An Evaluation of the Proposed Chowilla Creek Environmental Regulator on Waterbird and Woodland Bird Populations

A Report Prepared for the

South Australian Murray-Darling Basin Natural Resource Management Board

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EXECUTIVE SUMMARY

The Chowilla Floodplain is considered a wetland system of high ecological value and is listed as one of six Significant Ecological Assets ('Icon Sites') in the Murray-Darling Basin by The Living Murray program of the Murray Darling Basin Commission. While Chowilla retains high ecological value, significant declines in ecosystem health have occurred, primarily in response to groundwater salinisation and a decrease in flood frequency. These declines have manifest themselves across the range of biological assets.

In response to this decline, a range of alternative management options have been proposed, with some of these (including pumping of water on to individual wetlands) having been implemented. Among the proposals is an environmental regulator to be placed across the downstream end of Chowilla creek near its confluence with the Murray River. This regulator would be used to increase the area and duration of floodplain inundation, under conditions of limited water availability. However, before such a proposal can be implemented, appropriate assessment of the benefits and risks for the ecological assets of Chowilla needs to be done. This report presents the results of such an analysis for the bird communities of Chowilla.

The responses of birds to regulator operation were compared among five alternative management scenarios. Scenarios 1 ('Do Nothing') and 2 considered low flow conditions (10,000 ML/day into SA), the difference between these being the operation of a regulator under full height (19.87m AHD), and Lock 6 raised to 19.87m, for Scenario 2. Under current conditions of water availability, these first two scenarios provide the most realistic comparison of the benefits and risks of regulator operation. Scenarios 3 and 4 consider the effects of regulator operation under a moderate flow scenario (50,000 ML/day to SA), while Scenario 5 allows for the comparison of these scenarios with a natural flood (80,000 ML/day to SA). For each of these scenarios we investigated the expected response of four components of Chowilla's bird fauna:

1. Opportunities for waterbird breeding
2. Availability of drought refugia for waterbirds
3. Habitat Availability for Ground-foraging Insectivorous Birds and other Ground-Dependent Terrestrial Birds
4. Habitat Availability for Leaf-Gleaning Insectivorous Birds

Within our analysis of availability of waterbird habitat, we also consider the specific responses of different waterbird guilds, such as piscivorous (fish-eating) birds, ducks and swans, and shorebirds. We also discuss some general aspects of the responses of birds to the alternative scenarios.

Bird responses to each scenario were classified (after Mallen-Cooper *et al.* 2007) to one of the following categories:

⬇ Major decrease in favourable conditions

↓ Slight decrease in favourable conditions

≈ Little or no change in favourable conditions

↑ Slight increase in favourable conditions

⬆ Major increase in favourable conditions

All of these changes in favourable conditions refer to changes relative to the conditions currently observed in Chowilla.

The responses of each of these components of Chowilla's bird community are summarised in Table i below. When compared to the current state, habitat conditions for birds in Chowilla are expected to continue to decline under a 'Do Nothing' scenario (Scenario 1). In contrast, all of the bird responses assessed in response to regulator operation and/or medium-high flows (Scenarios 2-5), were positive. Furthermore, some additional benefits of operating the regulator under low flow conditions (Scenario 2) are predicted, above even those responses expected under medium flow / no regulator conditions (Scenario 3).

Table i. A summary of the expected responses of birds to regulator operation. See text for explanations of Scenarios and responses arrow symbols. [1] the responses of ground-foraging and leaf-gleaning insectivores referred to here are the medium-term responses; for ground-foraging insectivores, some short-term negative impacts may be expected, through the inundation of terrestrial foraging habitats.

	Scenarios				
	1	**2**	**3**	**4**	**5**
General waterbird responses					
a) Breeding Opportunities	↓	⬆	↑	⬆	⬆
b) Refugia Availability	↓	⬆	↑	⬆	⬆
Specific waterbird responses					
a) Grazers (ducks & swans)	↓	↑	↑	⬆	⬆
b) Shorebirds	↓	↑	↑	⬆	⬆
c) Piscivores	↓	↑	↑	↑	⬆
Terrestrial Bird Responses					
Ground-foraging insectivores[1]	⬇	↑	↑	⬆	⬆
Leaf-gleaning Insectivores[1]	⬇	⬆	⬆	⬆	⬆

A number of risks of regulator operation to Chowilla bird communities were also identified, although the analysis suggests that these risks can generally be mitigated through appropriate management. In particular, the currently proposed rate of drawdown following floodplain inundation (10 cm /day at the regulator) is much higher than the recommended maximum drawdown rate, to minimise nest abandonment by breeding waterbirds (5 cm / day). Some flexibility may be required, both at the regulator and at smaller regulators operating on individual wetlands, to ensure that rates of drawdown do not result in the loss of breeding opportunities for waterbirds.

More generally, operation of the proposed regulator would provide significant benefits to overall ecosystem function, primarily through improvements in wetland function and positive responses by floodplain vegetation (Red Gum *Eucalyptus camaldulensis*, Black Box *E. largiflorens* and Lignum *Muehlenbeckia florulenta*). The recovery of this floodplain vegetation in particular will drive positive responses in wetland productivity that will flow through the higher trophic levels, including birds.

With regard to monitoring the response of birds to regulator operation, we recommend an approach using multiple approaches (transects, point counts, and behavioural studies) that are designed to monitor bird communities in the long-term. We recommend that these bird monitoring strategies be done in conjunction with the monitoring of ecological processes that are relevant to birds, such as arthropod community change and leaf litter accumulation. Using this long-term monitoring approach, the responses of birds to a range of interventions and other perturbations can be assessed, including operation of the proposed regulator.

The expected responses of birds to regulator operation presented in this report are based on best available information. However, little precedent exists for the planned operations, and as a result the actual responses may vary from expectations. Given the flexibility available in how the proposed regulator can be operated, and assuming an established and rigorous monitoring program is maintained, such variations will be detected, and, if they prove deleterious, regulator operation can be modified to suit (adaptive management). We recommend the implementation of the environmental regulator for Chowilla under a flexible, truly adaptive management framework.

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BACKGROUND

The Chowilla Floodplain (hereafter referred to as ‘Chowilla’) is on the Murray River, straddling the South Australian, Victorian and New South Wales borders (Figure 1). It lies principally (75%) in South Australia’s Riverland region, approximately 250 km north-east of Adelaide, and 40 km north-east of Renmark. Chowilla covers an area of approximately 17,700 ha, and forms part of the Bookmark Biosphere Reserve, a 900,000 ha reserve complex. Chowilla is regarded both nationally and internationally as an important wetland site, forming a significant part of the Riverland Ramsar Site of South Australia, designated as a Wetland of International Significance in 1987. The site is also one of six Icon Sites for The Living Murray program, and one of three that occurs at least partly in South Australia. Amongst its most valuable ecological assets are the floodplain vegetation communities, comprised principally of River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*E. largiflorens*). In addition, Chowilla supports populations of breeding waterbirds and freshwater fish species, and a range of state and federal-listed threatened fauna (MDBC 2006).

Among the ecological Targets identified in the Icon Site Management Plan (MDBC 2006), three are directly relevant to the site’s bird fauna (bird components in italics):

- Provide conditions conducive for successful breeding of *colonial waterbirds* in a minimum of 3 temporary wetland sites at a frequency of not less than 1 in 3 years
- Maintain the abundance and distribution of the Southern bell frog, *Bush Stone Curlew*, and Broad-shelled Tortoise
- Maintain the current nesting locations of the *Regent Parrot*

However, the responses of birds to environmental change and management actions are likely to be indirect, and Targets aimed at other features of the system (such as aquatic and terrestrial vegetation, invertebrates and fish) will often bare some influence on the distribution and abundance of Chowilla’s avifauna. This theme, relating the indirect links between hydrological change and bird responses, will become a universal feature of the analyses presented in this report.

While Chowilla remains a valuable ecological asset, its value has become severely degraded. Five key threats to the ecological value of Chowilla have been identified (MDBC 2006):

1. altered flow regimes
2. elevated saline groundwater

3. obstruction to fish passage
4. grazing pressure
5. pest flora and fauna

In particular, altered flow regimes has led to dramatic declines in the ecological value of temporary wetlands (as flood frequency has declined), and the health of floodplain vegetation (Red Gums and Black Box) has been severely affected by both altered flow regimes and saline groundwater incursions (Jensen *et al.* 1998; MDBC 2006). Management interventions, aimed primarily at addressing these two hydrological issues, are urgently required.

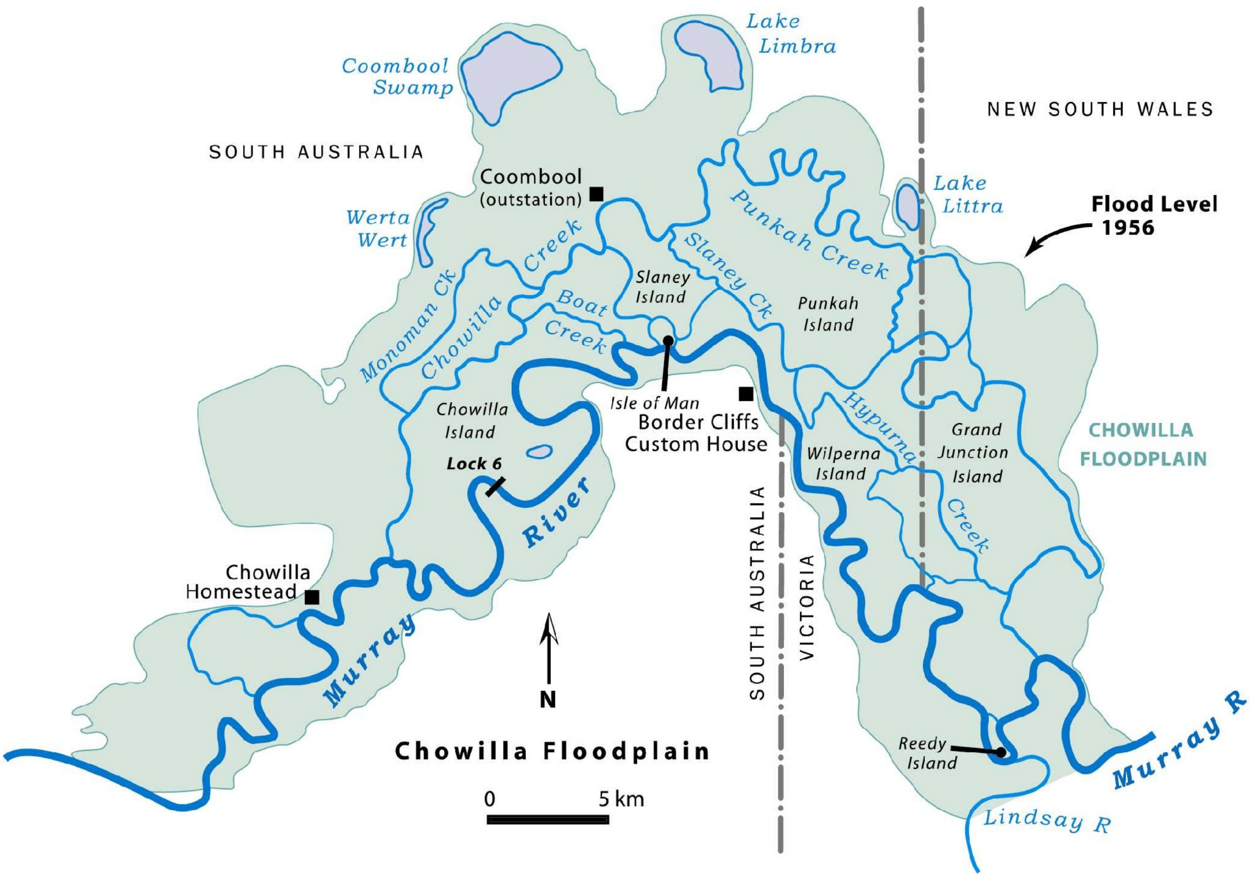

Figure 1. The Chowilla Floodplain (MDBC 2006).

The Chowilla Environmental Regulator

In an effort to mitigate the ecological decline of Chowilla, a range of management options were assessed (Overton *et al.* 2006). Among those assessed was the construction of a “new large regulator structure at the downstream end of the floodplain”, the objective of which was to increase the extent of floodplain inundation. A more detailed assessment of this option (Brookes *et al.* 2006) found that the use of such an ‘Environmental Regulator’ would result in significant ecological benefits, particularly to floodplain vegetation and wetland function. (Brookes *et al.* 2006) also identified risks associated with the proposed structure, including cyanobacterial blooms and weed invasion. In particular, there are some concerns that the loss of lotic habitats, and interrupted fish passage (particularly between the floodplain and the river) would pose significant risks to key fish species, including the threatened Murray Cod and Silver Perch (Mallen-Cooper *et al.* 2007). However, (Brookes *et al.* 2006) also suggest that an appropriately designed and managed regulator would ensure maximum benefits with minimum risk.

Assessment Outline

This report describes the potential benefits and risks of the operation of an environmental regulator in Chowilla (as described in Hollis *et al.* 2008) on the bird communities of Chowilla. We focus our analysis on the following components of the bird community:

1. Opportunities for waterbird breeding events
2. Availability of waterbird drought refugia
3. Availability of habitats for ground-foraging and ground-dependent terrestrial birds
4. Food availability for leaf-gleaning terrestrial birds

For each of these components, an assessment as to their response to each of five alternative scenarios was made:

1. Low flow/no regulator (‘Do nothing’)
2. Low flow, regulator
3. Medium flow, no regulator
4. Medium flow, regulator
5. High flow, no regulator.

These scenarios are described in detail below. The predicted response of each component of the bird community was then summarised in a similar fashion as was used to assess fish responses (Mallen-Cooper *et al.* 2007), although the nature of the response (e.g. change in abundance) will depend on the nature of the community and their interaction with hydrological change. Favourable conditions here provide a general definition for the habitat requirements of a species, community or process. For example, an increase in favourable conditions for waterbird breeding opportunities would be defined as an increase in the opportunities available for breeding waterbirds, while an increase in favourable conditions for ground-foraging terrestrial birds would suggest that the abundance and availability of food would increase under that scenario.

The general responses are classified as follows:

⬇ Major decrease in favourable conditions

↓ Slight decrease in favourable conditions

≈ Little or no change in favourable conditions

↑ Slight increase in favourable conditions

⬆ Major increase in favourable conditions

DESCRIPTION OF THE CHOWILLA BIRD COMMUNITY

Chowilla supports a diverse avifaunal assemblage. In a one-off bird survey conducted in 1988, Carpenter (1990) recorded 170 species in the floodplain region, and identified a further 33 species that may potentially be found on the site. While focussing on the terrestrial fauna of the floodplain, a recent Biological Survey of the South Australian component of Chowilla confirmed this diversity, recording 67 species in a one-off survey (report in preparation). Among these species were 20 that were listed as Rare, Endangered or Vulnerable (South Australian National Parks and Wildlife Act 1975), highlighting the conservation significance of Chowilla to the regional and national avifauna. This diversity and abundance is driven by the diversity of habitats within the floodplain and adjacent region, including a range of habitats for both terrestrial and aquatic birds. Among the most important broad habitat types for birds in Chowilla are: River Red Gum (*Eucalyptus camaldulensis*) woodlands, Black Box (*E. largiflorens*) woodlands, Lignum (*Muehlenbeckia florulenta*) shrublands, temporary shallow wetlands (± Lignum), and permanent wetlands (including anabranches and the Lock 6 weir pool). These habitat types will support different bird communities, and the presence of functional habitats in all of these vegetation communities thus supports the highly diverse bird assemblages supported by Chowilla. In addition, these key vegetation communities are also all dependent on periodic floodplain inundation, although the nature of this dependence varies among these communities.

Waterbirds

Based on regular waterbird counts undertaken by Michael Harper (SA DEH), 52 species of waterbird have been recorded on Chowilla (Table 1). Of these, 12 species are considered to breed regularly on Chowilla, with occasional breeding recorded by an additional six species (one breeding record each; Table 1). This species list is comparable, but more extensive, than the species recorded by Carpenter (1990) in his single survey of nine wetlands in Chowilla, in which eight species were recorded breeding.

By far the most common waterbird recorded on Chowilla is Grey Teal (*Anas gibberifrons*), with an abundance six times as great as the next most common species, Eurasian Coot (*Fulica atra*). The pattern of relative abundance presented in Table 1 concurs with that found by Carpenter (1990), who found a ten-fold difference between the abundance of Grey Teal and the next most common waterbird.

In line with this high abundance, Grey Teal are also extremely widespread, being recorded at all nine sites that M. Harper surveyed. Other widespread species include Australian White Ibis, Pacific Black Duck, Yellow-billed Spoonbill, and Great Egret, all of which were also recorded at all nine sites.

Table 1. List of waterbird species recorded at Chowilla by Michael Harper (pers. comm., 2008). For abundance, the number of dots refers to the number of recorded individuals across all counts; - - <10 records; • - 10-100 records; •• - 100-1000 records; ••• - 1000-10,000 records; •••• - >10,000 records. For distribution, the number of dots refers to the number of sites (total number of sites counted = 9) at which the species was recorded; - - 1 site; • - 2-3 sites; •• - 4-5 sites; ••• - 6-7 sites; •••• - 8-9 sites. For breeding, the number of dots refers to the number of records across all counts in which evidence of breeding was recorded (nests or young); - - 1-2 records; • - 2-10 records; •• - 11-20 records; ••• - 21-30 records; •••• - >30 records.

Species	Abundance	Distribution	Breeding
Australasian Grebe	•••	•••	••
Australasian Shoveler	•••	••	
Australian Darter	••	•••	•
Australian White Ibis	••	••••	•
Australian Pelican	•••	••••	
Australian Shelduck	••	••••	••
Australian Spotted Crake	-	•	
Australian Wood Duck	•••	••••	
Black Swan	••	••••	••
Black-fronted Dotterel	••	•••	•
Black-tailed Native-hen	•••	••••	
Blue-billed Duck	•	-	
Buff-banded Rail	-	-	
Caspian Tern	•	•	
Chestnut Teal	•	••	-
Common Greenshank	•	•	
Dusky Moorhen	-	•	
Eurasian Coot	•••	•••	
Freckled Duck	••	•••	
Glossy Ibis	-	•	
Great Egret	••	••••	
Great Cormorant	••	••••	
Great Crested Grebe	-	•	
Grey Teal	••••	••••	•••
Hardhead	•••	•••	-
Hoary –Headed Grebe	•••	••	•
Intermediate Egret	-	-	
Little Black Cormorant	••	•••	
Little Egret	-	-	
Little Pied Cormorant	••	••••	-
Masked Lapwing	••	•••	•
Musk Duck	••	•••	•
Pacific Black Duck	•••	••••	••••
Pied Cormorant	-	••	
Pink-eared Duck	•••	•••	-
Purple Swamphen	•	•••	
Red-capped Plover	•	•	
Red-kneed Dotterel	••	••	
Red-necked Avocet	•••	•	
Royal Spoonbill	•	•••	
Rufous Night-Heron	-	•	
Sharp-tailed Sandpiper	•	•	
Silver Gull	•	••	
Spotless Crake	-	-	
Straw-necked Ibis	••	•••	
Swamp Harrier	•	•••	-
Whiskered Tern	•	•	
White-bellied Sea-Eagle	-	-	-
White-faced Heron	••	••••	•
Black-winged Stilt	•••	••	
White-necked Heron	•	•••	
Yellow-billed Spoonbill	••	••••	-

Table 2. Wetlands considered historically important to breeding waterbirds in Chowilla, showing the number of species for which breeding has been recorded. Wetlands that are important for colonial nesting species are also listed. Data provided by M Harper (2008).

Site	# species	colonial species
Coppermine	4	-
Lake Littra	6	1
Lake Limbra	1	1
Lock 6 weir pool	3	-
Lock 6 Depression	4	-
Pilby Lagoon	10	-
Pilby Creek	4	-
Pipeclay Billabong	6	-
Slaney Billabong	6	1
Werta Wert	3	-

The most important sites for breeding waterbirds in Chowilla are presented in Table 2. The most important breeding sites include Pilby Lagoon, Pipeclay Billabong, Lake Littra, Lake Limbra, Slaney Billabong, and Coppermine Complex. In particular, Lake Littra and Lake Limbra are considered the most important breeding sites for colonial nesters, such as Australian White Ibis and Yellow-billed Spoonbill (M. Harper pers. comm.). However, these colonial breeding events have historically been relatively small in comparison to others in the Basin (e.g. Macquarie Marshes; (Kingsford and Johnson 1998).

Terrestrial Birds

In a one-off survey conducted in October 1988, Carpenter (1990) recorded 98 terrestrial bird species, the most widespread of which are listed in Table 3. The most species-rich terrestrial habitats in Chowilla were Black Box woodlands (68 species) and Red Gum woodlands (41 species), with Lignum shrublands being the most species-rich (46 species) of the non-woodland vegetation communities (Carpenter 1990). Among the most common species recorded were Southern Whiteface, Red-rumped Parrot, Tree Martin, Willie Wagtail and Chestnut-rumped Thornbill. Black Box woodlands were seen to support the most species as a result of the relatively widespread distribution of this vegetation type within Chowilla, but also because it acts as an ecotone between more mesic, low-lying floodplain habitats (such as Lignum and Red-Gum), and drier mallee habitats, thus supporting components of the avifauna from both of these communities. As such, while Black Box habitats form an integral part of the broader requirements for some species, many are able to also utilise surrounding habitats (particularly mallee) and should persist regionally (if not only the floodplain per se). Other species that depend exclusively on floodplain habitats (such as those species that depend on River Red Gum woodlands), however, may become regionally extinct with the complete loss of these floodplain habitats. The species that are at risk here include common species such as White-plumed Honeyeater, which is widely distributed across SA and Australia. Other floodplain-dependent species of more concern are Blue-faced Honeyeater and Little Friarbird, that might become regional extinct with a further decline in floodplain vegetation condition.

The most common species recorded in each vegetation community are listed in Table 3. Other species that were not recorded in Lignum by Carpenter (1990), but that might be expected to occur in this habitat, are Superb and Variegated Fairy-wrens (*Malurus* spp.), species that were commonly recorded in the recent SA DEH BioSurvey (Table 4).

Table 3. Species richness and common species recorded by Carpenter (1990) for each terrestrial vegetation community in Chowilla. Common species were those recorded in at least half of the quadrats in which the vegetation community occurred.

Vegetation Community	Total # of bird species	Common species
Red gum woodland	41	Magpie-Lark
		Red-rumped Parrot
		Tree Martin
		Whistling Kite
		Willie Wagtail
		Brown Treecreeper
		White-plumed Honeyeater
		Striated Pardalote
		Peaceful Dove
		Australian Ringneck
		Sacred Kingfisher
		Rainbow Bee-eater
		Grey Shrike-thrush
		Superb Fairy-wren
		Little Friarbird
Black Box Woodland	68	Australian Ringneck
		Red-rumped Parrot
		Red-capped Robin
		Rufous Whistler
		Chestnut-rumped Thornbill
		Southern Whiteface
		Brown Treecreeper
		Grey Shrike-thrush
		Variegated Fairy-wren
		Weebill
		Spiny-cheeked Honeyeater
		Crested Pigeon
		Tree Martin
		Willie Wagtail
		White-browed Babbler
Tea-tree tall shrubland	17	Red-capped Robin
		Chestnut-rumped Thornbill
		Yellow Thornbill
		Spiny-cheeked Honeyeater
		Mistletoebird
		Rufous Whistler
		Grey Shrike-thrush
		Weebill
		Southern Whiteface
Lignum Shrubland	46	Southern Whiteface
		Red-capped Robin
		Australian Raven
		Chestnut-rumped Thornbill
Blackbush shrubland	25	Variegated Fairy-wren
		Southern Whiteface
		Welcome Swallow
		Richard's Pipit
		Chirruping Wedgebill
		White-winged Fairy-wren
		Redthroat
		Chestnut-rumped Thornbill
		Yellow-rumped Thornbill
		Singing Honeyeater
		White-fronted Chat
		Black-faced Woodswallow
		Australian Magpie
Forb/grassland	26	Masked Lapwing
		Southern Whiteface

A subsequent survey of the Chowilla bird community was undertaken in November 2003, by the South Australian Department for Environment and Heritage (BioSurvey). This survey formed part of a broader biological survey of the South Australian Murray River floodplain (report in prep.). Focussing on terrestrial fauna, this investigation recorded 67 bird species (four of which can be considered aquatic). The 63 terrestrial species recorded are listed in Table 4. As with the survey described by Carpenter (1990), many of the terrestrial species recorded in this survey were generalist in nature, able to use mallee and floodplain habitats. In addition, the more common species recorded in this survey were among those most commonly recorded by Carpenter (1990), including Red-rumped Parrot and Chestnut-rumped Thornbill, although Southern Whiteface was less frequently recorded in this survey (4 of 13 sites).

The assessment presented here is based on a very limited dataset, and for this reason only the more common species are represented. The danger here is that those species at most risk of regional extinction fail to be recorded among the existing data. In particular, two terrestrial floodplain-dependent species (Bush Stone Curlew and Regent Parrot) that are the focus of the EMP Targets were not recorded in either of survey dataset presented here. A discussion of the predicted responses of Bush Stone Curlew and Regent Parrot to regulator operation is presented below.

Table 3. Species recorded on the Chowilla floodplain during the 2003 River Murray BioSurvey performed by the South Australian Department for Environment and Heritage. Frequency refers to the number of sites in which the species was recorded (total sites surveyed = 13).

Species	Frequency
Crested Pigeon	12
Chestnut-rumped Thornbill	11
Red-rumped Parrot	11
Superb Fairy-wren	10
Australian Magpie	8
Australian Ringneck	8
Blue Bonnet	8
Grey Shrike-thrush	8
Pied Butcherbird	8
Red-capped Robin	8
Rufous Whistler	8
Spiny-cheeked Honeyeater	8
Weebill	8
Little Friarbird	7
Magpie-lark	7
White-plumed Honeyeater	7
Willie Wagtail	7
Australian Raven	6
Black-faced Cuckoo-shrike	5
Brown Treecreeper	5
Grey Butcherbird	5
Striated Pardalote	5
Emu	4
Crimson Rosella	4
Rainbow Bee-eater	4
Regent Parrot	4
Southern Whiteface	4
Striped Honeyeater	4
White-browed Babbler	4
White-winged Chough	4
Apostlebird	3
Common Bronzewing	3
Variegated Fairy-wren	3
Wedge-tailed Eagle	3
Whistling Kite	3
White-winged Triller	3
Yellow-rumped Thornbill	3
Australian Owlet-nightjar	2
Budgerigar	2
Chestnut-crowned Babbler	2
Hooded Robin	2
Horsfield’s Bronze Cuckoo	2
Peaceful Dove	2
Tawny Frogmouth	2
Varied Sittella	2
Diamond Dove	1
Grey Fantail	1
Laughing Kookaburra	1
Little Corella	1
Little Crow	1
Little Eagle	1
Masked Woodswallow	1
Mulga Parrot	1
Nankeen Kestrel	1
Noisy Miner	1
Red Wattlebird	1
Red-backed Kingfisher	1
Redthroat	1
Restless Flycatcher	1
Sacred Kingfisher	1
Tree Martin	1
White-browed Woodswallow	1
Yellow Thornbill	1

DESCRIPTION OF ALTERNATIVE OPERATIONAL SCENARIOS

The focus of this report is to provide an assessment of the expected responses of Chowilla's bird communities to operation of the proposed environmental regulator. In order to achieve this assessment, we compared the expected responses of different components of the Chowilla bird community to five alternative scenarios:

Scenario 1 – *Low flow / No Regulator* ('Do Nothing'). This scenario presumes a peak flow of 10,000 ML/day to SA, with no regulator in operation, and most closely reflects the current hydrological scenario. Under this scenario, surface water is restricted to those areas with an elevation below weir pool level (19.25 m) that are connected to the pool, essentially limiting inundation to channels and anabranches.

Scenario 2 – *Low flow / Regulator*. As with scenario 1, this scenario presumes a peak flow of 10,000 ML/day to SA. However, this scenario also involves operation of the proposed environmental regulator at full height (19.87m AHD), and the operation of Lock 6 at 19.87m. This is the most likely hydrological scenario under current flow conditions, with a regulator in place.

Scenario 3 – *Medium flow / No Regulator*. This scenario presumes a peak flow of 50,000 ML/day to SA, with no regulator. This scenario results in a similar extent of floodplain inundation as scenario 2, although the distribution of inundation differs between these scenarios (see below).

Scenario 4 – *Medium flow / Regulator*. As with scenario 3, this scenario presumes a peak flow of 50,000 ML/day to SA, but, as with scenario 2, also involves the operation of the proposed environmental regulator at full height.

Scenario 5 – *Natural flood*. Presumes a peak flow of 80,000 ML/day to SA.

When assessing the expected responses of birds to the scenarios listed here, however, we are presuming an operational scenario for the regulator following from (Hollis *et al.* 2008). Briefly, for a 10,000 ML/day to SA flow, stop-logs would be added progressively to the regulator bays over at least two weeks, following one week of flow (serving as an attractant flow for fish). With the regulator at full height after two weeks, maximum floodplain capacity would then be achieved after a further 18 days. The regulator would then be managed to allow water levels to fluctuate for ~50 days (the "holding" phase), followed by a period of drawdown (of 10 cm/day over 30 days). However, a positive aspect of the current regulator design comes from the way in which it can be operated flexibly. One outcome of this report is to provide recommendations on how regulator operation may be modified to benefit birds in Chowilla (see below).

EVALUATION OF THE RESPONSES OF BIRDS TO ALTERNATIVE OPERATIONAL SCENARIOS

Here we assess the responses to the scenarios described above, for each of the following components of the Chowilla bird community:

1. Opportunities/Habitat for Breeding Waterbirds
2. Waterbird Drought Refugia
3. Ground-dependent terrestrial birds
4. Leaf-gleaning insectivorous birds

General Responses of Breeding Waterbirds to Regulator Operation

During flood periods, temporary wetlands become extremely productive habitats for freshwater aquatic organisms, including waterbirds (Murkin *et al.* 1997; Parkinson *et al.* 2002). These floodplain wetlands are typically shallow (or at least have shallow margins), allowing for extensive macrophyte habitats. These in turn are important direct or indirect food sources for waterbirds that may not be found to the same extent in deeper, permanent wetlands (such as channels). Inundation of temporary wetlands also creates highly productive conditions, that are much higher than those of permanent wetlands (Junk *et al.* 1989), primarily in response to greater availability of nutrients in the water column following detrital accumulation and decomposition (Crome 1988). Under conditions of high flow, this increase in productivity is utilised by higher trophic levels, including fish and birds. As a result, temporary, shallow wetlands are typically used “more intensively” by waterbirds than permanent wetlands (Parkinson *et al.* 2002). In addition, this spike in productivity also provides the resource conditions that allow for waterbird breeding opportunities.

A simple conceptual model between wetland hydrology and waterbird breeding habitat is presented in Figure 2. While this model provides a basic structure for how waterbirds will respond to hydrological changes in a wetland, the details of this response are complex, and specific to each bird species or group. The relationship between breeding habitat and each of the environmental variables highlighted in Figure 2 are presented below.

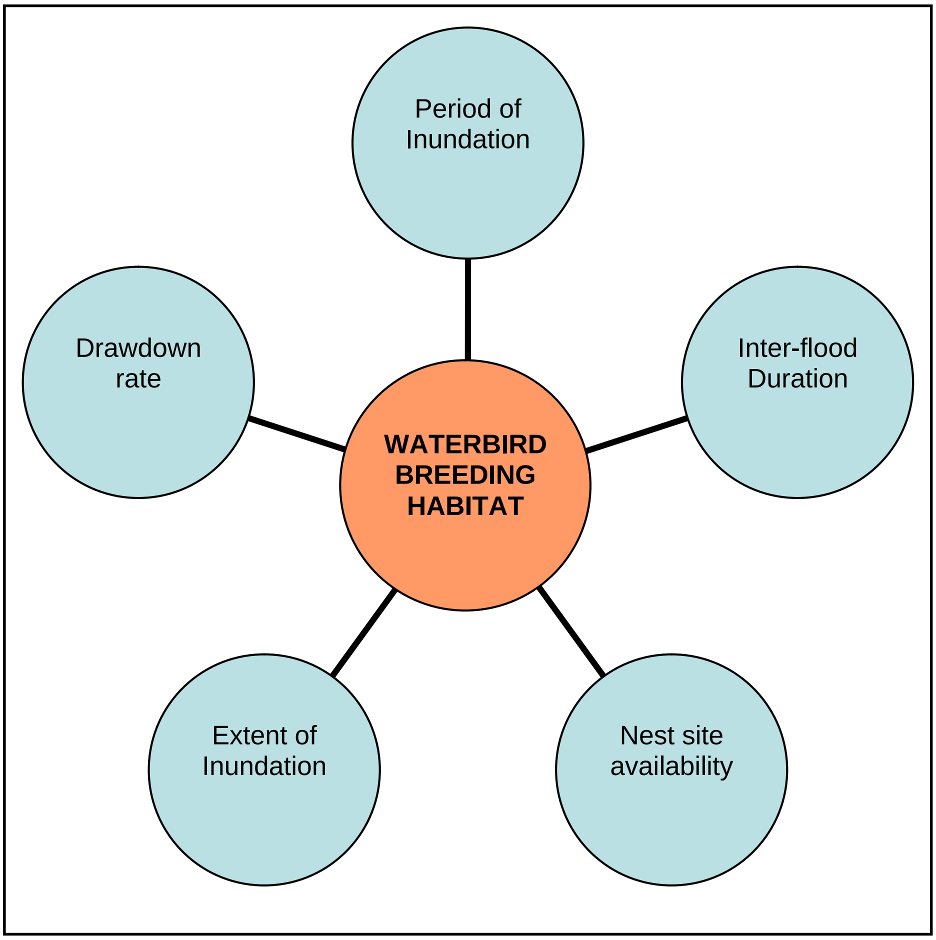

Figure 2. Conceptual model identified important hydrological and habitat parameters for waterbird breeding. After (Scott 1997).

In order for a successful breeding event to occur, species-specific thresholds for all five of these general features must be met. However, as suggested above, different waterbird species will demand different thresholds on each of these features, in a way that largely depends on the ecological requirements of each species.

The principle driving relationship in this conceptual model are the hydrological conditions that drive resource availability. The availability of waterbird breeding habitat is only partially driven directly by appropriate hydrology; the actual response is indirect, through the influence that floodplain and wetland re-wetting have on resource (food) abundance (see below for further discussion).

Extent of inundation

There is a general consensus that a positive relationship exists between wetland inundation extent and the size of a waterbird breeding event (Briggs *et al.* 1997; Crome 1988; Scott 1997). While the duration of inundation primarily determines the success of an individual nesting attempt, the area over which a flood occurs is the primary determinant of how many birds are able to nest, as large areas of productive wetland are able to support more individual nesting attempts. Furthermore, there is a strong positive relationship between the area and period of inundation (i.e. large floods result in floods over longer time periods); as such the area of inundation can be seen as a good overall indication of waterbird breeding potential.

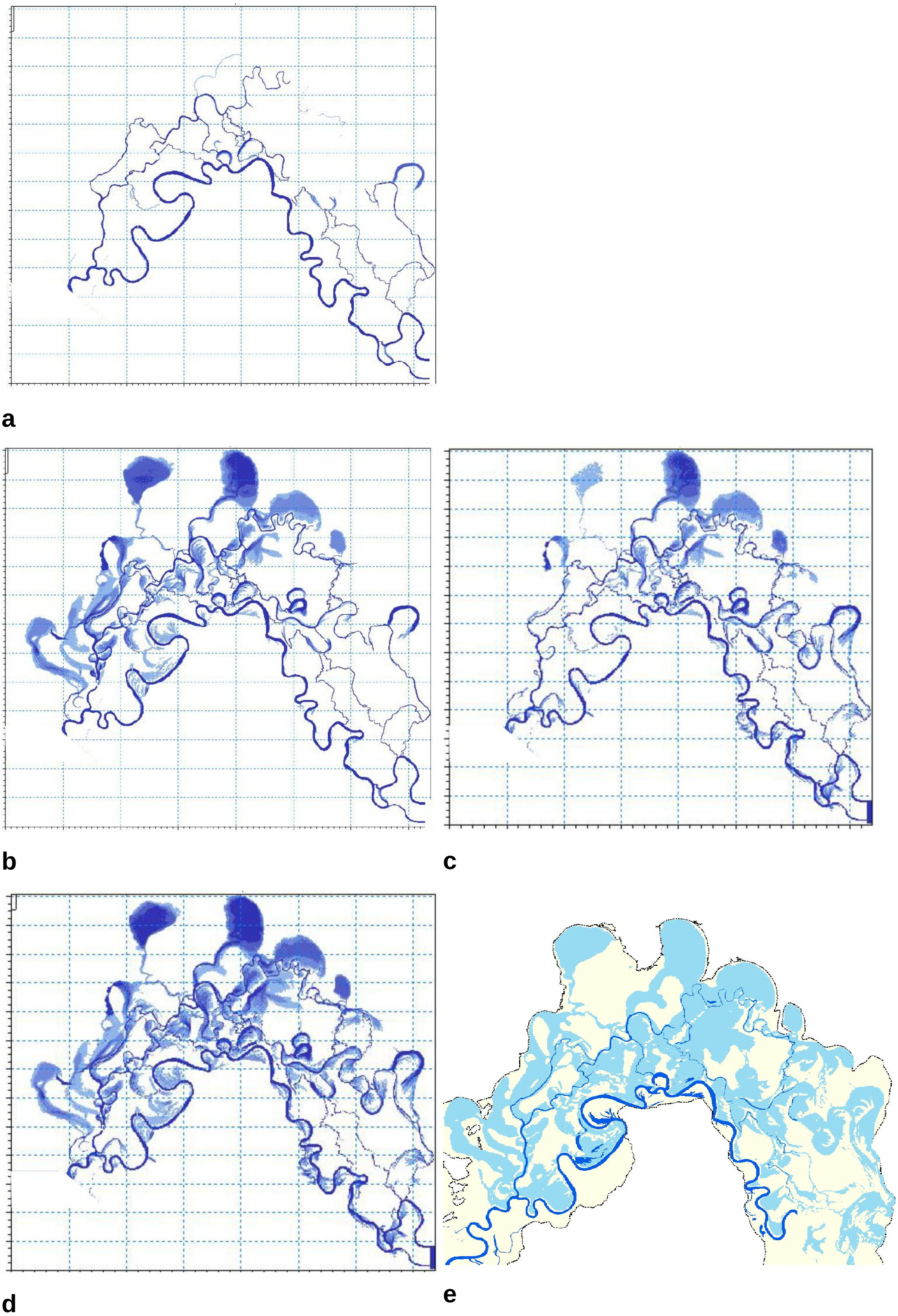

Figure 3. Predicted area and depth of inundation across Chowilla, under the alternative scenarios described above. a) Scenario 1 (10,000 ML/day to SA, no regulator); b) Scenario 2 (10,000 ML/day to SA, regulator at 19.87m AHD); c) Scenario 3 (50,000 ML/day to SA, no regulator); d) Scenario 4 (50,000 ML/day to SA, regulator at 19.87m AHD); e) Scenario 5 (80,000 ML/day to SA, no regulator).

Table 5. Estimated area of inundation under alternative scenarios. [1] – based on hydrological modelling for a peak flow of 80,000 ML/day to SA

Scenario	Maximum Area of inundation (ha)	% of floodplain inundated
1	1,330	7.5
2	5,580	31.5
3	4,740	26.8
4	8,100	45.8
5	9,400[1]	53.1

The extent and depth of inundation of Chowilla under the five scenarios tested are presented in Figure 3. An analysis of the maximum area of inundation under the alternative scenarios suggests some significant benefit of regulator operation to this aspect of waterbird breeding in Chowilla (Table 5). Under the alternative low-flow scenarios (scenarios 1 and 2), area of inundation is increased four-fold through regulator operation (5,580 ha vs 1,330 ha), and results in a larger area of inundation than under larger (50,000 ML/day) flows without a regulator (scenario 3, 4,740 ha). With regard to the area inundated, benefits from regulator operation thus appear to be maximised under low-flow conditions. However, the extent of inundation can also be significantly increased through regulator operation under higher flow conditions (scenario 3 vs scenario 4; Table 5,6).
In Chowilla, the area inundated during a flood event will also determine the probability of key breeding wetlands being flooded. The key wetlands for waterbird breeding in Chowilla (Table 2) will vary in their response to regulator operation, depending primarily on their height relative to pool level (19.25m). Pipeclay Billabong, Slaney Billabong, Pilby Creek and Lagoon, and Lock 6 Depression, all lie below pool level, and inundation of these wetlands is thus under controls that are independent of regulator operation. These wetlands can potentially be inundated “at will”, so long as pool level above Lock 6 is maintained at 19.25m (or 19.87m during regulator operation). The critical benefits of regulator operation to waterbird breeding opportunities lie in the wetlands at the outer extent of Chowilla that lie above pool level. The wetlands of primary importance in this

Table 6. Inundation of key wetlands for waterbird breeding under alternative operational scenarios. Under the different scenarios, wetlands that become inundated are represented by a green cross (+), while those wetlands that fail to be inundated are represented by a red dash (-).

Scenario	Coppermine	Littra	Limbra	Werta Wert
1	-	-	-	-
2	+	+	+	+
3	-	+	+	-
4	+	+	+	+
5	+	+	+	+

category are Lake Littra, Lake Limbra, Werta Wert and Coppermine Waterhole (Table 5). Lakes Littra and Limbra are also considered particularly important for colonial breeding waterbirds (Australian White Ibis, Yellow-billed Spoonbill). The overall extent to which Chowilla is inundated thus determines whether these key wetlands become inundated (or not).

The key breeding wetlands that become inundated under the alternative scenarios are presented in Table 5. Under the Low-flow / No Regulator scenario (scenario 1), none of these four wetlands are inundated. However, all four of these wetlands are inundated under a Low-flow scenario with regulator operation (scenario 2), further supporting the notion that the benefits of regulator operation are particularly significant under low-flow conditions. This scenario, in fact, provides more opportunities for breeding waterbirds across Chowilla than the equivalent flood extent under no regulator operation (scenario 3), which fails to inundate Coppermine Waterhole, and only partially fills Werta Wert. All of these key breeding wetlands become inundated under the medium flow (50,000 ML/day) / regulator scenario (scenario 4), and natural flood (80,000 ML/day) scenario (scenario 5).

Duration of Inundation of Key Breeding Wetlands Under Different Scenarios

The period of time over which a wetland is inundated is, perhaps, the hydrological feature of primary importance in determining the probability of success for a breeding waterbird. In order for a breeding event to be successful, the wetland must remain inundated for the period required to complete all stages of the breeding cycle (Box 1). The actual time required will depend on the physiological demands on adults and nestlings, and the preferred food sources of the species. The flood duration required may also depend on regional hydrological events, as smaller wetland inundations elsewhere may provide suitable conditions for breeding preparation (see Box 1).

The length of time required for successful breeding varies between species, and is dependent on a number of intrinsic (time required for nestling development) and extrinsic (time required for prey populations to reach suitable densities) factors. For example, some aquatic invertebrates respond more rapidly to flooding events than fish species, and therefore birds that feed primarily on these different food sources will differ in the time required for successful breeding.

Table 7 presents the minimum inundation time required for those waterbird species recorded breeding on Chowilla, that depend on flooded temporary wetlands for successful breeding. However, these times should be considered the minimum time required for successful breeding, as

Table 7. Estimated minimum times (number of days) required for successful breeding event, for species that require flooded temporary wetlands and have been recorded breeding in Chowilla. Time estimates taken from Marchant and Higgins (1990).

Species	Incubation	Nestling - Dependent	Total
Australasian Grebe	~23	~56	~80
Australian Darter	28	~60	~90
Australian White Ibis	20-23	~70	~93
Australian Shelduck	30-33	~70	~103
Black Swan	~40	95-140	140-180
Grey Teal	~28	46-64	74-92
Musk Duck	~24	90-120	114-144
Pacific Black Duck	~29	52-66	81-95
White-faced Heron	~25	~64	~90
Yellow-billed Spoonbill	26-31	~35	~61-66

they do not take into account the potential period required for physiological preparation and egg development. As suggested above, these times may also vary in a way that is spatially and temporally-specific, largely determined by spatiotemporal variation in the productivity of wetlands (e.g. following dry periods). Furthermore, some of these species (in particular, Australian Darter) do not depend on flood events to initiate breeding, but can breed successfully on permanently inundated wetlands (e.g. weir pools).

Even for these wetlands, the critical issue is not the duration of inundation, but whether these wetlands are inundated at all. As described above, four of the nine waterbird breeding wetlands identified in Table 2 (Coppermine, Lake Littra, Lake Limbra and Werta Wert) are relevant to regulator operation, as they lie above weir pool level. With the exception of Coppermine, the extent and duration of inundation can be controlled locally, through the operation of local flow regulators. As such, once inundation is achieved, the duration of inundation can be extended for periods longer than that of the surrounding floodplain (i.e. longer than the period of environmental regulator

Box 1. The length of inundation time required for successful breeding will depend on the time taken by a species to complete all of the breeding stages. These are:

Physiological preparation Fat reserves are often required prior to the onset of breeding, due to the high energetic demands that successful breeding incurs. These can be (although not exclusively) gained through local food intake.

Egg-laying Typically for waterbirds, one egg is produced per day, and clutch size will therefore determine the period of egg-laying (clutch size for key waterbirds can vary from 3 to 10)

Incubation The period between egg-laying and hatching

Nestling The period between hatching and fledging

Dependent Fledgling The period between fledging, and young becoming independent of parents (only relevant if young and adults remain in natal wetlands) operation), if required. For all of these wetlands, the period of inundation will be equivalent to the period of regulator operation at least. However, these outer wetlands will be inundated for less than the operational period of 120 days suggesting that, without local control of wetland water levels, period of inundation may be marginal for successful waterbird breeding.

However, under conditions where inundation of these key wetlands can occur, local wetland-specific environmental regulators are thus able to determine the period of inundation. The minimum period of inundation under any scenario in which inundation occurs (scenarios 2-5) for the four outer breeding wetlands is likely to be four to five months (120-150 days; Hollis pers. comm.). If we compare this minimum value to the inundation periods required for successful breeding to occur (Table 6), only two waterbird species (Black Swan and Musk Duck) have minimum period requirements that overlap with this expected period of inundation. In cases where breeding opportunities were available to these species, extension of the inundation period at individual wetlands (through the operation of local regulators and pumps) might be considered.

A minimum 4 month (120 day) inundation also concurs with (Young *et al.* 2003), who suggested a linear benefit to waterbird breeding habitat with inundation durations beyond this length of time. The critical benefit of the regulator on breeding wetland inundation, therefore, is in allowing these wetlands to be flooded at all (to ~maximum extent); once these wetlands do become inundated, the expected periods of inundation using local flow control structures (under a minimum operating period of 120 days) should not limit the successful breeding of waterbird species that have historically bred in Chowilla.

Interflood duration and wetland inundation frequency

We compared the interflood durations under no regulation and regulation, for the period 1980-2006, to reflect potential future flow regimes. The hydrograph for this period is presented in Figure 4, with columns in red showing years in which regulator operation would have been likely to occur. From a breeding waterbird perspective, the outer breeding wetlands (Table 6) are only likely to be inundated under a minimum 60,000 ML/day flood extent equivalent (10,000 ML/day with regulator operation). This is equivalent to 1,800 GL/month to SA in Figure 4. In the period 1980 to 2006, under no regulator operation, an extended period of flooding of at least 60,000 ML/day was recorded five times (1981, 1990, 1992, 1993 and 1996). Under regulator operation at full height, the number of extended flooding events over this time period would have increased to ten (as above, with additional events in 1984, 1987, 1989, 2000 and 2003). Critically, two of these four extra events would have occurred between 1996 and 2006, breaking up the extended dry period that these wetlands are currently experiencing. Regulator operation would thus increase the frequency of a 60,000 ML/day flow to SA event (flood extent equivalent) from an average of one event every 4 years, to one event every 2 years, with the maximum time between inundation events also decreasing from ten years (1996-2006), to four (1996-2000).

This increase in flooding frequency provides important benefits for waterbird breeding in Chowilla. The extra breeding opportunities allow for recruitment of juveniles to regional waterbird populations, thereby assisting with the maintenance of these populations. These extra breeding opportunities under regulator operation would have been particularly significant under the hydrograph presented in Figure 3. Two of the four additional inundation events provided by regulator operation occurred within an extended period (>10 years) of drought, that has affected the southern parts of the entire Murray-Darling Basin. Waterbird breeding opportunities in this broader region were extremely restricted during this time, and the provision of these opportunities at Chowilla under regulator operation would have presumably contributed significantly to recruitment of the entire region's waterbird populations.

In addition, the scale of ecological responses to re-wetting in temporary wetlands depends partly on the interflood duration. (Young *et al.* 2003) suggest that peak benefits for breeding waterbird habitat are found with interflood durations of ~8-12 months, and a linear decrease in habitat quality with interflood durations greater than 12 months. These values, however, do not fit with the natural hydrograph (average flood frequency 1 in 3 years), suggesting that Australian waterbirds are well adapted to longer interflood periods that this 12 month period suggests. Generally, however, reducing the mean and maximum interflood duration would thus also provide benefits for the per-unit-area wetland productivity (and thus breeding success of waterbirds). This increase in wetland productivity during breeding events would have strong flow-on benefits, including increased

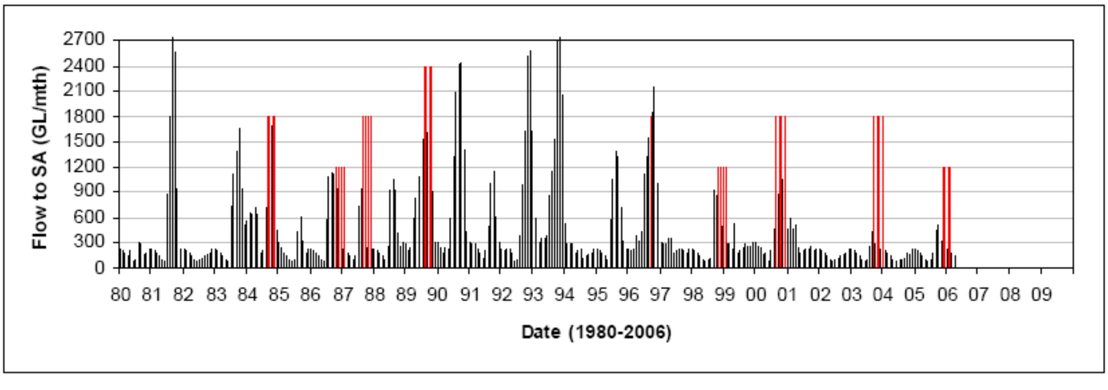

Figure 4. Hydrograph of modelled current flows from 1980-2006, including potential operation (highlighted in red) of the proposed Chowilla Creek environmental regulator (Hollis *et al.* 2008).

fledging success, and a reduction in the time required for successful breeding to occur.

Drawdown Rate

As suggested above, the rate of water level decline in breeding wetlands is a critical feature related to the success of waterbird breeding. (Young *et al.* 2003) suggest a linear relationship between rate of fall and waterbird breeding success, with their preference curve reaching a value of 0 at a fall of 5 cm/day. The working operation proposal suggests a drawdown rate of 10 cm/day (head of 3m drawn down over 30 days; Hollis *et al.* 2008). If this drawdown rate was reflected in key breeding wetlands, there is a strong risk of nest abandonment/failure for breeding waterbirds. This risk of abandonment is principally driven by a behavioural response: that is, adult birds, detect rapid changes in water levels, and abandon in preparation for the nest site becoming unsuitable (even if this situation does not eventuate). However, controlling the period of inundation (above) and the drawdown rate within individual breeding wetlands (using local regulating structures) should minimise these risks. The model proposed by (Young *et al.* 2003) suggests that drawdown rate should be kept as low as possible while waterbirds are breeding, and if waterbirds are breeding at the initiation of drawdown, local regulatory structures should be managed to minimise the rate of drawdown. Furthermore, if the length of inundation in an individual wetland is maintained for long enough such that breeding is successfully completed (and breeding has ceased), drawdown rate can be managed for other objectives (e.g. drawdown can occur at the same rate as the surrounding floodplain).

Nest Site Availability

While the hydrological features described above determine the abundance of food resources required for breeding, the availability of nesting habitat is of equal importance. Optimal nest sites vary among waterbird species (see below). However, in Chowilla, key nesting habitats across the floodplain are provided by areas of contiguous Lignum (*Muehlenbeckia florulenta*). As a result, the availability of nest sites will be influenced by wetland hydrology, through the impacts that wetland hydrology has on survival and recruitment of this key plant species. With this in mind, (Young *et al.* 2003) considered the optimal length of inundation to be between 30 and 120 days, although declines in habitat quality post-120 days inundation are slight. In addition, their analysis suggested an optimal interflood duration of up to three years, although dry periods of up to 5 years could be tolerated. The optimal hydrology for Lignum, therefore, does not generally conflict with the hydrological conditions required for other components of successful waterbird breeding. More

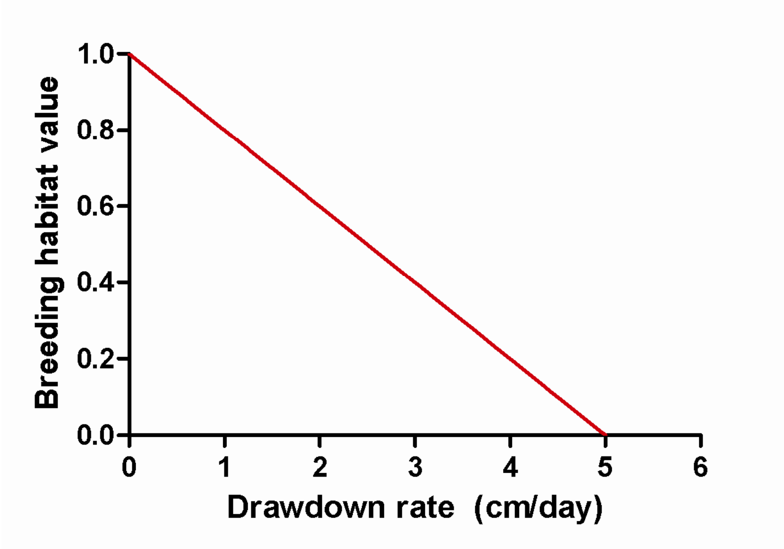

Figure 5. Preference curve relating breeding waterbird habitat to wetland drawdown rate. After Young et al. (2003).

detailed information on the predicted response of Lignum to regulator operation will assist in assessing changes to this component of the waterbird breeding response.

Nest sites also need to be available within reasonably close proximity to foraging habitat. While Australian waterbirds are extremely mobile when travelling, breeding waterbirds will only be willing to travel below some threshold distance from an active nest to acquire food. These distances can be relatively small, and food quality must be sufficiently high for birds to be willing to travel longer distances to access it (as predicted by optimal foraging theory for central-placed foragers). As a rule, an individual wetland must encompass appropriate nest site opportunities, as well as a hydrological regime that provides the energetic requirements for successful waterbird breeding. However, this will depend on the spatial arrangement of wetlands and wetland complexes.

Summary

Table 8 summarises the predicted response of waterbird breeding opportunities in Chowilla, to the alternative scenarios, relative to breeding responses to scenario 1. This analysis strongly suggests that opportunities for waterbird breeding in Chowilla will be enhanced by the operation of the regulator, where suitable nesting habitats occur. Both the extent (area) and period of inundation will increase in response to regulator operation, while interflood interval will decrease (i.e. flood frequency will increase). Furthermore, there appear to be some additional benefits of regulator operation under low flows (scenario 2), above the benefits provided by natural, medium flows with no regulator (scenario 3); this difference is largely related to the distribution of inundation under the different scenarios, with more historically important wetlands (i.e. in the west of Chowilla) being

Table 8. A summary of the effects of alternative scenarios on key hydrological variables for waterbird breeding in Chowilla, relative to the response predicted by Scenario 1. These responses to regulator operation are expected to be limited to those wetlands listed in Table 2, that lie above pool level. Negative impacts of drawdown rate under Scenarios 2 and 4 are under the currently proposed operation regime, assuming a drawdown rate of 10cm/day, with no operation of individual wetland regulators.

Scenario	Extent	Period	Drawdown Rate	Interflood	Overall
1	≈	≈	≈	↓	↓
2	↑	⬆	↓	⬆	⬆
3	↑	↑	↑	↑	↑
4	⬆	⬆	↓	⬆	⬆
5	⬆	⬆	↑	⬆	⬆

inundated under regulator operation than natural flooding. As discussed above, all three of these hydrological parameters are primary determinants of waterbird breeding success on ephemeral floodplain wetlands (Scott 1997), and the overall influence of regulator operation on waterbird breeding opportunities is thus positive.

As discussed above, one risk identified with regulator operation is the rate of drawdown that occurs under proposed operation procedures. However, there are opportunities in place to minimise these risks, through local regulation of drawdown rate at individual breeding wetlands.

Finally, the analysis above suggests that regulator operation can improve waterbird breeding *opportunities*, particularly under low flow conditions. Specifically, regulator operation will improve the availability of *waterbird breeding habitat*. However, providing suitable local conditions for waterbird breeding does not necessarily translate into waterbird breeding *per se*. As discussed below, waterbirds are extremely mobile, and select breeding sites based on their relative quality, in comparison to other available breeding sites. Furthermore, a natural flood across Chowilla occurs following similar floods upstream, and this upstream flooding may provide a cue to waterbirds to prepare for breeding on downstream locations (such as Chowilla). Regulator operation may provide suitable local conditions for breeding to occur, but will be missing this upstream flooding cue. Broadly, the regional and continental cues used by waterbirds to select nest sites and initiate breeding are complex and poorly understood; travelling flood pulses may be one of a number of cues used to initiate breeding in Australian waterbirds (Kingsford and Norman 2002). However, the presence of small breeding events on artificially watered wetlands in Chowilla suggest that the significance of this issue may not be great. However, we suggest that both the conditions for waterbird breeding (habitats, food resources) be monitored in conjunction with actual waterbird breeding.

Response of Waterbird Refugia Availability to Regulator Operation

During inter-flood periods, permanent and semi-permanent wetlands on the floodplain provide refugia in which adult survival can be maintained until conditions become suitable for breeding. While productivity, and hence food availability, are lower on these refugia than is required for breeding (see below), they are critical for the maintenance of existing populations, by creating conditions for adult survival. Braithwaite (1975) suggested that, in the long-term waterbird populations in Australia were primarily controlled by the availability of drought refugia (rather than ephemeral breeding opportunities), as food availability during these dry periods will determine the number of birds that are available to exploit the next breeding opportunity. The maintenance of suitable refugia habitats for a range of waterbirds during dry periods is thus critical for the regional, long-term maintenance of these species.

While a primary benefit of regulator operation for waterbirds will be to increase the frequency of breeding opportunities, an important additional benefit might come from regulator operation during times of regional drought. While accessing the water required for operation might be difficult during these times, such a strategy will maximise the regional benefit to waterbirds, by ensuring that drought refuge habitats are made available at times when other regional wetlands (that are less likely to be regulated for environmental purposes) are unlikely to contain water (and thus provide waterbird habitat). This would be particularly important during dry periods that are basin-wide, and as such drought refugia are rare across the basin. The use of a regulator at Chowilla provides an opportunity to improve the availability of such refugia. During periods of extended drought, regulator operation might also be used to provide “artificial” breeding opportunities; however, the provision of inundated wetlands under conditions of low flow will still be important for refugia creation (even if conditions are not suitable for breeding). We thus recommend that, in addition to regulator operation during times of high water availability, investigating opportunities for regulator operation during regional droughts. These investigations would need to consider the regional need for refugia maintenance in Chowilla. Many of the historically important drought refugia for Australian waterbirds are currently under extreme threat. For example, the historic drainage of permanent swamps across SE Australia, and the continued degradation of many coastal wetlands (e.g. Coorong) have significantly reduced the capacity of these traditional refugia to support large waterbird populations during drought. This would suggest that, under the current landscape, the provision of flooded areas in Chowilla during regional droughts would provide significant benefits, even if the area flooded at a regional scale is relatively small.

Specific Responses of Waterbird Groups to Regulator Operation

While the general principles to regulator operation described above apply, the broad array of ecological niches filled by waterbirds suggests a diversity of responses to regulator operation within these general guidelines. These different responses will be determined primarily by the abundance of, and access to, food resources, and for breeding species, access to nest sites. Here we outline the ecological features of each waterbird guild that are relevant to regulator operation.

Waterfowl (Ducks, Swan)

Important species in Chowilla: Australian Shelduck, Australian Shoveler, Australian Wood Duck, Black Swan, Blue-billed Duck, Freckled Duck, Grey Teal, Musk Duck, Pacific Black Duck, Pink-eared Duck, Hardhead

Waterfowl generally, though certainly not exclusively, rely on submerged aquatic macrophytes and aquatic invertebrates associated with these as food sources (Barker and Vestjens 1989), and their response will be primarily be driven by the availability of these resources in response to alternative scenarios. Invertebrates in particular are important for breeding waterfowl, as they provide the protein source required for egg and nestling development.

Aquatic invertebrates, and to a lesser extent aquatic macrophytes, are more abundant in re-flooded temporary wetlands than permanent wetlands (Boulton and Lloyd 1991); these wet-dry wetland habitats are thus crucial habitat for ducks and swans, that can rarely breed on permanent wetlands. A critical benefit of regulator operation, therefore, is to provide shallow wetlands that are periodically inundated (and dried), particularly for breeding waterfowl.

With the exception of terrestrial foragers such as Australian Wood Duck, all waterfowl species rely on inundated wetlands for foraging habitats, and, in some cases, for the creation of nesting sites that are surrounded by water (and thus less vulnerable to predation; Marchant and Higgins 1990). For those species in which submerged aquatic macrophytes form at least a significant part of their diet, responses will be determined by the growth responses of these plants. Permanent inundation, however, may not necessarily affect the abundance of submerged macrophytes in the long-term, except under conditions that restrict light availability (e.g. deep and/or turbid water; (Brock and Casanova 1991). Water depth would also affect the ability of grazing waterbirds to access submerged macrophytes, with the largest (Black Swan) able to access benthic resources to a depth of up to 1m (Bonner 2007). However, as stated above, wetlands that undergo wet-dry cycles respond with an increase in the abundance of aquatic macro-invertebrates that form an important food source for many duck species. Furthermore, areas of suitable shallow habitat will always be available at wetland margins (see also shorebirds below).

Waders & Shorebirds

Important species in Chowilla: Australian White Ibis, Yellow-billed Spoonbill, Great Egret, Greenshank, Red-capped Plover, Red-necked Avocet, Black-winged Stilt, White-faced Heron

The diets of waders and shorebirds are very broad, both within and between the species listed. The common feature of all these bird species, therefore, is foraging mode: all of these species forage by walking (or wading) while searching for prey, either in shallow water or exposed (and open) shorelines. An important common feature of the preferred habitats for this group, therefore, is access to shallow water or recently exposed shoreline habitats. These species are thus largely excluded from deep and permanently inundated wetlands that do not possess shallow gradients at their margins. However, many of the wetlands of Chowilla do possess these shallow-gradient habitats. While, under exceptional flooding conditions, shallow-water and exposed shoreline habitats may be reduced in area, these habitats will inevitably be restored as wetlands go through drawdown.

Within this broad foraging mode, the prey species harvested by this guild are very broad. The diet of some species are dominated by small-bodied fish (e.g. Greenshank, White-faced Heron, Great Egret), and the abundance of food items for these species will be consistent with the response shown by other piscivores (see below). Other large waders feed on a larger variety of prey, including large aquatic macro-invertebrates and fish (Australian White Ibis, Yellow-billed Spoonbill), or smaller aquatic invertebrates, such as insect larvae (Black-winged Stilt, Red-necked Avocet). A smaller group of shoreline specialists (Red-capped Plover) feed on washed-in aquatic invertebrates (including insect larvae), but will also feed opportunistically on terrestrial invertebrates near the shoreline. This last group also includes long-distance migratory birds, for which Chowilla is listed under various international agreements (JAMBA, CAMBA), although these are not especially common in Chowilla. The responses of this guild will principally depend on: a) availability of shallow-water habitats (<0.4m), b) response of small-bodied fish and aquatic macro-invertebrates, including aquatic insect larvae. Brookes (2007) suggest that these shallow water habitats will be extensive under regulator scenarios, at least under low-flow conditions.

Piscivores

Important species in Chowilla: Australasian Grebe, Darter, Australian Pelican, Great Egret, Great Cormorant, Hoary-headed Grebe, Little Black Cormorant, Little Pied Cormorant, Musk Duck, Pied Cormorant, Whiskered Tern, White-faced Heron, Swamp Harrier

Of the groups of waterbirds described, some piscivorous species have been impacted least of all by the hydrological changes to Chowilla. Many diving piscivorous species (such as cormorants, darter and pelican) can utilise permanent, deep-water habitats (Hoyer and Canfield 1994; Parkinson *et al.* 2002), and may have benefited locally from the maintenance of weir pool levels in the river and permanent anabranches. Species such as darter can also breed under permanent inundation conditions, in association with suitable nest sites (Marchant and Higgins 1990). However, permanent water bodies are not universally favoured by piscivorous species: grebes, for example, are likely to benefit from the provision of shallow temporary wetlands. While some species are able to access large-bodied fish (that might be disadvantaged by the operation of the regulator), the predominant component of the diet of most (if not all) piscivorous birds are small-bodied fish species, and juvenile (smaller-sized) larger-bodied species (e.g. Barker and Vestjens 1989; Marchant and Higgins 1990). The abundance of the most important food items for piscivorous birds in Chowilla is thus likely to be more abundant under regulator operation. However, we have considered the responses of piscivores to be slightly less strong than for other waterbird guilds, as some piscivorous species (particularly cormorants, Darter and Pelican) are provided with some habitats (in permanently inundated channels) under all scenarios.

Table 8. Responses of different waterbird groups to alternative scenarios, relative to scenario 1 (low-flow / no regulator). See pp5 for explanation of symbols used.

Scenario	Waterfowl	Shorebirds	Piscivores
1	↓	↓	↓
2	↑	↑	↑
3	↑	↑	↑
4	⬆	⬆	↑
5	⬆	⬆	⬆

Response of Terrestrial Birds to Regulator Operation

The Australian waterbirds described are likely to respond behaviourally to inundation events rapidly; longer-term ‘flow regime’ responses for these species are more likely to be observed at a population level (i.e. through an increase in recruitment during breeding events, and the maintenance of adult survival during interbreeding periods). While the response of terrestrial birds will occur at both behavioural and population levels, all of these responses will be strongest at the temporal-scale of the flow-regime (i.e. multiple inundation events). While habitat conditions for many species may be altered following from single inundation events, the strongest sustained responses will be to a change in inundation frequency.

Here we focus our discussion on two key groups of terrestrial birds, ground-foraging insectivores, and leaf-gleaners, providing representative examples for each.

Response of Ground-foraging Insectivorous Birds to Regulator Operation

Important species in Chowilla: Southern Whiteface, Willie Wagtail, Red-capped Robin, Brown Treecreeper, White-browed Babbler

As with other bird assemblages, ground-foraging insectivorous birds will principally respond to hydrological changes on a floodplain, through changes in the availability of food sources. This, in turn, is determined by the abundance of food items (terrestrial arthropods), and the availability of these food items to the birds (through the availability of appropriate foraging habitats). Both of these, in turn, relate primarily to the responses of floodplain vegetation, either through an increase in leaf litter accumulation, and/or changes in the structure of understorey and ground layers.

The abundance of food for ground-foraging insectivorous birds is likely to be influenced by floodplain hydrology, through its effect on the abundance and species richness of the terrestrial arthropod fauna. The response, however, may be mixed. (Ellis *et al.* 2001) found that, for most higher-order taxa, species richness was not influenced by flooding, and while the abundance of carabid beetles and crickets increased following inundation, the effect was not seen until the second year of an annual flooding regime. Medium- to long-term hydrological regimes (rather than single inundation events) may thus be an important determinant of the availability of terrestrial floodplain arthropods for ground-foraging insectivores.

However, in a study on red gum floodplains in south-east Australia, (Ballinger *et al.* 2005) reported an increase in the abundance and distribution of both carabid beetles and lycosid (wolf) spiders in response to a single flood event. A further result of this study was the identification of a positive relationship between the abundance and diversity of beetles, and flood duration, although the response observed in spiders was not related to flood duration. Leaf fall from *E. camaldulensis* is greatest immediately following an extended period of inundation (Briggs and Maher 1983) and that this leaf litter would provide a food source for detrivorous invertebrates both during inundation (which would support waterbirds) and after inundation (to support terrestrial ground-foraging insectivorous birds). However, the rate of leaf fall (and availability of carbon for invertebrates) will obviously depend on initial tree condition. Under initially stressed conditions, one might expect a delay before leaf litter volume increases to the point where positive invertebrate and bird responses are detected. The relationship between leaf litter accumulation, invertebrate responses and bird responses should potentially be incorporated into a proposed monitoring framework (see below). In summary, this evidence suggests that a positive habitat response may be possible from single flood events for ground-foraging insectivores, although these responses are likely to be enhanced by suitable, longer-term inundation regimes. However such a response may not occur for a number of years in the first instance, given the current stressed state of floodplain vegetation.

In the short-term, direct inundation of the floodplain will obviously remove areas of habitat for ground-foraging insectivores (and other terrestrial ground-dependent birds; Table 9). This may impact on resource availability during the inundation period, although under all of the operational scenarios considered, some of the floodplain remains above the water (see Table 5). Furthermore, many ground-foraging insectivores are able to utilise non-floodplain (mallee) regions to supplement the local and temporary loss of ground-foraging habitat. However, the movement dynamics of ground-foraging birds between floodplain and mallee areas is poorly understood, and we additionally require more information regarding the relative habitat value of floodplain vs mallee habitats (and other habitats above the waterline during inundation).

This short-term decline in habitat availability, however, is more than off set by the medium- long-term improvements in habitat (Table 9), through increases in the floodplain tree health, leaf fall, and subsequent increases in the abundance of terrestrial arthropods (as described above). When looking at changes in habitat availability to ground-foraging insectivores from a flow regime perspective (rather than single flood perspective), the overall response is certainly positive.

A potential risk of regulator operation to ground-dependent terrestrial birds is the potential increase in understorey vegetation density, particularly through the invasion of weeds. Fine-scale alterations to ground-layer structure are known to have significant impacts on food availability for ground-foraging insectivores (Cousin 2004; Gillespie 2005; Maron and Lill 2005). In particular, a shift from a natural ground cover of (for example) leaf litter, bare ground and tussock grasses to one dominated by exotic sward grasses can significantly hamper the ability of ground-foragers to access prey (Rogers unpubl. data). Among those weed species assessed by (Nicol 2007), Couch Grass (*Cynodon dactylon*) was considered a species of high invasion risk in response to regulator operation, and we would also predict this species to negatively impact on habitat for ground-foragers in those areas it did invade. While (Nicol 2007) also note that *C. dactylon* has not been recorded near areas of natural or artificial flooding, future vegetation monitoring should account for the distribution of this, and other risky species, in relation to habitat for ground-dependent birds.

Table 9. Response of ground-foraging insectivorous birds to alternative scenarios, across short, medium and long temporal scales. See p5 for an explanation of the arrow symbols used.

Scenario	Short-term[1]	Medium-term[2]	Long-term[3]
1	↓	⬇	⬇
2	≈	↑	⬆
3	≈	↑	⬆
4	↓	⬆	⬆
5	↓	⬆	⬆

An additional component of the ground-dependent avifauna are those species that nest on the ground. In particular, the Bush Stone-Curlew is a ground-forager and ground-nester that has become locally extinct in many parts of its former range. Furthermore, breeding for this species is now totally restricted to the floodplain, making the conservation of this habitat critical for the species' regional persistence. One proposed reason for this decline is predation pressure, principally by Red Fox *Vulpes vulpes* (Gates and Paton 2005). However, Chowilla maintains breeding populations for this threatened species (Garnett and Crowley 2000), a fact that is recognised in the EMP Targets for the Icon Site (MDBC 2006).

Being a ground-forager, the principles applied above with regard to food availability equally apply to Bush Stone-Curlew. With regard to the species' ground-nesting habit, some additional benefit may be drawn from certain levels of inundation, through the creation of islands (that are not inundated), surrounded by barriers that are difficult for foxes to negotiate (thereby reducing predation pressure). Alternatively, however, the creation of islands (with foxes as well as Bush Stone-Curlew inhabiting these islands) may lead to 'hyper-predation', in which predation rates by foxes are actually higher due to the restriction in search area resulting from island creation. In relation to the overall response of Bush Stone-Curlew, we recommend that intensive monitoring of Bush Stone-Curlew be undertaken, in conjunction with targeted fox control efforts. Both of these should occur independently of regulator operations, as part of management plans for this threatened species.

Response of Leaf-gleaning Insectivorous Birds to Regulator Operation

[1] Short-term refers to the period during floodplain inundation
[2] Medium-term refers to the period immediately following floodplain inundation, once drawdown is complete
[3] Long-term refers to the response to a multi-year operational regime, during which multiple inundation events have occurred

Important species in Chowilla: Rufous Whistler, White-plumed Honeyeater, Blue-faced Honeyeater, Striated Pardalote

Food availability for leaf-gleaning insectivores is largely driven by the condition of host trees, and the response of leaf-gleaners to changes in floodplain hydrology will reflect the tree responses to these changes. However, the relationship between leaf insect abundance and tree condition is complex. Conflicting theories relate plant condition to the performance of herbivorous insect populations that link increased herbivore performance to either healthy plants, or, conversely, stressed plants. In both cases, the feeding mode of the insects largely determines their response to plant condition (Inbar *et al.* 2001). For Eucalypt trees that are under stress, lerp *density* may be high, in response to the plant's poorer ability to chemically defend leaf tissue. However, lerp (and other herbivorous insects) are also found in moderate-high densities on new growth, and are thus likely to have high levels of overall abundance on unstressed trees, following the greater volume of leaf material found on these trees (A. Jensen pers. comm.). Furthermore, the diversity and abundance of the broader leaf arthropod community are both likely to be higher on new growth than stressed leaves (Inbar *et al.* 2001). From the perspective of food availability for leaf-gleaning insectivorous birds, canopy arthropod abundance may indeed be higher on trees in good condition. (Trotter *et al.* 2008) found that the abundance (and diversity) of canopy arthropods in *Pinus edulis* canopies was positively correlated with tree condition, although the abundance of many herbivorous arthropod species was skewed towards trees under stress. A final complication stems from interspecific interactions among leaf-gleaning birds, such as Noisy Miner (Grey *et al.* 1997; Loyn *et al.* 1983). In summary, while canopy insect density may be higher on the leaves of stressed trees (particularly for herbivorous insects), overall canopy insect abundance is likely to be at least as high on trees displaying abundant new growth (although overall density is lower). Stressed trees in particular are likely to respond to watering (through floodplain inundation) with new growth, while healthy trees produce new growth seasonally, in a way that is relatively independent of inundation. This pattern applies most to Red Gum *E. camaldulensis,* although Black Box *E. largiflorens* appears to respond more broadly to inundation events (i.e. with less of a seasonal pattern). As such floodplain inundation will, at the very least, not adversely affect the availability of canopy arthropods to leaf-gleaning insectivorous birds, and will most likely have a longer-term positive impact (Table 10).

Table 10. Response of leaf-gleaning insectivorous birds to alternative scenarios, across short, medium and long temporal scales. See pp5 for an explanation of the arrow symbols used.

Scenario	Short-term	Medium-term	Long-term
1	↓	⬇	⬇
2	↑	⬆	⬆
3	↑	⬆	⬆
4	⬆	⬆	⬆
5	⬆	⬆	⬆

Response of Regent Parrot to Regulator Operation

One of the three EMP Targets that are relevant to Chowilla's avifauna relates to the nationally threatened Regent Parrot. Specifically, the EMP states that one of the targets for the Chowilla Icon Site is to "maintain the current nesting locations of Regent Parrot". Given the species' inclusion in the current Icon Site management objectives, this report would be remiss to ignore the potential impacts of regulator operation on Regent Parrot nesting habitat.

However, within the icon site, Regent Parrot currently nest in only three colonies, all located in stands of mature dead red gums on the weir pool above lock 6 (e.g. Smith 2006). An increase in floodplain inundation as a result of regulator operation will thus have no influence on the extent of breeding sites for this species, as the distribution of suitable nest sites is unlikely to change in the medium term (i.e. in the next 50-100 years). Over extremely long periods of time, maintenance of Regent Parrot nest sites will require red gum recruitment and survival to a size where the trees are able to bear suitable hollows; however, this process will take over 100 years, clearly outside of the current scope of regulator operation. Given that Regent Parrot rely almost exclusively on food sources located outside of the floodplain, maintenance of Regent Parrot populations in Chowilla will depend on management decisions made outside of the Icon Site.

MONITORING AVIAN RESPONSES TO REGULATOR OPERATION

The assessment provided above is essentially limited to expert opinion, and by the fact that the proposed regulator operation is unprecedented. A critical component of regulator operation, therefore, will be an appropriately designed monitoring framework. This can be used to measure the responses of avifauna (and other biota) to regulator operation (and other environmental changes), such that management can be adjusted to suit the project's objectives.

The monitoring framework described below has been designed primarily to determine changes in habitat condition through time for terrestrial and aquatic birds. Specifically this monitoring will determine:

- changes in the abundance and distribution of terrestrial bird species
- changes in the abundance and distribution of aquatic bird species
- changes in the abundance and distribution of breeding attempts for aquatic bird species

As pointed out below, Chowilla bird monitoring should be conducted in such a way that data collected for other monitoring programs (e.g. vegetation condition, fish) can be used to infer changes in habitat condition for birds. Other, more direct measures of habitat condition for birds are available. In particular, for breeding birds, reproductive performance is the most direct measure of habitat, and measuring the success of nesting attempts by waterbirds in the context of this project would be the best measure of changes in waterbird breeding habitat. However, the nature of waterbird breeding in Chowilla (mostly dispersed nesters in lignum shrublands) would make monitoring breeding success difficult (M. Harper pers. comm.). For non-breeding habitats, body condition (e.g. body fat reserves) are also seen as a more direct measure of habitat condition than simple abundance (Johnson *et al.* 2006); again, however, monitoring body condition requires animal capture and handling, and large sample sizes per target species. While these more direct techniques may be considered, the monitoring framework described here relies on standard survey techniques for monitoring a less powerful (but logistically practical) measure of habitat condition, namely abundance. The abundance and distribution of birds is also seen as a strong measure of habitat condition for these birds (Bock and Jones 2004), at least relative to other habitats and regions available to the birds.

The monitoring framework proposed here uses two techniques, transects of floodplain habitats, and point-counts of open wetlands. Justifications for adopting these different techniques are provided below.

1. Floodplain transects

Bird data should be collected along a series of established transects, with each transect being 1 km in length and 100m wide (50m each side of the central line). Within each 100m long section of the transect the total number of birds of each species would be counted, giving ten 1 ha (100m x 100m) counts per transect. A modified form of this survey methodology has been used successfully to monitor the responses of birds to fire and drought in semi-arid heathland (e.g. Paton *et al.* 2005). We suggest that transects in Chowilla should run approximately parallel to topographic contours, such that the ten 1 ha cells on each transect replicate a particular topographic habitat. Across Chowilla, however, transects should be stratified across three key environmental parameters:

- topography (determines probability and extent of inundation)
- plant community (particularly Red Gum, Black Box woodlands, and Lignum shrublands)
- distance from regulator (determines probability and extent of inundation)

The selection of sites needs to ensure that the complete range of values for these key parameters is covered by the sites collectively. Site selection must also account for logistical issues such as accessibility. In addition, advantage should be taken of the current variation in vegetation condition that occurs across Chowilla (i.e. flush zone vegetation versus 'outer', stressed vegetation).

We recommend that these transects be used to count birds on a semi-annual basis. One set of counts would occur in mid-late Spring (early Summer) to coincide with peak inundation of floodplains. This flood count would be used to monitor waterbird use of inundated floodplain, and in particular, breeding waterbirds using flooded Lignum shrublands (that, due to their cryptic nature, may be missed by wetland point counts). However, terrestrial species should also be monitored at this time, as their use of the system will be different during inundation versus post-drawdown.

A second set of counts would occur in mid-late Autumn, soon after the completion of drawdown. This second survey would principally monitor the responses of terrestrial birds to recent inundation.

2. Point Counts of Individual Wetlands

In addition to transect counts of floodplain habitats, a series of point counts of key wetlands should be undertaken. These would build on the historic dataset for waterbirds in Chowilla (M. Harper pers. comm.), and allow for direct comparison with these historic data (i.e. through common methodology). From a breeding waterbird perspective, this report has identified a number of key breeding wetlands that will be particularly sensitive to regulator operation, and a program designed to monitor breeding responses of waterbirds should principally focus on these key wetlands.

Point counts of waterbirds should be timed to coincide with inundation events which, as suggested above, are generally timed to coincide with inundation of suitable wetlands. Historically, timing of breeding has typically been over Spring-Summer (coinciding with Spring floods in Chowilla), which also coincides with the proposed timing of regulator operation (thereby allowing for direct monitoring of regulator responses).

The number of sites selected to monitor will principally be determined by resource (time, personnel) constraints. In semi-arid heathlands, we have found that one 3 km transect, located in intact (>10 years postfire) vegetation, can be completed twice in 2-3 hours; for a 1 km transect in floodplain vegetation, we estimate that 45 minutes-1 hour would suffice (longer if inundated). Twenty transect sites would thus require up to 20 person-hours to complete. If we consider that terrestrial bird surveys should only be conducted in the morning, it should be possible for two people to complete 20 sites in three days (although flexibility would be required depending on weather conditions etc.). Given that sampling of aquatic birds are less limited to time of day, point counts of individual wetlands could be performed in the afternoons of the same days in which transect bird surveys were performed in the morning. Because of the heterogeneity that can occur between bird counts, we would recommend that each transect count and wetland point count be repeated five times within a two month period; this will ensure that such a monitoring program will be statistically robust. Under this design, an entire survey can thus be conducted in 15 days by two people.

Additional Monitoring Considerations

A significant challenge in monitoring nomadic waterbirds stems from their high mobility. Because of this mobility, many Australian waterbird species are able to select among sites, at large regional scales (including continental). The value of a particular wetland or floodplain, therefore, is only measured (by the birds) relative to the value of other available wetlands. For monitoring, the implications of this are that changes in local abundance may relate as much to changes in the quality of wetlands elsewhere, as to local environmental changes. For example, a decline in waterbird numbers in Chowilla may relate to flooding of other inland waterways, and the subsequent movement of birds to those waterways, even in the absence of any habitat changes in Chowilla.

A number of alternatives are proposed to help address this challenge. Richard Kingsford and colleagues (Kingsford and Porter 2008; Nebel *et al.* 2008) have attempted to overcome regional mobility of waterbirds by surveying at large regional scales. These large-scale surveys were done using aerial survey techniques (from an aircraft). While this technique has the obvious benefit of allowing large areas to be covered, limitations include the necessarily coarse spatial resolution of the surveys, as well as issues related to the accuracy of counts and species identification. Alternatively, monitoring may be designed to directly measure habitat quality for waterbirds, in addition to the abundance and distribution of the birds themselves. One of the most direct measures of habitat quality is the behavioural response of individuals to their environment. For example, spatiotemporal variation in the foraging performance of migratory shorebirds has been successfully used to monitor changes in habitat quality for these species, at multiple spatial scales (Wilson 2007; Rogers *et al.* in prep). In addition to monitoring the local distribution and abundance of waterbirds, we recommend that monitoring of such habitat performance measures (that may also include breeding success of individual birds) for targeted species will enhance the ability of such programs to detect responses to environmental change independent of changes in numbers of birds.

More generally, we propose that avian monitoring programs in Chowilla not be designed to specifically monitor responses to regulator operation, but be designed to broadly monitor changes in the distribution of the bird communities, with regulator operation being one of a number of managed and unmanaged ‘interventions’ that birds might respond to. Incorporating (and continuing with) long-term monitoring datasets will allow the responses of birds to regulator operation to be placed in the context of long-term trends and patterns. Bird monitoring programs should also be done in conjunction with programs that aim to monitor the status of key avian resources, such as fish, aquatic invertebrates and flora, and condition of overstorey trees and terrestrial food resources. Monitoring that addresses these other components of the ecosystem should be coordinated with each other, and with bird monitoring.

Finally, we recommend that monitoring the response of bird communities to regulator operation be undertaken prior to initial operation, to conform with the principles of BACI (Before-After-Control-Impact) monitoring design (Johnson 2002). In this way, we are ensuring that changes to the bird community following regulator operation are a result of operation rather than natural variation.

SUMMARY AND DISCUSSION

This report presents an expert opinion analysis of the predicted responses of Chowilla's avifauna to the operation of the proposed environmental regulator on Chowilla Creek. They are, however, expert opinion models, and not based on a quantitative analysis of the options. Our strongest recommendation is, therefore, that regulator operation should only be undertaken under the true spirit of Active Adaptive Management, and that all responses should be monitored before, during and after operation.

The analyses presented here suggest that operation of the proposed environmental regulator in Chowilla will provide ecological benefits to the floodplain's bird community. The proposed regulator is not without risks to bird populations, however. A flexible operational strategy, underpinned by a truly adaptive management framework, should ensure that the benefits to birds are maximised, while risks are mitigated.

For waterbirds, significant and immediate increases in breeding opportunities can be provided by regulator operation, primarily through increasing inundation extent, duration and frequency of temporary wetlands and floodplains. Inundated temporary wetlands provide much more productive conditions than permanent wetlands, at levels that allow for the energetically demanding activity of successful breeding. In Chowilla, the benefits provided to waterbirds are particularly significant under low-flow scenarios (10,000 ML/day to SA). However, the sensitivity of many breeding waterbirds to wetland drawdown rate means that this aspect of regulator operation requires careful monitoring and evaluation. Waterbird breeding events should be carefully monitored, and either drawdown postponed until breeding has ceased, or adjusted on individual wetlands, to such a rate (<5cm/day) that minimises the risk of nest abandonment. This risk can also be minimised if inundation duration is long enough to ensure successful completion (and cessation) of breeding.

For two key groups of terrestrial birds (ground-foraging and leaf-gleaning insectivores), the benefits of regulator operation are likely to be less immediate, following from an increase in the health and functionality of floodplain vegetation (Red Gum and Black Box). For ground-dependent species, improvements in habitat will follow from an increase in leaf litter accumulation, leading to increases in the abundance and diversity of ground-dwelling arthropods. Additional benefits of regulator operation may be found for ground-nesting species (including Bush Stone-Curlew), through the creation of nesting islands during inundation. In the short-term, ground-dependent species will be excluded from the floodplain habitats that are inundated during operation, and the relative value of floodplain and other (e.g. mallee) habitats needs to be assessed, to ensure that these other areas provide for suitable habitat during the floodplain inundation phase. An additional slight risk for ground-dependent birds is potential invasion by exotic weeds, most notably Couch Grass, which can significantly and negatively alter the structure of the ground layer. However, this risk has yet to be realised under current artificial watering projects, and should be minimal with appropriate monitoring and weed management.

The relationship between regulator operation and leaf-gleaning terrestrial birds appears to be complex, with leaf insects responding positively to both healthy and stressed trees. While insect density (insects / leaf surface area) may be higher on stressed trees, the increased canopy volume of healthy trees, coupled with moderate increases in density in response to new foliage, mean that overall insect abundance (insects / tree) is likely to be higher on healthy trees. Furthermore, leaf arthropod diversity will also be higher on healthy trees than stressed trees, and should potentially support a broader suite of leaf-gleaning birds.

With regard to the seasonality of regulator operation, we would, as a first measure, recommend an operational strategy that best mimics “natural” flooding seasonality for the region (i.e. flood peaks in late Spring). For some waterbird species, breeding is only partly driven by responses to wetland inundation; some bird species naturally gear their breeding towards particular times of the year (that happen to coincide with seasonal flooding). If there were operational requirements that required Autumn-Winter flooding, we would again recommend that the responses to this ‘out-of season’ flooding be monitored to determine whether similar ecological responses as to what would be expected ‘naturally’ have occurred. Such monitoring to alternative operational regimes fits in well with the monitoring philosophy outlined above.

As birds are typically found at the top of food webs, their responses to environmental change tend to be indirect, manifesting through the responses of the trophic levels below them. The predicted benefits provided by regulator operation to Chowilla’s bird communities are thus dependent on benefits being provided to the aquatic and terrestrial organisms on which the food web relies, such as aquatic and terrestrial vegetation, macroinvertebrates and fish. While some of these responses are well understood (e.g. fish and terrestrial vegetation) others are complex and poorly understood (e.g. aquatic macroinvertebrates). The underlying assumption that birds will benefit through positive responses by these other organisms should be tested and confirmed for the Chowilla system. Improving this required information can be achieved through a robust and comprehensive monitoring framework, which will help to adapt regulator operation and Chowilla management through time.

More generally, the links between Chowilla's bird communities and the floodplain ecosystem suggest that, while some aspects of the response are species-specific, a general improvement in productivity and ecosystem functionality, brought on by an increase in extent, duration and frequency of inundation, will result in a general improvement of the region for birds and bird habitats.

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