An Evidence-based Recovery Plan for the Calperum Floodplain 2020-2025

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Contents

Introduction

Established in 1996 by Patricia Feilman AM, the Australian Landscape Trust (ALT) was born from the Potter Farmland Plan, a strategy that engaged families to rethink the long-term environmental sustainability of their farms. The trust manages two substantial operations; Calperum and Taylorville Stations in the Riverland, South Australia; and Strathfieldsaye in East Gippsland, Victoria, each providing educational and volunteering programs. The ALT philosophy encourages collaborative partnerships between land managers, ecologists, and the wider community to support and improve the management of regional landscapes and ecologically significant environments.

Calperum Station is 238,638 ha of pastoral leases near Renmark, SA. In 1993, Calperum Station was purchased with the intent of managing it as a model program reflecting the goals of the UNESCO Man and the Biosphere Programme. From 1996 to 2012 it was managed by ALT under contract from the Director of National Parks. In 2013 the leases were transferred to the Australian Landscape Trust and the property was placed under a South Australian Heritage Agreement. The Deed of Assignment and its goals remain as conditions on the property's management. Calperum Station is to be managed for *"… conservation of its mallee vegetation associations and wetland areas, and their dependent wildlife, and for public education on the ecologically sustainable use of natural resources*."

The Calperum floodplain is part of the Riverland Ramsar site and is a significant ecological area supporting a wide range of aquatic and terrestrial plants and animals (Appendix I), as well as significant indigenous cultural heritage. The management of this floodplain has, wherever possible, been done in collaboration with National and State agencies responsible for managing the ecosystems of the Murray-Darling Basin.

Management approach

The Calperum floodplain has been subject to substantial change in the past 170 years and ecological characteristics, such as flooding regimes, have now permanently changed. Therefore, management of such a landscape should not focus on returning the system to a previous 'natural' state, but instead should maintain those components of the system that are functioning in a desirable way and restore those that are degraded and dysfunctional. The target state should be one, which retains as much of the original ecosystem character as possible and has desirable ecological function that is sustainable under the new hydrological regimes of the Murray-Darling Basin.

Achieving the desired ecological state of this floodplain will require more than simply protecting existing conditions, because some elements of the landscape are now dysfunctional and without some form of intervention will continue to degrade and lose ecological value. There are three levels of restoration that can be used to achieve the management goals for the floodplain. These differ in the level of management intervention and consequently the costs and risks of implementation:

> **'Natural' Recovery** – where the removal of threats allows the system to respond in a way that leads to the desired ecological state, without further intervention. An example of this is the recovery of floodplain understorey communities with the reduction in total grazing pressure through management of kangaroos and introduced herbivores.
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> **Assisted Recovery** – where the system requires more than just the removal of threats. It also requires management interventions to correct abiotic and/or biotic damage impeding recovery, or initiates triggers to ecological disturbance responses. An example of this is environmental watering, which triggers flood disturbance responses that restore composition, structure and/or function to floodplain systems.

Reconstruction – where the ecological system is damaged to a degree that removal of threats and impediments to recovery are insufficient and management to alter abiotic and biotic components is required for the system to shift toward a more desired state. In this situation the initial goals of management are not always focused on the final desired state, but may seek to achieve transitional states before the final goal can be achieved. An example of this is the restoration of scalds where the initial management using branching is focused on returning abiotic and biotic function. The structure and composition of this transitional state is less important than the return of function (i.e., soil dynamics and plant germination processes). Once the capacity to responded to ecological processes has been restored, assisted recovery can be implemented that will move the site toward an appropriate floodplain community.

The management approach taken in this plan is to use the form of restoration that requires the least intervention to achieve the ecological objectives for the Calperum floodplain. This should result in the most cost-effective and lowest risk management program possible. It is likely, however, that what is required to achieve the desired objectives will change over time as other issues become more important due to improving conditions; and our understanding of the ecosystem's requirements develop through the review of management and monitoring actions. The planning process, will therefore, allow for adaptation over time to incorporate these changing restoration requirements. This is also why longer-term planning structures—5-years in this case—are important to maintain certainty in the delivery of what are long-term goals. Annual plans, though necessary to determine expenditure in a particular year, do not create an effective management environment for delivering outcomes that may not result in any substantive change in a one- or two-year timeframe. Equally management across longer timeframes must be balanced by appropriate review of short-term targets to ensure expected progress is likely to be achieved.

The scientific literature has highlighted problems in transferring scientific theory and empirical information to management actions (Knight *et al.* 2006, Cabin *et al.* 2010). This is a result of unrealistic expectations of the relative roles of science and practice in management. The effective use of research requires the ongoing collaboration between scientists and managers, working through the problems on the ground as they become apparent. In other words, research is integral to an iterative management approach, if it is to be effective. This recovery plan is titled evidence-based recovery, because it is premised on this philosophy that application of both research and practice will be needed throughout the recovery program to gain better understanding of how the system functions and the most practical way to restore it.

The plan

This plan outlines the current state of the Calperum floodplain through a conceptual model of how the system functions and an appraisal of the floodplain's current ecological state. Using these foundations, it identifies ecological objectives for managing the floodplain and describes management options and targets for delivering the desired outcomes. Finally, it outlines a costed 5-year implementation strategy for delivering the identified management. This plan should be supported by annual implementation plans, that adjust actions according to changing conditions (e.g., river flows and water availability, drought, *etc.*) and identified opportunities/issues from implemented monitoring.

The core of the plan is detailed in the main body of text; with analyses of specifics components, used to determine the plan's focus and implementation, being detailed in appendices.

Aim

To protect and restore the ecological and cultural values of the Calperum floodplain, through evidence-based management.

To achieve its aim the plan applies the following principles to all management decision being assessed and implemented:

1. Management is based on the best scientific evidence on the threat being addressed and the expected outcome from the management actions being implemented.
2. That all ecological management is consistent with the protection and restoration of the integrity and quality of significant cultural landscapes, heritage structures and other heritage features.
3. That management contributes to regional, state, and national strategies for the conservation and restoration of the ecological values of the River Murray.

The objectives of this plan have been derived from the issues identified within the situation appraisal of the site, the conceptual model, and from the existing management plans/strategies associated with the Calperum floodplain (Appendix II). The first three are ecological objects, the fourth delivers ecological and social outcomes, while the final objective has a focus on social outcomes.

Objectives

1. Facilitate the movement of water across the floodplain landscape in ways that benefit and enhance biological diversity, and is consistent with the maintenance of the Riverland Ramsar site's ecological character.

2. Restore impaired ecological diversity and function within floodplain communities, including state and nationally listed threatened species.

3. Protect and restore the functioning of native ecosystems by limiting the impacts of introduced species and over-abundant native species.

4. Conduct or facilitate research and monitoring that ensures effective evidence-based management of the floodplain.

5. Promote awareness, education, and participation within the community that assists in maintaining the floodplain's ecological, cultural, and wise-use values.

Situation Appraisal

The current state of the Calperum floodplain has been assessed with the framework of a conceptual model (Appendix III). Detailed analysis has been done for specific aspects of floodplain ecology associated with the objectives (Appendices IV to VI) and forms the basis for the management options identified in this plan.

Site Description

The Murray River floodplain on Calperum Station is 8,400 ha, and forms part of the Riverland Ramsar site. The Riverland Ramsar Site was first listed in 1987, and following a revision of its boundaries in 2007, now encompasses 30,640 hectares of River Murray floodplain, between Renmark and the Victorian and NSW border (Newall *et al.* 2009, DEH 2010). The Calperum floodplain encompasses three major wetland basins that are connected via the Ral Ral anabranch of the Murray River. Lake Woolpolool and Lake Merreti are connected directly to Ral Ral Creek, while Clover Lake is filled via a channel at the northern end of Lake Merreti. Historically, Woolpolool swamp, which lies between Lakes Merreti and Woolpolool, provided a direct connection between the two lakes during large floods but these flow paths have been disrupted. Reny Island, Hunchee Island and Little Hunchee Island lie between the anabranches (Ral Ral, Hunchee and Amazon) and the River Murray. At a regional scale, groundwater flow moves radially inwards towards the centre of the Murray-Darling Basin, and the Calperum/Chowilla region acts as a natural discharge area for the regional groundwater system (Jolly *et al.* 1994). This groundwater is naturally saline (40,000- 90,000 EC).

Floodplains support a wide range of plant communities, because of the diverse conditions caused by flooding events. Woodlands dominated by red gum *Eucalyptus camaldulensis* and/or black box *Eucalyptus largiflorens* cover 44% of the Calperum floodplain and have a diverse array of understorey communities from shrubs, forb, grass or herbland species to taller shrublands of lignum *Duma florulenta* or river saltbush *Atriplex rhagodioides* (Appendix IV). Treeless areas, depending on soil type and soil salinity, have tall shrublands (e.g., *A. rhagodioides*), low chenopod or samphire shrublands, herbfields of pale beauty-heads *Calocephalus sonderi* and peppercress (L*epidium* spp.), or grasslands of river couch *Sporobolus mitchellii*. The permanently inundated wetlands, such as creeks and billabongs are often fringed by; spiny sedge *Cyperus gymnocaulos*, cumbungi *Typha domingensis* and common reed *Phragmites australis*. Aquatic plant communities including red milfoil *Myriphyllum verrucosum* and ribbonweed *Vallisneria americana*.

The Calperum floodplain supports a diverse fauna, many species of which are restricted to floodplain communities. The floodplains also provide breeding and foraging habitat for waterbirds and migratory waders. Since 1984, 69 species of waterbirds have been recorded on the Calperum floodplain, with numbers as high as 37,886 individuals using the lakes at any one time (Appendix VI). During medium to large flood events, colonial-nesting waterbirds breed at Lakes Merreti and Woolpolool. Large colonies of up to 1000 nests of six species can occur at Lake Merreti, with species including the Australian white ibis *Threskiornis molucca* and straw-necked ibis *Threskiornis spinicollis* (DEH 2010). The floodplain is also important for terrestrial bird species, and their woodlands are refugia for some terrestrial birds during droughts. Species such as the bush stone-curlew and regent parrot are restricted to floodplain habitats in the region for at least part of their life (Appendix VI).

Three mammals are restricted to the Calperum floodplain; the water rat *Hydromys chrysogaster* inhabits aquatic habitats, the common brush-tail possum *Trichosurus vulpecula* uses the floodplain woodlands, while Paucident's planigale *Planigale gilesi* favours the flood-dependent, cracking clays (Appendix VI). The floodplain also has a distinctive assemblage of reptiles, ranging from tortoises (*Chelodina expansa* and *Emydura macquarii*) and water skinks *Eulamprus quoyii* to lace monitors *Varanus varius,* and geckos (tessellated gecko *Diplodactylus tessellatus*). Ten frog species are recorded on Calperum Station of which seven are restricted to floodplain habitats, including the threatened southern bell-frog *Litoria raniformis.* Since 1990, 12 native fish species have been recorded within the lakes and creeks on Calperum Station, including the nationally vulnerable Murray Cod *Maccullochella peelii*, and the state protected Silver Perch *Bidyanus bidyanus* and Freshwater Catfish *Tandanus tandanus* (Appendix I).

This diverse flora and fauna include 13 species of plant and 12 fauna species that are threatened at national and state levels (Appendix I: Tables 1 & 2). Along with the significant ecological characteristics that define it as part of the Riverland Ramsar site (Appendix I) they make this floodplain a nationally significant riverine ecosystem.

The upper reaches of the Murray River in South Australia have been occupied by humans for at least 25,000 years (Flinders University Arts and Social Sciences *unpublished data*). The Murray River territories of aborigines were one of the most densely inhabited and culturally dynamic landscapes within Australia (Incerti 2018). Calperum Station was the intersection between five different indigenous tribal groups, but the floodplain on Calperum is part of the lands of the Erawirung people (Thredgold 2017, Incerti 2018). This long occupation of the floodplain by indigenous people and its significance as a food and water resource has resulted in a significant number of cultural heritage sites. Sites include all aspects of indigenous culture from day to day living to burial sites, and include physical structures (e.g., earth mounds), fixed artefacts (e.g., scar trees) and mobile stone artefacts (Thredgold 2017, Incerti 2018, Dardengo 2019).

The Calperum floodplain is part of an extensive broad floodplain upstream of the Riverland irrigation area and major rural towns, such as Renmark. This floodplain provides numerous ecosystem services to these important human systems primarily; as a flood mitigation zone where floodwaters can escape the Murray River's channel reducing the risks of human infrastructure being flooded, and as an ecological filter delivering clean, low salinity water downstream.

Changes to the Calperum Floodplain

Although the Calperum floodplain has significant ecological and cultural values it is not without ecological problems. A range of threats have been identified by previous management processes (Appendix II) and some have been refined within this plan. The primary threats are altered hydrological regimes, historical and current grazing pressure and introduced species. These threats have affected aquatic and terrestrial components of the floodplain ecosystem differently, but in general the result has been a loss of ecological function and a decline in biological diversity.

Aquatic System Changes

Since European settlement, the surface hydrology of the Calperum floodplain has altered significantly, predominantly through regulation of the flow regime of the River Murray, storage of floodwaters in the lakes and manipulation of flows across the floodplain (Steggles & Tucker 2003). Regulation of the River Murray has reduced the magnitude, frequency, and duration of river flows (Walker & Thoms 1993, Maheshwari *et al.* 1995), and has altered the connectivity between the River Murray and its floodplain. The most significant impacts to the natural flow regime of the

Calperum floodplain would have occurred with the construction of Lock 5 in 1927 and Lock 6 in 1930 (MDBC 2006). These structures changed river flows and dramatically reduced variation in river height. The result of these changes to groundwater hydrology have been a rise in the water table and increased soil salinisation, leading to an accumulation of salt in floodplain soils. These changes in surface and groundwater hydrology, have adversely affected wetland function, the health of floodplain vegetation and its associated fauna (Steggles & Tucker 2003).

Under natural conditions Lake Merreti would have been a temporary wetland subjected to irregular wetting and drying events according to fluctuations in River Murray flows. Changes to the water regime of Lake Merreti have arisen over time through regulation of the river, its anabranches, and the wetland itself (Steggles & Tucker 2003). Historical maps from the 1870-80s show Lakes Merreti and Woolpolool as reservoirs, so regulation of the lake's flow have likely been operating for 150 years. Formal regulation of Lake Merreti commenced in 1914 to maintain an adequate supply to the Chaffey Irrigation Area. Then in 1927 Weir 5 was constructed on the River Murray, which created stable water levels in Ral Ral Creek and Lake Merreti. Stable water levels meant Lake Merreti was less important as a water supply and the regulator fell into disrepair (Steggles & Tucker 2003). Lock 5 did not result in the permanent inundation of Lake Merreti as there is oral and photographic evidence to indicate that the lake dried on at least four occasions after the weir was installed, in 1934-35, between 1939 and 1944, in 1950 and again in 1958 (Steggles & Tucker 2003). However, around 1960 a levee was installed at the junction of Hunchee and Ral Ral Creeks, which appears to have resulted in the permanent inundation of the wetland, up until 1983 when a regulator was constructed on the inlet creek to Lake Merreti. This structure was used to again store water in Lake Merreti for managing salinity levels in Ral Ral Creek, however, this was ineffective as salinity levels in the lake generally exceeded those in the creek (Steggles & Tucker 2003). In 1991, lake levels were lowered by 150 mm, resulting in the germination of hundreds of river red gums and the establishment of spiny sedge (*Cyperus gymnocaulos*) on the dried margins of the lake. Unfortunately, these young plants drowned over the following years as the lake returned to pool level, but the outcome resulted in alternative management of the lake being considered. In 1994 the regulator in the Merreti inlet was modified to allow for better regulation of water levels in the lake. From 1994 to 2002 a wetting and drying regime was re-established for Lake Merreti and the response was monitored (Steggles & Tucker 2003). The Millennium drought disrupted this program, with the lake only filling once between 2002 and 2009. A new regulator was then constructed in 2014 and the wetting and drying regime was recommenced.

Salinity in Lake Merreti, between 1983 and 2002, was highly variable averaging 999EC, but ranging from 166EC to 7,000EC (Steggles & Tucker 2003). Therefore, the lake could be considered a temporary freshwater wetland, though periods of high salinity would have affected some sensitive species. Since the re-establishment of the wetting/drying regime after 2014, salinity levels have been lower than 900EC.

Prior to river regulation Lake Woolpolool would have been a temporary, freshwater wetland. However, the construction of lock 5 would have had similar consequences for the lake as those described for Lake Merreti. Lake Woolpolool was disconnected from Ral Ral Creek prior to the 1950s, and in 1953-56 this separation was increased by extending the length and height of the levee along Ral Ral Creek and building a second levee preventing bank overflows from Lake Merreti entering Lake Woolpolool via Woolpolool Swamp (Jensen *et al.* 2002). These changes resulted in increased salinisation of the lake basin and substantial mortality of riparian vegetation, especially red gums.

In 1983 a regulator was constructed through the Ral Ral levee reconnecting Lake Woolpolool, when river flows were above 15,000ML/day. However, the levee was still in place and so flushing of the lake during flood recessions was limited. Periodic wetting and drying cycles in the lake were reinstated in 1984 through to 2002, which substantially improved the lake's condition, reducing soil salinity and allowing for the regeneration of red gum and lignum on the Lake's south-western end. However, surface water salinity in the lake still reached levels of 24,000EC, so it was effectively a temporary brackish wetland (Jensen *et al.* 2002). From 2003 to 2009 the lake remained dry due to low river flows during the Millennium drought. This event caused the loss of some recovering riparian vegetation and an increase in soil salinity on and around the lake. The 2010-12 flood reversed some of these declines and reduced soil salinity levels in the lake's basin. In 2014 a new regulator was constructed as part of the SA Riverine Recovery Program and this opened a gap in the Ral Ral levee, improved the capacity of the inlet channel and consequently improved the capacity for flushing of the lake during floods. This work and a continued wetting/drying hydrological regime for the lake has resulted in continued improvement in conditions, with riparian vegetation increasing in extent and surface water salinity levels dropping to below 2,000EC for most of each inundation period. At the same time the capacity for water to enter low lying areas adjacent to the lake's riparian zone during weir pool raising events, has allowed for an expansion of riparian woodland areas and localised reductions in soil salinity at the southern end of the lake.

Along with the hydrological and geophysical changes to the aquatic system there have been substantial changes in species assemblages and ecology. Waterbird populations have changed substantially (Appendix VI), and many native aquatic species are threatened (Appendix I). Introduced fish species are present in the Lower Murray, including common carp *Cyprinus carpio*, redfin perch *Perca fluviatilis,* gambusia *Gambusia holbrooki* and Oriental weatherloach *Misgurnus anguillicaudatus*. The common carp is the most significant of these introduced species and became established in the 1960s (Koehn 2004). The major negative impacts of carp to native fish populations and other aquatic fauna and flora are competition with native fish, increased water turbidity, undermining of riverbanks and loss of submerged aquatic vegetation due to their feeding behaviour (Hammer *et al.* 2009).

The result of these ecological changes to the Murray-Darling Basin is that seven aquatic species are now listed as threatened in SA (Appendix I) and the major lakes on Calperum support fewer waterbirds than they once did (Appendix VI). Other smaller temporary wetlands on the Calperum floodplain have also changed because of the changes in hydrological regimes and other threats. Cane-grass swamps were once a significant wetland type on Calperum, but inadequate flooding and over-grazing has resulted in the loss of the swamp cane-grass *Eragrostis australasica* from most historic sites. Some temporary wetlands have transitioned into low samphire shrublands due to reduced inundation and increased soil salinity.

Terrestrial System Changes

The terrestrial components of the Calperum floodplain have also changed because of the changes in the River Murray's hydrological regimes, along with changes to ecological processes and species composition. Historical livestock grazing had a substantial effect on the vegetation composition and structure of the Calperum floodplain, as well as the structure and dynamics of the soil. Although livestock were removed from the properties in 1993, there are substantial legacy problems from the high grazing pressure and other introduced herbivores remain of concern, including rabbits, hares, goats, and feral pigs. Further, the abundance of western grey and red kangaroos has increased substantially in the past four decades and now represent a serious component of the overgrazing that still occurs on the floodplain (Appendix V). Feral predators (feral cats and foxes) are also prevalent. These two species are listed as a key threatening process under the EPBC Act, and are likely to have significant effects on the populations of many mammal and bird species, including the bush stone-curlew and common brush-tailed possum that are regionally threatened and restricted to floodplain habitats (Appendix VI). Further, interaction between feral predators and more open vegetation caused by high total grazing pressure are likely to increase the risk of population declines in species that use the ground for foraging and/or breeding.

There are more than 70 species of introduced plant recorded on the floodplain. Significant floodplain species that alter plant community structure and prevent recovery are African boxthorn *Lycium ferocissimum*, and match-head plant *Psilocaulon tenue*. The Bathurst burr *Xanthium spinosum,* California burr *Xanthium californicum,* and golden dodder *Cuscuta campestris* are found throughout the seasonal/intermittent wetlands and the areas of the floodplain that flood regularly. Bridal creeper *Asparagus asparagoides* and willow trees *Salix sp*. occur in only a small number of restricted locations along the main water courses, but if not managed appropriately can have serious impacts on vegetation dynamics.

These changes have resulted in substantial declines in the health of floodplain woodlands with 14% being dead or highly degraded and 52% being in a stressed condition (Appendix IV). The long-term outlook for these communities is poor unless management to alleviate the threats is implemented (Overton *et al.* 2018). Other floodplain vegetation communities have also changed due to increased grazing, reduced frequency of flooding and increased soil salinity, which have favoured more drought and salt-tolerant understorey species at the expense of more flood-dependent species, such as grasses and floodplain herbs (Gehrig *et al.* 2010). Twelve plants restricted to the floodplain at Calperum are now listed as threatened within SA (Appendix I). Fauna species restricted to the floodplain have also suffered, with five species being listed as threatened within SA (Appendix I).

Management Targets

There are many actions that could be implemented to address problems on the Calperum floodplain, but as with all management programs there will be limited resources (e.g., people, funds, expertise) available to deliver on-ground works. Therefore, it is important to identify those actions that are most likely to advance the aim and objectives of this plan. This can be done by setting specific targets for each objective. However, the consequences of achieving or failing to meet management targets is not always equal, so the priority of management options is dependent on the consequences to the plan's objectives of failing to meet the targets. Although, social outcomes are important to the plan, failing to meet the targets associated with those objectives is unlikely to have serious negative effects they simply represent a missed opportunity. Therefore, targets are assigned to one of three consequence levels that reflect the consequences of success or failure in implementing them with regards to achieving ecological outcomes.

C1: Failure to meet the target has negative consequences for the ecological objective(s), whereas implementation is likely to have positive consequences for objective(s).

C2: Failure to meet the target is unlikely to have negative consequences for the ecological objective(s), whereas implementation is likely to have positive consequences for the objective(s).

C3: These targets, if achieved, support effective action, but do not, of themselves, directly achieve the ecological objective(s).

Targets might not be met for a range of reasons, including failure to effectively deliver the program, environmental constraints during the period assessed (e.g., a drought), or targets not accurately reflecting the desired ecological outcome. Therefore, failure to meet a target does not necessarily mean failure of the program, but it does mean the program should be reviewed to determine changes to its future directions or refinement of the targets to better reflect the ecological system.

The management of the Calperum floodplain also achieves outcomes for the whole Murray-Darling Basin as articulated in the Murray-Darling Basin Plan 2012[1]. This recovery plan delivers on all but four of the Basin plan's specific objectives, and represents delivery of Basin objectives across 8,400ha of a Ramsar listed floodplain, including protecting or restoring 3,789ha of floodplain woodland, restoring appropriate hydrological regimes to 550ha of floodplain wetlands, improving soil salinity across 750ha, and restoring specific floodplain communities across 1,050ha (Appendix II)

1. *Facilitate the movement of water across the floodplain landscape in ways that benefit and enhance biological function and diversity, and is consistent with the maintenance of the Riverland Ramsar site's ecological character.*
    1.1. Increase by ≥300ha the area of floodplain that has improved lateral hydrological connectivity by 2025. [C1]
    1.2. Re-establish, by 2025, floodplain hydrological elements across ≥550ha through the strategic use of environmental water. [C1]
    1.3. Reduce soil salinity by ≥20% across ≥250ha of the floodplain by 2030 through the strategic use of environmental water and infrastructure management. [C1]

2. *Restore impaired ecological diversity and function within floodplain communities, including state and nationally listed threatened species.*
    2.1. Maintain ≥70% of trees at current or better condition and improve the condition of ≥10% of trees in existing floodplain woodlands by 2030. [C1]
    2.2. Restore ≥400ha of floodplain woodland communities by 2030. [C2]
    2.3. Re-establish wetland vegetation communities on ≥4 wetlands by 2030. [C2]
    2.4. Facilitate the recovery of other floodplain communities across ≥50ha of the floodplain by 2025. [C2]
    2.5. Restore ≥50ha of floodplain scalds by 2030. [C2]
    2.6. Restore populations of threatened plant species in at ≥3 floodplain areas by 2025. [C2]
    2.7. Protect and restore appropriate wetland conditions, through use of environmental water, to enable waterbirds breeding in at least two wetlands each year; [C1]
    2.8. Restore a cane-grass swamp community in ≥2 sites by 2035. [C2]
    2.9. Improve the condition of *Planigale gilesi* habitat in ≥2 locations by 2030. [C1]
    2.10. *Planigale gilesi* population increases in abundance or extent by 2035. [C2]
    2.11. Improve the condition of *Trichosurus vulpecula* habitat in ≥5 places by 2035. [C1]
    2.12. *Trichosurus vulpecula* population increases in abundance or extent by 2030. [C2]
    2.13. Improve the condition of *Burhinus grallarius* habitat in ≥5 places by 2035. [C1]
    2.14. *Burhinus grallarius* population increases in abundance or extent by 2030. [C2]

[1] Murray-Darling Basin Plan 2012 is available online https://www.legislation.gov.au/Details/F2012L02240

3. *Protect and restore the functioning of native ecosystems by limiting the impacts of introduced species and over-abundant native species.*
    3.1. Reduce kangaroo densities on the floodplain to 5 kangaroo/km^2 by 2022. [C1]
    3.2. Maintain kangaroo densities on the floodplain at 5-10 kangaroo/km^2 until 2035 to allow vegetation recovery. [C1]
    3.3. Maintain kangaroo densities on the floodplain between 10-15 kangaroo/km^2 beyond 2035 to maintain viable kangaroo and vegetation populations. [C1]
    3.4. Maintain rabbit densities on the floodplain below 2 rabbits/km^2. [C1]
    3.5. Maintain goats on the floodplain at densities below 1.0 goats/km^2. [C2]
    3.6. Control, annually, feral pig out-breaks associated with inundation events on the floodplain. [C2]
    3.7. By 2025, control specific weed populations that are inhibiting the recovery of native floodplain communities in targeted restoration sites. [C2]
    3.8. Implement control of foxes that generates a consistent ≥25% reduction in densities for 5 years, by 2035. [C2]
    3.9. Implement control of feral cats that generates a consistent ≥25% reduction in densities for 5 years, by 2035. [C2]

4. *Conduct or facilitate research and monitoring that ensures effective evidence-based management of the floodplain.*
    4.1. Develop and implement a monitoring and evaluation program, based on the existing monitoring framework that effectively assesses and reviews all management actions implemented under this plan by 2025. [C2]
    4.2. Complete, by 2025, research on two or more aspects of ecological function/diversity, the information from which is used to refine management actions. [C2]
    4.3. Assess, review, and refine the monitoring and research conducted in this plan at the end of the plan's life (2025). [C2]
    4.4. Assess, review, and refine the conceptual model, based on the findings of the monitoring and research program, at the end of the plan's life (2025). [C2]

5. *Promote awareness, education, and participation within the community that assists in maintaining the floodplain's ecological, cultural, and wise use values.*
    5.1. Implement ≥1 volunteer project/year that delivers one or more outcomes required to meet the management actions identified in the current plan. [C3]
    5.2. Conduct ≥1 project/year that enables the community, especially students, to be involved in aspects of the management of floodplain ecological and/or cultural values. [C3]
    5.3. Conduct ≥2 education projects/year that provide information to the participants on the management and/or ecology of the floodplain. [C3]

Management Options

The management approach taken in this plan is to first identify constraints to 'natural' ecological process (i.e., lateral connectivity between the river channels and the floodplain), as these will only require an initial investment to reinstate and then will deliver long-term environmental benefits from normal river flow management with minimal ongoing costs (MDBA 2013). These constraint options are then followed by actions where the only available option involves ongoing management, such as environmental watering or total grazing pressure management. Opportunities to gain multiple benefits from ongoing management actions (e.g., multiple site watering with the same water), and actions that will enhance the outcomes from other actions are identified (e.g., strategic restoration associated with hydrologically improved sites). Finally, actions that enhance the effectiveness of management, such as monitoring, research and community education are considered in relation to the on-ground management being implemented. The costings identified under each action is the total cost, including existing funds from ALT and other funding agreements.

Overton *et al.* (2017) accessed the potential of six management options for black box protection and recovery, based on successful management in other parts of the Murray-Darling Basin. Their investigation of these options has been used as the basis for some of the specific management actions outline below.

1: *Reconnecting existing floodplain channels in higher flow conditions.*

Floodplain channels are the primary foundations for lateral connectivity between the floodplain and the river, but many have lost connection due to human changes to the floodplain or fail to function effectively in the lower flow regimes of the regulated Murray River. Two management actions address this issue; lowering sill levels along the river to allow inundation of floodplain channels during weir pool raising and removing human barriers (i.e., levees) to floodplain flow during floods. Overton *et al.* (2017) investigated the value of four possible sill lowering actions; two of which are now addressed using environmental water in adjacent areas (sites 1 & 2), one already functions during some weir pool raising conditions (site 3), and the final site (site 4) was not deemed to be cost effective. The SA Riverland Floodplain Integrated Infrastructure Program (SARFIIP) is currently doing detailed costed plans for another site, which would reconnect Argo Creek during weir pool raising events and support red gum and black box woodland regeneration along this creek (Action 2.1). Two options for the removal of infrastructure that is preventing floodplain flow at Calperum have also been identified.

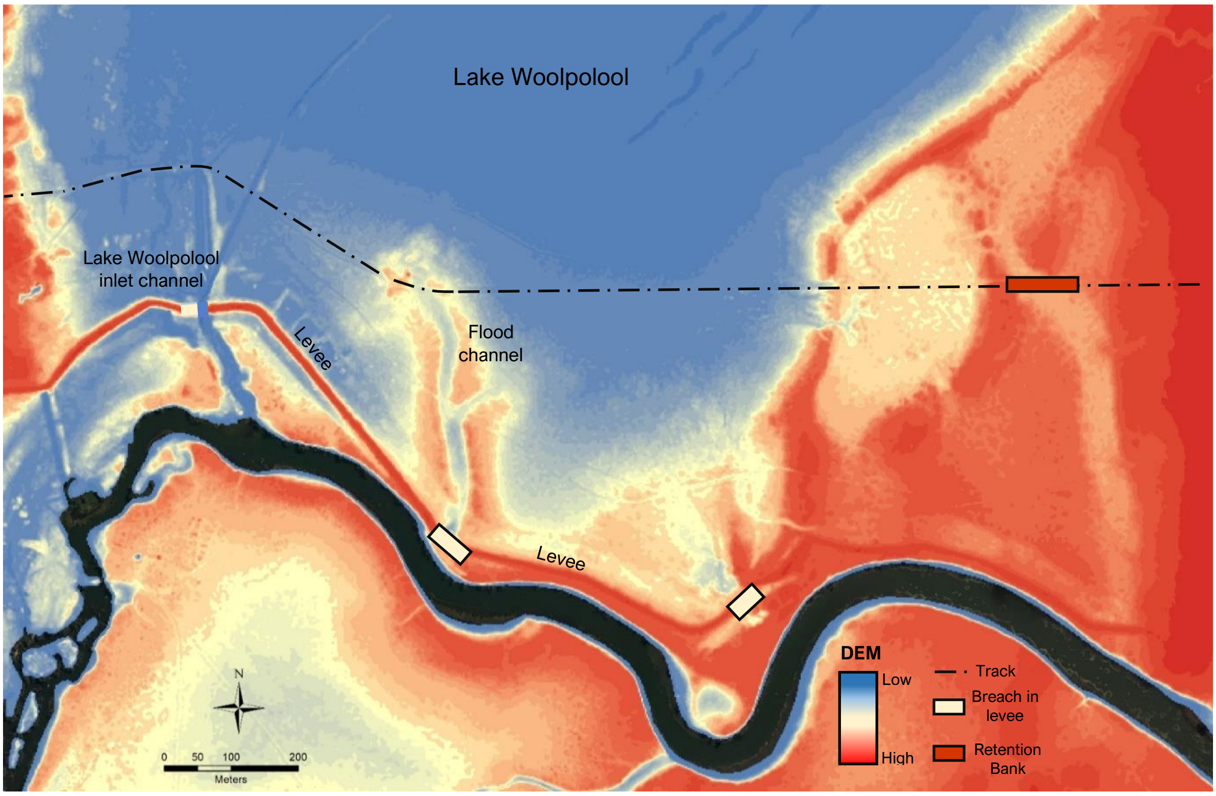
Action 1.1: *Removal of part of the Ral Ral Creek levee near Lake Woolpolool*

Lake Woolpolool was disconnected from Ral Ral Creek prior to the 1950s by a levee along Ral Ral Creek, which prevented any overbank flows into the Lake Woolpolool basin until they exceeded 19m AHD. A regulator was built in 1983 that allowed water into the lake, but the levee remained preventing floodwaters flushing out the lake's basin during recession. This levee was partially breached with the construction, by SA Riverine Recovery Program, of a new regulator in 2014. The works to install a new regulator at Lake Woolpolool opened the levee that runs along Ral Ral Creek at one point, which has improved flood access in the area. However, the levee still restricts floodwater flow along 1.7km of the creek. Further breaches of the levee (lowering it to the river channel sill level) to reconnect flood channels to Ral Ral creek would reduce this flow barrier (see Figure 1).

This area supports an open black box woodland (29ha) that is considered a high risk of loss under the 'do nothing' scenario, because it is threatened by a lack of flooding and shallow groundwater generating increase soil salinity (Overton *et al.* 2017). It also supports 15ha of coobah woodland, most of which is now dead, but in some places has been successfully returned through planting. This action would reconnect floodplain channels during floods greater than 40,000ML/day, but more importantly would allow for more effective flushing of the floodplain south of Lake Woolpolool during flood events. Therefore, the expected outcome of these works would be reduced salt accumulation in the floodplain south of Lake Woolpolool, with a consequent reduction to the risk of the loss of the black box woodland.

Additional costs are required to remove the levee bank material from the site, because it is degraded soil and so cannot be spread on the floodplain. Adding it to the existing levee is possible, but this would increase the negative effects of the levee. The preferred option is to use the material to raise a section of an existing track to form a small retention bank to hold environmental water in part of the southern Woolpolool floodplain (see Action 2.2). This option costs less, supports adjacent black box and enables the restoration of a cane-grass swamp.

Figure 1: Digital elevation model (DEM) showing the location of two breaches of the Ral Ral levee and location of a proposed retention bank on the southern Woolpolool floodplain.



Targets: 1.1 & 1.3

Risks: Low. The only possible risk is saline water returning to the river on flood recession. However, given that the sill level of the Ral Ral Creek bank would still be higher than the floodplain, this would only happen during high floods that would dilute salinity levels.

Confidence Level: High. Data collected on site and during actual flood conditions and based on well-established principles of floodplain ecology.

Action 1.2: *Re-opening the flow channels between Lake Merreti, Woolpolool Swamp and Lake Woolpolool.*

Currently, Lake Merreti is hydrologically connected to Woolpolool Swamp at 19.0m AHD and so Woolpolool Swamp has not filled via floodwaters since the 1974 flood. A levee between Lake Woolpolool and Woolpolool Swamp prevents flows between Lakes Merreti and Woolpolool except in high floods. In the 1980s an attempt to lower the flood height at which Woolpolool Swamp was filled from Lake Merreti was made. However, it failed to generate flooding of Woolpolool Swamp in the flood events of the 1980-90s. Currently the constructed channel is in disrepair and has partially filled, further reducing the likelihood of filling the swamp.

Works to open the channel between Lake Merreti and Woolpolool Swamp and lower its sill level may increase the likelihood that Woolpolool Swamp is flooded naturally, but this would only be during large floods. There is no value in opening the levee between Lake Woolpolool and the swamp unless Woolpolool swamp is being flooded via Lake Merreti.

The cost of reconstructing this artificial channel would be relatively high, because of the need to protect against the risks of erosion during floods. Therefore; as the result would only be a small increase in the likelihood of Woolpolool Swamp flooding, and there is uncertainty about the risks of negative outcomes (e.g., sedimentation of Woolpolool Swamp), this action was not deemed appropriate to proceed to a full design assessment and costing.

Targets: 1.1 & 1.3

Risks: Moderate. There is a risk of erosion of the channel during floods and the consequent sedimentation of Woolpolool Swamp. To alleviate this would require increased construction costs for re-opening the channel.

Confidence Level: Low. Moderate evidence for the likelihood of flooding Woolpolool Swamp, but low certainty of the consequences (e.g., sedimentation) and frequency of that flooding.

Action 1.3: *Re-establish flow through Argo Creek during weir pool manipulations.*

Argo Creek was a natural anabranch of the Murray River, that was modified for agricultural purposes. When its use was no longer required it was left unmanaged and with reduced flooding it has slowly silted up at the Widewaters end of the channel. The lack of water flow through this system has resulted in increased salinity and the consequent death or decline in the condition of red gum and black box in its riparian zone. Agro Creek would fill during standard weir pool raising events and therefore, re-opening the channel would allow for regular flows into the creek and an improvement in the salinity levels in the system.

The SA Riverland Floodplain Integrated Infrastructure Program (SARFIIP) is currently doing a detailed costed design for reconnecting Argo Creek. If it is deemed a viable project and implemented, then the site will be monitored and assessed over the remainder of this plan period to look at further opportunities for restoration of the area.

Targets: 1.1 & 1.3

Risks: Moderate. Rigorous construction design is required to ensure there is no risk of channel erosion during floods.

Confidence Level: Good. Good evidence from past flooding and weir pool manipulations of the flow issues through the channel. Clear evidence of salinity issues in Argo Creek and the solution is a well-established management response in other parts of the Murray River.

2: *Infrastructure to improve the efficiency of environmental watering.*

Several potential environmental watering sites (Action 3.2, Appendix VII) currently cannot be inundated because water would simply return to the river channel or there is no easy access to a pumping site that can deliver water to the area. Small infrastructure projects would enable these sites to be managed with environmental water. The maintenance of this infrastructure would be delivered by ALT as part of its long-term management of the Calperum floodplain.

These six actions are prerequisite to the delivery of some environmental watering activities (Action 3); but are considered separately from environmental watering, because they are once off infrastructure projects that enable effective environmental watering. Action 3, on the other hand, relates to long-term delivery of water for environmental purposes, which will be subject to annual review and change. The first two actions involve the construction of low retention banks to allow for environmental watering, while the remaining three actions involve rural poly pipeline infrastructure that would allow for the delivery of environmental water either through traditional inundation or through irrigation. The watering regimes associated with these actions are detailed in the environmental watering plan (Appendix VII).

Action 2.1: *Construction of a low retention bank to allow for an environmental water site on the southern Woolpolool floodplain.*

The floodplain on the southern end of Lake Woolpolool has suffered from restricted flooding due to the Ral Ral levee that has increased soil salinity levels, which have shifted many parts of the floodplain toward a low samphire shrubland. However, against the base of the levee patches of cane-grass remain. This area is bordered by stressed black box woodland. Providing periodic inundation through environmental water (Action 3.2, Appendix VII) would allow for the recovery of both the cane-grass swamp and the black box woodland. It would also provide another potential patch of planigale habitat, once the soil and vegetation have been remediated. However, watering this site is currently not possible as there is a flood channel through which the water would flow to Lake Woolpolool (Figure 1). The construction of a low retention bank where the current track crosses this flood channel would make it possible to inundate this site. The bank would be constructed using the material removed from the Ral Ral levee, eliminating the costs of removing the levee material (Action 1.1), reducing overall costs and delivering this additional ecological outcome.

Targets: 1.2-1.3, 2.1, 2.2, 2.3, 2.6, 2.8 & 2.10.

Risks: Low. There is always a risk of bank failure. For this low bank, this risk is small, and will be reduced further by ongoing monitoring and maintenance by ALT. The retention bank is part of an existing track so it would have no impact on existing vegetation or heritage sites. Its low height would have little effect on the movement of flood waters, but to ensure this is minimised a pipe will be built into the bank to allow flow through the bank during natural flooding.

Confidence Level: High. Data collected on site based on well-established principles of floodplain management.

Action 2.2: *Construction of a low retention bank to allow for an environmental water site on the western Widewaters floodplain.*

The floodplain to the west of the Widewaters was once covered by a black box woodland, but now most of the trees have died, due to a lack of inundation and consequent increased soil salinity. Many of the remaining mature black box occur around a central depression, and there are patches of black box recruits in the same areas. An environmental watering regime is proposed for this site, but this is dependent on the construction of a low retention bank near the Widewaters (Action 3.2, Appendix VII).

Reny Island, where this site is situated, has limited access preventing large machinery from being used without substantial transportation costs. This retention bank is therefore being constructed in a different way, which will allow for the use of small machinery. The bank will be stabilised with a geofabric that will prevent the bank from eroding when subject to environmental water flows. The retention bank constructed in 2018/19 at the Reny Lagoon site (Appendix VII) showed that these small banks can be reliably constructed using small machinery. The bank will be made as low as possible to allow for floodwaters to inundate the site, and to ensure this natural connectivity is not impaired. The bank will also have a pipe through it to allow for low flood heights to enter the site. This pipe, which will be sealed during environmental watering events, will have the added benefit of providing the opportunity in the future to allow water from the temporary wetland to return to the river, should the site improve sufficiently for that to be an option.

Targets: 1.2-1.3, & 2.1-2.3.

Risks: Low. There is always a risk of bank failure, but this will be reduced by ongoing monitoring and maintenance by ALT. The retention bank will be built as low as possible to minimise its effect on the movement of flood waters, but to ensure this is minimal a pipe will be built into the bank to allow flow through the bank during natural flooding.

Confidence Level: Moderate-High. Data collected on site based on well-established principles of floodplain management. There is a degree of uncertainty associated with the retention bank construction. However, the successful bank at the Reny Lagoon site showed these small banks can be reliably constructed using small machinery.

Action 2.3: *Construction of irrigation infrastructure to support environmental watering of the Amazon uplands.*

Upland woodlands were once infrequently inundated by large floods (>120,000ML/day), but these floods have substantially reduced in frequency and it is expected that they will become a rare event in the future. These sites cannot be supported by traditional environmental watering activities, because the topography in most areas sheds water instead of retaining it. However, trials using irrigation infrastructure to support woodlands showed that this approach could improve the condition of watered trees (Gehrig 2013 & 2014).

The upland black box woodlands adjacent to the Amazon wetland (Action 3.2, Appendix VII) are currently in a stressed to degraded state and have shown deterioration in tree condition in some patches since the 2010-12 flood. A trial at this site was successfully implemented in 2018/19. The proposed environmental watering program would use inundation of small depressions and irrigation watering (19mm poly pipe infrastructure) of higher areas that shed water rapidly (Action 3.2, Appendix VII). For this site to be effective across the entire area, some additional irrigation infrastructure will be needed. Once installed this infrastructure should be effective for several decades at a small cost in ongoing maintenance (paid for by ALT). The irrigation lines will deliver water via a small temporary pump connected to the infrastructure for each watering event.

Targets: 1.2, 2.1, 2.2 & 2.6.

Risks: Low. The only risk is that the infrastructure does not deliver the desired improvements in tree condition, which is unlikely.

Confidence Level: High. Based in research data collected on sites with a similar woodland system in the same region of the Murray River.

Action 2.4: *Construction of a pipeline to allow for an environmental water site on the south-eastern section of Woolpolool Swamp.*

Woolpolool Swamp is a significant wetland site that now rarely receive floodwaters. It is a proposed environmental watering site, that involves pumping water to the major northern depression and then re-using some of this water to inundate adjacent areas of open black box woodland to the south (Action 3.2, Appendix VII). Due to the topography of the floodplain the eastern end of the adjacent black box woodland is difficult to provide water to using these traditional techniques. However, there is an existing operational water pipeline that once pumped water to mallee dams, which could be used to deliver water to this section of the complex (see Appendix VII). The proposal is to create a 1 km branch-line from the existing pipeline, using 50mm poly pipe that would deliver water to the western end of the SE depression, where gravity would spread the water to the woodland's eastern extent.

Targets: 1.2-1.3, 2.1, 2.2, 2.11 & 2.13.

Risks: Low. There are no obvious risks associated with this proposal.

Confidence Level: High. Delivery based on a digital elevation model of the Calperum floodplain.

Action 2.5: *Construction of an irrigation pipeline to allow for an environmental water site on the eastern Calperum uplands.*

Upland black box woodlands were once infrequently inundated by large floods (>120,000ML/day), but these floods have substantially reduced in frequency and it is expected that they will become a rare event in the future. The site cannot be supported by traditional environmental watering activities, because of the distance from river channels, and for some areas the topography sheds water instead of retaining it. However, some areas can be inundated and trials using irrigation infrastructure to support woodlands showed that this approach could improve the condition of watered trees in elevated areas (Gehrig 2013 & 2014).

The upland black box woodlands on the eastern boundary of the Calperum floodplain are currently in a stressed state, but the condition of tress is variable across the area. Larger trees are generally in a more stressed condition than smaller trees and patchiness associated with the topography creates additional variation in the woodland state. It is proposed to lay a 50mm rural poly pipeline 1.5km out to the furthest site that would allow for water to be pumped to the area (using a small temporary pump) where it could be applied using both inundation of small depressions and irrigation watering (19mm poly pipe infrastructure) of higher areas that shed water rapidly. The pipeline could provide water to two woodland patches covering a total of 31ha.

Targets: 1.2, 2.1, 2.2 & 2.6.

Risks: Low. The only risk is that the infrastructure does not deliver the desired improvements in tree condition, which is unlikely.

Confidence Level: High. Based in research data collected on sites of similar woodland system in the same region of the Murray River.

Action 2.6: *Upgrade/repair of the retention bank at Amazon floodplain.*

The Amazon floodplain is a significant environmental watering site and the first on Calperum to use built infrastructure to allow inundation of degraded areas. The original bank constructed on the site was too low to achieve the desired environmental outcomes (see Appendix VII), and consequently failed during a storm event. An additional issue with this site was the continued flow of water from the top lagoon section onto the western floodplain area after pumping had stopped. This meant that gauging the correct time to stop pumping operations was very difficult, because the water height on the retention bank continued to rise after pumping. Therefore, upgrading this retention bank, during repairs of the current breach, by increasing its height (additional 50cm) will enable reliable and more extensive inundation of this site. An additional modification to this bank will be made to reduce the threat of erosion of the top of the bank by wave action. This modification involves the construction of a low shade-cloth fence along the inside wall of the bank, that will dissipate the power of the waves against the wall of the bank. This fence will be replaced when annual monitoring indicates the need, as part of the ALT maintenance program.

Targets: 1.1-1.3, 2.1-2.10 & 2.13-2.14.

Risks: Low. There is always a risk of bank failure, but this will be reduced by ongoing monitoring and maintenance by ALT. The increased height of the bank will reduce overbank flows from small floods, but the pipe system and regulator will allow flooding under any flood conditions.

Confidence Level: High. Data collected on site based on well-established principles of floodplain management.

3: *Environmental Watering*

Environmental watering supports a wide range of ecological targets for the Calperum floodplain and is a foundation of the current management plan. The ecological characteristics and proposed watering regime for twelve environmental watering sites are provided in Appendix VII. The scheduling of watering events will vary depending on antecedent conditions and so proposals are indicative of actual management, which will need to be determined in an annual watering plan.

The environmental watering plan maximises the efficiency of the environmental water used, by re-using water in adjacent sites, and where appropriate obtaining additional ecological benefits by allowing water from these temporary wetlands to return to the river to improve river productivity (Furst 2013, Roshier *et al.* 2001, Brandis *et al.* 2009).

Action 3.1: *Purchase of appropriate pumps to deliver components of the environmental watering program.*

Environmental watering on the Calperum floodplain can only be delivered through pumping water to sites, using mobile pump systems, except for one site that can use an existing pipeline and fixed pump (see Appendix VII). It is proposed to deliver the environmental watering program through a combination of:

1. large pumps (generally 12" pumps) contracted from commercial operators (currently Millewa Pumping) to deliver the bulk of water to the larger sites,
2. a smaller pump (6" pump) owned/operated by ALT to deliver water to smaller sites and maintenance water to larger sites, and
3. two smaller pumps (4" pumps) owned/operated by ALT used for delivering water through pipe and irrigation infrastructure.
4. ALT pipeline and fixed pump (see Action 2.4).

This gives the program the flexibility to enable water to be delivered to each site whenever it is required in the most cost-efficient way. Conservative estimates of the cost savings to the CEWO over the five-year plan using this infrastructure model is $62,810 for a $49,636 investment. The $62,810 saving will continue in future, for the life of the pump, which should be more than 10 years. These savings are conservative, because they do not include additional set-up costs or pump rentals for periodic watering, and the potential ecological and financial savings associated with the use of less water to deliver the same environmental outcomes.

The most important reason for preferring this infrastructure model is that it will ensure that the smallest quantity of environmental water necessary to deliver the outcome will be used. It will also ensure that the water is delivered based on ecological timing requirements, not on cost and the availability of pumps. Many of the proposed sites need to maintain their inundation for several months longer than would occur if the wetland was simply filled and then allowed to drawdown. The most significant ecological outcome requiring this is managing water regimes for waterbird breeding, where the length of inundation and drawdown rates need to be carefully controlled to ensure breeding success (Appendix VI). This sort of watering requires small additions of water periodically over many months with long periods of no pumping. This fine scale water allocation is difficult to deliver with contracted pumps, which are not always available on short notice as required. Contract pumps in these circumstances are also costly because periods of inactivity need to be paid for or additional set-up and removal costs are incurred.

A secondary benefit of this infrastructure model is that it provides further opportunities to train land managers, primarily through the Riverland Indigenous Ranger program, in the on-ground management and delivery of an environmental watering program. As part of this process, ALT will contract Millewa Pumping (funded through the Riverland Ranger program) to provide specific training in the set-up, operation, and maintenance of the environmental watering pumps.

Targets: 1.2-1.3, 2.1-2.4, 2.7-2.8.

Risks: Low.

Confidence Level: High. Need is based on previous watering events and well-established principles of floodplain management.

Action 3.2: *Environmental watering program.*

Thirteen sites, eight wetlands and five upland areas, were identified and are proposed for environmental watering through to 2025 (Appendix VII). The wetland sites cover 450ha, while the upland woodland sites provide water to 100ha of black box woodland and other floodplain communities. The program involves delivery of water directly from the Murray River and the re-use of pumped water (6.5%) in additional sites. The sites deliver different ecological objectives, but most support floodplain woodland persistence and recruitment; and most wetland sites provide increased spatial and temporal diversity of wetland habitats for fauna, especially waterbirds (see Appendix VI). The costs are based on the delivery of Action 3.1, if this is not delivered total annual costs will be higher (see Appendix VI for details).

Targets: 1.2-1.3, 2.1-2.4, 2.6-2.9, 2.11 & 2.13.

Risks: Variable dependent on site (see Appendix VII).

Confidence Level: Moderate-High. For most sites, management is based on previous watering events and well-established principles of floodplain management. (see Appendix VII). New sites have greater uncertainty, but are still based on outcomes from similar sites and well-established principles.

4: *Management of total grazing pressure*

Grazing pressure on the Calperum floodplain is primarily driven by over-abundant kangaroos, with the addition of grazing from rabbits and feral goats (Appendix V). Rabbit and feral goat abundance have been under control at Calperum for the past 4-5 years, but in the past decade kangaroo abundance has increased. Feral pigs are now rare on the Calperum floodplain, but to ensure that they remain so, surveys to identify areas requiring control are conducted annually. This plan identifies ongoing maintenance of the low abundance of rabbits, goats and pigs, and a concerted program of control to reduce kangaroo numbers to levels that will allow recovery of the floodplain vegetation. All control measures will focus on sites being managed, but the intent is to maintain appropriate levels across the entire floodplain as this is the only sustainable management option.

These management actions are focused on enhancing natural recovery in the ecosystem by removing the major impediment to this recovery—overgrazing. Delivery of this set of actions is therefore an essential precursor if other management actions, such as environmental watering (assisted recovery) and strategic site restoration (reconstruction), are to achieve their outcomes.

Action 4.1: *Control over-abundant kangaroo populations on the Calperum floodplain.*

Western grey and red kangaroos are the major contributors to the total grazing pressure on the floodplain, and their numbers have generally increased in the past 25 years (Appendix V). Traditional culling for the commercial kangaroo meat industry has not maintained sustainable populations of either species, because of the large populations. The primary purpose of culling kangaroos is to generate viable populations that do not degrade floodplain vegetation communities. To achieve this, kangaroo densities need to be initially reduced to levels that allow for vegetation recovery (5 kangaroos/km^2) and then they need to be managed at sustainable levels (10-15 kangaroos/km^2) once floodplain communities are on viable recovery trajectories. The initial control stage will require kangaroo numbers to be reduced to one quarter of their current density.

However, the abundance of red and grey kangaroos across the floodplain vary. So, to achieve a good ecological outcome specific targets will be applied to each part of the ecosystem to maintain similar relative abundances of the species. This level of control cannot be achieved by standard commercial harvesting and so support for commercial harvesters will be necessary to reach the target, and the sex ratio of harvested animals will need to be modified from the current 30% female to 40% (Appendix V). Once the initial density targets are achieved a return to traditional commercial harvesting should be able to maintain the desired population numbers. Annual ongoing monitoring of these populations will be necessary to ensure this is the case and if not, additional control actions targeted at problem areas will be required.

This is the proposed control program for the Calperum floodplain, but ALT is also collaborating with DEW and the SA MDB NRM Board to coordinate kangaroo control across the Riverland Ramsar area. This will increase the efficacy of the proposed management and the likelihood that once population have been reduce maintaining them at sustainable levels will be achievable.

The approach to this control will be to pay professional shooters to cull animals at the desire species numbers and sex ratios for each ecologically distinct area across the floodplain and adjacent terraces. Although environmental watering sites will be a major beneficiary of this control—as they often face increased densities of kangaroos during and after inundation—the intention is to reduce the entire floodplain population to desired levels, as this is the only sustainable approach.

Targets: 2.2-2.6, 2.8-2.14, & 3.1-3.3

Risks: Low. Only risk is a crash in the population of the kangaroo species, which will be prevented by clear population targets and careful monitoring of management outcomes throughout the control process.

Confidence Level: High 25 years of monitoring on site has established the characteristics of the problem. The control methods used are well established and research in the Murray-Darling Basin has determined the approach to control. Research in the mallee has demonstrated the efficacy of the target densities on vegetation recovery.

Action 4.2: *Integrated rabbit control to maintain low population densities.*

Rabbit control on the Calperum floodplain has been undertaken since the property was purchased in 1993. Since 2010 an integrated control program involving a range of standard methods (SAMDB NRM 2007) has been implemented on the floodplain and terraces. Areas are assessed by warren surveys and a rapid assessment survey (Cooke & McPhee 2007) to identify priority areas for control. The control methods used vary depending on the vegetation and topography of each site, and the density and location of warrens. Warren ripping is only used for serious outbreaks on the floodplain, because of the risks to indigenous heritage sites. Baiting plus warren fumigation is used for most warren-based control, while ripping with a single tine back-hoe system is used in areas with trees, but a low likelihood of heritage sites. All control activities are followed by monitoring of controlled warrens and additional control where burrows are re-opened.

The floodplain control program is currently funded by ALT with support from the Riverland Indigenous Ranger program. Additional localised control by baiting plus warren fumigation will be applied annually to each restoration site (see Actions 5).

Targets: 2.2-2.6, 2.11, 2.13, & 3.4.

Risks: Low. Only risks are to unknown heritage sites, for which appropriate assessment and monitoring protocols have been established.

Confidence Level: High The methods used are well established with a decade of monitoring on site assessing their effectiveness.

Action 4.3: *Control of feral goats to maintain low population densities.*

From 2010 to 2016 a regional control program for feral goats operated across 2.1 million hectares of pastoral leases in the South Australian Murray-Darling Basin region (Cale & Setchell 2017). This program removed 109,554 feral goats and supported the removal of more than 250,000 animals funded by landholders. This resulted in a 77% reduction in the density of feral goats (from 3.5 goats/km^2 to 0.8 goats/km^2) in the conservation estate, and a 30% decline in the adjacent pastoral properties (Cale & Setchell 2017). Since 2016, ALT has concentrated goat control activities on the floodplain (Appendix V) and has been supported by an aerial shoot in 2018 by the SA Department for Environment and Water (DEW). Consequently, feral goat densities are low, and it is the objective under this plan to maintain these low numbers.

The floodplain control program is currently funded by ALT with support from the Riverland Indigenous Ranger program, and funds raised from selling mustered goats. SAMDB NRM, through their NLP2 Riverland Ramsar funds is also supporting control efforts through regional scale programs, such as aerial shooting.

Targets: 2.2, 2.4-2.6, 2.8-2.9, 2.11, 2.13, 3.5 & 3.7.

Risks: Low.

Confidence Level: High The methods used are well established with a decade of monitoring on site assessing their effectiveness.

Action 4.4: *Control of feral pig outbreaks associated with inundated wetlands.*

Feral pigs are periodic invaders onto the Calperum floodplain, mainly when wetlands are inundated, and riparian sedge communities are growing around these wetlands. In 2009 a collaborative project to control pigs was established between landholders along the Murray River and the SAMDB NRM board. After three years, pig populations on the Calperum floodplain were almost zero. Since 2013, surveys for feral pigs using ground searches for areas of pig disturbance and then remote camera traps to establish activity have been conducted. The few animals that have been recorded during the past 7 years have all been associated with inundated wetlands. One of the major contributions to the decline of feral pig numbers on Calperum has been the ongoing control on the Chowilla floodplain as invading animals are generally coming down stream. The SAMDB NRM Board have also conducted periodic aerial shoots and have included the Calperum floodplain.

The floodplain control program is currently funded by SAMDB NRM, through their NLP2 Riverland Ramsar funds and ALT with support from the Riverland Indigenous Ranger program.

Targets: 2.2-2.3, 2.8-2.9 & 3.6-3.7.

Risks: Low.

Confidence Level: High The methods used are well established with a decade of monitoring on site assessing their effectiveness.

5: Restoration of floodplain communities

The restoration of floodplain vegetation communities is targeted at sites associated with environmental watering, as the purpose of the restoration actions are to complement facilitated recovery derived from improved inundation regimes. Environmental watering provides the fundamental requirement for many floodplain vegetation communities, but some areas have transitioned into alternative states that are resistant to recovery without additional restoration support. Other, important sites, like floodplain sand dunes, which are not regularly inundated, also require these restoration strategies. These drier sites differ in that they will need initial watering to enable seedling establishment, because they do not get this from environmental watering. ALT has designed a mobile irrigation system, using 1000 litre shuttles and 19mm poly pipe, which has been successfully used to restore semi-arid woodland communities on terrace sand dunes adjacent to the floodplain. ALT has 30 of these units available for use in this program, which require only poly pipe replacement and so are substantially cheaper than initial establishment would be. Sheet flooding of some of these sand dune sites is also possible by re-using environmental water delivered to an adjacent wetland (See Appendix VII).

ALT has invested substantial resources into the production of facilities and expertise in the collection, storage, and propagation of native species for use in restoration programs. So, most seed and/or seedlings used in restoration programs is sourced from Calperum Station and propagated on site. Direct seeding and broadcast seeding have been found to have low success rates in the arid climate of Calperum, but opportunities for this form of vegetation recovery do exist in relation to environmental watering sites, if coordinated with the inundation program. It is likely however that seedlings will be needed to establish target species in some restoration sites. The species propagated and the numbers used at each site will depend on the restoration strategy and the seedlings produced will be the desired number of plants for the site plus 30% to account for mortality. This is based on past restoration programs at Calperum. Seedlings will be protected from grazing during initial establishment and ALT has found that wire mess guards (600mm high) are the only reliable protection from rabbit and kangaroo grazing. Although initially more expensive than standard commercial guards they are re-usable and so in the long-term they are a cost-effective option. Revegetation requires on-going support (e.g., watering, guard maintenance and weeding) until plants are established—generally for 1-2 summers post-planting (Cale 2016).

Restoration is more than revegetation, it also involves a range of actions designed to facilitate natural recovery or overcome impediments to recruitment or seedling survival, such as soil remediation and stabilisation, the removal of environmental weeds that reduce the recruitment of native species, and site-specific control of feral species. The actions required for each site will differ depending on its ecological issues and the restoration objectives, and these actions will be determined during the site assessment and restoration design. The costings identified include design and indicative costs for restoration actions. The proposed restoration projects are based on the presumption that the management of total grazing pressure proposed in this plan is also implemented, as this is required for facilitated vegetation recovery and revegetation to be viable.

Restoration of individual species or communities is a long-term management objective, which will face variable success at the start. Consequently, it is often difficult to access if management objectives are being achieved. It is, therefore, essential to have short and medium-term targets that indicate if the management is on an appropriate trajectory to meeting the desired outcomes. This is the approach taken within this plan. Establishment and persistence of specific ecological components, via facilitated recovery or revegetation, is the first short-term goal to recovery and this plan seeks to achieve this target within identified sites.

Action 5.1: *Restoration of threatened plants within floodplain communities.*

This restoration program will operate in conjunction with site-specific restoration projects, but will focus on assisting the recovery of threatened floodplain species within appropriate communities. The focus is on six species (Table 1) that can be propagated from seed or cuttings. Swamp cane-grass has been included in this project, despite not being a threatened species, because the wetland community it forms is considered to have declined substantially in the region. These species are known from some proposed environmental watering sites or adjacent vegetation communities and these areas will be the initial focus, which will complement other management actions.

Initially (Year 1 & 2), the project seeks to create a population of each threatened species within the Calperum Seed Nursery, which can then be used as the parent stock for enhancing existing populations or for the re-establishment of the species where it has been lost. During this establishment phase assessments of sites for restoration or re-establishment will be conducted and in year 2 initial restoration will be commenced for at least two species (Appendix VII). Other species will be incorporated as restoration sites are developed.

Table 1: The six threatened plant species that are the focus of the threatened plant restoration project (see Appendix I). Community indicates the broad ecological system in which each species exists.

Species	Common Name	Community
Maireana decalvans	black cotton-bush	Riparian woodlands
Dianella porracea	yellow-anther flax-lily	Riparian woodlands
Brachyscome melanocarpa	black-fruit daisy	Sand dune woodlands
Swainsona reticulata	variable swainsona-pea	Riparian and sand dune woodlands
Calocephalus sonderi	pale beauty-heads	Clay flats
Duma horrida	spiny lignum	Clay flats
Eragrostis australasica	Swamp cane-grass	Wetland clays

Targets: 2.2-2.4, 2.6, & 2.8.

Risks: Low. The only risk is that the achievement of the identified restoration targets won't deliver the desired long-term sustainable improvements in the populations of species, which is the long-term objective. This will be addressed by appropriate monitoring and refinement of the project. Requires implementation of 4.1-4.4 as these provide an appropriate level of total grazing pressure to allow for recovery. The risk of extreme drought conditions reducing the effectiveness of restoration activities is always present and will be addressed by altering effort in extremely dry years.

Confidence Level: Moderate-High. The restoration techniques are well established and have been successful on Calperum. The only uncertainty is that there is little direct research on the ecological requirements and threats to the threatened species being restored.

Action 5.2: *Restoration of Thookle Thookle sand dunes.*

Thookle Thookle is a major environmental watering site (Appendix VII), but it is also one of the major known sites for the paucident planigale (Bignall 2001). Research conducted at this site showed that the species used the cracking clay habitat on the bed of the wetland when it was dry, and then moved onto the adjacent sand dunes during floods. These sand dunes now support black box woodland in a stressed condition and a degraded semi-arid shrubland with significant scalds. Restoring the shrubland and the woodland understorey would assist with water retention in the dune and consequently assist the recovery of the black box trees. This site would also provide potential habitat for the bush stone-curlew, because of the mosaic of wetland, woodland and semi-arid shrubland habitats.

The site is a significant indigenous heritage site, which is threatened by the erosion of the dune due to the poor vegetation cover, so appropriate restoration of the vegetation communities would also protect these cultural values.

This community has severe erosion scalds and minimal cover of a few shrub species. Soil remediation using branching, broadcast seeding within branching sites and targeted planting of structurally important species will be used to initially increase vegetation cover to stabilise the dunes and then generate a diverse shrubland community (see Appendix VII). Restoration activities will be aligned with watering events to enable the re-use of environmental water, delivered to Thookle, to inundate these dunes (Action 3, Appendix VII). This will provide good conditions for initiating germination and establishing seedlings and will improve the condition of fringing black box.

Targets: 2.1-2.2, 2.4-2.5, 2.9, 2.13, 3.4 & 3.7.

Risks: Low. The only risk is that the achievement of the identified restoration targets won't deliver the desired long-term sustainable improvements in the vegetation communities, which is the long-term objective. This will be addressed by appropriate monitoring and refinement of the project. Requires implementation of 4.1-4.4 as these provide an appropriate level of total grazing pressure to allow for recovery. The risk of extreme drought conditions reducing the effectiveness of restoration activities is always present and will be addressed by altering effort in extremely dry years.

Confidence Level: High. The restoration techniques are well established and have been successful on Calperum.

Action 5.3: *Restoration of the Merreti East wetland and sand dunes mosaic.*

The Merreti East wetland complex is a significant environmental watering site (Appendix VII) and like Thookle Thookle has the appropriate habitat mosaic to support the paucident planigale and the bush stone-curlew. It also supports the best remnant cane-grass swamp on Calperum, and has important indigenous cultural heritage sites associated with its sand dunes. These values can be protected and/or restored by the proposed management.

This project looks to restore the black box woodlands and chenopod shrublands growing on the Merreti East sand dunes, through remediation of erosion scalds using the branching technique. Broadcast seeding of an appropriate mix of chenopod shrubland species will be conducted within the branching areas and adjacent bare sand areas. If necessary targeted planting will be used to improve restoration outcomes. For the wetland component (cane-grass swamp), an assessment of recruitment from the 2018/19 watering event will determine where targeted planting to expand the cover of swamp cane-grass will be implemented. This planting will be conducted in conjunction with future watering events, which will enhance establishment success (see Appendix VII).

Targets: 2.1-2.6, 2.8-2.9, 2.13, 3.4 & 3.7.

Risks: Low. The only risk is that the achievement of the identified restoration targets will not deliver the desired long-term sustainable improvements in the vegetation communities, which is the long-term objective. This will be addressed by appropriate monitoring and refinement of the project. Requires implementation of 4.1-4.4 as these provide an appropriate level of total grazing pressure to allow for recovery. The risk of extreme drought conditions reducing the effectiveness of restoration activities is always present and will be addressed by altering effort in extremely dry years.

Confidence Level: High. The restoration techniques are well established and have been successful on Calperum.

Action 5.4: *Restoration of Amazon wetland complex.*

The Amazon wetland is a significant environmental watering site (Appendix VII) and parts of it are severely degraded by soil salinity issues and a lack of flooding. With the implementation of appropriate inundation regimes, it is expected that soil salinity will improve, and some vegetation components will recover. However, given the degraded nature of this system, it is doubtful that all components of the wetland vegetation communities associated with this area will recover without some assistance. The recovery of the degraded lignum swamp will be based on an assessment of recruitment from the past watering events that will determine if and where targeted planting to expand the cover of lignum needs to be implemented. This planting will be conducted in conjunction with future watering events, which will enhance establishment success (see Appendix VII). The clay flat is currently very degraded with only remnants of the grass/herbfield vegetation community being present but including the rare species *Calocephalus sonderi* and *Duma horrida*. More regular inundation of this system, control of high grazing pressure (Actions 4.1-4.4) and site-specific protection of vegetation from grazing using exclosures and branching techniques will facilitate the recovery of this community. Specific management for threatened plants will be addressed through Action 5.1. Monitoring the community's response will allow for assessments as to the need for additional restoration actions to achieve the desire outcomes. There is also the opportunity to enhance and diversify the riparian vegetation associated with this clay flat. Using the established exclosures and branching patches, planting of coobah and black box along the outer edges of the flat will provide structural variability to the system (see Appendix VII).

The effectiveness of the branching techniques is supported by separately funded research into this approach (see Action 5.6).

Targets: 2.1-2.3, 2.6, 3.4 & 3.7.

Risks: Low. The new restoration techniques may not deliver the desired outcomes, but this will be addressed by appropriate adaptive management processes. There is a risk that the achievement of the identified restoration targets won't deliver the desired long-term sustainable improvements in the vegetation communities, which is the long-term objective. This will be addressed by appropriate monitoring and refinement of the project. Requires implementation of 4.1-4.4 as these provide an appropriate level of total grazing pressure to allow for recovery.

Confidence Level: Moderate-High. Most of the restoration techniques are well established and have been successful on Calperum. The new techniques are subject to adaptive management to improve confidence in their efficacy.

Action 5.5: *Restoration of Woolpolool south floodplain.*

The floodplain south of Lake Woolpolool has been subject to increasing soil salinity due to the construction of the Ral Ral levee. The removal of sections of this levee to increase flushing of this floodplain during floods, will improve the viability of the area (Action 1.1). The proposed environmental watering site in this area will further improve conditions, by re-establishing periodic inundation to low lying clay flats (Appendix VII). The vegetation communities in this area are highly modified, though they do retain components of past wetland communities (e.g., swamp cane-grass). Strategic revegetation and soil remediation in this area is expected to substantially improve the rate of recovery of this site and will allow for appropriate manipulation of the sites response to ensure that an appropriate vegetation complex will develop. This project will also use branching and fencing approaches to generate improved recovery of vegetation on the wetland margins. This work is supported by separately funded research into the effectiveness of these approaches. Ongoing monitoring of the response of the more frequently inundated areas will also occur (Appendix VII) to assess whether additional interventions are required.

Targets: 2.1-2.3, 2.5-2.6, 2.8, 2.9 3.4-3.5 & 3.7.

Risks: Low. The new restoration techniques may not deliver the desired outcomes, but this will be addressed by appropriate adaptive management processes. There is a risk that the achievement of the identified restoration targets won't deliver the desired long-term sustainable improvements in the vegetation communities, which is the long-term objective. This will be addressed by appropriate monitoring and refinement of the project. Requires implementation of 4.1-4.4 as these provide an appropriate level of total grazing pressure to allow for recovery.

Confidence Level: Moderate-High. Most of the restoration techniques are well established and have been successful on Calperum. The new techniques are subject to adaptive management to improve confidence in their efficacy.

Action 5.6: *Restoration of floodplain scalds.*

Scalds, caused primarily by past overgrazing and consequent soil loss, have substantially reduced the function and productivity of large areas of the Calperum floodplain. Over the past 15 years branching (laying of cut branches over exposed scald areas) has been used to facilitate soil remediation and vegetation recruitment and this has proved successful. Initially this work was opportunistic, but since 2010, more strategic and larger scale restoration has been undertaken.

Many of the vegetation community restoration sites (Actions 5) have scalds that require remediation to improve the outcomes of the broader restoration projects. These scalds are addressed within these specific actions. However, these site-based projects do not address this issue across the landscape and so this project will enhance targeted restoration sites, though expansion of habitat, reduction of edge-effects, or connectivity between habitats, that are not addressed in the site-specific actions.

Recently, ALT commenced studies on the role branching of scalds could play in restoring temporary and long-term habitat for fauna. It is also looking at the role branching has in reducing grazing pressure on vegetation recruitment in these scald sites. This on-going research will complement this management action and will provide important design information to expand the benefits of the established scald restoration techniques.

Targets: 2.2-2.5.

Risks: Low. The restoration techniques may not deliver the desired outcomes, but this will be addressed by the adaptive management process. Implementation of some of the actions 5.1-5.5 is important as this project seeks to enhance these site-based projects through management across a broader landscape.

Confidence Level: Moderate to High. The techniques are well established in delivering vegetation recovery on scalds, but it is not certain what other benefits it will deliver and so is the subject of this adaptive management program.

Action 5.7: *Restoration of focal fauna habitats.*

The broad habitat of the paucident planigale is primarily being restored through specific restoration and environmental watering actions (see Actions 5.1-5.5). The restoration of habitat for the common brush-tailed possum and the bush stone-curlew is primarily delivered through the management of total grazing pressure (Actions 4.1-4.3) and through the control of introduced predators (Action 6.1). However, the persistence of these species is not solely related to these major threats, but is also affected by site specific issues associated with each species' use of the particular patches of habitat. To ensure that the populations of these species do benefit from other management, the targeted sites need to be assessed and appropriate actions developed for any species-specific issues identified. Priority will be given to sites being managed for other values such as through environmental watering (see Appendix VII).

The initial assessment and design will also generate appropriate monitoring to assess the efficacy of the proposed management to enhance outcomes from the primary management tasks and a process for triggering adaptive management should additional issues arise.

Targets: 2.8-2.14 & 3.1-3.9.

Risks: Low. This action will improve the likelihood that other actions (i.e., 4.1-4.3, 5.1-5.6 & 6.1) will produce the desired outcomes for specific fauna species of concern.

Confidence Level: High. Information based on data collected on site.

6: *Management of other floodplain threats*

Inappropriate flooding regimes and increased total grazing pressure are the primary drivers of stress and degradation on the Calperum floodplain, but they are not the only threats. Other threats also have significant consequences for specific species, communities, and ecological processes. These need to be addressed especially where they are seen to be preventing other management actions from achieving their goals. The importance of these threats will vary for each site, but one threat, introduced predators (i.e., foxes and feral cats), is clearly already impeding the recovery of some ecological components at the landscape scale and is therefore, relevant to most site-based restoration. The combined changes from increased grazing pressure and introduced predators has had significant consequences for species such as; the bush stone-curlew, common brush-tailed possum and possibly also the paucident planigale (Appendix VI). There are also a range of site-based threats that will only become significant as recovery progresses and they start limiting recovery. These threats will become apparent through the monitoring process and if required management to address them can be developed. This is part of adaptive management and contingencies for these masked threats must be considered in any plan (see Actions 7).

Action 6.1: *Control of introduced predators.*

Managing foxes and feral cats is a difficult process, but baiting is successful against foxes and trapping does work with a proportion of the feral cat population. It is essential that feral cats are also controlled when fox baiting occurs, because research has shown that cats can increase in abundance or change their use of the landscape when fox numbers are reduced (Marlow *et al.* 2015, Molsher *et al.* 2017).

Effective management of introduced predators is also dependent on good information about their abundance across the area being controlled. New techniques using remote camera traps are now providing better information about predator densities and how they change with control efforts (Robley *et al.* 2010). This monitoring is limited on the Calperum floodplain to date and needs to be established to ensure control efforts are effective. It is intended to use both spotlighting and camera-trap methods to assess population changes in these introduced predators. This monitoring is addressed and costed in Actions 7.2 & 7.3.

Targets: 2.9-2.14, 3.8 & 3.9.

Risks: Moderate. The control may not deliver the desired outcomes for one or both species. The ineffective control of one species compared to the other can generate unintended increases in the predation threat as these predators interact with each other. This will be addressed by appropriate monitoring and refinement of the management through time.

Confidence Level: Moderate. The control techniques are well established but their effectiveness is variable depending on site conditions. Improved monitoring of population change is an important requirement to address the uncertainty associated with the risk of ineffective control of one or other species.

7: *Monitoring and refining management actions*

Good management requires appropriate monitoring of the implementation of each management action (operational monitoring) and of the outcomes resulting from those actions with respect to identified targets (intervention monitoring) and ultimately the plan's objectives (ecological monitoring). Good management also requires information about how management actions are interacting and the effects of those interactions on the ecological system. These assessments are best conducted at the management sites, but sometimes this is not possible given available resources. Work from other areas can substitute for site-based data in these cases. Along with site-based monitoring this will allow for refinement of management actions to prevent undesired outcomes (adaptive management). Most management actions require monitoring that could be viewed as part of the action, but for an integrated management program it is useful to view monitoring as a separate set of actions, because there is duplication and potential synergies between the monitoring for each action that can be conducted in a more cost-effective manner. There is also monitoring required to implement adaptive management that is associated with multiple types of actions as it is looking at interactions and broader outcomes (Appendix VIII).

The costings outlined here are based on the entire program, unless otherwise indicated, and are indicative as the precise monitoring regime will depend on the specifics of each action delivered and the timing of delivery.

Action 7.1: *Operational monitoring*

Monitoring of the delivery of management activities will be conducted for all activities under the eight major actions. Most of this monitoring is collected on an event-by-event basis with annual analysis and reporting, but for the environmental watering program operational monitoring is collected daily and compiled and reported on monthly (Appendix VIII).

Targets: All targets.

Risks: Low. Monitoring is designed to reduce the risks of other actions.

Confidence Level: High. Methods well established.

Action 7.2: *Intervention monitoring*

Intervention monitoring measures the achievement of site-specific management targets, and so are based on specific management actions (Appendix VIII). It is, therefore, the primary measure of the immediate ecological effectiveness of the proposed management actions in delivering the management targets. Intervention monitoring is primarily related to environmental watering or restoration projects. The environmental watering program is detailed in the site-specific implementation plan (Appendix VII), which identifies the necessary intervention monitoring for each watering site. Implementation plans for restoration projects are part of the proposed actions, so the identified intervention monitoring is indicative for these sites.

Intervention monitoring for the environmental watering program is incorporated into the costs of that program (Appendix VII) apart from waterbird breeding. The costs of this and all other intervention monitoring is detailed here.

Monitoring groundwater requires test-wells, but new State regulations make it impossible to establish these wells without using licensed drilling operators. This greatly increases the costs for establishing new wells. ALT already have an extensive test-well array on the Calperum floodplain associated with the major lakes, but most of the environmental watering sites being considered in this plan are not covered by this array. Therefore, to monitor the effects of environmental watering on ground water at wetland sites it will be necessary to establish up to 20 new test wells, and the costs of this monitoring infrastructure is included in the first-year costings.

Targets: 1.2-1.3, 2.1-2.10, 2.12, 2.14, 3.1-3.9, & 4.1-4.3.

Risks: Low. Monitoring is designed to reduce the risks of other actions.

Confidence Level: High. Methods well established.

Action 7.3: *Ecological monitoring and research*

Intervention monitoring will not be enough to determine if the plan's objectives are being met, because it only addresses the outcomes of each specific action at the site(s) where it was conducted. Ecological monitoring assesses broader, longer-term outcomes in relation to the objectives of the recovery plan. It also assesses the risks to the entire floodplain of site-specific actions. These risks take two forms; consequences to areas not being directly managed by an action, such as changes in ground water or soil salinity in upland areas because of environmental watering; and potential antagonistic interactions between management actions (e.g., increased grazing pressure due to the concentration of grazers at watered sites). The ecological monitoring is collected in two forms: 1/ data collected across the entire Calperum floodplain to address large scale questions; and 2/ up-scaling, to the entire floodplain, of site-specific data collected as part of the intervention monitoring (Appendix VIII). The design of a monitoring program assessing indicators of in-stream productivity and biological diversity would be part of the planned process for implementing return flows from the environmental watering program (Appendix VII); and therefore, is not funded in this current plan.

The role of research within this recovery plan is to advance the long-term refinement of management through improved understanding of how the system functions (conceptual model) and consequently responds to changes induced by management actions. Much of this research can be delivered directly through implementation of the management plan, but independent research projects can contribute to this process by providing information on aspects of the system's ecology that are not currently manipulated by management, or by investigating mechanism that drive ecological change. The Australian Landscape Trust has always encouraged and where possible facilitated researchers to deliver such research at Calperum Station, and as a result there has and continues to be a range of research projects operating on the Calperum floodplain. This research is conducted by ALT and others generally through independent funding, and so the costs are not included here.

Targets: 1.2-1.3, 2.1-2.14, 3.1-3.9, & 4.1-4.4.

Risks: Low. Monitoring is designed to reduce the risks of other actions.

Confidence Level: High. Methods are well established.

8: *Community Engagement and Education*

Education and engagement of the community in management and conservation programs are core elements of ALT's mission at Calperum Station. This recovery plan for the Calperum floodplain provides an excellent vehicle for delivering on both activities. The focus of the education program will be on practical teaching about management of landscapes, and although most of the current projects involve school-aged participants, it can be delivered to any sector of the community. The volunteer program will focus on our established relationships with Rotary Australia and the local Riverland community to deliver floodplain management outcomes and a sense of ownership for volunteers in the recovery plan. The final component of this action is the delivery of training to the Riverland Indigenous Ranger team through management of the floodplain. This team has been in operation since 2010 and funding has been agreed until the end of the 2020-21 financial year subject to an annual approval. Funding after this date will be dependent on a new funding agreement being made available by the Australian Government.

Action 8.1: *Volunteer restoration projects*

ALT has a long history of volunteer-based restoration programs including the restoration of the semi-arid woodlands, lake restoration and the paddock manager scheme. This plan identifies sites that require the restoration of specific communities (Action 5) mainly associated with environmental watering sites. The restoration plans for these sites will be developed as part of their implementation, but all are likely to require some level of revegetation and weed control. The delivery of these two actions will be done through volunteer-based projects. The costs of delivering the actual restoration, including the contribution of volunteers, is covered in the specific restoration actions. The costs outlined here relate to the implementation and management of the volunteer involvement in activities and are covered by ALT funds.

Targets: 2.2-2.6, 3.7, & 5.1-5.2.

Risks: Low. Risks are associated with OH&S and satisfaction of volunteers, which are considered low based on the 20 years of running volunteer programs at Calperum.

Confidence Level: High. Based on well-established practices conducted by ALT.

Action 8.2: *Ecology in Action*

Ecology in Action is a bespoke education program designed for each target audience, but all program's use the management at Calperum Station to demonstrate good management practice and to involve participants in actual management activities. Past Ecology in Action programs have delivered activities on; the respectful management of cultural sites, vegetation outcomes from environmental management using tree health assessments as the task, soil restoration and managing grazing pressure on restored vegetation using branching techniques, and fauna outcomes from environmental management using pitfall trapping and possum surveys as the task.

Ecology in Action is funded through ALT, grant funding and sometimes fee for service delivery. The costs detailed here are based on only one weekly program for 16-22 participants.

Targets: 5.2 & 5.3.

Risks: Low. Risks are associated with OH&S and satisfaction of participants, which are considered low based on previous programs run at Calperum.

Confidence Level: High. Based on well-established programs conducted by ALT.

Action 8.3: *Collaborative education projects*

ALT collaborate with other NGOs (e.g., Rotary Australia and Earthwatch Australia) and sometimes government agencies to deliver education programs on land management and conservation issues. These programs cover a wide range of issues, but all seek to:

1. have participants work alongside Calperum Ecologists and Rangers learning about and participating in environmental research and management projects; and
2. expose participants to field-based challenges and scenarios that help develop a range of skills including teamwork, analytical thinking, scientific methodologies, and data collection.

ALT is currently finalising an agreement with TAFE SA to deliver a Vocational Education Training in Schools program for the Riverland, which will begin in 2020. This program will use current management at Calperum Station, including that on the floodplain, to provide a Certificate III in Conservation and Land Management for participants.

These programs have a range of different funding models and costs, so the costs provided here are indicative only and represent what is generally delivered in a year's program.

Targets: 5.2 & 5.3.

Risks: Low. Risks are only associated with OH&S and satisfaction of participants.

Confidence Level: High. Based on well-established programs conducted by ALT.

Action 8.4: *Training of the Riverland Indigenous Rangers*

ALT has run the Riverland Indigenous Rangers program since 2010. This program employs and trains at least 7 FTE Indigenous Rangers in the delivery of the management of significant conservation values on Calperum and Taylorville Stations. Over the years of its operation, it has employed and trained 31 people, with the current team consisting of eight Rangers. Apart from the important on-ground training and experience participants receive; all Rangers have, as a minimum, completed TAFE Certificate III level training in Conservation & Land Management or some other related course.

This recovery plan provides an important vehicle for training the Riverland Indigenous Rangers, though the delivery of management, monitoring, and research activities on the floodplain. The costs of delivering training to the Riverland Indigenous Rangers is covered by the Ranger program funding. The contribution the Ranger program has on the delivery of this recovery plan is outlined for each management action (Tables 3 & 4).

Target: All targets.

Risks: Low. Risks are only associated with OH&S and satisfaction of participants.

Confidence Level: High. Based on a well-established program delivered by ALT.

Implementation

Many of the ecological processes being addressed operate at time scales of decades to centuries, so many of the changes resulting from management actions are not expected from a single event or within a year or two of implementation. Further, some management actions require certain environmental conditions to be met, which might be achieved through other management or be dependent on large-scale factors such as the climate. Therefore, ecological restoration is a long-term process, and it is essential that planning and funding processes are considered within longer timeframes to provide some surety that the plan's objectives can be met.

This document addresses the first five years of this recovery plan time frame. The schedule and budgets outlined are as accurate as possible, but must be considered indicative. What is delivered is dependent on funding approvals, antecedent condition on the floodplain, and annual modifications of the plan as the result of the monitoring and review process. Many of the management actions identified are dependent on other actions being delivered, so any changes to specific actions can have consequences for the implementation of a range of actions. Detailed budgets for approved management actions will be produced within annual delivery plans.

Schedule

Management actions vary in duration and some can will be started later in the program because there are limited resources available to deliver the annual management program (Table 2). Some actions require the delivery of other actions before they can be implemented and consequently their timing is driven by these precursor actions. Infrastructure projects (Actions 1 & 2) are precursors to the delivery of the environmental watering program. Actions 2.4 and 2.5 allow for environmental watering that are not planned to commence until year 3 (Appendix VII).

The initial reduction in the kangaroo population (Action 4.1) is considered a precursor to the restoration program. It may take several years to obtain a stable reduction in kangaroo populations, but this should not prevent early restoration activities from being implemented once an initial reduction program has been completed. Ongoing kangaroo management focusses on maintaining appropriate population levels to allow for the recovery of the floodplain without risking the viability of kangaroo populations and so is complementary to other management. Control of other herbivores is an ongoing management action and so these actions are not considered precursors to restoration actions.

The drilling of new test-wells, should that be considered appropriate, is a precursor to some aspects of the intervention and ecological monitoring. Although some of these wells may not be affected by management until later in the plan, the earlier they are established the better the pre-management data will be.

Table 2: Schedule for the implementation of management actions. +++ indicates an action that is a precursor to another action; *** indicates a year in which that action will be delivered.

Action		Year 1	Year 2	Year 3	Year 4	Year 5
Developing appropriate infrastructure						
1.1	Removal of Ral Ral Creek levee near Lake Woolpolool	+++				
2.1	Retention bank southern Woolpolool floodplain	+++				
2.2	Retention bank western Widewaters floodplain	+++				
2.3	Infrastructure for e-watering Amazon uplands	+++				
2.6	Upgrade/repair of Amazon retention bank	+++				
2.4	Pipeline for e-water Woolpolool Swamp		+++			
2.5	Pipeline for e-water eastern Calperum uplands		+++			
Environmental watering						
3.1	Purchase of pumps to deliver environmental watering	+++				
3.2	Environmental Watering [1]	***	***	***	***	***
Management of introduced and over-abundant species						
4.1	Control over-abundant kangaroo populations	+++	+++	***	***	***
4.2	Integrated rabbit control	***	***	***	***	***
4.3	Control of feral goats	***	***	***	***	***
4.4	Control of feral pig outbreaks	***	***	***	***	***
6.1	Control of introduced predators	***	***	***	***	***
Restoration of floodplain communities						
5.1	Restoration of threatened plants	***	***	***	***	***
5.2	Restoration of Thookle Thookle sand dunes	***	***	***	***	***
5.3	Restoration of the Merreti East complex		***	***	***	***
5.4	Restoration of Amazon wetland complex		***	***	***	***
5.5	Restoration of Woolpolool south floodplain			***	***	***
5.6	Restoration of floodplain scalds	***	***	***	***	***
5.7	Restoration of focal fauna habitats		***	***	***	***
Monitoring program						
7.1	Operational Monitoring	***	***	***	***	***
7.2	Drilling test-wells for monitoring	+++				
7.2	Intervention Monitoring	***	***	***	***	***
7.3	Ecological Monitoring	***	***	***	***	***
Community Engagement and Education						
8.1	Volunteer restoration projects	***	***	***	***	***
8.2	Ecology in Action	***	***	***	***	***
8.3	Collaborative education projects	***	***	***	***	***

[1] A detailed schedule for the environmental watering program is provided in Appendix VII.

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Appendix I

Significant Ecological Values of the Calperum Floodplain

Riverland Ramsar site

The ecological assets identified in the Riverland Ramsar site that are relevant to the Calperum section of the floodplain are:

- The Riverland Ramsar Site contains a representative example of a near-natural wetland type found within the Riverina biogeographical Region of the Murray Darling Basin.
- The site provides habitat for listed threatened species defined under the *EPBC Act 1999*, including the regent parrot, southern bell frog, and Murray cod.
- The site supports populations of plant and animal species important for maintaining the biological diversity of the Riverina biogeographical region.
- The site provides critical summer or stopover habitat for migratory birds listed under international agreements (JAMBA, CAMBA and ROKAMBA).
- The site provides habitat for nomadic waterbirds during times of drought, and habitat for nomadic bush-bird species during summer.
- The site regularly supports 20,000 or more waterbirds involving 59 species.
- Greater than 1% of the estimated global population of 3 species, freckled duck *Stictonetta naevosa*, red-necked avocet *Recurvirostra novaehollandiae* and red-kneed dotterel *Erythrogonys cinctus* occur at times on the wetlands.
- The site supports 16 (12 species on Calperum) of the 26 species of freshwater native fish represented in the Murray-Darling Basin.

Threatened Species

Table 1: Threatened flora recorded on Calperum floodplain that are listed in Schedule 7,8 or 9 of the South Australian *National Parks & Wildlife Act 1972* and Murraylands Regional Conservation Assessment (Gillam & Urban 2010). E, Endangered; V, Vulnerable; R, Rare; LC, Least Concern.

Scientific Name	Common Name	Listing	Murraylands
Maireana decalvans	black cotton-bush	E	R
Brachyscome melanocarpa	black-fruit daisy	V	V
Dianella porracea	yellow-anther flax-lily	V	V
Swainsona reticulata	variable swainsona-pea	R	E
Duma horrida	spiny lignum	R	V
Elacholoma prostrata	small monkey-flower	R	V
Exocarpos strictus	pale-fruit cherry	R	V
Brachyscome basaltica var. gracilis	swamp daisy	R	R
Calocephalus sonderi	pale beauty-heads	R	R
Maireana pentagona	slender fissure-plant	R	R
Maireana suaedifolia	lax bluebush	R	R
Myoporum parvifolium	creeping boobialla	R	LC

There are no State recovery plans for the threatened plants recorded on the Calperum floodplain, nor is there a lot of information regarding ecology or threats for these species. Black cotton-bush, black-fruit daisy, spiny lignum and the small monkey-flower all generally grow on heavy clay soils subject to flooding. The yellow-anther flax-lily, variable swainsona-pea grow on sandy soils, but again usually in the vicinity of water. The flax-lily is susceptible to grazing, especially from goats but also eastern grey kangaroos. Sites where they are present on Calperum vary in ecological conditions, but are generally in areas that are not frequently flooded, but are subject to inundation during large floods. Grazing pressure is clearly an important threat to many of these species, with specific populations showing clear grazing impacts during the current (2018-19) drought.

Cane-grass swamps are a community that has become rare in the Riverland. Cane-grass, *Eragrostis australasica,* is not a listed species at the state level, but is considered rare in the Murraylands (Gillam & Urban 2010).

Table 2: Threatened species recorded on the Calperum floodplain that are listed under the National *EPBC Act 1999* (E, Endangered; V, Vulnerable), and in Schedule 7& 8 of the South Australian *National Parks & Wildlife Act 1972* (E, Endangered; V, Vulnerable).

Common Name	Species name	EPBC Act 1999	SA National Parks & Wildlife Act 1972
MAMMALS			
Common Brushtail Possum	*Trichosurus vulpecula*	-	R
BIRDS			
Regent Parrot (eastern)	*Polytelis anthopeplus monarchoides*	V	V
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	-	E
Freckled Duck	*Stictonetta naevosa*	-	V
Banded Stilt	*Cladorhynchus leucocephalus*	-	V
Brown Quail	*Coturnix ypsilophora*	-	V
REPTILES & FROGS			
Southern Bell Frog	*Litoria raniformis*	V	V
Carpet Python	*Morelia spilota variegata*	-	R
Lace Monitor	*Varanus varius*	-	R
Broad-shelled Tortoise	*Chelodina expansa*	-	V
Macquarie Tortoise	*Emydura macquarii*	-	V
FISH			
Murray Cod	*Maccullochella peelii*	V	-

Regent Parrot Polytelis anthopeplus monarchoides

The eastern subspecies of the Regent Parrot *Polytelis anthopeplus monarchoides* is restricted to a single population occurring along the lower Murray-Darling basin of South Australia, New South Wales and Victoria. The population is estimated to be no more than 1,500 adult breeding pairs. Within this range it occurs in riverine and mallee woodlands and forests (Baker-Gabb & Hurley 2011). They nest in hollows and form loose breeding colonies almost entirely of red gum forests and woodlands along major river courses. The breeding birds Regent Parrots feed in large blocks of intact mallee within 20 km of their nest sites (Baker-Gabb & Hurley 2011). During the non-breeding period birds expand over a much wider range and in the Riverland, this includes the mallee of the Riverland Biosphere Reserve.

The eastern Regent Parrot has declined in range and abundance over the last 100 years. The major threats include clearing and degradation of nesting and foraging habitat, disturbance around nesting sites, competition for nest hollows, deliberate killing of birds, road kills and accidental poisoning (Baker-Gabb & Hurley 2011). The major threat is the fragmentation of suitable breeding (red gum riparian forest) and adequate undegraded, feeding habitat (mallee) during the breeding season.

Southern Bell Frog Litoria raniformis

There are two apparently distinct biogeographical groups which differ in biology and ecology (Clemann & Gillespie 2012). The South Australia population, of the southern bell frog is part of the northern biogeographical group of this species, which breeds in flooded ephemeral waterbodies during spring or summer. In this group the breeding cycle is short with tadpoles completing development in as short as two months (Wassens 2006, Schultz 2007, 2008). During non-breeding periods these frogs are concentrated in refugia (permanent waterbodies) prior to flooding, then disperse across the landscape during flooding to breed (Wassens *et al.* 2008; Schultz 2007). They are a mobile species being able to disperse at least 1km between refugia and breeding sites (Schultz 2008, Clemann & Gillespie 2012).

This species breeds in wetlands with fringing vegetation such as Lignum, Typha, and nitre goosefoot. However, the critical habitat features appear to be that the floodplain has large, continuous areas containing both permanent and ephemeral waterbodies that undergo regular flooding. The species tolerates saline water (< 7,000EC), but is dependent on freshwater for breeding (Clemann & Gillespie 2012). The mobile population dynamics of this species means absence of breeding frogs in a wetland does not mean the wetland is unsuitable, as frogs from nearby refugia may be using other breeding wetlands instead (Schultz 2007).

The major threat to the Riverland population of the southern bell frog is the loss and fragmentation of habitat primarily through changes in hydrological regimes that prevent temporary wetlands being flooded regularly and/or increase salinisation of temporary wetlands. Fragmentation can then occur between remaining wetlands that become isolated from permanent water refugia, and potentially by modification to terrestrial vegetation (i.e., by increased grazing pressure), which reduces the capacity of frogs to disperse (Clemann & Gillespie 2012).

Murray Cod Maccullochella peelii peelii

The Murray cod is the native, apex aquatic predator of the Murray-Darling Basin. It is a large (up to 1.8m long and >100kg), long-lived (>100yrs, average 47yrs) species that does not become sexually mature until 4-6 years of age (NMCRT 2010b). It occurs in a range of flowing and standing waters, from small, clear, rocky streams on the inland slopes and uplands of the Great Diving Range, to the large, turbid, meandering slow-flowing rivers, creeks, anabranches, and lakes and larger billabongs, of the inland plains of the Murray-Darling Basin. A critical habitat component is complex structural cover, such as large rocks, large snags and smaller structural woody habitat, undercut banks and over-hanging vegetation.

Although the Murray cod remains widely distributed throughout the Murray-Darling River system it has undergone an extensive decline in abundance since European settlement, especially in the last 70 years (NMCRT 2010a). This decline relates to numerous historic changes such as extensive snag removal (i.e., fallen trees), movement barriers from Locks and Weirs, historic overfishing, and the introduction of fishes which compete for food or modify habitat conditions (i.e., redfin and carp). An overarching and continuing threat, however, is reduced and altered flow patterns from massive upstream regulation and abstraction, which appears to interfere directly in Murray cod ecology or impact ecological processes (e.g., food resources and appropriate habitat for juveniles) (Hammer *et al.* 2009, NMCRT 2010a).

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Appendix II

Key Threats and Ecological Objectives from other Planning Processes

Planning processes operate at a range of spatial scales from the regional to the local. The focus of plans at these different scales differs by necessity. For instance, lateral connectivity between rivers and the floodplain, relates to the management of river flows to maintain the frequency of freshes, bank-full and over-bank flows at the whole of basin scale; while for a given reach of the river, such as the Calperum floodplain, it relates to addressing issues impeding flows across the floodplain during different flow regimes. Consequently, some regional targets will have little relevance to local planning as they cannot be addressed at the local scale (e.g., improved age structure of fish populations). So, plans at smaller spatial scales should be consistent with regional planning and seek to contribute to regional targets where possible, but they will also have site specific objectives and targets that would not necessarily be considered a priority issue at larger scales.

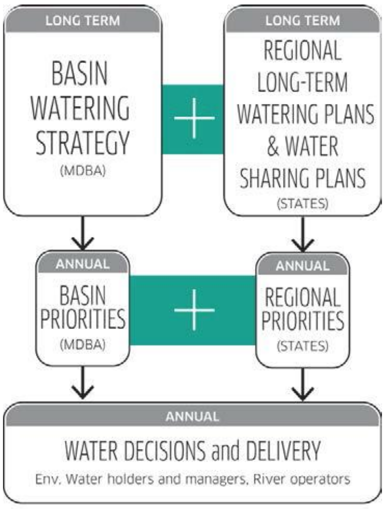


Figure 1: Levels of planning for the Murray-Darling Basin (from MDBA 2014). The current plan for the Calperum floodplain sits at the lowest of these levels.

This appendix outlines important threats to the Calperum floodplain identified in other planning documents and the key objectives/targets of planning processes that operate at larger spatial scales than the current Calperum floodplain plan.

Murray-Darling Basin Plan 2012

The Murray-Darling Basin Plan 2012[2] has three broad environmental objectives, which then have several specific objectives. This recovery plan if implemented will deliver a number of these specific objectives for the 8,400ha of the Calperum floodplain. The management targets identify the expected quantum of this delivery and direct outcomes for each specific Basin plan objective are identified below.

The relationship between the Murray-Darling Basin Plan 2012 objectives and the management targets identified within this recovery plan. Basin plan objectives that are not directly addressed by this recovery plan are in grey text. Management targets detailed on pages 13-14.

Objective of Murray-Darling Basin Plan 2012	Management Targets
Protection and restoration of water-dependent ecosystems	
Protect and restore a subset of all water-dependent ecosystems of the Murray-Darling Basin, including by ensuring that: · declared Ramsar wetlands that depend on Basin water resources maintain their ecological character; · water-dependent ecosystems that depend on Basin water resources and support the life cycles of species listed under the Bonn Convention, CAMBA, JAMBA or ROKAMBA continue to support those species; · water-dependent ecosystems are able to support episodically high ecological productivity and its ecological dispersal.	All targets Calperum floodplain is 27% of the Riverland Ramsar site. Calperum wetlands provide important habitat for CAMBA, JAMBA or ROKAMBA listed species
Protect and restore biodiversity that is dependent on Basin water resources by ensuring that: · water-dependent ecosystems that support the life cycles of a listed threatened species or listed threatened ecological community are protected and, if necessary, restored so that they continue to support those life cycles; and · representative populations and communities of native biota are protected and, if necessary, restored.	Targets 2.6 and 2.9-2.14
Protection and restoration of ecosystem functions of water-dependent ecosystems	
The water quality of Basin water resources does not adversely affect water-dependent ecosystems and is consistent with the water quality and salinity management plan.	Targets benefit this objective
Protect and restore connectivity within and between water-dependent ecosystems, including by ensuring that: · the diversity and dynamics of geomorphic structures, habitats, species and genes are protected and restored; · protect and restore ecological processes dependent on hydrologic connectivity: longitudinally along watercourses, laterally between watercourses and their floodplains (and associated wetlands) and vertically between the surface and subsurface; · the Murray Mouth remains open at frequencies, for durations, and with passing flows, sufficient to enable the conveyance of salt, nutrients and sediment from the Murray-Darling Basin to the ocean; · the Murray Mouth remains open at frequencies, and for durations, sufficient to ensure that the tidal exchanges maintain the Coorong's water quality (in particular salinity levels) within the tolerance of the Coorong ecosystem's resilience; · the levels of the Lower Lakes are managed to ensure sufficient discharge to the Coorong and Murray Mouth and help prevent riverbank collapse	All Targets Targets 1.1-1.2

[2] Murray-Darling Basin Plan 2012 is available online https://www.legislation.gov.au/Details/F2012L02240

and acidification of wetlands below Lock 1, and to avoid acidification and allow connection between Lakes Alexandrina and Albert; and · barriers to the passage of biological resources (including biota, carbon and nutrients) through the Murray-Darling Basin are overcome or mitigated.	
Natural in-stream and floodplain processes that shape landforms (for example, the formation and maintenance of soils) are protected and restored.	Targets 1.2-1.3
Support habitat diversity for biota at a range of scales (including, for example, the Murray-Darling Basin, riverine landscape, river reach and asset class).	All Targets
Protect and restore ecosystem functions of water-dependent ecosystems that maintain populations (for example recruitment, regeneration, dispersal, immigration and emigration) including by ensuring that: · flow sequences, and inundation and recession events, meet ecological requirements (for example, cues for migration, germination and breeding); and · habitat diversity, extent, condition and connectivity that supports the life cycles of biota of water-dependent ecosystems (for example, habitats that protect juveniles from predation) is maintained.	Targets 2.1-2.4, and 2.7 Targets 1.2, 2.1-2.14, and 3.1-3.9
Protect and restore ecological community structure, species interactions and food webs that sustain water-dependent ecosystems, including by protecting and restoring energy, carbon and nutrient dynamics, primary production and respiration.	Targets 1.2, 2.1-2.8, and 3.1-3.9
Ensuring water-dependent ecosystems are resilient to climate change and other risks and threats	
Protect refugia in order to support the long-term survival and resilience of water-dependent populations of native flora and fauna, including during drought to allow for subsequent re-colonisation beyond the refugia.	Targets 1.1-1.3, 2.1-2.3, and 3.1-3.9
Provide wetting and drying cycles and inundation intervals that do not exceed the tolerance of ecosystem resilience or the threshold of irreversible change.	Targets 1.1-1.2
Mitigate human-induced threats (for example, the impact of alien species, water management activities and degraded water quality).	Targets 1.1-1.2 and 3.1-3.9
Minimise habitat fragmentation.	

As part of the Murray-Darling Basin Plan, a basin-wide environmental watering strategy (MDBA 2014) was developed that outlined key environmental objectives and targets in relation to the specific management actions associated with the delivery of environmental water.

These targets are relevant to the Calperum recovery plan in two ways; firstly, river flow targets provide basin-wide environmental conditions that enable the management proposed for the Calperum floodplain to occur. Native vegetation and waterbird targets on the other hand identify basin-scale goals for these communities, to which the Calperum floodplain recovery plan can directly contribute.

Ecological Targets from MDBA 2014 (relevant to the Calperum floodplain)**:**

1. **River flows and connectivity**
   - 1.1. to keep base flows at least 60% of the natural level (note: this will be especially important during dry years)
   - 1.2. a 30% overall increase in flows in the River Murray: from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively

1.3. a 30 to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows in the Murray, Murrumbidgee, Goulburn–Broken and Condamine–Balonne catchments

2. **Native vegetation**
    - 2.1. to maintain the current extent of forest and woodland vegetation
    - 2.2. no decline in the condition of river red gum, black box and coolibah across the Basin
    - 2.3. by 2024, improved condition of river red gum in the Lachlan, Murrumbidgee, Lower Darling, Murray, Goulburn–Broken and Wimmera–Avoca
    - 2.4. by 2024, improved recruitment of trees within river red gum, black box and coolibah communities—in the long-term achieving a greater range of tree ages
    - 2.5. to maintain the current extent of extensive lignum shrubland areas within the Basin
    - 2.6. by 2024, improvement in the condition of lignum shrublands
    - 2.7. to maintain the current extent of non-woody vegetation
    - 2.8. by 2024, increased periods of growth for communities that closely fringe or occur within the main river corridors
3. **Waterbirds (from 2024 onwards)**
    - 3.1. that the number and type of waterbird species present in the Basin will not fall below current observations
    - 3.2. a significant improvement in waterbird populations in the order of 20 to 25% over the baseline scenario, with increases in all waterbird functional groups
    - 3.3. breeding events (the opportunities to breed rather than the magnitude of breeding *per se*) of colonial nesting waterbirds to increase by up to 50% compared to the baseline scenario
    - 3.4. breeding abundance (nests and broods) for all of the other functional groups to increase by 30–40% compared to the baseline scenario, especially in locations where the Basin Plan improves over-bank flows

Calperum and Taylorville Stations Management Plan 2013 - 2023

The management plan for Calperum and Taylorville Stations covers a wide range of ecological and cultural issues of which the Calperum floodplain is only a small component. This summary identifies those elements of the plan relevant to the current floodplain plan.

Key Objectives associated with the floodplain identified in the Management Plan for Calperum and Taylorville Station

- Facilitate the movement of water across the floodplain landscape in ways that benefit and enhance biological diversity.
- Restore the functioning of native ecosystems by limiting the impacts of environmental weeds.
- Restore the functioning of native ecosystems by limiting the impacts of introduced fauna.
- Conserve and maintain the integrity and quality of significant cultural landscapes, heritage structures and other heritage features.

Key threatening processes and their impacts on the floodplain identified in the Management Plan for Calperum and Taylorville Station.

Threatening processes	Impact
Historical	
Loss of vegetation components due to land clearance and timber harvesting	High
Fragmentation of habitat	Moderate
Historical grazing pressure	Extreme
Altered soil structure due to introduced grazers, loss of native medium-sized mammals	Extreme*
Altered regional hydrology leading to increased salinity of groundwater & soil	Extreme
Altered local hydrology due to construction of dams, drainage lines, levee banks	High
Ongoing	
Altered river flow regimes (lack of environmental flows, flow control structures)	Extreme
Elevated grazing pressure (introduced herbivores & increased kangaroo abundance)	Extreme
Increased predation (feral cats & foxes)	Moderate
Altered soil structure due to introduced grazers	High*
Other degradation of habitat quality by introduced species (carp, weeds)	High
Inappropriate recreational use (off-road vehicles, track proliferation)	Low
Illegal harvesting (firewood collection, trapping of birds for aviculture industry)	Low
Climate Change	?

* Significant spatial variability.

Management Plan for the Riverland Ramsar Site

Key threating processes identified in the management Plan for the Riverland Ramsar Site

- Altered flow regime
- Elevated and altered groundwater regime
- Salinity
- Very high sedimentation rates for wetlands
- Obstructions to fish passage and de-snagging
- Grazing pressure
- Introduced flora and fauna

- Visitor Use
- Climate change, particularly compounding effects of decreased rainfall and increased evaporation
- Fire

Key Objectives identified in the Management Plan for the Riverland Ramsar Site:

- Re-establish the hydrological processes that maintains the ecological character.
- Restore and maintain health of vegetation communities and fauna across the floodplain.
- Manage threatening processes or activities to mitigate their impacts on the site's ecological and cultural values.
- Ensure recreational activities are in accordance with the wise use of the site's natural and both Aboriginal and European cultural heritage values.
- Promote Communication, Education, Participation and Awareness (CEPA) within the community to maintain the ecological, cultural and wise use values.
- Enable programs for ongoing scientific research and monitoring to ensure effective management and provide for appropriate data storage.
- Redefine the Ramsar boundary that appropriately embraces the diversity of hydrological and ecological characteristics of the Riverland Ramsar Site.

Appendix III

Conceptual Model for the Calperum Floodplain

Introduction

In 2011 the Australian Landscape Trust developed a draft conceptual model for the Calperum floodplain (Cale & Cale 2011). This model was not prescriptive as at that time there was limited empirical data for Calperum to generate reliable prescriptions. The model was instead heuristic, designed to aid in refining understanding of the floodplain and consequently allowing the collection of appropriate empirical data to solve the management problems observed. Its primary focus was on issues that related to restoring the ecological function of the floodplain that were lost/impaired by inappropriate water and land management.

The aim of this appendix is to summarise and refine the conceptual model in relation to empirical data that has since been collected on Calperum and elsewhere in the Murray-Darling Basin, within the specific focus of identifying potential prescriptive management action that can be implemented to meet our ecological objectives.

Conceptual Model

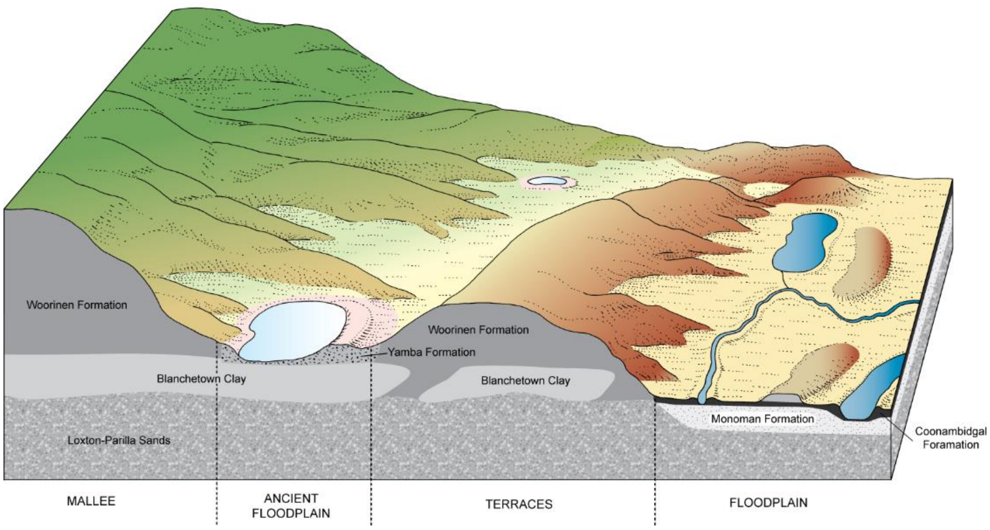
This model is equally applicable to flora and fauna, but the primary focus is on flora and its interactions with the bio-physical components of the floodplain. This is because currently areas once occupied by many floodplain communities on Calperum lack both the structural and functional attributes of this ecosystem, and at least initially these problems are best addressed by restoring vegetation components. The model is also focused on the floodplain not the river channels, because restoring most ecosystem functions within the river channels requires regional management actions (e.g., river flow management), which is beyond the capacity of single landowners. Further, we have put little emphasis on components of the system that are completed solely within a flood, because management of such components—beyond managing the basic building blocks of the system—cannot be controlled at a local scale. These restriction on the current model do not precluded considering some of these aspects within our model, nor do they imply that such issues are unimportant—merely that they are beyond current management capacity at the scale of the Calperum floodplain. Future expansion of the model and its application to additional management issues, once the primary vegetation issues have been addressed, will be part of the model review process.

This conceptual model can be used to identify potential manipulations of the system that may enhance recovery and to assess the likely response of the system to the chosen recovery approaches. This will improve initial decision-making for actions attempting to facilitate the recovery of parts of the system. More importantly, it will allow greater capacity for learning from the actions attempted, because it provides an appropriate context for considering the outcomes of recovery actions.

Geomorphology

The Murray Geological Basin contains sedimentary sequences formed by marine, fluvial and aeolian depositional environments, and its depositional history largely reflects changes in sea-level fluctuations that occurred in the past (Lewis *et al.* 2008, Bone 2009). About 3 million years ago, as the sea regressed and the climate became more arid, extensive sand deposits were laid down, the **Loxton-Parilla Sands** (Barnett 1996, Bone 2009) (Figure 1). About 2 million years ago the ancestral River Murray was blocked by coastal dune barriers, and this, together with a wetter climate, lead to the formation of an extensive freshwater lake, Lake Bungunnia (Barnett 1996). Within the lake, very fine-grained sediments were deposited and formed the **Blanchetown Clay** (Barnett 1996, Bone 2009). When the barrier to Lake Bungunnia was breached, some 620,000 years ago, the River Murray developed as we see it today (Bone 2009), and the Woorinen Sands were wind deposited over the Blanchetown Clay. Before being covered with Woorinen Sands, it is likely that Lake Bungunnia split into smaller lakes, which became saline. On the clay beds of these saline lakes, gypsiferous clay and gypsum-sand mixtures were formed, the **Yamba Formation** (Barnett 1996, Cupper *et al.* 2003). Over the last 500,000 years, strong westerly winds have eroded the landscape and formed extensive areas of east-west, red-brown dunes separated by broad swales, the **Woorinen Formation** (Barnett 1996). In isolated hollows, the removal of the overlying sand by wind action has exposed the Blanchetown Clay. While this was occurring, the River Murray was cutting through the sedimentary layers and depositing sediments on the new floodplain. These younger valley deposits, the **Coonambidgal Formation**, consist of alluvial clays, silts and sands, and the unit varies in thickness (commonly 2-4 m) (Yan *et al.* 2006). The high clay content of this unit means it forms a relatively impermeable layer to water. Beneath this layer lies an unconsolidated alluvial sand deposit, the **Monoman Formation**, which is comprised of a mixture of channel and sheet sand deposits with intervening sequences of silty clay (Jolly *et al.* 1994, Yan *et al.* 2006). This formation is described as an unconfined aquifer (Jolly *et al.* 1994).

Figure 1: Ecological systems within the Calperum landscape occur along an edaphic catena from the mallee to the floodplain



The River Murray at Calperum Station can be described as an anabranch deposition zone of the lower Murray River (Alluvium 2010), which is characterised by a series of channels (anabranches) which flow across a very broad, flat, floodplain. In an unregulated river, the main channel at low flows is a series of large pools and sandy point bars with no riffle sections. At high flows the system provides a diverse array of aquatic habitats, including in-channel benches at different levels, diverse flood runners, large anabranches and an extensive floodplain with frequent billabongs (Alluvium 2010). Anabranch channels and wetlands become isolated from the main channel at different flow levels, so they provide a diversity of habitat conditions across the floodplain.

The primary production that drives the river food web for this type of river system is provided by filamentous algae and/or phytoplankton derived from in-stream and floodplain sources plus some contribution from emergent vegetation (Alluvium 2010, Furst 2013). During low flows the source of most production within the river is likely to be from instream and emergent vegetation. However, at high flows floodplain sources are likely to become a significant contribution to river productivity, and river sources of sediment and propagules is likely to be important for floodplain productivity and aquatic diversity (Furst 2013). This exchange of sediment, nutrients and organics between the river channels and the floodplain makes lateral connectivity an important component of this river ecosystem.

Regulation and river modification of the Murray River and the consequent changes in the flooding regimes and lateral connectivity have changed the extent, magnitude and frequency of the ecosystem processes that operated within this part of the river, but the fundamental processes and functions remain.

Climate and Flooding Regimes

The South Olary Plains experiences a warm, dry climate with short, cool to cold winters, and rainfall that is highly variable with no distinct seasonal patterns (Laut *et al.* 1977). During summer months, incursions of cyclonic and monsoonal depressions occur, resulting in occasional heavy rainfall. The region has high temperatures and low relative humidity for most of the year, which results in high evaporation rates for substantial periods of the growing season.

At Renmark (c.15 km SW of the Calperum floodplain) mean annual rainfall is 256 mm (median 250 mm), but annual rainfall is highly variable, ranging from 90 mm to 517 mm (427 mm range). The region has on average 24 rain events (>1 mm) per year (based on 2005-2009 data), but only 6.4/yr (27%) with more than 10 mm of rain and only 2.5/yr produce >25 mm. Although on average the period May to October has slightly higher rainfall than November to April, during any given year there is no clear pattern to when these rainfall events will occur.

Prior to regulation, the lower Murray showed highly variable river flows (Walker & Thoms 1993), and these reflected the variable climate of the Murray-Darling Basin. However, average monthly river flows do show some seasonality with the highest flows occurring in late winter and early spring, and the lowest flows in late summer and autumn (Walker & Thoms 1993, Maheshwari *et al.* 1995). Although this seasonality has not changed since river regulation, the magnitude of river flows has been substantially reduced, with most flows now being maintained below or at bank capacity (Walker & Thoms 1993, Maheshwari *et al.* 1995). River regulation has reduced the frequency and magnitude of floods. For instance, at nearby Chowilla floodplain, River Murray flows of 35,000 ML/day occurred 94 times in 100 years under 'natural' conditions, but since regulation only occur 46 times in 100 years (Sharley & Huggan 1995). Larger flows of 80,000 ML/day have been reduced from 45 to 12 times in a 100-year period, while 150,000 ML/day floods have reduced from 12 to 4 times in a 100-year period. The reduction in flood frequency has meant there is a greater period of time between beneficial flood events, with Chowilla shifting from one every 5.7 years prior to regulation to one every 28.7 years under current regulation (CSIRO 2008).

Water Cycle

Water differs from other limiting resources in that most of it is not recycled within a single landscape. Noy-Meir (1973) described water as "…. *essentially a non-cyclable, periodically exhaustible resource, replenished only by new input.*" At the scale of a landscape or patch, water cascades through the system, with the amount recycled from plants and animals back to the soil being relatively small. For most systems water enters as **rainfall**, but for floodplains run-off, in the form of rivers and creeks, is a primary driver of the water cycle (Figure 2). During periodic flood events the primary mechanisms driving the water cycle shift to those associated with flood waters, but even during these times upland areas that are not inundated are still strongly affected by rainfall mechanisms of the water cycle.

Floods generate abundant water that **inundates** extensive areas of the floodplain. **Infiltration** replenishing **sub-soil storage** and interacts with **groundwater** altering levels and salinity. When the flood has finished water is lost through **runoff** into channels, **channel flows** downstream, and **evaporation** of remaining standing water. Due to the abundance of water during a flood the loss of water from all these processes is substantially higher than during rainfall events, but channel flows are the most significant process.

Rainfall and flood waters become available to organisms either through infiltration into the soil, capture on plant surfaces, or the formation of standing water. **Infiltration** allows for the replenishment of soil moisture where it is taken up by plants (**plant uptake**). Infiltration is a function of the soil type, its current soil moisture and soil structure. As soil moisture increases toward saturation, the process is driven more by gravity and water descends into the sub-soil (**sub-soil storage**), where it is less accessible to many plants. **Hydraulic redistribution** moves water through plant root systems from the sub-soil towards the soil surface (hydraulic lift) or in the opposite direction (inverse hydraulic lift) depending on the relative soil moisture of these two water storages. Hydraulic redistribution, therefore, assists in replenishing storages that are in deficit between rainfall events.

Some rainfall is intercepted by plants (**plant interception**) and is lost as evaporation. This is relatively low in arid systems, because of the low vegetation cover. Further, some of this intercepted water reaches the soil via **stem flow** and **drip flow**. Stem flow can be as high as 10% of total precipitation (Noy-Meir 1973). Flow from plants to the soil can result in variations in the amount of water entering the soil in different parts of the system (Specht & Rayson1957).

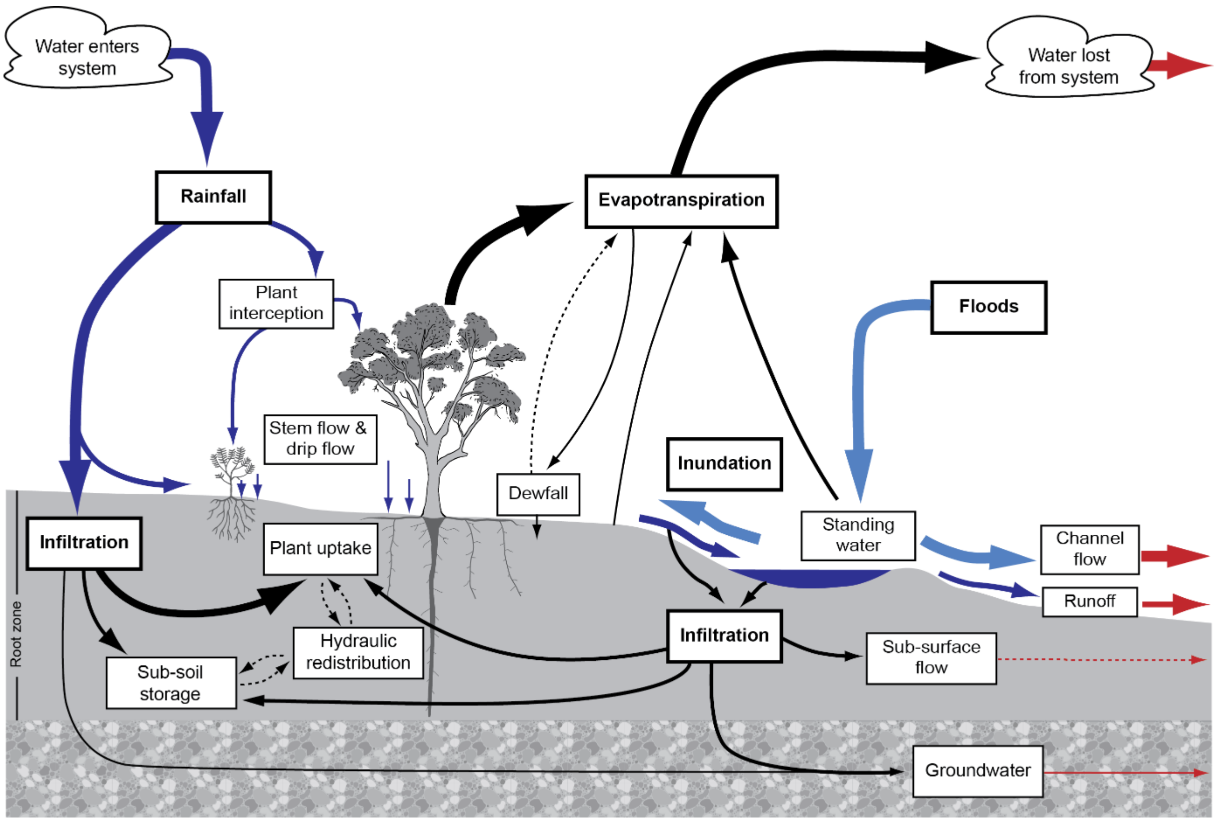
Standing water forms in depressions where the soil has become saturated, and is a relatively ephemeral component of the water cycle. This water is lost through evaporation and ongoing infiltration, with its persistence depending on soil type and climatic conditions.

The most significant loss of water from the system is through **evapotranspiration**, which is the combination of transpiration from vegetation and evaporation from surfaces such as soil, foliage and standing water (Burba *et al.* 2010). The annual actual evapotranspiration for Calperum is about 300 mm, with a potential evapotranspiration of 1100 mm, indicating the potential negative water balance of the system (Australian Bureau of Meteorology).

Some evapotranspiration is returned to the system via **dewfall** that forms from condensed atmospheric moisture (Noy-Meir 1973). Dewfall is the only significant recycling of water at a local scale, and in arid systems, it can be a substantial proportion of total moisture. Malek *et al.* (1999) found that in a desert valley with an annual rainfall of 125 mm, dewfall contributed almost 9% of the water for evapotranspiration, while in a wetter irrigated area (1000 mm rainfall and irrigation) this dropped to only 3%.

Dew also redistributes water at the local scale, as dew formation is influenced by patch characteristics. Liu *et al.* (2006) showed that the presence of a biological soil crust can double the quantity of dew, compared to bare sand. Biological soil crusts also absorb more dew than sand before it evaporates, as the moss component can absorb large amounts of moisture via their rhizines. The development and reabsorption of dew in association with biological soil crusts results in a positive feedback that forms and maintains these biological crusts (Liu *et al.* 2006). Pan *et al.* (2010) found that dew formed at much high rates in the spaces between plants than under them. They argued that at a larger scale, the cover of vegetation would have an important influence on the overall levels of dew formation, through the impact of evapotranspiration on the relative humidity (Pan *et al.* 2010). This results in a redistribution of water from plants to the spaces between plants.

Figure 2: The water cycle for the Calperum floodplain. Boxes represent stores or water movement processes. Bolded black boxes represent the most significant processes during rainfall events, while bolded blue boxes are more significant during floods. Arrows represent the flow of water with their increased thickness indicating increasing significance.



Water loss from the system occurs through **evapotranspiration**, run-off, and groundwater flow. The relative importance of these four processes differs for each system and the conditions the system is currently in (e.g., a flood event). Water redistribution within or lost from the system by **run-off** varies greatly in magnitude depending of conditions. During floods run-off through channel flow is the most substantial water movement mechanism, but during dry times it is insignificant. There is also **sub-surface flow** of water on sloping ground, which is limited until the soil is saturated and its rate depends on slope and hydraulic conductivity. The hydraulic conductivity of sand can be several metres per day. Flow channels created by roots or animals can increase the speed at which sub-surface flows occur, resulting in heterogeneity in flow through the soil. **Surface evaporation** becomes a more significant component of evapotranspiration during flood events as large surface areas of water are generated.

Finally, some water enters the **groundwater** and is lost as groundwater flows. Groundwater flows are much slower than sub-surface flows, which in turn are slower than run-off. Consequently, these different flows can maintain water flow within a system for longer periods than a specific rainfall or flood event, generating temporal variability in the availability of water in different soil stores.

Soil Water Dynamics

There is a continuous interaction between surface water and various water stores within the soil profile (Figure 3). Groundwater is the zone of soil or rock that is permanently saturated, while soil water is water held in the soil above the water table (the upper boundary of groundwater). This water varies in quantity depending on available external sources—primarily infiltration of surface water from rainfall or floodwaters, or the lateral movement of water through the soil from waterbodies (i.e., river, creek, lakes). The zones in which groundwater and soil water occur within the soil profile are dynamic and fluctuate in response to groundwater and surface water flows at local and regional scales.

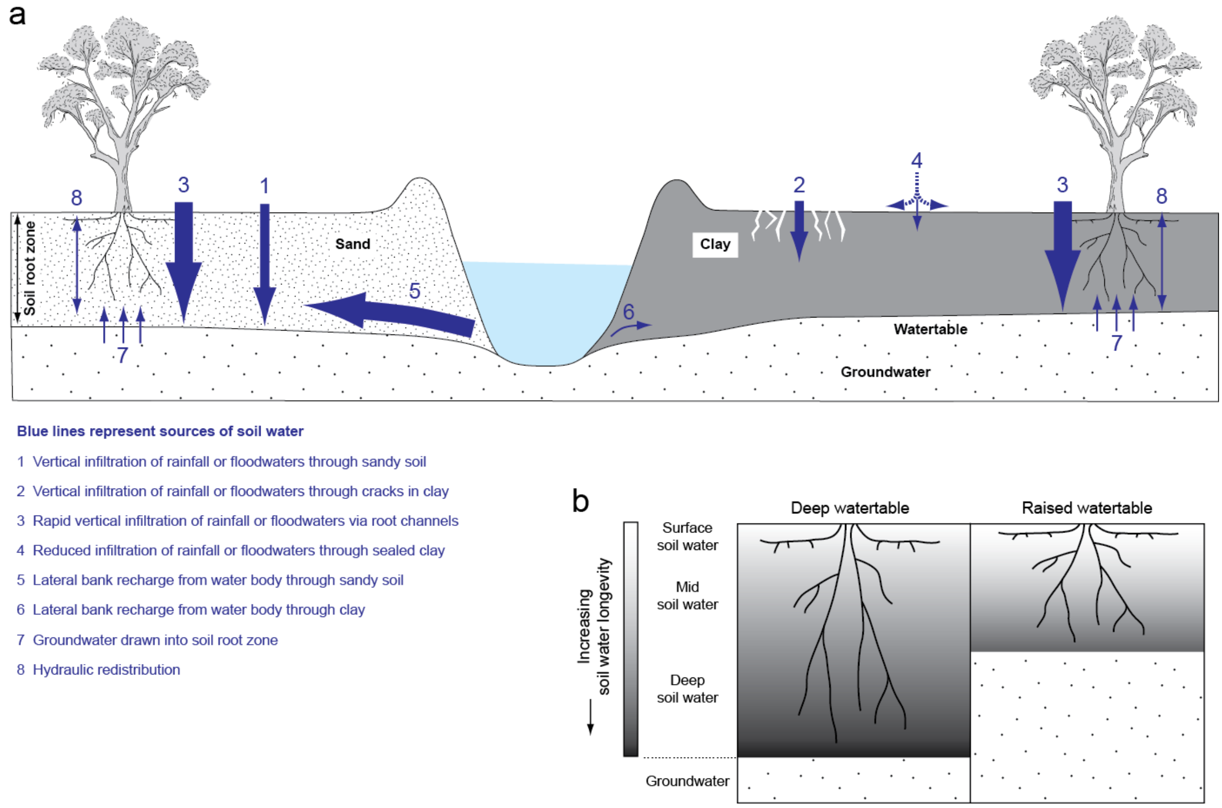
Vertical infiltration of rainfall or floodwaters into soil will vary depending on soil type, with water movement occurring more rapidly and to a greater depth though sandy soil than through clay (Noy-Meir 1973, Grigg *et al.* 2008) (Figure 3a). Movement of water through soil can be significantly enhanced (up to seventeen times faster) by the presence of macropores formed by root channels and faunal biopores (Eldridge 1993, Bramley *et al.* 2003) or the presence of cracks in the soil matrix (Holland *et al.* 2006) (Figure 3a). On Calperum floodplain some clay soils have a greater propensity to form cracks than others, with soil cracks being most common in lakebed, lignum and clay flat areas (Bignall 2001). As the formation of cracking clay is reliant on inundation, a reduction in flooding frequency will limit how often such conditions occur and hence affect infiltration of future flood or heavy rainfall events.

High levels of sodicity in clay soils can reduce water infiltration due to the changes that occur to the soil structure on wetting (Jolly *et al.* 1994). Sodicity is not the same as salinity. Sodic soils have high concentrations of sodium ions that attached to clay particles. When these soils are inundated the clay particles disperse disrupting soil structure and greatly reducing soil permeability. When the soil dries the surface sets hard and crusty, thus limiting the ability of seedlings to penetrate the surface. The Coonambidgal Clay has a high clay/silt content and can be sodic (Jolly *et al.* 1994), so in upland areas of the floodplain when this substrate is exposed by erosion scalds are formed that resist vegetation recovery.

Lateral bank recharge from a water body will be greater and travel over longer distances through sandy soil than through clay (Lamontagne *et al.* 2005, Holland *et al.* 2009) (Figure 3a). In lower Murray floodplain systems bank recharge can freshen and replenish soil water stores up to 50 m from the edge of a water body (Bacon *et al.* 1993; Holland *et al.* 2006, 2009).

Soil water can also be replenished via groundwater when the water table is within two metres of the soil surface by groundwater rising due to surface evaporation—capillary rise (Figure 3a). In clay soils capillary rise is slow but covers a long distance, while in sand it is quick but covers only a short distance. A result of capillary rise is the redistribution of salt that is drawn up with the groundwater but then left in the soil when that water evaporates. The result is increase soil salinity that requires flushing of the soil by surface water infiltration. This flushing process can be enhanced by root channels which increase infiltration rates (Bramley *et al.* 2003). Finally, soil water stores can also change via hydraulic redistribution, where roots absorb, transport and exude water in response to gradients in water potential between themselves and the soil (Figure 3a). Roots can transport and exude water up or down the profile when transpiration ceases, and thus, bypass soil layers with low permeability (Burgess *et al.* 1998, 2001).

Figure 3: Soil water dynamics for the Calperum floodplain: a) differences in the relative importance of soil water sources in clay and sand substrates and b) the influence of groundwater height on soil water and its longevity.



The accumulation of salt in the soil is a natural characteristic of Murray River floodplain ecosystems, but changes in flooding have prevented the flushing of salt from soils leading to increased soil salinity (Overton *et al.* 2006, Jolly *et al.* 2008). Salinity in the root zone lowers the osmotic potential of soil water, and if it continues to build up, the osmotic potential will become so negative that plants are unable to extract water from the soil. This denies the plant access to the existing soil moisture leading to water stress and eventual death (Thorburn *et al.* 1995, Bramley *et al.* 2003).

The longevity of soil water stores varies with their depth within the soil profile, with water persisting for longer periods at greater depth (Figure 3b). Where the water table is deep, the surface soil water will persist for hours to days, while mid soil water will persist days to months and deep soil water for years (Nicol 2004, Holland *et al.* 2009). A rising water table, due to changes in groundwater hydrology, therefore, results in less long-lived deep soil water. So, if the groundwater is not accessible by plants due to high salinity, a rising water table will result in an increased variability in the soil water resource and likely a decline in water availability to plants in periods of dry conditions.

Flooding Dynamics

The biota of semi-arid lower Murray floodplains is, by definition, primarily driven by the flooding regime of the River Murray, but local rainfall also plays an important role. The complex dynamics between these two factors result in a diverse range of communities across the floodplain. Over the long term, each flooding event is a significant but short-term disturbance to the system, but species also need to cope with the dry conditions between floods. This fluctuation between wet and dry conditions means most biota face one set of conditions to regenerate (regeneration regime) and a different set of conditions while maintaining their population (maintenance regime). Therefore, in managing a floodplain, it is important to consider how the system functions, both during floods and dry inter-flood periods.

Floodplain communities of a system exist along a continuum from low to high inundation frequency. The relative influence of local rainfall and flooding varies along this continuum with terrestrial communities predominantly being driven by local rainfall with occasional flooding events, while flood-adapted communities are primarily driven by the flooding regime with rainfall influencing dry periods.

Inundation occurs when river flows are high enough to overrun riverbanks, enabling water to spread laterally via anabranches and low-lying areas across the floodplain. Heavy local rainfall can also create areas of inundation, but such areas differ from floods in both duration, magnitude and ecological processes. Flood events vary in magnitude; with the peak flow being the primary determinant of the extent of the floodplain that is inundated, which in the past was largely determined by climate. The flow regime of the River Murray is now strongly influenced by extraction rates and modified by construction of levee banks, dams, weirs and locks; and river management that mitigates flood peaks and maintains baseflow rates (Maheshwari *et al.* 1995, Kingsford 2000). These changes have reduced flood magnitude, frequency and duration (Walker & Thoms 1993, Maheshwari *et al.* 1995), and altered the connectivity between riverine and floodplain habitats (Walker & Thoms 1993, Kingsford 2000).

The duration of inundation is an important characteristic of floods, because it affects terrestrial and flood-tolerant communities' persistence or mortality, with terrestrial communities being less likely to persist the longer the period of inundation (Siebentritt *et al.* 2004, Gehrig *et al.* 2015, Nicol & Ganf 2017). As well as species differences in tolerance to inundation, the age of the plant can be important. Mature flood-tolerant red gums have been observed to cope with continuous periods of inundation for 2-4 years (Roberts & Marston 2000), but seedlings and young plants can be susceptible to water stress and immersion. When the period of inundation exceeds the tolerances of species, mortality of individuals occurs and at the most extreme the loss of the community. Such flooding disturbance events result in the release of nutrients and creates an opportunity for the establishment of new communities.

The exchange of carbon, nutrients and propagules between the river and floodplain, which occurs during flooding, is an important driver of community dynamics in both the floodplains and the river (Jensen 2008, Furst 2013, Wallace & Furst 2016). Woodlands were found to be the most important floodplain source of organic matter on the Chowilla floodplain, but livestock grazing may have reduced the importance of shrub communities by reducing biomass during inter-flood periods (Wallace & Furst 2016). The exchange of nutrients between the floodplain and the river is an important ecological process, but when this is created in non-flood periods, there can be issues with blackwater events, which occur when the rapid metabolism of carbon deoxygenates the water column. These events can degrade macroinvertebrate and fish populations (Baldwin & Wallace 2009). The timing (cooler conditions reduce chances of blackwater), antecedent conditions of site (long inter-flood periods increase potential for blackwater) and the relative level of return-flows to river flows (dilution by higher river flows) can all reduce the risks of blackwater events (Baldwin & Wallace 2009).

The duration of inundation is governed by floodplain attributes including topography, soil structure, vegetation composition and distribution, seasonal conditions, and interactions with groundwater. Topography determines storage capacity of low-lying areas (e.g., wetlands), and the way in which water flows across the floodplain. In lower Murray floodplains, the extremely low relief means small impediments can alter the pattern of surface flow and even sedges or lignum can impede the rate of surface outflows and trap organic material. Seasonal conditions determine rates of evapotranspiration, and in arid and semi-arid regions, have a significant influence on how long water remains on the surface. Finally, the duration of inundation can be influenced by the interaction between surface water and groundwater. Areas of the floodplain where water remains the longest (e.g., wetlands) tend to occur at low points in the landscape where heavy-textured soils (e.g., clay) have low hydraulic conductivity that impedes water movement between the surface and groundwater (Jolly *et al.* 2008). Conversely, permeable soils (i.e., sand or relic gravels) increase surface-ground water exchange and can result in features lie freshwater lenses (Jolly *et al.* 2008). Since floodplains are characterised by complex patterns of geomorphology, sediment distribution, soil type and historic geological features the interaction between surface water and groundwater can vary substantially over small spatial scales (tens of metres).

Long-lived perennial plants such as the floodplain trees, red gum, black box and coobah, increase vegetative growth and increased fruiting during floods and high rainfall periods, which then affects germination and recruitment in subsequent flooding events (Jensen 2008, George 2004). However, recruitment is not solely dependent on an adequate flood to allow germination, but must be followed by another flood or adequate rainfall to maintain the seedlings until they develop adequate sinker roots (George 2004, Jensen *et al.* 2008). Not only is the length of the sinker roots critical for survival, but also the height of seedlings is critical to surviving immersion from the next flood. If conditions between floods favour rapid growth, the seedlings will stand a better chance of persisting the next flood. Factors, such as salinity, can slow seedling growth altering the flood regimes suitable for species subject to this change in soil chemistry.

The previous state of the system and seasonal conditions will modify a flood-induced response of species. Factors influencing the previous state of the system include the condition of persistent propagules in the soil, stress of organisms, soil nutrient levels and soil structure (e.g., presence of cracking) and salinity. The longer the inter-flood period, the worse antecedent conditions are and the poorer the response the community will have to a flood event, as plants under high stress have less ability to respond to favourable conditions (George 2004, Jensen *et al.* 2008).

Biotic and Abiotic Interactions

The condition and persistence of floodplain vegetation is primarily driven by the availability of soil moisture. Shorter-lived elements are also affected by the frequency of flood disturbances that generate mortality of terrestrial components and resurgence of flood-dependent species (see flooding); and how this process interacts with total grazing pressure that modifies species composition, community structure and productivity (Appendix V).

Long-lived deep-rooted perennial vegetation, which persists through flood disturbances and non-flood periods, is strongly influenced by the interaction between rainfall/flooding frequency and magnitude (Figure 2), depth to groundwater and soil salinity (Figure 3). These processes are in turn influenced by soil type, geomorphology and groundwater salinity. The consequent complexity in conditions can be spatially variable even at small scales of metres (Telfer 2015). The recruitment of new cohorts of long-lived species is dependent on the frequency and duration of floods, post-flood conditions (see flooding), and the level of grazing pressure on germinated seedlings and developing recruits. Other factors, such as soil salinity, can interact with these primary factors making seedlings more sensitive to inadequate conditions for recruitment. For example, salinity reduces the growth rate of red gum seedlings, which means they can be smaller when subsequent floods occur, and this makes them more susceptible to mortality due to inundation stresses (see flooding).

The dynamics of terrestrial understorey vegetation within less-frequently inundated floodplain woodlands (e.g., uplands and sand dunes: see Appendix IV) is driven by two ecological processes. The disturbance generated by flooding, kills terrestrial understorey plants and resets the community structure and composition post-flood (Siebentritt *et al.* 2004, Gehrig *et al.* 2015, Nicol & Ganf 2017). Facilitation by woodland trees affects the survival of plants during periods of low soil moisture generating a mosaic of species composition between areas under the canopy and those in open patches between the canopies of trees (Gehrig & Nicol 2010, Cale 2014, 2016, 2018). These two processes interact to generate a spatially and temporally variable understorey community within these woodlands.

Aquatic faunal communities in both the river and the temporary wetlands of the floodplain are strongly influenced by lateral hydrological connectivity generated by high flows and the water quality of these flows (Furst 2013, Roshier *et al.* 2001, Brandis *et al.* 2009), but reduced by impediments to this lateral flow (e.g., levee banks, silting of channels due to reduced flood frequency). Terrestrial fauna dependent on the floodplain is also strongly influenced by lateral hydrological connectivity as this generates the habitats these species depended on (e.g., cracking clays for paucident planigale, healthy floodplain woodlands for regent parrots and brush-tailed possums), but they are also influenced by total grazing pressure—which modifies these habitats—and introduced predators—that add additional population stress during periods of recovery or persistence during drought.

Use of the model for management

This conceptual model is a description of how processes affect the availability of water in the system and how species respond to this pattern of availability. Its value to management, therefore, is to provide potential avenues for manipulating water availability and distribution for the benefit of facilitating recovery and/or restoring lost components of the system.

There are three ways in which water availability and distribution, or a species' response to this pattern can be manipulated. The first is by increasing water availability. Environmental watering is an obvious means of achieving this goal. However, it is not the only means. Many cost-effective approaches revolve around manipulating modifiers of water availability such as improving the lateral connectivity between the river channel and the floodplain by managing flow barriers. Flood water is not the only source of water on the floodplain, rainfall is also very important for many upland communities or during periods of lower flow. Management to improve the capture of rainfall by the system, through managing soil dynamics and vegetation community structure, improve water infiltration and reduce run-off. Water quality management is also an important component of enhancing floodplain water availability, because salinity effectively reduces water availability.

The second form of management is to influence the ecosystem response to available water by reducing other stresses on a species or system. The greatest opportunities for this on the Calperum floodplain is through the management of total grazing pressure. Other options include reducing competition from introduced species and improving landscape structure and composition to enhance features or species that provide essential ecological services, such as facilitation, pollination and seed dispersal. Finally, recovery can be enhanced by managing processes that increase a species' capacity to persist through periods of water stress or respond when water availability improves. Improving soil structure and stability is an important means of enhancing seed germination and reducing the loss of soil seed banks through erosion. For fauna, managing predation pressure and habitat decline due to over-grazing or water stress are important means of generating resilience in populations.

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Appendix IV

Mapping of Floodplain Woodlands

Introduction

Woodlands cover almost half of the Calperum floodplain and are therefore a spatially significant ecological component of the ecosystem. However, these woodlands are also functionally significant to the floodplain ecosystem; affecting hydrology, channel stability and geomorphology, and generating habitat components for floodplain plants and animals through effects on micro-climate and the provision of specific habitat resources. Laurance *et al* (2011) argued that these floodplain trees were key 'framework' species for the Murray-Darling Basin floodplains. Consequently, due to this reliance on floodplain woodlands, floodplains were at a high risk of crossing an ecological tipping point into an alternative ecological system. Therefore, threats to red gum and black box should be considered of great significance in the risk of dramatic ecological change on the Calperum floodplain.

Aim

The purpose of this mapping is to describe the distribution of woodlands on the Calperum floodplain in relation to ecological processes. This provides the basis for determining the threats to specific woodland patches and the potential management options to address these threats.

Approach

The distribution and characteristics of woodlands across the Calperum floodplain were digitised in ArcGIS from aerial photography and then refined by ground truthing. The mapping was based on mature trees only, but included both live and dead individuals. The presence of juvenile trees was also recorded, but mapped separately. This base mapping was then used to define patches of woodland with similar ecological characteristics (see Table 1).

Woodland patches were classified into three communities, mixed woodland dominated by red gum and black box, black box woodland and coobah woodland. This classification was based on live trees, so represents the current community structure, as some mixed woodlands have lost their red gum component and become either black box or coobah woodlands. This change was noted for these patches. Red gum woodlands were not defined as a specific community, because they generally occurred in small patches within the mixed woodland community and so their classification was too dependent on the scale of mapping. The dominant tree species was identified in the mixed woodland community to indicate where pure red gum stands could occur. Coobah was a sub-dominant species through large areas of the floodplain, but again the patchiness of this prevented accurate mapping, so it was only identified where it was the dominant species.

The spatial distribution of trees within each woodland patch was broadly classified as closed, open and sparse. Tree distribution varied substantially across broad areas of woodland forming a continuum of spatial patterns, so only substantial, consistent shifts were mapped, and these patches should be seen as having fuzzy boundaries. The spatial distribution was first determined using only live trees and then an historical spatial distribution was defined using both live and dead trees to indicate areas of significant change.

Floodplain communities are strongly influenced by geomorphology and soil type. The floodplain is dominated by clay and sandy soils, but many areas have variable quantities of both. However, the distinction between predominantly clay and sandy soil types is still a useful description of parts of the floodplain as they respond differently to flooding and groundwater hydrology (Appendix III) and support different plant and animal communities. Clay soils occur in low lying areas that are frequently inundated, while sandier soils can occur as high banks along some channels, as broad shallow rises across the floodplain or as deeper sand dunes.

The geomorphic characteristics of each woodland patch was classified primarily on its relationship to river and wetland banks and flats and dunes across the floodplain. However, additional characteristics (soil type and the frequency of inundation) were also collected to refine the geomorphic characteristics of each patch. These characteristics are interrelated (e.g., the soil type of dunes is always sand), but when combined generate finer categories that are likely to have relevance to the ecological response of the plant community in the patch.

Table 1: Ecological characteristics used to classify woodland patches, and the methods used to derive them in the mapping process.

Characteristic	States	Method
Primary Ecological Classification		
Dominant Tree Species	Red gum/black box, black box, and coobah	Ground-based assessment
Tree Spatial Distribution	Closed, open and sparse	Aerial photography
Geomorphology	Channel/wetland banks, flats and dunes	Aerial photography and digital elevation model
Additional Characteristics		
Current State	Category 0-5	Ground-based assessment and aerial photography
Age Structure	Mixed age cohorts, single age cohort, presence of recent recruits	Ground-based assessment
Soil Type	Clay and sand	Ground-based assessment
Inundation frequency	Riparian, regular flood zone and infrequent flood zone (uplands)	Digital elevation model & flood models

A healthy floodplain woodland has trees in a wide range of states from dead to healthy mature individuals. The state of any given tree within healthy woodlands will vary in condition through time depending on changes in environmental conditions (e.g., drought, post-flood period), but will remain fundamentally 'healthy' until it starts to decline with old age. These changes in condition are important to the ecology of the woodlands, but from a management perspective are of secondary importance, because they are normal variation in a dynamic ecological system. Management is interested in long-term directional change in state that will likely result in a fundamental change in the ecological character of the woodland patch and ultimately the loss of the woodland's ecological function. Woodland patches subject to these circumstances will have more dead trees than would be expected from normal mortality levels; and more live trees that show the results of extreme periodic stress, such as large proportions of permanent canopy loss. These were the characteristics used to define the current state of each woodland patch (Table 2). The focus on the proportion of live and dead trees was used to indicate the change in state over long timeframes, with sites containing more dead than live trees being in a poor long-term state than those with few dead trees. The state of living trees focused on their broad health (overall proportion of potential canopy permanently lost from past stress events) not the immediate condition such as that used in tree condition assessments processes.

Black box cannot be reliably aged from trunk diameter or tree height and so the age structure of the floodplain woodlands is not well understood. However, most woodland patch types had a range of tree states consistent with different age cohorts, but some showed little apparent age structure, and many showed no signs of recent (last two floods) recruits. These characteristics were broadly classified in the age structure character.

Table 2: Classification of woodland patch state used in the floodplain mapping.

	'Degraded' woodland		'Stressed' woodland		'Healthy' woodland	
	0	**1**	**2**	**3**	**4**	**5**
Population state	*Trees dead*	*Most trees dead*	*Equal dead and live trees*	*Equal dead and live trees*	*Most trees alive*	*Most trees alive*
Tree State		*Live trees poor-good state*	*Live trees poor-moderate state*	*Live trees moderate-good state*	*Live trees poor-moderate state*	*Live trees moderate-good state*

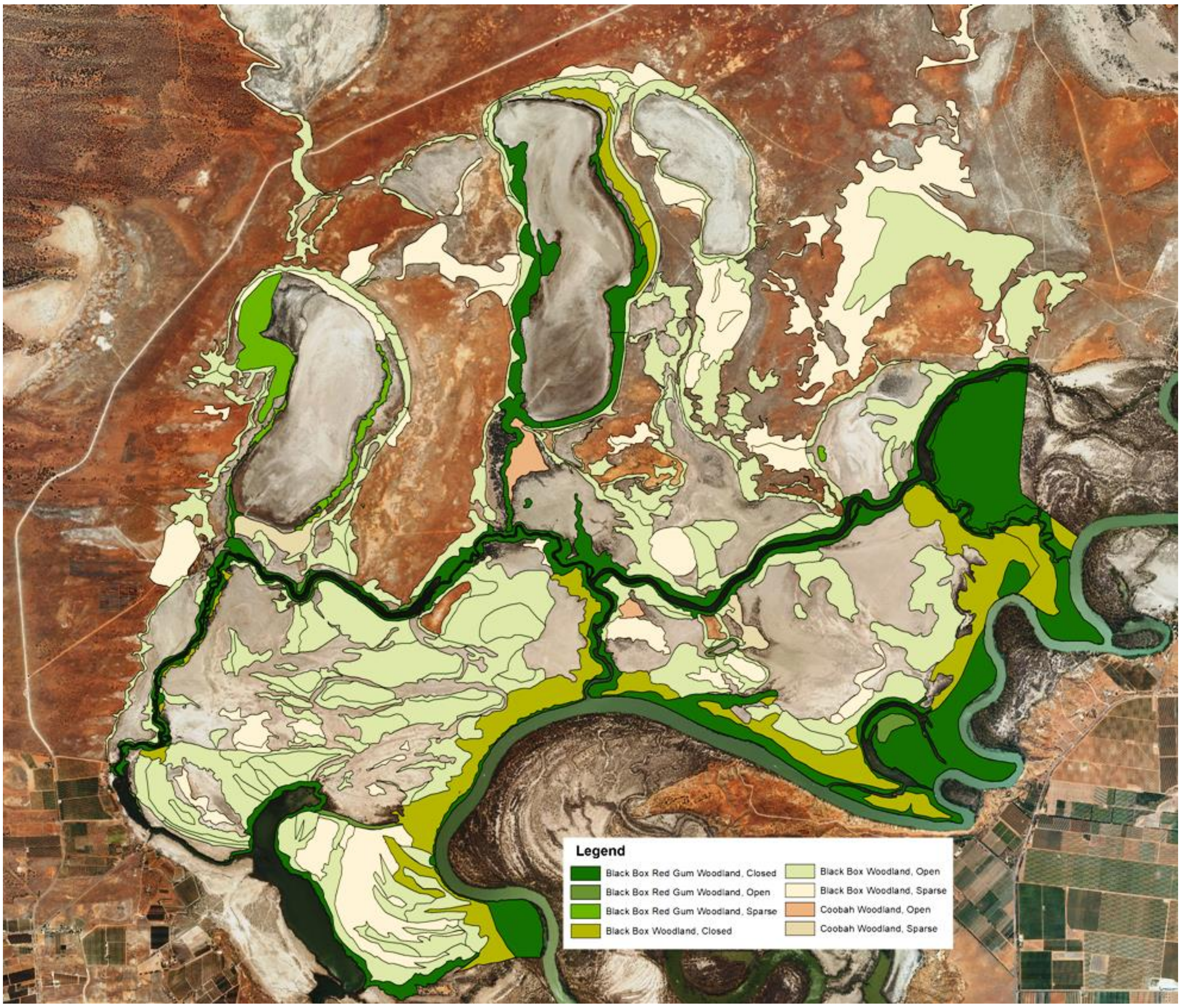
Results and Discussion

Woodland communities cover 3,789ha (45%) of the Calperum floodplain (Figure 1). Most of these woodlands are dominated by black box (2,851ha 75%), while mixed red gum/black box woodlands cover 883ha (23%) and coobah woodland covers only 55ha (2%). Floodplain woodlands occur on most floodplain substrates including clay (27% of woodlands), sand (29%), riparian clay/sand mixes (26%), and a range of clay/sand upland soils (18%) (Table 3). These broad woodland types occur in patches with similar ecological characteristics such as geomorphology, soil type and the frequency in which they are inundated. Consequently, it is expected that they will support similar biological communities and require similar management strategies to protect and/or restore them.

Table 3: The extent of floodplain woodland communities on the Calperum floodplain. Percentages are the proportion of that community in each floodplain substrate.

Community		Extent	
Black Box Woodland	Riparian	295.9	10%
	Clay	928.2	33%
	Dune	941.1	33%
	Upland	685.6	24%
Black Box Red Gum Woodland	Riparian	671.7	76%
	Clay	53.7	6%
	Dune	157.1	18%
Coobah Woodland	Clay	55.1	

Figure 1: Distribution of floodplain woodland communities across the Calperum floodplain.



Black box woodland is the most diverse floodplain woodland, occurring across a wide range of geomorphic and soil substrates (Table 3). On wetter, clay sites coobah is a common sub-dominant tree species and has a lignum understorey. There appears to be several areas of sparse black box woodland that likely had a cane grass, *Eragrostis australis* understorey, but most are degraded and have lost this understorey community. These black box on clay sites have soils that can form the unique cracking clay substrates that allow for rapid water infiltration and are important faunal habitat. Clay flats in upland areas support more open black box with a shrub understorey, dominated by *Atriplex* spp. and other chenopods. Upland clay areas, with or without woodland elements, appear less resilient than other clay areas to erosion when over grazed. This erosion exposes sodic sub-soils that form hard scalds that resist vegetation recovery.

Black box woodland on sandier soils support a wider diversity of shrub species, but in more frequently inundated areas the understorey becomes more open with herbaceous species including pigface, prostrate *Atriplex* spp. and *Maireana* spp. Black box woodland also occurs on floodplain sand dunes. This community has a mosaic shrub layer with a diversity of chenopods under the tree canopy and a more open lower shrub/herb community in open areas. Sand dunes are susceptible to wind erosion when the associated understorey vegetation is reduced by over-grazing and/or extreme drought. This erosion frequently exposes sub-soils that form scalds resulting in poor vegetation recovery.

Red gum/black box woodland occurs primarily as riparian vegetation associated with the river, its anabranches and the frequently inundated Lake Merreti and Lake Woolpolool (Table 3). Where it occurs on sand dune and clay systems, they are in areas that were hydrologically similar to the riparian zone, with frequent inundation. The woodland has two primary forms one dominated by red gum—mainly associated with wetter areas—the other a more even mix of both eucalypts that occurs on higher riparian banks (i.e., less frequently inundated) and/or sandy riparian and dune areas. Both communities have coobah as a sub-dominant. Some mixed woodland patches have lost their mature red gums becoming either black box or coobah dominated communities. However, a number of these sites have red gum recruits from recent floods (i.e., 1990, and 2011-12) and are recovering their mixed woodland status.

The understorey in this mixed woodland is variable depending on the soil and the frequency of inundation. Drier and/or sandier sites support a shrub understorey, while frequently inundated, clay sites have either a lignum or grass/herb dominated understorey. The soils occupied by mixed woodlands are generally resilient to both wind and water erosion because they have little slope and form stable bio-physical crusts when vegetation cover is limited.

Coobah is generally a sub-dominant tree with red gum and black box, but there are some coobah-dominated woodlands (2% of woodlands). These woodlands are in areas of low-lying clay that would have been frequently inundated, but not frequently enough to support red gum woodland. These woodlands generally support a lignum understorey. On Calperum most of this community has declined, as the frequency of inundation has declined causing both inadequate soil moisture conditions but also increased soil salinity. The result is not just the loss of the woodland canopy, but also the lignum understorey. Consequently, these woodlands have transitioned into a samphire-dominated low shrubland and the historic extent of coobah woodland is probably under-estimated in the current mapping.

The state of woodland patches varies with the ecological unit occupied (Figure 3). Most riparian woodlands are in good health (51%, score 5), while woodlands on clay flats and sand dunes have only 5% and 2% of trees in the healthiest state (Figure 2). These patterns differ, however, for different woodland communities. Red gum/black box woodland occurs rarely on clay flats (6%) and most of this community is dead, while red gum/black box woodland growing on sand dunes (18%) is all in moderate condition (state 3). Coobah woodland is now only recorded on clay flats and 80% of it is in a degraded state, while the remainder is stressed.

Figure 2: The relative proportions of all woodland patches in different states on different ecological units. See Table 2 for an explanation of the patch state scores.

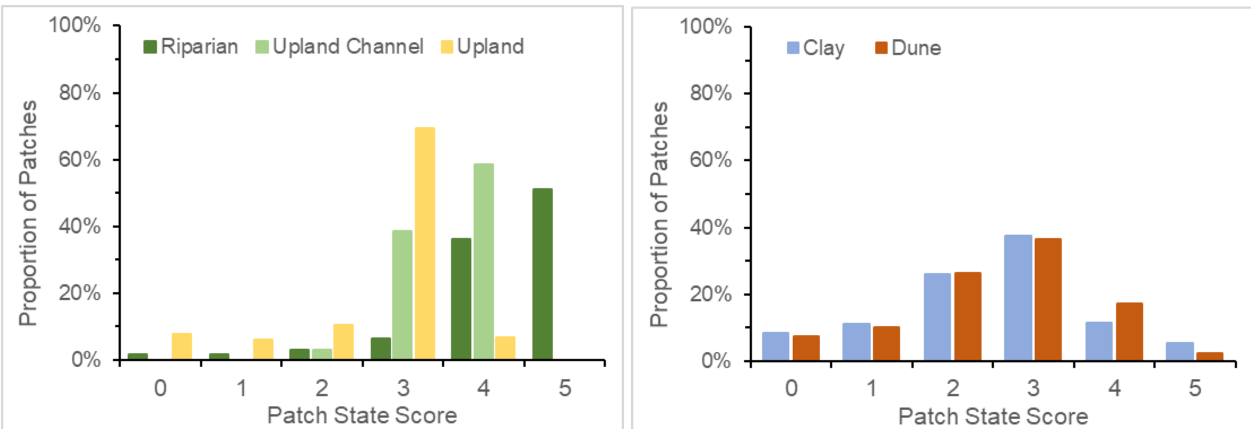
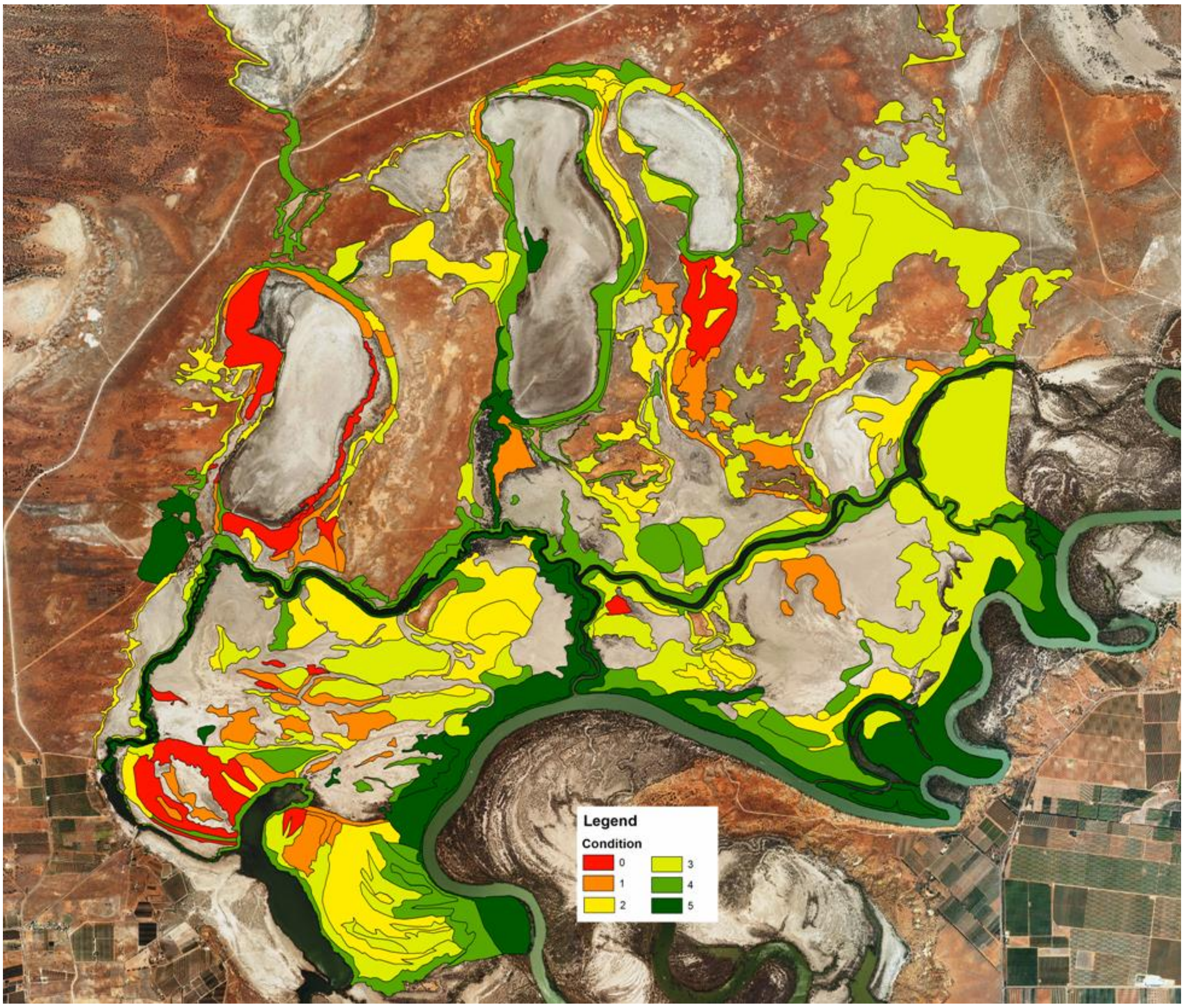


Figure 3: The state of woodland patches across the Calperum floodplain. See Table 2 for an explanation of the patch state scores.



Black box woodland occupies the broadest range of ecological units. As with all woodlands, black box woodlands in the riparian ecological unit are generally healthy (72% score 4 & 5), but have more stressed patches (25%) than red gum/black box woodlands. This reflects the greater distance from river channels and lake shores that black box will grow in this ecological unit. Most black box woodlands occur on clay flats and sand dunes (66%) and in both ecological units the general state of these woodlands is poorer than for the riparian zone (Figure 4). The clay flat ecological unit shows the greatest stress for black box woodlands, with 82% of patches in a stressed or degraded state compared to 64% of patches on sand dunes. Black box is the only woodland community to occupy upland areas and in these ecological units it is in a slightly better state along the upland channels (Figure 3).

The differences in woodland state between ecological units is related to the primary drivers of soil moisture availability in these different systems (Appendix III). Riparian zones are frequently inundated and are recharged from river channels and lakes, so they support healthy woodlands. The recharge generally declines with distance from the channel (Lamontagne *et al.* 2005, Holland *et al.* 2009), although this is modified by soil type and other geomorphic factors such as underground paleochannels that allow for greater soil and ground water movement. Therefore, as was observed in riparian black box woodlands, the health of riparian trees would also be expected to decline further from the water source, as they become more dependent on floods than recharge to replenish soil moisture. Clay flats and sand dunes in the same part of the floodplain will be affected by similar flooding frequencies, but dunes will also have higher soil moisture replenishment from rainfall between floods, because of the greater infiltration through sand than clay. Upland ecological units only receive soil moisture from large floods and so are driven more by rainfall events, but woodlands on channels would receive greater inputs from floods and as these channels also generally have sandier soil types they are likely to have better soil moisture reserves than the flatter upland areas. This is reflected in the better state of these woodland patches on Calperum and suggest that simulating floods through these channels may increase the persistence of these woodlands.

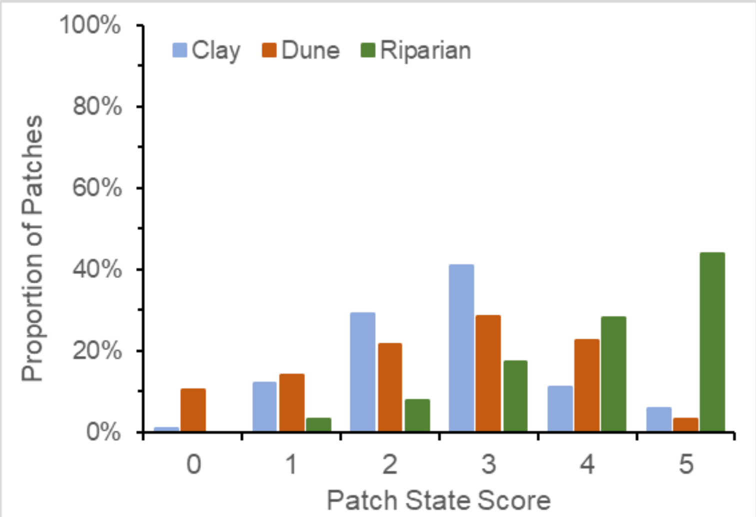


Figure 4: The relative proportions of black box woodland patches in different states on different ecological units. See Table 2 for an explanation of the patch state scores

The interaction between floods and substrate is not the only factor driving the availability of soil moisture. Soil salinity reduces available soil moisture by limiting access to the water dependent on the tree's salt tolerance (Thorburn *et al.* 1995, Bramley *et al.* 2003), and ground water is another source of water if it is sufficiently fresh to be used. Groundwater can also increase soil salinity when it is saline and close to the surface, and floods are not available to flush out accumulating salt (Appendix III). Overton *et al.* (2017) found no relationship between black box tree condition and a combination of soil salinity and groundwater depth. This is not surprising, because these two characteristics interact with the substrate and the frequency of flooding to generate conditions that can stress black box trees. When woodland state in different ecological units is compared to high soil salinity and shallow saline groundwater it is clear that woodlands on clay flats are in greater stress than adjacent sand dune woodlands, because the dunes increase the depth to the groundwater, increase the capacity to flush salt from the sandy soil and are better supported by rainfall events because of increased infiltration. These two ecological units are therefore likely to respond differently to environmental watering or require a different watering regime to generate the same response in health.

The risk assessment conducted by Overton *et al.* (2017) identifies important potential areas for management, and when combined with the woodland ecological units mapped here specific management options can be identified. This is the basis of the management for woodland communities proposed in the current plan.

The health of mature trees is not the only factor that needs to be considered when assessing the long-term persistence of woodlands. Recruitment of new cohorts of trees is also an important requirement of a sustainable woodland. Tree recruitment has still not been adequately mapped on the Calperum floodplain. It is clear from the current level of assessment that red gum recruitment is high post-floods in every patch of this woodland community, except where soil salinity and shallow saline groundwater occurs. In these patches, recruitment is variable from entirely absent to high densities of recruitment. For black box, recruitment after the 2010-12 floods was moderate to high in riparian areas and clay flats that were inundated by the flood, but there was little to no recruitment on sand dunes in areas that were inundated and no recruitment occurred in upland areas as these were not flooded. The lack of recruitment on sand dunes is likely the result of two interacting factors: 1/the repeated floods from 2010 to 2012, which supported the establishment of black box seedlings by maintaining high soil moistures, did not occur on many sand dunes as they were dry during the lower flood peak in 2012; and 2/ grazing pressure from kangaroos and rabbits immediately after the recession of the floods removed many potential recruits. The negative affect of this interaction on recruitment was supported by plantings of black box and coobah on the recession of the 2011 flood. These plantings were protected from grazing by guards. Trees planted high on the dune were less successful than those near the dune's base, and all were heavily grazed, but persisted because the guards prevented total defoliation. Further, those at the base of the dune took less time to grow to a height where grazing no longer threatened their survival, and when guards were removed in 2014-15 many smaller saplings failed due to further defoliation by kangaroos.

Appendix V

Total Grazing Pressure on the Calperum Floodplain

Introduction

Since the removal of livestock from Calperum Station in 1993-94, grazing pressure on the Calperum floodplain is primarily the result of rabbits, grey and red kangaroos and occasionally feral goats. Feral pigs are also present on the floodplain, but their numbers have been reduced to almost zero in the past decade due to ongoing management on the adjacent Chowilla floodplain and control of those animals that enter Calperum.

Spotlight surveys of the entire Calperum floodplain and the adjacent semi-arid woodland terraces have been conducted since 2009 and some spotlight surveys were conducted on the floodplain islands between 1996 and 2003. These surveys provide a sound baseline data set to assess the potential total grazing pressure levels occurring in floodplain communities.

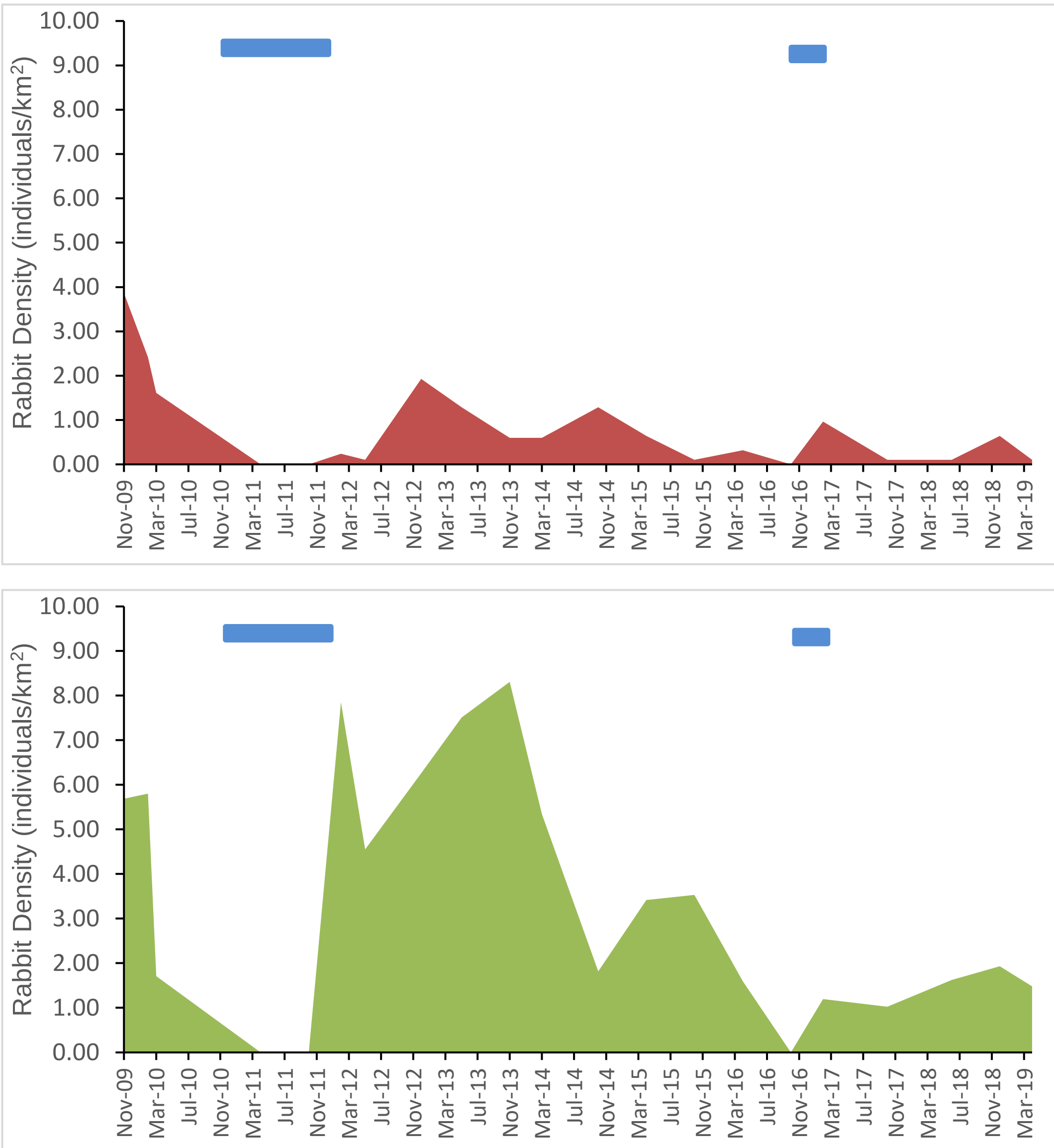
Results and Discussion

Rabbits were considered by Calperum managers as the greatest grazing concern for vegetation communities and consequently management of rabbits, through integrated control (i.e., baiting, warren ripping and fumigation), has been carried out since the 1990s. However, prior to 2010, rabbit control was periodic when rabbit numbers were noticeably high. Consequently, in 2009—despite a prolonged drought—rabbit densities were around 4-6 rabbits/km^2 (Figure 1). In 2010 the semi-arid woodland restoration program set a target of 1 rabbit/km^2 to allow for improved regeneration of Murray pine *Callitris gracilis*, and consistent integrated control of rabbits commenced (Cale 2016). Rabbit densities showed a substantial increase after the 2010-12 flood, and it was not until 2014 that control efforts resulted in a consistent decline in rabbits (Figure 1). Densities in the semi-arid woodland and on the islands have been maintained below the target density of 1 rabbits/km^2 since April 2016, while the lakes area of the floodplain could only be consistently maintained below 2 rabbits/km^2 (Figure 1). The results of this consistent rabbit control were improved recovery of semi-arid woodland vegetation communities and plantings conducted as part of the restoration program (Cale 2016).

The spotlight surveys conducted on the floodplain are not a reliable method for assessing feral goat numbers, because they travel in groups and on the floodplain spend much of their time in the dense riparian vegetation around the lakes. Between 2012 and 2015 the maximum number of feral goats recorded in the spotlight surveys was a group of 30, while from 2016 to 2019 the maximum recorded was a group of 19 animals, while in the adjacent semi-arid woodland densities were consistently twice as high. General observations by staff support this data, suggesting goat density on the floodplain has always been relatively low; and periodic mustering of goats prevents an increase. For example, 4 months of mustering effort on the floodplain and semi-arid woodland in 2018 resulted in only 260 goats being mustered and removed.

Although kangaroo densities were high after livestock had been removed from Calperum (Figure 2: 1996 – 30.4 kangaroos/km^2), the grazing management focus was on rabbits. This was presumably because kangaroos were native species, though the difficulty of separating the effects of rabbits and kangaroos may also have delayed the realisation that over-abundant kangaroos were having serious impacts on vegetation communities. In the SA semi-arid rangelands populations of red kangaroos steadily increased after the 1983 drought, reaching average densities of c.5/km^2, despite an increase in both commercial harvesting and culling (Alexander 1997). In Victorian rangeland national parks kangaroo numbers started to increase dramatically with the removal of livestock in the 1980s, and then the reduction in rabbits due to the release of RCD allowed further increases (Sandell 2011). By 1994, western grey kangaroo density had reached 47/km^2 in the Murray-Sunset National Park (DNRE 1996). With the decline of rabbits as a major grazing pressure, it became apparent that increasing kangaroo density was preventing the expected recovery of vegetation communities (Sandell 2011). This belief was confirmed when kangaroo populations were also managed within these Victorian parks.

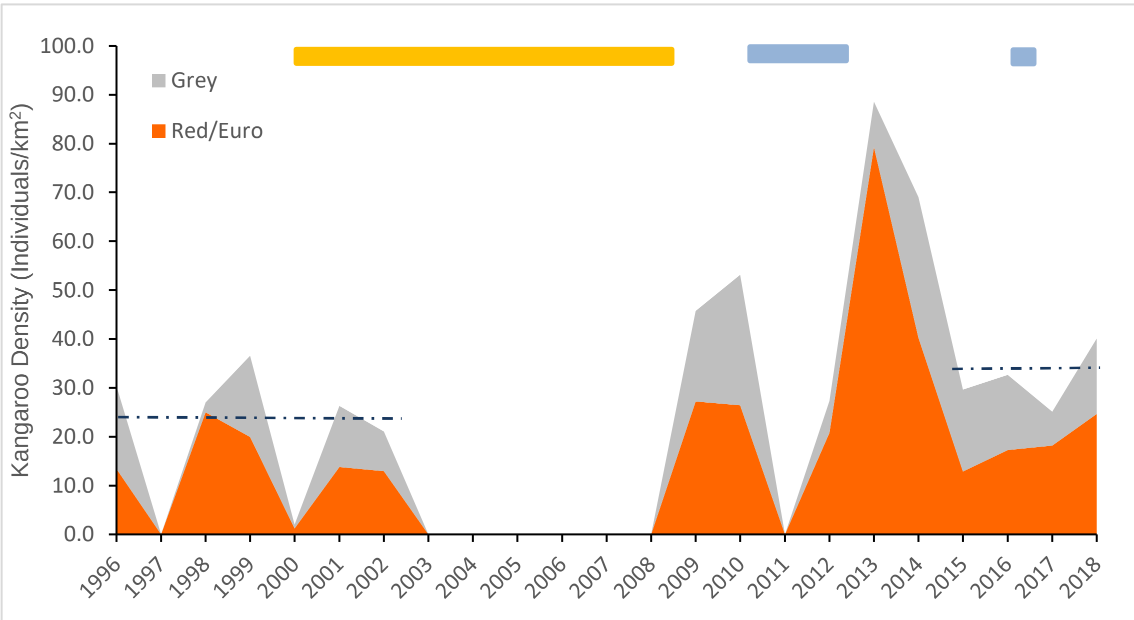
Figure 1: Rabbit density on a) Reny and Hunchee Islands and b) the Lakes floodplain from 2009 to 2019. The blue bars represent the 2010-12 and 2016 floods when much of the floodplain was inundated.



Studies comparing low/high kangaroo density sites, or fenced and unfenced sites found that reduced kangaroo grazing—to between 0-5 kangaroos/km^2—resulted in improved regeneration of a suite of perennial sub-shrubs and herbs—including some rare or threatened plants—and some woody perennial species such as Murray pine *Callitris gracilis*, buloke *Allocasuarina luehmannii*, and hooked needlewood *Hakea tethrosperma* (Sandell 2011). Sluiter *et al.* (1997) showed that kangaroo density was negatively correlated with monocotyledon biomass, and increased browsing by kangaroos of woody plants occurred when grass biomass declined below 400 kg DW/ha. Based on these findings, they argued that non-mallee woodland and shrubland communities could only sustain a kangaroo density of 5 kangaroos/km^2 in high rainfall years (Sluiter *et al.* 1997). At Calperum, the semi-arid restoration program found significant grazing effects from kangaroos on the growth and survival of *Callitris gracilis* saplings that were guarded from rabbits, but not kangaroos or were protected from all grazing in exclosures (Cale 2016).

Kangaroo numbers on the Calperum floodplain islands fluctuated around 20-30/km^2 through 1996-2003, but when surveys were re-established in 2009 densities had increased considerably (45.7/km^2) despite the long drought from 2000-2009 (Figure 2). The flood in 2010-12 saw a major spike in densities post-flood, reaching a peak of 88.6 kangaroos/km^2 in 2013. From 2015 to 2018 a new level was established with densities around an average of 31.9/km^2. The change in densities was observed for both red and western grey kangaroos, but red kangaroos were always more abundant on the islands and their changes in density were more dramatic.

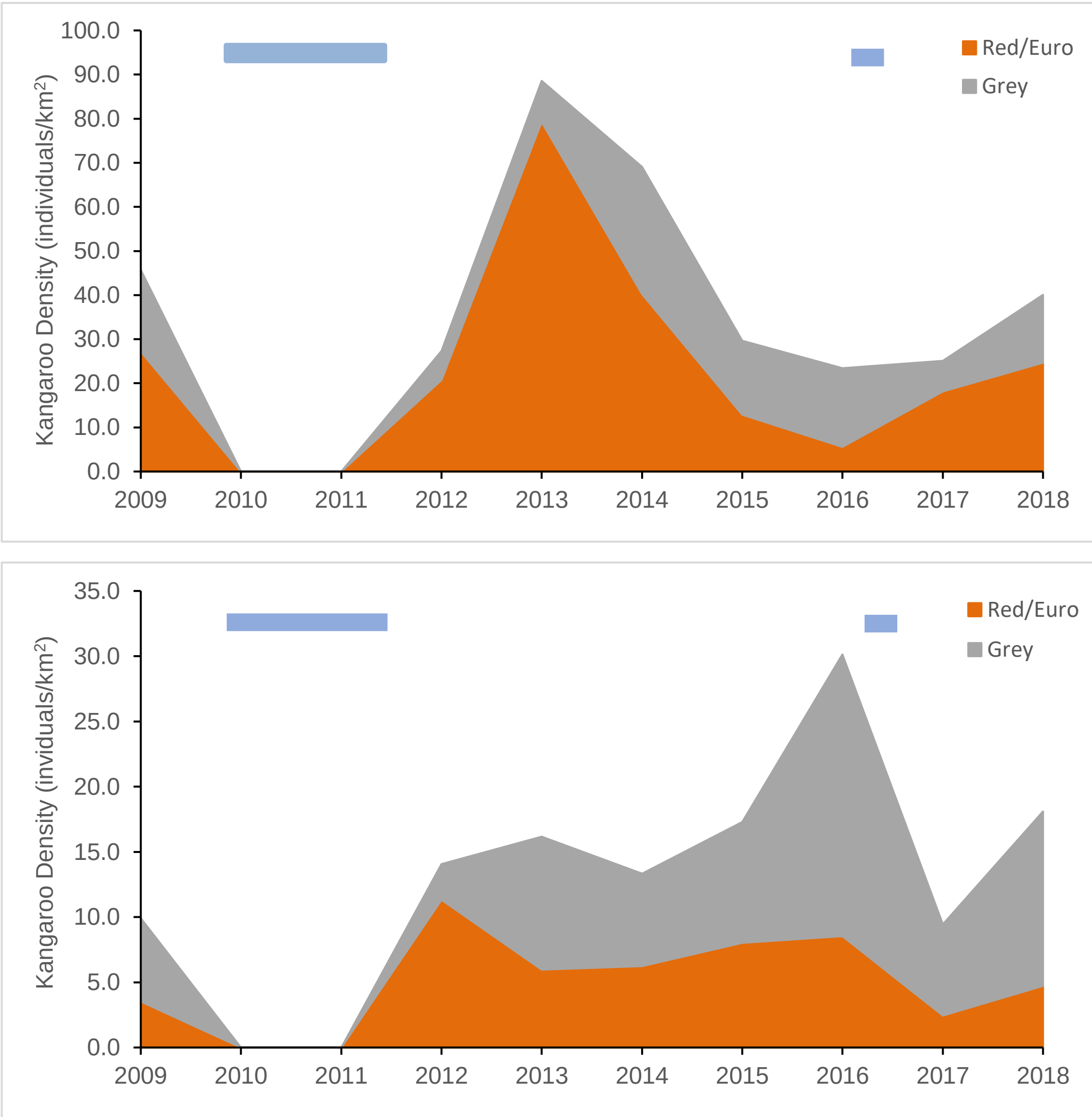
Figure 2: Kangaroo density on Reny and Hunchee Islands from 1996 to 2019. The black dashed lines are the average density for 1996-2003 and 2015-2018 (31.9/km^2). The brown bar represents the period of the millennium drought, while the two blue bars represent the 2010-12 and 2016 floods when the islands were inundated.



Surveys on the lakes section of the Calperum floodplain were not conducted until 2009, and these showed that, although kangaroo densities rose after the 2010-12 flood, densities were substantially lower than on the islands (average 2009-2018: 16.1/km^2 compared to 43.6/km^2). The lake area surveys also showed that the relative abundances of red and grey kangaroos were different between these floodplain habitats. Western grey kangaroos on average represented 59% of all kangaroos in the lakes area, but only 39% on the islands.

Red and grey kangaroos also responded to flooding differently. Red kangaroos showed a rise in density 6-12 months after the floods had receded, and peaks were short in duration (1-2 years) (Figure 3). Western grey kangaroos had a delayed but more sustained response to the 2010-12 flood with a rise in densities 18 months post-flood reaching a peak abundance 3-4 years post-flood. This difference may be due to the more mobile behaviour of red kangaroos, which appear to have increased through dispersal onto the floodplain after the flood. For western grey kangaroos the increase is more consistent with local breeding generating increased densities. The consequence of these different ecological responses is a sustained increase (4-5 years) in total kangaroo density, initially from red kangaroos but maintained by grey kangaroos.

Figure 3: Spring kangaroo density on a) Reny and Hunchee Islands and b) the Lakes floodplain from 2009 to 2019. Note the difference in density scale. The blue bars represent the 2010-12 and 2016 floods when much of the floodplain was inundated.



Grazing impact on vegetation communities

The effect of these very high kangaroo densities on the floodplain vegetation communities at Calperum is being assessed using exclosures that reduce kangaroo activity within them. Most of the exclosures are associated with environmental watering sites, which generate vegetation responses more similar to flood conditions than dry floodplain conditions. One site, however, is a long-term exclosure on a sand dune, which is rarely floods.

A floodplain herbfield had greater cover (Figure 4) and a more diverse species composition within exclosures than in adjacent areas open to grazing (Table 1). These differences occurred in the three sites that received environmental water in 2018/19 (Reny 2-4) and in the site that has not been inundated since the 2010/11 flood (Reny 1). Most annual species were more abundant in the watered sites, especially *Calocephalus sonderi,* an annual daisy, which dominated the annual component of sites 2 and 3 inside exclosures. However, where these areas were subject to grazing from kangaroos this species is completely absent. *Calocephalus sonderi* is listed as Rare in South Australia and represents a group of species that could potentially be at risk of local extinction due to grazing; as they emerge from soil seed banks after floods and/or heavy rains, but germinating seedlings are generally consumed before they produce new seeds. Only after large floods, when numerous plants emerge over such large areas, does this species set good quantities of seed, because grazing pressure is insufficient to remove them all. However, local emergence and continued removal by grazing will eventually deplete soil seed banks reducing mass germination during large floods. Consequently, these plants are at risk during environmental watering as the localised watering sites concentrate kangaroos on the resulting high vegetation biomass, generating very high grazing pressure.

Another clear outcome from the high grazing pressure in this herbfield is the increased abundance of some unpalatable introduced species, such as *Mesembryanthemum nodiflorum*. This weed was the dominant cover in the control areas at Reny Site 2 & 4 and can suppress the germination of native species, because it emerges early, quickly establishes, and, because it is not suppressed by grazing, can completely cover the ground.

The vegetation condition within the Reny Island dune exclosure (Table 2) suggests that although the larger, woody components of the vegetation are somewhat resilient to the long-term consequences of high grazing pressure, smaller, herbaceous plants and in particular ground covers are severely affected. In this site, which has been protected from kangaroo grazing for 12 years, three species of native grass are significant components of the ground cover, but outside of the exclosure are completely absent (Figure 5). Herbaceous ground cover species, except *Bulbine semibarbata,* are also entirely missing from the vegetation assemblage when subject to current grazing pressure. *B. semibarbata* is a small, annual plant that, although often very abundant, has little capacity to cover the ground or stabilise soils. The result of these grazing induced changes is a vegetation community with little vegetation covering the ground, which on sand dunes results in the potential for high levels of wind erosion. This erosion exacerbates the structural changes in the community, because when sub-soils are exposed, they form scalds that prevent germination of any plant species including larger shrubs and trees. This erosion also degrades indigenous heritage sites, which are particularly abundant on floodplain sand dunes.

Introduced plants also respond differently to differing grazing levels. Two weeds, wild turnip and barley grass, were only present within the exclosure, while four species were absent from the exclosure (Table 2). Wild turnip, *Brassica tournefortii,* and barley grass, *Hordeum glaucum,* are heavily grazed by kangaroos, while onion weed, *Asphodelus fistulosus,* and Arabian grass, *Schismus barbatus,* are less palatable. Onion weed and matchhead, *Psilocaulon granulicaule,* are opportunistic weeds that benefit from disturbances that create gaps in vegetation cover. The abundance of wild turnip and barely grass within the exclosure also indicate the problem of total grazing exclusion, because these species can dominate areas to the detriment of native species if not kept in check by some grazing pressure.

Table 1: Species composition, 4 months after the 2018/19 environmental watering, in 5mx5m exclosures and grazed controls on Reny Island (established in June 2017). These sites should support an annual herbfield with open low perennial shrubs. **I** – indicates an introduced species. Numbers in parentheses are richness of introduced species.

Exclosure	**Control**
Reny Island 1 Not watered	
Atriplex lindleyi	
Calocephalus sonderi	
Duma florulenta	
Native Couch (Species to be identified)	
Bulbine semibarbata	
Sclerolaena diacantha	
Sclerolaena brachyptera	
Senecio glossanthus	*Senecio glossanthus*
Myriocephalus rhizocephalus	*Myriocephalus rhizocephalus*
Mesembryanthemum nodiflorum I	*Mesembryanthemum nodiflorum* I
Species Richness 9 (1)	**Species Richness** 2 (1)
Reny Island 2 Watered	
Calocephalus sonderi	
Myriocephalus rhizocephalus	
Tecticornia indica	*Tecticornia indica*
Mesembryanthemum nodiflorum I	*Mesembryanthemum nodiflorum* I
	Senecio glossanthus
Species Richness 3 (1)	**Species Richness** 2 (1)
Reny Island 3 Watered	
Calocephalus sonderi	
Senecio glossanthus	
Myriocephalus rhizocephalus	
Atriplex lindleyi	
Plantago cunninghamii	
Hyalosperma demissum	
Mesembryanthemum nodiflorum I	
Bulbine semibarbata	*Bulbine semibarbata*
Species Richness 8 (1)	**Species Richness** 1
Reny Island 4 Watered	
Sclerolaena brachyptera	
Calocephalus sonderi	
Goodenia fascicularis	
Senecio glossanthus	*Senecio glossanthus*
Disphyma crassifolium	*Disphyma crassifolium*
	Bulbine semibarbata
	Mesembryanthemum nodiflorum I
Species Richness 5	**Species Richness** 3 (1)

Figure 4: Vegetation cover, 4 months after the 2018/19 environmental watering, in 5mx5m exclosures (right) and grazed controls (left) on Reny Island (established in June 2017). These sites should support an annual herbfield with open low perennial shrubs.

Table 2: Species composition in a 2ha exclosure (established in 2002) and grazed control on a sand dune on Reny Island. This site supports an open black box woodland. Numbers in parentheses are the percentage of total species in the life-form group.

Exclosure		Control	
Canopy			
Eucalyptus largiflorens		*Eucalyptus largiflorens*	
Acacia stenophylla		*Acacia stenophylla*	
Melaleuca lanceolata		*Melaleuca lanceolata*	
Species Richness	3 (100%)	Species Richness	3 (100%)
Woody Shrubs			
Dodonaea viscosa angustissima		*Dodonaea viscosa angustissima*	
Atriplex rhagodioides		*Atriplex rhagodioides*	
Maireana pyramidata		*Maireana pyramidata*	
Enchylaena tomentosa		*Enchylaena tomentosa* *	
Maireana appressa		*Maireana appressa* *	
Salsola kali			
Tecticornia indica			
		Acacia ligulata	
		Olearia pimeleoides	
Species Richness	7 (78%)	Species Richness	7 (78%)
Shrubs/Herbs			
Calotis cuneifolia			
Atriplex leptocarpa			
Sarcozona praecox			
Nicotiana velutina		*Nicotiana velutina*	
Pimelea trichostachya		*Pimelea trichostachya*	
Crinum flaccidum		*Crinum flaccidum*	
		Stemodia florulenta	
Species Richness	6 (86%)	Species Richness	4 (57%)
Ground Covers			
Tetragonia tetragonioides			
Einadia nutans			
Swainsona microphylla			
Polycalymma stuartii			
Sclerolaena decurrens			
Sclerolaena diacantha			
Osteocarpum acropterum			
Actinobole uliginosum			
		Bulbine semibarbata	
Species Richness	8 (89%)	Species Richness	1 (11%)
Grasses			
Triodia scariosa			
Austrostipa sacbra			
Austrostipa sp.			
Panicum effusum			
Species Richness	4 (100%)	Species Richness	0
Introduced species			
Brassica tournefortii			
Gazania linearis			
Hordeum glaucum			
Lycium ferocissimum		*Lycium ferocissimum*	
		Asphodelus fistulosus	
		Psilocaulon granulicaule	
		Heliotropium europaeum ?	
		Schismus barbatus *	
Species Richness	4 (50%)	Species Richness	5 (62%)

Figure 5: Fence-line comparison between the Reny sand dune exclosure (right) and outside the exclosure (left) in August 2019. This exclosure was established in 2002. The control survey was done within the shrub area to the left of the photo.

These small grazing studies indicate that kangaroo grazing pressure is now too high to allow for the recovery of floodplain vegetation communities. Exclosures allow for this recovery, but are not a long-term solution across the whole floodplain, because they cannot cover an adequate extent and they result in virtually no grazing pressure on the vegetation causing other issues for recovery. Exclosures are however, an important tool to assist local recovery and to assess the impacts of grazing pressure and the effectiveness of management to reduce it. Other methods of protecting vegetation from over-grazing, such as branching, are also being investigated at Calperum, but like fencing these are only useful at small scales for specific purposes. The only reliable means of dealing with the issue of over-grazing by kangaroos is to reduce kangaroo densities to more appropriate levels. In Victoria a target of 5 kangaroos/km^2 was set as a mid-term target to allow for vegetation recovery followed by a relaxation of control to allow densities to rise to around 10/km^2 once vegetation has recovered to a state where it can be maintained under the slightly higher grazing pressure (DNRE 1996). This is the approach proposed for the Calperum floodplain.

Management of grazing pressure

Ongoing control of rabbits and goats is likely to maintain these species at densities, where vegetation recovery on the floodplain is possible under the grazing pressure they generate. However, current management of kangaroo densities is not adequate to allow vegetation recovery, in fact it is likely to result in ongoing vegetation decline. Unlike rabbit and feral goat control, however, the objective of kangaroo management is not to eliminate populations, as kangaroos are an essential and desirable component of the ecosystem. Therefore, the management strategy must seek to reduce kangaroos to ecologically sustainable densities, but maintain a population that is not at risk of local extinction through population variability (Hacker *et al.* 2004).

To allow for vegetation recovery on the floodplain a target density of 5 kangaroos/km^2 is considered necessary. To achieve this, kangaroo numbers on the floodplain and semi-arid woodland need to be reduced to one quarter of their current density. However, the abundance of red and grey kangaroos across the floodplain vary. So, to achieve a good ecological outcome specific targets would need to be applied to each part of the ecosystem to maintain similar relative abundances of the species.

Currently harvesting of kangaroos for commercial purposes is conducted on the Calperum floodplain as a means of managing numbers, but the harvest level and targeted animals (i.e., sex ratio, species composition and body size) are not adequate to achieve the desired outcome. It is also clear that the resources obtained from commercial harvesting alone are insufficient to generate the culling target, so support for commercial harvesters will be necessary to reach the target. Kangaroo harvest modelling has found that manipulating the harvest rate and the sex ratio of harvested animals is the most effective means of generating desired population density changes (Hacker *et al.* 2004). Increasing the proportion of animals taken that are female increases the rate of population decline, so an initial higher female harvest rate (i.e., 40% instead of 30%) would facilitate the population decline to the desired density.

Once maintenance of the population at the desired density is the management focus the modelling indicates that a harvest rate of 20% with males comprising 70% of the harvest will achieve target densities with economic viability for the commercial harvester (Hacker *et al.* 2004). This modelling also indicated that appropriate harvest management reduced boom-bust cycles in populations, which is a desirable long-term outcome, as these increase the risks of over-grazing and the local loss of kangaroos. These targets are achievable on the Calperum floodplain and if this program was coordinated across the whole Riverland Ramsar site it would likely be more economically viable.

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Appendix VI

Changes in Floodplain-dependent Fauna

Introduction

The Calperum floodplain has not only seen changes in vegetation. Altered flooding regimes and increased grazing pressure, especially from kangaroos, has also resulted in the decline of fauna that were once relatively common on the floodplain. These species are important because they are restricted to the floodplain within this region and so their persistence on Calperum is dependent on floodplain management.

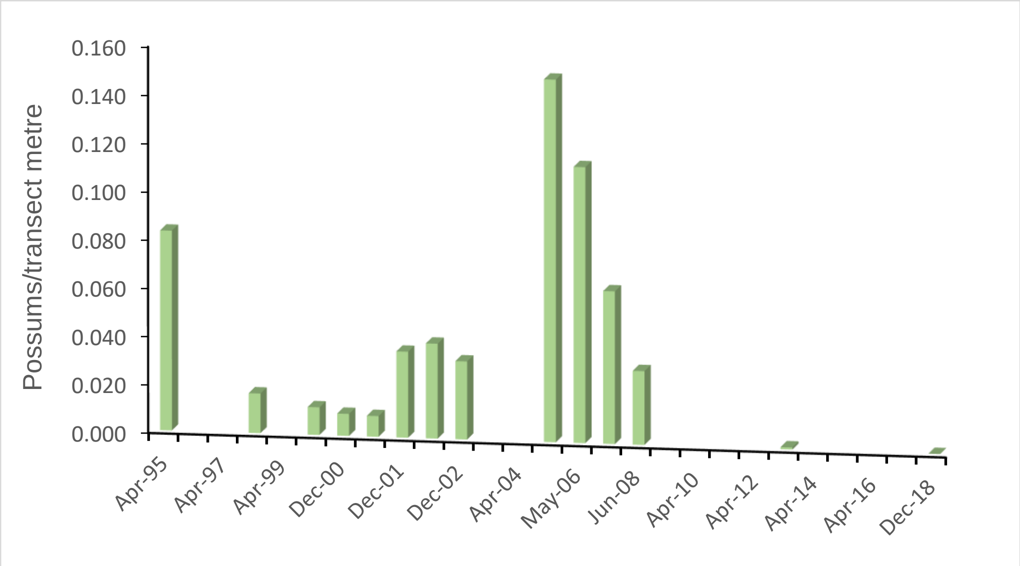
Terrestrial fauna

Common brush-tail possum

The common brush-tail possum *Trichosurus vulpecula* is a medium-sized mammal (1.5-4.5 kg) that is predominantly an herbivore. In the Riverland they are dependent on red gum and black box for hollows used for day roosts and breeding dens. However, they do not survive solely on eucalypt foliage for food, as they are intolerant to the tannins in the leaves, which reduce nitrogen metabolism (Marsh *et al.* 2003). Generally, they feed on a wide range of vegetation from the canopy and the shrub layer, eating foliage, fruits and flowers; and they also include invertebrates in their diet (Evens 1992). Poor body condition has been related to declining food resources during drought and this results in lower breeding rates (Ramsey *et al.* 2002). Recovery of possum populations may be slow, because males are the primary dispersing sex (Stow *et al.* 2006) and in poor conditions a male biased sex-ratio in young occurs (Johnson *et al.* 2001). The result of these two processes is that recovery from dispersal is unlikely as dispersing males contribute little to population viability in the 'rescue' or parent population, and can inhibit it in the 'rescue' population by competing with females for limited resources (Clinchy 1997).

In the Riverland the common brush-tail possum is largely confined to floodplain woodlands and is listed as rare in South Australia (Appendix I). It was considered only near threatened in the Murray Scroll Belt IBRA sub-region (Gillam and Urban 2010). However, survey data from Calperum indicate that, although numbers fluctuate, the population has declined substantially between 2008 and 2013 (Figure 1). The floodplain woodlands in some survey areas have declined in health over the past 15 years and this is a likely cause of the loss of possums from these areas. However, declining tree condition does not explain the population declines everywhere, as in general tree condition across the whole Calperum floodplain has improved since the 2010-12 floods (Appendix IV). Understorey vegetation has declined in many parts of the floodplain since 2012, due to increased grazing pressure mainly from kangaroos, and this has reduced the abundance and diversity of ground strata food resources for possums. Further, the declining understorey vegetation has resulted in a more open ground strata, which is likely to increase the risk to possums of predation by foxes and feral cats.

Figure 1: Changes in the density of common brush-tail possums *Trichosurus vulpecula* on the Calperum floodplain from 1995 to 2018.



Management of total grazing pressure to allow for the recovery of shrub and ground cover communities, along with the maintenance of tree condition is likely to improve the habitat value of the Calperum floodplain for brush-tail possums. Control of feral predators, targeted to areas where possums remain, would increase their capacity to recover when vegetation communities improve. The common brush-tail possum has shown to be sensitive to both canopy and ground vegetation condition and to high levels of predation from introduced species. There population also appears to respond to changes in these ecological characteristics of the floodplain with substantial increases and declines. Therefore, this species is likely to be a good indicator species of ecosystem health for the floodplain. Thus, establishing a reliable monitoring program for brush-tail possums including would assist in managing the species and could be used to assess overall floodplain response to management. Abundance and capture surveys should be used, because the first provides a simple and rapid method of assessing population changes while the latter would allow for measures of body condition and the sex ratio to be collected, which may provide an early warning system for population trajectory.

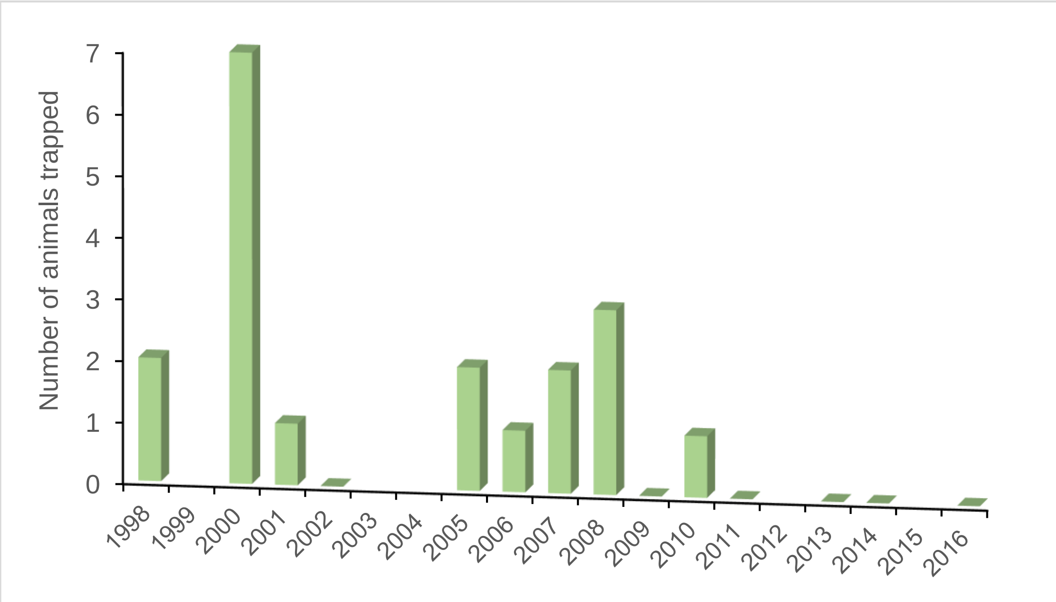
Paucident planigale

The paucident planigale *Planigale gilesi* is a small (5-16 grams) carnivorous dasyurid that lives for 2-3 years. It occurs across much of arid and semi-arid eastern Australia. The population on the Murray River in South Australia is isolated from northern populations in the state, but is continuous with other river populations in NSW. In the arid areas of South Australia, the paucident planigale is associated with drainage depressions, swamps, floodouts and creek channels supporting low open shrublands, sub-shrublands and grassland (Brandle 1998). On the floodplain of the Murray River it occupies lakebeds and clay flats inundated by floods, supporting vegetation communities such as lignum (Bignall 2001). The most important habitat characteristic for this species is large and frequently distributed cracks in the clay substrate where the animals live (Read 1987, Bignall 2001). During floods planigales retreat to shrublands on sand dunes that remain above flood waters. Therefore, the health of these sand dune shrubland communities adjacent to their lakebed habitat is also important for their long-term persistence (Bignall 2001).

Paucident planigales breed at one year old in late winter and mid-summer. In good seasons they may produce two litters, so have the potential to increase rapidly in response to good conditions with population peaks usually occurring in summer (Morton *et al.* 1989). This species manages metabolic stress from high and low temperatures, by entering torpor. This can occur frequently when food was available, but in periods of low food availability torpor is very common (Geiser & Baudinette 1988).

The paucident planigale is not listed as threatened at the state level in South Australia, but Gillam and Urban (2010) considered it to be Vulnerable in the Murray Scroll Belt IBRA sub-region where the Calperum floodplain occurs. Long-term surveys on the Calperum floodplain show that the population has declined substantially with only one caught—a single adult male—in the adjacent semi-arid woodland in 2010 during the flood and no recordings of the species in surveys between 2011 to 2016 (Figure 2). However, the capture of a single animal in October 2019 indicates that the species still occurs on the Calperum floodplain.

Figure 2: Changes in the number of paucident planigales *Planigale gilesi* trapped (pitfall trapping) on the Calperum floodplain from 1998 to 2016.



Management of temporary wetlands on the Calperum floodplain to promote and maintain good cracking clays and the associated vegetation communities, by providing environmental water, is likely the most important action to assist with the recovery of the paucident planigale. To achieve improved vegetation communities on these clay systems a reduction in total grazing pressure will also be necessary. This species needs healthy sand dune habitat adjacent to its wetland habitat to retreat to during inundation, so management of this habitat is also essential. It is possible that the species suffers from unsustainable predation from foxes and feral cats when inundation events occur, because the planigales are more mobile and introduced predators increase in abundance because of the good conditions generated by adding water. This would need to be addressed by control of foxes and feral cats targeted at areas where populations of planigales are recovering.

Bush stone-curlew

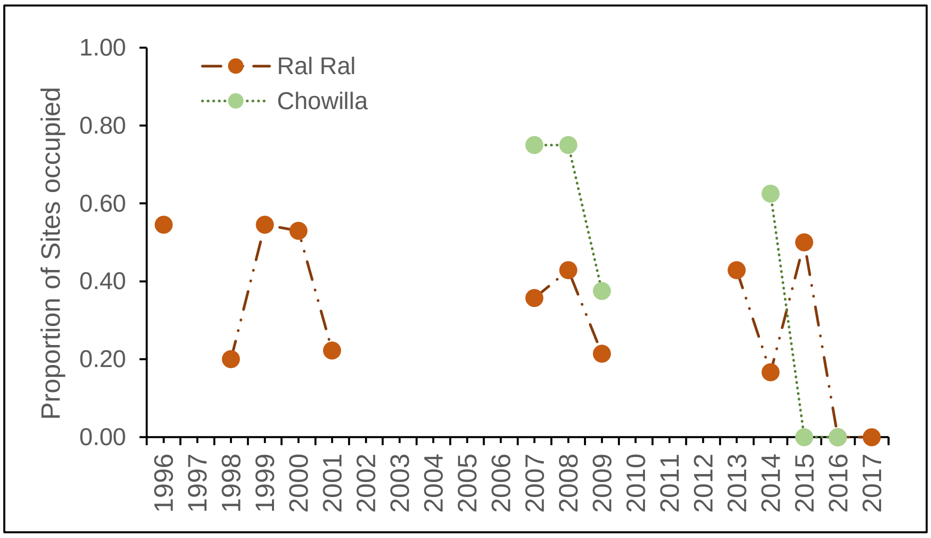
The bush stone-curlew *Burhinus grallarius* is a large (625-670g), long-lived bird. They are ground dwelling, with plumage that makes them extremely well camouflaged. Although it spends most of its time on the ground, it is a good flier and so is capable of long-distance dispersal. They are nocturnal, feeding mainly on invertebrates, but also take frogs, reptiles, small mammals and fruits and seeds (Gates 2001, Treilibs 2006a). Bush stone-curlews are sedentary and territorial, maintaining their territories with their loud and distinctive call. They nest on the ground, often with logs as a form of cover. Although the parents defend their young, the young, like their parents, depend on their cryptic plumage to avoid predation (Gates 2001, Treilibs 2006a). Anecdotal evidence suggests predation by foxes may limit numbers, as Bush Stone-curlews remain common in some areas where foxes are absent (e.g., northern Australia and Kangaroo Island) (Gates and Paton 2005).

It is likely that the degradation of floodplain vegetation, especially the understorey of woodlands, has been a major driver of the decline in bush stone-curlew populations. Not only does this reduce food resources, the more open vegetation also increases the potential for predation from foxes and feral cats on these ground birds. This issue is additionally problematic as introduced predators showed a sharp increase in abundance (based on spotlight data) after the 2010-12 floods.

The bush stone-curlew, which is distributed across most of Australia except the arid centre, occupies a wide range of habitats (Treilibs 2006a). In the Riverland, however, it is almost exclusively found on the floodplain of the Murray River, which somewhat isolates this population from other populations in Australia. Their distribution on the floodplain appears to be concentrated in three areas, the NSW/SA border, the Chowilla floodplain around Coppermine waterhole, and the Calperum floodplain. However, these distinct areas may at least partially reflect survey effort (Treilibs 2006b).

The bush stone-curlew is currently listed as Rare in South Australia, but is considered Critically Endangered in the Murraylands region (Gillam and Urban 2010). Long-term monitoring of this species on the Calperum and Chowilla floodplains has shown substantial annual variation, but indicates a possible decline in the species since 2015, with no recording from the past two surveys on Calperum and the past three surveys on Chowilla. Two opportunistic records, one in December 2017 and one in April 2019, indicate that the species is still present on Calperum.

Figure 3: Changes in the bush stone-curlew population index for the Calperum and Chowilla floodplains from 1996 to 2017.



Waterbirds

The Calperum floodplain has supported 69 species of waterbird at some stage over the past 20 years and at its peak has had up to 38,000 waterbirds (2002: 37,886) on it at any one time (Figure 4). This significant waterbird assemblage is one of the criteria characterising the Calperum floodplain as part of the Riverland Ramsar site (Appendix I). Of the 69 species recorded, 12 were rarely seen; four as they are vagrants in the region, four are small waders that only occasional stop-over in the region and the remaining four use wetland habitats that are rarely available on Calperum. The remaining 57 species are regular visitors when the two major lakes (Merreti and Woolpolool) are inundated. Although there is a high species richness in the waterbird assemblage 13 species (11 ducks, black swan and Eurasian coot) on average comprised 78% of the waterbird abundance at peak periods in Lake Merreti and 69% in Lake Woolpolool. These 13 species make up three of nine functional groups (dabbling and grazing ducks and deep-water foragers) based on the wetland habitats they use (Table 1). Fish-eating species (Piscivores) were the most diverse functional group with 22 species, but on average only represented 6% of abundance in Lake Merreti and 8% in Lake Woolpolool. Small waders were also a diverse functional group, but many species in this group were infrequent visitors to the floodplain. Consequently, this functional group varied greatly in its contribution to peak abundance ranging from 0% to 54% (average Merreti 9% and Woolpolool 13%).

A regional, annual waterbird survey showed a 74% decline across the Murray-Darling Basin in mean abundance of all waterbirds during the first decade (1983-1992) to the last decade (2003-2012). (Kingsford *et al.* 2013). Abundance also declined within each functional group, with shorebirds declining by 76% and large waders by 57%. These declines were also reflected in breeding with the number of species breeding declining by 72%. Species richness however, varied little during the 30-year period. Modelling of this data suggested that these declines in abundance were driven by regional and local changes, but river flow and wetland area were consistently important drivers (Kingsford *et al.* 2013). Most of these changes were between the first decade and the other 2 decades; which also reflected the frequency of floods during these periods—3 floods in the first decade and only 1 and 2 in the second and third decades.

At the local scale, such as the Calperum floodplain, other factors can change abundance, but data from the two largest lakes (Merreti and Woolpolool) are generally consistent with the regional survey. They did, however, show some lake specific differences related to the frequency with which they were inundated and dried. In Lake Merreti peak abundance for inundation events were twice as high in the 2000 to 2004 period—when the lake went through a series of wetting and drying phases—compared to 2009 to 2018 when wetting and drying phases resulted in the lake being inundated for longer periods of time (Figure 4a). The same pattern was not evident for Lake Woolpolool, where the highest recorded abundance in 2002 to 2004 was similar to that in 2010-2018 (Figure 4b). Lake Woolpolool dries more rapidly than Lake Merreti, and so in the second wetting and drying phase underwent longer drying periods. This suggests that extended periods of inundation can reduce the abundance of waterbirds using the wetlands, which has been found in other Murray-Darling Basin wetland systems (Roshier *et al.* 2001), and has been explained by lower wetland productivity compared to periods with more wetting and drying cycles.

The diversity of functional groups using the major lakes on Calperum did not change substantially during annual peak periods of waterbird abundance (Figure 5). The diversity of the largest functional group (Piscivores) was frequently lower during periods of lower abundance (e.g., 2003 & 2004 Lake Merreti and 2000 & 2013 Lake Woolpolool), but this was not always the case (e.g., 2014 & 2017 in both lakes). Changes in functional group representation do, however, change throughout a watering event as habitats become available or change in extent due to changing water levels (Brandis *et al.* 2009).

Table 1: Functional groups of waterbirds and the number of species in each group found on the Calperum floodplain. Modified from Roshier *et al.* 2002.

Functional Group	Characteristics	Species
Dabbling Ducks	Feed upside down in the water. column on aquatic invertebrates and/or aquatic vegetation.	6
Grazing Ducks	Graze on vegetation in shallow water or dried areas.	2
Piscivores	Eat fish from the water column.	22
Deep-water Foragers	Feed by diving or dabbling in deep water for aquatic invertebrates and/or aquatic vegetation.	5
Shoreline Foragers	Feed on invertebrates or vegetation along the shoreline of wetlands.	7
Riparian Foragers	Feed and/or breed in riparian vegetation, especially reeds and sedges.	4
Raptors	Forage on waterbirds and/or fish on wetlands. Nest in riparian or wetland vegetation.	3
Large Waders	Large birds that feed on fish and/or invertebrates in the water or mudflats of wetlands.	5
Small Waders	Small birds that feed invertebrates in shallow water or mudflats of wetlands.	15

Thirty-four species (49% of total species) have been recorded breeding on Lakes Merreti and/or Woolpolool. These lakes are also important nesting sites for colonial nesting species, such as ibis and cormorants. The nests of ibis, spoonbills, egrets, and herons need to be surrounded by water, so breeding events in these colonial nesters are generally initiated by flooding (Arthur *et al.* 2012, Brandis & Bino 2016). In the Calperum lakes they generally occur when water depths exceed one metre above normal pool height (9 of 10 events) (Figure 6), which occurred in floods above 60,000ML (Arthur *et al.* 2012). In a number of Murray-Darling Basin systems high flow volumes for 10 days appear to initiate breeding, but these flows needed to be maintained for 50-90 days for reliable colonial breeding to occur (Arthur *et al.* 2012, Brandis & Bino 2016). In Lake Merreti breeding was associated with high flows in September and less so with long periods of high flow. This is likely because Lake Merreti holds water for extended periods of time after filling (Arthur *et al.* 2012)

Of the colonial nesters found at Calperum, ibis and spoonbills have short breeding cycles, requiring between 48 and 92 days to complete a breeding event once eggs have been laid (Cale 2009). The great cormorant on the other hand requires up to 108 days to complete a breeding event (Brandis & Bino 2016). This means for the range of colonial nesters to complete breeding high water is required for 5-6 months from initiation to viable juveniles (Cale 2009, Brandis & Bino 2016). The Black Swan has the longest breeding period of 7-8 months (Cale 2009). The conditions required for most colonial nesting species are usually only met by significant floods.

However, ibis have been recorded breeding in small numbers at Calperum during a weir pool raising events (2015, Figure 6). This may be because ibis mainly use lignum as a nest substrate and both lakes have lignum beds that are permanently inundated when the lakes are at pool level. The weir pool raising may have been enough to initiate breeding, which then persisted in these permanently inundated sites. Other waterbirds, such as ducks, tend to have shorter breeding periods and are less sensitive to drawdown rates and so can generally complete breeding within 4-5 months (Cale 2009). Therefore, the lakes and wetlands would need to be inundated until at least March from a September initiation, for breeding to be successful for most waterbird species.

Figure 4: The peak abundance of waterbirds from 2000 to 2018 in a) Lake Merreti and b) Lake Woolpolool. Bars indicate periods of inundation (blue) and drying (tan). During inundation the lakes underwent shorter wetting/drying phases when water levels varied from full to almost dry.

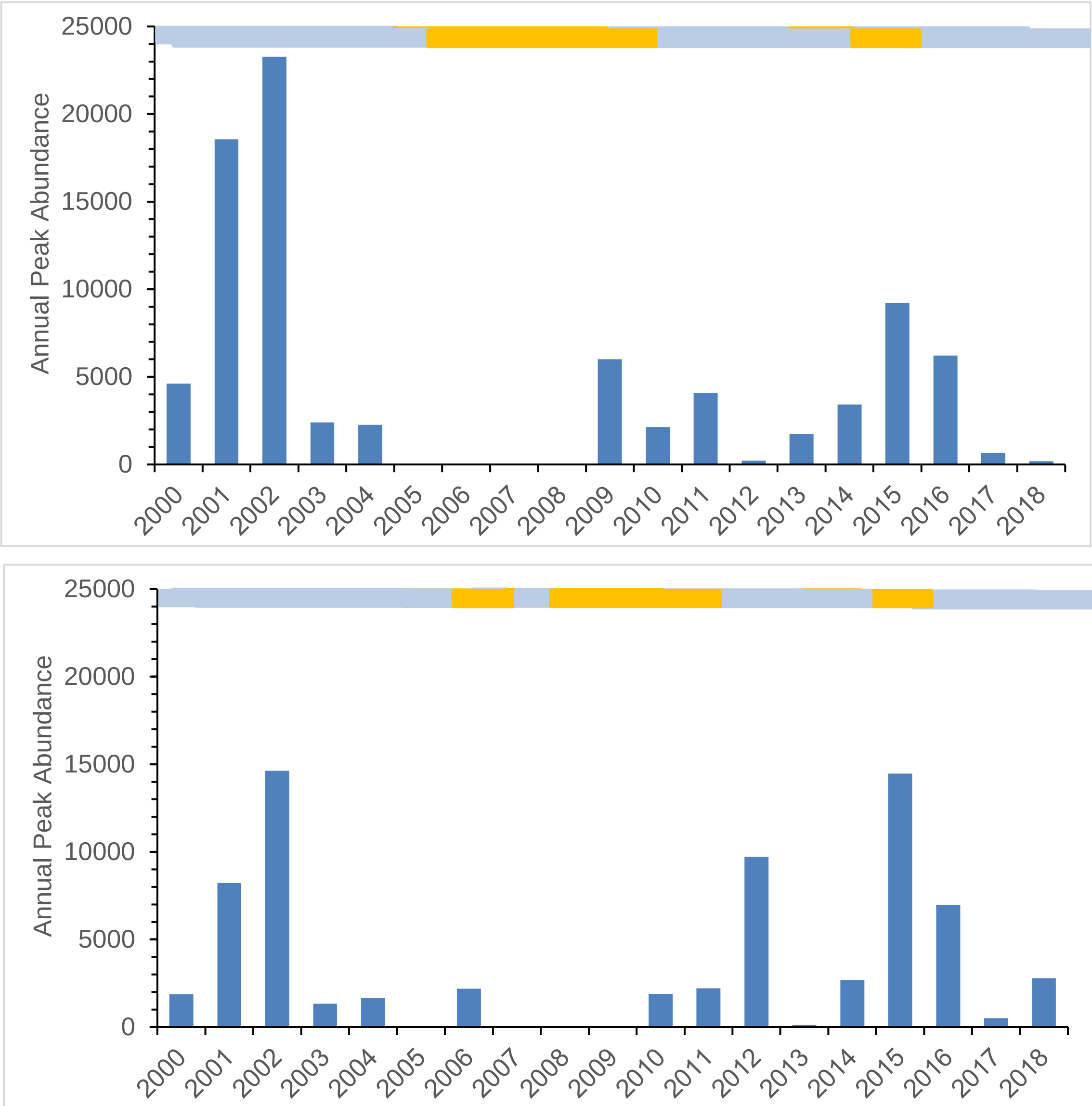


Figure 5: The proportion of the total waterbird species diversity recorded annually from 2000 to 2018 in a) Lake Merreti and b) Lake Woolpolool.

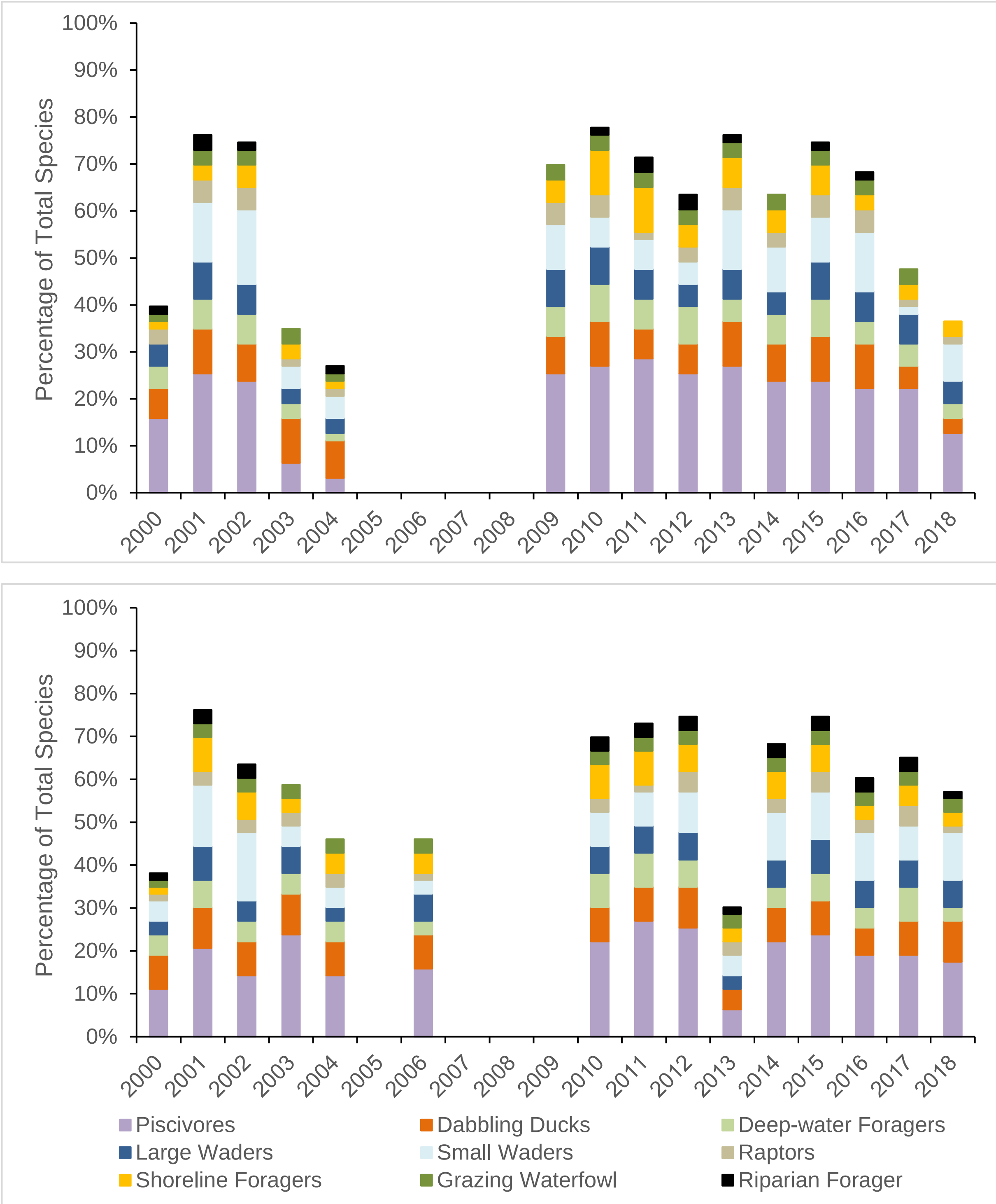


Figure 6: The number of nests of colonial nesting waterbirds in Lakes Merreti and Woolpolool between 1987 and 2018 in relation to lake inundation and peak water depth. # species was recorded nesting, but the number of nests was not estimated. **Note:** Arthur *et al.* (2012) recorded white ibis nesting at Lake Merreti in 2001, but there are no records of this event in ALT data.

SPECIES	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998-2004	2005-09	2010	2011	2012	2013-14	2015	2016	2017-18
Straw-neck Ibis	250	no surveys	550	600	no surveys	500	20	no nests	90	no surveys	no nests	no nests	220	50+	16	no nests	#	120	no nests
White Ibis	250		245	304		80	20		50				200	50+	18		40	170	
Yellow-billed Spoonbill			4	2									10+						
Royal Spoonbill			1																
Darter			2	3		14	18		#				75	10+	10+				
Great Cormorant						3							130	20+			30	40	
Little Black Cormorant													120	#			20	10	
Pied Cormorant			140	60		38	6												
Little Pied Cormorant			54			6							50+						
Lake Condition	Wet											Dry	Wet			Dry	Wet		Dry
Height above pool	1.07	2.17	2.46	2.79	2.16	1.92	2.2		1.42	1.7			1.5	1.5			0.45	2.1	0.45

Environmental watering sites were used by 48 species of waterbird during 8 watering events on five different wetlands (Table 2). The species assemblage found of environmental watering sites was very similar to with only the piscivore guild being slightly less diverse. This is not surprising as the environmental watering sites are unlikely to support fish populations, because they are disconnected from the river. Given the small number of watering events, the diversity of waders in these sites is high relative to that in the major lakes, and this is probably due to the extended periods of broad shallow water and mud flat habitats these wetlands create when inundated with environmental water.

Table 2: The waterbird assemblage and their functional group composition recorded in different wetland systems of the Calperum floodplain. Lakes Merreti and Woolpolool based on data from 2000 to 2018. E-water sites based on five environmental watering sites (Merreti east, Lake Clover, Woolpolool Swamp, Thookle Thookle and Reny Lagoon) during watering events from 2014 to 2018.

	Lake Merreti		Lake Woolpolool		E-Water Sites		ALL Species	
Dabbling Ducks	6	10%	6	10%	6	13%	6	9%
Grazing Ducks	2	3%	2	3%	2	4%	2	3%
Piscivores	21	33%	19	30%	14	29%	22	32%
Deep-water Foragers	5	8%	5	8%	4	8%	5	7%
Shoreline Foragers	7	11%	7	11%	4	8%	7	10%
Riparian Foragers	4	6%	3	5%	1	2%	4	6%
Raptors	3	5%	3	5%	3	6%	3	4%
Large Waders	5	8%	5	8%	5	10%	5	7%
Small Waders	10	16%	13	21%	9	19%	15	22%
Total	**63**	91%	**63**	91%	**48**	70%	**69**	

The diversity of waterbirds using the Calperum floodplain from 2014 to 2018 was enhanced by inundation of the different wetland systems. Most species were recorded in all three systems (45 species), six were found in two systems (mainly the two Lakes), and seven species were found in only one of the three wetland types (Table 3). This reflects the different types of habitats these wetland systems create, and so diversifying what parts of the floodplain that are inundated each year will help to maintain the diversity of waterbirds using the Calperum floodplain.

An additional value of environmental watering sites is that greater temporal and spatial diversity of wetland habitats can be generated across the floodplain by inundating environmental watering sites at different times to the two major lakes.

Table 3: The waterbird assemblage for the three wetland systems of the Calperum floodplain during 2014 to 2018. E-water sites: based on five environmental watering sites (see Table 2).

	Merreti	Woolpolool	E-water	All
Species common to all systems	45	45	45	45
Species common to two systems	6	5	1	6
Species unique to one system	2	3	2	7
Total	**53**	**53**	**48**	**58**

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Appendix VII

Management through Environmental Watering

Background

The Australian Landscape Trust (ALT) commenced, in partnership with the Nature Foundation SA and the Commonwealth Environmental Water Office, an environmental watering program for the Calperum floodplain in the summer of 2014/15. In the five watering seasons since it started, the program has delivered 7GL of water to 11 wetlands covering 460ha (Table 1). This program commenced with small sites that allowed ALT to work through the logistical management of the program and test possible approaches to watering specific sites on Calperum. Subsequently, the construction of small wetland structures to manage water flow and the implementation of weir pool raising between Locks 5 and 6 has allowed for larger sites to be watered more efficiently and pumping to some smaller sites to be halted as they are now inundated by weir pool rises.

Table 1: The Calperum floodplain environmental watering program from 2014 to 2019.

Wetland	Area (ha)	2014/15	2015/16	2016/17	2017/18	2018/19	Total (ML)
Thookle Thookle	28.9	111.0	142.0			273.5	**526.5**
Reny Lagoon	20.2	96.0		37.0		68.9	**201.9**
Argo Creek	4.7	51.0					**51.0**
Woolpolool Inlet	7.4	12.0					**12.0**
Hunchee Crossing	3.4	4.0					**4.0**
Widewaters	8.0	3.0					**3.0**
Merreti East	121.4		588.0	582.0	101.0	331.0	**1602.0**
Amazon	64.6		70.0	67.0		174.7	**311.7**
Clover Lake	133.5				1938.0		**1938.0**
Woolpolool Swamp	65.6			574.0	1854.9		**2428.9**
Amazon Uplands	1.9					6.0	**6.0**
Total	**459.6**	**277.0**	**800.0**	**1260.0**	**3893.9**	**854.2**	**7085.2**

Changes to water management at the regional scale, including weir pool manipulations and reliable water availability for the two large gravity-fed lakes (Lakes Merreti and Woolpolool), has provided the opportunity for the whole of floodplain management of the Calperum floodplain that is proposed in this plan. The proposed environmental watering program focuses on wetlands that support overall floodplain objectives or are complementary to the hydrological management of Lakes Merreti and Woolpolool.

Proposed Sites

Overton *et al.* (2017) assessed threats to the Calperum floodplain and the risks for black box woodlands resulting from those threats. These analyses generated a vulnerability map based on a "Do nothing" scenario, which identified black box woodlands that were likely to be lost without active management. This analysis was based on three threats, inadequate flooding, elevated groundwater and salinity, which combine to generate limitations in the availability of soil moisture. Environmental watering as a replacement for real flooding is one action that can ameliorate these threats. Potential environmental watering sites were identified from a combined assessment of the vulnerability analysis, temporal NDVI analysis, and the mapping of floodplain woodland and ecological units (Appendix IV). Sites were then refined by the potential to be effectively inundated, additional benefits of inundation and the likelihood that other river management (i.e., weir pool manipulations) would assist sites without the need for environmental watering (Table 2).

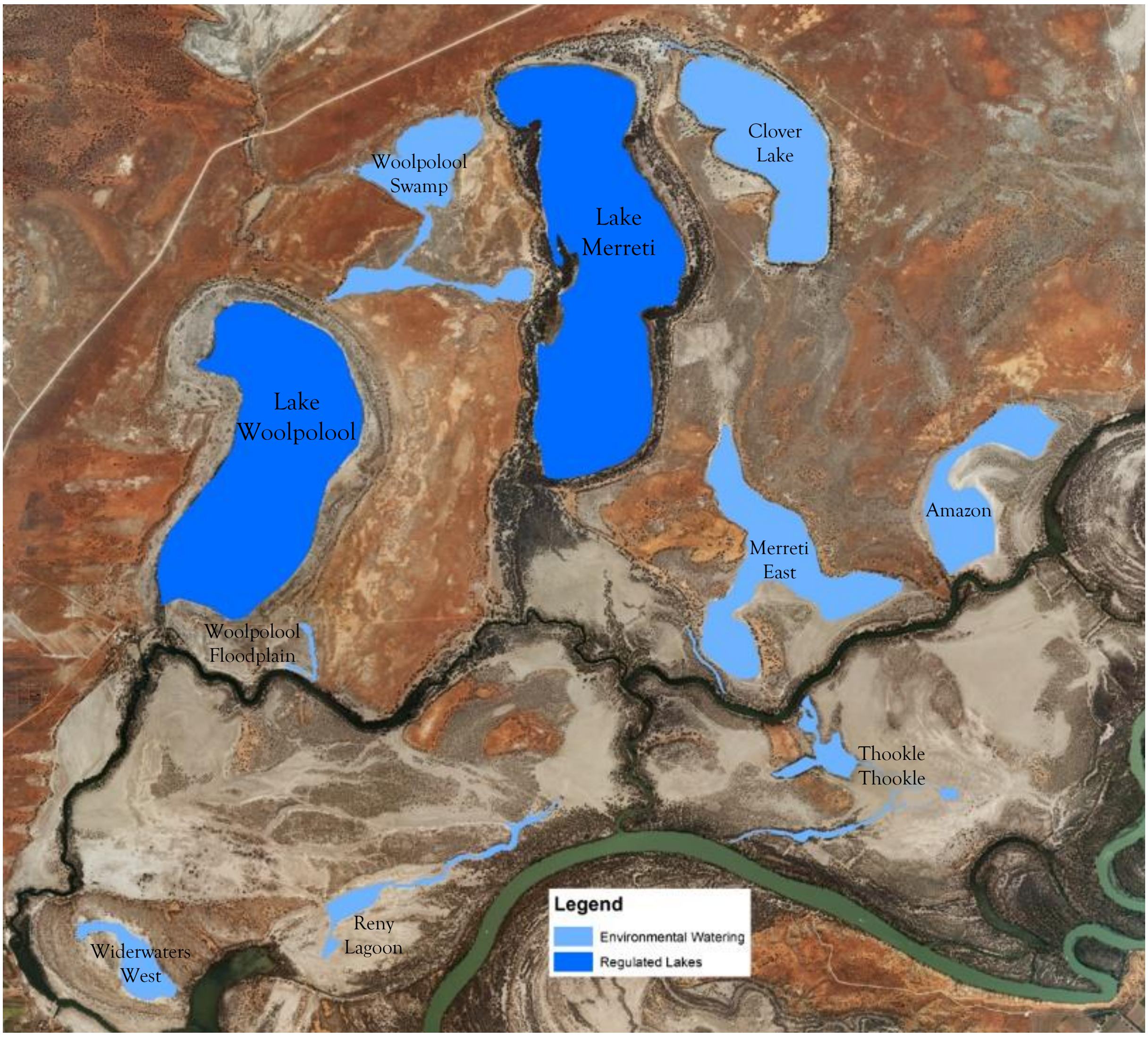
Table 2: Vulnerability analysis of viable environmental watering sites (Overton *et al.* 2017). Indented sites are associated with the primary site above, but show different responses or require different management.

Site	NDVI Response		Stressors			Do-Nothing Scenario
	2005-2012	2005-2017	Flooding	GW Depth	Salinity	
Proposed Environmental Watering Sites						
Woolpolool Swamp	Positive	Partially maintained	Yes	Primary	Primary	Loss
Amazon	Positive	Partially maintained	Primary	Yes	Yes	Loss
Amazon Uplands	Positive	Substantial loss	Partial	Yes		Loss
South Woolpolool Floodplain	Positive	Partially maintained	Primary	Yes	Primary	Loss
Merreti East	Partial Positive	Partially maintained	Primary	Yes	Primary	Loss
Thookle Thookle	Partial Positive	Substantial loss	Primary			Loss
Lower Thookle Thookle	Partial Positive	Positive	Primary			Loss
Thookle Dunes	Partial Positive	Substantial loss	Primary	Yes		Loss
Widewaters West	Partial Positive	Substantial loss	Yes	Primary	Primary	Loss
Reny Lagoon	Partial Positive	Partially maintained	Primary	Partial	Yes	Partial Loss
Reny Uplands	Positive	Substantial loss		Primary	Primary	Partial Loss
Clover Lake	Positive	Partially maintained	Partial	Primary	Primary	Potential loss
East Calperum Uplands	Positive	Partially maintained		Primary	Yes	Potential loss
Sites benefitting from Weir Pool Manipulation						
Hunchee East Channel	Partial Positive	Positive	Primary		Partial	Loss
Lake Woolpolool Inlet	Positive	Positive	Partial	Primary	Partial	Potential loss
Widewaters	Positive	Positive	Partial	Primary	Primary	Maintain
Nelbuck Creek	Partial Positive	Positive	Partial	Primary	Primary	Maintain

Analysis of the normalized difference vegetation index (NDVI) that was conducted by Overton *et al.* (2017) provides an objective, temporal assessment of the state of woodland patches, and was an important component of the assessment of potential environmental watering sites. NDVI measures changes in the density of green in satellite images and has been found to reflect increased biomass of foliage in the dominant foliage layer (the woodland canopy in this case) and is a relatively good indicator of vegetation health (Griffith *et al.* 2002). One of the issues with NDVI measures is that the understorey of woodlands influences the index and this influence increases in more open woodlands. Images from February were used as these minimise understorey cover, but the influence of understorey in NDVI analyses can still increase as canopy foliage declines, masking the declining state of the trees. Therefore, NDVI should not be the sole means of assessing changes, but must be assessed in conjunction with ground-based assessments (Overton *et al.* 2017).

Thirteen sites, eight wetlands, and five upland woodlands, were identified and are proposed for environmental watering through to 2025. The wetland sites cover 450ha, while the upland woodland and sand dune sites provide water to up to 100ha of black box woodland and semi-arid shrubland. The program involves delivery of water directly from the Murray River and the re-use of pumped water (6.5%) in additional sites. The sites deliver different ecological objectives, but most support the persistence and recovery of floodplain woodland communities; and most wetland sites provide for the restoration of wetland communities, and consequently spatial and temporal diversity of wetland habitats for fauna, especially waterbirds (see Appendix VI).

Figure 1: Calperum Floodplain wetlands (eight sites) proposed for environmental watering during 2020-25. The two lakes managed by regulators (Lakes Merreti and Woolpolool) are also shown.



Merreti East Floodplain

Description

The Merreti east floodplain is a 119.7 ha wetland comprised of two depressions connected by a shallow flat (Figure 2). The wetland is connected to Ral Ral Creek by a flood channel on the western side, which starts to fill the wetlands at flood levels in excess of 60,000ML/day.

Prior to the commencement of environmental watering the eastern depression was covered by low samphire and chenopod shrublands, suggesting there were high levels of soil salinity. The lower western depression had minimal cover, mainly remnant lignum and swamp cane-grass with sparsely distributed black box. Adjacent to the wetlands are black box woodland communities on clay flats (42ha), sand dunes (66ha) and the outer edges of riparian woodland (15ha). These woodlands have an open mixed chenopod shrubland understorey. Currently, most of the woodland on clay flats, and on the edge of the riparian zone is in a stressed to good state (score 3 & 4), while those woodlands on dunes are variable with a third in a degraded state (score 1-2), most (31ha) in a stressed state (score 3) and only the central dune is in a good state (score 4).

Figure 2: Merreti East Floodplain environmental watering site. Yellow boundary indicates extent of inundation during 'standard' environmental watering event.

The Merreti East wetland complex is a significant site on the Calperum floodplain for waterbirds, as it provides different habitats than the two major lakes (Appendix VI). The two basins of this wetland complex differ in topography and vegetation communities, which provides different habitats for waterbirds. The eastern basin generates extensive beds of sedge with shallow water, plus deeper pools surrounded by reed beds. The western basin has more open water surrounding a lignum/cane-grass swamp. The two basins also provide extensive mud flats during filling and drying stages. During previous watering events 39 species of waterbirds were recorded on this wetland, and this is the only environmental water site at which six of these species have been recorded. At least one species from every functional guild has been recorded on this site indicating the diversity of wetland habitats it provides. Significant use was from the white-breasted sea-eagle, which uses the site regularly as a foraging habitat, and a diversity of small wader species that forage on the mad flats.

Recent History

The wetland complex was flooded in both 2010-12 and 2016. It received environmental watering during the summers of 2015/16, and 2016/17 (Table 1). The 2015/16 environmental watering event only filled the eastern depression, while the western depression was first filled in 2016/17. The wetland was in a drying phase between these inundations, but never completely dried. The 2016 flood maintained the site in a flooded state, which had almost completely dried by October 2017 when it received a small amount of water to extend the inundation into Summer. The wetland was dry for 12 months before being filled again in the Autumn of 2019 to be dry in September 2019.

Black box woodlands associated with the wetland have showed some changes in response to the 2010-12 floods. In 2005, all woodland patches were in a stressed condition, based on NDVI analysis (Table 2). In 2012 after the floods, sand dune woodlands showed improvement, which then declined again post-flood. Upland woodlands showed substantial improvement post-flood, but some areas have now declined to a more degraded state than prior to the flood.

After environmental watering commenced the eastern depression was replaced by a sedge land (*Cyperus* spp. and *Eleocharis acuta*) with *Typha orientalis* growing around deeper pools. The western depression develops extensive cracking clays post-watering. Lignum and swamp cane-grass cover has increased, but is still heavily grazed, and an herbfield community has developed around the edges of the depression, but is also heavily grazed resulting in the dominance of the ungrazed, *Centipeda crateriformis*.

Values and Targets

The primary values of the Merreti east floodplain are: –

1. the wetland habitats – specifically the cane-grass swamp in the western depression and the extensive sedgeland in the eastern depression;
2. the provision of waterbird habitat;
3. the black box woodlands;
4. the habitat mosaic (cracking clay flats and sand dune black box woodland) for the paucident planigale;
5. potential habitat for bush stone-curlew; and
6. potential for lateral connectivity between the wetland and Ral Ral Creek that will increase in-stream and floodplain productivity and aquatic biodiversity.

The wetland is also an important site for education and community engagement activities.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland annually for 5 years for a period of 5-12 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.3, 2.5-2.9);

2. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.1-2.3, 2.5, 2.7-9 & 3.1-3.6);
3. control any weeds within the wetland or adjacent habitats that are impeding recovery or restoration of habitat components (Targets 2.1-2.5 & 3.7);
4. restore and/or facilitate the recovery of swamp cane-grass across 4ha of the western depression, through inundation, protection from grazing, and targeted planting by 2025 (Targets 2.3, 2.6- 2.9);
5. restore the chenopod understorey cover to >20% in 3ha of the black box woodland on the sand dune adjacent to the western depression by 2025 (Targets 2.1-2.2, 2.8-2.9 & 2.12-2.13); and
6. establish the protocols & procedures and implement before 2025 return flows to Ral Ral Creek of environmental water delivered to the wetland (Target 1.1).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. The process required for water delivery at this site is well established, and the necessary infrastructure has been constructed.

The western depression provides the components for the habitat mosaic required by the paucident planigale (cane-grass swamp and sand dune black box woodland) and the sand dune woodlands also provide habitat for the bush stone-curlew. To restore this habitat, remediation of erosion scalding using the branching technique will be conducted on the sand dune adjacent to the western depression (Actions 5.3 & 5.6). The recovery of swamp cane-grass within the western depression will be achieved through, environmental watering and if necessary targeted planting to expand the cover of swamp cane-grass (Action 5.3). Managing grazing pressure will also be essential for effective restoration of these two habitats (Actions 4.1-4.3).

This wetland complex is a significant waterbird site on the Calperum floodplain. So, management of the water regime to maximise the value of the wetland as feeding and breeding habitat for species is a focus of the environmental watering program. Wetlands need to provide appropriate breeding habitat and a sufficient period of inundation for successful breeding. The Merreti East wetland provides non-emergent and emergent macrophyte breeding habitat if the wetland is inundated for at least two sequential years. Most waterbirds require 5-6 months to complete their breeding cycle so for a September initiation of inundation the wetland needs to be maintained until February/March for successful breeding. The eastern depression is a potential breeding site for black swans, which have the longest breeding cycle (7-8 months), so it is planned to have this site inundated at least in some years, for longer periods if not continuously by providing top-up environmental water.

The Merreti east wetland complex is a very productive system. Past surface water monitoring showed that the water in the system during environmental watering events is high quality (salinity <400 EC), so this site provides an opportunity to allow real ecological connectivity to be restored between this floodplain and Ral Ral Creek. The opportunity to allow return flows to Ral Ral Creek from this site already exist, via the flood channel on the western side of the system. Therefore, development of the necessary protocols (e.g., water quality assessments and timings of releases) to enable these return flows to happen will be pursued in collaboration with the CEWO and the SA government. Once approvals for these flows are obtained implementation will be included in annual water plans.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Waterbird surveys during filling, peak fill and on drying.
4. Surface water quality assessments at 3 locations least 3 times during inundation period.

Specific Risks

Restoration of the sand dune black box woodland is in an area with significant cultural heritage values, so it is important these are protected as part of the restoration process. Since the restoration approaches being used are the same as those used to restore cultural heritage sites there is little risk that they will be incompatible with heritage protection.

Return flows of environmental water to the river have potential risks associated with declining water quality and black water events. These risks are low for this site, based on existing monitoring data from past watering events. Appropriate risk assessments and protocols will be developed to ensure the risk from return flows are minimised, before they are implemented.

Amazon Floodplain

Description

The Amazon floodplain (64.6ha) consists of a shallow depression in the east and a clay flat connected directly to the Ral Ral anabranch (Figure 3). This wetland complex is inundated during floods in excess of 75,000ML/day.

The eastern depression once supported a lignum swamp, but most of the lignum died over the millennium drought. The 2010-12 floods resulted in some lignum recovery, but by 2015 most of this recruitment was dead. The western clay flat supported little vegetation, being primarily an exposed saline flat with scattered chenopod and samphire shrubs, with remnant grass/herbfield patches that include the rare species *Calocephalus sonderi* and *Duma horrida*.

The wetland areas are surrounded by black box woodland on sand dunes (20ha) and infrequently inundated upland clay/sand soils (40ha). These woodlands have an open mixed chenopod shrubland understorey. Currently most of the woodland on upland clay/sand soils are in a degraded state (score 1-2), while those woodlands on the dunes are stressed (score 2-3).

The Amazon wetland complex is a new environmental watering site but in its first year of full operation it was an important site on the Calperum floodplain for waterbirds (Appendix VI). The eastern depression of this wetland complex has a lignum swamp and deep open water, which is used by many ducks and has the potential to be a breeding site for the swamp harrier (recorded foraging at the site). It has also been used as a breeding site by black swans. During the 2018/19 watering event 18 species of waterbirds were recorded on this wetland. The western clay flat supported large numbers of ducks and large waders (>1000 birds) during the first short fill and has the potential to provide significant mad flat habitat once the site has started to recover from high soil salinity.

Figure 3: Amazon Floodplain environmental watering site. Yellow boundary indicates extent of inundation during 'standard' environmental watering event. Blue boundary indicates the potential area for watering of the Amazon uplands woodland. The brown line represents a retention bank built in 2019.

Recent History

The Amazon floodplain was last flooded during the 2010-12 floods. The eastern depression was inundated with environmental water in 2015/16 and 2016/17, with a drying phase during winter between these events. An attempt was made to inundate the western section during 2016/17, but the retention bank failed and so the attempt had to be suspended. In 2019 a more substantial retention bank was constructed, with the support of the CEWO, and both sections of the floodplain were successfully inundated in autumn 2019, drying by October 2019.

Black box woodlands associated with the wetland have shown significant changes in response to recent floods and environmental watering. In 2005, all woodland patches were in a stressed condition, based on NDVI analysis (Table 2). In 2012 after the floods, some patches showed improvement, and some have continued to improve with the environmental watering activity since 2015. Some localised patches of upland black box have, during the current drought, showed declining condition with some in a more stressed state than they were in 2009 at the end of the millennium drought.

The eastern depression has cracking clays that are now developing larger cracks post-watering. Lignum in this depression has recovered to some degree, but live lignum still has a poor coverage across the depression. Grass (*Sporabolis* sp.) and herbfield cover developed on the western clay flats after the 2019 watering, but much of its development has been supressed by heavy grazing pressure, except in the two fenced exclosures.

Values and Targets

The primary values of the Amazon floodplain are: –

1. the black box woodlands;
2. the wetland habitats – specifically the lignum swamp in the eastern depression, riparian woodland, and the potential grass/herbfield in the western clay flats;
3. the habitat mosaic (cracking clay in lignum swamp and upland black box woodland) for the paucident planigale;
4. the waterbird habitat;
5. populations of threatened plant species;
6. potential habitat for bush stone-curlew and common brush-tailed possum; and
7. potential for lateral connectivity between the wetland and The Ral Ral anabranch that will increase in-stream and floodplain productivity and aquatic biodiversity.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland in 4 of every 5 years for a period of 6-12 months, dependent on antecedent conditions (Targets 1.2-1.3, & 2.1-2.13);
2. pump and re-use environmental water (from Target 1) on 10ha of upland black box woodland 2-3 times/year annually for 5 years for a period of 1-2 months, dependent on antecedent conditions (Targets 2.1-2.2, 2.5 & 2.7-2.13);
3. restore and/or facilitate the recovery of a canegrass/lignum swamp across 8ha of the eastern depression, through inundation, protection from grazing, and targeted planting by 2025 (Targets 2.3, & 2.8- 2.9);
4. restore and/or facilitate the recovery of riparian and grass/herbfield communities including threatened plant species, on the edges of the western clay flat, through inundation, protection from grazing, and targeted planting by 2030 (Targets 2.4, 2.5 & 2.12-2.13);
5. restore and/or facilitate the recovery of the *Atriplex*/chenopod understorey cover to meet identified health and structural measures in 10ha of upland black box woodland by 2025 (Targets 2.1-2.2, 2.5, 2.8 & 2.13);
6. restore and/or facilitate the recovery of threatened plant species in 10ha of upland black box woodland by 2025 (Targets 2.1-2.2 & 2.5);
7. manage specific total grazing pressure threats identified for the wetland and adjacent woodlands (Targets 2.1-2.5, 2.7-2.13 & 3.1-3.6);
8. control any weeds within the wetland or adjacent woodlands that are impeding recovery or restoration of habitat components (Targets 2.1-2.5 & 3.7); and
9. establish by 2025 if return flows to The Ral Ral anabranch of environmental water delivered to the wetland will be beneficial to in-stream ecology (Target 1.1).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. The necessary infrastructure has been constructed to enable watering. This is a new environmental watering site, so careful annual evaluation of the wetland's response to watering will be implemented to ensure the proposed regime is delivering the desired outcomes.

The upland black box woodland associated with the Amazon floodplain does not all benefit from the inundation of the wetland, so the delivery of environmental water to parts of the uplands through pumping into smaller depression across the woodlands and through irrigation infrastructure (Action 2.3) will complement the wetland inundation to assist woodland recovery. Some of this watering can re-use water pumped into the wetland. Grazing pressure management will be essential for effective management of the upland woodlands (Actions 4.1-4.4). This upland woodland restoration will also improve the potential of these woodlands to provide flood habitat for the paucident planigale. Restoring populations of two threatened woodland plants (*Maireana decalvans* and *Dianella porracea*) will focus on the areas where this upland watering is delivered (Action 5.1). The management focus will be on minimising the impacts of grazing and increasing the abundance of the species. This will be done, using established grazing exclosures as nuclei for generating a source population of each species. These upland woodlands are connected to riparian woodlands along the Ral Ral anabranch and so provide potential habitat for the bush stone-curlew and common brush-tailed possum. Once the control of foxes and feral cats is achieved (Action 6.1), the management of the tree and understorey health within these woodlands will enhance this habitat for these declining species.

The recovery of wetland areas across this complex will be facilitated and enhanced by specific restoration activities (Action 5.4). All of floodplain control of high grazing pressure (Actions 4.1-4.4) and site-specific protection of vegetation from grazing using exclosures and branching techniques will facilitate the recovery of this community (Action 5.6).

This wetland complex could be an important waterbird site on the Calperum floodplain. So, management of the water regime to maximise the value of the wetland as feeding and breeding habitat for species in a focus of the environmental watering program. Wetlands need to provide appropriate breeding habitat and a sufficient period of inundation for successful breeding. The eastern depression of Amazon provides non-emergent and emergent macrophyte breeding habitat. Most waterbirds require 5-6 months to complete their breeding cycle so for a September initiation of inundation the wetland needs to be maintained until February/March for successful breeding. The eastern depression is a potential breeding site for black swans, which have the longest breeding cycle (7-8 months), so the potential to have this site inundated, at least in some years, for longer periods by providing top-up environmental water will be investigated.

The Amazon floodplain has the potential to be a productive wetland system. Surface water monitoring showed that the water in 2018/19 had low salinity levels (Salinity <350EC) even after only one year of inundation. This suggests the site provides an opportunity to allow real ecological connectivity to be restored between this floodplain and the Ral Ral anabranch. The opportunity to allow return flows to the Ral Ral anabranch from this site already exist, via the pipes included in the retention bank built to allow this site to be inundated. Assessments of water quality will be collated in the initial watering events to determine if return flows are appropriate. Then development of the necessary protocols (e.g., water quality assessments and timings of releases) to enable these return flows to happen will be pursued in collaboration with the CEWO and SA government.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Waterbird surveys during filling, peak fill and on drying.
4. Surface water quality assessments at 3 locations least 3 times during inundation period.

Specific Risks

Return flows of environmental water to the river have potential risks associated with declining water quality and black water events. These risks need to be assessed before this potential management action can be considered for this new environmental watering site. If return flows are deemed possible then appropriate risk assessments and protocols will be developed to ensure the risk from return flows are minimised, before they are implemented.

Thookle Thookle

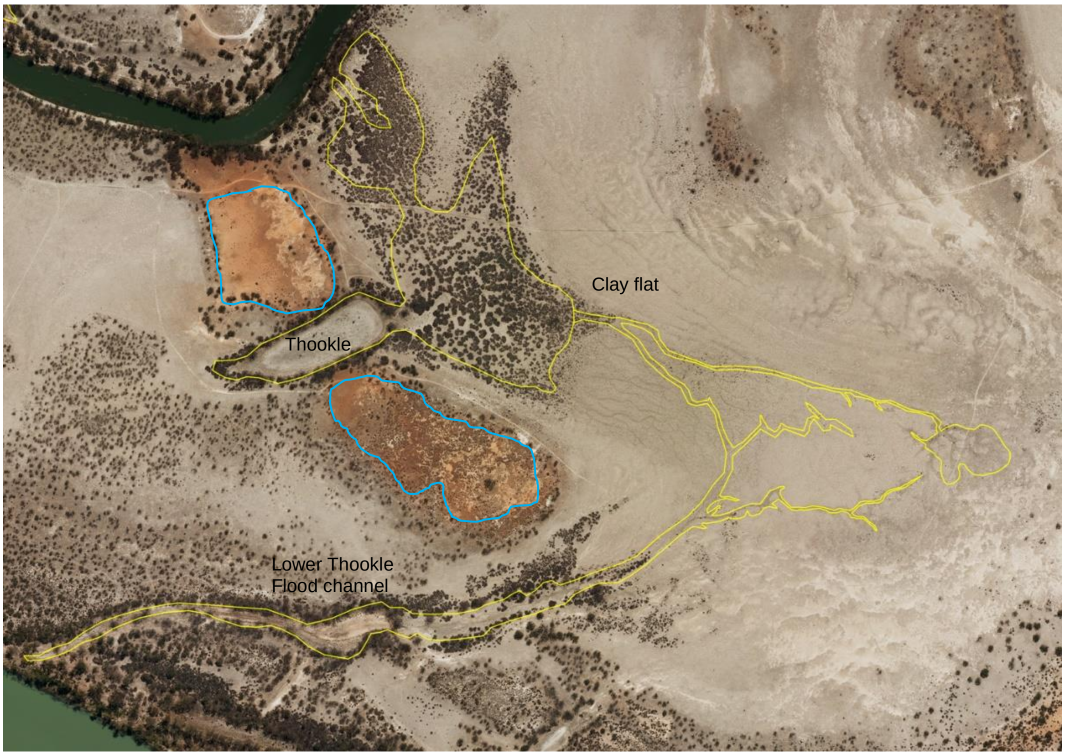
Description

The Thookle Thookle wetland complex consists of an island clay flat between sand dunes, a deep basin formed by a channel cutting through a sand dune (Thookle), and a flood channel (lower Thookle) running into the Murray River (Figure 4). The wetland complex commences inundation via the lower Thookle flood channel during floods in excess of 55,000ML/day.

The clay flat of the wetland complex was a lignum swamp with scattered coobah, with higher areas supporting nitre goosefoot *Chenopodium nitrariaceum* shrubland or low *Sclerolaena muricata* shrubland. The majority of the lignum died during the millennium drought, with some recovery during the 2010-12 floods and the recruitment of scattered coobah and black box. Adjacent sand dunes support a stressed black box woodland (13.5ha) along the base and a degraded semi-arid shrubland on the crest. Thookle once supported a red gum/black box riparian woodland (15ha), but inadequate flooding resulted in the death of all mature red gums. A watering event in 2006 and the 2010-12 floods, resulted in the recruitment of red gum and black box and the riparian woodland has returned to a mixed tree community. The bed of Thookle supports little vegetation on the deep cracking clays. The lower Thookle flood channel consists of a series of small depressions with a red gum/black box riparian woodland (17ha). Most mature red gums have died during periods of infrequent flooding, but substantial recruitment of both red gums and black box has occurred along the length of the channel.

Although waterbirds are not the primary value of the Thookle Thookle wetland complex, it has some significant values for this group of species (Appendix VI). The major basin provides deep water that persists for a long time, and is regularly used by many species of duck, including the vulnerable freckled duck. The basin's riparian red gum/black box woodland also provides good breeding opportunities for hollow-nesting ducks. During previous watering events 23 species representing all but one of the functional guilds were recorded on this site. Recovery of the lignum swamp is likely to improve the waterbird habitat and in future years this may increase the significance of the wetland complex as a waterbird habitat.

Figure 4: Thookle Thookle environmental watering site. Yellow boundary indicates extent of inundation during 'standard' environmental watering event. Blue boundary indicates the potential area for watering of the Thookle sand dunes.



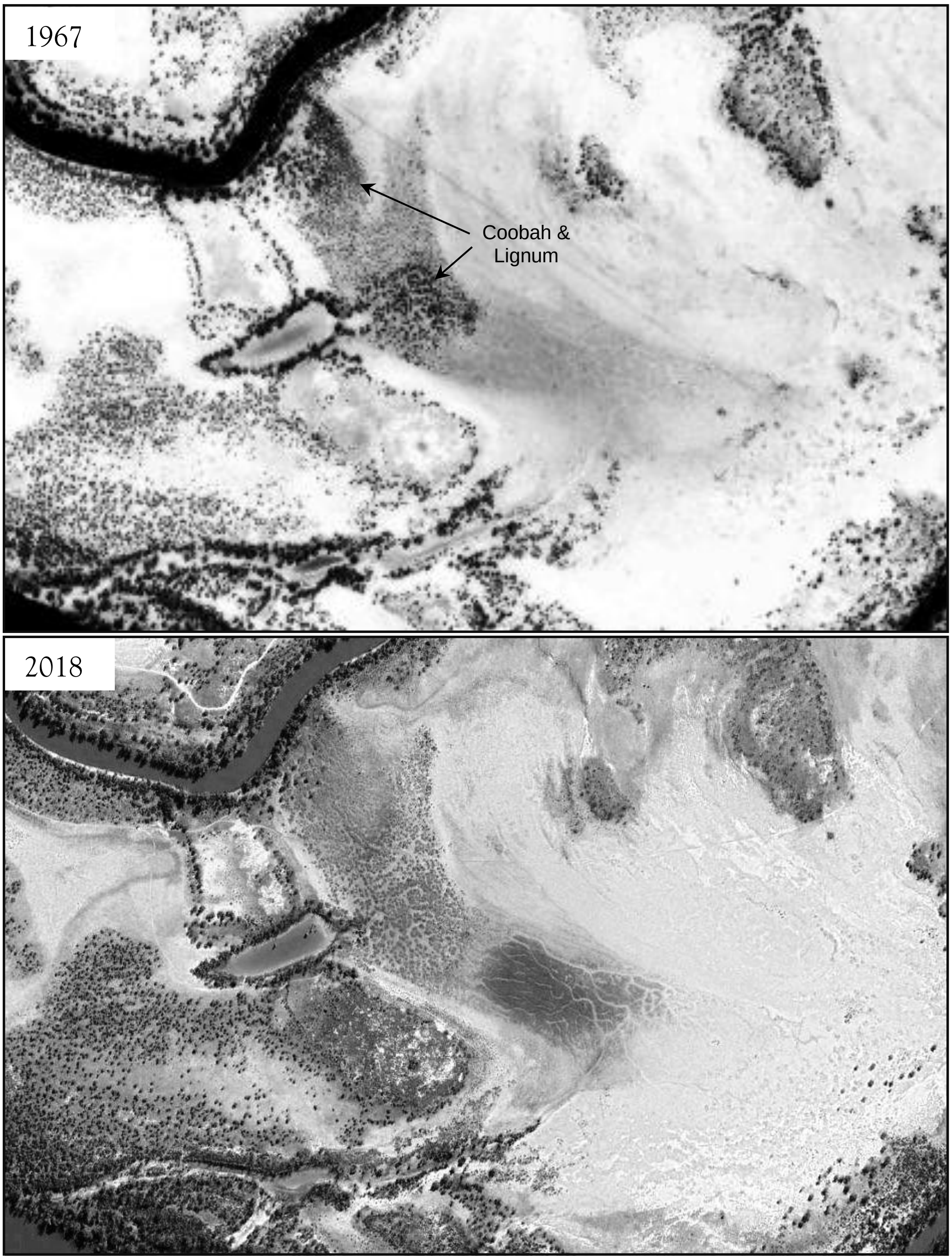
Recent History

Thookle Thookle received an environmental fill in 2006, which only filled the basin in an unsuccessful attempt to prevent the death of the remaining mature red gums. The entire wetland complex was flooded in 2010-12. Environmental watering inundated Thookle Thookle and the north part of the clay flat in 2014/15 and 2015/16 and the 2016 flood extended this flooding up the lower Thookle flood channel. In 2018/19 the entire wetland complex was inundated in autumn, with the flat being inundated for 3 months, lower Thookle for 7 months and Thookle was still partially full in November 2019.

Woodlands across the entire Thookle Thookle complex were in a severely stressed state in 2005 (Table 2). The black box on dunes and the clay flats showed substantial recovery after the 2010-12 floods, but by 2017 most patches were showing stress again. The lower Thookle flood channel showed limited recovery immediately after the floods, but by 2017 had improved substantially (Table 2).

The clay flat of the Thookle Thookle wetland complex has progressively lost the coobah and lignum cover that it supported during the 1950-60s (Figure 5). Aerial photographic comparisons also showed minor improvements in vegetation cover on the sand dunes adjacent to Thookle Thookle (presumably due to the removal of livestock grazing in 1993), and some red gum and black box recruits in the bed and entry channel to the basin. There are also signs of recruitment of red gums within the lower Thookle flood channel.

Figure 5: Changes in the Thookle Thookle wetland complex between 1967 and 2018, showing the loss of lignum and coobah (dark speckling) in the flats.



Values and Targets

The primary values of Thookle Thookle are: –

1. the black box and red gum/black box woodlands;
2. the remnant coobah/lignum swamp on the clay flat,
3. the black box woodland and semi-arid shrubland on sand dunes;
4. the habitat mosaic (cracking clay in lignum swamp and semi-arid shrubland on dunes) for the paucident planigale;

5. potential for lateral connectivity between the wetland and the Murray River that will increase in-stream and floodplain productivity and aquatic biodiversity;
6. potential habitat for bush stone-curlew and common brush-tailed possum; and
7. the existing and potential waterbird habitat.

The wetland is also an important site for education and community engagement activities.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland in 3 of every 5 years for a period of at least 2-3 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.4, 2.6, & 2.8-2.13);
2. maintain water in the main Thookle depression for at least 6 months (Target 2.6);
3. restore and/or facilitate the recovery of a coobah/lignum swamp across 6ha on the clay flat, through inundation, protection from grazing, and targeted planting by 2030 (Targets 2.3-2.4, & 2.8-2.9);
4. restore the semi-arid shrubland cover to >20% in at least 6ha of the two sand dunes adjacent to Thookle by 2030 (Targets 2.4, 2.8-9 & 2.12-2.13);
5. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.1-2.4, 2.8-2.13 & 3.1-3.6);
6. control any weeds within the wetland or adjacent habitats that are impeding recovery or restoration of habitat components (Targets 2.1-2.4 & 3.7); and
7. establish the protocols & procedures and implement before 2025 return flows to the Murray River of environmental water delivered to the wetland (Target 1.1).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. The process required for water delivery at this site is well established, and the necessary infrastructure has been constructed. The duration of each inundation is variable depending on what part of the system is being considered. Thookle remains inundated for a long time, as does parts of the lower Thookle flood channel. The clay flat has the shortest inundation duration and it is initially intended to maintain water in this section for 2-3 months.

The riparian woodlands associated with this wetland complex are potential habitat for the common brush-tailed possum and the improved woodland state and structural diversity resulting from the environmental watering regime will enhance the habitat for this declining species.

Thookle Thookle was a site used for research into the habitat requirements for the paucident planigale (Bignall 2001). Restoring the semi-arid woodland community on the sand dunes (Figure 5) will provide flood habitat for the paucident planigale and habitat for the bush stone-curlew. This community has severe erosion scalds and minimal cover of a few shrub species. Restoration will initially focus on increasing vegetation cover to stabilise the dunes and then generating a diverse shrubland community (Actions 5.2 & 5.6). Restoration activities will be aligned with watering events to enable the re-use of environmental water, delivered to Thookle, to inundate these dunes to support recovery and plantings (Tables 3 & 4).

The recovery of the degraded coobah/lignum swamp on the clay flat and the semi-arid shrubland on the dunes adjacent to Thookle will require a reduction in grazing pressure, especially from kangaroos and rabbits (Actions 4.1 & 4.2). An assessment of recruitment from the past watering events will determine if and where targeted planting to expand the cover of coobah and lignum needs to be implemented. Should planting occur it will be conducted in conjunction with future watering events, which will enhance establishment success.

Thookle Thookle could be an important waterbird habitat for the Calperum floodplain once the coobah/lignum swamp has been restored. Currently, Thookle provides the opportunity for hollow nesting ducks and piscovores, such as little grebes, to breed. Waterbirds require 5-6 months to complete their breeding cycle which is easily achieved for the Thookle depression as it maintains water for 6-8 months after cessation of the watering event. Once the coobah/lignum swamp has recovered adequately, assessment of the watering regime to maintain adequate inundation periods for this part of the system will be assessed.

The Thookle Thookle wetland complex is a productive wetland system. The site provides an opportunity to allow real ecological connectivity to be restored between this floodplain and the Murray River. The opportunity to allow return flows to the Murray River from this site already exist, via the lower Thookle flood channel. Therefore, development of the necessary protocols (e.g., water quality assessments and timings of releases) to enable these return flows to happen will be pursued in collaboration with the CEWO and SA government. Once approvals for these flows are obtained implementation will be included in annual water plans.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Waterbird surveys during filling, peak fill and on drying.
4. Surface water quality assessments at 3 locations least 3 times during inundation period.

Specific Risks

Given the degraded state of the sand dunes, there is a low risk that re-used water pumped on to the dunes could return to the Thookle wetland and reduce water quality. Close monitoring of pumped water to prevent flow off the dune will prevent this potential risk

Return flows of environmental water to the river have potential risks associated with declining water quality and black water events. These risks are low for this site based on past watering events. Appropriate risk assessments and protocols will be developed to ensure the risk from return flows are minimised, before they are implemented.

Woolpolool Swamp

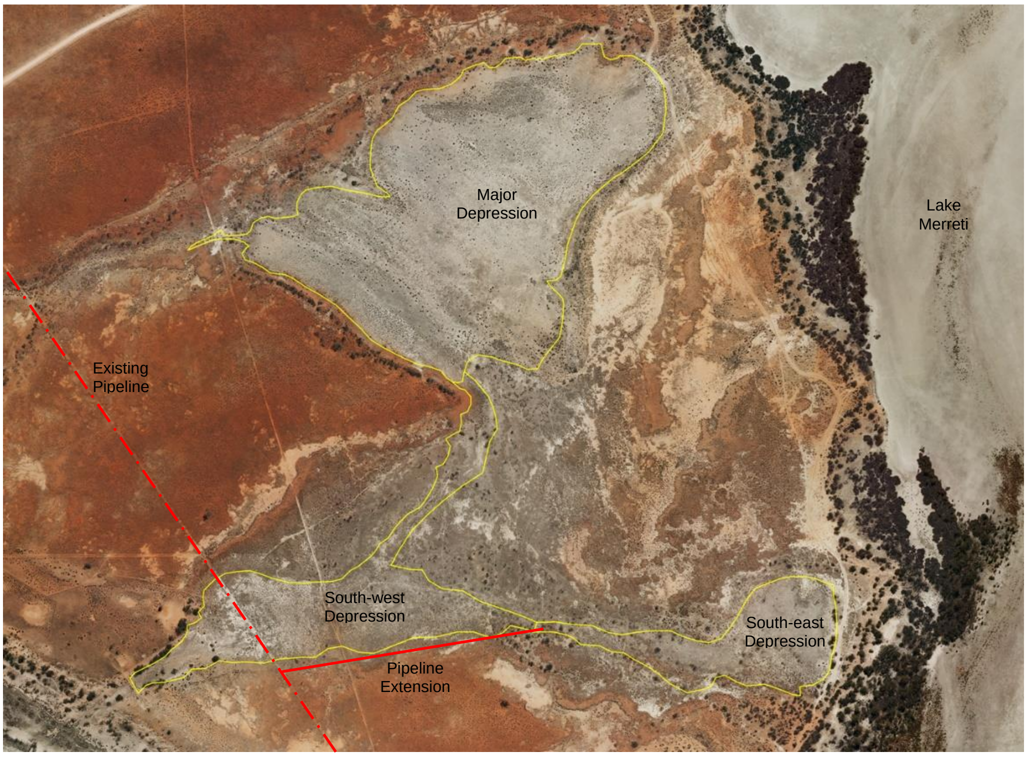
Description

Woolpolool Swamp consists of a depression surrounded by sand dunes and then two shallow depressions one flowing toward Lake Woolpolool and the other flowing south-east back toward Lake Merreti (Figure 6). Historically, Woolpolool Swamp was filled when Lake Merreti flooded above 19m AHD (>110,000ML/day) and these flood waters then continued down to Lake Woolpolool, providing a direct connection between the two lakes. These natural flow paths have now been disrupted with a levee built at the Woolpolool inlet channel.

The major depression has supported a degraded chenopod and samphire shrubland since the 1970s when it was last flooded (1973). There were extensive scalds across the floor of the depression. The depression is surrounded by sand dunes that support open black box woodlands (18ha). These woodlands are in a stressed state (scores 2-3), though the condition of trees is variable. The southern shallow depressions are covered by sparse black box woodland (47ha) with a low samphire shrubland understorey. These woodlands are also stressed (score 2), with some patches entirely dead and others in good condition.

Woolpolool Swamp is a relatively new environmental watering site, but previous watering events indicate it could provide important habitat for waterbirds (Appendix VI). During previous watering events 35 species of waterbirds representing all functional guilds were recorded on this wetland. This included a large breeding event for black swans and a pair of swamp harriers breeding.

Figure 6: Woolpolool Swamp environmental watering site. The northern yellow polygon (Major Depression) indicates the extent of inundation during a 'standard' environmental watering event. The two southern yellow polygons can be inundated by secondary pumping of water either from the major depression or via a pipeline (indicated in red).



Recent History

Woolpolool Swamp was last naturally flooded in 1973. Sections of the major depression held rainwater for several months during heavy falls in 2010-11, but the wetland was not flooded. During the 2016/17 summer the major depression was inundated with environmental water, and then both the major depression and the south-western section of the lower system were inundated during the 2017/18 summer. During these watering events the live black box inundated in the southern section showed improved condition, while those on the surrounding sand dunes varied in response, indicating that some are hydrologically connected to surface inundation in the depression.

All black box woodlands associated with the wetland showed positive changes in condition after the 2010-12 floods, based on NDVI analysis (Table 2). However, in the southern sections of the system most of the improvements recorded in 2012 were lost by 2017, and woodlands had returned to a stressed state.

Values and Targets

The primary values of Woolpolool Swamp are: –

1. the extensive black box woodlands;
2. the waterbird habitat;
3. potential connectivity for the common brush-tail possum;
4. the temporal habitat mosaic – specifically the shifts from terrestrial to wetland habitats that will occur within the major depression after the watering regime has been established; and
5. habitat for the bush stone-curlew.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland initially in 4 of every 5 years for a period of 5-7 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.4, 2.6 & 2.10-2.11);
2. re-use environmental water (from Target 1) to inundate the south-western depression initially in 4 of every 5 years for a period of 2-3 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.2, 2.4 & 2.10-2.11);
3. deliver environmental water to the south-eastern depression over a period of 8 months in 4 consecutive years, dependent on antecedent conditions (Targets 1.2, 2.1-2.2, 2.4 & 2.10-2.11);
4. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.1-2.4, 2.10-2.13 & 3.1-3.6);
5. control any weeds within the wetland or adjacent habitats that are impeding recovery of habitat components (Targets 2.1-2.2, 2.4 & 3.7); and
6. investigate the potential to restore and/or facilitate the recovery of a temporal habitat mosaic across the major depression, through inundation, protection from grazing, and other restoration actions by 2025 (Targets 2.3 & 2.12-2.13).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. Filling the major depression has been successfully implemented on two previous occasions, but only partial success has been achieved for the southern depressions. The SW depression was partially filled in 2017/18, but this required over-filling of the major depression, which is not desirable on a regular basis both ecologically and with respect to the quantity of environmental water required. Therefore, the option of re-using environmental water by pumping from the major depression into the SW depression would be a more effective management approach. The SE depression has, to date, not been successfully inundated using environmental water. The approach proposed for the SW depression is not viable for this area due to the topography. However, creating a branch-line in an existing pipeline would provide a means of providing water to this area (Action 2.4). It is proposed to initially fill the entire Woolpolool Swamp complex four times over a five-year period (Table 4) to assist with the recovery of the wetland vegetation community and the black box woodlands, but once this has been achieved the watering frequency would be reduced.

The main depression of Woolpolool Swamp is a significant waterbird site on the Calperum floodplain. So, management of the water regime to maximise the value of the wetland as feeding and breeding habitat for species is a focus of the environmental watering program. Wetlands need to provide appropriate breeding habitat and a sufficient period of inundation for successful breeding. Currently, Woolpolool Swamp provides emergent vegetation breeding habitat formed by the inundation of terrestrial vegetation, and the depression remains inundated for enough time after a filling event to complete breeding. As the wetland system for this lake develops with more regular inundation events the potential breeding habitat at this site will be assessed and if necessary, management will be adjusted to maximise the value of the wetland for waterbirds.

The riparian woodlands of Lakes Merreti and Woolpolool were once used by the common brush-tailed possum. Recovery of possum populations, through the control of grazing pressure (Action 4.1) and introduced predators (Action 6.1), will increase the likelihood of them re-establishing in these woodlands. The black box woodlands associated with Woolpolool Swamp, if in a reasonable condition, would then provide valuable habitat corridors connecting the lakes for this species. The temporal mosaic between wetland and terrestrial habitats within the main depression will provide potential habitat for the bush stone-curlew.

Recovery of woodland and wetland vegetation communities will require the reduction in total grazing pressure across the site (Actions 4.1-4.4) and annual assessment and control of weeds that are preventing native vegetation recovery or restoration will also be implemented.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Waterbird surveys during filling, peak fill and on drying.

Specific Risks

There is a risk that pumping water via the pipeline to the SE depression will not adequately deliver inundation to the woodland, because the water flows through the depression and into Lake Merreti. Close monitoring of the water will allow changes to the regime to prevent this, including the possibility of using irrigation infrastructure to deliver the water.

Clover Lake

Description

Clover Lake is a shallow depression that is filled via a channel from the north-east end of Lake Merreti when floods exceed 65,000ML/day. In larger floods (>100,000ML/day) the lake is also connected to the Ral Ral anabranch via flood channels entering the southern end of the lake.

During dry phases the floor of Clover Lake has grass/herbfield vegetation with extensive areas of bare ground due to high grazing pressure. The lake's riparian dunes are covered by a narrow black box woodland with a sparse chenopod shrub understorey (45ha), with clay depressions on the outside of the lake dunes being covered in sparse black box with open chenopod/samphire shrubland (22ha). The state of the woodlands on the riparian dunes is variable with some areas having predominantly dead or highly stressed trees (score 1 & 2), while substantial areas (20ha) are in a healthy state (score 4). The woodlands on clay depressions are all in a stressed state (Score 2-3).

Figure 7: Clover Lake environmental watering site. The northern yellow polygon indicates the extent of inundation during a 'standard' environmental watering event.

Clover Lake, it is a large shallow waterbody and so has the potential to provide valuable habitat for waterbirds when inundated (Appendix VI). During previous inundations, which occurred in flood situations where waterbird populations are broadly distributed across the whole Murray-Darling Basin, 27 species, representing all functional guilds of waterbirds, were recorded using this wetland.

Recent History

Clover Lake flooded in 2010/11 and dried by June 2012. It flooded again in December 2016 and was drying in October 2017, when it was provided with environmental water to extend the inundation stage. The lake fully dried by October 2018.

Most black box woodlands in the riparian dunes of the lake were in a highly stressed state in 2005, based on NDVI analysis (Table 2). The only exception were woodlands on the south-east corner of the lake, which, though stressed, were in better condition. After the 2010-12 floods, the condition of most black box woodlands associated with the lake had improved in condition, but many were still in a stressed state. Those woodlands on clay flats away from the lake that were not inundated during the flood, showed little improvement post-flood, remaining in a very stressed state. Some areas that showed improvements post-flooding showed returns to pre-flood states by 2017, but most woodlands appeared to maintain their improved state.

Values and Targets

The primary values of Clover Lake are: –

1. the black box woodlands;
2. waterbird habitat;
3. habitat for the bush stone-curlew; and
4. the temporal habitat mosaic – specifically the shifts from terrestrial to wetland habitats that will occur within the lake after the watering regime has been established.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland in 2 of every 5 years for a period of 5-7 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.4, 2.6, & 2.12-2.13);
2. investigate the re-use of environmental water (Target 1) to inundated black box woodlands on adjacent clay flats and if feasible implement by 2025 (Targets 1.2, 2.1-2.2 & 2.12-2.13);
3. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.1-2.4, 2.12-2.13 & 3.1-3.6);
4. control any weeds within the wetland or adjacent habitats that are impeding recovery of habitat components (Targets 2.1-2.4 & 3.7); and
5. investigate the potential to restore and/or facilitate the recovery of a temporal habitat mosaic across the major depression, through inundation, protection from grazing, and other restoration actions by 2025 (Targets 2.4 & 2.12-2.13).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. The process required for water delivery at this site is well established, and the necessary infrastructure has been constructed. The habitat mosaic of the grass/herbfield community on the lakebed during dry-phases and the riparian woodland is valuable habitat for the bush stone-curlew. The improved health of these vegetation communities resulting from an appropriate environmental watering regime will enhance this habitat for this declining species.

The possibility of re-using environmental water delivered to the lake to inundate clay flat woodlands adjacent to the lake requires assessment of infrastructure needs to pump from a shallow water body. If these constraints can be resolved, then including an inundation program into annual watering plans will be done. Additional restoration actions for these sites will be assessed at this planning stage.

Recovery of woodland and wetland vegetation communities will require the reduction in total grazing pressure across the site (Actions 4.1-4.4) and annual assessment and control of weeds that are preventing native vegetation recovery or restoration will also be implemented.

The waterbird habitat value of Clover Lake is primarily as feeding habitat, which would support waterbird population across the Calperum floodplain. Therefore, there are no specific duration requirements for inundation.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Waterbird surveys during filling, peak fill and on drying.

Specific Risks

There is a risk that filling Lake Clover during non-flood periods will result in a rise in the ground water in adjacent clay flat woodlands. This could put additional stress on the black box in these areas. Currently there are 3 test-wells in these flats, but additional wells would be needed to adequately assess this risk. Inundating these clay flats using water from Lake Clover would be a potential means of mitigating this risk and providing additional ecological benefits. This will be assessed during environmental watering events.

Reny Lagoon

Description

Reny Lagoon is a series of small depressions running across Reny Island into the alluvial fan formed by the Widewaters (Figure 8). The northern depression starts to fill via underground recharge during floods that exceed 60,000ML/day. The lower end of the alluvial fan starts to inundate in small floods >5,000ML/day, which includes standard weir pool raising events. However, the entire wetland complex does not fill until floods exceed 90,000ML/day.

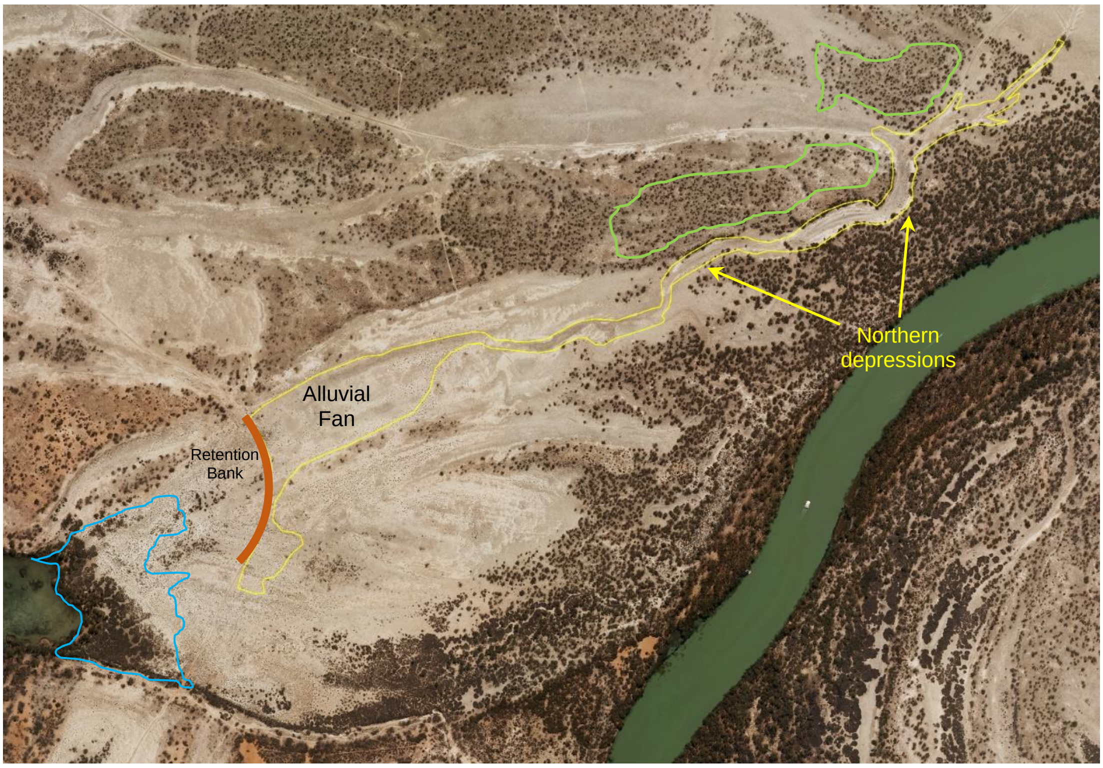
The floor of the two northern depressions supports little vegetation during dry phases. They are surrounded by open black box woodland with a sparse chenopod understorey. Some remnants of lignum grow on the edges of the depressions, but most has died during periods of infrequent flooding. The upper channel that flows into the major depression is bordered by black box woodland, with a very sparse chenopod understorey. The clay flat of the alluvial fan has small patches of black box woodland, scattered coobah and extensive areas of low samphire/chenopod shrubland in dry phases or grass/herbfields post-inundation. This herbfield has extensive areas of the rare species *Calocephalus sonderi* and *Maireana pentagona*, and on the outer edges *Duma horrida*. Lignum extends from the edge of the Widewaters up the alluvial fan wherever it is frequently inundated.

Waterbird habitat is not a primary value of the Reny Lagoon wetland complex. However, the persistent, deep water of the two major depressions will provide valuable habitat for some species, when fringing wetland vegetation communities recover. The alluvial fan also has the potential to provide additional areas of mud flat and herbfield habitat for small waders and grazing waterbirds.

Recent History

Reny Lagoon was flooded in 2010-12 and again in 2016. The wetland system was provided with environmental water for the first time in 2014/15, when the two depressions were filled, and water was pulsed down the alluvial fan over a period of weeks to saturate it. The same process was done in 2016 prior to the arrival of the flood. These attempts were only partially successful as the water showed little lateral spread due to the central shallow channel running down the alluvial fan. Reny Island has limited access and so large machinery is not a viable option for constructing infrastructure such as banks. In 2018, an existing track was raised using ALT's small machinery to create a retention bank (Figure 8). This bank has pipes running through it to allow for natural flows, but can be closed to hold water above the bank's position. The site was watered in 2018/19 using this bank to increase the extent of inundation on the alluvial fan. Successful lateral spread was achieved, but the bank was not high enough and was consequential breached at a low point, causing the loss of the retained water. The bank has since been raised and extended to ensure that it retains water within the alluvial fan in future watering events. This process has also demonstrated that these low retention banks can be created without heavy machinery.

Figure 8: Reny Lagoon environmental watering site. The yellow polygon indicates the extent of inundation during a 'standard' environmental watering event. The blue polygon shows the inundation extent of a 'standard' weir pool raising event. The green polygons show black box woodland that can be watered by re-using environmental water from the major depressions.



Apart from the woodlands in the riparian zone between Reny Lagoon and the Murray River, which have maintained a relatively healthy state over the past 20 years, most black box woodlands associated with this wetland complex showed positive changes in condition after the 2010-12 floods, based on NDVI analysis (Table 2). The woodland patches on the alluvial fan showed less response in the condition of the mature trees, but these areas did have some black box recruitment after the flood. The improvements recorded in 2012 were lost by 2017 for most woodlands based on NDVI measures, but most areas had reasonable recruitment of black box after the flood. The established saplings show some stress, because many are still small enough that high grazing pressure can suppress growth or kill them.

Two lines of lignum were planted across the alluvial fan in 2017 and have been manually watered to allow for their establishment. These lignum strips are designed to slow water flow across the fan and assist with lateral spread to increase the area inundated.

Values and Targets

The primary values of the Reny Lagoon floodplain are: –

1. the black box woodlands;
2. the grass/herbfield community on the alluvial fan;
3. populations of threatened plant species;
4. habitat for the bush stone-curlew;
5. habitat for the common brush-tailed possum; and
6. potential for lateral connectivity between the wetland and the Widewaters that will increase in-stream and floodplain productivity and aquatic biodiversity.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland in 3 of every 5 years for a period of 2-3 months, dependent on antecedent conditions (Targets 1.2, 2.1-2.5 & 2.12-2.13);
2. re-use environmental water on at least 6ha of black box woodlands twice/year for 5 years, dependent on antecedent conditions (Targets 1.2, 2.1-2.2 & 2.10-2.13);
3. restore and/or facilitate the recovery of a grass/herbfield community across at least 5ha on the alluvial fan, through inundation, protection from grazing, and other restoration activities by 2025 (Targets 2.4, 2.5 & 2.10-2.13);
4. restore and/or facilitate the recovery of threatened plant species in 5ha of alluvial fan habitat by 2025 (Targets 2.2 & 2.4-2.5);
5. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.1-2.5, 2.12-2.13 & 3.1-3.6);
6. control any weeds within the wetland or adjacent habitats that are impeding recovery or restoration of habitat components (Targets 2.1-2.5 & 3.7);
7. establish the protocols & procedures and implement before 2025 return flows to the Widewaters of environmental water delivered to the wetland (Target 1.1).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this wetland system. The process required for water delivery at this site is established, and the necessary infrastructure has been constructed. The black box woodlands to the north of the major depressions are in a low stress state (score 3), but their understorey is generally in poor condition and there are some small depressions with elevated soil salinity—indicated by the simple understorey dominated by pigface and samphire. These woodlands also have patches of black box recruits that germinated after the 2010-12 floods, but are stressed by limited water and high grazing pressure. Re-using environmental water from Reny Lagoon to inundate the small depression and/or through irrigation infrastructure will complement the wetland inundation to assist the recovery of these woodlands.

The alluvial fan develops an extensive grass/herbfield after inundation and this community supports large populations of threatened plants, especially *Calocephalus sonderi* and *Maireana pentagona*. These annual species are often grazed before they can complete their life cycle and so watering may be depleting their soil seed banks. Managing grazing pressure on these species will be essential (Actions 4.1-4.4), but providing opportunities for seed production on site and generating seed reserves within the seed nursery will protect and enhance these populations (Action 5.1). Spiny lignum *Duma horrida* once occurred extensively along the margins of the inundated areas, but is now restricted to one small patch. New patches would be established supported by the environmental watering (Action 5.1).

The floodplain woodland/grass/herbfield mosaic that will result from an appropriate environmental watering regime at the Reny Lagoon is excellent habitat for the bush stone-curlew. The floodplain woodlands are connected to the riparian woodlands along the Murray River, which support common brush-tailed possums. Once the control of foxes and feral cats is achieved (Action 6.1), the management of these vegetation communities will enhance this habitat for these declining species.

Past surface water monitoring at Reny Lagoon has showed that the water in this wetland during environmental watering events is high quality (Salinity <450 EC), so this site provides an opportunity to allow real ecological connectivity to be restored between this floodplain and the Widewaters. The opportunity to allow return flows to the Widewaters from this site already exist, via pipes in the retention bank. Therefore, development of the necessary protocols (e.g., water quality assessments and timings of releases) to enable these return flows to happen will be pursued in collaboration with the CEWO and SA government. Once approvals for these flows are obtained implementation will be included in annual water plans.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed elsewhere. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Ongoing Tree Condition Assessments.
3. Surface water quality assessments at 3 locations least 3 times during inundation period.

Specific Risks

There is a low risk that re-used water pumped on to adjacent woodlands could return to Reny Lagoon and reduce water quality. Close monitoring of pumped water to prevent flow back into the depression will prevent this potential risk.

Return flows of environmental water to the river have potential risks associated with declining water quality and black water events. These risks are low for this site, based on existing monitoring data from past watering events. Appropriate risk assessments and protocols will be developed to ensure the risk from return flows are minimised, before they are implemented.

Southern Woolpolool Floodplain

Description

The Ral Ral levee has altered the hydrology of the floodplain south of Lake Woolpolool, preventing flood waters returning to the river and subsequently increasing soil salinity (Figure 9). Consequently, the floodplain, which once supported extensive areas of coobah woodland, now supports low samphire shrublands and, on high elevation flats, *Atriplex* shrublands (Figure 10).

Low sand dunes now support scattered black box (22ha) in a degraded state (score 1-2), with trees on the sides of dunes in better condition than those on dune crests and adjacent clay flats.

Figure 9: The southern Woolpolool floodplain in March 2011 showing the lack of connectivity between the floodplain and Ral Ral creek (right of picture) due to the Ral Ral levee.

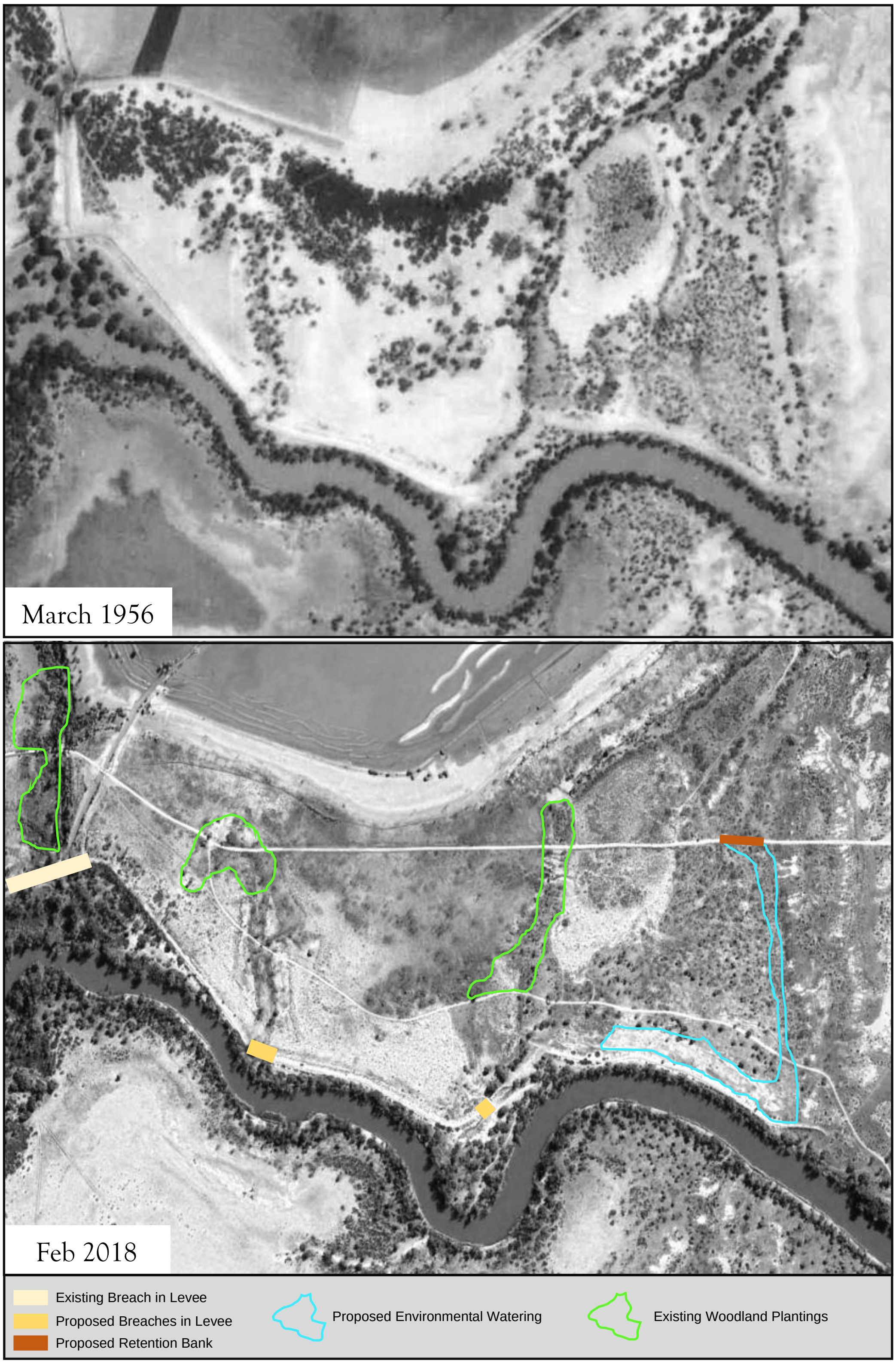
Recent History

Lake Woolpolool was disconnected from Ral Ral Creek prior to the 1950s by a levee along Ral Ral Creek, which prevented any overbank flows into the Lake Woolpolool basin until they exceeded 19m AHD. A regulator was built in 1983 that allowed water into the lake, but the levee continued to prevent floodwaters flushing the floodplain. The levee was partially breached with the construction of a new regulator in 2014. However, the levee still restricts floodwater flow along 1.7km of the creek.

The coobah woodland that extended across the floodplain adjacent to the southern boundary of Lake Woolpolool (see Figure 10) was almost completely lost between 1983 and 2005. The black box woodlands on the dunes in this floodplain were in a severely stressed state in 2005, based on NDVI analysis (Table 2). Significant improvements in the state of these woodlands occurred after the 2010-12 floods and a substantial proportion of these improvements were maintained through to 2017. The condition of individual trees tended to decline more after the floods, at the river end of the flood channels.

In 2011 on the recession of the flood, black box and some coobah seedlings were planted along two sand dunes, which have successfully recruited and are now established saplings (Figure 10). Black box and coobah seedlings were also planted on the flats adjacent to the Lake Woolpolool inlet and these have also successfully established. Minor environmental watering of the Lake Woolpolool inlet (7.4 ha) was delivered in 2014/15 to support establishing saplings (Table 1).

Figure 10: Changes in the vegetation cover of the southern Woolpolool floodplain between 1956 and 2018. Areas of restoration actions are shown on the 2018 photograph.



Values and Targets

The primary values of the Reny Lagoon floodplain are: –

1. the black box woodlands;
2. the cane-grass swamp community;
3. potential coobah woodlands;
4. habitat for the common brush-tailed possum; and
5. potential for lateral connectivity between the floodplain and Ral Ral Creek that will increase in-stream and floodplain productivity and aquatic biodiversity.

The wetland is also an important site for education and community engagement activities.

To protect, maintain and/or restore the values of this wetland system the following specific targets need to be achieved: –

1. deliver environmental water to the wetland, every year for 5 years for a period of 1-2 months, dependent on antecedent conditions (Targets 1.2, 2.2-2.3, 2.5 & 2.10-2.11);
2. restore and/or facilitate the recovery of at least 2ha cane-grass swamp, through inundation, protection from grazing, and other restoration activities by 2030 (Targets 2.2-2.3 & 2.5);
3. restore and/or facilitate the recovery of threatened plant species in at least 2ha by 2025 (Targets 2.2-2.3 & 2.5);
4. manage specific total grazing pressure threats identified for the wetland and adjacent habitats (Targets 2.2-2.3, 2.5, 2.10-2.11 & 3.1-3.6);
5. control any weeds within the wetland or adjacent habitats that are impeding recovery or restoration of habitat components (Targets 2.2-2.3, 2.5 & 3.7);

Management Actions

Along with the opening of the Ral Ral levee (Action 1.1), delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets of this floodplain system. Delivery of water to this site requires the construction of a retention bank (Action 2.1). The black box woodland to the north of the depression is in a degraded state (score 1), but the trees near the depression are in moderate condition and there are black box recruits that would benefit from additional water (6ha of woodland). The understorey of this woodland would also benefit from additional water, especially as soil salinity levels decline.

The recovery of swamp cane-grass within the depression will be achieved through watering, soil remediation and if necessary targeted planting to expand its cover (Action 5.5). Managing grazing pressure (Actions 4.1-4.3) and control of weeds impeding the recovery of species will also be essential for effective restoration of this habitat.

Opportunities to expand on the existing successful plantings of black box and coobah along flood channels and around the environmental watering site will be assessed while monitoring the response of the site to initial watering events.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Tree Condition Assessments.

Specific Risks

There are no site-specific risks for this floodplain site, except those outlined in other actions (see (Action 1.1., 2.1 & 5.5).

Widewaters West

Description

The Widewaters West site is a broad shallow depression surround by sand dunes. It is inundated via the Widewaters when floods exceed 90,000ML/day (Figure 11). This part of the floodplain is in a severely degraded state, with most of the black box woodland (69ha) on the surrounding sand dunes being dead (scores 0-1). These sand dune woodlands now support a degraded, open chenopod shrubland and has extensive areas of bare ground including erosion scalds. Most of the living trees are found adjacent to the depression or scattered across the floor of the depression (9.5ha), and are generally in moderate to good condition. There are also large numbers of black box recruits (around the edge of the depression) from the 2010-12 floods (Figure 11), and these are in moderate condition. The floor of the depression has extensive salt scalds and scattered low shrubs, mainly *Sclerolaena* sp. The lowest part of the depression has a dense cover of *Sclerolaena muricata* with remnant lignums.

Figure 11: Widewaters West environmental watering site. The yellow polygon indicates the extent of inundation during a 'standard' environmental watering event. The green polygons represent areas which contain black box recruits from the 2010-12 floods. The brown bar represents a proposed retention bank.

Recent History

The western side of the Widewaters was last flooded during 2010-11. It has had no management directed toward addressing the increasing soil salinity problem across the area.

All black box woodlands associated with the wetland were in an extremely stressed state in 2005, based on NDVI analysis (Table 2). These woodland areas showed positive changes in condition after the 2010-12 floods. However, many of these trees had died, so the observed NDVI response was likely driven by the understorey as opposed to the tree canopy. The observed improvements recorded in 2012 were lost by 2017, which is not unexpected if it was primarily due to increased understorey cover. Individual trees associated with the depression were and remain in relatively good condition after the flood, but because they are so sparsely distributed their response is not reflected in NDVI measures. The site also had significant recruitment of black box (see Figure 11), and these established saplings are still in moderate to good condition, though some have suffered from over-grazing.

Values and Targets

This floodplain is in a degraded state and so its value is in the potential should it be restored: –

1. the recovery of the black box woodlands;
2. the recovery of the lignum swamp;
3. future potential for lateral connectivity between the floodplain and the Widewaters that will increase in-stream and floodplain productivity and aquatic biodiversity.

To restore the values of this floodplain the following specific targets need to be achieved: –

1. deliver environmental water to the wetland, initially in 4 of every 5 years for a period of 2-3 months, dependent on antecedent conditions (Targets 1.2, & 2.1-2.3);
2. restore and/or facilitate the recovery of at least 25ha of black box, through inundation, protection from grazing, and other restoration activities by 2035 (Targets 2.1-2.2);
3. restore and/or facilitate the recovery of at least 2ha of the lignum swamp, through inundation, protection from grazing, and other restoration activities by 2025 (Targets 2.3);
4. manage specific total grazing pressure threats identified for the floodplain (Targets 2.1-2.3 & 3.1-3.6);
5. control any weeds that are impeding recovery or restoration of this floodplain (Targets 2.1-2.3 & 3.7); and
6. establish by 2025 the potential benefit to in-stream ecology of return flows of environmental water to the Widewaters (Target 1.1).

Management Actions

The delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets for this floodplain system. Delivery of water to this site requires the construction of a small retention bank (Action 2.2). The remnant black box trees and recruits associated with the central depression are in moderate to good condition. These trees would be directly supported by the proposed environmental watering. More importantly, the inundation would address the high soil salinity levels in the depression, and this will allow for the recovery of both trees and the woodland understorey. It is possible that once the soil has recovered through frequent inundation, it may be necessary to actively restore components of the woodland understorey through plantings, but this will not likely be required within the period covered by the current plan. Managing grazing pressure, predominantly from kangaroos (Action 4.1), will be required for the black box recruits to persist.

The recovery of the lignum swamp within the depression will be achieved through watering, soil remediation (Action 5.6) and if necessary targeted planting to expand the cover of lignum. Managing grazing pressure (Actions 4.1-4.3) and control of weeds impeding the recovery of species will also be essential for effective restoration of this habitat.

The floodplain to the west of the Widewaters has never had environmental water provided to it, so it is not known what the quality of the water would be once applied to this system. However, this site provides an opportunity to allow real ecological connectivity to be restored between this floodplain and the Widewaters, once soil salinity has been addressed. So investigation of if and when this opportunity can be realized will be conducted throughout the period of this plan, in collaboration with the CEWO and SA government. These investigations will include development of triggers for when return flows could be considered, and the protocols (e.g., water quality assessments and timings of releases) to enable these return flows to happen when they are deemed appropriate.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Tree Condition Assessments.
3. Surface water quality assessments at 3 locations least 3 times during inundation period.

Specific Risks

The recovery of highly degraded communities is never a certain process, so there is a risk that the proposed management will not achieve the desired outcomes. Detailed monitoring of the site will be implemented to assess the level of response to the applied management and any adjustments will be made based on annual reviews of this monitoring.

Return flows of water to the river have potential risks associated with declining water quality and black water events. These risks need to be assessed for this new site before this management action can be considered. If return flows are deemed possible then appropriate risk assessments and protocols will be developed to ensure the risk are minimised, before they are implemented.

East Calperum Uplands

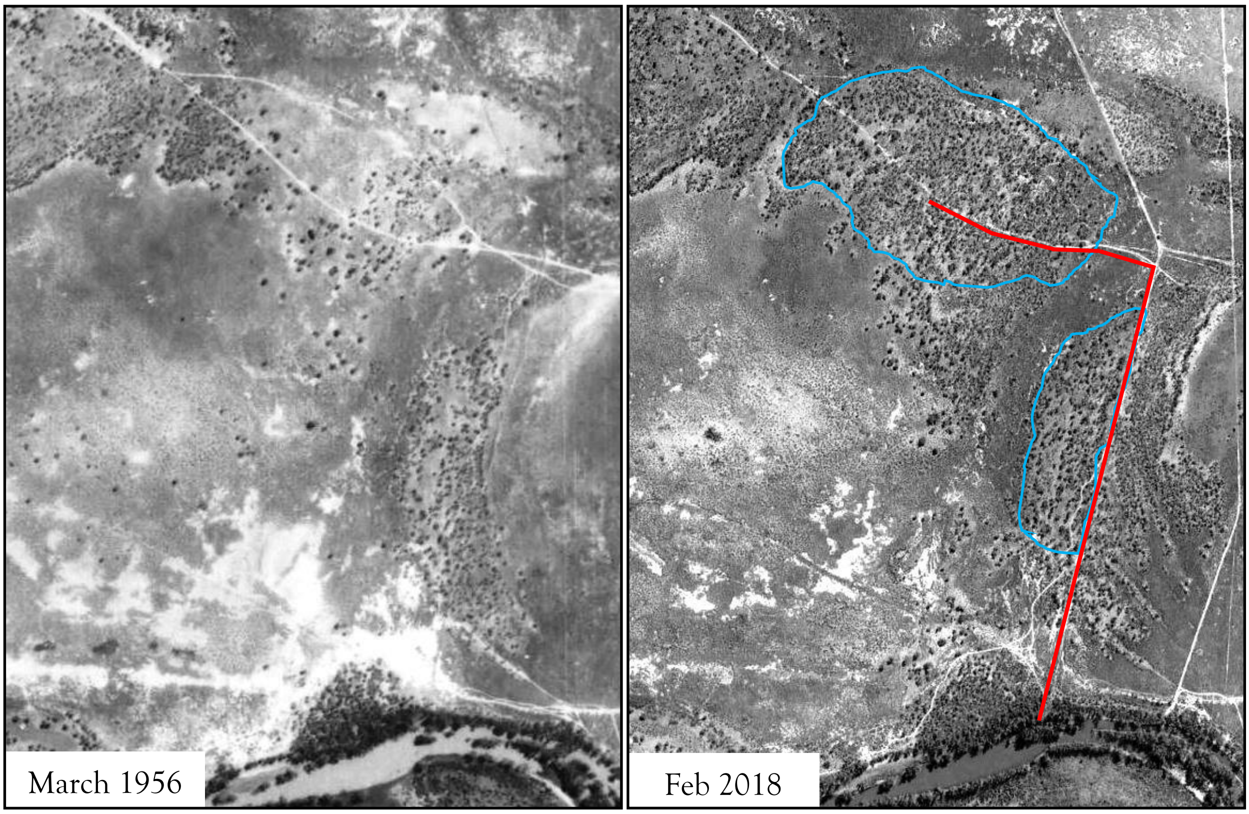
Description

The black box woodland on the eastern boundary of Calperum is a low open woodland with a variable understorey of open to closed *Atriplex* shrubland. The black box in these woodland patches appear to have two distinct size cohorts. Currently, most trees in the smaller cohort are in moderate to good condition, while the larger trees are dead or in poor to moderate condition.

Recent History

It is not clear when the upland black box woodlands were last flooded, but remote data since the 1980s show it has not been flooded since then. It was flooded in 1956 and analysis of 1956, 1979 and current aerial photography suggests that the small-sized tree cohort was established in the 1956 flood (Figure 12). This cohort now represents the best condition trees within the woodland, but there is no evidence on any recruitment since this event.

Figure 12: Changes in black box woodland extent after the 1956 flood. Blue polygons represent the areas for the proposed environmental watering. The red line represents the proposed pipeline for delivering water.



Black box woodlands associated with the eastern uplands were in a stressed condition in 2005, based on NDVI analysis (Table 2). In 2012 these woodlands showed significant improvement, despite not being inundated, which was likely due to the high rainfall during 2010 and 2011. By 2017, NDVI data suggested that these woodlands were again stressed, but they were still in a better state compared to their 2005 state.

Values and Targets

The primary values of the eastern Calperum uplands are: –

1. the black box woodlands;
2. potential populations of threatened plant species; and
3. potential habitat for bush stone-curlew.

To protect, maintain and/or restore the values of this woodland system the following specific targets need to be achieved: –

1. deliver environmental water 4 times/year annually for the next 5 years to protect and recover >22ha of upland black box woodland, dependent on antecedent conditions (Targets 1.2 & 2.1-2.2);
2. establish a new cohort of black box within the upland woodland, through inundation, protection from grazing, and targeted planting by 2030 (Target 2.2);
3. restore and/or facilitate the recovery of the *Atriplex*/chenopod understorey cover to meet identified health and structural measures in >22ha of upland black box woodland by 2025 (Targets 2.2, 2.5 & 2.12-2.13);
4. investigate the potential to restore and/or facilitate the recovery of threatened plant species in the upland black box woodland by 2022 (Targets 2.2 & 2.5);
5. manage specific total grazing pressure threats identified within the woodlands (Targets 2.2, 2.5, 2.12-2.13 & 3.1-3.6); and
6. control any weeds within the woodlands that are impeding recovery or restoration of habitat components (Targets 2.2, 2.5 & 3.7).

Management Actions

Delivery of environmental water, as outlined in Tables 3 & 4, is the primary action required to achieve the targets for this woodland system. The infrastructure required to deliver the environmental water needs to be constructed (Action 2.5) and will provide an opportunity to water two woodland patches covering 31ha. This is a new environmental watering site, so careful annual evaluation of the site's response to watering will be implemented to ensure the proposed regime is delivering the desired outcomes. The intention is to inundate at least two areas each year on 2-4 occasions throughout the year. The precise regime will depend on the response of the woodland patch to each event.

The site has the potential to support threatened plant species and this will be assessed and if appropriate restoration activities will be implemented (Action 5.1); and site-specific protection of vegetation from grazing using exclosures and branching techniques, plus soil remediation for scalds will facilitate the recovery of this woodland community (Action 5.6).

These upland woodlands also provide potential habitat for the bush stone-curlew. Once total grazing pressure (Actions 4.1-4.3) and the control of foxes and feral cats is achieved (Action 6.1), the management of the tree and understorey health within these woodlands will enhance the habitat for this species.

Specific Intervention Monitoring

Operational monitoring, ecological monitoring and monitoring associated with restoration programs are detailed in Appendix VIII. The intervention monitoring to assess the delivery of site-specific targets for this wetland system are:

1. Photopoints before, during and after (on drying) event.
2. Tree Condition Assessments.

Specific Risks

There are no site-specific risks for this woodland site, except those outlined in other actions (see (Action 2.5, 5.1 & 5.6).

Implementation

The site watering schedules outline in this plan are indicative only (Tables 3, 4 & 5). The annual delivery of environmental water to these sites is dependent on a range of regional and local considerations. The first is the effect of any flood events in the Murray-Darling Basin, which would alter the conditions at each site and therefore when it would need to receive water again. When there is limited environmental water available to the Commonwealth Environmental Water Holder prioritisation of the sites intended to be watered will be made, based on risks to the ecological recovery of each site and maximising the environmental benefit gained from the available water. The requirements of the individual sites will also vary from year to year depending on antecedent conditions, driven mainly by what water it received in previous years. However, because many of these sites are new, it also depends on the response of management targets to past watering events. Finally, watering activity can vary depending on what other sites are being watered or what other management actions are being implemented that may by complementary to an environmental watering event. These various factors will be assessed and the proposed watering actions for a given year will be outlined in an annual watering plan. This annual plan, given the proposed water schedule, will be finalised and ready for approval in July of each year.

Environmental watering will be delivered through a combination of: -

5. large pumps (generally 12" pumps) contracted from commercial operators (currently Millewa Pumping) to deliver the bulk of water to the larger sites,
6. a smaller pump (6" pump) owned/operated by ALT (see Action 3.1) to deliver water to smaller sites and maintenance water to larger sites, and
7. two smaller pumps (4" pumps) owned/operated by ALT (see Action 3.1) used for delivering water through pipe and irrigation infrastructure.

This gives the program the flexibility to enable water to be delivered to each site whenever it is required in the most cost-efficient way. Many of these sites need to maintain their inundation for several months longer than would occur if the wetland was simply filled and then allowed to drawdown. Therefore, they need additional water sometime after filling has been completed. Contract pumps would need to either remain on site for several months incurring rental costs for an inactive pump, or the costs of setting up the pump again would be incurred. Further if the initial pump is retained on site, this large pump is not the most cost-effective means of delivering the smaller, slower fill requirements of maintenance water. ALT's approach is to have a smaller pump that will be able to move to each site as required to provide maintenance water as needed (estimated saving over 5 years $62,810: see Action 3.1). This also gives ALT the flexibility to provide only the water needed at the time it is needed, which is difficult to do when using contract pumps.

Other complementary management activities, such as control of total grazing pressure and weeds (Action 4), restoration projects (Action 5) and management of introduced predators (Action 6) will be coordinated with the watering regime to maximise their effectiveness. Operational, intervention and ecological monitoring will be conducted on all sites during each watering event as detailed in Action 7. Finally, environmental watering actions will be used for training the Riverland Indigenous Rangers—who will carry out much of the fieldwork—and for engaging with the community through volunteer restoration activities and education programs (Action 8).

Table 3a: Environmental watering parameters for the eight wetland sites. Woolpolool Swamp SW and SE are part of the Woolpolool Swamp complex. All volumes are in megalitres. The estimated volume to fill the site includes seepage and loss due to evaporation during filling. The duration of fill is the period when the site is maintained in a fill state before allowing it to drawdown. Water to maintain the wetland in a full state is based on loss due to evaporation.

Site	Area filled (ha)	Estimated volume to fill	Duration of fill (Days)	Estimated volume to maintain	Estimated Total Volume	Method	Infrastructure required
Thookle Thookle	28.9	260	30	60	270	Pump	None
Reny Lagoon	20.2	80	30	42	122	Pump	None
Merreti East	121.4	330	30	251	581	Pump	None
Amazon	64.6	209	30	134	343	Pump	None
Woolpolool Swamp	54.4	602			602	Pump	None
Woolpolool Swamp SW	20.1	47	30	42	89	Re-use, pump	None
Woolpolool Swamp SE	11.2	17	30	58	75	Pipeline	Pipeline
Clover Lake	133.5	1287			1287	Pump	None
Widewaters West	24.0	99	30	50	149	Pump	Retention bank
Woolpolool Floodplain	3.2	5	30	10	15	Pump	Retention bank

Table 3b: Environmental watering parameters for the five upland woodland sites. All volumes are in megalitres. The estimated volume includes seepage and loss due to evaporation (where appropriate) during the watering event.

Site	Area filled /event	Estimated volume to fill	Times /year	Estimated Total Volume	Method	Infrastructure required
Thookle Dunes	13.8	6.5	4	26	Re-use, pump	None
Reny Floodplain	11	10	2	20	Re-use, pump/irrigation	Irrigation
Amazon Uplands West	9	15.5	2	31	Re-use, pump/irrigation	Irrigation
Amazon Uplands	6	4.5	4	18	Pump/irrigation	Irrigation
Eastern Uplands	11.0	18.5	4	74	Pipeline/irrigation	Pipeline & Irrigation

Table 4: Environmental watering regime for nine primary systems and six associated sites (indented) for 2019/20 through to 2024/25. Sites in red involve the re-use of environmental water from their primary site.

Management Site	Area (ha)	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	Total Proposed
Thookle Thookle	28.9	155		270	245		270	940
Thookle Dunes	13.8		26	26	26	26	26	130
Reny Lagoon	20.2	65	120		120	120		425
Reny Floodplain	11.0	10	20	20	20	20	20	110
Merreti East	121.4		580	580	200	580	580	2,520
Amazon	64.6	160	345	210		345	210	1,270
Amazon Uplands West	7.0	11	31	31		31	31	135
Amazon Uplands	6.0	9	18	18	18	18	18	99
Woolpolool Swamp	54.4		600	600		600	600	2,400
Woolpolool Swamp SW	20.1		90	90		90	90	360
Woolpolool Swamp SE	11.2			75	75	75	75	300
Clover Lake	133.5				1,300		1,300	2,600
Widewaters West	24.0	100	150		150	150		550
Woolpolool South	3.2		15	15	15	15	15	75
East Calperum Uplands	31.0			75	75	75	75	300
Environmental Water	**498 ha**	**489**	**1,828**	**1,843**	**2,198**	**1,978**	**3,143**	**11,479**
Re-used Water	**52 ha**	**21**	**167**	**167**	**46**	**167**	**167**	**735**
Total Water Pumped	**550 ha**	**510**	**1,995**	**2,010**	**2,244**	**2,145**	**3,310**	**12,214**

Table 5: Annual environmental watering schedule for the proposed sites. Sites in red involve the re-use of environmental water from their primary site. Blue represents months during which water is pumped from the river to the site, while green represents re-use of water by pumping it from the main site.

Site	Water (ML)	2020-21									
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Thookle Thookle											
Thookle Dunes	26										
Reny Lagoon	120										
Reny Floodplain	20										
Merreti East	580										
Amazon	345										
Amazon Uplands West	31										
Amazon Uplands	18										
Woolpolool Swamp	600										
Woolpolool Swamp SW	90										
Woolpolool Swamp SE											
Clover Lake											
Widewaters West	150										
Woolpolool South	15										
East Calperum Uplands											
Total	**1995**										

Table 5 contd: Annual environmental watering schedule for the proposed sites. Sites in red involve the re-use of environmental water from their primary site. Blue represents months during which water is pumped from the river to the site, while green represents re-use of water by pumping it from the main site.

Site	Water (ML)	2021-22									
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Thookle Thookle	270										
Thookle Dunes	26										
Reny Lagoon											
Reny Floodplain	20										
Merreti East	580										
Amazon	210										
Amazon Uplands West	31										
Amazon Uplands	18										
Woolpolool Swamp	600										
Woolpolool Swamp SW	90										
Woolpolool Swamp SE	75										
Clover Lake											
Widewaters West											
Woolpolool South	15										
East Calperum Uplands	75										
Total	**2010**										

Site	Water (ML)	2022-23									
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Thookle Thookle	245										
Thookle Dunes	26										
Reny Lagoon	120										
Reny Floodplain	20										
Merreti East	200										
Amazon											
Amazon Uplands West											
Amazon Uplands	18										
Woolpolool Swamp											
Woolpolool Swamp SW											
Woolpolool Swamp SE	75										
Clover Lake	1300										
Widewaters West	150										
Woolpolool South	15										
East Calperum Uplands	75										
Total	**2244**										

Table 5 contd: Annual environmental watering schedule for the proposed sites. Sites in red involve the re-use of environmental water from their primary site. Blue represents months during which water is pumped from the river to the site, while green represents re-use of water by pumping it from the primary site.

Site	Water (ML)	2023-24									
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Thookle Thookle											
Thookle Dunes	26										
Reny Lagoon	120										
Reny Floodplain	20										
Merreti East	580										
Amazon	345										
Amazon Uplands West	31										
Amazon Uplands	18										
Woolpolool Swamp	600										
Woolpolool Swamp SW	90										
Woolpolool Swamp SE	75										
Clover Lake											
Widewaters West	150										
Woolpolool South	15										
East Calperum Uplands	75										
Total	**2145**										

Site	Water (ML)	2024-25									
		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Thookle Thookle	270										
Thookle Dunes	26										
Reny Lagoon											
Reny Floodplain	20										
Merreti East	580										
Amazon	210										
Amazon Uplands West	31										
Amazon Uplands	18										
Woolpolool Swamp	600										
Woolpolool Swamp SW	90										
Woolpolool Swamp SE	75										
Clover Lake	1300										
Widewaters West											
Woolpolool South	15										
East Calperum Uplands	75										
Total	**3310**										

Monitoring

The monitoring required to effectively deliver this environmental watering program consists of: –

1. Operational – assessing the delivery of water and project management (Appendix VIII);
2. Intervention –assesses site-specific outcomes based on management targets (in site descriptions and Appendix VIII); and
3. Ecological – assesses the short and long-term ecological outcomes of the program (Appendix VIII).

Operational monitoring will be collected daily and reported to CEWO monthly and an annual report will be complied at the completion of the watering program (Action 7.1). Intervention monitoring will be collected on an events basis and reported annually. while ecological monitoring will be on-going on an annual basis with at least 5-yearly assessments and review. The costs for intervention and some ecological monitoring are included in the costings of this Appendix. The costs of additional ecological data collected from the entire Calperum floodplain and addressing multiple management actions are covered by the ecological monitoring and research action of the plan (Action 7.3).

The intervention monitoring is site or project-specific and so is detailed under each site, or in the action associated with the management objective. The minimum intervention monitoring will involve photopoints of the sites and some measures indicating delivery of the identified management targets. The monitoring outlined under each site is included in the costings outlined in this Appendix. Intervention monitoring will be reported on annually, and a full report will be compiled at the end of each planning phase (5 years).

Ecological monitoring assesses the short and long-term delivery of the plan's ecological objectives and ultimately its aim. Therefore, much of this monitoring addresses more than one site and/or management issue and so it has been outlined in the monitoring section of the main plan (Action 7). One exception is the monitoring the ecological responses of woodland communities to environmental watering. The cost of delivering this for each site is included in this Appendix, while additional tree condition monitoring across other parts of floodplain are costed within Action 7.3. This monitoring also provides complements the data for research done by ALT, through external funding from the Ian Potter Foundation, looking at floodplain woodland fauna responses to environmental watering.

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Overton, IC, Boyd, A and Coff, B 2017. *Site Investigation for Black Box at Calperum Station South Australia: Trial Implementation of the Draft Black Box Management Framework*. Report prepared by Jacobs Pty Ltd for the Commonwealth Environmental Water Office, Adelaide, South Australia

Risk Assessment for Environmental Watering Program

This assessment is of the overall program where the issues are potentially related to most or all sites. Additional site-specific risks are outlined in each site proposal and those associated with specific infrastructure or complementary management are outlined under the specific action proposal.

Risk	Description of risk (location, timing, etc)	Controls in place or planned for managing risk	Likelihood	Consequence	Risk rating
			(After controls in place)		
Social, Cultural, Heritage and Economic					
Inundation impacts on people, home and property, farmland (pasture, crops and stock), infrastructure, recreational areas, Aboriginal and European cultural heritage sites through direct inundation; or contribution to downstream inundation	No risks	All environmental watering is conducted on Calperum Station, which is owned and operated by the Australian Landscape Trust.	No likelihood		None
Reputational damage to Australian Landscape Trust and/or CEWO as a result of community concern about the planning, implementation and/or consultation on an event.	Negative attitude of local community to use of environmental water, especially when irrigation water restrictions are in place.	Well documented plan/justification for environmental watering program. Education and communication of program to the local community through ALT's community programs.	Likely	Minor	Low
Environmental					

Risk	Description of risk (location, timing, etc)	Controls in place or planned for managing risk	Likelihood	Consequence	Risk rating
			(After controls in place)		
Hypoxic blackwater (low dissolved oxygen). Refer to Basin Plan target (s.9.14(5a))	Flow of low-quality water from inundated wetland into river.	Only allow return flows if they meet established water quality levels.	Rare	Moderate	Low
Increases in river salinity Refer to Basin Plan target (s.9.14(5c))	Flow of higher salinity water from inundated wetland into river.	Only allow return flows if they meet established water quality levels. When return flows occurring, monitor salinity levels and prevent flow to river if measurable increase in salinity downstream is observed.	Rare	Minor	Low
Blue-green algal blooms Refer to Basin Plan target (s.9.14(5b))	Flow of high nutrient water from inundated wetland into river.	Natural floodplain so no high nutrient risks from human activity. Only allow return flows if they meet established water quality levels.	Rare	Minor	Low
Disturbance of acid sulphate soils/mobilisation of poor sediment affecting water quality	No evidence of acid sulphate soils at Calperum.	All water movement is monitored and will cease if undesirable sediment movement occurs.	Rare	Moderate	Low
Spread of weeds	Establishment of weeds such as golden dodder on inundated wetland sites.	Assessment/control of weeds during planning for sites. Monitoring/control of weeds post-watering and after site has dried.	Unlikely	Moderate	Low

Risk	Description of risk (location, timing, etc)	Controls in place or planned for managing risk	Likelihood	Consequence	Risk rating
			(After controls in place)		
Enhancement of existing threatening processes (over-hunting, over-fishing, over-grazing)	Over-grazing of fringing vegetation during watering event and of wetland vegetation post-inundation.	Management Actions 4.1 to 4.4, which outline an integrated control program for total grazing pressure. **Risk will decline with time.**	Unlikely	High	Medium
Adverse impact on native, endemic or high priority species	Unintended consequences of management on native species.	Comprehensive management plan addressing whole of floodplain management. Monitoring of flora and fauna to assess management outcomes.	Rare	Moderate	Low
Unintended geomorphic impacts (including erosion)	Creation of banks altering floodwater inundation patterns	Insert pipes in banks to allow floodwater inundation. Minimise size and height of banks to maximise flood overflow. Remove banks if no longer required.	Unlikely	Moderate	Low
Environmental damage resulting from pumps or other delivery infrastructure	Access tracks to pumping sites causing vegetation damage.	Use of existing tracks wherever possible. Appropriate management of track to prevent deterioration with constant use. Rehabilitation of tracks when sites are no longer used. Monitoring and control of weeds on created tracks.	Unlikely	Minor	Low
Operational					

Risk	Description of risk (location, timing, etc)	Controls in place or planned for managing risk	Likelihood	Consequence	Risk rating
			(After controls in place)		
Environmental objectives not achieved	Environmental water fails to deliver proposed targets.	5-year planning process to ensure certainty of management delivery for long-term objectives. Ongoing monitoring and adaptive management processes for plan ensuring progress is made. Cessation of future watering if expected response not evident and no adaptation feasible.	Rare	Moderate	Low
Infrastructure failure	Retention banks fail during inundation preventing delivery of outcomes	Annual monitoring to determine maintenance requirements. Budgeting of funds by ALT to cover required maintenance.	Rare	Moderate	Low
Water required exceeds planned allowance	Estimates of water required inadequate for expected response.	Previous site responses assessed against water delivery. Conservative estimates with continuous evaluation of delivery to use only what is required.	Rare	Minor	Low
Transmission loss	Pumping short distances through pipes, so no transmission loss	Appropriate monitoring of pumping infrastructure to assure it is operating effectively.	Rare	Minor	Low
Diversionary loss	No water diversion direct pumping to site		No likelihood		None

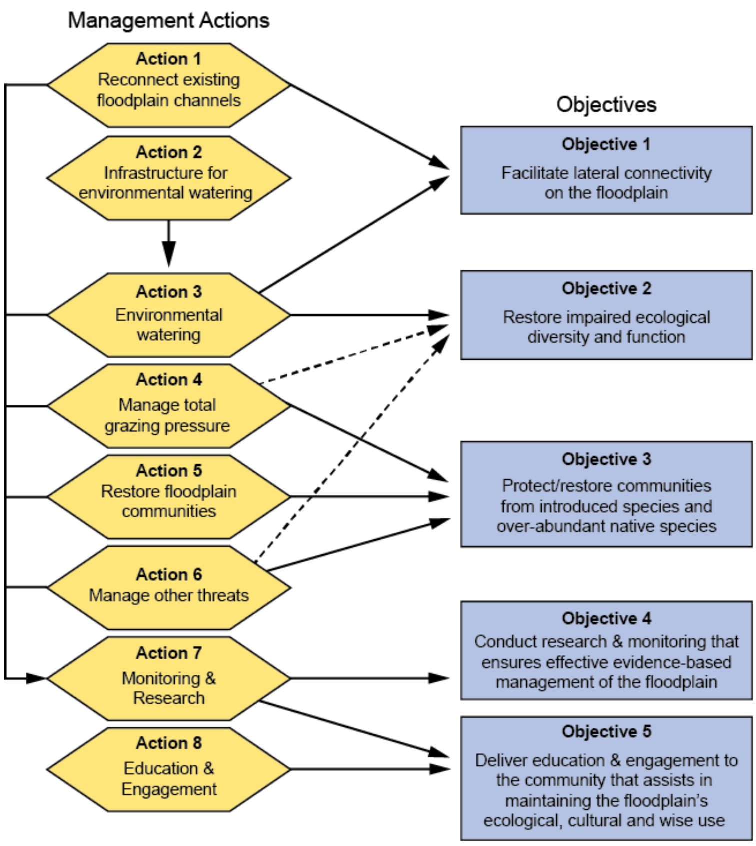
Appendix VIII

Framework for the Evidence-based Management of the Calperum Floodplain

Introduction

A fundamental requirement of management approaches is the collection and review of information about management actions and how the system responded to them—monitoring. Monitoring seeks to determine if the management actions delivered have progressed the system toward the outcomes articulated by the objectives of the recovery plan, and if they have achieved this in an efficient manner. Therefore, the design of a monitoring framework requires a clear statement of the relationships between management actions and recovery objectives (Figure 1). This recovery plan has identified six sets of management actions that will deliver outcomes for four ecological objectives. One of these actions (Action 2) does not directly deliver on any objective, but is required to the deliver other management (Action 3) and is therefore essential to delivering objectives 1 and 2. A seventh set of management actions (monitoring and research) delivers improve ecological outcomes and provides information for the final set of management actions (Action 8), which delivers broader ecological and social outcomes through the dissemination to the community of information gained from the recovery process.

Figure 1: The relationship between the eight broad management actions and the five objectives of the Calperum floodplain recovery plan. Dashed lines indicate indirect relationships between actions and objectives.



This framework outlines the monitoring approach and the core monitoring that will be conducted in this plan. The specifics of some monitoring will depend on the precise nature of the management actions implemented, so specific monitoring actions are addressed elsewhere (Action 7 and Appendix VII) or will be identified in annual implementation plans.

Monitoring and Research Framework

The scientific literature outlines many approaches to implementing restoration of ecological systems (e.g., Margoluis & Salafsky 1998, Sabine *et al.* 2004, Overton *et al.* 2018). These approaches have a common form with sequential steps from planning to implementation, followed by review and reassessment of the plan (Figure 2). However, it is rarely possible to implement these systems sequentially in real restoration programs. Projects usually start with broad goals based on general knowledge of what is possible in the given situation. These goals then direct the development of some form of conceptual model that then refines the project's goals. This iteration is essential—one component cannot follow the other—because an appraisal of the situation is predicated on some form of conceptual model, and a good conceptual model needs the relevant context from the situation that is being dealt with. A consequence of this iterative process is that management generally commences before the model is complete. Providing there is appropriate assessment and review, this is not a problem to effective management. One benefit of these early on-ground works is that they can provide valuable site-specific information that can refine the program's conceptual model and management strategies.

As restoration is implemented, good project teams will review and reassess their program and refine all aspects of it (Figure 2). This assessment and review take a wide range of forms, from gains in knowledge due to new research (either as part of the project or from the literature) to evaluation of targeted monitoring of both implementation outputs and ecological outcomes. Refinements from this review process are not only via the fundamentals of the project (i.e., conceptual model and situation appraisal), but also directly through specific restoration actions identified in implementation plans. Some management will be abandoned on practical grounds (e.g., adequacy of available equipment or staff, financial constraints) without reference to either the conceptual model or its appropriateness to the site. Assessment, review and refinement are an ongoing and incremental process, with many small improvements occurring continuously, with rare monumental changes in approach. Each cycle improves the overall effectiveness of the restoration program, either through improved understanding of the site or how it functions, better focus on what really matters to achieve the program objectives, and/or more effective restoration techniques.

Monitoring is "*… the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective*." (Elzinga *et al.* 2001). Consequently, monitoring is only necessary if changes to management options exist, because there is little point in monitoring something if the results of the monitoring make no difference to future management. There are many terms used to describe the types of monitoring that are conducted as part of a management program. In this plan we differentiate monitoring by three terms (modified from CEWO 2013), which distinguish between outputs and outcomes, and site-based and system-based results of management (Figure 2):

> **Operational monitoring** is the how, when and quantity of management output implemented in relation to specific site-based actions. Its purpose is to address question of management efficiency and to provide measures of management output that can be used to interpret intervention and ecological monitoring.

Intervention monitoring is the means for measuring the outcomes of management actions on specific sites against site-based targets. Its purpose is to assess the effectiveness of the action in achieving the desired result at the specific site. However, the data collected during intervention monitoring can also be used by research projects that seek to understand how the system operates; and therefore, refines the conceptual model on which the plan is based.

Ecological monitoring is the means of understanding if management is achieving the objectives of the plan. It addresses questions of whether the actions resulted in the expected outcomes for the Calperum floodplain and has that resulted in the ecosystem changing in the desired ways. Like intervention monitoring it also provides data that can be used by research projects that seek to understand how the system operates; and therefore, refines the conceptual model on which the plan is based.

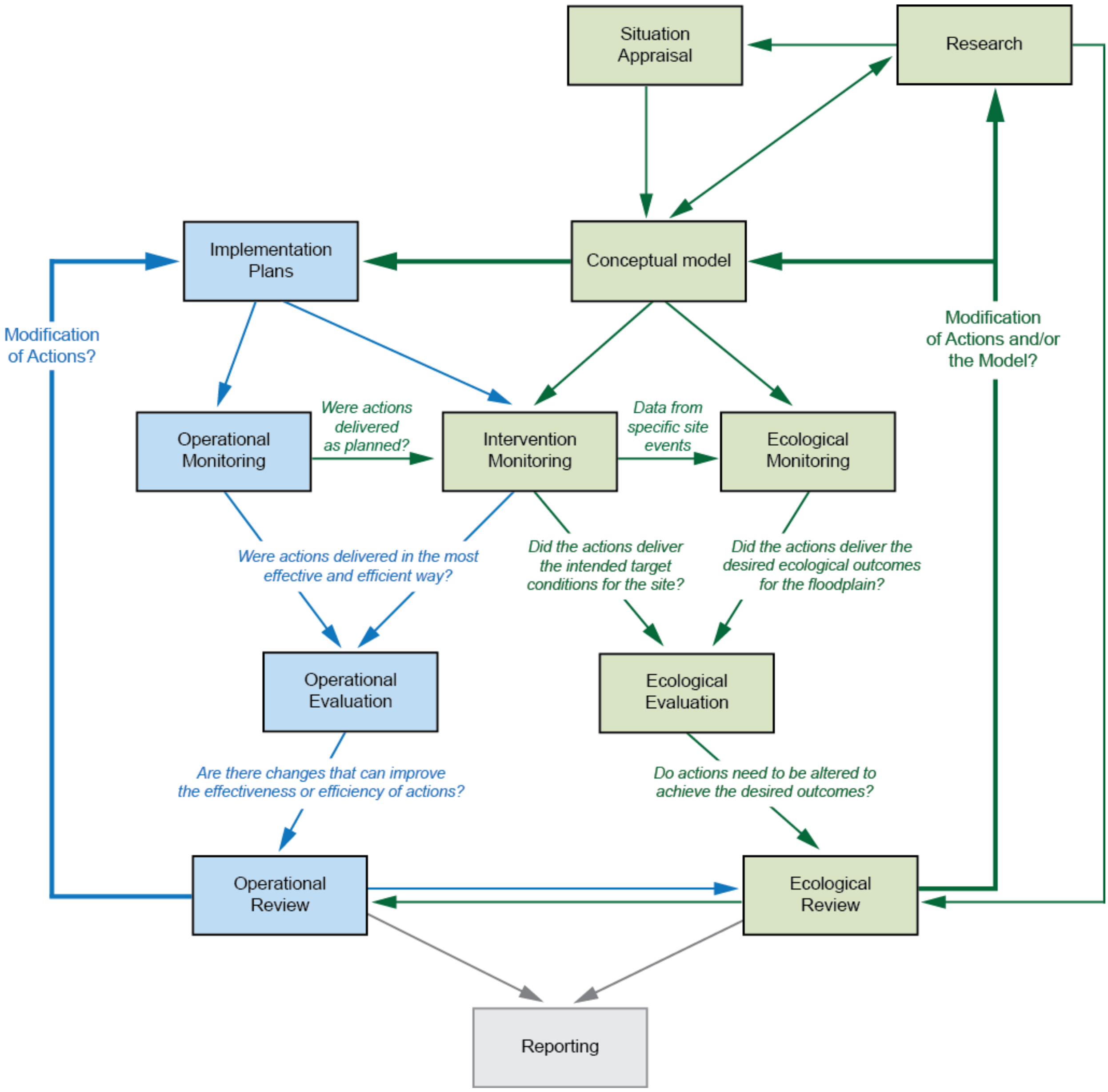


Figure 2: The monitoring and research framework for the Calperum floodplain recovery plan. Blue relates to operational monitoring and green relates to intervention and ecological monitoring.

Effective management requires information about the current state of the site being managed and how the ecological characteristics of the site are changing in response to threats and implemented management. Generally, this information is seen as providing the ability to assess what has been achieved by management, but in fact this information is as fundamental to the delivery of restoration as the specific management actions applied to induce change (e.g., environmental water delivery). Without this data being collected before and throughout the management phase the outcomes of management will fail to achieve the desired objectives. For instance, inundation of a floodplain site is a disturbance; and, as with all disturbances, it has positive and negative consequences for different elements within the community. Therefore, indiscriminately applying environmental water to a site can do as much damage to the site's ecology as taking no action or preventing inundation. Management sites are effectively unique, because of the complex interaction between ecological characteristics and the threats they are subject to. So, although generic management protocols can be developed for similar sites with similar problems, they are indicative only. The next management requirements for a site can only be determined through ongoing assessment of how the site has responded to past management (ecological review) and for effective actions how efficiently they were delivered (operational review). Some have mistakenly termed this process adaptive management, but it is simply good management. Adaptive management differs in that its focus is advancing management through the broader understanding of how the system works and responds to generalised management approaches. In other words, it is as much about research as management. This is important for improved long-term management, but initially site management has more immediate needs to ensure it is generating the desired outcomes.

This recovery plan is titled evidence-based recovery, because it is premised on the philosophy that application of both monitoring and research are fundamental requirements of effective management practice. Without both it is not possible to gain a better understanding of how the system functions and the most practical way to restore it. Although monitoring and research have different purposes, much of the data collected as part of monitoring management actions is the same data required for good research on the system being managed. Therefore, within a management program, the differences between the two are often differences in focus not content. The monitoring and research framework developed here seeks to maximise the integration of the two, while clearly recognizing the different questions being address by the two activities.

Operational Monitoring

Operational monitoring documents management outputs and this monitoring can be broadly grouped into six program areas with similar monitoring outcomes. This operational monitoring will provide documentation on what was actually delivered under each management action, when it was delivered, what resources were used to deliver it (e.g., staff time, and financial costs), and any issues that occurred in delivering the outputs.

Infrastructure Program

The infrastructure program (Actions 1 & 2) delivers various forms of infrastructure (e.g., retention banks, irrigation pipelines) that allow for other management programs to be delivered. The monitoring associated with this program is all operational and will collect data on the following generic outputs:

1. Characteristics of the infrastructure (e.g., length and height of retention bank, length of pipe, etc.);

2. Capacity of infrastructure (e.g., area inundated by bank or irrigation pipe);
3. Efficiency of infrastructure (e.g., volume of water used to irrigate site);
4. Outcomes of establishment (e.g., condition of retention bank post-inundation);
5. Resource costs of delivery (e.g., staff time, financial costs); and
6. Issues encountered in delivery of infrastructure.

Infrastructure monitoring generally involves once off data collection related to its construction, but some monitoring involves annual data collection to assess the efficiency of the infrastructure in delivering the required outcomes.

Environmental Watering Program

The environmental watering program is outlined in Appendix VII and involves delivery of environmental water to a range of sites across the Calperum floodplain using several different techniques. Operational data relates to the water delivered, temporal aspects of delivery and consequent drawdown, and the resource costs.

1. Start and finish dates for each pumping event;
2. Volumes of water pumped and at what rate;
3. Duration of drawdown period;
4. Duration of inundation for each site;
5. Fuel required to deliver water volume;
6. Resource costs of delivery (e.g., staff time, financial costs); and
7. Issues encountered in delivery.

Most of this monitoring is collected daily throughout a watering event and is compiled and reported on monthly, with a final report at the end of each watering season.

Integrated Control of Pest Species

An integrated control plan for managing total grazing pressure (Action 4), introducer predators (Action 6) and weeds (within Action 5) will be developed based on the proposed sites that are approved for delivery, and this will detail the monitoring regime. Operational monitoring for pest control covers the quantities of control substances (e.g., fox baits, trap nights, etc.), the area covered and timing of control activities, where possible the number of individuals controlled, and the resources required to deliver the activities.

1. Area and timing of pest surveys;
2. Area and timing of control actions;
3. Number of control units (e.g., fox baits laid, kilometres of rabbit baiting, traps set, *etc*.);
4. Numbers controlled (e.g., kangaroos shot, goats mustered, weeds removed, *etc*.);
5. Resource costs of delivery (e.g., staff time, financial costs); and
6. Issues encountered in delivery.

This data varies in the frequency of collection, but all data will be collected and reviewed annually.

Restoration Program

The restoration program involves the management of specific patches on floodplain vegetation communities associated with environmental watering sites, threatened plant recovery and the remediation of scalds. A restoration plan will be developed based on the proposed sites that are approved for delivery, and this will detail the monitoring regime. Operational monitoring for these restoration projects provides data on the plant resources collected or produced to deliver restoration outcomes, area covered by the activity, and the resources required to deliver the activities.

1. Plant resources (e.g., seed collected, number of plants propagated, *etc.*);
2. Location and number of plants established for each species;
3. Area of each restoration activity (area branched, area seeded, etc.);
4. Level of support for establishment (e.g., number of seedlings guarded, watering regimes, etc.);
5. Resource costs of delivery (e.g., staff time, financial costs); and
6. Issues encountered in delivery.

This data varies in the frequency of collection, but all data will be collected and reviewed annually.

Monitoring Program

The monitoring program itself is also monitored to ensure that all the relevant information is being collected, analysed and reviewed in an appropriate manner to achieve the purpose of the monitoring. This monitoring will also document the resources required to deliver it.

Community and Education Program

Community engagement in the delivery of this recovery plan is an important focus for ALT. The recovery program will also serve as an opportunity for practical learning in our education programs. The specific activities associated with engagement and education will be determined based on the proposed sites that are approved for delivery.

1. Numbers of volunteers and duration of involvement in activities;
2. Number of participants involved in education units;
3. Number of communication resources and the number of individuals exposed to them;
4. Resource costs of delivery (e.g., staff time, financial costs); and
5. Issues encountered in delivery.

This monitoring will be collected on an event by event basis and reviewed annually.

Intervention Monitoring

Intervention monitoring measures the achievement of site-specific targets, which are subsets of the Calperum floodplain management targets. Therefore, intervention monitoring is best determined for each management target, with the location of each monitoring activity being guided by which sites contribute to the delivery of the Calperum floodplain target.

Management target 1.1 and 1.2 relate to changes in hydrological regimes across the floodplain, and so are addressed in ecological monitoring. Likewise, management targets related to the recovery or control of fauna populations (Targets 2.8, 2.10, 2.13, 3.1-3.6 and 3.8-3.9) apply to the whole floodplain and so are addressed in ecological monitoring.

All intervention monitoring is primarily related to environmental watering or restoration projects. The environmental watering program is detailed in the site-specific implementation plan (Appendix VII), which identifies the necessary intervention monitoring for each watering site. The implementation plan for the restoration projects identified in Action 5 is part of the proposed action and this plan will identify the necessary intervention monitoring for each site.

Table 1: Intervention monitoring for relevant management targets. This monitoring is related to environmental watering (Action 3) and restoration (Action 5) activities, so the site-specific monitoring protocols will be determined within the relevant implementation plans for these actions.

Management Target		Relevant Actions	Monitoring Measures
1.3	Reduce soil salinity.	1.1, 1.3 & 3.2	· Field soil salinity testing · Laboratory soil chemical testing · Groundwater depth and salinity testing
2.1	Maintain/improve the condition of floodplain trees.	3.2	· Tree condition assessments
2.2	Restore floodplain woodland communities.	3.2 & 5.1-5.6	· Understorey health & structure measures · Understorey species diversity · Seedling abundance & survival (natural & planted)
2.3	Re-establish wetland vegetation communities.	3.2, 5.1, 5.4 & 5.5	· Vegetation health & structure measures · Vegetation species diversity · Seedling abundance & survival (natural & planted)
2.4	Facilitate recovery of other floodplain communities.	3.2, 5.2 & 5.6	· Vegetation health & structure measures · Vegetation species diversity · Seedling abundance & survival (natural & planted)
2.5	Restore floodplain scalds	5.2, 5.3, 5.5 & 5.6	· Soil accumulation measures · Abundance of seedlings · Vegetation cover · Vegetation species diversity
2.6	Restore populations of threatened plant species.	3.2, 5.1 & 5.3-5.6	· Species cover, abundance & health · Seedling germination · Seedling abundance & survival (natural & planted)
2.7	Protect/restore conditions for waterbird breeding.	3.2	· Species nest abundance · Breeding completion rates · Nest success
2.8	Restore cane-grass swamp communities.	3.2, 5.1, 5.3 & 5.5	· Species cover, abundance & health · Seedling germination · Seedling abundance & survival (natural & planted)
2.9	Improve *Planigale gilesi* habitat.	3.2, 5.1-5.4 & 5.7	· Extent of cracking clay · Mean depth & length of cracks · Vegetation cover
2.11	Improve *Trichosurus vulpecula* habitat.	3.2 & 5.7	· Tree condition assessments · Understorey health & structure measures · Understorey species diversity
2.13	Improve *Burhinus grallarius* habitat.	3.2, 5.2, 5.3 & 5.7	· Vegetation cover · Extent of coarse woody debris · Proportion of site with degraded soil condition
3.7	Control specific weeds inhibiting recovery.	3.2 & 5.1-5.5	· Species cover before & after control · Species recruitment post-control

Ecological Monitoring

Ecological monitoring assesses broader, longer-term outcomes in relation to the objectives of the recovery plan (Table 2). The ecological monitoring identified takes two forms: 1/ data collected across the Calperum floodplain to address large scale questions, such as hydrological connectivity and the management of fauna populations; and 2/ up-scaling, to the entire floodplain, of site-specific data collected as part of the intervention monitoring (see Table 1).

Results chains are a diagrammatical approach to identifying the expected outcomes from management and consequently the key factors that need to be monitored to assess whether the outcomes have been achieved (Margoluis *et al.* 2013, Schwartz *et al.* 2018). The content of results chains is derived from the conceptual model (Appendix III), which describes how the system functions and therefore how it is expected to respond to any form of manipulation. Results chains can take a range of forms, but all contain three core elements; they identify the action, the expected results of that action in the short and medium-term, and the expected long-term outcome from the action if it is implemented successfully. Monitoring can then be identified to access the various stages of the chain. This is the approach taken to identify and describe the ecological monitoring for this recovery plan.

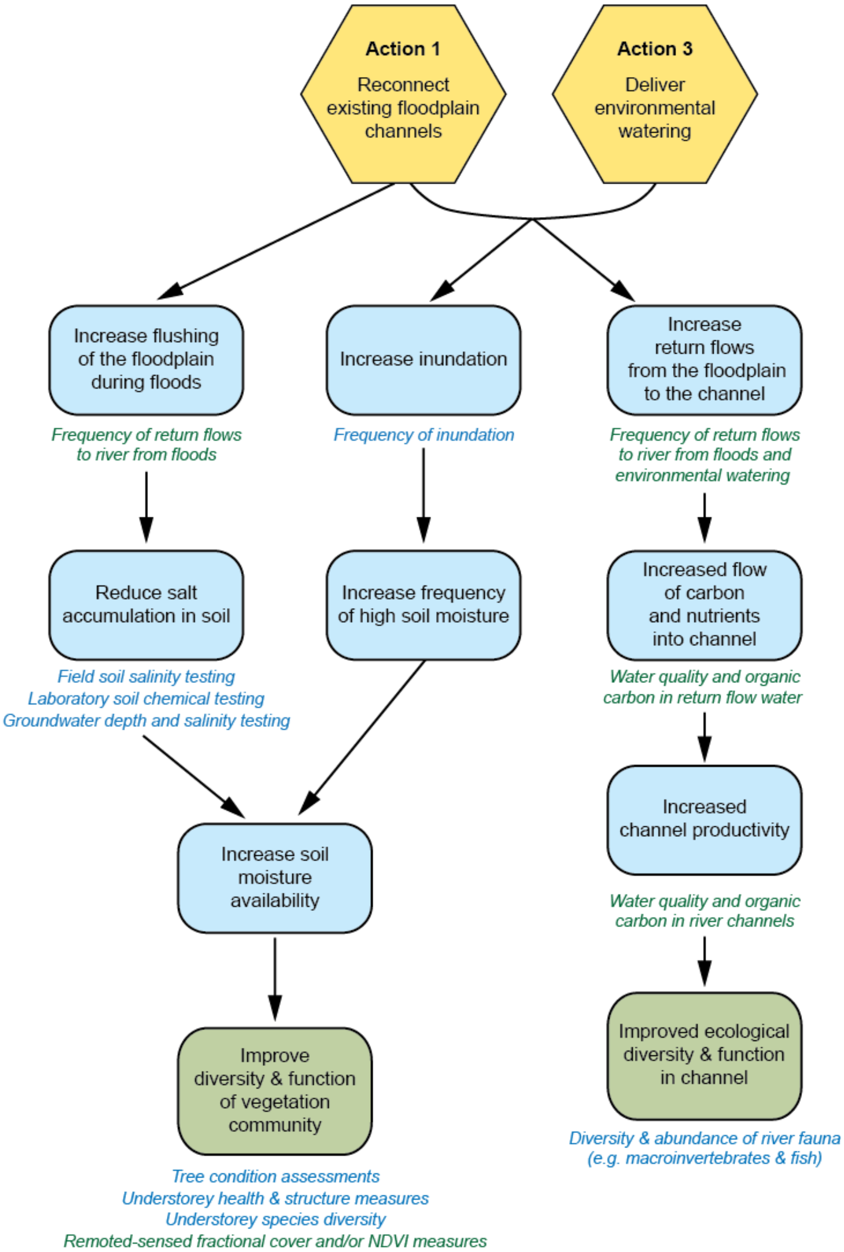
The monitoring described in each chain is either intervention monitoring that delivers ecological monitoring outcomes or is monitoring addressing whole of floodplain outcomes. The six results chains are categorised within the three core ecological objectives of the plan (Objectives 1-3 in Figure 1). These objectives are interdependent and so the actions considered may have outcomes for multiple objectives. However, the results chains only identify those components that are being considered for ecological monitoring.

Objective 1 *Facilitating the movement of water across the floodplain landscape*

Enhancing the lateral connectivity of the Calperum floodplain and thereby facilitating the movement of water across the landscape is delivered by two sets of actions (Figure 1). There are two long-term outcomes expected from these actions (Figure 3). The first, is an improvement in vegetation condition on the floodplain, due to an increase in soil moisture availability resulting from reduced soil salinity and an increased frequency of inundation. The second, will depend on the viability of allowing return flows to river channels from environmental watering. If possible, return flows will result in an improvement in ecological diversity and function within the river system due to an increase in carbon and nutrient inputs from the floodplain.

The ecological monitoring of these outcomes will be delivered primarily through intervention monitoring at environmental watering sites, which will identify the frequency and type of flows between the river channels and the floodplain (Figure 3). Achieving the first outcome of this objective can be assessed by measures of floodplain vegetation condition in areas with and without increased connectivity. This will be delivered, in part, by intervention monitoring of vegetation condition in management sites, but other sites across the floodplain will also have to be monitored to cover the whole Calperum floodplain. The design of a monitoring program assessing indicators of in-stream productivity and biological diversity in relation to return flows would be part of the process for implementing return flows from the environmental watering program (Appendix VII).

Figure 3: The results chain diagram for Objective 1: *Facilitating the movement of water across the floodplain landscape*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.

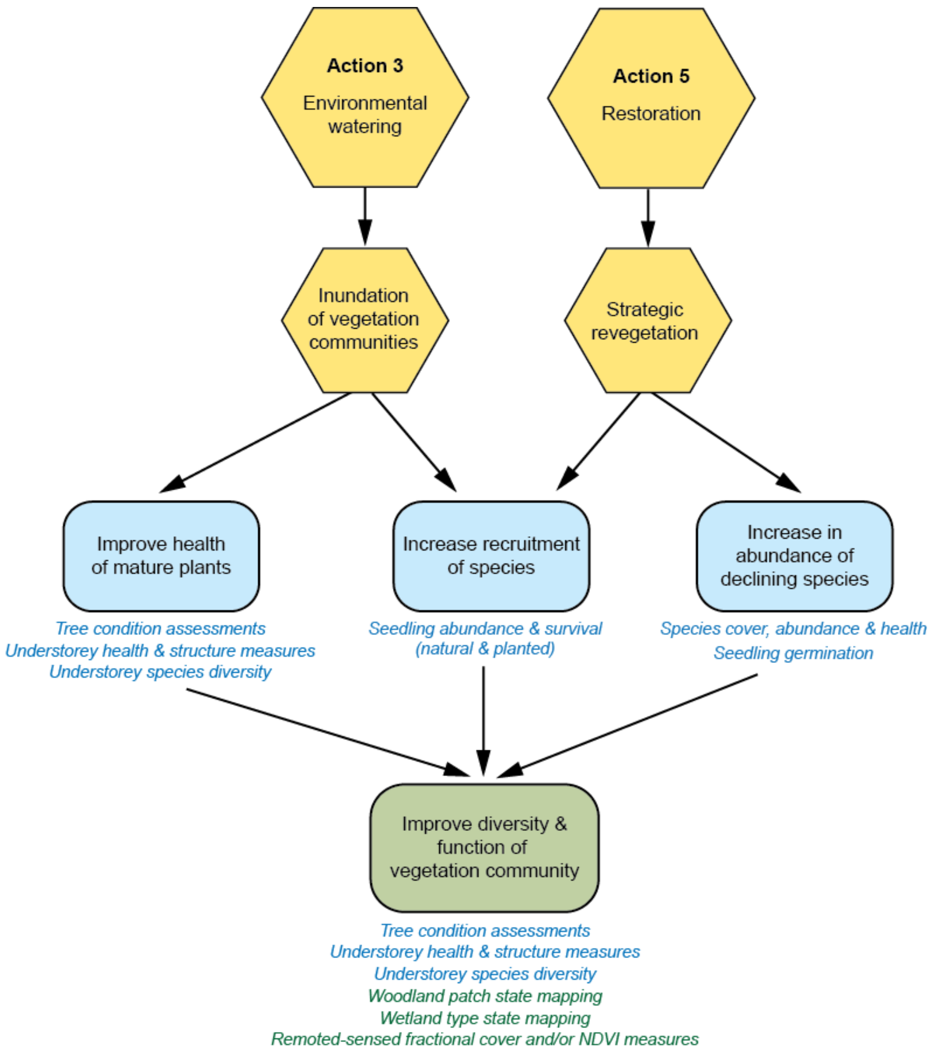


Objective 2 Restoring impaired ecological diversity & function within floodplain communities

The actions required to restore community diversity and function can be varied and are specific to the site being considered. Therefore, detailed results chains can only be developed for each site and these will be created within the site restoration plans. However, there are three core floodplain outcomes from this objective, the ecological monitoring for which has been documented here. The first is restoration of diversity and function in floodplain communities through the delivery of environmental water and supporting restoration actions (Figure 4). The second is protection and recovery of the waterbird community on the Calperum floodplain (Figure 5); and the third addresses the remediation and recovery of the most degraded areas of the floodplain—soil scalds (Figure 6).

Maintaining the existing floodplain trees is a core focus of this recovery plan; because if they were lost it would require decades if not centuries of active management to restore the ecological functions these trees provide. The primary means of delivering this outcome is through environmental watering (Figure 4). However, trees don't live in isolation and other components of the floodplain woodlands are essential for the successful maintenance of the tree canopy. Many of these other community components are also supported by environmental watering, but for some this action is not enough to maintain the health of mature individuals and enhance recruitment of new individuals. In these situations, additional restoration actions will be needed to achieve the desired outcome (Action 5).

Figure 4: The results chain diagram for Objective 2: *Environmental watering to improve vegetation communities*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.



As this management needs to be site specific, most of the ecological monitoring required to assess this outcome is related to intervention monitoring associated with environmental watering (Appendix VII) and that collected for restoration actions associated with the recovery or planting of vegetation (see Table 1: Targets 2.1-2.6 & 2.8). However, periodically it will be important to assess the collective outcome of the site-based restoration activities, and so landscape-scale assessments of the state of floodplain woodlands and wetland ecosystems will be done. The floodplain woodland mapping conducted for this plan (Appendix IV) provides half of this monitoring, the second component looking at wetland systems will need to be developed as part of wetland restoration planning (see Actions 5.4 & 5.5).

The intervention and ecological monitoring collected on the effect of environmental watering on tree health will be enhanced by the current research conducted by CSIRO and past collaborative research looking at detailed responses of floodplain trees to changes in available water (see Collaborative Research)

Waterbirds are an important component of floodplain communities. Maintaining the existing use of the Calperum floodplain and facilitating the recovery of waterbird populations are therefore core goals of Objective 2. Achieving this requires management that will produce the appropriate spatial and temporal elements of wetland habitats through the delivery of environmental water (Figure 5). The provision of foraging habitat and the delivery of water to allow for the successful completion of breeding events within Calperum wetlands are the requirements of this management. The monitoring required to assess these two results is delivered primarily through the wetland-based intervention monitoring described in Appendix VII (Figure 5). However, the desired outcome of increased diversity and abundance of waterbirds on the Calperum floodplain can only be adequately determined from landscape-scale, long-term monitoring of waterbirds, which will be done on a seasonal basis across the whole Calperum floodplain.

Some areas of the Calperum floodplain have been degraded to an extent where they are now in a new ecological state that resists recovery. The most obvious of these are soil scalds across the floodplain, which support virtually no vegetation cover. These scalds can cover extensive areas effectively forming new ecological systems, or be localised patches within degraded vegetation communities. In both situations the management is similar, but for the extensive areas the focus turns to site remediation prior to considering restoration of a vegetation community.

Intervention monitoring at each scald management site will determine if remediation of the scald has been successful and when combined will identify if scalded areas of the floodplain are returning to a state where recovery of floodplain communities is possible. A landscape-scale assessment, using remote and ground-based measures of scald extent and condition, will be developed and implemented for the entire Calperum floodplain to ascertain if the ultimate outcome of this management—improvement in the overall condition of the floodplain—is being achieved. The ecological and intervention monitoring associated with managing scalds will also provide data for the research being conducted through the Ian Potter Foundation early-career ecology fellowship (see Collaborative Research). This research will expand the knowledge of how branching to remediate scalds assists with fauna habitat and with over-grazing of plants regenerating in scald areas.

Figure 5: The results chain diagram for Objective 2: *Environmental watering to create wetland habitats for waterbirds*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.

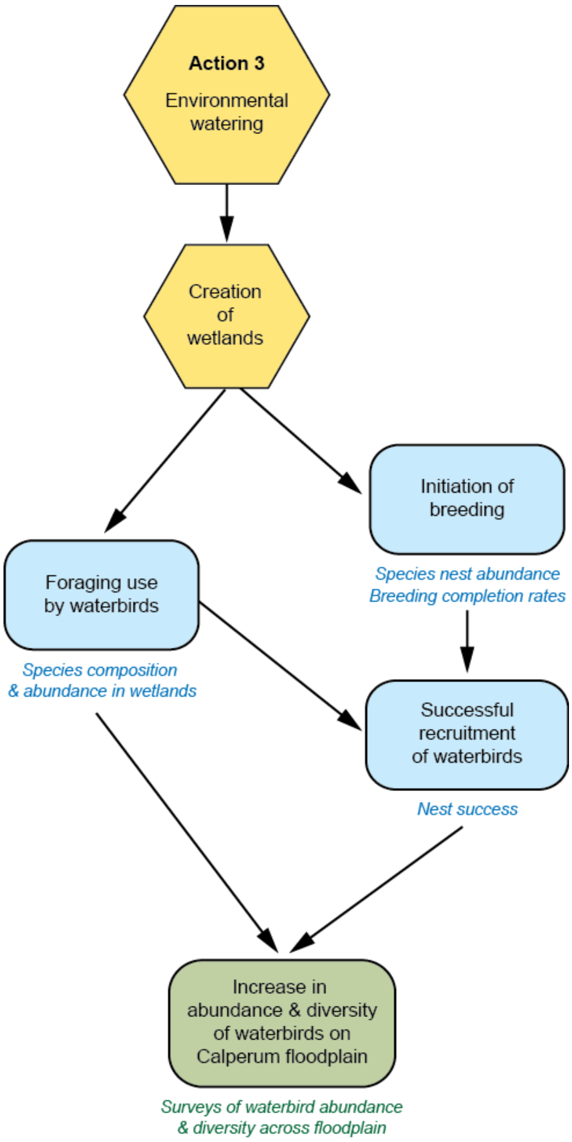
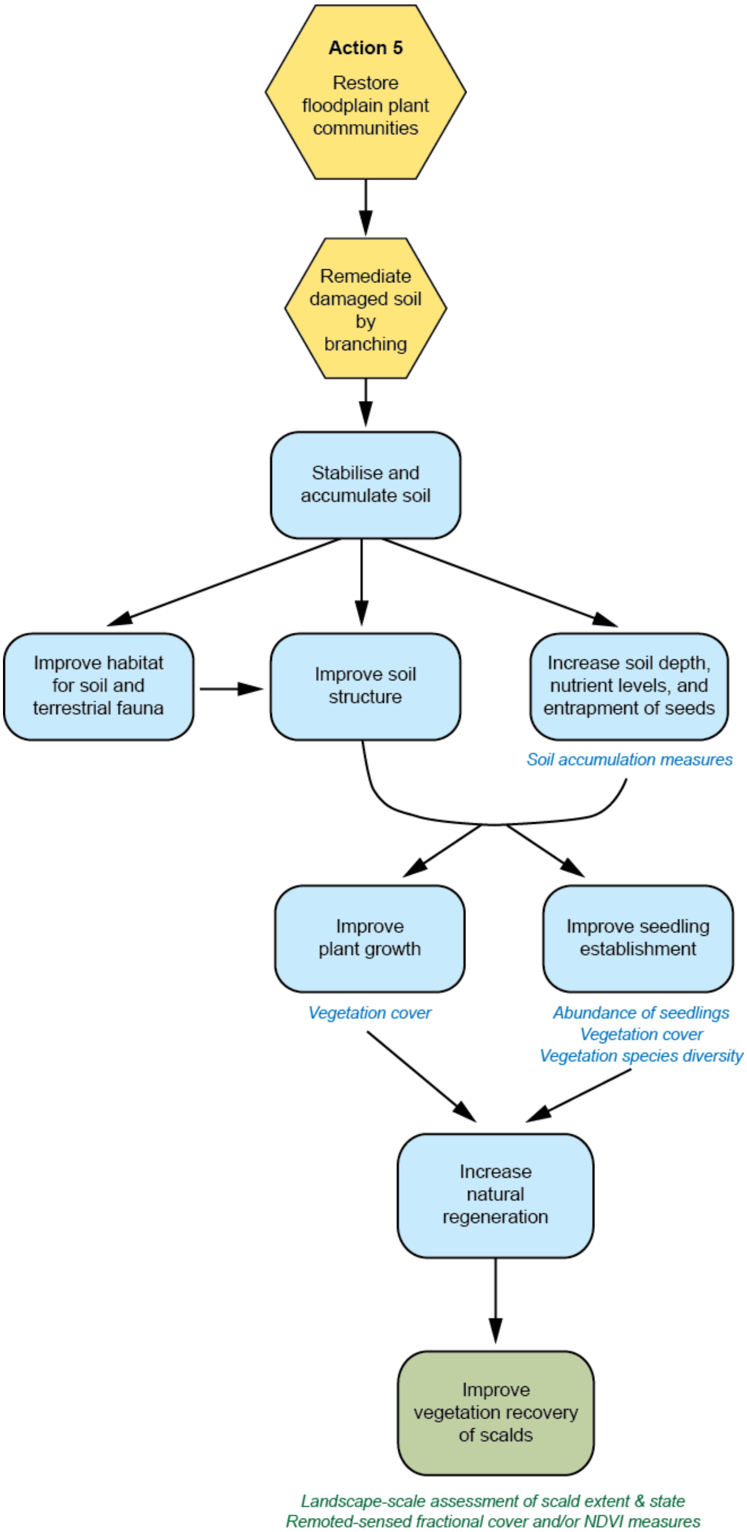


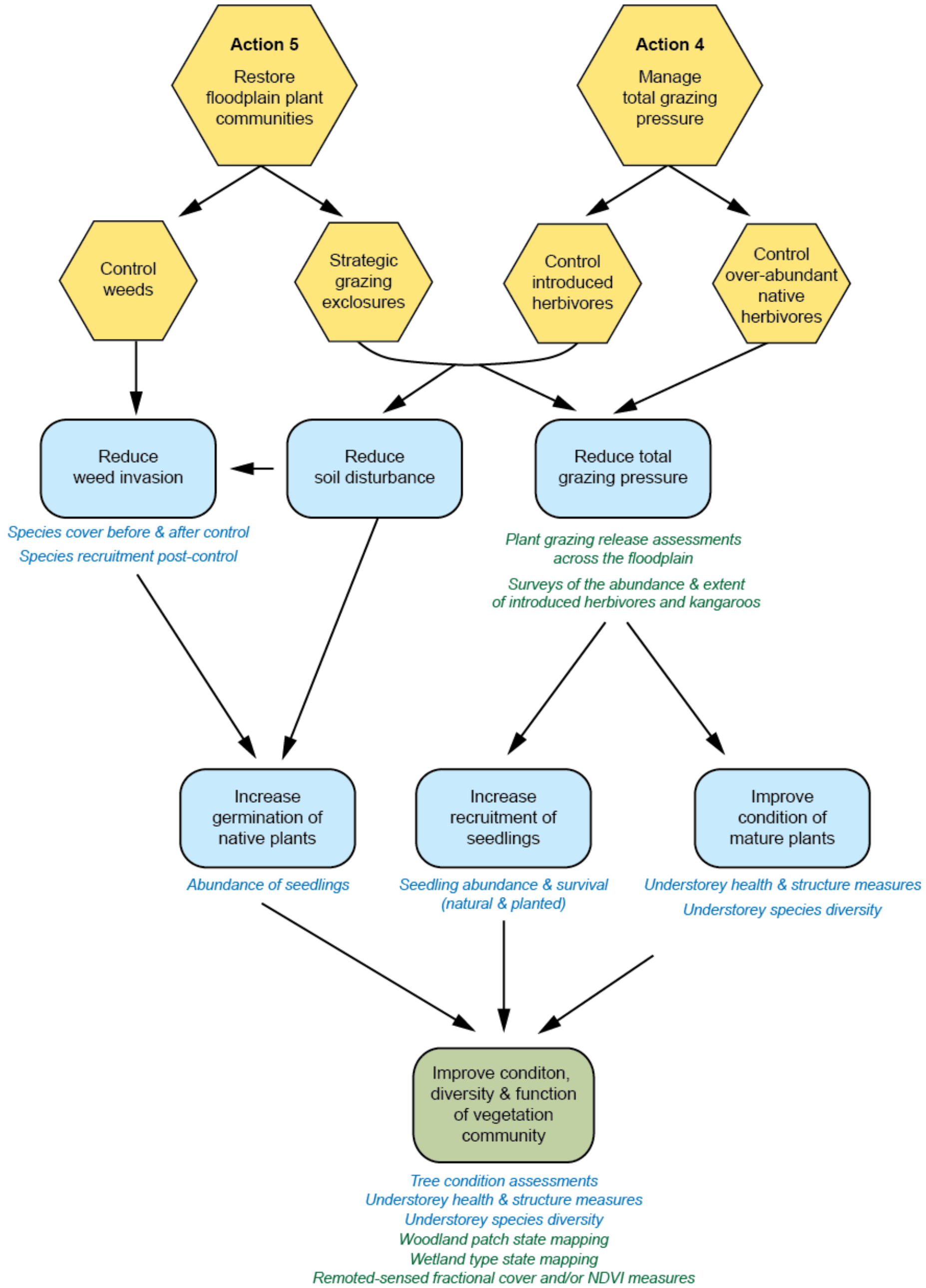
Figure 6: The results chain diagram for Objective 2: *Improving ecological function through the remediation of soil scalds*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.



Objective 3 Protecting/restoring ecosystems by managing pest species

Over-grazing of vegetation by introduced and over-abundant native herbivores, and mortality of fauna from introduced predators are major threats to the viability and recovery of the Calperum floodplain ecosystem. Managing total grazing pressure allows for the recovery of plant and animal populations and improves the success of restoration activities designed to increase species abundance and recruitment (Figure 7). Ecological monitoring to determine if reductions in grazing pressure have led to improved recovery from other restoration actions (Action 5) is best done through intervention monitoring of those restoration sites.

Figure 7: The results chain diagram for Objective 3: *Protecting/restoring vegetation communities by managing total grazing pressure*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.



Determining if there is improved recovery of vegetation across the floodplain requires a landscape-assessment. Monitoring of managed and unmanaged sites will allow a determination of the level of influence reduced grazing pressure is having. This ecological monitoring will comprise ground-based assessments, including grazing exclosures, and possibly remote-sensed fractional cover and/or NDVI measures from Landsat imagery. Assessing whether reductions in the abundance of herbivores has been achieved is conducted across the entire landscape, though site specific differences can provide important context to this landscape-scale monitoring.

Foxes and feral cats are common across the Calperum floodplain and these species are a significant threat to a range of native animals dependent on the floodplain. The purpose of controlling these introduced species is to reduce the level of predation in relation to the population size and productivity of predated native species (Figure 8). This can also be achieved by improving the quality of the vegetation these native species occupy, so this management action is strongly interrelated to other restoration actions. Further, determining predation levels is extremely hard to do. Therefore, the focus of the ecological monitoring for this action is on the changes to introduced predator populations and changes in the abundance of focal native species, as opposed to direct measures of changes in predation rates.

Figure 8: The results chain diagram for Objective 3: *Protecting/restoring fauna communities by controlling introduced predators*. Yellow hexagons describe the core action and the specific actions relevant to this chain. Blue boxes describe the expected short/medium-term results from the action and the green box describes the expected long-term outcome. Blue text indicates ecological monitoring via collation and up-scaling of intervention monitoring. Green text indicates ecological monitoring focused on the whole floodplain.

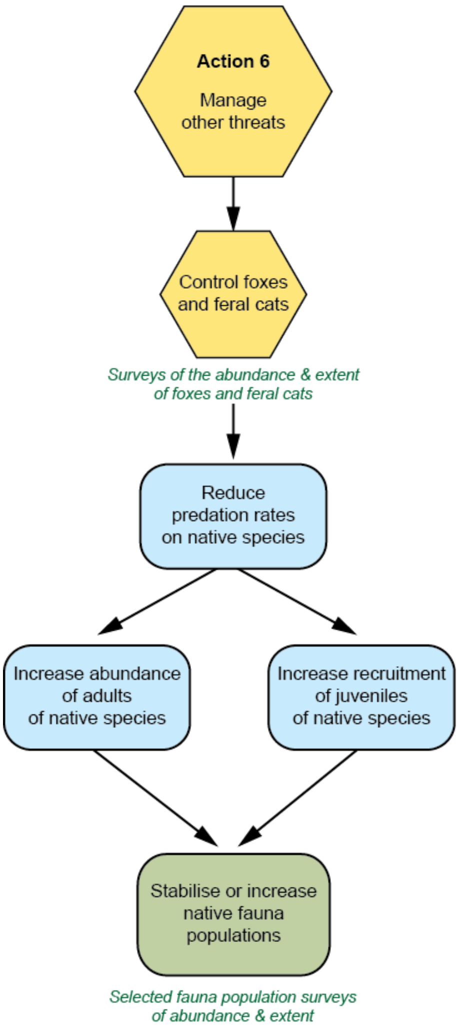


Table 2: Summary of ecological monitoring. This monitoring is supported by the up-scaling of intervention monitoring associated with specific management actions at specific sites (see Table 1).

Outcome	Results chain	Objective monitored	Ecological Monitoring
Improved condition of vegetation	Figure 3, 4 & 8	1-3	· Vegetation condition assessments from intervention monitoring and additional sites · Woodland patch state mapping · Remoted-sensed fractional cover and/or NDVI measures
Improved ecological diversity & function in river channels	Figure 3	1	· Measures of abundance & diversity of fauna (e.g., macroinvertebrates, fish)
Increased abundance & diversity of waterbirds	Figure 5	2	· Surveys of waterbird abundance and diversity across the Calperum floodplain
Improved vegetation recovery of scalds	Figure 6	2	· Landscape-scale assessment of scald extent & state · Remoted-sensed fractional cover and/or NDVI measures
Improved diversity & function of vegetation communities	Figure 4 & 7	2-3	· Vegetation health, structure & diversity measures from intervention monitoring and additional sites · Plant grazing release assessments across the floodplain · Woodland patch state mapping · Wetland type state mapping · Remoted-sensed fractional cover and/or NDVI measures
Reduced abundance of introduced herbivores and kangaroos	Figure 7	3	· Surveys of the abundance & extent of introduced herbivores and kangaroos
Reduced abundance of introduced predators	Figure 8	3	· Surveys of the abundance & extent of foxes and feral cats
Stabilised or increased native fauna populations	Figure 8	3	· Surveys of the abundance & extent of common brush-tailed possums · Surveys of the abundance & extent of *Planigale gilesi* and other small native mammals · Surveys of the abundance & extent of bush stone-curlews

Collaborative Research

The role of research within this recovery plan is to advance the long-term refinement of management through improved understanding of how the system functions (conceptual model) and consequently responds to changes induced by management actions. Much of this research can be delivered directly through implementation of the management plan, but independent research projects can contribute to this process by providing information on aspects of the system's ecology that are not currently manipulated by management, or by investigating mechanism that drive ecological change. The Australian Landscape Trust has always encouraged and where possible facilitated researchers to deliver such research at Calperum Station, and as a result there has and continues to be a range of research projects operating on the Calperum floodplain.

In 2017 ALT was successful in securing at least 3 years of funding from the Ian Potter Foundation for an Early-career Ecologist position to work on evidence-based restoration of semi-arid landscapes. Dr Heather Neilly is the current recipient of this grant and her research includes two research projects directly related to the recovery of the Calperum Floodplain. The first looks at the role of branching in the restoration of soil scalds and the role it plays for fauna habitat, while the second looks at the effect of environmental watering on the recovery of floodplain-dependent fauna. Dr Neilly's research has also resulted in collaborations with Adelaide University to look at the effect of environmental watering on the use of floodplain trees by reptiles (McKenzie 2019) and Michelle Ward (University of Queensland) looking at the use of remote-sensed fractional cover measures from Landsat imagery as an independent measure of vegetation community condition in relation to fauna habitat. Other potential student projects have been developed with Adelaide University (related to fauna health on the floodplain) and La Trobe University (Prof Heloise Gibb) looking at the effect of branching on invertebrate populations. These projects will be implemented when appropriate students become available.

The Calperum Supersite (https://supersites.tern.org.au/supersites/clpm) (Assoc. Prof. Meyer, Adelaide University), which is part of the Terrestrial Ecosystem Research Network, has been in operation since 2010. Part of its research program is looking at carbon and water cycling, and soil respiration within black box/red gum woodlands on Calperum. It has supported students looking at the interaction of surface and groundwater on trees (Telfer 2015) and floodplain salinity (Bretherton 2015).

CSIRO Land & Water (Dr. Tanya Doody) is currently running a three-year program investigating floodplain evapotranspiration in relation to environmental water. This project is a continuation of aspects of research led by Dr. Todd Wallace (Adelaide University) in collaboration with CSIRO Land & Water and others looking at improving the knowledge base for prioritising environmental watering of wetland and floodplain trees.

The Australian Landscape Trust also conduct their own research, such as the work funded by the Native Vegetation Council of South Australia on the role of facilitation in the restoration of semi-arid plant communities (Cale 2014, 2016, 2018). This research continues through ALT funds and monitoring data collected as part the restoration projects (Action 5), will contribute to the outcomes of this research.

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