquifer in the vicinity of the national park.

A study conducted by Lamontagne et al (2002) investigated groundwater-surface water interactions and the spatial patterns in nutrient concentration at the interface between surface water and groundwater. A key outcome of the study was that the River Murray in this area is a ‘losing’ river for most of the time, with the exception of short periods following medium to large flood events where bank storage contributed to flow in the river. It was observed that little, if any, regional groundwater discharges directly to the River Murray in this region.

Recent work conducted by Australian Water Environments in the Hattah Lakes region using geophysical methods measuring the resistivity of the subsurface materials beneath the river supports the presence of losing stream conditions in the study area (A. Telfer pers. comm.).

In summary:

- Hattah Lakes overlies a highly transmissive aquifer
- There is an uncertain amount of infiltration.
- There is significant impedance for infiltration to the Parilla Sands aquifer due to the presence of 20m thickness of Blanchetown Clay.

7.3 Likely impacts

Typical water depths across the floodplain from the proposed works will be of the order of 1 – 1.5 m with a maximum of 3 – 4 m in some lakes. Infiltration is likely to be low due to the presence of Blanchetown Clays and since the salinity of water in the Parilla Sands is high suggesting that freshwater has not displaced saline water over the long term. This conclusion is further supported by SKM water balance modelling for the Hattah Lakes where no provision for infiltration was required (D. Enever, pers. comm.).

7.4 Conclusions

Whilst it is not currently possible to quantify the salinity impacts of the proposed works for Hattah Lakes, it is clear that there is a low risk of increased salt movement from the floodplain to the River Murray.

A separate study by MDBC is currently developing a suggested methodology for quantifying impacts of the Living Murray Actions along the River Murray and will provide a basis for quantitative impacts in the future.

8.1 Introduction

An approach has been adopted to assesses the cost-effectiveness of the modelled water management options. The most cost-effective options are those that achieve the greatest environmental benefit for the money invested.

The effects of the options vary in terms of the extent of their impact, the degree to which they address ecosystem water requirements and the conservation priority of the ecosystems themselves. An approach was developed to allow the options to be compared on an equal footing using semi-quantitative measures of these factors.

8.2 Approach

The underlying principal in determining priority was that cost-effective options provide the greatest environmental benefit for the amount of money spent:

cost-effectiveness = environmental benefit / cost

Two factors were considered when calculating the term 'environmental benefit'. Benefit was increased by:

- the degree to which the options address the water management priorities of the system; and
- the area affected, or the 'quantity' of the benefit.

A score was applied to each factor and these were combined to give an overall 'environmental benefit' score. Cost was determined from the engineering option assessments.

Contribution to Water Requirements

A framework to compare the conservation significance of the water regime classes affected by the options is presented in Section 4. This framework provided the water regime classes with a priority score based on the conservation significance and the degree to which their water requirements are threatened.

The contribution of the options to the water management priorities was assessed by multiplying the priority score of the water regime classes by factor that represents the 'effectiveness' of the options (Table 15).

An effectiveness score of 3 was given where the option provides scope to significantly address the water requirements of the area by promoting and controlling flood duration and frequency. A score of 2 was applied where the option provides some scope to increase flooding frequency and duration, but where there is limited control over water or where the option can only be implemented rarely. A score of 1 was applied where the option will improve flooding in the water regime class, but only in rare circumstances or to a very limited degree. A score of 0 was applied where the option does not benefit the water regime class.

Table 15. Contribution to Environmental Water Requirements

(SPW – Semi-permanent Wetlands, PTW – Persistent Temporary Wetlands, TW – Temporary Wetlands, EW – Episodic Wetlands, RGF / FRG – Red Gum Forest / Fringing Red Gum Woodland, RG FTU – Red Gum with Flood Tolerant Understorey, BBX – Black Box Woodland, LS – Lignum Shrubland, CK – Creek)

Option	Water Regime Class									Total Score
	SPW	PTW	TW	EW	RGF / FRG	RG FTU	BBX	LS	CK	
Water Regime Class Priority	45	39	10	3	38	14	5	10	16	
1. Lower Chalka Creek	2 x 45	2 x 39	2 x 10	0 x 3	0 x 38	0 x 14	0 x 5	0 x 10	3 x 16	**236**
2. Retain Floodwater in Central Lakes Region	3 x 45	3 x 39	3 x 10	0 x 3	2 x 38	2 x 14	1 x 5	0 x 10	2 x 16	**423**
3. Confine Flooding North of Lake Hattah	3 x 45	3 x 39	0 x 10	0 x 3	3 x 38	2 x 14	1 x 5	1 x 10	2 x 16	**441**
4. Confine Flooding South of Lake Yerang	3 x 45	3 x 39	2 x 10	0 x 3	3 x 38	2 x 14	1 x 5	1 x 10	2 x 16	**461**
5. Confine Flooding in Lakes Lockie and Little Hattah	0 x 45	3 x 39	0 x 10	0 x 3	3 x 38	2 x 14	1 x 5	1 x 10	2 x 16	**306**
6a. Lower Cantala Creek	0 x 45	3 x 39	0 x 10	0 x 3	0 x 38	0 x 14	0 x 5	0 x 10	2 x 16	**149**
6b. Lower Cantala Creek and Regulate Lake Cantala	0 x 45	3 x 39	0 x 10	0 x 3	3 x 38	2 x 14	1 x 5	1 x 10	2 x 16	**306**

Lowering Chalka Creek benefits Semi-permanent, Persistent Temporary and Temporary Wetlands. This option will significantly increase the frequency and duration of inflows to the system, so that these wetlands are more likely to receive inflows. This option provides an insignificant benefit to woodland areas which are only inundated by major inflow events that are not significantly affected by the current sill level of Chalka Creek. Chalka Creek will receive more frequent inflows and a more persistent flooded environment.

Constructing regulators at Mournpall Island provide benefits both to wetlands and to the surrounding woodland areas. The regulators will increase the frequency and duration of flooding in the wetlands by reducing outflow to the north and by allowing water to be stored to a greater depth in the enclosed area. The regulators will also allow woodland areas to be inundated, most significantly Fringing Red Gum, but also Red Gum FTU and Black Box to some extent. This option will impound water in Chalka Creek and increase the duration of flooding.

Options to partition flooding to the north or south of Lake Lockie provide similar benefits to the Mournpall Island regulators. They are more effective in flooding the surrounding floodplain, although over a smaller area (see below).

The option to lower and regulate Cantala Creek benefits the Persistent Temporary wetland of Lake Cantala and its surrounding woodland communities.

Extent of Benefit

Greater importance was given to options that affect a larger area and, presumably, provide greater benefits to plant and animal communities. The extent of the benefits of the options was compared based on the area affected, calculated using GIS (Table 16). The 43.4 m AHD contour was used to calculate the areas for options 2, 3, 4, 5 and 6a. The wetland bed area within the 43.5 m AHD contour was used to calculate the area of wetlands affected by options 1 and 6b.

Table 16. Extent of Benefits of Water Management Options

Option	Extent of Benefit	Area (Ha)
1. Lower Chalka Creek	Lakes Lockie, Yerang, Mournpall, Yelwell, Konardin, Hattah, Little Hattah, Bulla, Arawak, Marramook, Brockie, Bitterang	783
2. Retain Floodwater in Central Lakes Region	Lakes Lockie, Yerang, Mournpall, Yelwell, Konardin, Hattah, Little Hattah, Bulla, Arawak, Marramook, Brockie and their surrounding floodplain	1500
3. Confine Flooding North of Lake Hattah	Lakes Little Hattah, Lockie, Yerang, Mournpall, Yelwell and Konardin and their surrounding floodplain	900
4. Confine Flooding South of Lake Yerang	Lakes Lockie, Little Hattah, Bulla, Arawak, Marramook and Brockie and their surrounding floodplain	850
5. Confine Flooding in Lakes Lockie and Little Hattah	Lakes Lockie, Little Hattah and Roonki	550
6a. Lower Cantala Creek	Cantala Creek and Lake Cantala	140
6b. Lower Cantala Creek and Regulate Lake Cantala	Cantala Creek, Lake Cantala and the surrounding floodplain	400

The option to lower Chalka Creek benefits the main group of lakes by increasing the frequency and duration of inflows. These lakes also benefit from the option to regulate Chalka Creek at Mournpall Island, but because this option allows water to be retained to 43.4 m AHD it also provides scope to enhance flooding in the surrounding floodplain. The options to partition flooding north or south of Lake Lockie provide similar benefits, but over a smaller area. The Cantala Creek options affect the smallest area of all the options.

8.3 Scores of Environmental Benefit

The environmental benefit scores assigned to the options is presented in Table 17. Environmental Benefit was calculated by multiplying the two component factors together.

Table 17. Environmental Scores Applied to Options

Option	Contribution to Water Requirements	Extent of Benefit	Environmental Benefit Score (/ 1000)
1. Lower Chalka Creek	236	783	185
2. Retain Floodwater in Central Lakes Region	423	1500	635
3. Confine Flooding North of Lake Hattah	441	900	397
4. Confine Flooding South of Lake Yerang	461	850	392
5. Confine Flooding in Lakes Lockie and Little Hattah	306	550	168
6a. Lower Cantala Creek	149	140	21
6b. Lower Cantala Creek and Regulate Lake Cantala	306	400	122

8.4 Cost-effectiveness

Option priority was calculated by dividing environmental benefit scores by cost (Table 18).

Table 18. Benefit - Cost Ratio for Water Management Options

Description	Environmental Benefit Score (/1000)	Cost*	Cost-Effectiveness (x 1000)
1. Lower Chalka Creek	185	$220,000	0.84
2. Retain Floodwater in Central Lakes Region	635	$460,000	1.38
3. Confine Flooding North of Lake Hattah	397	$545,000	0.73
4. Confine Flooding South of Lake Yerang	392	$460,000	0.85
5. Confine Flooding in Lakes Lockie and Little Hattah	168	$425,000	0.40
6a. Lower Cantala Creek	21	$310,000	0.07
6b. Lower Cantala Creek and Regulate Lake Cantala	122	$460,000	0.27

*Costs are for manually operated structures

The most cost-effective option is Option 2, to lower Chalka Creek and retain flood water with Messengers Regulator and new regulators at Mournpall Island. This option capitalises on the benefits of Option 1, which are significant in their own right. While Option 1 mainly affects the water regime in the wetland, Option 2 additionally addresses water requirements in the surrounding floodplain. The ecological interactions between the lakes and the floodplain, outlined Section 4, are central to the conservation significance of the Hattah Lakes system.

Options 3, 4 and 5 are alternatives to Option 2 and do not provide additive effects to Option 2. All three options are less cost effective than Option 2. They improve the inundation of the floodplain marginally more effectively, but over a smaller area. These options warrant further consideration if limited amounts of water available because they allow hydrological objectives to be addressed effectively albeit in a small area.

The proposed works at Lake Cantala are the least cost-effective. The work required to lower Cantala Creek is very expensive and benefits a relatively small area. In this investigation, the effects of the regulators in Option 6b were only considered in combination with work on Cantala Creek. Although the regulator adds significant value to the Cantala Creek works, it does not make the option cost-effective in comparison to other options.

Nevertheless, it is important to recognise that only options within this project have been evaluated. If the work at Lake Cantala were compared with water management options at River Murray sites elsewhere (e.g. Ecological Associates 2006a) it may rank relatively highly.

9.1 Discussion and Recommendations

This investigation has demonstrated that lowering Chalka Creek (Option 1) is viable and is cost-effective in comparison to other options. This option significantly increases the permanence of lakes throughout the system, with the exception of Lake Kramen and Lake Cantala.

It is recommended that planning commences to implement Option 1.

This investigation has also found that the use of regulators to capture water (Option 2) capitalises on the improved inflows provided by Option 1 by significantly increasing flooding on the surrounding floodplain. This option addresses a key hydrological objective for Hattah Lakes, which is to provide sustained, regular flooding in wetlands and adjacent woodland areas.

It may be possible to improve the effectiveness of Option 2.

In this study a retention level of 43.4 m AHD was modelled, to approximately match the existing retention level of Messengers Regulator. The regulators do not increase flooding at elevations above their retention levels. The current water regime of some water regime classes at and above these levels is deficient. A higher retention level would enable the flooding of these areas to also be increased. This would involve modifications to Messengers Regulator and larger structures at sites NL1 and NL2.

Option 2 may also be enhanced by regulating Chalka Creek North at site B1 instead of NL1 and NL2, so that Lakes Bitterang and Woterap are included in the confined area. Site B1 is likely to provide shorter and less frequent floodplain inundation compared with the modelled scenario for Option 2, however the benefits will apply over a greater area. The use of a higher retention level than 43.4 m AHD may compensate for the difference.

It is recommended that the hydraulic model is used to further optimise the design of Option 2 by investigating the effects of a regulator at B1 and the use of higher retention levels. Suitable scenarios would include:

- B1 and Messengers with retention levels of 43.4 m AHD; and
- NL1, NL2 and Messengers with retention levels of either 44 or 44.5m AHD;
- B1 and Messengers with retention levels of either 44 or 44.5 m AHD.

A spell analysis of the results would be required as set out in Appendix G for comparison with existing model runs.

Options 3, 4 and 5 are alternatives to Option 2 but are less cost-effective. It is recommended that they are only considered further as contingency plans to manage limited volumes of water.

Work to lower Cantala Creek appears to be prohibitively expensive, although it does improve inflows to Lake Cantala significantly. **It is recommended that Option 6a is revisited once costs for modifying**

Chalka Creek have been confirmed through detailed planning. It is possible that the costs would be less than anticipated here and that this option would be viable.

Regulation of Lake Cantala, Option 6b, is effective in promoting inundation of the surrounding floodplain. In this investigation, the effects of this option were only considered in combination with lowering Cantala Creek, Option 6a. Given that floodplain inundation occurs at levels well above the existing creek level, it is possible that regulators would still provide significant environmental benefit even if the creek were not lowered. **It is recommended that the hydraulic model is run to assess the effectiveness of the proposed Lake Cantala Regulator C1 with Cantala Creek at the existing level.**

The proposal to raise the rock bar in the River Murray at the mouth of Chalka Creek provides no significant benefit. It is recommended that this option is not considered further.

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Appendix A
Tabulated yearly inflows to Hattah Lakes

Proportion (%) of Years with Inflow Events, 1908-1999

Lake	Natural Conditions		Current Conditions	
	URS	SKM	URS	SKM
Little Hattah	80	NA	58	NA
Hattah	80	86	58	57
Roonki	NA	NA	NA	NA
Bulla	80	86	47	47
Arawak	76	86	42	41
Marramook	76	86	41	40
Brockie	74	86	39	40
Boich	74	86	39	36
Tullamook	73	NA	39	NA
Nip Nip	64	70	30	30
Yerang	80	86	53	51
Mournpall	80	86	53	51
Yelwell	73	80	39	36
Konardin	70	79	35	34
Bitterang	62	64	25	27
Cantala	84	91	47	47
Kramen	22	23	8	11

Notes:

- SKM indicated figures reported in SKM (2004). These figures are shown for comparison.
- Critical flows in the River Murray at Euston under both natural and current conditions were not identified for Lake Roonki in SKM (2004) thus the proportion of years with inflow events could not be calculated.
- The proportion of years with inflow events to Tullamook and Little Hattah were not presented in SKM (2004).

Appendix B
Tabulated monthly inflows to Hattah Lakes

Monthly inflows based on River Murray flows at Euston, 1908 to 1999

Lake	Condition	Flow @ Euston (ML/d)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Lockie	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	36700	0	0	0	1	3	5	11	22	11	5	3	0	61
Little Hattah	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	36700	0	0	0	1	3	5	11	22	11	5	3	0	61
Hattah	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	36700	0	0	0	1	3	5	11	22	11	5	3	0	61
Roonki	Natural		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Current		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bulla	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	45000	0	0	0	0	3	2	5	17	13	3	2	2	47
Arawak	Natural	50500	0	0	0	2	2	5	16	25	11	5	6	1	73
	Current	50500	0	0	0	0	1	2	4	13	14	6	3	1	44
Marramook	Natural	52000	0	0	0	2	2	4	14	29	11	5	7	1	75
	Current	52000	0	0	0	0	1	2	4	13	14	7	2	1	44
Brockie	Natural	53000	1	0	0	2	2	3	13	30	9	7	7	2	76
	Current	53000	0	0	0	0	1	2	4	11	13	8	2	1	42
Boich	Natural	54000	1	0	0	2	2	3	13	29	10	6	8	1	75
	Current	54000	0	0	0	0	1	2	4	10	13	9	2	0	41
Tullamook	Natural	55000	1	0	0	2	2	3	13	28	10	9	8	0	76
	Current	55000	0	0	0	0	1	1	4	8	15	9	2	0	40
Nip Nip	Natural	65000	0	0	0	0	1	3	7	24	16	8	6	0	65
	Current	65000	0	0	0	0	1	1	4	4	11	6	3	0	30
Yerang	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	40000	0	0	0	1	3	4	9	19	12	6	1	1	56
Mounpall	Natural	48900	0	0	0	2	3	6	17	24	12	8	5	2	79
	Current	40000	0	0	0	1	3	4	9	19	12	6	1	1	56
Yelwell	Natural	55000	1	0	0	2	2	3	13	28	10	9	8	0	76
	Current	55000	0	0	0	0	1	1	4	8	15	9	2	0	40
Konardin	Natural	60000	0	0	0	0	1	3	8	27	16	6	11	0	72
	Current	60000	0	0	0	0	1	1	4	5	13	8	3	0	35
Bitterang	Natural	70000	0	0	0	0	1	3	7	19	18	7	10	2	67
	Current	70000	0	0	0	0	1	1	3	5	7	6	4	1	28
Cantala	Natural	45000	1	1	0	2	4	8	17	24	14	9	4	2	86
	Current	45000	0	0	0	0	3	2	5	17	13	3	2	2	47
Kramen	Natural	152000	0	0	0	0	0	1	3	5	5	5	3	0	22
	Current	152000	0	0	0	0	0	1	0	2	1	3	0	0	7

Appendix C
Statistics of Lake Level Time Series

Statistics of Lake Level Time Series for Hattah Lakes (m AHD)

Lake	Natural Condition					Current Condition				
	Avg	Median	SD	Max	Min	Avg	Median	SD	Max	Min
Lockie	42.41	42.16	0.92	45.67	41.24	41.84	41.65	0.78	45.66	41.24
Little Hattah	42.20	41.99	0.94	45.67	41.30	41.69	41.31	0.72	45.66	41.30
Hattah	42.18	42.18	1.14	45.67	39.20	40.91	41.01	1.38	45.66	39.20
Roonki	42.24	42.15	0.98	45.67	40.98	41.64	41.37	0.86	45.66	40.98
Bulla	42.14	42.13	1.10	45.68	39.85	41.05	40.98	1.17	45.67	39.85
Arawak	42.01	42.05	1.14	45.67	39.94	41.08	40.98	1.14	45.66	39.94
Marramook	42.35	42.04	0.77	45.67	41.88	42.02	41.88	0.50	45.66	41.88
Brockie	41.92	42.04	1.18	45.67	39.99	40.75	40.01	1.11	45.66	39.99
Boich	42.30	42.36	1.01	45.67	41.00	41.54	41.00	0.87	45.66	41.00
Tullamook	42.28	42.36	1.02	45.67	40.90	41.48	40.90	0.90	45.66	40.90
Nip Nip	42.41	42.47	0.96	45.67	41.22	41.71	41.23	0.81	45.66	41.22
Yerang	42.15	42.00	1.01	45.60	40.89	41.48	41.01	0.86	45.59	40.89
Mounpall	41.86	41.90	1.19	45.60	39.22	40.63	40.52	1.35	45.59	39.22
Yelwell	42.07	42.17	1.07	45.60	40.57	41.20	40.57	0.83	45.59	40.57
Konardin	42.07	42.17	1.07	45.60	40.57	41.20	40.57	0.96	45.59	40.57
Bitterang	41.78	41.94	1.03	45.10	40.11	40.82	40.12	1.01	45.09	40.11
Cantala	41.45	41.47	1.08	45.17	40.16	40.71	40.16	0.91	45.16	40.16
Kramen	41.27	40.75	1.09	46.15	40.75	40.94	40.75	0.70	46.14	40.75

Appendix D
EVC Classes, Areas and Inundation Levels

Region	Lakes Covered	EVC	Area	Inundation Level (mAHD)										
				40	40.5	41	41.5	42	42.5	43	43.5	44	44.5	45
Lockie	Lockie	FRGW	Ha	-	0.1	2.13	4.7	12.29	57.53	147.07	283.08	364.23	414.67	445.67
	Roonki		%	-	0.02	0.45	0.99	2.58	12.08	30.88	59.44	76.47	87.06	93.57
		BBW	Ha	-	-	0.25	2.09	3.94	6.99	17.16	66.94	171.56	306.6	426.51
			%	-	-	0.04	0.31	0.58	1.04	2.55	9.93	25.45	45.49	63.28
		RGW-FTU	Ha	-	-	-	0.04	0.58	2.92	14.75	66.06	138.58	195.78	235.99
			%	-	-	-	0.01	0.18	0.88	4.44	19.89	41.72	58.93	71.04
		Not Subject to Inundation	Ha	-	-	-	-	-	-	0.04	0.48	2.26	6.49	13.82
			%	-	-	-	-	-	-	0.01	0.13	0.6	1.72	3.65
		Wetland	Ha	-	-	2.69	109.37	166.73	208.71	222.11	250.2	254.61	255.04	258.82
			%	-	-	1.03	41.72	63.59	79.61	84.72	95.43	97.12	97.28	98.72
Hattah	Hattah	FRGW	Ha	-	0.17	1.79	8.74	21.45	38.03	55.27	75.43	89.39	98.14	104.52
	Bulla		%	-	0.14	1.45	7.08	17.37	30.8	44.76	61.08	72.38	79.47	84.63
	Arawak	BBW	Ha	-	-	-	-	0	0.41	6.82	38.44	67.5	86.78	103.75
			%	-	-	-	-	0	0.3	4.94	27.85	48.9	62.88	75.17
		RGW-FTU	Ha	-	-	-	-	0.04	0.63	2.79	10.44	24.25	35.23	44.9
			%	-	-	-	-	0.06	0.95	4.2	15.71	36.5	53.03	67.57
		Not Subject to Inundation	Ha	-	-	-	-	-	-	-	0.38	6.66	16.38	29.69
			%	-	-	-	-	-	-	-	0.39	6.82	16.75	30.38
		Wetland	Ha	37.88	88.56	108.87	122.79	132.17	136.84	139.05	139.33	139.39	139.39	139.39
			%	27.17	63.53	78.1	88.09	94.82	98.17	99.76	99.95	100	100	100

Appendix D
EVC Classes, Areas and Inundation Levels

Region	Lakes Covered	EVC	Area	Inundation Level (mAHD)										
North Lakes	Konardin	FRGW	Ha	0.01	0.25	1.47	6.12	25.84	74.77	129.49	202.2	256.98	296.7	332.97
	Yelwell		%	0	0.06	0.34	1.4	5.92	17.14	29.68	46.34	58.89	68	76.31
	Yerang	BBW	Ha	0	0	0.02	0.38	1.04	2.42	9.8	41.8	103.45	190.69	301.34
	Mournpall		%	0	0	0	0.07	0.18	0.42	1.69	7.21	17.84	32.88	51.96
		RGW-FTU	Ha	0	0.28	2.29	7.02	13.58	26.6	65.11	136.12	202.65	249.92	283.6
			%	0	0.08	0.63	1.93	3.73	7.31	17.89	37.39	55.67	68.65	77.91
		Not Subject to Inundation	Ha	0	0	0	0.02	0.06	0.11	0.2	0.38	1.85	12.32	35.11
			%	0	0	0	0	0.01	0.02	0.03	0.06	0.31	2.07	5.89
		Wetland	Ha	132.93	156.03	203.87	292.09	329.32	340.13	342.95	344.28	344.81	353.8	364.79
			%	35.89	42.12	55.04	78.86	88.91	91.83	92.59	92.95	93.09	95.52	98.49
Kramen	Kramen	RGF	Ha	-	-	-	-	-	0.01	0.03	0.22	0.47	0.77	1.16
			%	-	-	-	-	-	0.57	1.33	10.15	22.18	36.22	54.03
		FRGW	Ha	-	-	-	0.9	5.1	8.12	11.85	17.3	32.67	88.74	200.33
			%	-	-	-	0.24	1.39	2.21	3.22	4.7	8.87	24.1	54.4
		BBW	Ha	-	-	-	-	-	0.01	0.04	0.57	3.4	35.58	128.37
			%	-	-	-	-	-	0	0.01	0.11	0.67	6.97	25.16
		Not Subject to Inundation	Ha	-	-	-	-	-	-	-	-	0	7.38	16.79
			%	-	-	-	-	-	-	-	-	0	13.79	31.38
		Wetland	Ha	-	0	1.1	53.65	70.3	80.84	91.75	108.25	137.68	165.83	199.49
			%	-	0	0.51	24.79	32.49	37.36	42.4	50.03	63.63	76.64	92.19

Appendix D
EVC Classes, Areas and Inundation Levels

Region	Lakes Covered	EVC	Area	Inundation Level (mAHD)										
Chalka Creek		RGF	Ha	0.96	5.44	13.31	21.96	28.85	35.39	43.29	56.17	77.56	108.38	142.33
			%	0.4	2.25	5.5	9.07	11.91	14.62	17.88	23.2	32.03	44.76	58.78
		FRGW	Ha	0.06	0.27	1.79	3.75	5.64	7.11	9.37	27.8	112.82	233.32	369.43
			%	0.01	0.04	0.28	0.58	0.88	1.11	1.46	4.32	17.55	36.29	57.46
		BBW	Ha	-	-	0	0.06	0.17	0.31	3.95	20.37	60.76	138.74	333.79
			%	-	-	0	0.01	0.01	0.03	0.32	1.66	4.96	11.31	27.22
		RGW-FTU	Ha	0.02	0.03	0.05	0.12	0.2	0.37	5.52	34.44	73.1	96.01	131.9
			%	0.01	0.01	0.02	0.04	0.07	0.13	1.94	12.11	25.7	33.75	46.37
		LS	Ha	-	-	-	-	0	0.31	6.15	7.72	9.86	17.96	41.59
			%	-	-	-	-	0	0.25	4.92	6.17	7.88	14.35	33.23
		Not Subject to Inundation	Ha	-	-	-	-	0	0.01	0.02	0.04	0.52	2.17	16.03
			%	-	-	-	-	0	0	0.01	0.01	0.12	0.49	3.63
		Wetland	Ha	-	-	-	-	-	0.49	4.13	4.73	12.86	21.23	23.72
			%	-	-	-	-	-	1.82	15.41	17.66	48	79.27	88.55
Brockie	Brockie	FRGW	Ha	0.41	1.29	3.18	7.32	15.09	29.39	44.87	60.15	74.67	86.01	0.41
	Tullamook		%	0.41	1.29	3.2	7.36	15.17	29.56	45.12	60.48	75.09	86.49	0.41
	Boich	BBW	Ha	-	0.13	0.67	3.1	5.32	12.54	37.84	96.46	175.81	286.59	-
	Nip Nip		%	-	0.02	0.11	0.53	0.91	2.14	6.47	16.49	30.06	49	-
		Not Subject to Inundation	Ha	-	-	-	-	0.01	0.02	0.04	1.09	5.06	10.99	-
			%	-	-	-	-	0.01	0.01	0.03	0.62	2.89	6.27	-
		Wetland	Ha	11.97	22.25	36.63	53.46	74	81.95	84.36	85.36	85.48	85.48	11.97
			%	14	26.03	42.85	62.54	86.57	95.87	98.69	99.86	100	100	14

Appendix D
EVC Classes, Areas and Inundation Levels

Region	Lakes Covered	EVC	Area	Inundation Level (mAHD)										
Bitterang	Bitterang	FRGW	Ha	-	0.31	5.85	16.29	37.44	69.25	109.26	163.15	200.38	220.75	233.38
			%	-	0.12	2.32	6.45	14.81	27.39	43.22	64.54	79.27	87.33	92.32
		BBW	Ha	-	-	-	-	0.04	0.51	2.98	24.92	71.26	133.83	218.14
			%	-	-	-	-	0.01	0.13	0.75	6.31	18.06	33.92	55.28
		RGW-FTU	Ha	14.6	17.74	21.18	25.58	32.58	71.12	140.32	229.45	325.4	409.49	487.28
			%	2.36	2.87	3.43	4.14	5.28	11.52	22.72	37.16	52.69	66.31	78.91
		Not Subject to Inundation	Ha	0	0	0.01	0.01	0.02	0.27	1.41	9.13	29.57	86.42	147.75
			%	0	0	0	0	0	0.04	0.23	1.46	4.74	13.86	23.69
		Wetland	Ha	0.11	86.89	124.88	135.75	142.22	146.4	147.54	147.97	148.21	148.28	148.37
			%	0.07	58.14	83.57	90.85	95.18	97.97	98.73	99.02	99.18	99.23	99.29
Cantala		RGF	Ha	1.6	3.08	5.86	12.97	27.92	51.87	80.48	101.16	115.82	128.24	136.26
			%	1.16	2.23	4.24	9.39	20.22	37.55	58.26	73.24	83.85	92.84	98.65
		FRGW	Ha	-	-	-	0	0.16	2.87	8.37	13.32	20.89	37.09	43.16
			%	-	-	-	0	0.37	6.52	19.02	30.27	47.46	84.28	98.07
		BBW	Ha	0.02	0.1	0.39	1.43	2.61	5.8	22.91	76.13	160.1	230.24	276.53
			%	0.01	0.03	0.12	0.43	0.78	1.74	6.88	22.88	48.11	69.18	83.09
		RGW-FTU	Ha	6.35	8.73	15.71	27.28	60.76	138.37	219.27	281.62	324.83	355.23	375.78
			%	1.6	2.2	3.97	6.89	15.34	34.93	55.36	71.1	82.01	89.69	94.88
		LS	Ha	-	-	-	-	-	-	0.23	0.33	14.22	25.65	26.78
			%	-	-	-	-	-	-	0.87	1.23	53.07	95.71	99.94
		Not Subject to Inundation	Ha	0.32	0.35	0.44	0.53	0.54	0.55	0.57	0.79	1.32	2.9	6.2
			%	0.34	0.37	0.47	0.57	0.58	0.59	0.61	0.84	1.41	3.11	6.63
		Wetland	Ha	0	53.4	83.96	110.74	128.16	132.59	135.39	137.37	138.75	140.05	140.98
			%	0	37.66	59.21	78.1	90.39	93.51	95.48	96.88	97.85	98.77	99.42
		Watercourse	Ha	6.58	7.29	7.63	7.97	8.55	9.18	9.56	9.66	9.72	9.81	9.85
			%	66.7	73.9	77.35	80.8	86.59	93.04	96.91	97.93	98.49	99.37	99.78

Appendix E
Fauna Reported from Hattah Lakes

Fauna reported from Hattah Lakes in the Atlas of Victorian Wildlife. Species are grouped into the guilds referred to in the text. Conservation ratings are reported for:

- significance in Victoria (VROTS where v=vulnerable, e=endangered, n=near threatened, c=critically endangered, d=data deficient);
- species of national conservation significance under the Environment Protection and Biodiversity Conservation Act (EPBC where VU=vulnerable)
- listing under the Flora and Fauna Guarantee Act (FFG);
- listing under the Japan Migratory Bird Agreement (JAMBA); and
- listing under the China Migratory Bird Agreement (CAMBA).

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
Waterbirds							
	Dabbling Ducks						
	Australasian Shoveler	*Anas rhynchotis*	v				
	Freckled Duck	*Stictonetta naevosa*	e		L		
	Grey Teal	*Anas gracilis*					
	Pacific Black Duck	*Anas superciliosa*					
	Chestnut Teal	*Anas castanea*					
	Pink-eared Duck	*Malacorhynchus membranaceus*					
	Mallard	*Anas platyrhynchos*					
	Deep Water Divers						
	Hardhead	*Aythya australis*	v				
	Musk Duck	*Biziura lobata*	v				
	Blue-billed Duck	*Oxyura australis*	e		L		
	Grazing Water Fowl						
	Australian Wood Duck	*Chenonetta jubata*					
	Australian Shelduck	*Tadorna tadornoides*					
	Black Swan	*Cygnus atratus*					
	Plumed Whistling-Duck	*Dendrocygna eytoni*					
	Large Waders						
	Royal Spoonbill	*Platalea regia*	v				
	Glossy Ibis	*Plegadis falcinellus*	n				1
	Yellow-billed Spoonbill	*Platalea flavipes*					
	Australian White Ibis	*Threskiornis molucca*					
	Straw-necked Ibis	*Threskiornis spinicollis*					
	Small Waders						
	Sharp-tailed Sandpiper	*Calidris acuminata*				1	1
	Marsh Sandpiper	*Tringa stagnatilis*				1	1
	Ruddy Turnstone	*Arenaria interpres*				1	1
	Red-necked Stint	*Calidris ruficollis*				1	1
	Common Greenshank	*Tringa nebularia*				1	1

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Common Sandpiper	*Actitis hypoleucos*	v			1	1
	Painted Snipe	*Rostratula benghalensis australis*	c	VU	L		1
	Black-winged Stilt	*Himantopus himantopus*					
	Black-fronted Dotterel	*Elseyornis melanops*					
	Red-necked Avocet	*Recurvirostra novaehollandiae*					
	Red-kneed Dotterel	*Erythrogonys cinctus*					
	Banded Stilt	*Cladorhynchus leucocephalus*					
	Red-capped Plover	*Charadrius ruficapillus*					
	Shoreline Foragers						
	Eurasian Coot	*Fulica atra*					
	Black-tailed Native-hen	*Gallinula ventralis*					
	Purple Swamphen	*Porphyrio porphyrio*					
	Dusky Moorhen	*Gallinula tenebrosa*					
	Australian Spotted Crake	*Porzana fluminea*					
	Masked Lapwing	*Vanellus miles*					
	Piscivores						
	Great Egret	*Ardea alba*	v		L	1	1
	Pied Cormorant	*Phalacrocorax varius*	n				
	Intermediate Egret	*Ardea intermedia*	c		L		
	Little Egret	*Egretta garzetta*	e		L		
	Whiskered Tern	*Chlidonias hybridus*	n				
	Caspian Tern	*Sterna caspia*	n		L	1	1
	Nankeen Night Heron	*Nycticorax caledonicus*	n				
	Australasian Bittern	*Botaurus poiciloptilus*	e		L		
	Gull-billed Tern	*Sterna nilotica*	e		L		
	Little Bittern	*Ixobrychus minutus*	e		L		
	White-faced Heron	*Egretta novaehollandiae*					
	Australian Pelican	*Pelecanus conspicillatus*					
	Great Cormorant	*Phalacrocorax carbo*					
	White-necked Heron	*Ardea pacifica*					
	Great Crested Grebe	*Podiceps cristatus*					
	Little Black Cormorant	*Phalacrocorax sulcirostris*					
	Australasian Grebe	*Tachybaptus novaehollandiae*					
	Darter	*Anhinga melanogaster*					
	Little Pied Cormorant	*Phalacrocorax melanoleucos*					
	Silver Gull	*Larus novaehollandiae*					
	Hoary-headed Grebe	*Poliocephalus poliocephalus*					
Birds of Prey							
	Large Carnivores						
	White-bellied Sea-eagle	*Haliaeetus leucogaster*	v		L		1
	Wedge-tailed Eagle	*Aquila audax*					
	Small Carnivores						
	Black-shouldered Kite	*Elanus axillaris*					
	Black Falcon	*Falco subniger*	v				

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Spotted Harrier	*Circus assimilis*	n				
	Nankeen Kestrel	*Falco cenchroides*					
	Swamp Harrier	*Circus approximans*					
	Brown Falcon	*Falco berigora*					
	Australian Hobby	*Falco longipennis*					
	Barn Owl	*Tyto alba*					
	Peregrine Falcon	*Falco peregrinus*					
	Brown Goshawk	*Accipiter fasciatus*					
	Collared Sparrowhawk	*Accipiter cirrhocephalus*					
	Whistling Kite	*Haliastur sphenurus*					
	Black Kite	*Milvus migrans*					
	Little Eagle	*Hieraaetus morphnoides*					
	Black-breasted Buzzard	*Hamirostra melanosternon*					
	Tawny Frogmouth	*Podargus strigoides*					
Bushbirds							
	Insectivores						
	Brown Songlark	*Cincloramphus cruralis*					
	Buff-rumped Thornbill	*Acanthiza reguloides*					
	Red-backed Kingfisher	*Todiramphus pyrrhopygia*	n				
	Apostlebird	*Struthidea cinerea*			L		
	Crested Bellbird	*Oreoica gutturalis*	n		L		
	Hooded Robin	*Melanodryas cucullata*	n		L		
	Bush Stone-curlew	*Burhinus grallarius*	e		L		
	Fork-tailed Swift	*Apus pacificus*				1	1
	Mallee Emu-wren	*Stipiturus mallee*	v	VU	L		
	Brown Quail	*Coturnix ypsilophora*	n				
	Ground Cuckoo-shrike	*Coracina maxima*	v		L		
	Banded Lapwing	*Vanellus tricolor*					
	Little Grassbird	*Megalurus gramineus*					
	Shy Heathwren	*Hylacola cauta*					
	Australian Magpie	*Gymnorhina tibicen*					
	Magpie-lark	*Grallina cyanoleuca*					
	Australian Raven	*Corvus coronoides*					
	Laughing Kookaburra	*Dacelo novaeguineae*					
	White-winged Chough	*Corcorax melanorhamphos*					
	Striated Pardalote	*Pardalotus striatus*					
	Willie Wagtail	*Rhipidura leucophrys*					
	Pied Butcherbird	*Cracticus nigrogularis*					
	Welcome Swallow	*Hirundo neoxena*					
	Grey Shrike-thrush	*Colluricincla harmonica*					
	Weebill	*Smicrornis brevirostris*					
	Chestnut-rumped Thornbill	*Acanthiza uropygialis*					
	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*					
	Splendid Fairy-wren	*Malurus splendens*					
	Red-capped Robin	*Petroica goodenovii*					
	Tree Martin	*Hirundo nigricans*					
	Southern Whiteface	*Aphelocephala leucopsis*					
	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*					
	Southern Boobook	*Ninox novaeseelandiae*					
	Yellow Thornbill	*Acanthiza nana*					

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Inland Thornbill	*Acanthiza apicalis*					
	Jacky Winter	*Microeca fascinans*					
	Spotted Pardalote	*Pardalotus punctatus*					
	Rufous Whistler	*Pachycephala rufiventris*					
	Brown Treecreeper	*Climacteris picumnus*	n				
	Little Crow	*Corvus bennetti*					
	White-browed Babbler	*Pomatostomus superciliosus*					
	Variegated Fairy-wren	*Malurus lamberti*					
	Pallid Cuckoo	*Cuculus pallidus*					
	Little Raven	*Corvus mellori*					
	Grey Fantail	*Rhipidura fuliginosa*					
	White-winged Triller	*Lalage sueurii*					
	Silvereye	*Zosterops lateralis*					
	White-browed Woodswallow	*Artamus superciliosus*					
	Fairy Martin	*Hirundo ariel*					
	Horsfield's Bronze-Cuckoo	*Chrysococcyx basalis*					
	Grey Currawong	*Strepera versicolor*					
	Dusky Woodswallow	*Artamus cyanopterus*					
	Rainbow Bee-eater	*Merops ornatus*					
	Restless Flycatcher	*Myiagra inquieta*					
	Common Starling	*Sturnus vulgaris*					
	Gilbert's Whistler	*Pachycephala inornata*					
	Australian Owlet-nightjar	*Aegotheles cristatus*					
	Masked Woodswallow	*Artamus personatus*					
	Rufous Songlark	*Cincloramphus mathewsi*					
	Varied Sittella	*Daphoenositta chrysoptera*					
	Western Gerygone	*Gerygone fusca*					
	Chestnut-crowned Babbler	*Pomatostomus ruficeps*					
	Richard's Pipit	*Anthus novaeseelandiae*					
	Black-faced Woodswallow	*Artamus cinereus*					
	Common Blackbird	*Turdus merula*					
	Fan-tailed Cuckoo	*Cacomantis flabelliformis*					
	White-breasted Woodswallow	*Artamus leucorynchus*					
	White-bellied Cuckoo-shrike	*Coracina papuensis*					
	White-fronted Chat	*Epthianura albifrons*					
	White-winged Fairy-wren	*Malurus leucopterus*					
	Crimson Chat	*Epthianura tricolor*					
	Flame Robin	*Petroica phoenicea*					
	Golden Whistler	*Pachycephala pectoralis*					
	Spotted Nightjar	*Eurostopodus argus*					
	Superb Fairy-wren	*Malurus cyaneus*					
	Crested Shrike-tit	*Falcunculus frontatus*					
	Miner	*Manorina* sp.					
	Southern Scrub-robin	*Drymodes brunneopygia*					
	Striated Thornbill	*Acanthiza lineata*					
	Stubble Quail	*Coturnix pectoralis*					
	Plains-wanderer*	*Pedionomus torquatus*	c	VU	L		
	Sacred Kingfisher	*Todiramphus sanctus*					
	White-backed Swallow	*Cheramoeca leucosternus*					
	Grey Butcherbird	*Cracticus torquatus*					

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Arboreal Granivores						
	Regent Parrot*	*Polytelis anthopeplus*	v	VU	L		
	Major Mitchell's Cockatoo	*Cacatua leadbeateri*	v		L		
	Elegant Parrot	*Neophema elegans*	v				
	Galah	*Cacatua roseicapilla*					
	Crimson Rosella	*Platycercus elegans*					
	Sulphur-crested Cockatoo	*Cacatua galerita*					
	Red-rumped Parrot	*Psephotus haematonotus*					
	Australian Ringneck	*Barnardius zonarius*					
	Little Corella	*Cacatua sanguinea*					
	Mulga Parrot	*Psephotus varius*					
	Blue Bonnet	*Northiella haematogaster*					
	Cockatiel	*Nymphicus hollandicus*					
	Budgerigar	*Melopsittacus undulatus*					
	Blue-winged Parrot	*Neophema chrysostoma*					
	Long-billed Corella	*Cacatua tenuirostris*					
	Musk Lorikeet	*Glossopsitta concinna*					
	Eastern Rosella	*Platycercus eximius*					
	Ground Granivores						
	Common Bronzewing	*Phaps chalcoptera*					
	Peaceful Dove	*Geopelia striata*					
	Crested Pigeon	*Ocyphaps lophotes*					
	Zebra Finch	*Taeniopygia guttata*					
	Nectivores / Omnivores						
	Grey-fronted Honeyeater	*Lichenostomus plumulus*	v				
	Painted Honeyeater	*Grantiella picta*	v		L		
	Purple-gaped Honeyeater	*Lichenostomus cratitius*	v				
	Noisy Miner	*Manorina melanocephala*					
	White-plumed Honeyeater	*Lichenostomus penicillatus*					
	Blue-faced Honeyeater	*Entomyzon cyanotis*					
	Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*					
	Singing Honeyeater	*Lichenostomus virescens*					
	Yellow-plumed Honeyeater	*Lichenostomus ornatus*					
	Red Wattlebird	*Anthochaera carunculata*					
	Yellow-throated Miner	*Manorina flavigula*					
	White-eared Honeyeater	*Lichenostomus leucotis*					
	Striped Honeyeater	*Plectorhyncha lanceolata*					
	Little Friarbird	*Philemon citreogularis*					
	Brown-headed Honeyeater	*Melithreptus brevirostris*					
	Noisy Friarbird	*Philemon corniculatus*					
	Black Honeyeater	*Certhionyx niger*					
	Fuscous Honeyeater	*Lichenostomus fuscus*					
	White-fronted Honeyeater	*Phylidonyris albifrons*					
	Pied Honeyeater	*Certhionyx variegatus*					
	Frugivores						
	Emu	*Dromaius novaehollandiae*					
	Mistletoebird	*Dicaeum hirundinaceum*					
	Rose-crowned Fruit-Dove	*Ptilinopus regina*					
Frogs							
	Terrestrial Frogs						

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Barking Marsh Frog	*Limnodynastes fletcheri*	d				
	Plains Froglet	*Crinia parinsignifera*					
	Spotted Marsh Frog	*Limnodynastes tasmaniensis*					
	Peron's Tree Frog	*Litoria peronii*					
	Common Froglet	*Crinia signifera*					
	Burrowing Frogs						
	Southern Bullfrog	*Limnodynastes dumerilii*					
	Mallee Spadefoot Toad	*Neobatrachus pictus*					
	Common Spadefoot Toad	*Neobatrachus sudelli*					
Mammals							
	Aquatic Mammals						
	Water Rat	*Hydromys chrysogaster*					
	Arboreal Herbivores						
	Common Brushtail Possum	*Trichosurus vulpecula*					
	Ground Insectivores						
	Short-beaked Echidna	*Tachyglossus aculeatus*					
	Ground Granivores						
	Mitchell's Hopping-mouse	*Notomys mitchelli*	n				
	Aerial Insectivores						
	Greater Long-eared Bat	*Nyctophilus timoriensis*	v	VU	L		
	Gould's Wattled Bat	*Chalinolobus gouldii*					
	Little Forest Bat	*Vespadelus vulturnus*					
	Lesser Long-eared Bat	*Nyctophilus geoffroyi*					
	Inland Broad-nosed Bat	*Scotorepens balstoni*					
	Southern Forest Bat	*Vespadelus regulus*					
	Southern Freetail Bat	*Mormopterus* sp. 1					
	White-striped Freetail Bat	*Tadarida australis*					
	Chocolate Wattled Bat	*Chalinolobus morio*					
	Inland Forest Bat	*Vespadelus baverstocki*					
	Piscivores						
	Southern Myotis	*Myotis macropus*					
	Large Grazers						
	Red Kangaroo	*Macropus rufus*	n				
	Western Grey Kangaroo	*Macropus fuliginosus*					
	Black Wallaby	*Wallabia bicolor*					
Reptiles							
	Aquatic Reptiles						
	Broad-shelled Turtle	*Chelodina expansa*					
	Snake-necked Turtle	*Chelodina longicollis*					
	Macquarie Turtle	*Emydura maccquarii*					
	Large Carnivores						
	Carpet Python	*Morelia spilota metcalfei*	e		L		
	Tree Goanna	*Varanus varius*	v				
	Sand Goanna	*Varanus gouldii*					
	Nobbi Dragon	*Amphibolurus nobbi coggeri*					
	Eastern Brown Snake	*Pseudonaja textilis*					

Appendix E
Fauna Reported from Hattah Lakes

Fauna Group	Guild and Common Name	Scientific Name	Conservation Rating				
			VROTS	EPBC	FFG	JAMBA	CAMBA
	Small Carnivores						
	Boulenger's Skink	*Morethia boulengeri*					
	Tree Dtella	*Gehyra variegata*					
	Grey's Skink	*Menetia greyii*					
	Spotted Burrowing Skink	*Lerista punctatovittata*					
	Carnaby's Wall Skink	*Cryptoblepharus carnabyi*					
	Beaded Gecko	*Diplodactylus damaeus*					
	Marbled Gecko	*Phyllodactylus marmoratus*					
	Peters's Blind Snake	*Ramphotyphlops bituberculatus*					
	Southern Spiny-tailed Gecko	*Diplodactylus intermedius*					
	West Australian Blind Snake	*Ramphotyphlops australis*					
	Regal Striped Skink	*Ctenotus regius*					
Fish							
	Large Fish						
	Golden Perch	*Macquaria ambigua*	v				
	Bony Bream	*Nematalosa erebi*					
	Silver Perch	*Bidyanus bidyanus*	c		L		
	Small Fish						
	Australian Smelt	*Retropinna semoni*					
	Vegetation-dependent Fish						
	Freshwater Catfish	*Tandanus tandanus*	e		L		
	Fly-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	d		L		
	Murray Hardyhead	*Craterocephalus fluviatilis*	c	VU	L		
	Flatheaded Gudgeon	*Philypnodon grandiceps*					
	Western Carp Gudgeon	*Hypseleotris klunzingeri*					
Invertebrates							
	Aquatic Invertebrates						
	River Snail	*Notopala sublineata*			L		

Appendix F
Threatened Flora Reported from Hattah Lakes

The distribution and conservation status of flora with conservation significance reported in the Flora Information System in the study area.

Conservation ratings are reported for:

- significance in Victoria (VROTS where v=vulnerable, e=endangered, x=extinct);
- species of national conservation significance under the Environment Protection and Biodiversity Conservation Act (EPBC where E=endangered); and
- listing under the Flora and Fauna Guarantee Act (FFG where L=listed, N=nominated for listing).

Scientific Name	Common Name	Conservation Status			Distribution					
		FFG	EPBC	VROTS	Lake Beds	Red Gum Forest	Fringing Red Gum Woodland	Red Gum with Flood-tolerant Understorey	Lignum Shrubland	Black Box Woodland
Amaranthus macrocarpus var. macrocarpus	Dwarf Amaranth			v					x	
Ammannia multiflora	Jerry-jerry			v			x			
Aristida holathera var. holathera	Tall Kerosene Grass			v			x			
Atriplex holocarpa	Pop Saltbush			v			x			x
Atriplex spinibractea	Spiny-fruit Saltbush			e	x					
Bergia trimera	Small Water-fire			v				x		
Cullen cinereum	Hoary Scurf-pea	L		e	x					
Cullen pallidum	Woolly Scurf-pea	N		e			x	x		x
Cullen patens	Spreading Scurf-pea	L		e						x
Cullen tenax	Tough Scurf-pea	L		e			x	x	x	
Cyperus flaccidus	Lax Flat-sedge			v				x		
Cyperus nervulosus	Annual Flat-sedge	N		e						x
Cyperus pygmaeus	Dwarf Flat-sedge			v	x		x			x
Cyperus rigidellus	Curly Flat-sedge			e						x
Dianella porracea	Riverine Flax-lily			v			x			
Digitaria ammophila	Silky Umbrella-grass			v			x			
Drosera indica	Flycatcher			v						
Eragrostis australasica	Cane Grass			v						x
Eragrostis lacunaria	Purple Love-grass			v	x		x	x		x
Eragrostis setifolia	Bristly Love-grass			v	x					
Glycine canescens	Silky Glycine	L		e				x		x

Appendix F
Threatened Flora Reported from Hattah Lakes

Scientific Name	Common Name	Conservation Status			Distribution					
		FFG	EPBC	VROTS	Lake Beds	Red Gum Forest	Fringing Red Gum Woodland	Red Gum with Flood-tolerant Understorey	Lignum Shrubland	Black Box Woodland
Isolepis congrua	Slender Club-sedge	L		v						x
Jasminum didymum subsp. lineare	Desert Jasmine			v						x
Lepidium monoplocoides	Winged Peppercress	L	E	e	x		x			
Lipocarpha microcephala	Button Rush			v			x	x		x
Olearia subspicata	Spiked Daisy-bush			v						x
Ophioglossum polyphyllum	Upright Adder's-tongue			v						x
Orobanche cernua var. australiana	Australian Broomrape			v						x
Phyllanthus lacunarius	Lagoon Spurge			v	x					
Scaevola depauperata	Skeleton Fan-flower			e						
Sclerolaena patenticuspis	Spear-fruit Copperburr			v						
Sida ammophila	Sand Sida			v			x	x		x
Sida fibulifera	Pin Sida			v				x		x
Sida intricata	Twiggy Sida			v				x		
Stenanthemum notiale subsp. notiale	Trident Spyridium			x				x		
Swainsona phacoides	Dwarf Swainson-pea	N		e				x		x
Swainsona sericea	Silky Swainson-pea	N		v				x		x
Zygophyllum compressum	Rabbit-ears Twin-leaf			v						x

Appendix G
Modelled Water Management Options
Spells Analysis

Region	Site	Level	Elevation mAHD	CURRENT Median Event Duration (weeks)	% Years with Exceedance	% Time Exceeded	Number of Spells
Far North	Bitterang	<25% full	40.71	143	73%	62%	13
		50% Full	41.3	76	47%	28%	15
		top of wetland	42.5	18	28%	7%	20
		A bit above wetland	43	4	17%	3%	19
		Above wetland	43.5	5	14%	2%	15
		Well above wetland	44	5	10%	1%	9
Cantala	Cantala 1	<25% full	40.72	69	74%	58%	27
		50% Full	41.28	56	53%	29%	26
		100% Full	42.4	4	25%	4%	29
		A bit above wetland	43	4	23%	4%	26
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5	12%	2%	12
Cantala	Cantala 2	<25% full	40.72	119.5	79%	69%	16
		50% Full	41.28	65	41%	25%	15
		100% Full	42.4	4	22%	3%	23
		A bit above wetland	43	3.5	20%	3%	22
		Above wetland	43.5	4	18%	3%	21
		Well above wetland	44	5	12%	2%	12
Central	Lockie	<25% full	41.48	35.5	74%	44%	30
		50% Full	41.72	44	76%	46%	37
		100% Full	42.2	23	70%	23%	46
		A bit above wetland	42.5	15	51%	14%	44
		Above wetland	43	6.5	40%	8%	44
		Well above wetland	43.5	4	28%	5%	33
Central	Little Hattah	<25% full	41.55	77	87%	65%	31
		50% Full	41.8	27	60%	28%	31
		100% Full	42.3	14.5	50%	13%	40
		A bit above wetland	42.5	11	41%	9%	37
		Above wetland	43	5.5	29%	5%	32
		Well above wetland	43.5	4	25%	4%	28
Northern	Mournpall	<25% full	40.02	81	52%	41%	17
		50% Full	40.81	85.5	64%	42%	20
		100% Full	42.4	16	35%	8%	27
		A bit above wetland	43	4	25%	4%	28
		Above wetland	43.5	3.5	23%	3%	26
		Well above wetland	44	4	20%	3%	22
Northern	Yerang	<25% full	41.56	79	87%	65%	30
		50% Full	41.91	20	57%	24%	34
		100% Full	42.6	8	42%	9%	43
		A bit above wetland	43	5	35%	6%	37
		Above wetland	43.5	4	25%	4%	28
		Well above wetland	44	3	22%	3%	24
Northern	Yelwell	<25% full	41.22	84	72%	51%	23
		50% Full	41.54	59	67%	39%	28
		100% Full	42.2	21	54%	16%	36
		A bit above wetland	42.5	10	40%	9%	37
		Above wetland	43	5	28%	5%	33
		Well above wetland	43.5	4.5	24%	4%	26
Southern	Hattah	<25% full	39.98	65	41%	32%	14
		50% Full	40.75	114	75%	56%	19
		100% Full	42.3	14.5	50%	13%	40
		A bit above wetland	42.5	11	41%	9%	37
		Above wetland	43	5.5	29%	5%	32
		Well above wetland	43.5	4	25%	4%	28
Southern	Arawak	<25% full	40.53	73	54%	41%	18
		50% Full	41.12	76.5	72%	47%	24
		100% Full	42.3	15	47%	11%	36
		A bit above wetland	42.5	12	37%	8%	33
		Above wetland	43	4	27%	5%	31
		Well above wetland	43.5	4.5	24%	4%	26
Southern	Brockie	<25% full	40.57	75.5	57%	41%	18
		50% Full	41.14	77	49%	29%	15
		100% Full	42.3	20	35%	9%	20
		A bit above wetland	42.5	14	27%	6%	20
		Above wetland	43	3.5	22%	3%	24
		Well above wetland	43.5	3.5	20%	3%	22

Region	Site	Level	Elevation mAHD	Scenario A Median Event Duration (weeks)	% Years with Exceedance	% Time Exceeded	Number of Spells
Far North	Bitterang	<25% full	40.71	136	71%	61%	13
		50% Full	41.3	84	49%	30%	15
		top of wetland	42.5	18.5	32%	8%	20
		A bit above wetland	43	4	17%	3%	19
		Above wetland	43.5	5	14%	2%	15
		Well above wetland	44	5	10%	1%	9
Cantala	Cantala 1	<25% full	40.72	32	68%	45%	35
		50% Full	41.28	22	71%	36%	43
		100% Full	42.4	5	34%	6%	35
		A bit above wetland	43	3.5	25%	4%	28
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5.5	12%	2%	12
Cantala	Cantala 2	<25% full	40.72	42	70%	47%	32
		50% Full	41.28	49	65%	34%	30
		100% Full	42.4	5	28%	5%	33
		A bit above wetland	43	4	23%	4%	25
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5	12%	2%	12
Central	Lockie	<25% full	41.48	42	62%	33%	28
		50% Full	41.72	65	84%	57%	34
		100% Full	42.2	25	78%	30%	53
		A bit above wetland	42.5	18	62%	20%	53
		Above wetland	43	7	42%	9%	45
		Well above wetland	43.5	5	28%	5%	33
Central	Little Hattah	<25% full	41.55	39	79%	49%	33
		50% Full	41.8	35.5	74%	39%	40
		100% Full	42.3	20	58%	18%	42
		A bit above wetland	42.5	10	46%	11%	43
		Above wetland	43	4	34%	6%	35
		Well above wetland	43.5	4	25%	4%	28
Northern	Mournpall	<25% full	40.02	32	39%	27%	17
		50% Full	40.81	101	76%	56%	23
		100% Full	42.4	17	42%	10%	31
		A bit above wetland	43	4	25%	4%	29
		Above wetland	43.5	4	23%	4%	26
		Well above wetland	44	4	20%	3%	22
Northern	Yerang	<25% full	41.56	37	86%	56%	40
		50% Full	41.91	17	70%	29%	49
		100% Full	42.6	8.5	45%	10%	44
		A bit above wetland	43	6	35%	6%	37
		Above wetland	43.5	4	25%	4%	28
		Well above wetland	44	3	22%	3%	24
Northern	Yelwell	<25% full	41.22	76	64%	48%	22
		50% Full	41.54	107	67%	47%	21
		100% Full	42.2	23	62%	21%	38
		A bit above wetland	42.5	15	47%	12%	41
		Above wetland	43	4	34%	6%	35
		Well above wetland	43.5	4	25%	4%	28
Southern	Hattah	<25% full	39.98	66.5	28%	19%	10
		50% Full	40.75	126.5	85%	70%	18
		100% Full	42.3	20	55%	17%	39
		A bit above wetland	42.5	10	46%	11%	43
		Above wetland	43	4	34%	6%	35
		Well above wetland	43.5	4	25%	4%	28
Southern	Arawak	<25% full	40.53	42	49%	34%	17
		50% Full	41.12	117	76%	53%	21
		100% Full	42.3	20	57%	17%	39
		A bit above wetland	42.5	11	46%	11%	43
		Above wetland	43	4	34%	6%	35
		Well above wetland	43.5	4	25%	4%	28
Southern	Brockie	<25% full	40.57	61	50%	36%	17
		50% Full	41.14	115	76%	53%	23
		100% Full	42.3	20	57%	17%	39
		A bit above wetland	42.5	14.5	42%	10%	38
		Above wetland	43	5.5	30%	5%	32
		Well above wetland	43.5	4	25%	4%	28

Region	Site	Level	Elevation mAHD	Scenario B Median Event Duration (weeks)	% Years with Exceedance	% Time Exceeded	Number of Spells
Far North	Bitterang	<25% full	40.71	136	71%	61%	13
		50% Full	41.3	84	49%	30%	15
		top of wetland	42.5	18.5	32%	8%	20
		A bit above wetland	43	4	17%	3%	19
		Above wetland	43.5	5	14%	2%	15
		Well above wetland	44	5	10%	1%	9
Cantala	Cantala 1	<25% full	40.72	30	46%	31%	21
		50% Full	41.28	31	78%	56%	31
		100% Full	42.4	59.5	50%	28%	22
		A bit above wetland	43	22	40%	12%	21
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5.5	12%	2%	12
Cantala	Cantala 2	<25% full	40.72	40	66%	45%	29
		50% Full	41.28	44.5	67%	36%	30
		100% Full	42.4	5	28%	5%	33
		A bit above wetland	43	4.5	24%	4%	26
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5	12%	2%	12
Central	Lockie	<25% full	41.48	33	45%	25%	23
		50% Full	41.72	90	87%	67%	29
		100% Full	42.2	37	79%	49%	39
		A bit above wetland	42.5	27	73%	38%	42
		Above wetland	43	17	55%	16%	41
		Well above wetland	43.5	5	28%	5%	33
Central	Little Hattah	<25% full	41.55	36	59%	39%	26
		50% Full	41.8	71.5	79%	52%	32
		100% Full	42.3	45	66%	36%	30
		A bit above wetland	42.5	36.5	59%	30%	30
		Above wetland	43	20	47%	13%	31
		Well above wetland	43.5	4	25%	4%	28
Northern	Mournpall	<25% full	40.02	29	32%	22%	14
		50% Full	40.81	139.5	80%	64%	16
		100% Full	42.4	60	50%	28%	21
		A bit above wetland	43	22	40%	12%	22
		Above wetland	43.5	4	23%	4%	25
		Well above wetland	44	4	20%	3%	22
Northern	Yerang	<25% full	41.56	35	64%	43%	31
		50% Full	41.91	24.5	77%	44%	42
		100% Full	42.6	19	57%	26%	34
		A bit above wetland	43	19	47%	13%	32
		Above wetland	43.5	4	25%	4%	28
		Well above wetland	44	3	22%	3%	24
Northern	Yelwell	<25% full	41.22	74	50%	37%	17
		50% Full	41.54	114	75%	57%	19
		100% Full	42.2	65	66%	39%	28
		A bit above wetland	42.5	42	60%	31%	29
		Above wetland	43	20.5	47%	14%	30
		Well above wetland	43.5	4	25%	4%	28
Southern	Hattah	<25% full	39.98	55	23%	16%	8
		50% Full	40.75	221	88%	76%	13
		100% Full	42.3	61	65%	36%	29
		A bit above wetland	42.5	36.5	59%	30%	30
		Above wetland	43	20	47%	13%	31
		Well above wetland	43.5	4	25%	4%	28
Southern	Arawak	<25% full	40.53	62	37%	28%	11
		50% Full	41.12	128	78%	63%	15
		100% Full	42.3	62	64%	35%	28
		A bit above wetland	42.5	36.5	59%	30%	30
		Above wetland	43	20	47%	13%	31
		Well above wetland	43.5	4	25%	4%	28
Southern	Brockie	<25% full	40.57	61	38%	29%	13
		50% Full	41.14	128	77%	63%	15
		100% Full	42.3	62	64%	35%	28
		A bit above wetland	42.5	56	55%	29%	26
		Above wetland	43	21	45%	13%	27
		Well above wetland	43.5	4	25%	4%	28

Region	Site	Level	Elevation mAHD	Scenario C Median Event Duration (weeks)	% Years with Exceedance	% Time Exceeded	Number of Spells
Far North	Bitterang	<25% full	40.71	136	71%	61%	13
		50% Full	41.3	84	49%	30%	15
		top of wetland	42.5	18.5	32%	8%	20
		A bit above wetland	43	4	17%	3%	19
		Above wetland	43.5	5	14%	2%	15
		Well above wetland	44	5	10%	1%	9
Cantala	Cantala 1	<25% full	40.72	30	46%	31%	21
		50% Full	41.28	31	78%	56%	31
		100% Full	42.4	59.5	50%	28%	22
		A bit above wetland	43	22	40%	12%	21
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5.5	12%	2%	12
Cantala	Cantala 2	<25% full	40.72	40	66%	45%	29
		50% Full	41.28	44.5	67%	36%	30
		100% Full	42.4	5	28%	5%	33
		A bit above wetland	43	4.5	24%	4%	26
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5	12%	2%	12
Central	Lockie	<25% full	41.48	33	45%	25%	23
		50% Full	41.72	90	87%	67%	29
		100% Full	42.2	35	80%	49%	41
		A bit above wetland	42.5	27	73%	38%	42
		Above wetland	43	10	58%	17%	45
		Well above wetland	43.5	5.5	30%	5%	32
Central	Little Hattah	<25% full	41.55	40	47%	31%	19
		50% Full	41.8	86	83%	62%	27
		100% Full	42.3	34	77%	45%	39
		A bit above wetland	42.5	26	72%	38%	41
		Above wetland	43	10	58%	17%	45
		Well above wetland	43.5	5.5	30%	5%	32
Northern	Mournpall	<25% full	40.02	27	25%	17%	9
		50% Full	40.81	136	86%	73%	14
		100% Full	42.4	56	66%	35%	29
		A bit above wetland	43	21	48%	14%	31
		Above wetland	43.5	4	25%	4%	28
		Well above wetland	44	3	22%	3%	24
Northern	Yerang	<25% full	41.56	37	54%	36%	24
		50% Full	41.91	76.5	80%	54%	30
		100% Full	42.6	25	63%	31%	36
		A bit above wetland	43	18	53%	15%	39
		Above wetland	43.5	5	27%	5%	32
		Well above wetland	44	3	22%	3%	24
Northern	Yelwell	<25% full	41.22	70	50%	37%	17
		50% Full	41.54	117	75%	58%	17
		100% Full	42.2	70	67%	41%	25
		A bit above wetland	42.5	42	63%	33%	29
		Above wetland	43	17	55%	15%	41
		Well above wetland	43.5	5	27%	5%	31
Southern	Hattah	<25% full	39.98	139	51%	44%	9
		50% Full	40.75	158	59%	48%	9
		100% Full	42.3	72	42%	26%	15
		A bit above wetland	42.5	67	41%	24%	15
		Above wetland	43	23	38%	11%	18
		Well above wetland	43.5	4	22%	3%	24
Southern	Arawak	<25% full	40.53	154	55%	49%	9
		50% Full	41.12	134	55%	44%	10
		100% Full	42.3	72	42%	26%	15
		A bit above wetland	42.5	67	41%	24%	15
		Above wetland	43	23	38%	11%	18
		Well above wetland	43.5	4	22%	3%	24
Southern	Brockie	<25% full	40.57	145.5	57%	50%	10
		50% Full	41.14	132	54%	43%	10
		100% Full	42.3	72	42%	26%	15
		A bit above wetland	42.5	67	41%	24%	15
		Above wetland	43	23	38%	11%	18
		Well above wetland	43.5	4	22%	3%	24

Region	Site	Level	Elevation mAHD	Scenario D			
				Median Event Duration (weeks)	% Years with Exceedance	% Time Exceeded	Number of Spells
Far North	Bitterang	<25% full	40.71	136	71%	61%	13
		50% Full	41.3	84	49%	30%	15
		top of wetland	42.5	18.5	32%	8%	20
		A bit above wetland	43	4	17%	3%	19
		Above wetland	43.5	5	14%	2%	15
		Well above wetland	44	5	10%	1%	9
Cantala	Cantala 1	<25% full	40.72	30	46%	31%	21
		50% Full	41.28	31	78%	56%	31
		100% Full	42.4	59.5	50%	28%	22
		A bit above wetland	43	22	40%	12%	21
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5.5	12%	2%	12
Cantala	Cantala 2	<25% full	40.72	42.5	66%	45%	28
		50% Full	41.28	44.5	67%	36%	30
		100% Full	42.4	5	28%	5%	33
		A bit above wetland	43	4.5	24%	4%	26
		Above wetland	43.5	3.5	20%	3%	22
		Well above wetland	44	5	12%	2%	12
Central	Lockie	<25% full	41.48	38	38%	23%	20
		50% Full	41.72	90	88%	69%	29
		100% Full	42.2	73	80%	55%	33
		A bit above wetland	42.5	36	77%	43%	41
		Above wetland	43	21	61%	20%	45
		Well above wetland	43.5	5	34%	6%	35
Central	Little Hattah	<25% full	41.55	34.5	50%	33%	22
		50% Full	41.8	85	82%	61%	27
		100% Full	42.3	70	73%	48%	27
		A bit above wetland	42.5	44.5	70%	39%	32
		Above wetland	43	21.5	58%	19%	38
		Well above wetland	43.5	5.5	29%	5%	32
Northern	Mournpall	<25% full	40.02	140	51%	44%	9
		50% Full	40.81	156	59%	47%	9
		100% Full	42.4	69	42%	25%	15
		A bit above wetland	43	23	38%	11%	18
		Above wetland	43.5	3.5	22%	3%	24
		Well above wetland	44	4	18%	3%	21
Northern	Yerang	<25% full	41.56	138	72%	62%	13
		50% Full	41.91	95	49%	32%	15
		100% Full	42.6	53	41%	22%	16
		A bit above wetland	43	23	38%	11%	18
		Above wetland	43.5	3.5	22%	3%	24
		Well above wetland	44	4	18%	3%	21
Northern	Yelwell	<25% full	41.22	128	66%	58%	13
		50% Full	41.54	118.5	52%	38%	12
		100% Full	42.2	76	45%	28%	15
		A bit above wetland	42.5	68	41%	24%	15
		Above wetland	43	23	38%	11%	18
		Well above wetland	43.5	3.5	22%	3%	24
Southern	Hattah	<25% full	39.98	80	20%	14%	7
		50% Full	40.75	277.5	89%	80%	8
		100% Full	42.3	70	73%	48%	27
		A bit above wetland	42.5	44.5	70%	39%	32
		Above wetland	43	21.5	58%	19%	38
		Well above wetland	43.5	5.5	29%	5%	32
Southern	Arawak	<25% full	40.53	42	35%	25%	11
		50% Full	41.12	126	82%	68%	14
		100% Full	42.3	79	67%	45%	23
		A bit above wetland	42.5	57	66%	37%	29
		Above wetland	43	21.5	58%	19%	38
		Well above wetland	43.5	5.5	29%	5%	32
Southern	Brockie	<25% full	40.57	43	35%	25%	11
		50% Full	41.14	128	80%	68%	13
		100% Full	42.3	79	67%	45%	23
		A bit above wetland	42.5	57	66%	37%	29
		Above wetland	43	21.5	58%	19%	38
		Well above wetland	43.5	5.5	29%	5%	32