FINAL REPORT:

Cockatoo Swamp – independent technical review

July 2016

Mountain Swamp Gum community, Yellingbo Nature Conservation Reserve, May 2016. Photograph by Paul Boon.

Document history

Revision:

Revision no.	02
Author/s	Paul I Boon
Checked	Dominic Blackham
Approved	Paul I Boon

Distribution:

Revision no.	01
Issue date	22 June 2016
Issued to	Edwina Manifold (Melbourne Water)
Description:	Draft report for comment.
Revision no.	02
Issue date	20 July 2016
Issued to	Edwina Manifold (Melbourne Water)
Description:	Final report

Citation:

Boon P (2016). Cockatoo Swamp – independent technical review, Alluvium Report P116051_R01V02 to Melbourne Water

Ref: R:\Projects\2016\052_Cockatoo_Swamp_expert_review\1_Deliverables\P116052_R01V02_CockatooExpertReview.docx

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Project aims and overarching approach

This report provides a technical review of information on Cockatoo Swamp, Yellingbo Nature Conservation Reserve, and makes recommendations to help guide investment for capital works to achieve the best environmental outcomes and value for money in rehabilitating the site. The review is based on a critique of the literature (scientific papers and consultants' reports) on Cockatoo Swamp and on Yellingbo Nature Conservation Reserve more generally, including on conservation value and ecological condition, vegetation communities, hydrological regime, groundwater, soil chemistry, and existing and proposed infrastructure. The desk-top review was complemented by interviews with some of those who undertook the original investigations[1] and with a site visit to clarify important constraints and opportunities. The report addresses three topics:

1. Findings of the technical review
2. Recommendations for a solution(s) to achieve the best environmental outcomes, based on the most appropriate (and achievable) wetting and drying patterns for a self-sustaining vegetation community
3. Assessment of value for money of various options to achieve those outcomes.

The three topics have been rephrased as a series of sequential questions. This approach, while perhaps unusual for a consultant's report, has a number of advantages. First, it provides an overarching framework to structure the critique. Second, it ensures the most critical issues are identified and stated explicitly. Third, it provides answers, or at least some resolution, to those questions. The result is a more transparent and easy-to-read report. The specific questions addressed in the review are:

1. What is Cockatoo Swamp?
2. Why is it important? Why should Melbourne Water invest in its rehabilitation?
3. What is the problem that investment into rehabilitation aims to resolve?
4. Have the cause(s) of the problem been identified with sufficient certainty?
5. What solutions have been proposed?
6. Are these sufficient and likely to be effective?
7. Do these, or indeed any option, provide value for money?

1 What is Cockatoo Swamp?

Cockatoo Swamp is a part of Yellingbo Nature Conservation Reserve (NCR), a protected area near the township of Yellingbo in the Upper Yarra Valley region of outer eastern Melbourne. Yellingbo NCR straddles Woori Yallock, Cockatoo and Macclesfield Creeks and covers an area of 661 ha (VEAC 2013). Cockatoo Swamp is located on Cockatoo Creek, just below the confluence with Macclesfield Creek (Figure 1). It covers an area of 181 ha (Figure 2).

[1] Dr Joe Greet (21/04/216; 24/05/2016); Nicola Logan (6/05/2016); Claire Quinlan (10/05/2016; 24/05/2016)

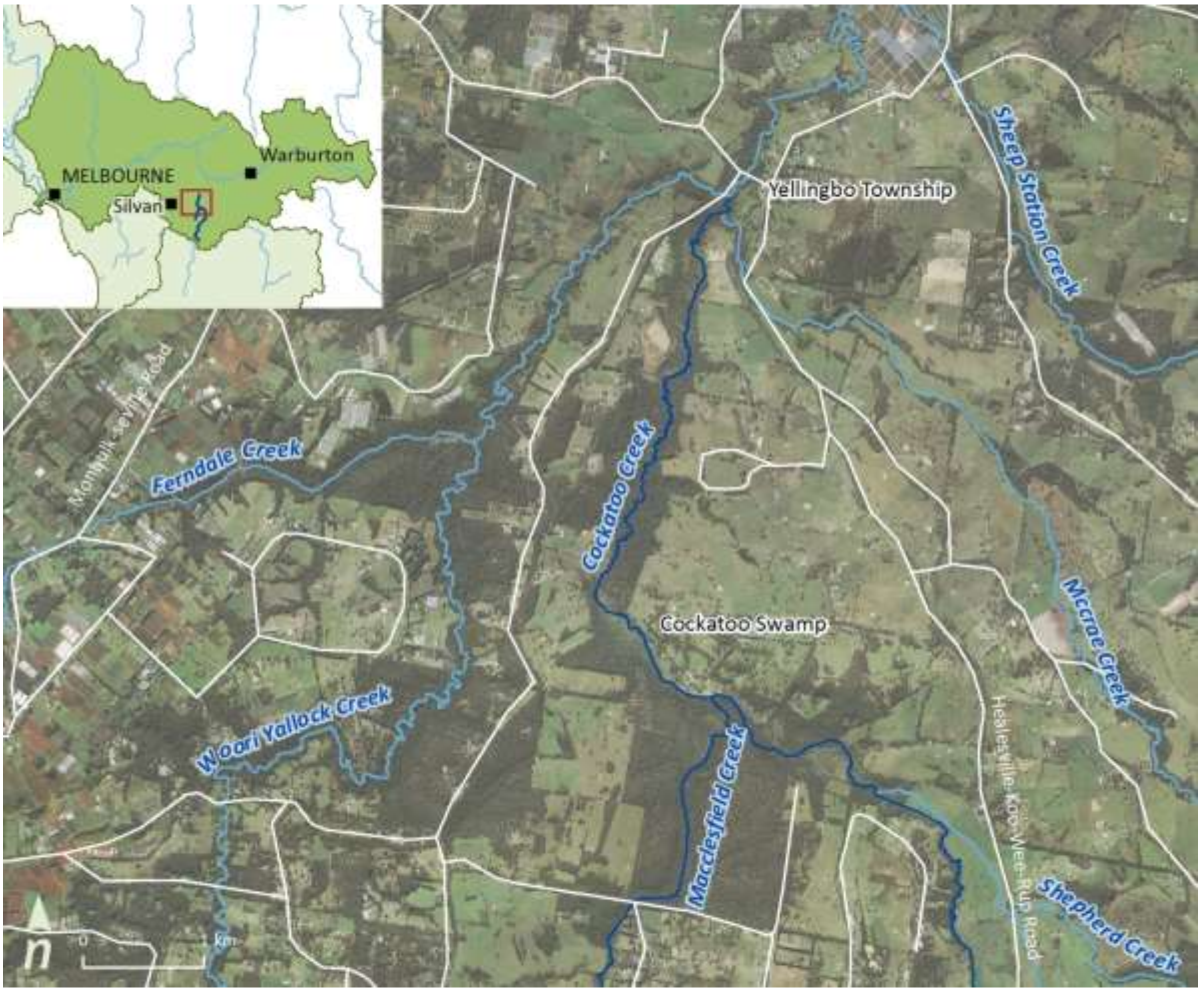

Figure 1. *Satellite image of Yellingbo Nature Conservation Reserve, Upper Yarra Valley region, Melbourne. Yellingbo township and Cockatoo Swamp are indicated, as well as some of the major roads. Source: Google Earth Pro, accessed 3 May 2016.*

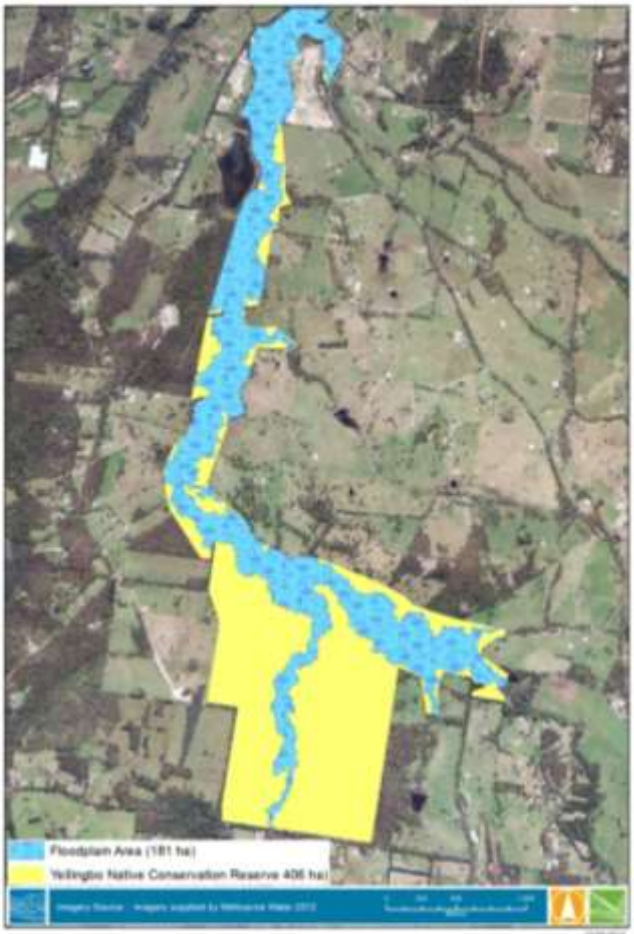

Figure 2. *Map of floodplain area encompassing Cockatoo Swamp in Yellingbo Nature Conservation Reserve. Source: Parks Victoria, from Melbourne Water original.*

Yellingbo NCR is assigned as a Category 1A (Strict Nature Reserve) area under the classification scheme used by the International Union for the Conservation of Nature for categorising protected areas and used as the basis for protected-area classification in Victoria (VEAC 2013). Nature conservation is the primary objective in areas set aside as conservation reserves, and the protection of natural values is their highest management priority. Other uses, such as recreational access, are permitted only if they are compatible with this primary objective.

2 Why is it important? Why should Melbourne Water invest into its rehabilitation?

Although all protected areas are valuable from various conservation and human-use perspectives, Yellingbo NCR is exceptionally valuable. It is listed on the Register of the National Estate (site ID 5718) on account of its outstanding natural values.[2] It protects a diverse range of fauna and fauna, including at least 285 species of native plants and 230 species of native vertebrates, including 170 species of native birds (Parks Victoria 2004). Of the 285 native plant species, 55 are classified as regionally significant. Of the 230 animal species, 11 are considered threatened in Victoria and one (*Bracteantha* sp. aff. *Subundulata /Xeroschrsum palustre*) is FFG- and EPBC-listed. Many of the bird species that use the Reserve have experienced significant decline across the wider Yarra Ranges region because of the loss of suitable habitat; examples include the FFG-listed Baillon's

[2] http://www.environment.gov.au/cgi-bin/ahdb/search.pl?mode=place_detail;search=place_name%3Dyellingbo%3Bstate%3DVIC%3Bkeyword_PD%3Don%3Bkeyword_SS%3Don%3Bkeyword_PH%3Don%3Blatitude_1dir%3DS%3Blongitude_1dir%3DE%3Blongitude_2dir%3DE%3Blatitude_2dir%3DS%3Bin_region%3Dpart;place_id=5718

Crake *Porzana pusilla*, Little Grassbird *Megalurus gramineus*, Clamorous Reed Warbler *Acrocephalus stentoreus*, Southern Emu-wren *Stipiturus malachurus* and the FFG-listed Lewin's Rail *Rallus pectoralis.*

Particularly noteworthy in Yellingbo NCR is the presence of a stand of Sedge-rich *Eucalyptus camphora* Swamp, a vegetation community considered to be of national significance (Department of Sustainability and Environment 2003), and the presence of the two iconic animal species: Helmeted Honeyeater *Lichenostomus melanops cassidix* and Leadbeater's Possum *Gymnobelideus leadbeateri*. Other significant (e.g. FFG-listed) vertebrates recorded for the Reserve include the Spotless Crake *Porzana tabuensis*, Powerful Owl *Ninox strenua*, Southern Emu-wren, Yellow-bellied Glider *Petaurus australis*, Platypus *Ornithorhynchus anatinus*, Water Rat *Hydromys chrysogaster*, Swamp Rat *Rattus lutreolus*, Swamp Skink *Egernia coventryi*, Mountain Galaxias *Galaxias olidus* and Southern Pygmy Perch *Nannoperca australis* (Parks Victoria 2004). Cockatoo Swamp provides important habitat for Swamp Skink, Southern Emu-wren, Spotless Crake, Lewin's Rail (McMahon & Franklin 1993).

2.1 Sedge-rich Eucalyptus camphora Swamp

Yellingbo Nature Conservation Reserve protects the only known occurrence of Sedge-rich *Eucalyptus camphora* Swamp in Victoria (Department of Sustainability and Environment 2003). This vegetation community seems not yet to have been attributed to an Ecological Vegetation Class (EVC), the typology used to classify and map native vegetation in Victoria.[3] It is best described as a subset of EVC 83 Swampy Riparian Woodland (Roberts 2013).

Sedge-rich *Eucalyptus camphora* Swamp is characterised by an open forest or woodland with a canopy of Mountain Swamp Gum *Eucalyptus camphora* ssp. humeana having an aerial projective cover of 20−50% and a height of 6−25 m (Department of Sustainability and Environment 2003). The shrub layer is typically species-poor but dense, and dominated by Woolly Tea-tree *Leptospermum lanigerum* and Scented Paperbark *Melaleuca squarrosa*. The ground layer is diverse and consists of a range of rushes, grasses and forbs, including Fen Sedge *Carex gaudichaudiana*, Tassel Sedge *Carex fascicularis*, Tall Sedge *Carex appressa*, Leafy Flatsedge *Cyperus lucidus*, Soft Twig-sedge *Baumea rubiginosa*, Australian Gipsywort *Lycopus australis*, Ridged Knotweed *Persicaria strigosa* and Showy Willow-herb *Epilobium pallidiflorum*. Variable Swordsedge *Lepidosperma laterale* var. *majus* occurs in areas that are seasonally inundated, along with other sedges and saw-sedges (*Carex* spp., *Gahnia* spp.), Blackwood *Acacia melanoxylon* and Slender Tussock-grass *Poa tenera*. Common Reed *Phragmites australis* occurs in more disturbed areas as a natural, but usually minor, component. McMahon & Franklin (1993) and Greet (2015a) provide a species list of native and introduced plants found in the community.

The total area of Sedge-rich *Eucalyptus camphora* Swamp within YNCR is 181 ha, but it is thought that the community was, before post-colonial clearing, widespread in the valleys between Healesville and Macclesfield. *Eucalyptus camphora* is closely related to two other eucalyptus species − Swamp Gum *Eucalyptus ovata* and Yarra Gum *Eucalyptus yarraensis* − and occurs in a restricted belt, mostly in montane areas, in Victoria and into New South Wales (Simmons & Brown 1986). The species, especially *E. ovata* and *E. camphora*, likely interbreed to produce hybrids, and the abundance of *E. camphora* in the lowland setting of Yellingbo NCR may be related to cold-air drainage from the adjacent uplands (McMahon & Franklin 1993; Joe Greet, pers. comm. 24/05/2016).

Sedge-rich *Eucalyptus camphora* Swamp is listed as a Threatened Community under the *Flora and Fauna Guarantee Act* 1988. It is listed because the vegetation community is:

1. Known from only one site in Victoria, Yellingbo NCR
2. Rare in terms of the total area it covers
3. Subject to future threats likely to result in its extinction

[3] http://www.depi.vic.gov.au/environment-and-wildlife/biodiversity/evc-benchmarks

4. In a demonstrable state of decline, also likely to result in its extinction (Department of Sustainability and Environment 2003).

2.2 Helmeted Honeyeater

Yellingbo Nature Conservation Reserve is the only area in Victoria that retains a breeding population of Helmeted Honeyeater, the State's avifaunal emblem. Helmeted Honeyeater was once widely distributed from Western Port to the mid-Yarra region, but is now almost entirely restricted to the Yellingbo area (Friends of the Helmeted Honeyeater Inc 2016a). It is among Victoria's rarest bird species (Parks Victoria 2004), and Yellingbo NCR currently provides the only breeding population in the State (Threatened Species Scientific Committee 2014b). Helmeted Honeyeaters were first found in 1933, at Woori Yallock Creek, ~ 3 km south of Yellingbo. In 1965 a portion of Yellingbo State Fauna Reserve was established specifically as a Helmeted Honeyeater sanctuary, and in 1967 the Yellingbo State Fauna Reserve was proclaimed, with an estimated 200 Helmeted Honeyeaters in the protected area (Menkhorst 2008).

Helmeted Honeyeaters inhabits streamside closed riparian or lowland swamp forest, particularly that dominated by Mountain Swamp Gum and rarely live far from water (McMahon & Franklin 1993; Threatened Species Scientific Committee 2014b). Individuals feed on invertebrates, lerps, nectar, manna and sap, all obtained from foliage, twigs or branches of eucalypts or tall shrubs in these forests or woodlands (Menkhorst 2008).

Helmeted Honeyeater is listed as Critically Endangered under the *EPBC Act* 1999 and as Threatened under the *Flora and Fauna Guarantee Act* 1988 (April 2015 list) (Department of the Environment 2016b). It is listed as Critically Endangered in Victoria under the *Advisory List of Threatened Vertebrate Fauna in Victoria – 2013* (Department of Sustainability and Environment 2013). The eligibility criteria for a species to be listed under the *EPBC Act* as Critically Endangered are exceptionally restrictive − the species has to have a very restricted extent of occurrence and area of occupancy (e.g. occurs at a single location only); there must be evidence of a continuing decline in the area of occupancy and the area, extent and quality of the required habitat; and there must be a documented decline in the number of locations where the species breeds. That all criteria are applicable to the Helmeted Honeyeater indicates the outstandingly high value of the Cockatoo Creek/Yellingbo NCR area for this emblematic and iconic bird species.

The primary threats to Helmeted Honeyeater relate to the small size of the remaining population, the limited extent and poor condition of its preferred habitat, and genetic issues related to the localised distribution within a tiny geographic area in Yellingbo NCR (Threatened Species Scientific Committee 2014b; Helmeted Honeyeater Recovery Team data). The population is threatened specifically by maturation or death of the principal eucalypt without regeneration of the midstorey.

2.3 Lowland Leadbeater's Possum

Yellingbo NCR is also a critical lowland location for Leadbeater's Possum, supporting the last lowland population which is genetically distinct from highland populations. Long thought to be extinct, Leadbeater's Possum was rediscovered in 1961 and is the State's faunal emblem. There are two genetically distinct populations in Victoria: i) a core population in an area of ~70 x 80 km in the Central Highlands at elevations of 400−1,200 m AHD; and ii) a smaller outlier at much lower elevation at Yellingbo, where only ~20 ha of suitable habitat remain (Harley 2016). Leadbeater's Possum was first recorded in Yellingbo NCR in 1986 (Smales 1994) and has been the subject of extensive surveys and population monitoring (Harley 2005, 2016; Harley *et al*. 2005). The 20-year population monitoring program undertaken for Leadbeater’s Possum at Yellingbo provides the most detailed data set on population dynamics for a mammal species in Victoria. This monitoring has shown that the population has declined in size by ~ 60% over the past decade and is now estimated to contain fewer than 50 individuals.

The small outlying lowland population at Yellingbo, which is managed as a Evolutionarily Significant Unit, is a remnant of a formerly much larger lowland subpopulation (Harley 2004, Hansen *et al*. 2009).). Leadbeater’s Possum is restricted to sites characterised by the presence of smooth or gum-barked species of *Eucalpytus*, hollow-bearing trees and a cold, wet climate. The best habitat also has *Acacia* spp., *Leptospermum* spp. or *Melaleuca* spp. in the midstorey, which provide important vegetation structure (e.g. movement pathways) and food resources. As the species exhibits long-term site fidelity, the maintenance of suitable habitat is essential to its persistence in local areas.

Leadbeater's Possum is listed as Critically Endangered under the *EPBC Act* 1999 (upgraded 2/05/2015 from Endangered), as *Threatened under the Flora and Fauna Guarantee Act* 1988 (April 2015 list), and as Endangered in Victoria under the *Advisory List of Threatened Vertebrate Fauna in Victoria – 2013* (Department of the Environment 2016a). Threats to the population of Leadbeater's Possum at Yellingbo Nature Conservation Reserve have been identified by the Threatened Species Scientific Committee (2014a) as follows:

> This habitat is subject to ongoing quality decline of eucalypt dieback and reduced regeneration, resulting in an altered, more open forest structure. The major cause of this change is thought to be a result of altered hydrology of the Cockatoo Creek floodplain (Harley and Antrobus, 2007). There is currently estimated to be less than 20 ha of high quality habitat available at Yellingbo. In 2007, an assessment across the reserve indicated that vegetation dieback was present at more than 40 per cent of sites (Harley and Lindenmayer, pers. comm., 2013). Habitat deterioration has resulted in the abandonment of 46 per cent of active territories at Yellingbo during the past nine years (Harley and Antrobus, unpublished data cited in Harley and Lindenmayer pers. comm., 2013).

2.4 Management directions

The currently available management plan for Yellingbo NCR (Parks Victoria 2004) – and therefore for Cockatoo Swamp – lists a number of management directions, including *inter alia*:

1. Conservation of Helmeted Honeyeater
2. Protection and enhancement of habitat for significant species, including Leadbeater's Possum and Powerful Owl
3. Protection of significant remnant vegetation, particularly the nationally significant *Eucalyptus camphora* Swamp community
4. Progressive restoration and revegetation of previously cleared areas of the reserve, in order to extend habitat for significant species.

2.5 Extent of public and organisational concern

Because of the large number of native plant and animal species recorded in Yellingbo NCR, as well as the presence of listed plant communities such as Sedge-rich *Eucalyptus camphora* Swamp and Critically Endangered and iconic fauna such as Helmeted Honeyeater and Leadbeater's Possum, the ecological condition of Yellingbo NCR has attracted media coverage and support from various conservation-orientated organisations. Strong and active Friends groups have been established, including Friends of the Helmeted Honeyeater, with its community nursery for growing plants for revegetation efforts, and Friends of the Leadbeater's Possum.[4] Zoos Victoria undertakes annual Leadbeater's Possum monitoring in the Reserve.[5] DELWP and its predecessors has employed a full time ornithologist and convened a Recovery Team since the beginning of the Recovery Program in 1989. Trust for Nature has, since the mid 1990s, progressively purchased private land adjacent to Yellingbo NCR to add to the Reserve, with the aim of having it revegetated to provide additional Helmeted Honeyeater habitat.[6] These additions are a vital component of proposals to establish a State Emblems Conservation Area centred on Yellingbo NCR (VEAC 2013).

These activities have been mirrored by interest shown in the mass media. One noteworthy article is a 2013 report in *The Age* by Arup & Smith, which recorded that:

> Yellingbo, 50 kilometres east of Melbourne, is the last stronghold of the critically endangered helmeted honeyeater. There are only 60 birds left in the wild, down from 90 a decade ago. Forty of the remaining birds are fed daily by volunteers like Anker and Wentworth, making their existence precariously reliant on humans. The

[4] http://www.helmetedhoneyeater.org.au/yellingbo.htm; http://leadbeaters.org.au/projects/yellingbo/
[5] http://www.zoo.org.au/news/update-on-leadbeaters-possum-monitoring; http://www.zoo.org.au/healesville/animals/leadbeaters-possum
[6] http://www.trustfornature.org.au/news/good-news-yellingbo-property-purchases-progressing/

honeyeater is not the only important Yellingbo resident. The reserve, largely unknown to Victorians and closed to the public, also hosts the last remaining population of lowland Leadbeater's possums, which are genetically distinct from their highland cousins. Both species are emblems of Victoria. Both are endemic to the state. And both are edging towards extinction. The fate of two iconic species is a heavy burden for Yellingbo to carry. At just 661 hectares, it is an oasis of isolated habitat amid a desert of cleared farmland. And its forests are dying. The eucalypts are waterlogged and the woolly tea-trees ageing, making possum and honeyeater habitat increasingly hard to find. Its decline has been so great that of the roughly 150 hectares of swamp forest at Yellingbo, less than 15 hectares contains suitable habitat for the honeyeaters and possums. The latest data puts the number of Leadbeater's possums in Yellingbo at 42, alongside the 60 honeyeaters. For Leadbeater's, the latest results represent a 30 per cent fall in numbers over the past 12 months and a 62 per cent drop on a decade ago, when the population peaked at 112.

3 What is the problem that investment into rehabilitation aims to resolve?

3.1 Identifying the fundamental problem

The fundamental problem at Yellingbo Nature Conservation Reserve, and Cockatoo Swamp specifically, is deterioration in the condition and decrease in the extent of Sedge-rich *Eucalyptus camphora* Swamp. Not only is this vegetation community itself listed as Threatened in Victoria, but it provides the habitat essential to the conservation of Helmeted Honeyeater and lowland Leadbeater's Possum. As pointed out by Roberts (2013), Helmeted Honeyeaters mostly prefer to use dense stands of Mountain Swamp Gum and associated paperbark and tea-tree thickets near to open water and preferring trees with decorticating bark so they can feed on manna and insects. During the breeding season they prefer open forest stands and use nearby paperbark and tea-tree scrub according to their availability. An adequate area of contiguous, extensive, good condition Sedge-rich *Eucalyptus camphora* Swamp is essential for the conservation of both species.

This raises the next question: 'Which component of the vegetation community, if any, is critical?' Is it only the adult Mountain Swamp Gum? Is it all the vegetation community, including the shrub- and ground-layers? Where should rehabilitation efforts be focussed?

3.2 Which component of the vegetation community should be focussed on?

Ecological Vegetation Classes consist not merely of a single canopy species but are defined more broadly, in terms of one or more floristic and structural types that appear to be associated with a recognizable environmental niche (Department of Natural Resources and Environment 2002). If we apply the same logic to the seemingly yet-to-be-classified Sedge-rich *Eucalyptus camphora* Swamp community and its related EVC 83 Swampy Riparian Woodland, consideration should be given to the canopy layer, the shrub layer and the ground layer components, at the floristic level as well as at the structural level. Are all of these components equally important, or is it only the adult Mountain Swamp Gum that require monitoring and rehabilitation? The question is not trivial, as Pierce & Minchin (2001) identified six riparian communities on the basis of floristics. Roberts (2013) re-organised the data collated by Pierce & Minchin (2001) into a table showing the various vegetation groups at the site (Table 1).

Table 1. Floristic groups at Yellingbo Nature Conservation Reserve. Source: Roberts (2013, Table 2), based on the data of Pierce & Minchin (2001)

Floristic group	Characteristics
Mountain Swamp Gum *Eucalyptus camphora* open forest (n=129 sites)	On seasonally to permanently inundated sites along Cockatoo Creek, and patchily on Sheepstation and Woori Yallock Creeks. Pure stands with dense graminoid understorey of *Carex* spp. and *Phragmites australis*. Shrub stratum is sparse, mainly *L. lanigerum*. Ranges from open woodland with tall trees (30–40 cm dbh) to dense spindly stands (10–15 cm dbh).
Woolly Teatree *Leptospermum lanigerum* closed scrub (n=81 sites)	Mainly along margins of Cockatoo Creek. Occurs under range of moisture conditions, from flowing water to seasonally waterlogged. Moderately dense stands of *L. lanigerum* with sparse understorey of sedges; Mountain Swamp Gum is an occasional emergent.
Scented Paperbark *Melaleuca squarrosa* closed scrub (n=46 sites)	Mainly along Macclesfield Creek, on drier sites than *L. lanigerum* closed scrub. Dense almost impenetrable thickets, with dense tangles of *Gleichenia* spp. Ground layer bare where canopy is very dense, and fern *Blechnum* and sedges where slightly more open.
Mountain Swamp Gum ecotone (n=77 sites)	Mostly on terraces adjacent Cockatoo Swamp, on sites generally drier than *E. camphora* open forest, being inundated for only short periods a year. Main canopy species are Mountain Swamp Gum and *Acacia melanoxylon*; also *E. ovata* and *E.obliqua*. Understorey is sparse, a mixture of *E. camphora* open forest and *E. radiata/E. obliqua* forest species.
Manna Gum *Eucalyptus viminalis* open forest (n=106 sites)	Margins of Sheepstation Creek, Woori Yallock Creek and Cardinia Creek, where seasonally inundated. Canopy dominant is Manna Gum, up to 30 m tall and moderate canopy cover (40–50%), with *Acacia melanoxylon* on wetter sites and *Acacia dealbata* on drier sites. Understorey is diverse, varying with site conditions.
Eucalyptus radiata/Eucalyptus obliqua open forest (n=89 sites)	Much cleared. Ranges from damp forest with understorey dominated by ferns to dry woodland. Open woodland on driest slopes has heath understorey of *Banksia*, *Hakea* and *Bossiaea*.

The Department of Sustainability and Environment's 2003 Action statement on Sedge-rich *Eucalyptus camphora* Swamp identified the loss of the canopy-forming Mountain Swamp Gum as the main problem. Even so, deterioration in condition and decrease in extent of the *Melaleuca*- and *Leptospermum*-dominated shrub layer and of the floristically diverse ground layer of rushes, grasses and forbs must contribute to the overall deterioration and loss of the community, and therefore have broader conservation implications (McMahon & Franklin 1993). As noted earlier, these midstorey plants provide important vegetation structure and food resources for Helmeted Honeyeater and Leadbeater's Possum.

The endangered Sedge-rich *Eucalyptus camphora* Swamp community, therefore, is not merely the adult Mountain Swamp Gum: it is also the paperbark and tea-tree thickets that form the shrub layer, and the diverse sedges, rushes, reed and grasses that form the ground layer. In other words, monitoring and efforts at rehabilitation need to be directed at the vegetation community as a whole, not merely the adult Mountain Swamp Gum. Figure 3 shows the type of Mountain Swamp Gum vegetation community that could act as what Willby (2011) termed 'the meaningful guiding image' for rehabilitation efforts to aim towards.

Figure 3. *An example of good-condition Sedge-rich* Eucalyptus camphora *Swamp community. Photograph by Dan Harley.*

3.3 How much has been lost, and from where?

Data on changes in the Sedge-rich *Eucalyptus camphora* Swamp vegetation community go back to the early 1990s,with an early focus on adult Mountain Swamp Gum (Department of Sustainability and Environment 2003). The vegetation of the Reserve was described by McMahon *et al*. (1991). McMahon & Franklin (1993) estimated that 30% of the canopy of Mountain Swamp Gum stands was affected by dieback; Carr (1998) reported ongoing deterioration and a further loss of 12% in canopy cover. Craigie *et al*. (1998) synthesised existing information on spatial trends in dieback until 1997, but did not provide quantitative estimates of loss. However, they did note (page 4) that the Yellingbo area had been regularly burnt prior to World War 2 and that Mountain Swamp Gum had established only with the cessation of burning:

> A 1945 aerial photograph in the Yellingbo State Nature Reserve office indicates that no major stands of *mature E. camphora* trees were evident in the main swamp areas. 1968 aerial photography shows some young *E camphora* was evidently growing in the main swamp area but was mainly located on the edge of the swamp. 1988 aerial photos showed extensive stands of *E. camphora* in the main swamp area.

A corollary of this observation is that environmental conditions must have changed since the species became established for the deterioration apparent since the early 1990s to have occurred. Reasons for the degradation are discussed later in this review.

The next report of interest is Whitten & O'Brien (2001), who devised a scheme for assessing die-back in Mountain Swamp Gum at Yellingbo NCR and reported on the extent of the problem. Unfortunately, their report seems to be unavailable and copies could not be obtained, even after extensive bibliographic searches (ThomsonReuters Web of Science®; Bonus® interlibrary loan service). Degradation continued and by 2003 at least 40% of monitored points along Cockatoo Creek were affected by dieback (Greet 2012). More recent vegetation surveys have indicated a continuing decline in the condition of Sedge-rich *Eucalyptus camphora* Swamp at a broader floristic level, not only in terms of condition of the adult trees.

Australian Ecosystems (2013) monitored the health of Mountain Swamp Gum trees in Yellingbo NCR with a visual method that was developed under The Living Murray program for monitoring River Red Gum *Eucalyptus camaldulensis* and Black Box *Eucalyptus largiflorens*. Tree health was assessed for 140 specimens according to the condition and extent of the crown, amount of tip growth, epicormic growth and leaf death, and condition of the bark. For floristically broader vegetation monitoring, twelve 10 m x 10 m plots were established in 2005 and vegetation cover assessed with a modified Domin scale. Assessments were made in 2005/06 and in 2012. Leaf die-off was recorded as the most common attribute of poor tree condition: 'Less than two percent of trees sampled within the Yellingbo Nature Conservation Reserve [in 2012] were recorded with abundant new tip growth' (Australian Ecosystems 2013, page 19). About 60% of trees returned a medium crown density of 41−60% (which was assessed as being within the 'healthy' range for this species) but 5% of trees had minimal to sparse crown densities.

Changes were recorded also for the shrub- and ground-layer vegetation: Common Reed *Phragmites australis* and Spotted Knotweed *Persicaria praetermissa* increased from 2005/06 to 2012, a change attributed to higher summer rainfall over the later years. Other taxa in the lower vegetation strata declined in cover/abundance, including Fen Sedge *Carex gaudichaudiana*, Common Maidenhair *Adiantum aethiopicum*, Soft Water-fern *Blechnum minus* and Centella *Centella cordifolia*. These changes were ascribed to a number of factors, including competition with the expanding beds of Common Reed, prolonged inundation causing plants to drown, and browsing pressure exerted by Sambar Deer *Rusa unicolor*. Roberts (2013) drew attention to the limitations of much standard vegetation monitoring, especially the absence of analysis on contrasting spatial scales (e.g. from single trees to entire landscapes) and the neglect of recruitment and of population dynamics (which inevitably drive the long-term sustainability and resilience of a site).

Parks Victoria (2015) reported on a landscape-scale assessment of the extent of dieback in the Reserve. Aerial photographs from 2006, 2011 and 2015 were analysed for crown cover on a scale of 1−5 (i.e. based on the dieback rating system of Whitten & O'Brien 2001), using a visible ranking protocol, in 100 m x 100 m grids. Quadrats of this size are necessary to provide coverage of the whole Reserve, but their large size means that they do not provide finely resolved information at scales appropriate for on-ground interventions. The report concluded that dieback was severe in the central arm of the Reserve, had moved into the northern section of the western arm, but had slowed in the eastern arm. The most severe area of dieback, both in severity and extent, was in the east−southeast running section of Cockatoo Creek, alongside the northern edge of the Macclesfield block. The northern end of Cockatoo Creek appeared to be an emerging area of crown thinning. Figure 4 shows how the incidence of severe dieback (a score of 1 or 2 on the ranking scheme, corresponding to a canopy loss of >50% and 25−50%, respectively) has increased since 2006.

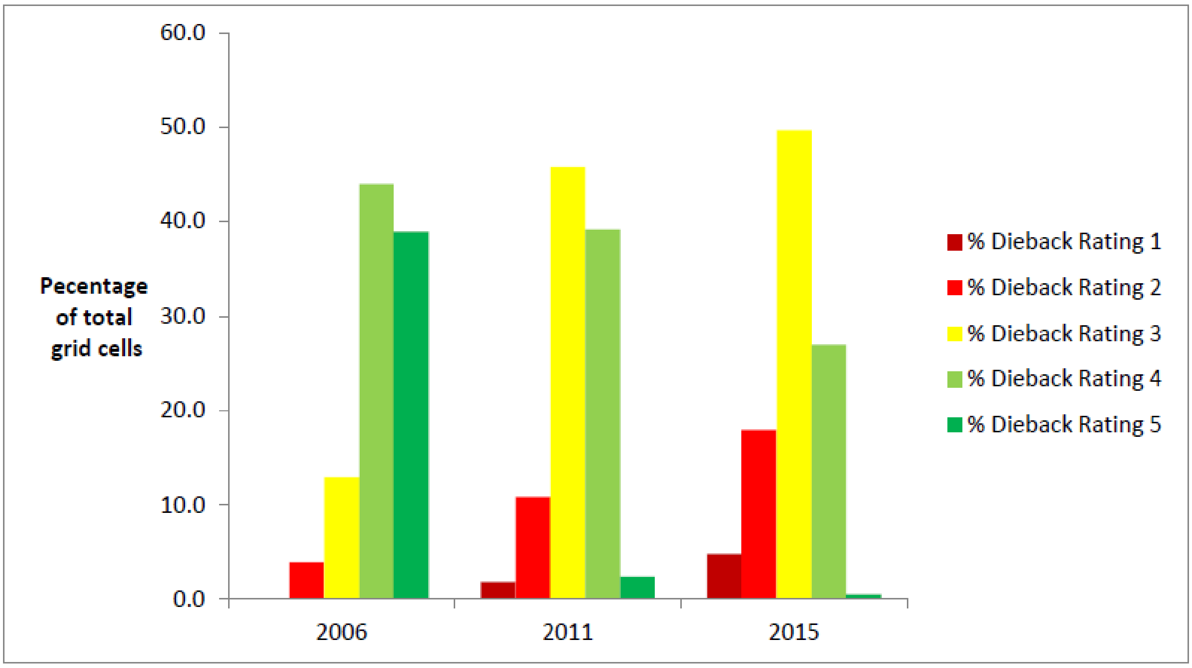

Figure 4. *Change across three sampling years in the incidence of dieback in Yellingbo Nature Conservation Reserve 2006–2015. Severe dieback is indicated by Rating 1; little or no dieback by Rating 5. Source: Parks Victoria (2015, Figure 9)*

Greet (2015a) reported on the initiation of a more detailed and rigorous monitoring program for Cockatoo Creek. This monitoring scheme marks a very significant advance on prior efforts because: i) it is targeted to answering a specific question using a robust experimental design amenable to analysis with inferential statistics; and ii) it includes a wide range of the vegetation-response criteria to make assessments. Monitoring commenced in April/May 2015 and continues currently. The monitoring protocols include measurement of the condition of individual adult trees (using a similar method to that of the 2013 Australian Ecosystems assessment); stand condition; hemispherical photography to quantify canopy cover; seed fall; seedling germination and recruitment; and projective cover of mid-storey and under-storey vegetation. A robust Before/After–Control/Reference/Impact experimental design has been established so that replicated measurements can be made of areas in different parts of the wetland. This design allows a statistically defensible answer to be obtained to the question as to whether improved drainage and the drying of previously waterlogged, dieback-affected areas and the engagement and more frequent wetting of currently disconnected areas of Cockatoo Swamp has beneficial impacts on the vegetation community. The major risk is that the modified BACI design will not hold-up over the long term; we have found when using a similar experimental design in the rehabilitation of brackish-water wetlands in the Gippsland Lakes that it was impossible to fully quarantine the putative 'impact' sites from the putative 'control' and 'reference sites (Raulings *et al*. 2010, 2011). Even if the design cannot be maintained over the long term, other options are available for statistical analysis of the data to address the questions the monitoring program aims to answer.

Results from the first set of monitoring (in 2015) demonstrated that:

> in dieback-affected areas, trees had the lowest mean crown extent, and stand condition and seedfall rates were lowest. Conversely, higher mean tree crown extent, stand condition and seedfall rates were observed at reference sites. However, negligible woody plant recruitment was observed at the reference sites (or at any of the sites). Neither the dieback-affected areas or areas behind the levee contain habitat suitable for Helmeted Honeyeaters or lowland Leadbeater's Possums: the former because of the poor condition of the woody vegetation; the latter due to its open structure (lack of midstorey and young woody plants). It is possible that both these areas could provide suitable habitat if they experienced more appropriate wetting and drying regimes. (Greet 2015a, page 2–3).

These monitoring reports are essential in that they quantify the problem, but the question then arises 'Is altered hydrology really the fundamental cause of the loss in condition and decrease in extent of the critical Sedge-rich *Eucalyptus camphora* Swamp vegetation community?' Are there any other likely, or even possible, causes?

4 Have the cause(s) of the problem been identified with sufficient certainty?

4.1 Historical overview of proposed causes of loss in condition and extent

A number of documents have listed putative causes of the deterioration in condition and the decrease in the extent of Sedge-rich *Eucalyptus camphora* Swamp in Yellingbo NCR. McMahon & Franklin (1993) tentatively identified psyllid attack, linked with increased abundance of Bell Miner *Manorina melanophrys*, as a cause of Mountain Swamp Gum dieback, but were concerned also by nutrient enrichment and by prolonged inundation. They recommended that further research be undertaken urgently to resolve the matter.

In one of the first detailed assessments, Craigie *et al*. (1998) identified a number of possible causes, including:

1. Tree mortality arising from attack by fungal pathogens
2. Defoliation caused by psyllid attack following changes to bird (especially Bell Miner) populations
3. Elevated nutrients
4. Water logging.

Craigie *et al*. (1998) excluded all but alterations to wetting and drying regimes that resulted in chronic water logging of existing stands of Mountain Swamp Gum. A change in hydrological regimes, attributed to climatic variation, was proposed to be the causal factor in an affected area near Macclesfield Creek. They argued that at this site a natural expansion and contraction of Mountain Swamp Gum would occur in response to long-term climate patterns. In other parts of the Reserve where dieback was apparent, they concluded that a combination of climatic change and sediment accumulation had caused existing stands to become waterlogged, with the loss of adult Mountain Swamp Gum. The accumulation of sediment was attributed to the construction of levee banks in the upstream areas and subsequent increased rates of stream erosion. The mechanism by which sediment accumulation led to dieback was not explained, but a range of possibilities − smothering, contamination (with toxicants or nutrients) and changes in nutrient bioavailability − was canvassed.

In the light of recent climatic conditions, especially the period of drought from 2001−2009 when many creeks ceased to flow in Yellingbo NCR (Greet 2012), an explanation based solely on climate change seems untenable. If climate change were to be the sole or even the major explanation, dieback would have become less severe during the recent prolonged dry spell. As the text in Section 4.3 shows, this is not the case. Moreover, the differential dieback occurring in the Cockatoo Creek and Macclesfield Creek subcatchments cannot be explained by generic climate change alone, nor can the good condition of Mountain Swamp Gum downstream of The Choke and its poor condition in the waterlogged areas upstream. Notwithstanding this, long-term changes in climate and especially in the alternation of wet and dry phases undoubtedly does play a role in alleviating or exacerbating dieback. Studies in other parts of south-eastern Australia have demonstrated unequivocally that long-term alternations in wet and dry periods, resulting in alternating flood-dominated and drought-dominated regimes, play a critical role in stream geomorphology and in modifying the ecological condition of aquatic systems (e.g. Erskine & Warner 1998; Warner 2009, 2014). Kasel (2001) provided comparable data on drought-dominated periods for the Upper Yarra region over the period 1895−1983.

The PhD thesis of Kasel (1999) concluded that the combination of water stress and nutrient enrichment was the critical factor causing the observed dieback, an explanation consistent with the explanations posited for dieback in drier eucalyptus woodlands elsewhere in Australia (e.g. Landsberg 1990; Yates & Hobbes 1997). In other words, the dieback at Yellingbo NCR was part of a broader syndrome of poor plant health initiated by landscape-scale changes including nutrient enrichment, water stress, insect attack, tree thinning and so on. Kasel concluded there was not a strong spatial correlation between the occurrence of dieback at Yellingbo and the areas subject to water logging. It is possible this conclusion was reached in part because her studies were undertaken in a period when much of south-eastern Australia was in drought (the 'Millennium Drought'[7]); thus

[7] http://www.bom.gov.au/climate/updates/articles/a010-southern-rainfall-decline.shtml

the deleterious impacts of waterlogging temporarily were obscured by the prolonged dry conditions. With the return of La Niña conditions in 2010 and 2011, the problem with waterlogging returned with even greater severity. Such a long-term and broad-scale explanation is consistent with the information on alternating flood-dominated and drought-dominated regimes discussed earlier.

In its 2004 management plan for Yellingbo Nature Conservation Reserve, Parks Victoria listed the causes as including:

1. Dieback and insect attack
2. Changed hydrology and sedimentation
3. Eutrophication and weed invasion, the latter exacerbated by the linear shape of the reserve.

The trouble is that this list includes almost all the potential causes and does not hone them down to the likely or, better, the most likely.

The Department of Sustainability and Environment's 2003 Action statement on Sedge-rich *Eucalyptus camphora* Swamp similarly attributed dieback in the critical Mountain Swamp Gum component being due to a range of possible causes, including:

1. Nutrient imbalances resulting from fertilizer inputs from nearby agricultural activities
2. Large numbers of Bell Miner, which aggressively exclude psyllid-eating birds and thus lead to an abundance of sap-feeding psyllids (Lyon *et al*. 1983)
3. Altered water distribution patterns in Cockatoo Swamp, caused by the construction of levees in the 1950s
4. Excessive sediment deposition, possibly as a consequence the altered hydrological regime.

It seems that at the time there was insufficient information to allow more definitive conclusions to be drawn. The 2003 assessment recognised this, noting on page 3 that:

> There has been no formal research into the vegetation community dynamics (e.g. vegetation change over time, recruitment processes etc.) of the Sedge-rich *Eucalyptus camphora* Swamp.

Pollino *et al*. (2005, 2007) came to a similar conclusion when attempting to construct a Bayesian belief network for the decline of Mountain Swamp Gum in Yellingbo NCR. They were also thwarted by the lack of quantitative data, but their Group D conceptual framework included nutrients, visitor pressure, roads, fire, erosion, insect attack, weeds and disease as contributing factors (Figure 5). Pollino *et al*. (2005, 2007) settled on two possible explanations: i) nutrient enrichment from surrounding land use (mainly horticulture); and ii) altered hydrological regimes.

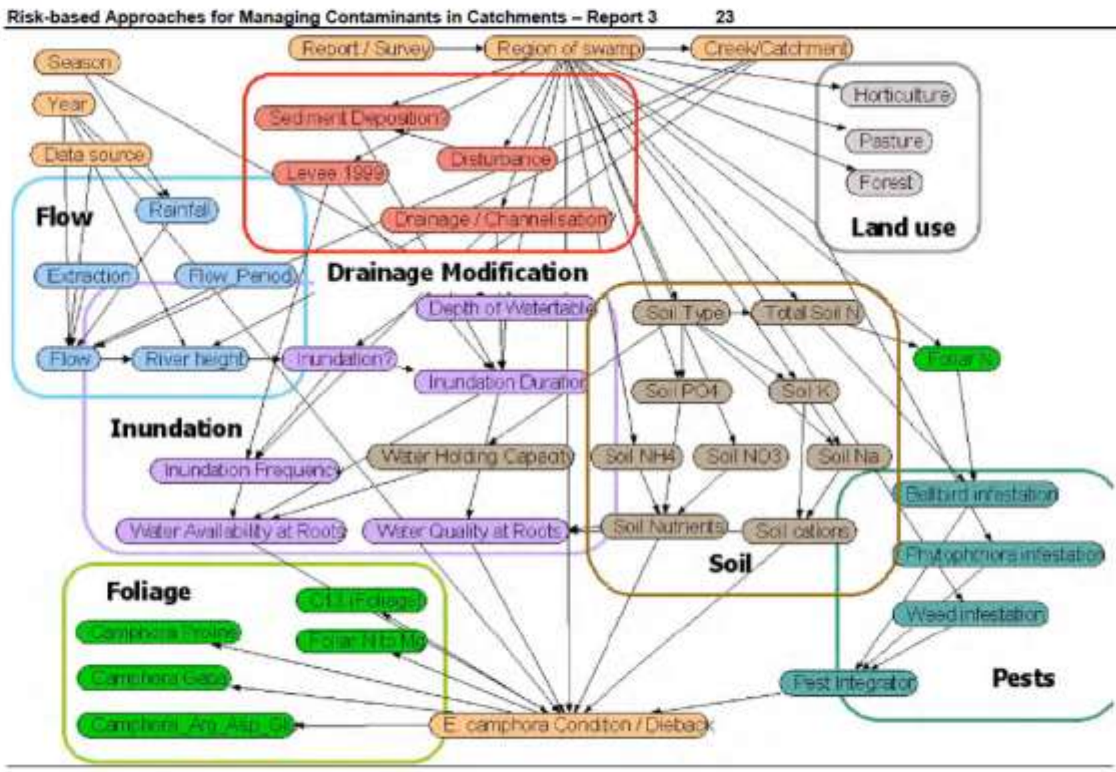

Figure 5. *Bayesian network for deterioration in Mountain Swamp Gum at Yellingbo Nature Conservation Reserve. Source: Pollino et al. (2005, Figure 7).*

Only with the knowledge generated by targeted, hypothesis-testing monitoring can the most likely cause be identified from this wide-ranging suite of possibilities. The most recent monitoring of (Greet 2015a) fills much of the knowledge gap. It concluded (page 4) that the deterioration in condition and loss of extent in the lower (waterlogged) parts of Cockatoo Swamp were a function primarily of altered hydrology:

> Inappropriate water regime is one of the main threats to the persistence of remnant wetland forests within the Cockatoo Swamp (Greet 2012). Prolonged inundation/waterlogging is driving the dieback of mature *E. camphora* wetland forest, and a lack of appropriate wetting and drying is preventing its regeneration. The altered water regime is a result of stream channelization and levee bank construction in the upper reaches of the swamp. This caused channel incision, erosion and deposition of sediments within low-lying areas of the swamp in the vicinity of a natural constriction in the Cockatoo Creek valley (known as the 'choke'), impeding drainage, leading to prolonged waterlogging and dieback…

Jacobs (2016b) also concluded that waterlogging was the primary cause of dieback in Mountain Swamp Gum in Cockatoo Swamp. This conclusion was based on multiple lines of evidence, including:

1. The worst sites for dieback occurred in the most waterlogged areas rather than along the intermittently dry margins of the swamp
2. Field observations correlating the severity of dieback in individual trees with the depth of inundation of their trunk
3. Laboratory trials on the sensitivity of *E. camphora* seedlings to waterlogging
4. Observations by Parks Victoria rangers that tree condition improved during drought conditions in the late 1990s
5. Expansion of dieback affected areas in the wet conditions experienced in 2010–2012.

4.2 Altered hydrological regimes: a more detailed assessment

The review above shows that many − but not all − reports on the degradation of Mountain Swamp Gum and the associated decrease in extent attributed the loss, at least in part, to altered hydrology. McMahon & Franklin (1993, page 236) hinted at the problem, noting that any further additions of water to Cockatoo Swamp from then-mooted discharge of sewage effluent into Cockatoo Creek could result in '…stressing trees that may already be at the limits of their tolerance to moisture'. Craigie *et al*. (1998) went further and concluded that waterlogging was the most critical of all the changes that had occurred within Cockatoo Swamp, albeit under the forcing of long-term climate change patterns. Greet (2012, 2015a) came to a similar conclusion as to the centrality of water regimes, noting that in contrast to the earlier findings of Kasel (1999) there was a correlation between the depth of water and dieback of individual trees in the field and that waterlogging adversely affected survival in *E. camphora* seedlings. As outlined earlier, Kasel's conclusions may have been influenced strongly by her studies having been undertaken during the early phases of the Millennium Drought.

The problem, however, is not a simple one of waterlogging across the whole of Cockatoo Swamp. Much of the existing literature fails to recognise that some areas of Yellingbo NCR are subject to chronic waterlogging and other areas to inundation less frequent than would have occurred in the past. The contrasting suites of changes to wetting and drying regimes have come about because of two circumstances.

The first is that the Yellingbo region was subject to extensive drainage works in the 1930s−1950s, and these channelised Cockatoo Creek and alienated it from the surrounding floodplain (SKM no date). Levee banks were constructed in the 1950s along the northern section of the creek upstream of Cockatoo Swamp (Parks Victoria 2004; see Figure 7). Cockatoo Creek subsequently formed a deep channel in the floodplain at this location and actively eroded upstream for ~1.5 km, resulting in deep head cuts. This erosion was calculated by Craigie *et al*. (1998) to have contributed 5,000 m^3 of sediment to the reaches immediate downstream. The levee banks have further alienated the floodplain to the east of Cockatoo Creek, resulting in it being inundated less frequently than in the past. Rockworks were placed into Cockatoo Creek ~2000 to prevent the head cuts from progressing upstream (Figure 6).

Figure 6. *Rockworks placed into Cockatoo Creek in Yellingbo Nature Conservation Reserve ~2000 to prevent upstream progression of head cuts resulting from stream deepening and channelisation. The inset shows the levee constructed along the right-hand bank of Cockatoo Creek in the 1950s. Photographs taken May 2016 by Paul Boon*

The second is that the sediment mobilised from upstream was deposited in a thick blanket, sometimes covering the trunks of trees by up to 50 cm, in the reach immediately downstream. A geomorphological structure known locally as The Choke seems to have restricted flow and thus the passage of suspended sediment, resulting in a localised accumulation of fine-grained material. This natural structure occurs where tectonic activity generated the Yellingbo Fault and altered regional drainage patterns, changed the creek's direction, and facilitated the creation of an area where sediments could accumulate and Cockatoo Swamp form (SKM no date).

Some remedial works were undertaken in 1999−2000 to address the floodplain alienation issue (as discussed later), but sediments from the prior in-stream erosion, together with sediments eroded from agricultural areas upstream of the Reserve, continue to be deposited in the downstream section of the swamp. It is these that are posited to have caused the change in wetting and drying cycles and to have resulted in the waterlogging of the downstream sections, in turn causing the progressive dieback of a large area of *Eucalyptus camphora* Swamp Community. Figure 7 shows the vegetation community that has developed in these waterlogged areas, and can be compared with the example of good-condition Sedge-rich *Eucalyptus camphora* Swamp community shown in Figure 3. This degraded area provides none of the habitat requirements of Helmeted Honeyeater or Leadbeater's Possum; moreover the thickets of paperbark and tea-tree have been lost, as well as the floristically diverse ground layer.

Figure 7. *An example of waterlogged Mountain Swamp Gum in Cockatoo Swamp. Shallow standing water can be seen in the left-hand side of the photograph. Photograph taken May 2016 by Paul Boon.*

It is important to point out that an area exists upstream which is not waterlogged: it suffers from alienation from Cockatoo Creek and thus potentially from inadequate inundation. In these upstream areas, successive revegetation efforts have successfully re-introduced Swamp Mountain Gum and a paperbark and tea-tree dominated shrub layer, but the ground layer is a near continuous sward of the exotic Reed Canary Grass *Phalaris arundinacea* (Figure 8). Paperbarks and tea-tree seem to have survived only in those areas fenced off and thus afforded protected from browsing by deer and wallabies. Moreover, the Mountain Swamp Gums have a different structure to those in more frequently inundated sites; they are tall and straight, rather than the jumbled disarray that occurs in wetter stands and results in great habitat diversity (*cf* Figures 3 and 8). In other words, these alienated areas still provide conditions suitable for the establishment of the canopy and shrub-layer strata in floristic terms, but the ground layer is floristically wrong and the structure and architecture of the Mountain Swamp Gum trees will not provide the habitat values required by Helmeted Honeyeater and Leadbeater's Possum.

Figure 8. *Stand of Mountain Swamp Gum upstream of Cockatoo Swamp behind the levee, showing the ground layer of Reed Canary Grass* Phalaris arundinacea *and thickets of revegetated paperbark and tea-tree successfully replanted but protected behind deer-proof fences. The inset shows a stand of Mountain Swamp Gum in a replanted area. Photograph taken May 2016 by Paul Boon.*

Figure 9 shows the spatial juxtaposition of the two areas with contrasting water regimes: the section of downstream Cockatoo Swamp subject to near-permanent inundation as a result in part of sediment deposition; and the area upstream in the Reserve that has been alienated from Cockatoo Creek (via stream incision and levee bank construction) and thus experiences less-frequent inundation than in the past.

The problem thus identified changes from a simple one of rectifying the wetting and drying regime in the lower, waterlogged portion of Cockatoo Swamp, the issue addressed in most of the earlier investigations, into a two-pronged matter of introducing more appropriate hydrological regimes in these two contrasting parts of the wetland. To do that requires robust information on the wetting and drying regimes required not only to arrest on-going dieback, but to maintain adult Mountain Swamp Gum in good condition, to facilitate seedling recruitment, and to maintain or improve the fringing thickets of paperbark and tea-tree that are a component of the threatened Sedge-rich *Eucalyptus camphora* Swamp community and provide the essential habitat for the two species of threatened fauna. Is this information available? If it is not, there can be little point in proceeding with rehabilitation works. If it is, there is a good basis for assessing various options to resolve the dieback problem.

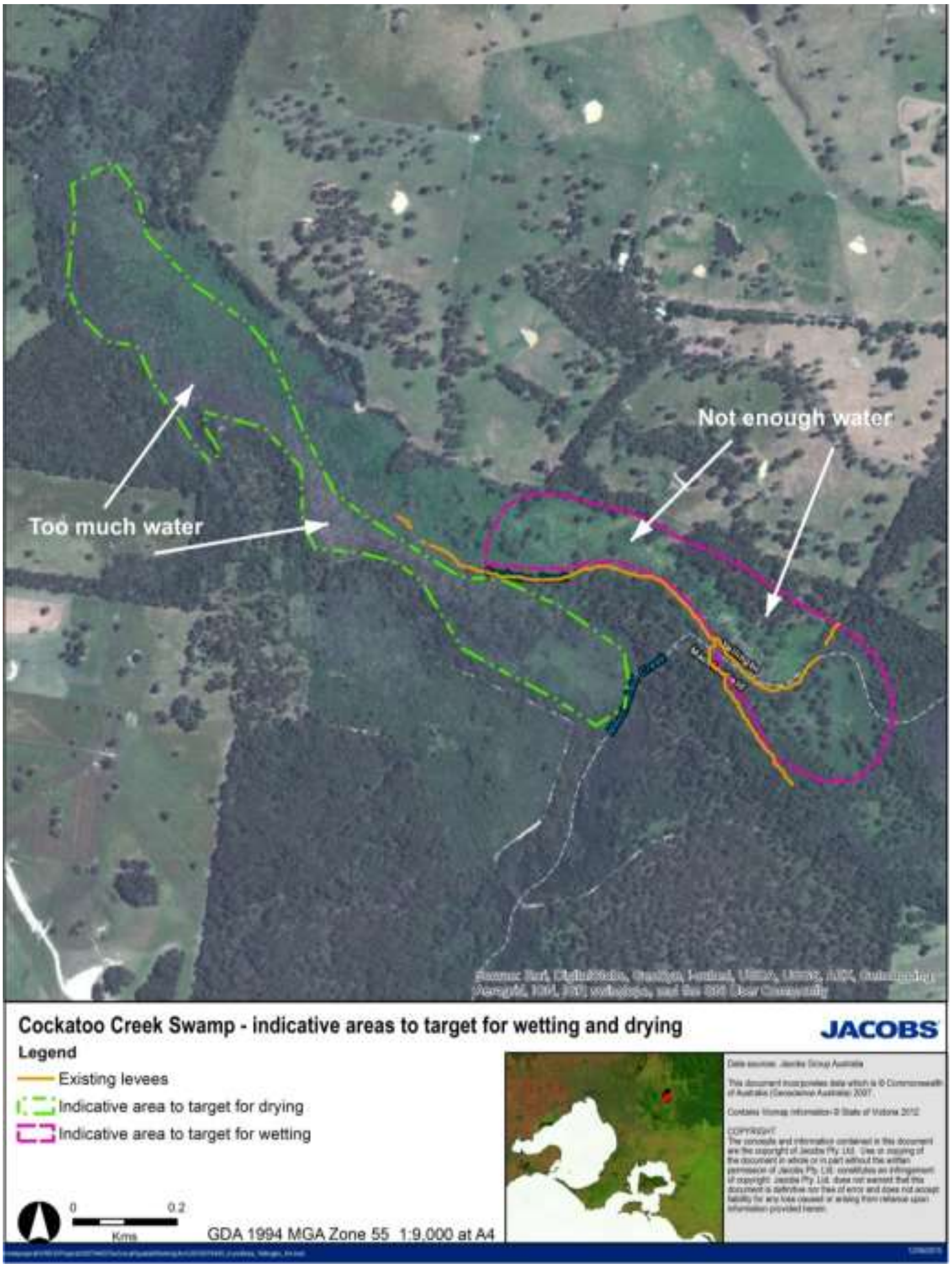

Figure 9. *Locations within Cockatoo Swamp that experience chronic water logging and the upstream areas that have been alienated from the creek and are inundated too infrequently. Source: Jacobs (2015a, Figure 2-2)*

4.3 Water-regime requirements for Mountain Swamp Gum & associated vegetation types

The water-regime requirements of only a few native woody wetland or riparian plant species have been determined, including for River Red Gum *Eucalyptus camaldulensis*, Black Box *Eucalyptus largiflorens*, Coolibah *Eucalyptus coolabah*, River Cooba *Acacia stenophylla* (Roberts & Marston 2011; Rogers 2011) and Swamp Paperbark *Melaleuca ericifolia* (Salter *et al*. 2007; 2010a, b; Hamilton *et al*. 2009). Fortunately, the list of well-studied species includes also Mountain Swamp Gum (Boden 1962; Greet 2012, 2015a, b). *Eucalyptus camphora* is well adapted to periodic waterlogging, having a stem filled with spongy aerenchyma to facilitate gas transfer, a shallow root system, and the ability to produce adventitious roots. McMahon & Franklin (1993) commented that the moisture tolerance of Mountain Swamp Gum was exceptional and probably unparalleled in Victoria, possibly exceeding that even of River Red Gum. The species' adaptations, however, are not sufficient to allow plants to withstand permanent inundation or waterlogging of the substratum; almost no woody wetland plant, including even mangroves, can withstand such conditions (Kozlowski 1997; Barrett-Lennard 2003). Greet (2015a) outlined the water regimes required to maintain adult Mountain Swamp Gum, facilitate recruitment by seedlings, and, more generally, maintain the paperbark and tea-tree thickets that occur in Cockatoo Swamp (Table 2).

Table 2. Water regime requirements to maintain Sedge-rich Eucalyptus camphora Swamp in Yellingbo Nature Conservation Reserve. Source: Greet (2015a, Table 1)

Objective	Hydrological component	Frequency	Timing	Depth	Duration
Arrest dieback in *E. camphora*	Dry waterlogged areas of low-lying floodplain	2 years out of 3	Nov–Mar	Watertable > 20 cm	> 3 months
Maintain adult *E. camphora* in good condition	Dry waterlogged areas of low-lying floodplain	2 years out of 3	Nov–Mar	Watertable > 20 cm	> 5 months
	Wet dry portions of low-lying floodplain		May–Nov		3–7 months
Promote regeneration of *E. camphora* seedlings	Expose moist sediments on low-lying floodplain	2 years out of 3	Nov–Dec	Watertable 0–20 cm	>5 months
	Reflood low-lying floodplain	Subsequent year	May–Nov	Watertable < 20 cm	<3 months
Maintain thickets of *Melaleuca* and *Leptospermum*	Dry swamp margins along drainage lines	2 years out of 3	Nov–Mar	Watertable > 20 cm	> 6 months
	Wet swamp margins along drainage lines	2 years out of 3	May–Nov		Fluctuating over a 1–5 month period

4.4 Are we sure other factors do not contribute to the problem?

As outlined in Section 4.1, a wide range of possible causes have been identified as contributing to the dieback in Mountain Swamp Gum in Yellingbo NCR. It is timely to examine critically on what grounds these alternatives have been discounted.

Fungal pathogens

Craigie *et al*. (1998) assessed this possibility, and on the basis of a report by Limongiello & Keane from Latrobe University in 1995 excluded it as a possible cause. Limongiello & Keane (1995) found no evidence of root-rotting fungal infections (e.g. caused by *Pythium* or *Phytophthora*) in dieback-affected areas. Greet (2012) also dismissed fungal pathogens as a viable explanation and there is no good reason to revisit this conclusion. Interestingly, Limongiello & Keane (1995) similarly attributed the dieback of Swamp Mountain Gum in Yellingbo NCR to waterlogging.

Nutrient enrichment, possibly linked with increased insect herbivory

Eutrophication (i.e. nutrient enrichment) arising from the movement of nutrients from nearby agricultural and urban land into Cockatoo Swamp was proposed as a possible cause of decline in the Sedge-rich *Eucalyptus* *camphora* Swamp by Parks Victoria (2004). McMahon & Franklin (1993) also thought it may have contributed to dieback. There is little information on the nutrient status of vegetation in Cockatoo Swamp but, on the basis of studies on other eucalypt species, there are some grounds for believing that elevated nutrients could play a role in the deteriorating condition of Mountain Swamp Gum. The explanation should not be excluded out of hand, as the Reserve sits within a highly modified landscape much of which is used for intensive agriculture (see Figure 1). Kasel (2001) provided an overview of the history of Yellingbo NCR; the critical point is that the forested perimeter along Cockatoo Creek has decreased and the area converted to pasture or to horticulture has increased, with almost inevitable impacts on nutrient and sediment loads entering the stream and being carried into Yellingbo NCR (Table 3). Similar patterns hold for Woori Yallock Creek.

Table 3. Changes in land use around the perimeter of Cockatoo Creek. Source: Kasel (2001, Table 4).

Year	Proportion of boundary along Cockatoo Creek allocated to different types of land use (%)		
	Forest	Pasture	Horticulture
1946	39	61	0
1968	22	78	0
1988	7	87	6
1998	15	79	6

Granger *et al*. (1994) reported that the decline of *Eucalyptus ovata* and *Eucalyptus camphora* in Yellingbo NCR was correlated with abnormally nitrogen-rich soils, especially with high nitrate concentrations. Similar results have been reported for *Eucalyptus blakelyi* by Landsberg (1990) in the Australian Capital Territory. Greet (2012) perceptively pointed out that Granger *et al*. (1994), although reporting the relationship between nutrient enrichment and dieback, 'refrained from describing this relationship as causal'. Grainger *et al*. (1994) found that Mountain Swamp Gum in poor condition had higher rates of nitrate-reductase enzyme activity than specimens in good condition. Moreover, concentrations of inorganic nitrogen (nitrate and ammonium) were higher in soils from deteriorating stands than from healthy stands, and the C:N ratio in soils was lower (indicating more nutrient-rich conditions) in deteriorating stands than from healthy stands. This suite of mutually consistent findings led the authors to conclude that nitrogen enrichment was an important factor contributing to the loss of Mountain Swamp Gum in the Reserve, although the role of other interacting and synergistic factors, such as salinity, was not discounted completely. Although not drawn out in the paper, nutrient status is closely linked with hydrological regime in wetlands (Boon 2006) and there could be an interaction between nitrogen enrichment and waterlogging as well.

Contrasting with the conclusions reached by Granger *et al*. (1994), there is some evidence that other eucalyptus species, most noteworthy River Red Gum, are more susceptible to nitrogen limitation than, for example, are *Melaleuca* paperbarks (Nyugen *et al*. 2003). There is also some evidence that previously stressed eucalyptus trees produce leaves of higher nutritional value once confronted with improved nutrient availability (Thomson *et al*. 2001; Naldony 2002). These young, nutrient-replete leaves may be more attractive to insect herbivores than leaves with a lower nitrogen content. Foliage with enhanced nutritional value (particularly available nitrogen) can increase the fecundity of insects and may increase the growth rates and survival of young insects (Landsberg 1990; Nadolny 2002), resulting in a positive feedback loop ultimately leading to deterioration in plant condition. Nutrient enrichment also facilitates invasions into native bushland of exotic weeds, especially garden escapees, as noted for other parts of outer-metropolitan Melbourne by Bidwell *et al*. (2006).

The difficulty is that it is exceptionally difficult to unravel the complex relationships among stand deterioration, plant stress, nutrient availability, waterlogging and insect herbivory. The Bayesian network shown in Figure 5 indicates some of the complexity in the issue. Moreover, there are two contrasting hypotheses regarding insect attack on plants: i) the 'plant stress hypothesis', which proposes that herbivores favour stressed plants as food; and ii) the 'plant vigour hypothesis', which argues that herbivores prefer vigorously growing plants with higher nitrogen and lower tannin contents (White 1974, 1983; Larsson 1989). The potential for nutrient enrichment linked with increased rates of insect herbivory in causing decline in the condition of Mountain Swamp Gum cannot be excluded until more detailed studies have been undertaken. These would need to include assessments of the complex interactions among soil nutrient availability, plant nutrient status, relationships between leaf nutrient status and potential insect herbivores, and the multifaceted interactions among plant stress, altered hydrological regimes, insect attack, and changes to the pressures exerted by avian predators on insect herbivores. It would be a daunting task.

Changes to psyllid numbers, linked with increased abundance of Bell Miner
Dieback has been linked in other parts of Australia with an increase in the population of Bell Miners, and was raised as a possible explanation in Yellingbo NCR by McMahon & Franklin (1993). The syndrome has a name − Bell Miner Associated Dieback − and has been reported for forests in southern Queensland, New South Wales, and Victoria (Department of Environment and Conservation 2004). Bell Miners are strongly territorial (native) birds and drive away other bird species from their territory, thus decreasing predation on psyllids and other sap-sucking insects. Relentless attack by these insects − now unconstrained by avian predation − leads to a marked decrease in the condition of the trees. The impact can extend over large areas, as the Bell Miners themselves maintain large territories and thus lead to the exclusion of other species of native birds from their area. Insect attack defoliates the crown and eventually can lead to the death of standing trees. A wide range of eucalyptus species can be affected, and the syndrome occurs in wet and dry forest types.

Craigie *et al*. (2008) dismissed an increase in psyllid attack consequent to changes in Bell Miner populations as unlikely to be a major cause in Yellingbo, on the basis that dieback was most evident in waterlogged areas and if increased insect attack were the issue it would be expected to occur also in drier areas of the Reserve. Greet (2012) also dismissed it, on the basis that large populations of Bell Miner have not been reported for Yellingbo (except in one area along Cockatoo Creek, downstream of the main dieback-affected site).

Browsing pressure
Could Mountain Swamp Gum be subject to such intensive browsing by introduced or native animals that plant condition is affected and habitat quality reduced? Swamp wallabies, rabbits and deer are abundant in the Reserve (Parks Victoria 2004) but there is no quantitative information on their impacts. That seedlings in revegetated zones within the Reserve have to be protected by tree guards or within fenced-off areas (e.g. see Figure 8) suggests browsing plays a powerful role in limiting plant regeneration, both of Mountain Swamp Gum and of the shrub layer paperbarks and tea-trees. However, it is not clear how browsing pressure alone could account for the observed deterioration in the condition and decrease in the extent of Sedge-rich *Eucalyptus camphora* Swamp. It is extremely improbably, for example, that browsing could account for dieback in established, mature trees. Native fauna, such as wallabies, could exert browsing pressure too, especially on seedlings (Greet 2012). Whether these factors are powerful enough to account for all the observed decline in unknown, but unlikely.

Altered fire regimes
That it seems Mountain Swamp Gum established in the Yellingbo area only after regular burning had ceased just after World War 2 was noted in Section 4.3. Kasel (2001) presented a fire history of the region over the period 1851−1997, noting that major fires occurred in 1926 and 1939 and a smaller fire in 1962. The question of the role played by burning seems not to have been addressed in detail in any assessment of the site other than by Greet (2012). This omission is curious, given the well-understood role that fires plays in eucalyptus woodlands elsewhere in Australia (e.g. Gill 1982). Greet (2012) posited that an absence of fire may have decreased floristic diversity and that weed-reduction burns at Yellingbo and at the nearby Bunyip State Park (as well as in the Australian Alps) prompted an abundance of Mountain Swamp Gum seedlings. The possible role of fire is disputed amongst researchers in the field. On the one hand, Greet (2012) noted that introducing a program of controlled burns at Yellingbo Nature Conservation Reserve would be controversial and difficult to implement, especially given that the current (2004) management plan indicates the Reserve should be protected from fire. Conversely, Harley argued (in feedback received on the draft version of this report) that there are areas within Yellingbo Nature Conservation Reserve where Helmeted Honeyeaters or Leadbeater's Possum were absent and where burning could be tested as an experimental framework.

Competition from or displacement by other plant species
The strongest competitors to Mountain Swamp Gum are likely to be the Common Reed *Phragmites australis* and Reed Canary Grass *Phalaris arundinacea*, the latter of which now dominates on the alienated floodplain on

the upper parts of Cockatoo Swamp (Figure 8) and the former on the deeply infilled floodplain on the lower parts (Figure 10). Both species form dense swards that can preclude other taxa from establishing, via shading effects, competition for nutrients, or simple physical exclusion (e.g. Thomson *et al*. 2012).

Figure 10. *Dense sward of Common Reed (with an overstorey of* Eucalyptus camphora*) within Cockatoo Swamp. Photograph by Dan Harley.*

It would seem highly unlikely that Mountain Swamp Gum seedlings could establish within such dense swards, and this could account for recruitment being unsuccessful in these areas. This mechanism, however, does not hold as an explanation for why dieback occurred in the first instance. It can explain only why Mountain Swamp Gum has been unable to recolonise areas from which it was excluded by other causes. Nor can it fully explain the inability of young Mountain Swamp Gum to recruit within sparser reed beds: Morris *et al*. (2008) showed that Common Reed could facilitate the establishment of Swamp Paperbark *Melaleuca ericifolia* seedlings by protecting them against being blown over by strong winds and thus drowned by shallow water. Similarly, Greet (2015b) showed that Mountain Swamp Gum seedlings could survive flooding, provided they were erect and emergent. Nevertheless, it remains a potent explanation for the progressive decrease in area covered by the Sedge-rich *Eucalyptus camphora* Swamp community, especially given the very wide hydrological niche of *Phragmites australis* in particular (Ganf *et al*. 2010; Roberts & Marston 2011; Rogers 2011).

Agricultural toxicants

If nutrient enrichment were to be a (partial) cause, it is also possible that toxicants from nearby agricultural or horticultural land (Table 3) could also contribute to the problem. O'Brien (2011) examined this possibility by measuring the concentration of organochlorine pesticides[8] in soils and sediments from the southern end of

[8] Organochlorine pesticides are a type of halogenated hydrocarbon, and are among the most persistent, ubiquitous and toxic of all pollutants. Examples include aldrin, chlordane, DDT, dieldrin and lindane. Halogenated hydrocarbons not only accumulate in the tissues of aquatic organisms, but can biomagnify along food webs to the extent that concentrations in high-level consumers (e.g. birds and humans) can be up to 10^7 times higher than in the background environment. Most were banned because of their non-target toxicity, but because

Cockatoo Swamp. As concentrations were below the detection limit of 5 μg kg^{-1}, it was concluded that this class of toxicant was unlikely to pose a threat to fauna and fauna. Contamination of groundwater was examined by Gagliardi (2012), who reported the presence of the insecticide imidacloprid in shallow groundwaters from the Reserve. This chemical has been shown to be toxic to other eucalyptus species, but at concentrations higher than those reported for Yellingbo NCR.

Potential or active acid sulfate soils

The presence of acid sulfate soils or activation of potential acid sulfate soils[9] might also be a contributing factor. A preliminary investigation was undertaken by SGS (2014). Samples of the upper 50 cm of soil at eight locations had pH values >4. This result can be explained in two ways: i) active acid sulfate soils were not present; or ii) acid sulfate soils were present, but were present in the 'potential' form which required oxidation (usually by disturbance) to be converted in to the 'active' form. The two can be discriminated by oxidising samples in the laboratory, and this test suggested that potential acid sulfate soils were present. Follow-up analysis indicated sulfur concentrations of 0.06−0.12% S, which are above the EPA defined limit and further indicative of the presence of potential acid sulfate soils.

A more detailed analysis was undertaken by Jacobs (2016a), using 51 soil samples from across the site, taken from depths of 0.25−1.75 m. The results were consistent with those obtained by SGS (2014): the pH of freshly collected soils was >4 but in the majority of cases fell to <3 once the samples had been oxidised in the laboratory. Soils had a small acid-neutralising capacity, so any acid generated by the activation of potential acid sulfate soils could be liberated into the environment. In other words, potential acid sulfate soils were present but in general they had not been activated into the 'active' form by disturbance. Surface water and ground water sampling indicated that some surface waters exceeded (ANZECC/ARMCANZ 2000) guidelines for aluminium, copper and zinc and that the one groundwater sample exceeded the guidelines for pH, aluminium, chromium, copper, lead, nickel and zinc. These results are significant for any works undertaken in Cockatoo Swamp that might disturb the soils, as this may activate the potential acid sulfate soils and convert them into the acid-producing 'active' form. Construction methods that limit disturbance (e.g. boring rather than excavation) or the application of lime to neutralise the acid generated are two options for addressing the problem. The other, of course, is not to undertake works that result in the activation of the potential acid sulfate soils.

What about groundwater?

Groundwater could contribute to the observed loss of Mountain Swamp Gum in a number of ways. First, it could be a conduit for pollutants from surrounding agricultural land into Cockatoo Swamp. As noted above, the herbicide imidacloprid has been detected in shallow groundwater from Yellingbo and its likely source is surrounding agricultural land. Groundwater could also act as a conduit for nutrients, and the section above has shown that nutrient enrichment is a logical contender as a contributing factor to dieback. Groundwater, if too saline, may also play a role. Gagliardi (2012) reported that shallow groundwater in Yellingbo had a variable salinity, ranging from 104−2,735 μS cm^{-1}. The higher values are slightly surprising as they indicate a Total Dissolved Solids concentration of ~1.6 g L^{-1}. Even these are unlikely to pose a salinity risk to Mountain Swamp Gum, as Macar *et al*. (1995) have shown that *E. camphora* is tolerant of root-zone salinities of up to 4,000 μS cm^{-1}.

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they are so long-lived, residues continue to be detected in agricultural soils of the Upper Yarra Valley. More biodegradable organophosphorus pesticides (e.g. malathion) have largely replaced the long-lived organochlorine compounds.

9 Acid sulfate soils are soils that produce sulfuric acid (H_2SO_4) when exposed to the air. They are common in aquatic systems, especially in wetlands. The central component of acid sulfate soils is pyrite (FeS_2), an insoluble crystalline form of iron sulfide produced by the reaction of ferrous sulfide (FeS) with sulfur. The ferrous sulfide in turn had been produced by the oxidation of organic matter by sulfate-reducing bacteria in a prior wetland. Sulfuric acid is produced if these potential acid sulfate soils are disturbed, leading to oxidation of the pyrite. It moves through the soil, stripping aluminium, iron and manganese, and in the worst cases makes available heavy metals such as cadmium. The soil becomes highly toxic and, combined with the very low pH (<3), can render plant growth impossible. Sufficient sulfuric acid can be produced that it seeps into adjacent waterways, resulting in marked reductions in pH, massive fish kills and the death of aquatic invertebrates.

Where groundwater is likely to be critical is in modulating surface-water hydrological regimes. Groundwater studies have been reported in SKM (2010), updated and synthesised in the poster *Yellingbo NCR (Cockatoo Swamp): GDEs and Hydrology* (SKM no date), and in Jacobs (2015b). These studies have shown that Yellingbo Nature Conservation Reserve is located on a small unconfined aquifer under laid by a larger, fractured-rock basement aquifer (Figure 11). The deeper aquifer is not connected directly to surface waters, but the shallower alluvial aquifer is in intimate contact with the surface and it responds quickly to climate and to stream discharge. It is recharged by rainfall and by high flows in Cockatoo and Macclesfield Creeks; conversely, during dry periods evapotranspiration from emergent vegetation provides an important pathway for water loss from the shallow aquifer, causing the watertable to progressively fall as plants draw water up through their roots and transpire it into the atmosphere. SKM (no date) calculated that groundwater moved seasonally on the upper alluvial terraces from 3 m to 0.5 m below the surface, depending on weather and stream discharge. Figure 12 shows an example of how much the watertable can vary from season to season. The general direction of groundwater flow is to the north, and this means groundwater will discharge into the streams during and after inundation events.

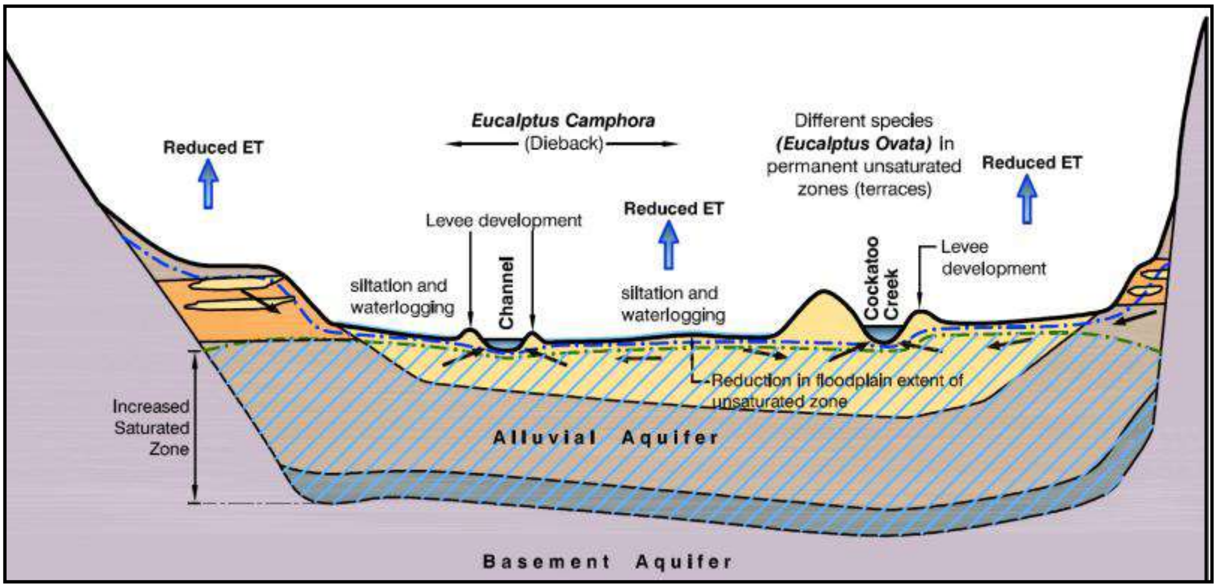

Figure 7. *Groundwater behaviour in Yellingbo Nature Conservation Reserve. Source: SKM (no date, Figure 4b)*

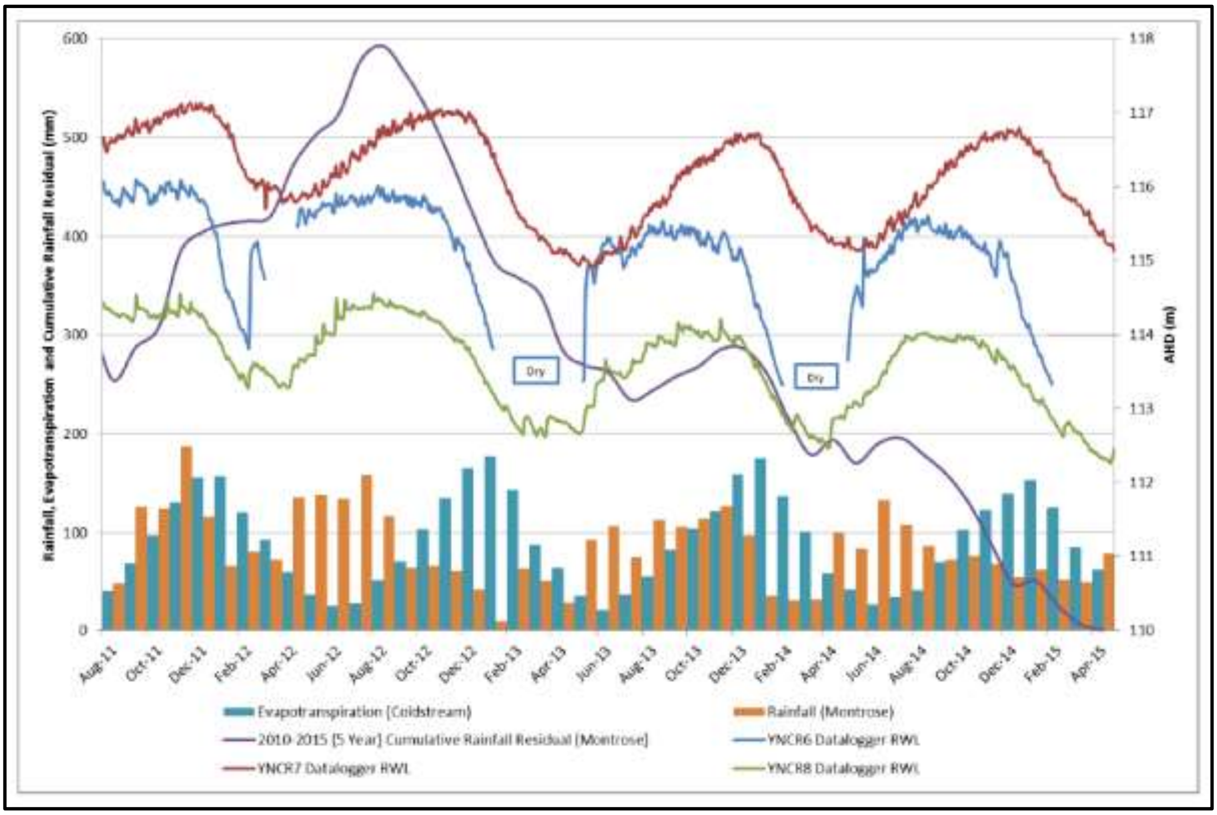

Figure 8. *Seasonal variation in groundwater levels at Yellingbo Nature Conservation Reserve, 2011−2015. Source: Jacobs (2015b, Figure 4-2)*

The close interaction between surface waters and the shallow alluvial aquifer is important for the provision of water to plants in the Sedge-rich *Eucalyptus camphora* Swamp community and to Cockatoo Swamp more generally. Figure 13 shows the conceptual model developed by Jacobs (2015b) to illustrate the role that shallow groundwater could have in exacerbating the water logging problem at the lower part of Cockatoo Swamp.

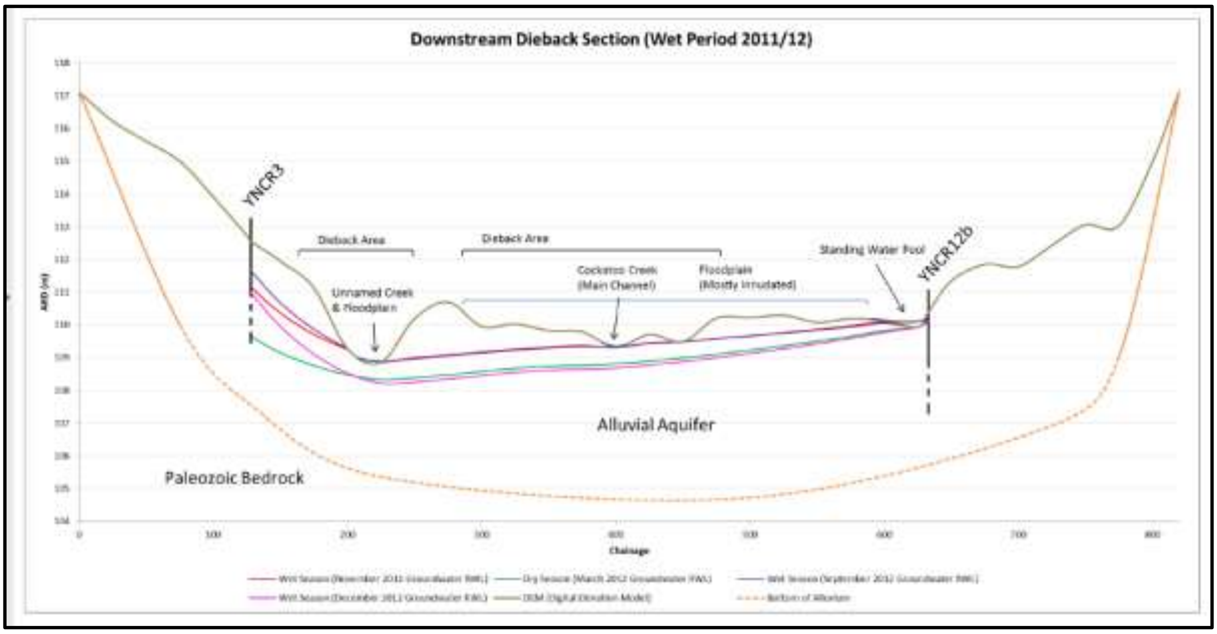

Figure 9. *Conceptual model of relationship between shallow groundwater and dieback zones in Yellingbo Nature Conservation Reserve. Source: Jacobs (2015b, Figure 5-11).*

Some conclusions
The body of evidence available in reports on dieback in Yellingbo NCR, going back nearly 25 years, suggests strongly that an inappropriate hydrological regime is the major cause of deterioration in plant condition and loss of extent of the threatened Sedge-rich *Eucalyptus camphora* Swamp community. The most serious dieback, in terms of both extent and severity, occurs in chronically waterlogged parts of Cockatoo Swamp (Figure 7). The most recent, and most detailed, studies undertaken by Greet (2014, 2015a, b) support this conclusion and suggest that rectifying the inappropriate wetting and drying cycles in the parts of Cockatoo Swamp subject to chronic inundation is a major part of the solution. Other parts of the Reserve, upstream of Cockatoo Swamp, suffer from alienation from Cockatoo Creek and here the issue is likely to be too infrequent inundation (Figure 8). The hydrological regime here allows the appropriate canopy layer and shrub layer plant species to grow, but the structure of the Mountain Swamp Gum under existing conditions provides suboptimal habitat conditions for the Helmeted Honeyeater or Leadbeater's Possum. Moreover, desirable taxa of native plants seemingly cannot establish unless protected from browsing, and the ground layer is a dense mat of Reed Canary Grass that likely further inhibits natural regeneration.

Whilst inappropriate hydrological regimes are the fundamental cause of dieback in Cockatoo Swamp and habitat simplicity in the upstream area, a contributory role for other stressors cannot be ruled out. Fungal pathogens, agricultural toxicants, impacts arising from Bell Miner populations and their effect on sap-sucking insects can be excluded, at least on the basis of the available information. What cannot so easily be excluded is the possible stressor effect of nutrient enrichment, which could be manifest either as a direct effect on plant health or as an indirect effect modulated by increased insect herbivory on nutrient-rich leaves. Altered fire regimes may also play a part in limiting Mountain Swamp Gum recruitment, possibly through effects on the provision of new areas for seeds to germinate and for seedlings to establish. Deer browsing and/or wallaby browsing seems to play a role in limiting recruitment of certain plant taxa. At least in the heavily sedimented parts upstream of The Choke subject to chronic water logging, competition from dense swards of Common Reed and Reed Canary Grass probably also inhibits seedling establishment. The role played by potential or active acid sulfate soils is unclear, but it is known that they occur across large parts of the wetland.

Although altered hydrological regimes are very likely to be the major factor causing the deterioration in plant condition and loss of extent of the threatened Sedge-rich *Eucalyptus camphora* Swamp community, it is not possible to separate surface waters from ground waters. A shallow alluvial aquifer underlies the swamp, and it can move over a 2.5 m range from season to season according to weather and stream discharge, and is an integral component of the waterlogging observed in dieback-affected areas.

5 What solutions have been proposed?

Because the problem of dieback at Yellingbo NCR has been recognised since the early 1990s, various solutions have been proposed for its resolution. Craigie *et al*. (1998) outlined five options:

1. Do nothing and continue to use the present dieback zone as a sediment deposition trap area for the protection of areas farther downstream
2. Modify drainage within the dieback areas to make conditions more favourable for *E. camphora* within the dieback zone
3. Modify drainage upstream of the dieback area to allow conditions within the dieback zone to become more favourable *for E. camphora* over time
4. Carry out plantings of *E. camphora* in more suitable areas
5. Some combination of any or all of the above.

The 'do nothing' option was rejected by Craigie *et al*. (1998). Breaching the levee bank to produce a more suitable wetting and drying regime was dismissed, on the grounds that 'it would have no significant impact on the present situation' (page ii) without complementary works to reduce the capacity of the channel. Notwithstanding this conclusion, levee breaches were scored as a Priority 1 item in the Section 6 recommendations and were expected to cost $2,000. Modifying drainage within the waterlogged dieback zone was also not favoured as a single remedy. A suite of actions intended to improve drainage of upstream areas was assessed, but none was considered suitable if used in isolation. Seemingly at odds with these general conclusions, a suite of works was proposed, to be complemented with a program of revegetation in areas thought most suitable to Mountain Swamp Gum. The most expensive undertaking was to restrict the hydraulic capacity of the stream channel and to stabilise the area upstream of the levee banks. This was estimated to cost $120,000. Craigie *et al*. (1998, page iii) concluded that there was 'no simple quick fix' to the problem. Apparently works to reconnect Cockatoo Swamp started in 1998 and continued into 2000, commencing with stabilisation of the creek and partial removal of the floodplain levee. This was followed by revegetation in the cleared are north of the levee. The second stage of works, to breach the levee, was not implemented in full but rocks were placed in Cockatoo Creek to limit the head cut from moving upstream (see Figure 6).

Aquatic Systems Management (2008) re-examined the proposal outlined in Craigie *et al*. (1998) to re-engage the existing stream channel with the alienated floodplain around the eastern margin of Cockatoo Creek. They recommended a wide-ranging suite of works, including:

1. Providing base-flow connection to the former courses so that >60% of the stream's base flow was directed to the former courses in the floodplain. This would be achieved by constructing two flow chokes in the channel and a 'swamp cell engagement structure' being cut through the levee, with an adjustable flow-control structure to allow bank-full flows to be directed to the former channels and hence onto the alienated floodplain. As well as watering the alienated and therefore desiccated floodplain, these interventions would create a larger area for sediment accretion, and thus reduce downstream sedimentation in the problematic sediment-accumulation area upstream of The Choke (see Figure 10).
2. Insert submerged bed-control weirs to create an area of tailwater upstream of the diversion structures. These would, it was proposed, slow the bed incision occurring upstream.
3. Create high-flow overbank depressions (so-called 'orifice diversions') to further increase the frequency of inundation in the alienated floodplain to the east of the creek
4. Close the array of old borrow pits and channels next to the existing levees, so that flows intended to inundate the floodplain are not short-circuited and allow a new − and eroding − channel to form.

Works were planned to be staged from 2008 to 2014/16, at a cost of just under $400,000. Central to the Aquatic Systems Management (2008) proposals was the inclusion of a rigorous program of weed control and of on-going adaptive management and monitoring. The 2008 proposals did not proceed because of lack of data and the potential lack of confidence that the intervention would deliver outcomes required (Sarah Gaskill, pers. comm. 30/06/2016).

The most recent proposals are outlined in Jacobs (2015a, 2016b). These reports include and are based on a surface-water hydrological model constructed to improve confidence in decision-making, with on-ground surveys used to enhance existing LiDAR information when developing the digital terrain model. The 2015 report assessed a wide range of infrastructure options to allow an improved wetting and drying cycle to be implemented in the hydrologically modified parts of Cockatoo Swamp, developed functional designs for the more appropriate options, and provided indicative costings for these alternatives. The 2015 report (page 6) marked a breakthrough over prior studies because it explicitly identified the three issues that needed to be addressed:

1. The upper swamp does not receive inundation from medium to high flows (reduced watering and sediment deposition)
2. Floodwaters that do reach the floodplain are often trapped and result in extended inundation and dieback of *E. camphora* habitat (overwatering when plants need dry conditions)
3. The Choke prevents the swamp (particularly the region around The Choke) from drying out after flood events (again creating overwatering when plants need dry conditions).'

These were to be redressed by:

1. Reducing the capacity of the channels in the upper swamp to low flows only, so the banks are overtopped by higher flows, allowing water and sediments to onto the floodplain more frequently (i.e., to water the currently alienated area delimited by the pink line in Figure 9).
2. Reconnecting floodplain areas so flow can enter and leave them more easily (i.e., again to water the alienated area delimited by the pink line in Figure 9)
3. Increasing low-flow capacity around The Choke so the surrounding area can drain and dry out, particularly after high flows (i.e. to drain the currently waterlogged area delimited by the green line in Figure 9).

A wide suite of options was considered to resolve each issue. Central to the assessment were issues related to construction and maintenance costs, with the ideal solution being a 'self-managing' system. To resolve issue 1 and reduce channel capacity, infilling the channels and constructing three types of weir (a porous rock weir, a concrete/steel pile weir, and a log weir) were considered. To resolve issue 2 and re-engage the floodplain, partial or complete removal of the levees was investigated. To resolve issue 3 and drain the currently waterlogged dieback-affected areas, the removal of existing flow obstructions and of excessive vegetation, the construction of a new channel through The Choke, widening the existing channel through the middle of The Choke, and the construction of a pipeline (on either the left or the right side of the stream) to short-circuit the current flow obstruction were considered.

The various options were informed by detailed hydrological and water-balance modelling (which built on earlier modelling undertaken by Water Technology 2013). Interactions between surface water and groundwater were also considered; these, for example, largely discounted the option of a right-hand channel on the basis that it would not effectively drain the left-hand side parts of the swamp that are currently waterlogged. In contrast, a pipeline along the left-hand side of the channel would improve the condition of existing Helmeted Honeyeater and Leadbeater’s Possum habitat − but with the risk that its construction would disturb that habitat, at least for an initial period time.

The Jacobs (2015a) investigation concluded that:

1. No further consideration should be given to modifying in-stream structures to infill the upstream channel and restrict its capacity. The ecological outcomes were uncertain and undesirable flooding of adjacent private land was likely.
2. A patterned process of partial levee removal should be implemented, with ~10 m of levee being removed per 20 m of existing structure. This would improve the distribution of water into the now desiccated floodplain to the north of Cockatoo Creek. It would be of low cost, purportedly result in substantial areas of habitat being improved, and easily reversible (or extendable) if required. Figure 14 shows the extent of the proposed works.
3. A gravity-fed pipeline be constructed along the left-hand side of Cockatoo Creek, upstream of The Choke (Figure 15). This option was chosen over the alternatives of a draining swale through the existing channel, a trenched pipeline, a combination trenched and bored pipeline, and an above-ground syphon next to the road. As noted earlier, a left-hand side location and a right-hand side location of the pipeline were considered. The left-hand option would remediate a larger area of waterlogged land currently experiencing severe dieback, and as a primary objective was to maintain and improve existing Helmeted Honeyeater and Leadbeater’s Possum habitat, it was preferred over the right-hand side option. The downside was disturbance of this existing habitat during the pipeline's construction, albeit a relatively small area that would be affected directly The cost was estimated at ~$360,000, but would be subject to more detailed design in the subsequent phase of the investigation. As shown next, the estimated cost increased markedly once the detailed design had been undertaken.

Figure 10. *Areas of levee to be removed (shown in green) to permit floodplain inundation in the upstream desiccated parts of Cockatoo Swamp. Source: Claire Quinlan, Jacobs.*

Figure 11. *Location of proposed pipeline ('Site of Works') along the left-hand side of Cockatoo Creek to permit draining of the currently waterlogged area upstream of The Choke. Source: Claire Quinlan, Jacobs.*

The detailed design is outlined in Jacobs (2016b). This report investigated the engineering requirements to provide the left-hand pipeline option (e.g. location of inlets, type and route of pipeline etc.) and revisited the earlier hydrological modelling, using updated LiDAR information to identify the areas likely to benefit from various inlet locations and pipe configurations. Of four possible inlet locations, the one most upstream (Alignment 4) offered the greatest environmental benefit. Discussions subsequent to the 2015 report but before the detailed design study of Jacobs (2016b) considered an option to move the inlet structure even further to the south (i.e. further upstream), but this was discounted on the basis that it would increase construction costs by ~30%, and bring them to considerably over $400,000, then considered the maximum budget Melbourne Water had for the project.

The most recent documentation (Melbourne Water minutes from the meeting 'Cockatoo Swamp − Options and next steps', of 14 April 2016) states the estimated cost of levee removal as $500,000, consisting of $330,000 construction costs plus a $170,000 contingency. Costs for the Alignment 4 left-hand side pipeline were estimated in October 2015 at $1,250,000 for a trenched construction, and at $3,550,000 for a combined trenched/bored structure. An above-ground syphon, dismissed in the 2015 assessment, would have cost $1,170,000. The Alignment 4 option was re-costed in February 2016: $5,660,000 for a trenched construction and $5,230,000 for the combined trenched/bored option.

6 Are these solutions sufficient and likely to be effective?

The Jacobs (2015a, 2016b) assessments, and the earlier Water Technology (2013) hydrological modelling in which they are partly based, are detailed and decisive. The reports took an appropriately sceptical position and comprehensively analysed the various options and their data limitations. It is difficult to see how they can be improved upon in this review. Even so, three points do stand out.

First, the soundness of any solution proposed to resolve the problem of dieback at Yellingbo NCR hinges on the validity of the hydrological modelling. This modelling, in turn, depends on the robustness of the hydrological record and on the accuracy and precisions of landform mapping. The hydrological modelling undertaken by Water Technology (2013) used the two-dimensional MIKE SHE model, combined with the outputs of an existing REALM model of the upper reaches of Woori Yallock Creek, to plot inundation regimes at Cockatoo Swamp. The REALM model made use of ~40 years of modelled stream flow data. The complexity of interactions between surface waters and ground waters limited the accuracy with which inundation patterns could be determined. Problems were also encountered with the accuracy of landform elevations, and these led to the Jacobs (2015a) report, which used a more accurate digital elevation model to represent the ground surface. Otherwise, the Water Technology (2013) model was used unaltered. The Jacobs (2015a) report used stream flow gauge data variously commencing in 1993, 1998, 1999 and 2008 (Jacobs 2015a, Table 6-1). Each dataset had between 30−77% missing data. Further refinement of the surface topography was incorporated into the Jacobs (2016b) report, and in this assessment a simple one-dimensional HECRAS hydrological model was applied to the area immediately around the proposed inlet pipe locations.

The conclusion might be drawn that the stream flow data that underpinned hydrological modelling were not particularly robust. But that was all that was available and the limitations would not seem to invalidate the general findings, which seem robust. The initial concern was the stream channel had become so incised (Figure 16) that very large flows would be required to inundate the floodplain after the partial removal of the levees was mollified by the magnitude of medium- and high-flow events (230 and 450 ML day^{-1}, respectively) and their modelled return periods. Table 6-2 of Jacobs (2015a) showed that bankfull flows in the upper parts of Cockatoo Swamp were 560−750 ML day^{-1}, and that they could be expected to occur once every 1½−3 years. Such a frequency is consistent with the water regime recommendations outlined in Table 2 for the establishment and maintenance of healthy Mountain Swamp Gum communities. The spells analysis shown in Figure 6-6 of Jacobs (2015a) supports this conclusion.

Figure 12. *Incised channel of Cockatoo Creek in the region of the proposed partial removal of the levees. Photograph taken May 2016.*

A other potential data limitation is that the data record, being short, covered few of the extreme events that might be expected to occur in such a small 'flashy' stream running through a modified landscape. How well the existing dataset will reflect changes to flow under future climate change scenarios is also unclear. The most recent modelling of the Southern Slopes region of south-eastern Australia (CSIRO & BOM 2015a, b, c) suggests that less rain will fall in winter and spring, but there will be an increased intensity of heavy rainfall events. The impact of such changes on the hydrology of Cockatoo Swamp − and thus on the vegetation communities − is unclear (but beyond the scope of the original investigations).

Second, the function of the two types of proposed intervention − partial removal of the upstream levees, and draining of the downstream water logged area − needs to be clarified. The function of the downstream pipeline is clear, but the upstream puncturing of the levees is designed not so much to allow Mountain Swamp Gum to establish *de novo* on the currently alienated floodplain as to allow the establishment of a floristically diverse vegetation community with a canopy layer of Mountain Swamp Gum having the appropriate structure to provide suitable animal habitat. Although the hydrological function is the same across the two rationales, the 'end point' will be different. If the aim was merely to re-instate a hydrological regime better suited to the establishment of Mountain Swamp Gum in this upstream area, there would be little point in partial removal of the levees as this species (as well as paperbarks and tea-tree) are already capable of growing there (see Figure 8). What the re-engagement of the floodplain aims to do is to allow the Mountain Swamp Gum to grow under wetter conditions and thus take on more of the complex structure shown in Figure 3. Figure 3, in fact, provides a possible 'guiding image' (*sensu* Willby 2011) that can be used to gauge the effectiveness of rehabilitation efforts. How well the implementation of an improved hydrological regime will alone meet these ends is unclear, given the negative role played by browsing and by the existing dense ground cover of Reed Canary Grass. In other words, the improved hydrology resulting from the partial removal of the levees is required but not sufficient by itself. Problems with browsing by exotic animals and with the existing dense ground layer will also have to be resolved at scales appropriate for the rehabilitation of this large area of alienated floodplain.

Third, to what extent do these two interventions address the fundamental cause of the problem? This is easiest to assess with the proposed partial removal of the upstream levees. The Jacobs (2015a) report provided convincing evidence that puncturing the levees would result in more frequent inundation of the currently alienated upstream floodplain. As far as existing information permits, it is likely that this will facilitate the extension of the Sedge-rich *Eucalyptus camphora* Swamp community. If flooding conditions are suitable, Mountain Swamp Gum will grow into large, gnarled tress that, with a shallow root system encouraged by frequent flooding, will topple and re-shoot from the trunk, creating the vegetation structure shown in Figure 3 thought ideal for Helmeted Honeyeater and Leadbeater's Possum habitat.

The situation with managing the downstream waterlogged area is more contentious. Whilst the proposed left-hand bank pipeline will in all likelihood result in large parts of this area being drained and a more appropriate water regime to become established in the lower and mid parts of Cockatoo Swamp, the fundamental problem remains that sediments (and perhaps nutrients) will continue to enter the Reserve from agricultural land surrounding the upstream reaches of Cockatoo Creek. The initial sedimentation of Cockatoo Swamp, arising from active erosion of Cockatoo Creek in the 1950s (Craigie *et al*. 1998), has largely passed. But sediment will continue to enter the swamp from the catchment and this long-term problem will need to be addressed.

7 Do these, or indeed any option, provide value for money?

7.1 What criteria should be used to assess 'value for money'?

Interventions aiming at improving the condition and spatial extent of the Sedge-rich *Eucalyptus camphora* Swamp community and thereby providing extended and improved habitat for Helmeted Honeyeater and Leadbeater's Possum must meet a number of criteria. First, one has to be reasonably sure that the intervention is required promptly and that it will achieve the desired outcomes. This means that the environmental problem has to have been well articulated, the fundamental causes of the problem satisfactorily identified, and all feasible remedial actions identified and assessed. In other words, are the aims of the inventions sufficiently clear? Does it have to be done soon?

Second, if the intervention entails the construction and operation of engineering structures, they have to be as fail-safe and require as little on-going maintenance as possible. In addition to being 'fail safe', they should be 'safe fail', meaning that if they malfunctioned the consequences should not be severe or too costly to correct. The expected life expectancy of any infrastructure should also be consistent with anticipated changes in the site (e.g. due to climate change) and likely site management. If monitoring shows the interventions to be successful, it might be advantageous if any works could be expanded with little cost. Conversely, if monitoring showed them to be ineffective − or worse, deleterious − they should be able to be replaced or reversed with little cost. The cost may be financial or environmental; for Melbourne Water a cost may include corporate reputation and standing in the community, especially among Friends groups and with related government agencies.

Third, is there a well-thought out plan for the rehabilitation and management of the site? Implementing an engineering solution is likely to be required but is unlikely to be sufficient alone. Craigie *et al*. (1998, page iii) concluded that there was 'no simple quick fix' to the problem and that isolated interventions were unlikely to be successful. Jacobs (2015a, 2016b) similarly devised a suite of interventions aimed at resolving different aspects of this multi-faceted problem. Revegetation is also certainly going to be required for rehabilitation of both the drained waterlogged area and the wetted desiccated areas shown in Figure 9. Have these ancillary actions been accounted for? Is there a monitoring program in place to gauge the effectiveness of the engineering intervention (e.g. in terms of an improved hydrology) and in terms of the expected ecological outcomes (e.g. improved condition and increase in area of the Sedge-rich *Eucalyptus camphora* Swamp vegetation community; a more sustainable population of Helmeted Honeyeater, etc.).

Fourth, is the proposed solution cost effective? Cost-effectiveness cannot be judged solely on the financial cost of the planned interventions; environmental costs (e.g. in terms of area damaged in making the interventions) also need to be considered. On the other side of the ledger, the value of the environmental asset the intervention will protect or enhance is also critical. There would be little point in investing substantial resources on an asset of low value. Conversely, the expenditure of even large sums could be easily justified if the asset were exceptionally valuable.

Fifth, could the planned 'solution' simply move the problem elsewhere? Is it possible that draining the currently waterlogged parts of Cockatoo Swamp via a pipeline result in waterlogging of downstream areas that are currently in good condition?

Finally, are the costs of intervening spread across multiple agencies or is Melbourne Water forced to 'go alone'? In other words, how much support for rehabilitation efforts be garnered from other sources?

7.2 How does the current proposal stack up?

Question 1: How urgent is the problem?
Answer: This is a pressing, and important problem that needs to be addressed as quickly as possible. Over two decades ago, McMahon & Franklin (1993) called for urgent action to address the loss of Mountain Swamp Gum and associated animal habitat in Yellingbo NCR. There is little reason to question their conclusions and recommendations. The increase in spatial extent and severity of dieback in Yellingbo NCR, reported in many later studies and most recently by Parks Victoria (2015), add to the sense of urgency.

Question 2: Are we reasonably sure the planned intervention will achieve the desired hydrological and ecological outcomes?
Answer: Yes. There is a robust body of information going back to the early 1990s covering hydrological, ground water, ecological and engineering studies. The fundamental issue − loss in condition and extent of Sedge-rich *Eucalyptus camphora* Swamp and its impact on Helmeted Honeyeater and lowland Leadbeater's Possum populations − is acknowledged and the causes of the deterioration are as well established as is reasonable for a complex ecological problem. The role of altered hydrological regimes − waterlogging in some parts, floodplain alienation in others − is acknowledged. There is a likely role of other co-stressors − particularly nutrient enrichment, browsing by exotic animals, and competition by other plant species, perhaps compounded by altered fire histories − in the degradation, but they have not been as well investigated as the role played by inappropriate wetting and drying regimes. It is almost certain that dieback in the mid and lower parts of Cockatoo Swamp is a direct result of chronic waterlogging. A suite of more appropriate wetting and drying regimes has been devised by Greet (2015a) and these provide an excellent basis for planning the types of intervention required.

Question 3: Are we confident the planned engineering interventions are appropriate in terms of reversibility, capacity to be extended etc?
Answer: Yes. There have been four engineering investigations (Craigie *et al*. 1998; Aquatic Systems Management 2008; Jacobs 2015a, 2016b) which outlined various solutions to redress the problem of deterioration in Mountain Swamp Gum communities at Yellingbo NCR. The most recent studies, by Jacobs (2015a, 2016b), built on a number of hydrological and geotechnical investigations (e.g. Water Technology 2013; Jacobs 2015b, 2016a). The 2015 and 2016 reports by Jacobs are exhaustive and seem to have addressed all the critical issues. In other words, the planned engineering interventions are well thought-out and the pros and cons of various options have been addressed exhaustively. The staggered breaking of the 1950s levees, aimed to improve inundation of the alienated upper floodplain, can be undertaken relatively easily, and even extended or reversed if need be. Undoing the proposed left-hand pipeline (or more explicitly, the vegetation changes it invoked) would be more problematic, as that would represent a substantial engineering structure. Extending the pipeline further downstream, if required, could prove feasible but would need additional investigation. Reputational risk to Melbourne Water is decreased by having a relative wealth of scientific and engineering knowledge − as opposed to simple anecdote − to support the proposed interventions.

Question 4: Is the intervention part of a well thought-out rehabilitation, monitoring and adaptive management plan?
Answer: Mostly, Yes. The monitoring program outlined by Greet (2015a) is essential. It is rare for the hydrological rehabilitation of a degraded wetland or floodplain to have such a robust monitoring program informing it (see critiques by Streever 1997; Finlayson & Mitchell 1999; Brookes & Lake 2007; Raulings *et al*. 2011; Boon 2012; Westgate *et al*. 2013). Revegetation activities will have to be integrated closely with local Friends groups and other stakeholders (e.g. Parks Victoria, Zoos Victoria, Greening Australia). The need to intermesh the various intervention, revegetation and monitoring activities will have to be managed carefully and with due consideration given to ongoing support (financial and personnel).

Question 5: Is the proposed solution cost-effective?
Answer: This depends on how 'cost-effectiveness' is gauged. As noted in the preamble to this section, cost-effectiveness depends in large part on the value of the asset you are trying to protect. Aquatic Systems Management (2008, page 25) put it well:

> The rehabilitation of the Cockatoo Swamp is a significant project with very high biodiversity gain potential. The values of the swamp are of national significance and the stream and swamp system are a key component of the critical habitat for the future of the Helmeted Honeyeater at the site.

On every account Yellingbo NCR is exceptionally valuable. It is notable for supporting the only wild populations of Helmeted Honeyeaters and lowland Leadbeater's Possums and the only significant remaining patch of Sedge-rich *Eucalyptus camphora* Swamp. Is the financial cost then too much? This can only be answered within Melbourne Water. I am not privy to the range of other possible activities pulling on their purse strings. One approach might be to undertake a benchmarking study to compare expenditure into the rehabilitation of aquatic systems elsewhere in Australia and their return on investment. Creighton *et al*. (2015) undertook this type of analysis to build a business case for investment into the rehabilitation of coastal rivers and wetlands. They concluded that an Australia-wide investment of $350 million into estuarine repair would be returned in less than 5 years merely from improved commercial fisheries productivity of a limited number of fish, shellfish and crustacean species. A benchmarking study to compare the value of the asset being protected in Yellingbo NCR with investments into the rehabilitation of aquatic systems elsewhere in Victoria might prove illuminating and help build a robust business case. It is likely such a study would show that it is a high-cost rehabilitation project, particularly when supporting activities such as supplementary feeding and captive-breeding are factored into the equation. The benefits, however, are likely to be long-lasting and this should be considered when assessing the high upfront costs. The downside to Melbourne Water's reputation among the wider community if nothing is done to address to problem is also a factor to consider: the deterioration in condition in Yellingbo Nature Conservation Reserve has been known since at least the paper by McMahon & Franklin in 1993. There must be considerable community and stake-holder pressure to act.

Question 6: Are we simply moving the problem downstream?
Answer: Possibly. The studies available to date show, convincingly I think, that large areas of Cockatoo Swamp in Yellingbo NCR will stand a very good chance of being rehabilitated by the interventions outlined in Jacobs (2015b, 2016), complemented with targeted and well monitored revegetation activities and control of animal browsing, and assessed by a robust monitoring program. On the one hand, it is not so clear that the fundamental problem with sediment accumulation within the lower parts of Cockatoo Swamp will not be transferred downstream. Counteracting this is the likelihood that re-engaging the upper floodplain with Cockatoo Creek by puncturing the levees will result in more water (and sediment) flowing onto that part of the Reserve.

Question 7: What is the chance of overall success? Is Melbourne Water attempting the rehabilitation alone, or can other partners assist?
Answer: There can be few other aquatic rehabilitation projects in Australia that have as high a public profile and with as diverse a range of supportive partners and stakeholders as at Yellingbo NCR. Two Friends groups exist, one for Helmeted Honeyeater and the other for Leadbeater's Possum. The Friends of the Helmeted Honeyeater has been active since 1989 and, interest in this iconic bird species among the birdwatching community goes back to the early 1950s.[10] It manages a native plant nursery that supplies material for revegetation of degraded sites. Healesville Sanctuary has a captive-breeding and release program for the Helmeted Honeyeater that was initiated in 1989, leads the Leadbeater's Possum monitoring program in the Reserve, and in 2012 established a captive-breeding program to prevent the extinction. Trust for Nature has, since mid 1990's, progressively purchased private land adjacent to Yellingbo NCR to add to the Reserve, with the aim of having it revegetated to provide additional Helmeted Honeyeater habitat. Greening Australia, undertake extensive revegetation of ~ 30 in 2013 as part of the State Government's Two Million Trees programme, and will build upon this work substantially though the Commonwealth Government's 20 Million Trees program, is also involved in revegetation in Yellingbo NCR.[11] Parks Victoria actively manages the Reserve

[10] http://www.helmetedhoneyeater.org.au/about_us.htm
[11] https://fieldcapture.ala.org.au/project/index/96a558b0-a451-433f-b4c8-0e896b79c4e6

with a small group of dedicated rangers; that management includes attempts at controlling Fallow and Sambar Deer populations.[12] This is a truly impressive list of collaborating organisations. The support rendered by such a wide range of complementary stakeholders must add to the positive side of the 'cost-effectiveness' ledger. Other catchment management activities complement the works, including Stream Frontage Upstream and the Rural Land Program which aim at helping landowners manage their land- and water-use practices to reduce run-off and sedimentation (Dan Harley, pers. comm. 30/06/2016).

Question 8: What other solutions might there be to rehabilitate the site? What has been missed?
Answer: as outlined in the response to Question 3, the investigations that have been undertaken to date are detailed and exhaustive. Options have been progressively proposed, critiqued and refined as information has become available and knowledge improved.

One option that remains to be explored more fully is the possibility that pumping could be used as a short-term ameliorative. This intervention has the attraction of being low cost. It would also indicate whether altering the hydrological regime in the downstream (waterlogged) parts of Cockatoo Swamp would achieve the expected improvement in vegetation condition. If a meaningful improvement did take place, the pumping trial would provide even stronger grounds for pursuing the more costly (but long-term) option of installing the pipeline recommended in the Jacob's investigations. Pumping would also be seen as a proof of demonstrable on-ground action, a benefit not readily dismissed given likely community and stakeholder pressure for something to be seen to be done at the site.

7.3 Overall conclusions

Table 4 summarises the responses to these various questions into a simple two-way overview. This table highlights the pros and cons associated with the rehabilitation proposals outlined by Jacobs (2015a, 2016b) and could be used to inform subsequent decisions on whether to proceed with the proposed works.

Table 4. Pros and cons of the rehabilitation works proposed for Cockatoo Swamp.

Pros	Cons
Exceptionally high conservation value of Yellingbo NCR and Cockatoo Swamp: • Sedge-rich *Eucalyptus camphora* Swamp • Helmeted Honeyeater • Leadbeater's Possum • Listed on the Register of the National Estate • VEAC (2013) proposal to establish a State Emblems Conservation Area centred on Yellingbo NCR.	High financial cost of left-hand bank pipeline, related to the complexity of the projected (underground) works.
Robust and lengthy ecological information is available in published literature and from grey-literature sources: • 25+ years of data on deterioration in condition and the decrease in the extent of Sedge-rich *Eucalyptus camphora* Swamp commencing with McMahon *et al.* (1991) • Extensive data and monitoring programs in place for the Helmeted Honeyeater and lowland Leadbeater's Possum • Exhaustive monitoring program established (Greet 2015a).	Disturbance of a (small) area of good-quality Helmeted Honeyeater and Leadbeater's Possum habitat for pipeline works program.
Fundamental cause of deterioration is well established: • water logging in dieback-affected areas arising	Possibility that waterlogging issue may be moved downstream (to good-quality Helmeted Honeyeater habitat) unless the underlying problem with high sediment

[12] http://parkweb.vic.gov.au/about-us/tenders-and-notices/deer-control-dandenong-ranges-national-park,-yellingbo-and-warramate-nature-conservation-reserves

from historic sedimentation of Cockatoo Swamp • floodplain alienation in upstream areas arising from levee construction.	loads from upstream (agricultural) catchment is addressed.
Detailed investigations into rehabilitation options have been undertaken and assessed: • Craigie *et al*. (1998) • Aquatic Systems Management (2008) • Water Technology (2013) • Jacobs (2015a, 2016b).	Whilst the fundamental cause of deterioration is well established, other contributing factors may exacerbate deterioration: • nutrient enrichment from upstream (agricultural) catchment • browsing by deer and wallabies • competition from dense swards of Common Reed and Reed Canary Grass • altered fire regimes.
Two clear rehabilitation options proposed to address the two fundamental causes of deterioration: • left-hand bank pipeline to redress waterlogging issue • partial levee removal to redress floodplain alienation issue.	Climate-change implications is not fully addressed. The option of a variable inlet on any pipeline, however, does provide some flexibility in operation and allows for adaptive management in response to any changes in climate.
Strong collaboration with allied agencies/organisations: • Parks Victoria • Zoos VictoriaVictoria • Trust for Nature • Greening Australia • DELWP • Greening Australia.	
Strong collaboration with local Friends groups: • Friends of the Helmeted Honeyeater • Friends of the Leadbeater's Possum.	

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